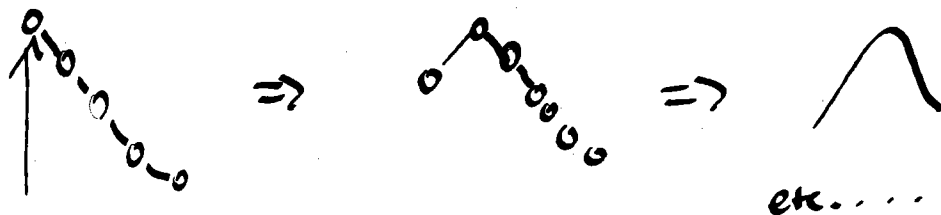


WAVES

Consider SHM when adjoining particles are affected by the motion



The "Disturbance" propagates in The "Medium"
This is known as a Mechanical Wave.

The disturbance does not have to be SHM in nature

⇒ Single Transverse pulse on Slinky

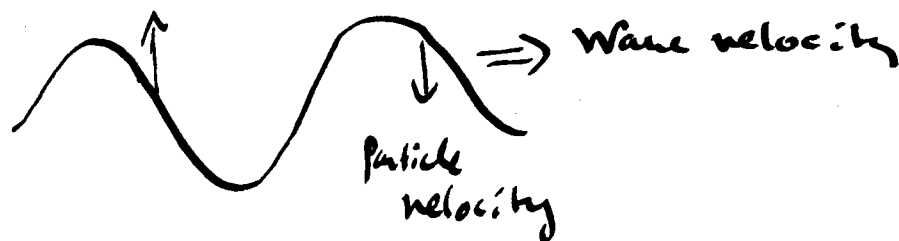


Pulse vs. Continuous or Periodic wave
(in medium)

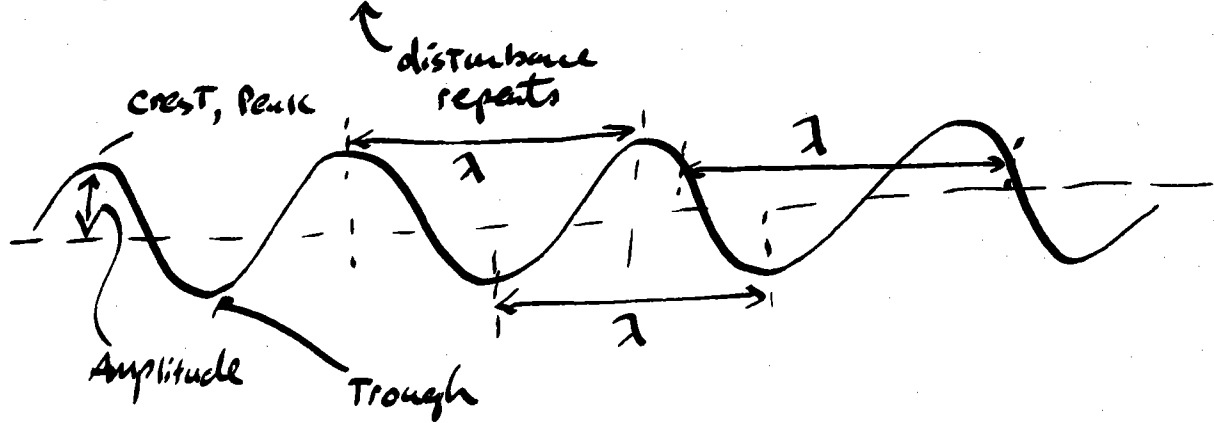
The motion of disturbed particles can be either transverse or longitudinal

⇒ longitudinal wave on Slinky

The wave disturbance Travels



Consider a Periodic harmonic wave



$\lambda \equiv$ wavelength (peak to peak distance, for example)

$T \equiv$ period Time (in s) for each peak to move to the old position of the next peak so that the wave looks the same. Or time for disturbance at one position to go through one complete cycle of its motion.

Consider peaks moving to right

$$\text{Velocity of wave} \equiv v = \frac{\lambda}{T}$$

$$\text{frequency} = \frac{1}{T} \quad (\text{just like in SHM})$$

$$\equiv \nu$$

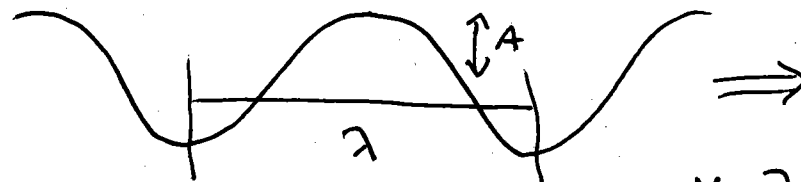
$$\therefore \boxed{v = \lambda \nu}$$

Lets freeze the wave at a given time (say $t=0$)
(wave already been propagating for a while)

Nov 30

Have Students do wave
Arbitrary SHO
tuned SHO

Waves



$$v = \lambda \nu = \lambda \frac{1}{T}$$

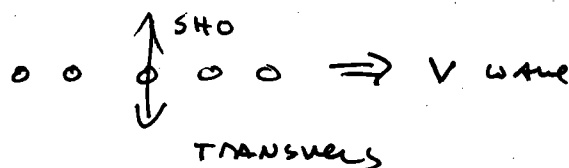
Moves to right

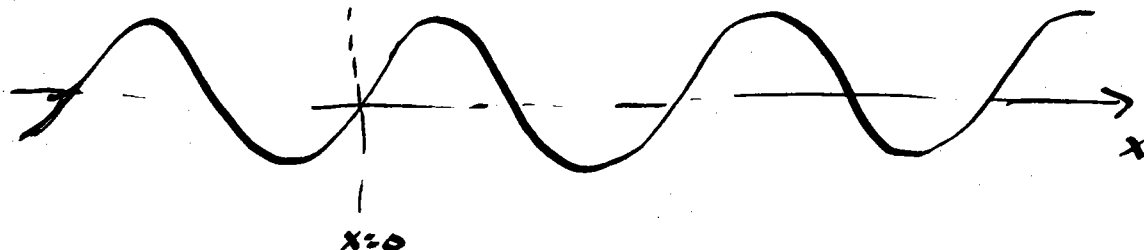
$$y(x,t) = A \sin(kx - \omega t + \phi) \quad \underline{\text{or}} \quad A \cos(kx - \omega t + \phi)$$

$$k = \frac{2\pi}{\lambda} \quad \omega = \frac{2\pi}{T}$$

Moves to left

$$y(x,t) = A \sin(kx + \omega t + \phi) \quad \text{or} \quad \text{" +}$$





$$y(x) = A \sin(kx)$$

where A gives the Amplitude

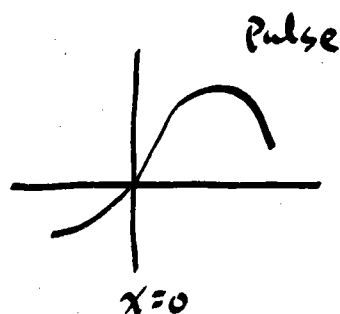
$$k = \frac{2\pi}{\lambda}$$

because if $x = \lambda$ or 2λ or $n\lambda$

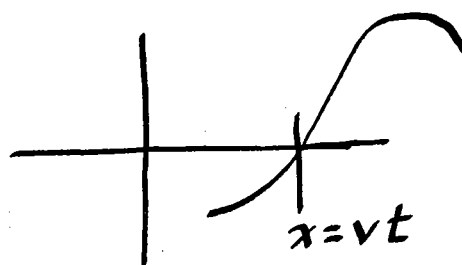
The fn must look the same

$k \equiv$ Wave number

let's let the wave travel for a time t



$$y = f(x)$$



$$\text{time} = t$$

$$y = f(x - vt)$$

So - mathematically we can take a "frozen" (inf) Equation of a wave and make it travel to

the right by letting $x \rightarrow x - vt$

Similarly can make it go to the left w/ $x \rightarrow x + vt$

let's make our frozen periodic wave above travel to the right

$$y(x) = A \sin[k(x - vt)]$$

$$y = A \sin(kx - kvt)$$

$$kvt = \underbrace{\frac{2\pi}{\lambda} v}_{\text{"} \nu} t = \underbrace{(2\pi \nu)}_{\text{"} \omega = \frac{2\pi}{T}} t$$

$$v = \lambda \nu$$

just as in SHM

So

Periodic wave moving to the right

$$y(x,t) = A \sin(kx - \omega t)$$

Two variables now!

Could have arbitrary starting phase

use either Sin or Cosine

general eqn for Harmonic wave —

$$y(x,t) = A \sin(kx - \omega t + \phi)$$

$$\left[\text{or } A \cos(kx - \omega t + \phi) \right]$$

Transverse waves moving on a string are a useful example for demonstrating wave characteristics

What properties of a wave depend on the medium??

Amplitude?

λ ?

ν ?

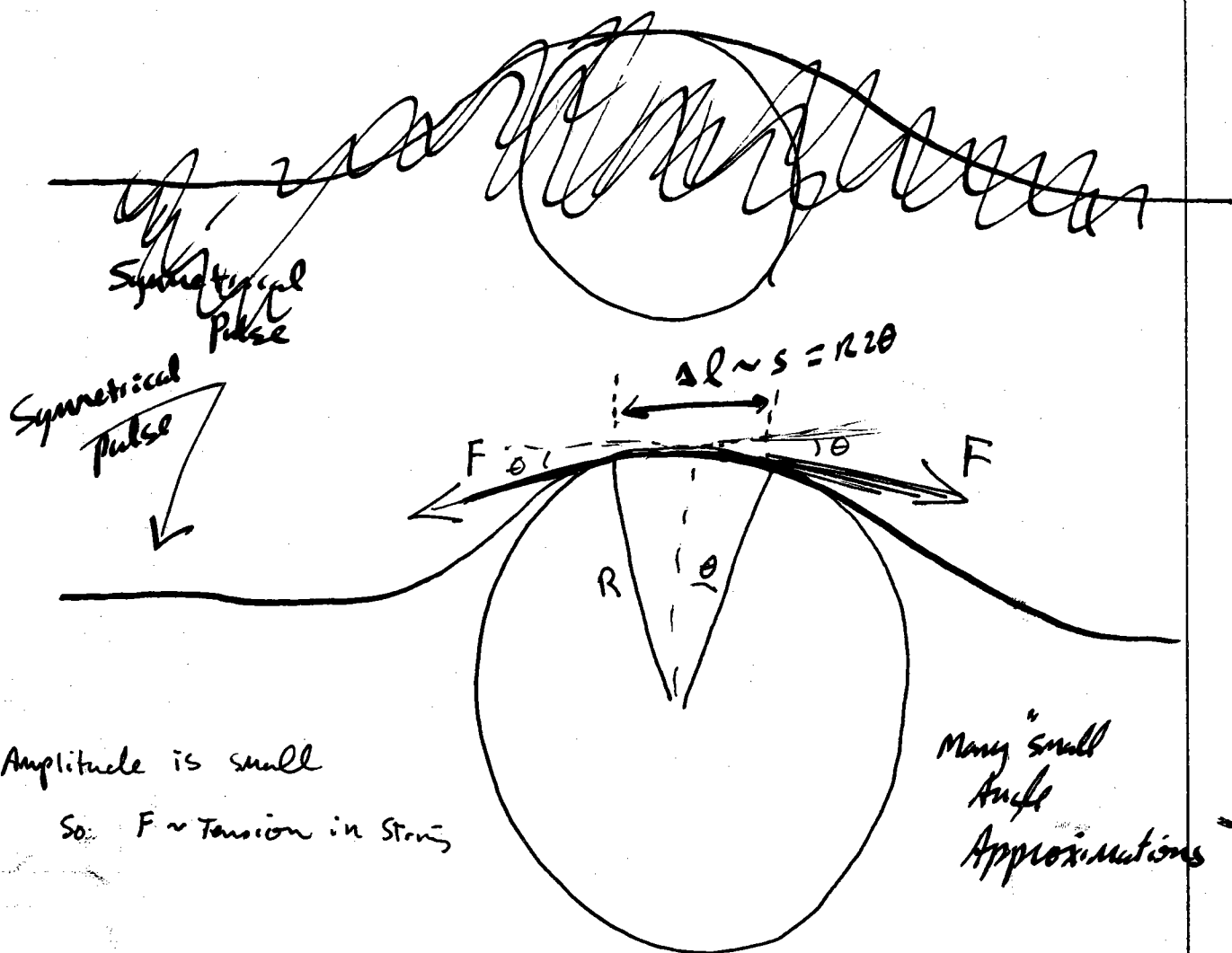
Velocity?

Know about medium should be able to calc. properties of wave

Calculate velocity of wave on a string w/ Tension $T \equiv F$

and Mass/length $\equiv \mu$

To avoid confusion
w/ Period



Amplitude is small

So: $F \sim$ Tension in String

Many "small
Angle
Approximations"

Horizontal components of 2 F vectors cancel

Vertical restoring force $\sim 2F \sin \theta \sim 2F\theta \sim \mu F \frac{\Delta l}{R}$

Mass of string segment $\Delta m = \mu \Delta l$

Mass Segment is moving on a circle for the moment

$\therefore \frac{mv^2}{r} =$ net radial force

$$F \frac{\Delta l}{R} = \frac{\mu \Delta l}{R} v^2$$

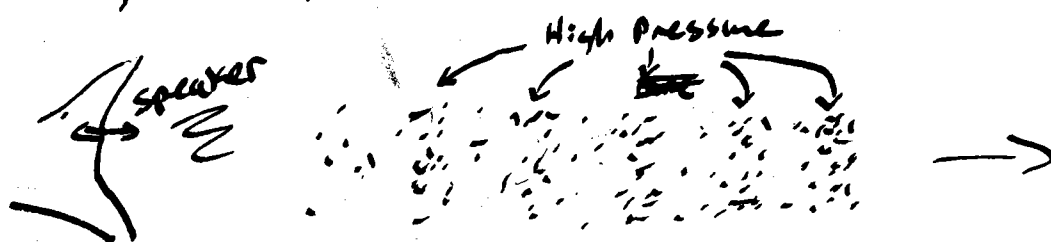
elastic force factor
inertial factor

$$\text{or } v = \sqrt{\frac{F}{\mu}} \text{ or } \sqrt{\frac{T}{\mu}} \text{ Tension}$$

heavier rope $\rightarrow v$ smaller
larger Tension $\rightarrow v$ faster

for longitudinal waves have a similar thing
Such as Sound waves

longitudinal pressure variations in medium

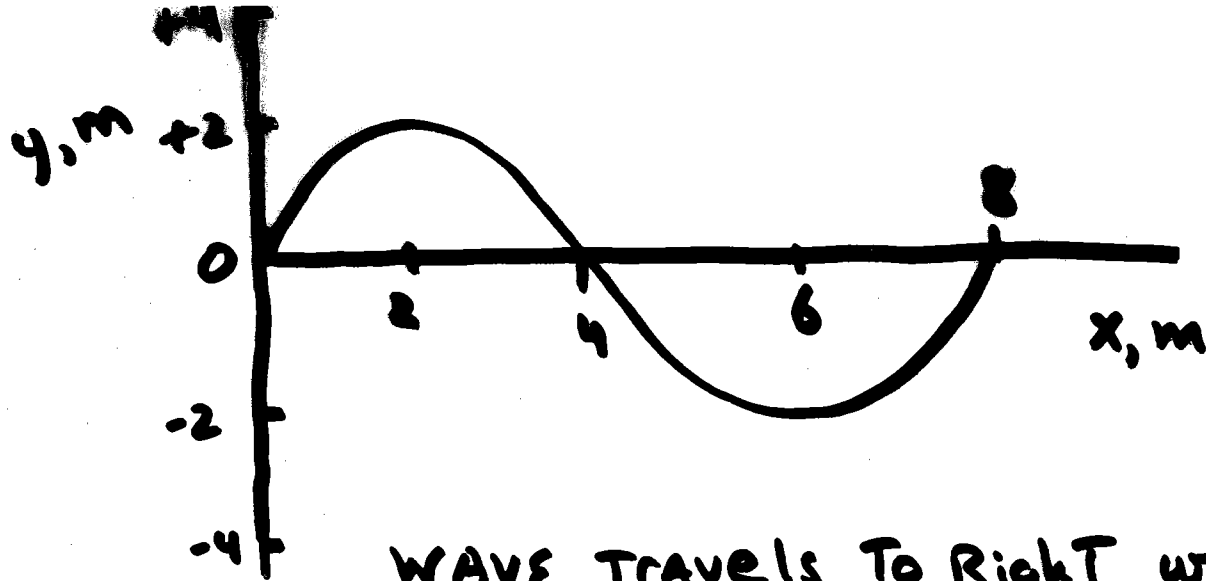


$$v_{\text{longit. wave in liquid or gas}} = \sqrt{\frac{B}{\rho}} \quad \text{Bulk Modulus}$$

just a constant for given medium

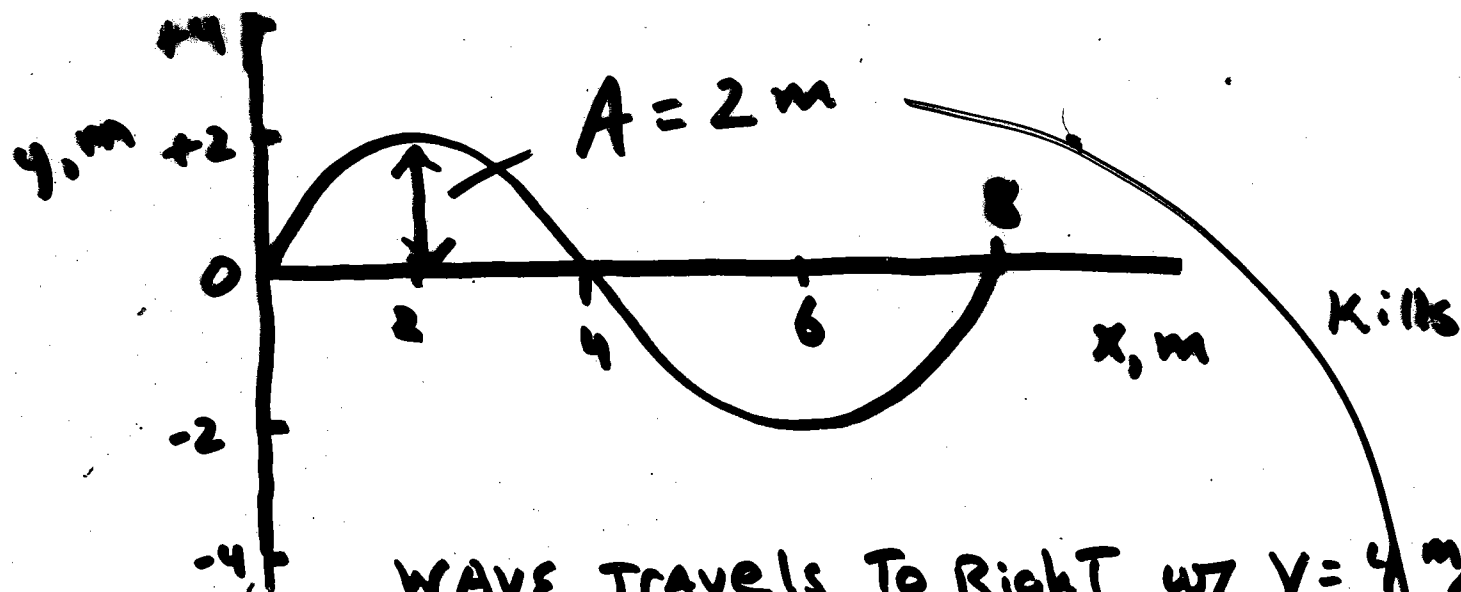
We did NOT cover $\rightarrow$ p. 342 of text

$B \sim$ Tells how compressible a gas, fluid is
for a given pressure



WAVE TRAVELS TO RIGHT w/ $v = 4 \text{ m/s}$.
Equation That best represents wave is

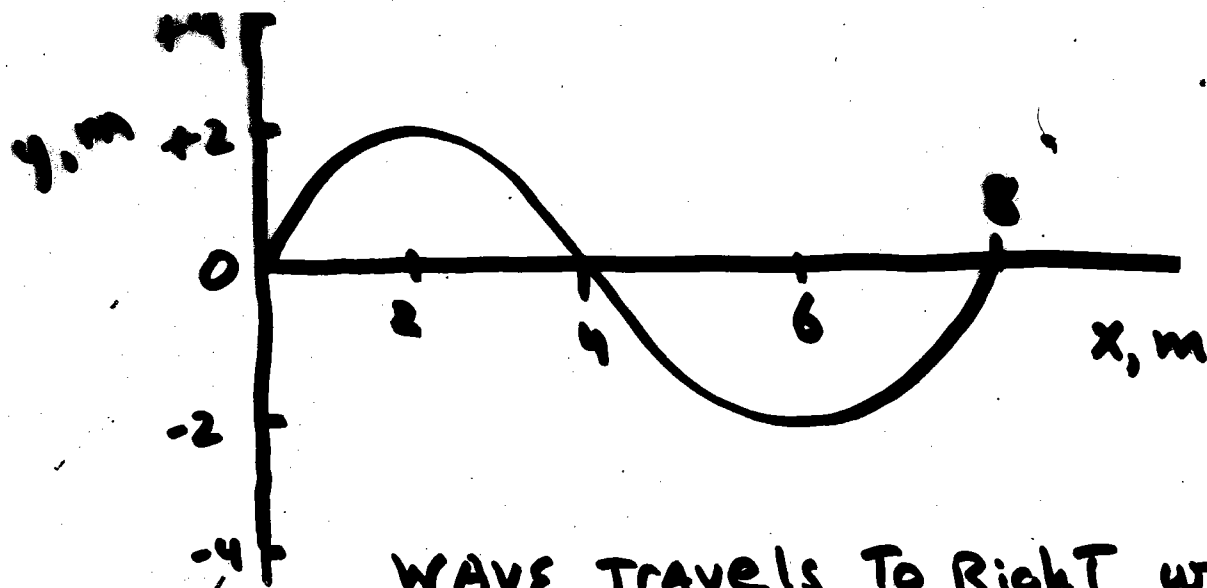
- ① $y(x, t) = 2 \sin\left(\frac{\pi x}{4} - \pi t\right) \text{ m}$
- ② $y(x, t) = 2 \sin(16\pi x - 8\pi t) \text{ m}$
- ③ $y(x, t) = 2 \sin\left(\frac{\pi x}{4} + \pi t\right) \text{ m}$
- ④ $y(x, t) = 4 \sin\left(\frac{\pi x}{4} - \pi t\right) \text{ m}$
- ⑤ $y(x, t) = 4 \sin(16\pi x - 8\pi t) \text{ m}$



WAVE TRAVELS TO RIGHT w/ $V = 4 \text{ m/s}$.
Equation That best represents wave is

- ① ✓ $y(x, t) = 2 \sin\left(\frac{\pi x}{4} - \pi t\right) \text{ m}$
- ② ✓ $y(x, t) = 2 \sin(16\pi x - 8\pi t) \text{ m}$
- ③ ✓ ~~$y(x, t) = 2 \sin\left(\frac{\pi x}{4} + \pi t\right) \text{ m}$~~
- ④ ✓ ~~$y(x, t) = 4 \sin\left(\frac{\pi x}{4} - \pi t\right) \text{ m}$~~
- ⑤ ✓ ~~$y(x, t) = 4 \sin(16\pi x - 8\pi t) \text{ m}$~~

Moves To Right $(kx - \omega t)$



WAVE TRAVELS TO RIGHT w/ $v = 4 \text{ m/s}$.
Equation That best represents wave is

- ① $y(x, t) = 2 \sin\left(\frac{\pi x}{4} - \pi t\right) \text{ m}$
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- ④ $y(x, t) = 4 \sin\left(\frac{\pi x}{4} - \pi t\right) \text{ m}$
- ⑤ $y(x, t) = 4 \sin(16\pi x - 8\pi t) \text{ m}$

PT on wave Moves 8 m in $2 \text{ s} \Rightarrow T = 2 \text{ s}$

$$\frac{2\pi}{\lambda} = k = \frac{2\pi}{8} = \frac{\pi}{4}$$

$$\frac{2\pi}{T} = \omega = \frac{2\pi}{2} = \pi$$

$$kx - \omega t = \frac{\pi}{4}x - \pi t$$



"slow to fast" media

Transmitted wave ... both cases $\rightarrow$ No phase inversion

Reflected wave $\left\{ \begin{array}{l} \text{fast to slow} \rightarrow 180^\circ \text{ phase inversion} \\ \text{low } \mu \text{ to high } \mu \end{array} \right.$

$\left\{ \begin{array}{l} \text{slow to fast} \rightarrow \text{No phase inversion} \\ \text{high } \mu \text{ to low } \mu \end{array} \right.$

What happens when two waves meet one another

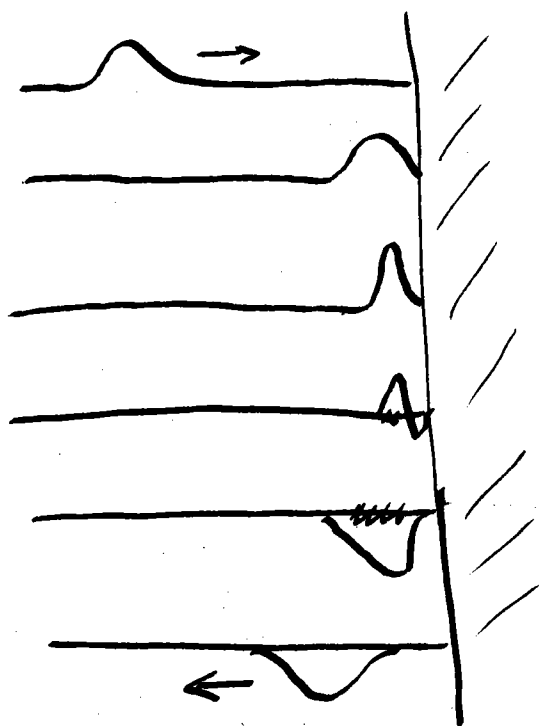
Principle of Superposition

When two or more waves pass thru a given point simultaneously, the resultant displacement is the sum of the individual displacements



Waves hitting obstacles

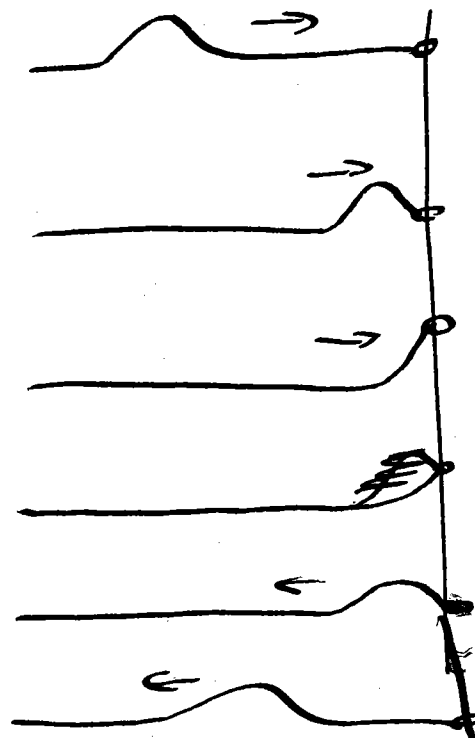
All reflected ... what is phase of reflected wave?



fixed end

→ phase change of 180°
at reflection

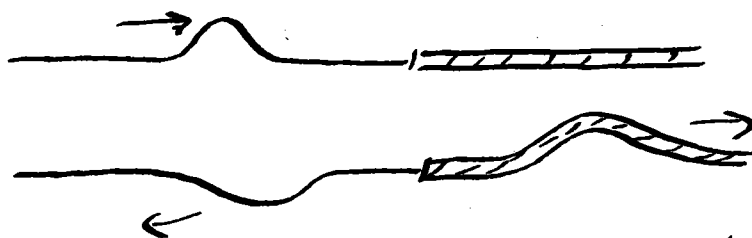
→ phase inversion



loose end

→ NO phase change at
reflection

Waves encountering an interface between media
w/ different characteristics have
reflected and transmitted components



Wave incident on boundary

Travelling from

"fast" to "slow" medium



$t = t_1$



t_2

waves said to add "destructively"



t_3



Two periodic waves superimposed on one another in some way are said to Interfere.

$\Rightarrow$ This is an incredibly rich + useful phenomenon!

Music

Antireflective coatings

best techniques for measuring small distances

Allows us to split light into colors

etc.

Consider 2 ^{harmonic} waves w/ Amplitude A and frequency f

Traveling opposite directions in a string

$\rightarrow$ one being the reflection of the other!



We've learned that two waves are out of phase by 180° due to the "boundary condition" of the fixed end at the wall