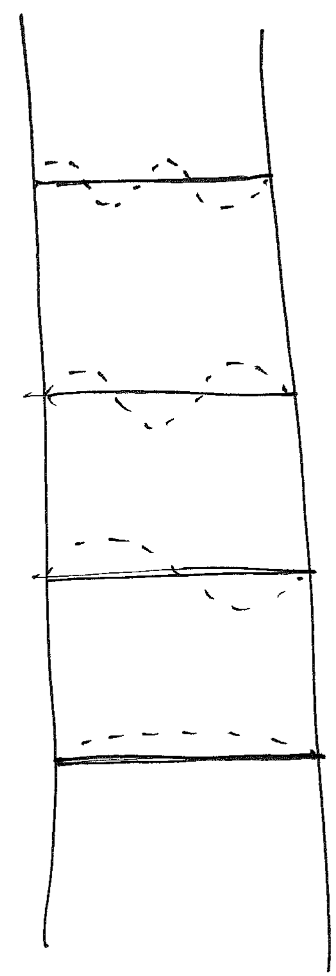
Standing Waves on string

"standing" wave = "stationary state" of string : wave stays in <u>same position</u>

ENERGY LADDER



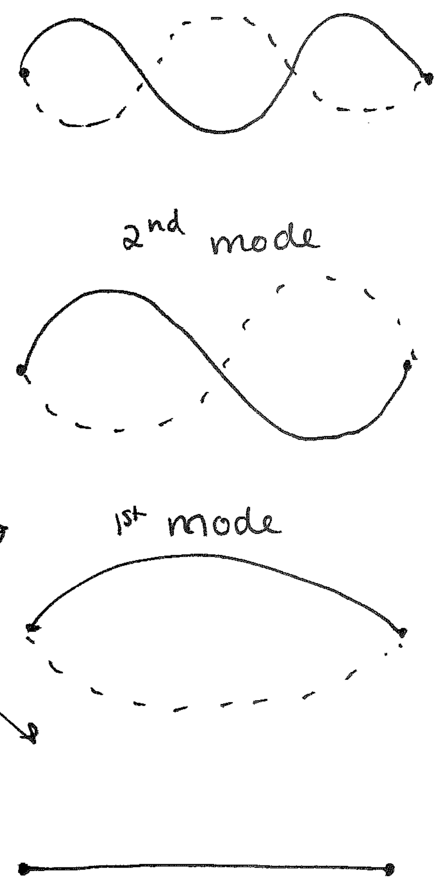
jump in energy between states
how big is jump?

no states in between
why?

3rd mode

2nd mode

1st mode



small bump = short wavelength
high pitch = high freq. hig energy

HIGH ENERGY

LOW ENERGY

big bump = long wavelength
low pitch = low freq. low energy

Standing Waves on String

boundary conditions - what is happening at edges of our system

system	edges of system
string	ends of string
paper	edges of paper

BC's determine how our system behaves (in this case, give rise to "standing" waves)

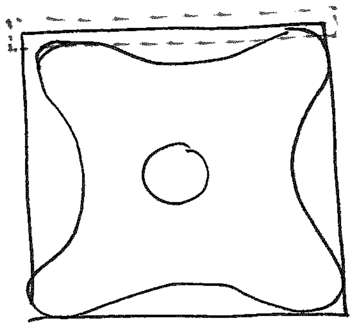
quantization : having a discrete set of values (a ladder of values) separated from one another

In this case: have a discrete set of vibrational states separated by energy gaps

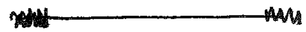
quantum: size of jump between ~~values~~ states

here: size of jump = $\frac{1}{2}$ wavelength / 1 bump

Sand on Vibrating Plate

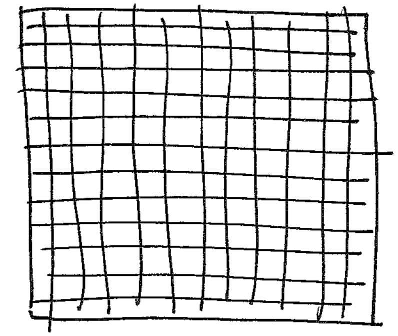


top view



side view

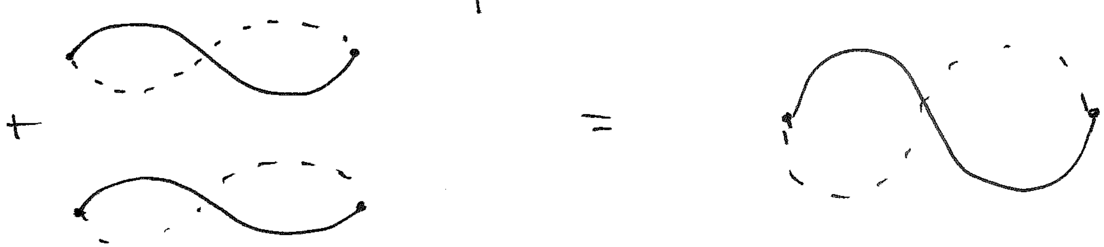
individual slice acts like string →



now our boundaries act like vibrating strings
(remember that BC's tell us what is happening in center)

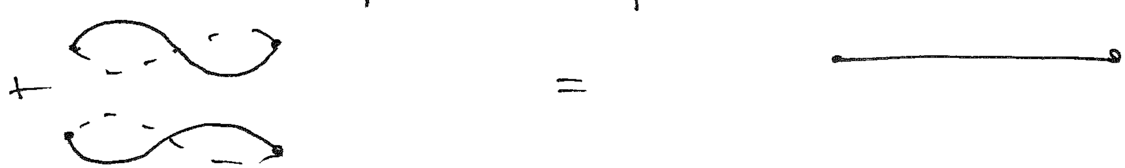
behavior of plate (2D) = sum of individual strings (1D) : superposition
need to know how to add waves

waves are lined up = "in phase"



constructive interference

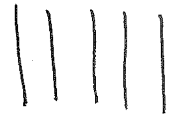
waves are anti-aligned = "out of phase"

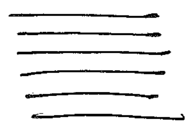
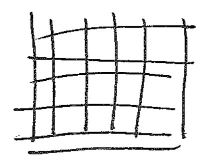


destructive interference

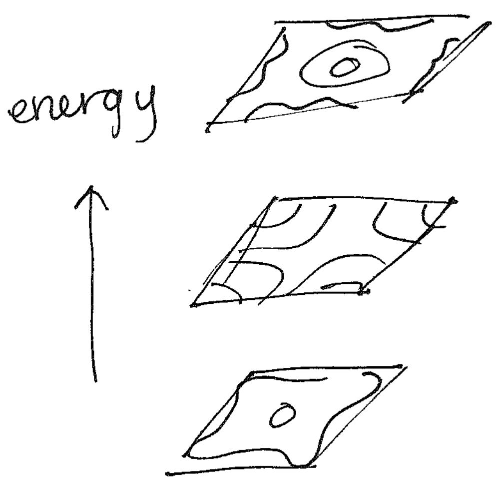
Sand on Vibrating Plate

Pattern is symmetric b/c all boundaries look the same

 looks same as 

 +  =  symmetric

As with vibrating string, we have quantization (ladder of states)



superposition: if two waves traverse same space, total wave is sum (superposition) of two

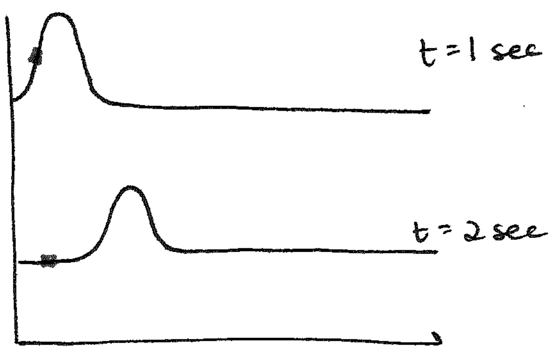
Interference: superposition of waves results in one wave interfering (canceling or adding to) another

constructive = add
destructive = cancel

symmetry if you change your viewpoint, system looks same

Traveling Waves in 2D - Ripple Tank

traveling wave: position of wave changes as time goes by

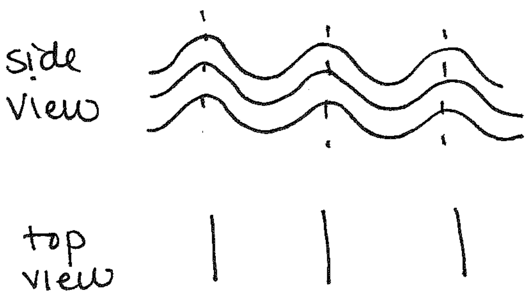


 wave moves from left to right

 individual point on string moves up and down

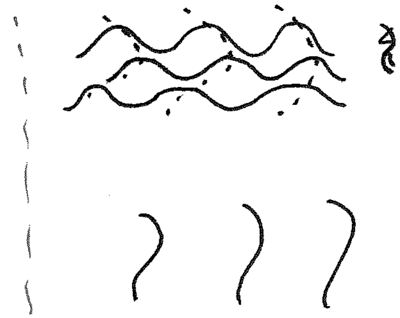
(same as boat on ocean)

water wave (2D) = many 1D waves next to each other

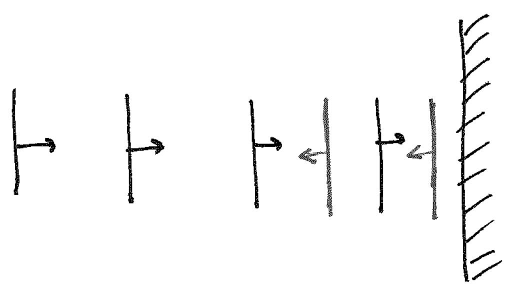


wave lined up = in phase
same λ, f

line marks wave peaks

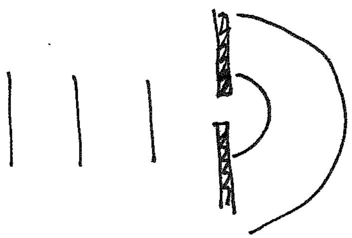


reflection from boundary

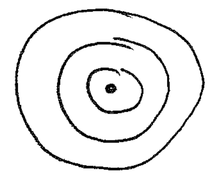


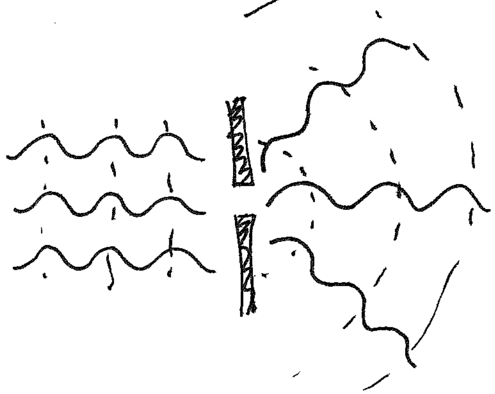
Traveling Waves in 2D

single slit : small



→ slit acts like point source "stone in pond"

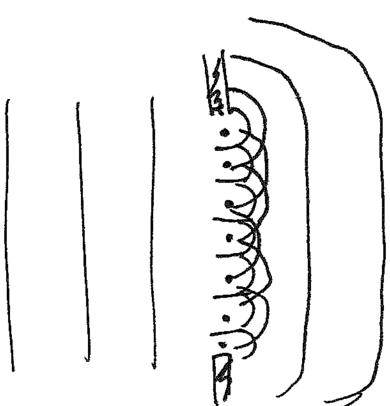




→ this phenomena is called diffraction = bending of waves around obstacle

big slit

how do we build big slit out of small slits?



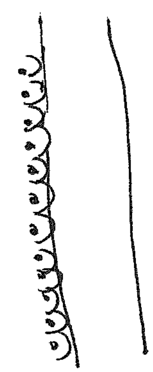
add up individual "stones", or point sources

two lines cross → constructive interference

two spaces cross → destructive interference

← * note that bend is due to edge, boundary, of slit

wavefront = series of stones

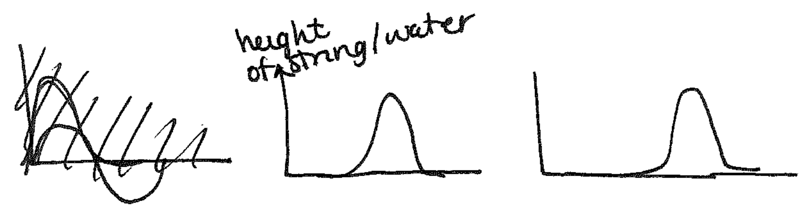


Disturbances that change in space and in time

Diffusion (of what?)

~~Key~~ distinguishing feature: spreads out as time goes on

Waves (of what?)



travels (propagates) as time goes on

> difference btw two is how they change in time

> if we just look at changes in space/position, they look the same

Energy Landscapes

Energy

kinetic (KE)

- energy due to motion

potential (PE)

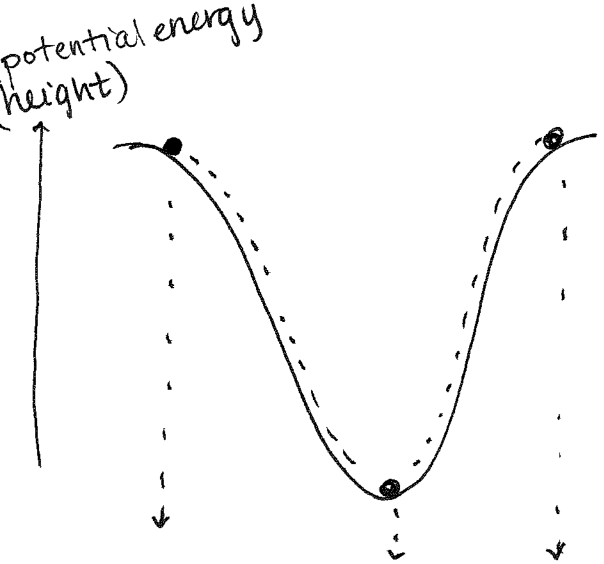
- energy due to the arrangement (configuration) of system
- energy associated w/ putting something where it doesn't want to be (due to forces acting on it)

type	example	why PE?
gravitational	ball on hill	wants to roll down (due to force gravity)
spring	stretched spring	wants to compress (due to force of spring)

KE ⟷ exchange ⟷ $ $ $ PE

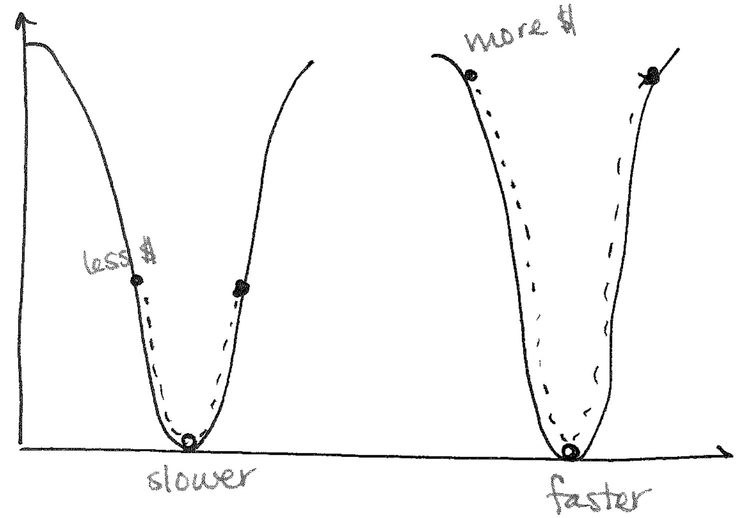
KE + PE = total energy (fixed)

Energy Landscapes



PE	✓	∅	✓
KE	∅	✓	∅

→

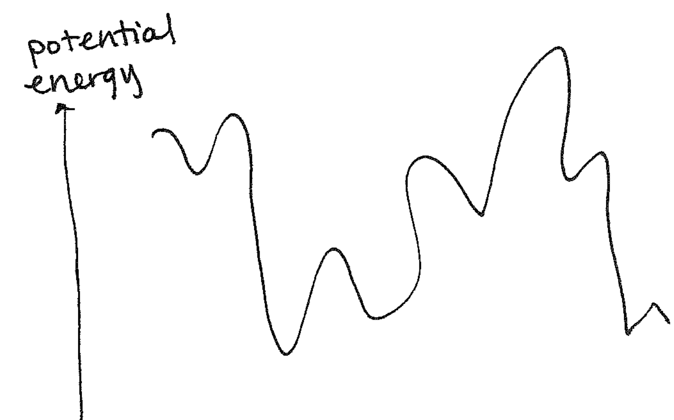


systems wants to move toward <u>lowest potential energy</u> (ball wants to roll down the hill)

can build many types of "hills" (depending on the type of PE) and "valleys"

type of PE	how to build "hill")
gravitational	variations in height
spring	variations in compression
electrostatic	variations in electric field

→

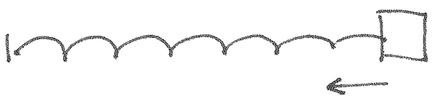


energy "landscape"

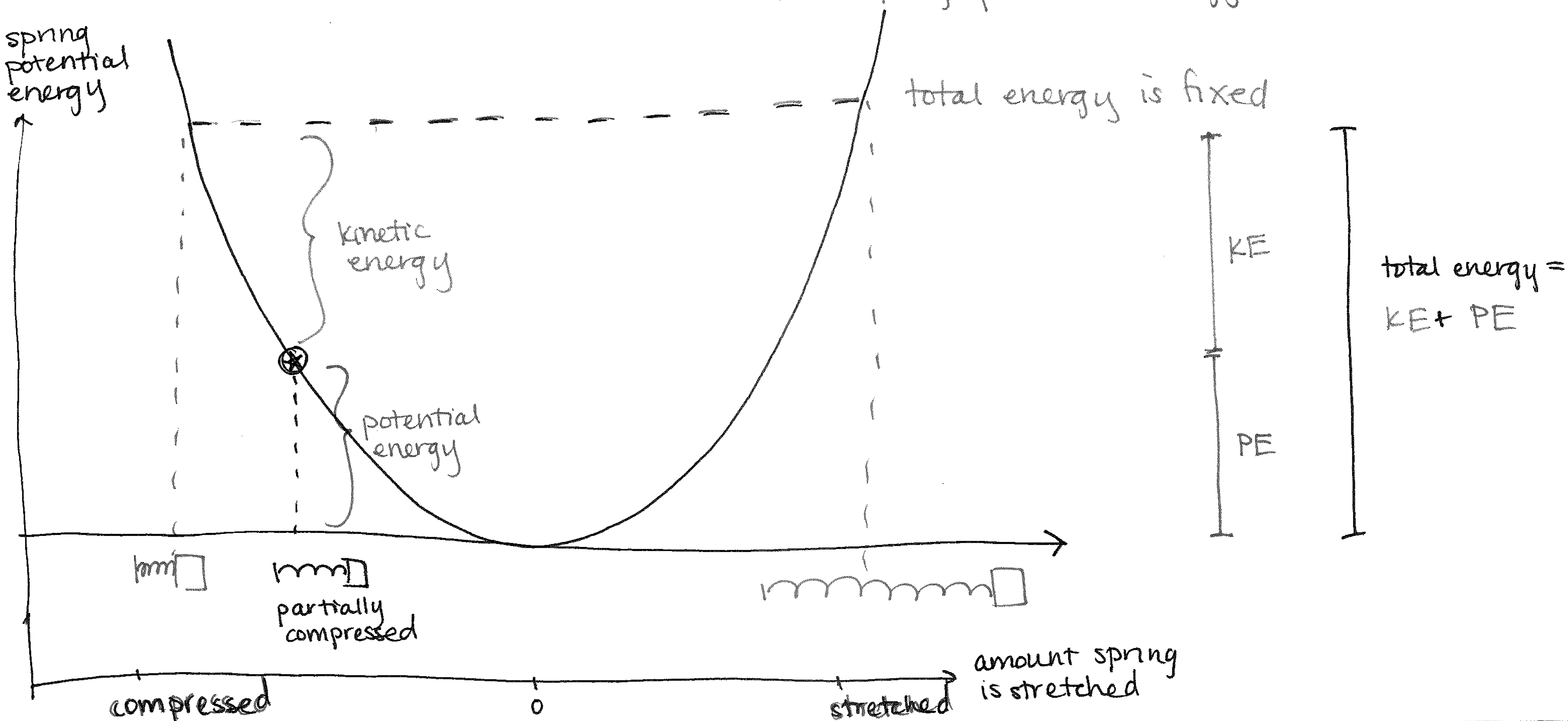
Classical Harmonic Oscillator

compressed - wants to move forward
(has ~~no~~ spring potential energy)

natural "equilibrium" position - doesn't want to move
<u>no</u> spring potential energy



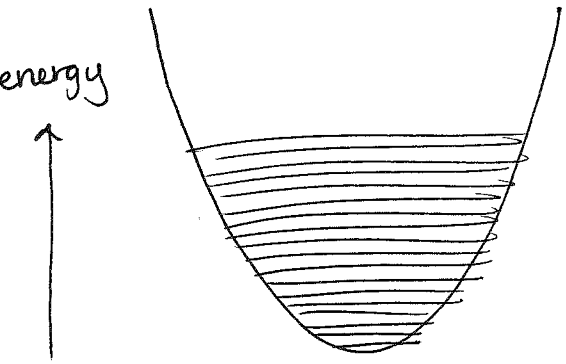
stretched - wants to move back
(has spring potential energy)



Classical Harmonic Oscillator

oscillator

Can give spring any amount of energy
b/c we can stretch/compress it by any amount

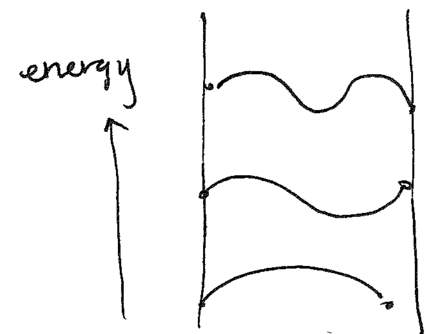


continuum
not quantized (classically)

compare to

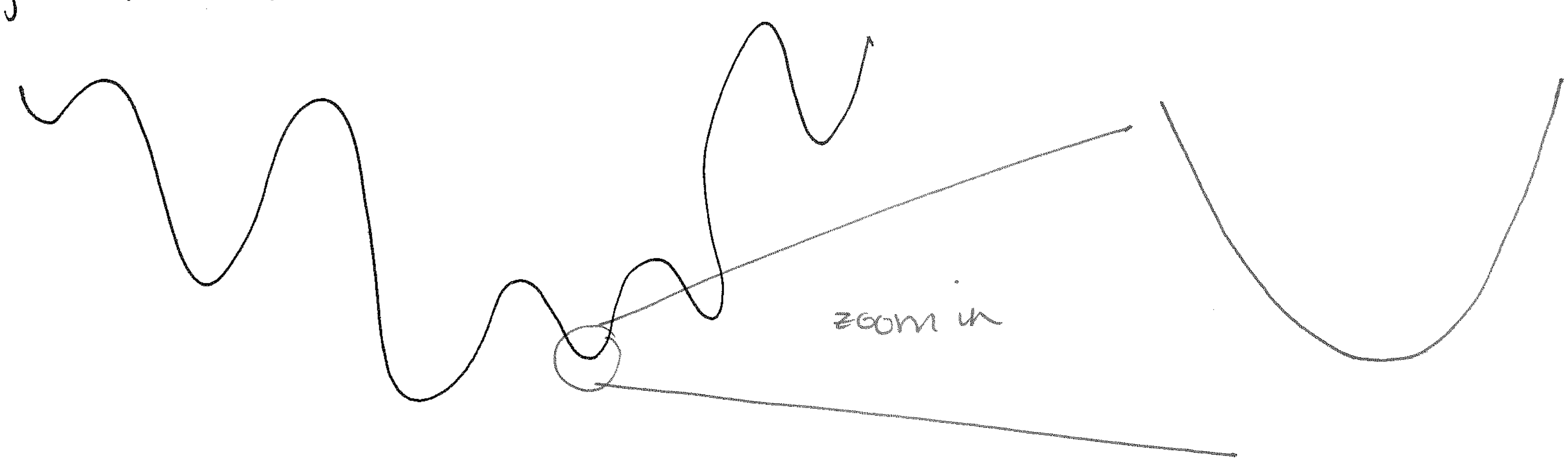
wave on string:

string can only have certain energies



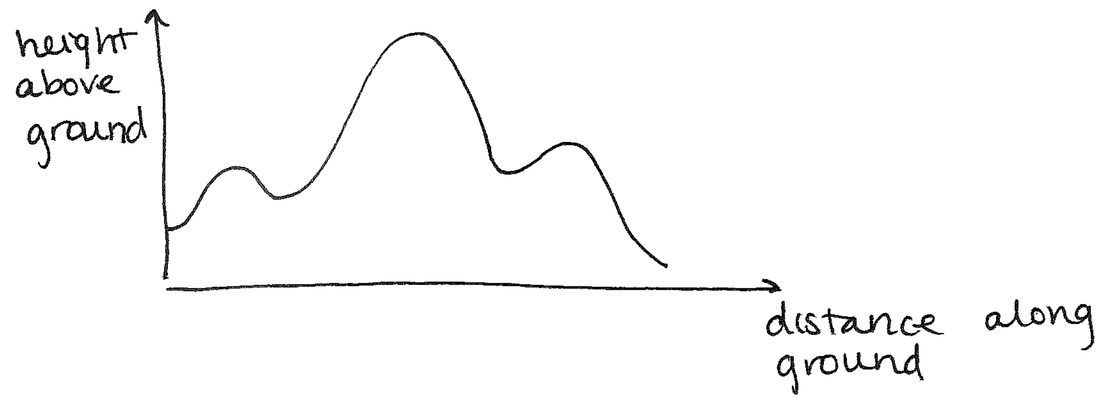
discrete
quantized

Why oscillator?



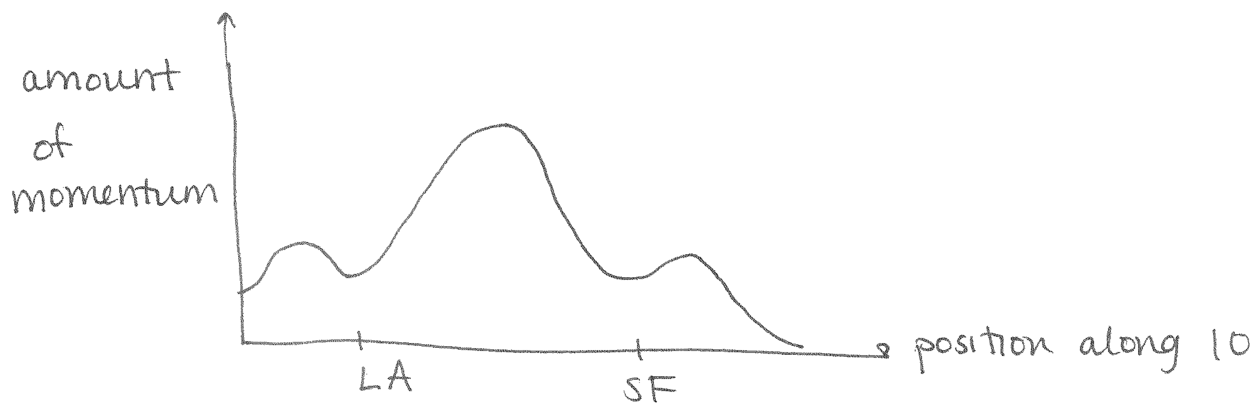
Spaces - What space are we living in?

Position Space



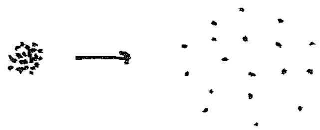
Energy Space

Momentum Space

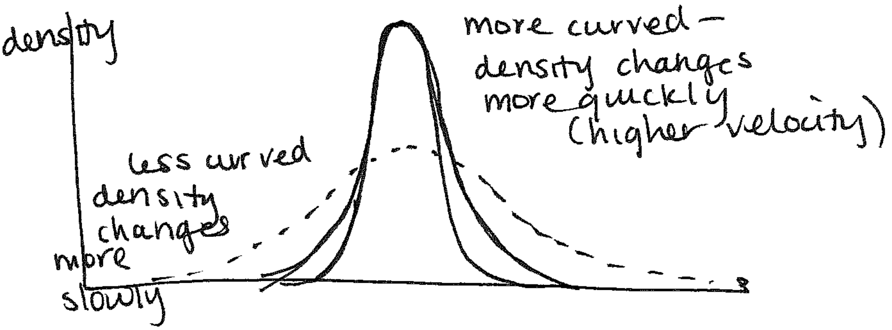


Mathematical Description

Diffusion (of what?)

of molecules: 

random motion / collisions causes molecules to spread out (density decreases)
(no forces → no acceleration) (on average)



~~curvature ← → velo~~

curvature (of density profile) ⟷ velocity (of density profile)

= changes in space

= changes in time

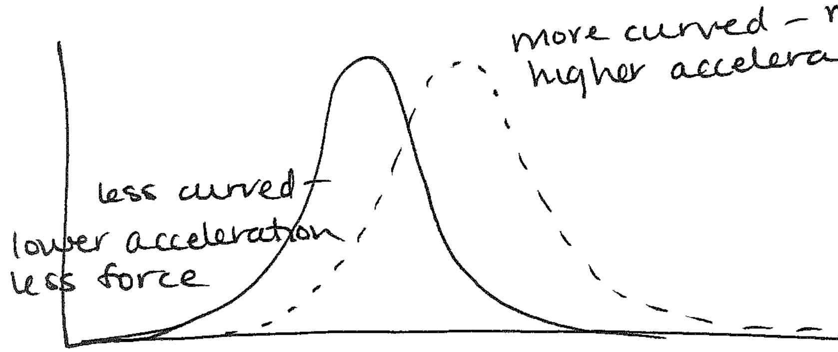
$$\frac{D\,\partial^2 \rho}{\partial x^2} = \frac{\partial \rho}{\partial t}$$

D = diffusion constant

Waves (of what?)

on string (waves of height) 

~~force of/of one part of string on another~~
one part of string pulls (exerts a force on) another, causing wave to propagate
forces → acceleration



curvature (of string) ⟷ acceleration (of string)

= changes in space

= changes in time

$$\frac{\partial^2 h(x,t)}{\partial t^2} = v^2 \frac{\partial^2 h(x,t)}{\partial x^2}$$

v = speed of wave