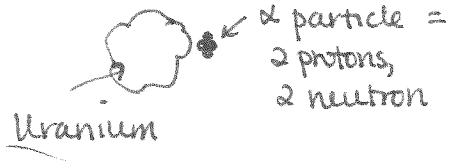
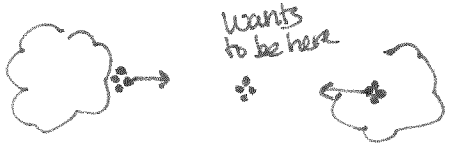
Review

heavy atom w/ α-particle bound to it



Uranium exerts a force on α-particle

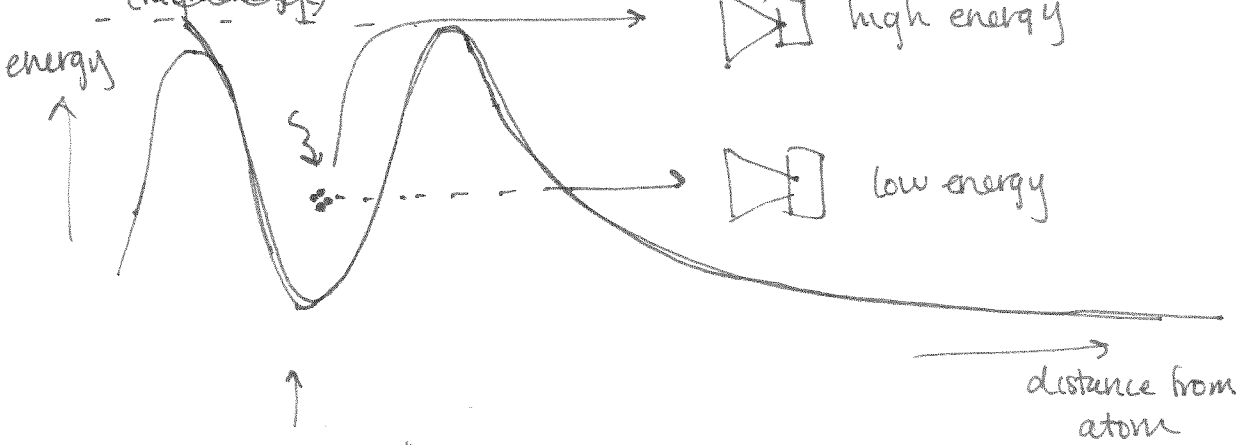


repulsive force
U doesn't want α sitting on top of it
high energy

attractive force
U pulls α toward it
(high energy)
~~high energy~~

repulsive force
⇄

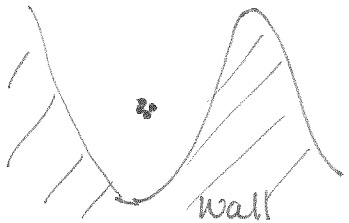
} these forces represent energies
(change in force = energy)



"energy box"
potential well

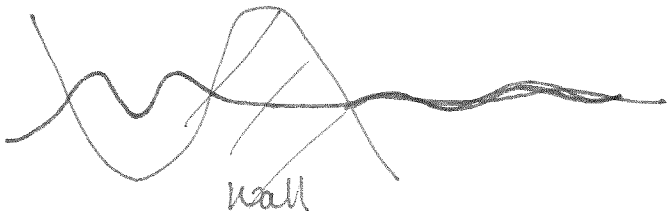
How can we describe what's happening?

x is particle →



classically, there is no reason to expect that particle can "walk through walls"

x is wave →



waves can exist where particles cannot (think sound + walls)

What's strange about this wave is that:

NOT a wave of particles

IS wave of probability

small probability of finding particle

small prob. of finding particle... inside wall / outside wall

called | quantum tunneling

Why does particle go through tunnel?

We don't know why, classically we have no reason to expect that it does. But it does happen, so we need a way to model this

How do we model this? describe it mathematical

How do we describe this process mathematically?

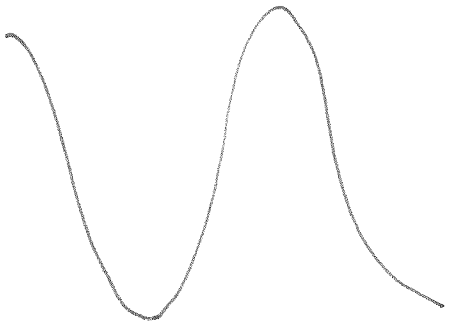
→ Schrodingers equation

equation that describes how the probability wave behaves
"wavefunction"

no derivation of ~~wave~~ S.E. (just like there is no derivation of Newton's laws)

Why do we care about the wavefunction?

→ contains all information we have about particle

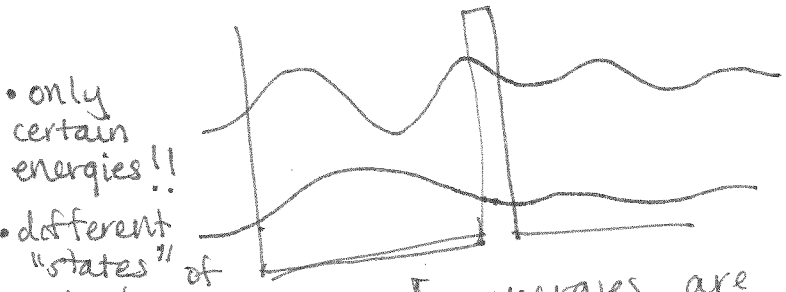


need to know 2 things:

1. how wave behaves (S.E)
2. what the potential well (energy box) looks like

↓

we approximated the shape of potential well:



if I throw baseball, I can throw it any speed

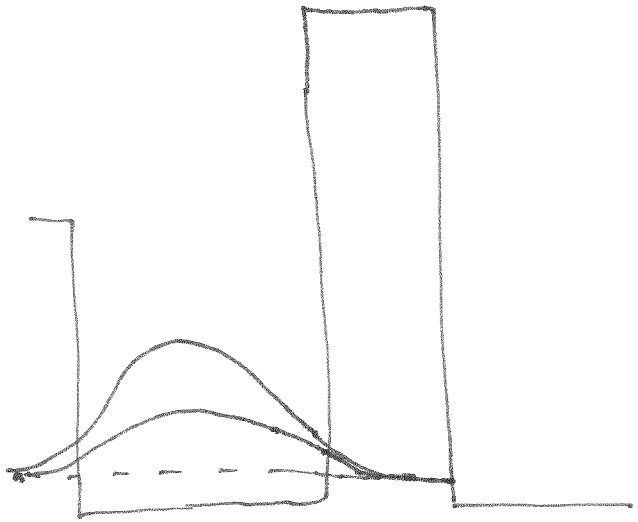
these electrons only have very specific speeds

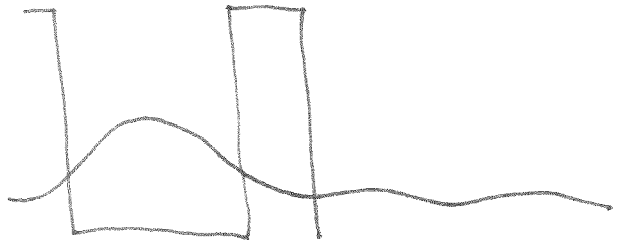
↑ energies are quantized

other things quantized - angular momentum

What determines whether we will see tunneling?

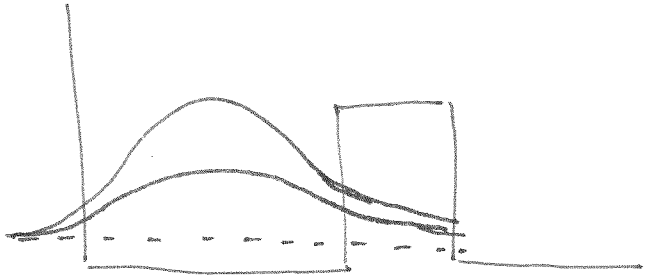
- height of wall
- thickness of wall

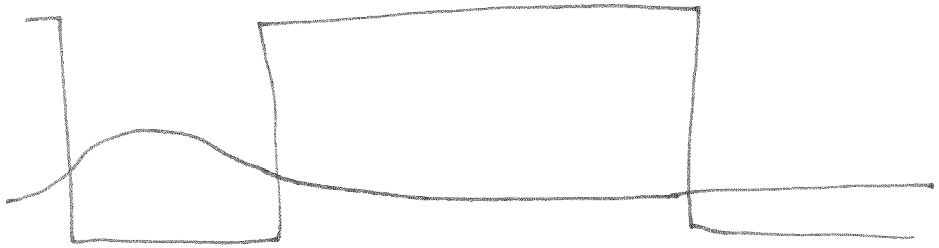




thickness of wall

height of wall
suppresses wavefunction
inside wall





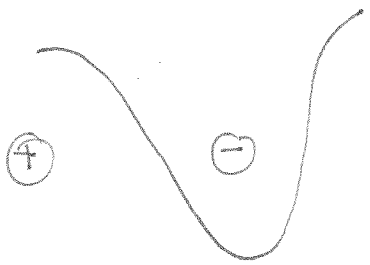
Why do we care so much about wavefunction?

→ tells us everything we can know about particle
(can't know everything!!)

W/ Reality:

Think about hydrogen atom (1 proton (+) + 1 electron (−))

proton exerts force on electron — keeps electron close to proton

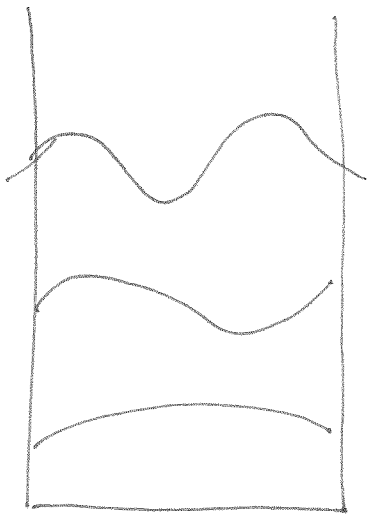


we keep drawing these forces / energies in 1D. But in reality, energy is 3D.

→ 3D potential well that keeps the electron in very specific locations

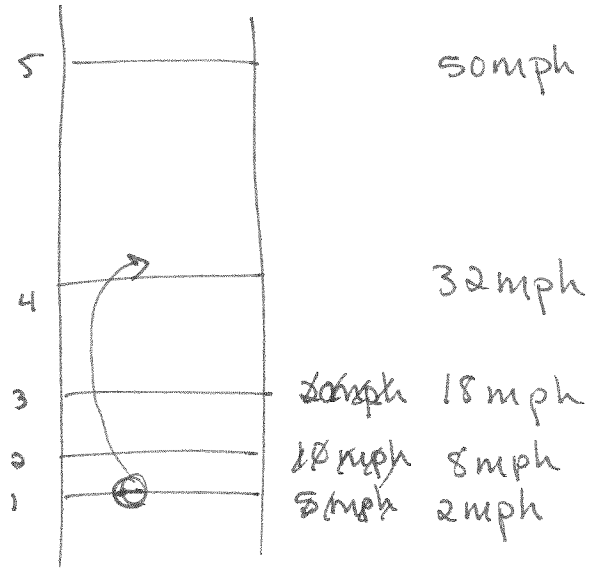
⊛ pass around toy hydrogen models — find electron

Spectroscopy



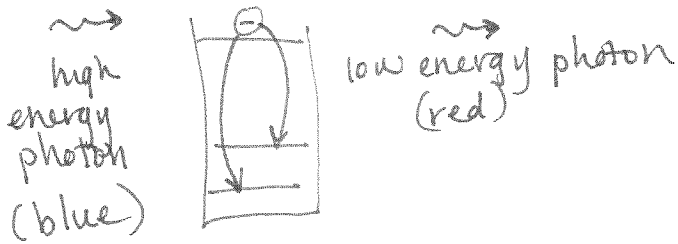
- electron lives on energy ladder

- can it hop btw rungs?
  - → yes, how?
    - → gets/gives energy



jump up - have to give electron some energy (typically we heat it up)

jump down - electron gives off energy (typically in form of light)



Types of Particles

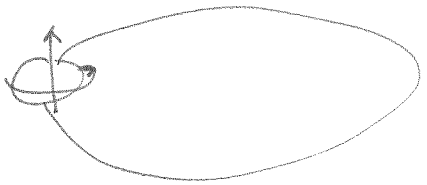
properties of particles

- mass
- charge

} properties that particle carries everywhere

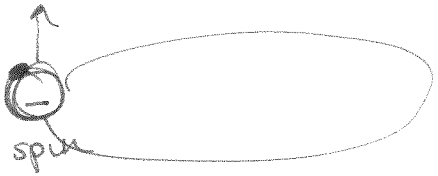
- spin

think of baseball/earth



2 different types of rotation

both can change / have different values



angular momentum (can have different values)

is fixed for given particle

(direction can be up or down)

Types of particles

Two fundamental types of particles:

bosons: integer spin (0, 1, 2, 3...) ex photon (light), group atom w/ p, n, $2e^-$ $\frac{1}{2}+\frac{1}{2}+1=2$

fermions: half integer spin ($\frac{1}{2}, \frac{3}{2}, \frac{5}{2}$...) ex. single electrons, protons, neutrons

Pauli-exclusion principle: no two fermions can occupy the same quantum state (but bosons can!)

Bosons

Cool Bosons ↓

Fermions

Types

See this very different behavior manifested in two very different situations:

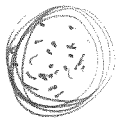
Bosons

group of Bosons all in different states

all have different momenta

looks like group of individual particles

cool them down to 10^{-9} K



"collapse" into single quantum state

all have same momenta, move together like one giant particle!

Bose Einstein Condensation

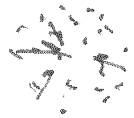
Fermions

neutron star - dense (lot of neutrons in area)

~~neutrons attract each other~~

no charge - no electrostatic force

mass - gravitational force



gravitational force wants to pull all neutrons together to form black hole. What keeps this from happening?

↓ P.E. principle balances

degeneracy pressure
gravitational force

Entanglement

n, ℓ, m_ℓ, m_s

can create

consider 2 electrons w/ same energy, same momentum,

→ know they can't have same energy - what is different?

→ direction of spin

↑ ↓

know that if one is "spin up",
other must be "spin down",
but we don't know which is which

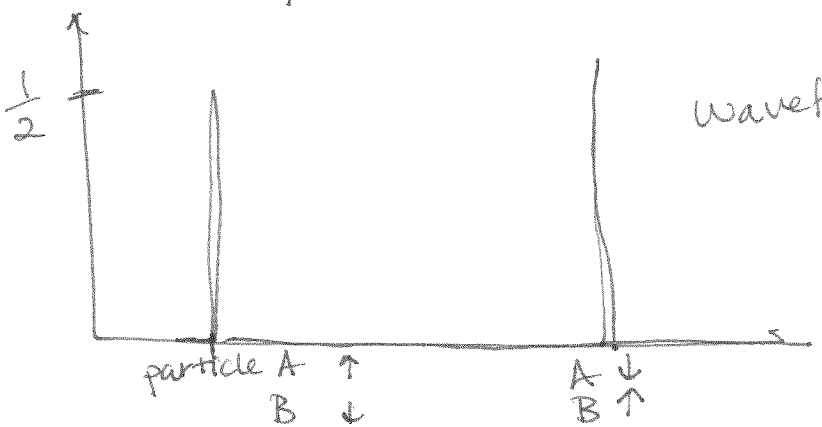
these two particles are tied together in some way, connected by the fact that they must have opposite spin directions

→ we cannot separate the wavefunctions $\psi_A(x)$, $\psi_B(x)$

→ one wavefunction for both

$\psi(x_A, x_B)$

spin space

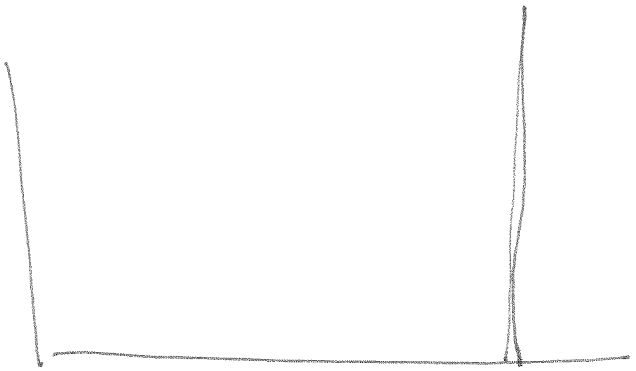


wavefunction

Entanglement

If we don't look at the particles, we don't know which is which,

But if we look (make a measurement):



know for certainty that
A ↑
B ↓

↑ this is called wavefunction "collapse"

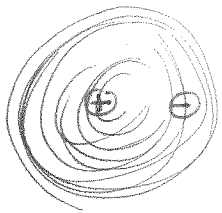
before measurement → wavefunction was delocalized

after " → collapse wavefunct to single state

mathematically, this is not well understood.
We don't know what happens when we make a measurement

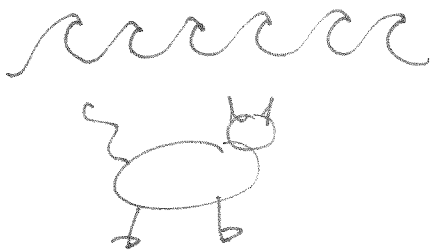
Bigger picture

wavefunction



atom (H)

molecules



ocean

or

cat

earth

solar system

solar system