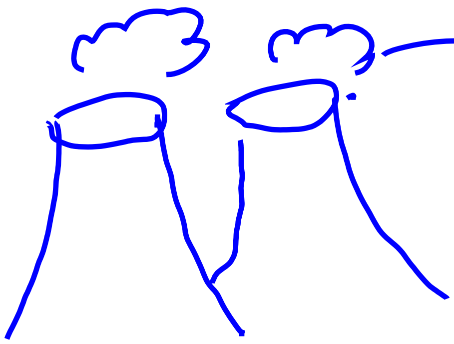
What do you think of when you talk about nuclear technology?

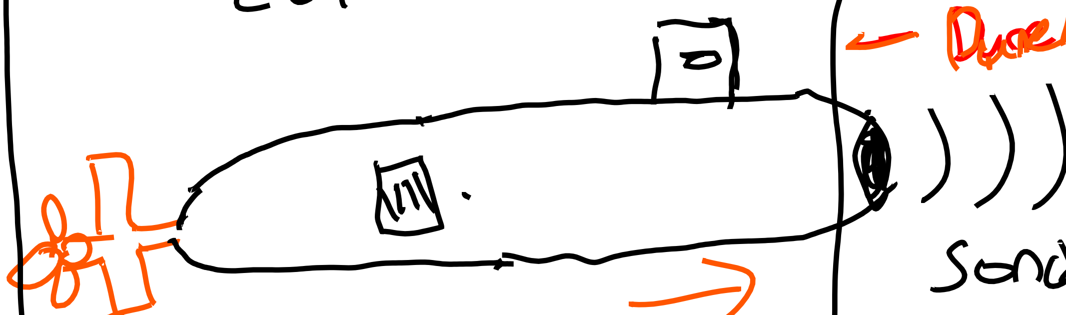


Picture 1

World War II

Picture 2

Cold War



Picture 3

26 knots

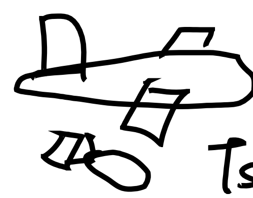
Gen Y

- Red Alert 2
- Yuri's Revenge
- C & C
  - ↳ Generals
  - ↳ Tiberium Wars
- Starcraft II
- ~~Dune~~ Dune part II
  - ↳ atomics

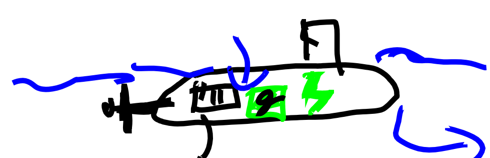
What's in the cold war?

- Nuclear tests
  - ↳ USA
    - ↳ Castle Bravo
    - ↳ Ivy Mike
    - ↳ ~~Operation~~ Baker (Bikini Atoll)
  - ↳ Russia
    - ↳ Tsar Bomba.
  - ↳ China
  - ↳ India
  - ↳ France
  - ↳ UK.

Bloons TD6.



U-boats.



- Submarines
  - ↳ reactors
  - ↳ mobile missile silo (SLBMs)

Nuclear Submarine movies.

U-571

↳ Hunt for the Red October

↳ Crimson Tide

Pop culture

- Nuclear is dangerous
- Nuclear is scary
- Nuclear is exotic

Nuclear accidents.

↳ Three Mile Island

↳ Chernobyl

↳ Fukushima Daiichi?

↳ check spelling

Nuclear safety.

For next lecture

① Accidents + pop culture

↳ BBC's Chernobyl.

② Nuclear security & cold war arms race

③ Outline of technical stuff.

cold war.

1945 2x atomic bombs
plane

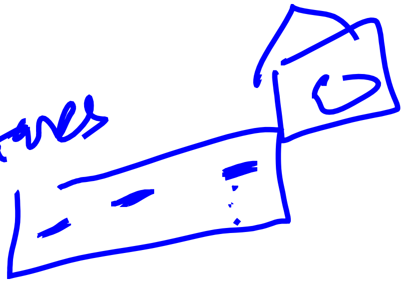
1945 – 1949 US → only major nuclear power

1949 USSR → explodes 1st atomic bomb.

Countervalue
drop bombs on cities

Counterforce
drop bombs to kill opponent's nuclear capability

airplanes



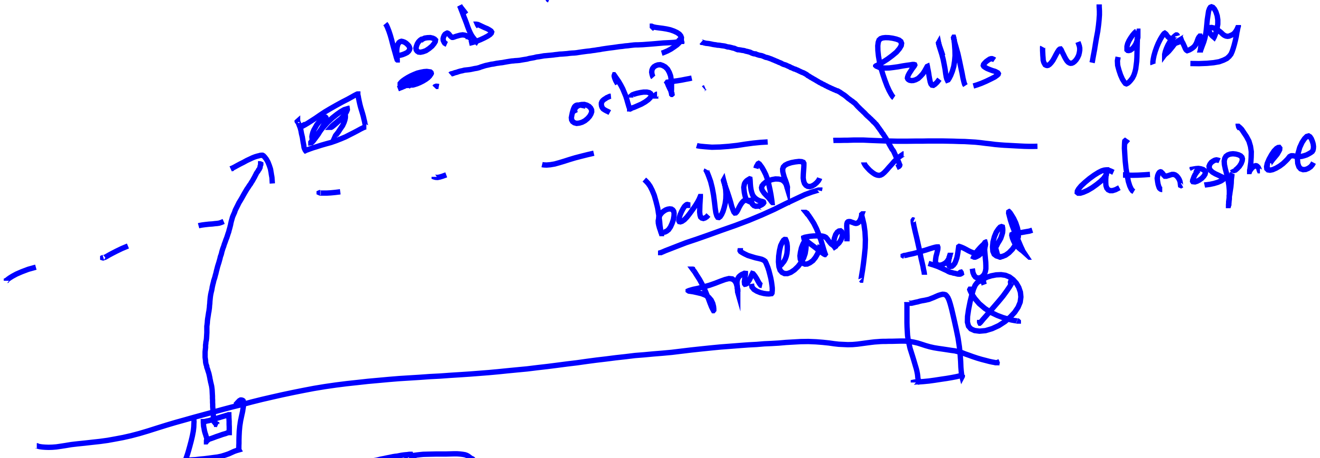
Red Alert

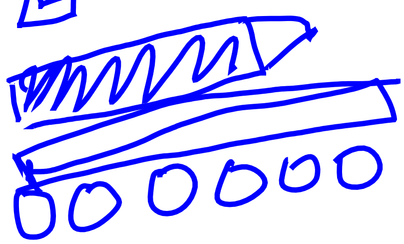
Red Alert 2

ICBMs

missile silos

Intercontinental Ballistic missile (ICBMs)





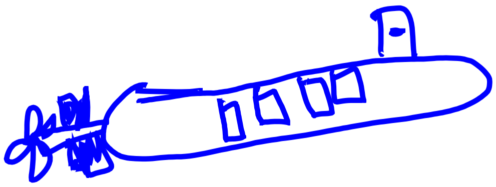
mobile ICBM

- SR 71 blackbird
- U2

nuclear deterrence

mutually assured destruction

MAD



submarine launched ballistic missiles (SLBMs) ← accuracy is a big problem for SLBMs.

① stay underwater very long

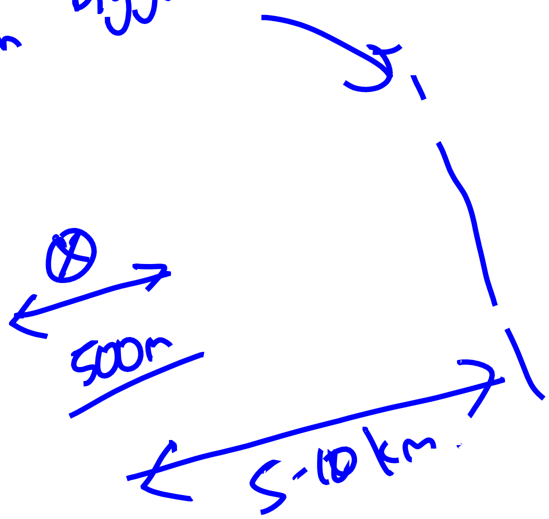
$\boxed{\text{nuclear propulsion}}$ **

② Big big explosions, much bigger than hiroshima.

$\boxed{\text{H-bomb}}$ **

↑

tech.



nuclear triad.

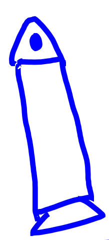
Air delivery

triad

SLBMs — ICBMs

Nuclear arms race → space race

rocket technology



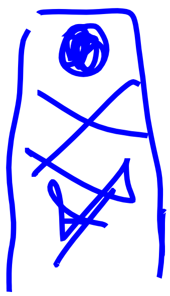
- GPS
- Lunar expeditions
- communications networks. — SpaceX
- telescopes → Hubble space telescope
- Advanced science & technology

Lecture 3

Manhatton project.

$\boxed{1942}$

trinity

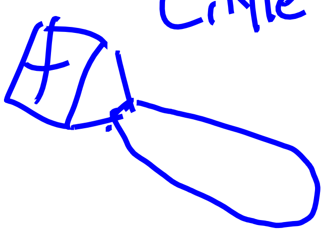


Pu-239

New Mexico

* Oppenheimer cooked Nasi Goreng

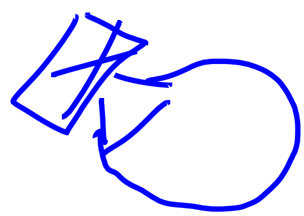
Little Boy



Hiroshima Bomb

U-235

Fat man



Nagasaki

Pu-239

Concepts w/ as little mathematics as possible

Physics

Pu-239

U-233

U-235

$^{235}_{92}U$

A (total no. of neutrons + protons)

Z (proton number)

$\boxed{^1_0 n} \longrightarrow$

$\downarrow$ fission

$^{235}_{92}U + {}^1_0 n$

$\swarrow \quad \downarrow \quad \searrow$

$^1_0 n \quad {}^1_0 n \quad {}^1_0 n$

$^1_0 n + {}^{238}U \rightarrow {}^{239}U \rightarrow \dots \rightarrow {}^{239}Pu$

Quantum Physics

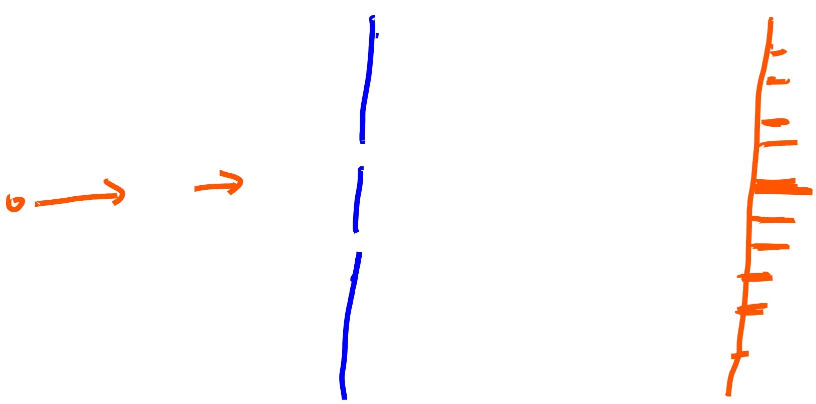
Key Idea of Quantum Physics

matter (protons, neutrons, electrons)

particle — wave

"billiard balls"

Young's Double Slit experiment

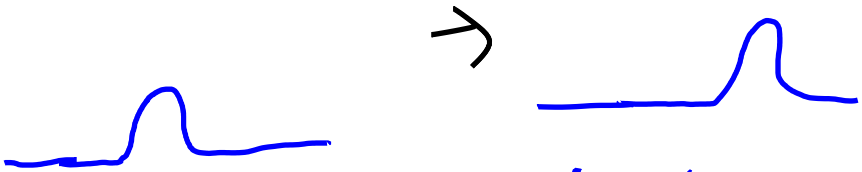


Interference Pattern.

Light → electromagnetic wave.

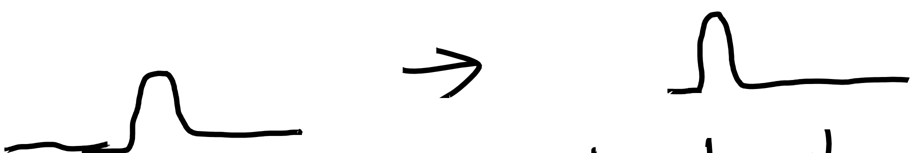
Waves & Superposition

$t=0$ $t=1$



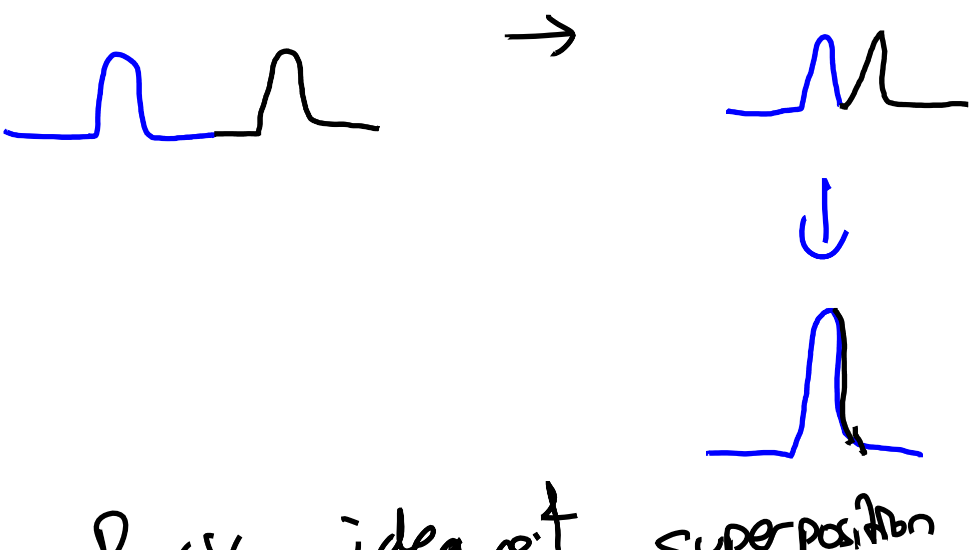
wave is travelling to ē right.

$t=0$ $t=1$



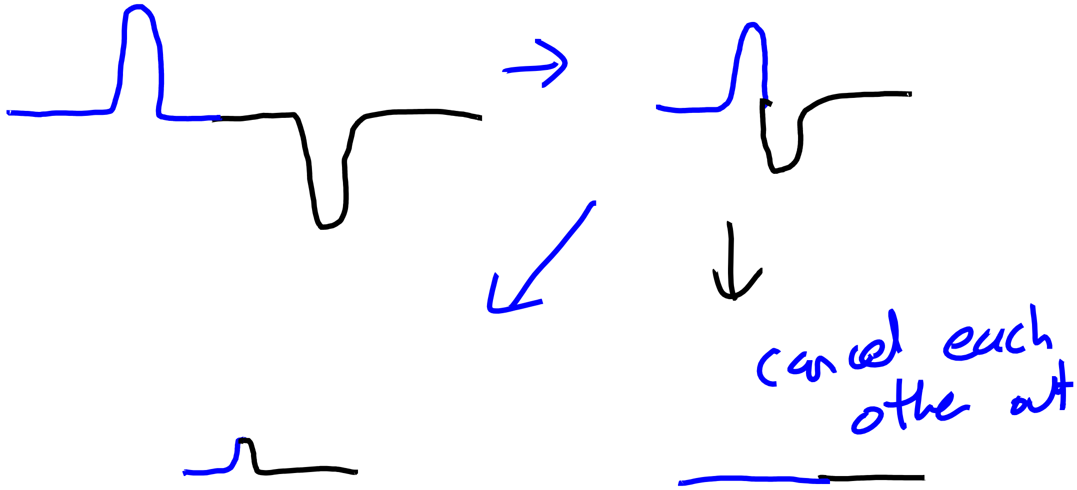
wave is traveling to the left

$t=0$ $t=2.5$?



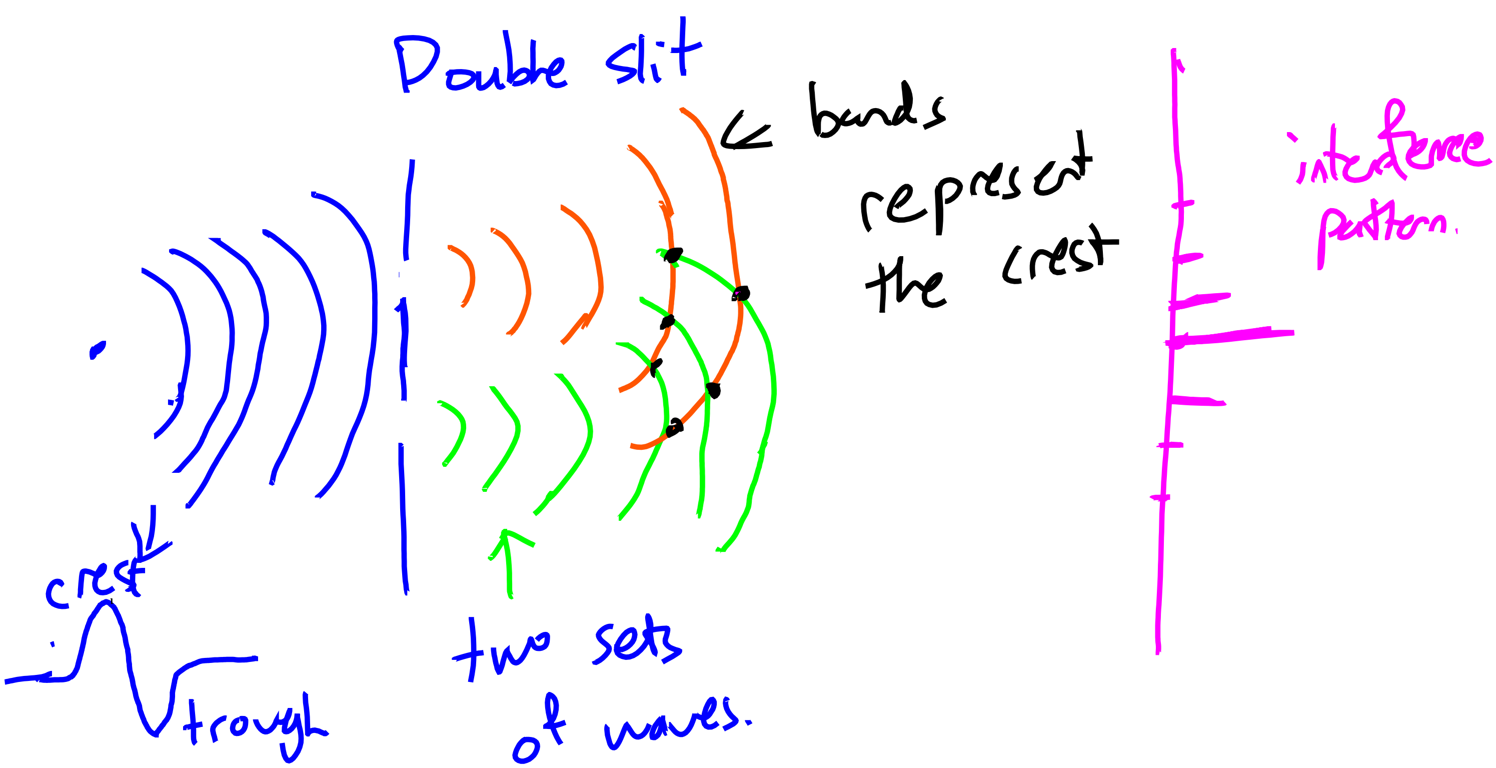
Big wave is contribution (sum) of two smaller waves.

Basic idea of superposition



(1) when waves build on each other → constructive interference

(2) when waves cancel each other out → destructive interference.



Lecture 4

Lot's of things in nuclear physics can be explained by waves.

---

consequences of wave behaviour

- electrons in atoms have discrete energy levels
- protons & neutrons in the nucleus have discrete energy levels

electrons fired one at a time

in quantum physics, the act of observation changes the experimental results

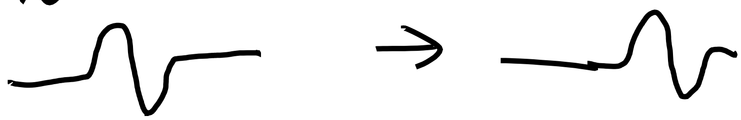
---

Discrete Energy levels

wave behavior → discrete energy levels.

standing waves.

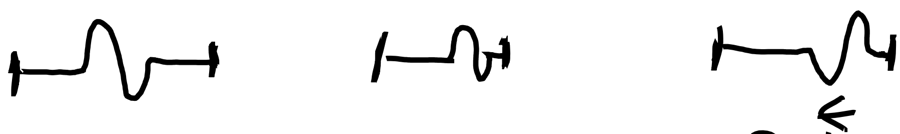
wave on water



"free"

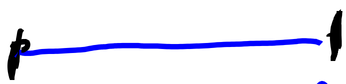
I make the wave "not free"

make the ends "stuck"



wave bounces back & forth & interferes with itself.

Guitar string

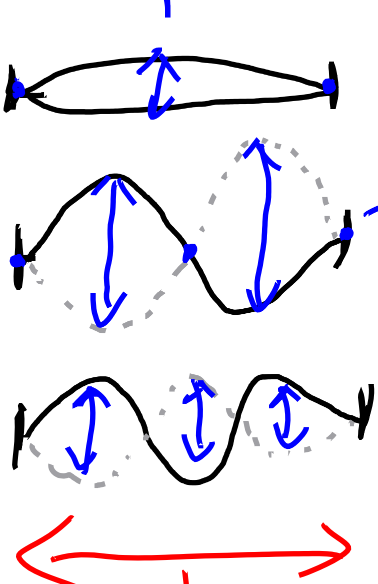


peak & trough → antinodes

$n = 1$ 2L

$n = 2$ — nodes L

$n = 3$



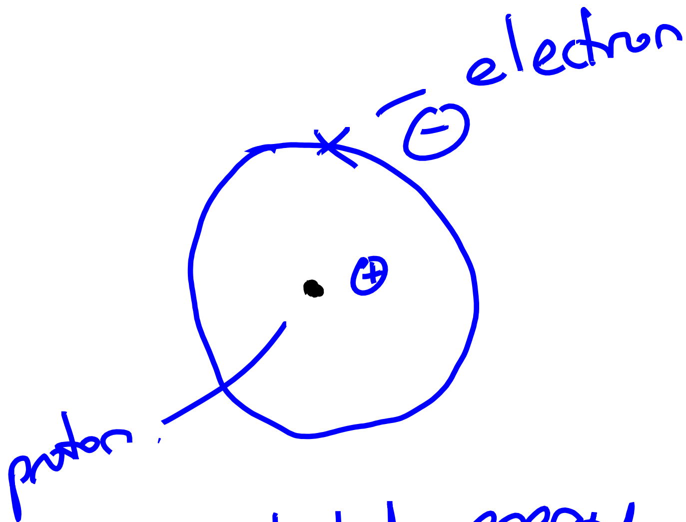
L

You can have a certain number of peaks & troughs.

You can store energy at different frequencies.

$v = f\lambda$

The frequencies (wavelengths) where you can store energy is **fixed**.



Hydrogen atom

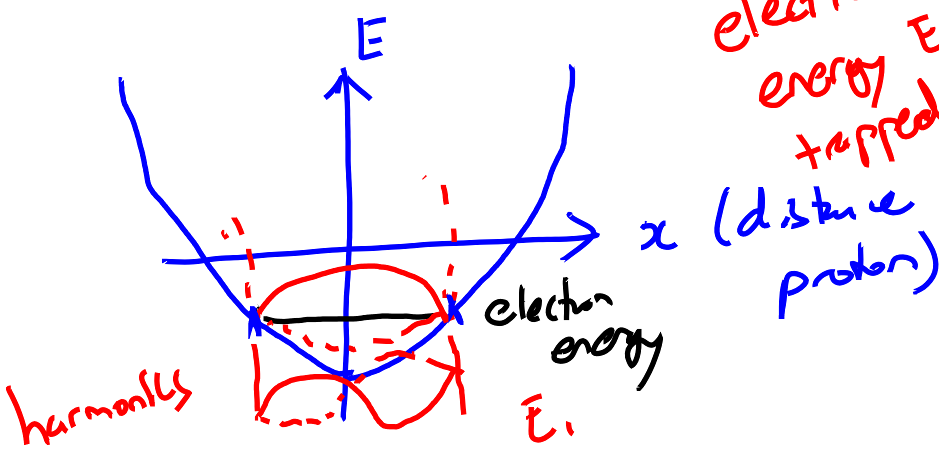
charge of each particle

$$F = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}$$

distance between particles.

potential energy.

electron has energy E_1 & trapped in potential well



electron's energy is not high enough to escape proton.

① Electrons behave as waves

② movement of electron waves is

Standing electron

restricted as electron energy < waves.
potential energy req'd to escape.

↳ standing waves consequence
1. frequency / wavelength is restricted ✓
2. Energy is correlated to frequency
3. Energy levels are therefore ✓
restricted.

---

what is true of electrons is also
true of the nucleus.

1. protons / neutrons behave as
waves

2. movement of proton / neutron
waves restricted by attractive
forces in nucleus → strong nuclear
force

↳ give rise to fixed energy levels with $\bar{e}$ nucleus.

Energy is "quantized"

↳ fixed energy levels.

If you are interested in the math.

Go read up:

- Schrodinger's equation
- wave function $\boxed{\psi(x)}$ ψ = "psi"

↳ "probability waves"

$$|\psi(x)|^2$$

↳ $\psi(x) \times \psi^*(x) \Rightarrow$ probability.

Lecture 5

schrodinger's equation

↳ implications

① Guitar string analogy

↳ Infinite square well.

↳ 1 D

↳ "force field" is infinite

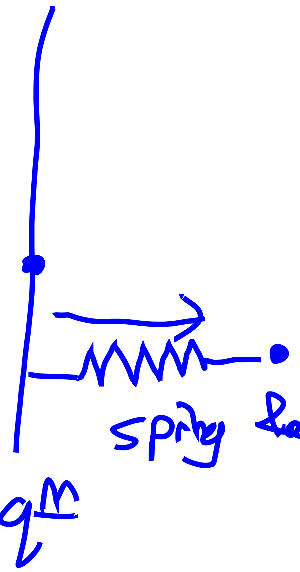
In ~~real~~ real life, force fields are finite

② Finite force fields

↳ 1D

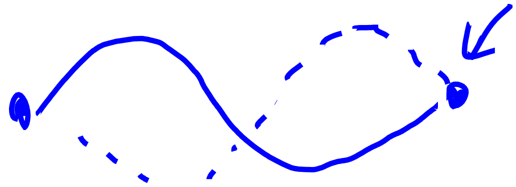
↳ finite force field,
finite well

↳ simple harmonic oscillator



- finite force field
- $F = kx$

Guitar string

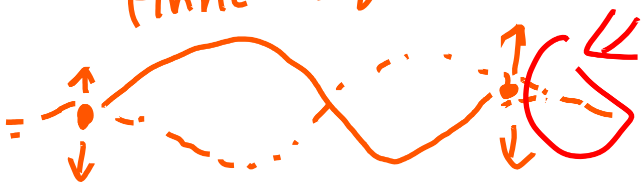


ends are fixed

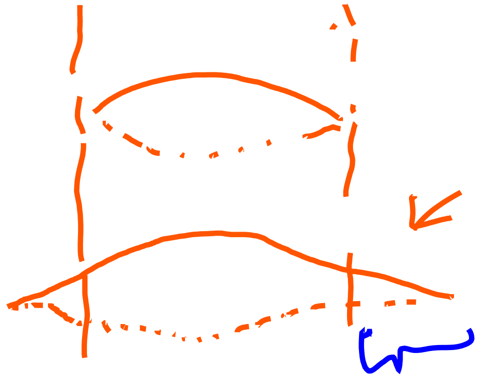
Infinite sq well

Guitar string

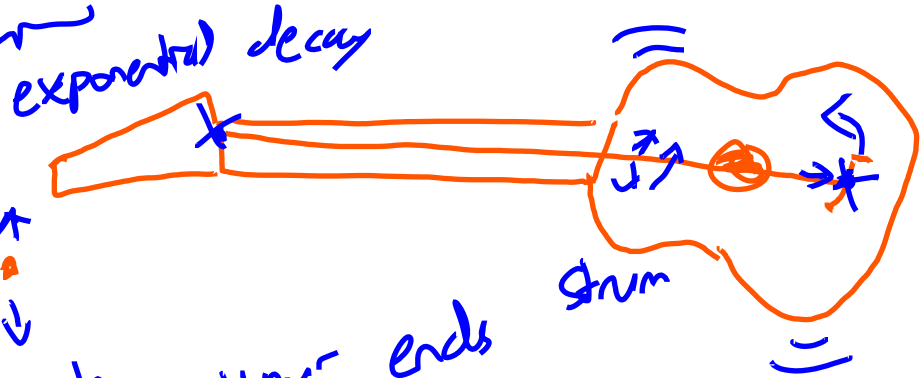
Finite sq well

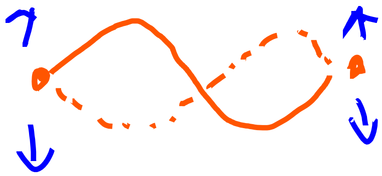


spillover effect



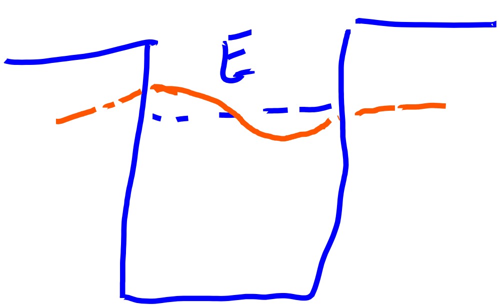
ends "leak out"





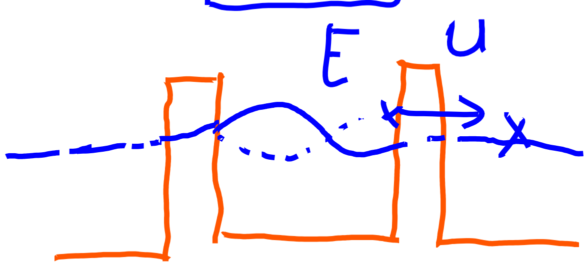
In reality, your ends vibrate

What do waves "leaking out" mean?



U = potential energy

$E < U$



$E < U$

$E = 1J$

$U = 2J$

$|\psi(x)|^2 \Rightarrow$ probability

particles leak through barrier

∴ Quantum Tunnelling

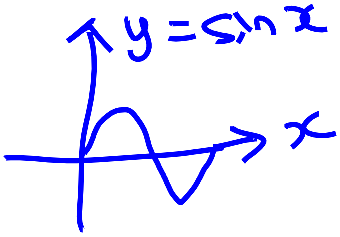
↳ Alpha decay

↳ Fusion process in the sun.

fusion

Lecture 6

In previous discussion, we talk about 1D waves, sine & cosine waves, or exponentials



reality : 1D geometry is not representative of an atom or nucleus, we need

3D version.

Force fields are spherical in nature : $F \propto \frac{1}{\underline{\underline{4\pi}}\varepsilon_0 \underline{\underline{r^2}}}$ ← sphere surf area $= 4\pi r^2$

↳ need a spherical version of the sine wave

Spherical harmonics

↳ 3D spherical version of sine waves

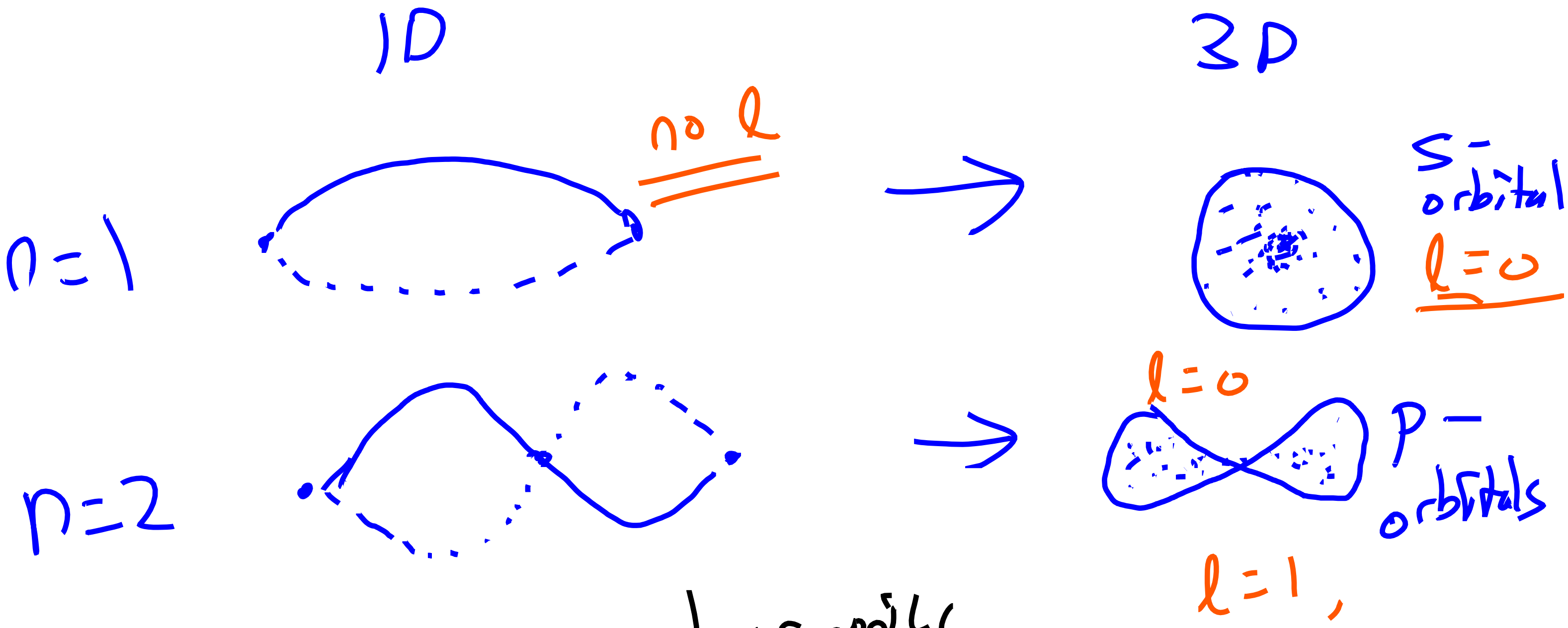
↳ explored in hydrogen atom

3D matter wave
electron 'cloud'

↳ implications of spherical harmonics

↳ angular momentum becomes important (l)

↳ angular momentum projection no. becomes important (m)



In spherical harmonics

↳ $\underline{n, \ell, m}$ become important in electrons

↳ same applies to the nucleus. protons & neutrons

↳ strong nuclear force is responsible for force field rather than electric.

Summary: Implications of Schrodinger's equation

① Infinite Sq well

↳ discrete energy levels

② Finite well (Simple harmonic oscillator)

↳ Quantum Tunnelling

③ 1D → 3D spherical harmonics

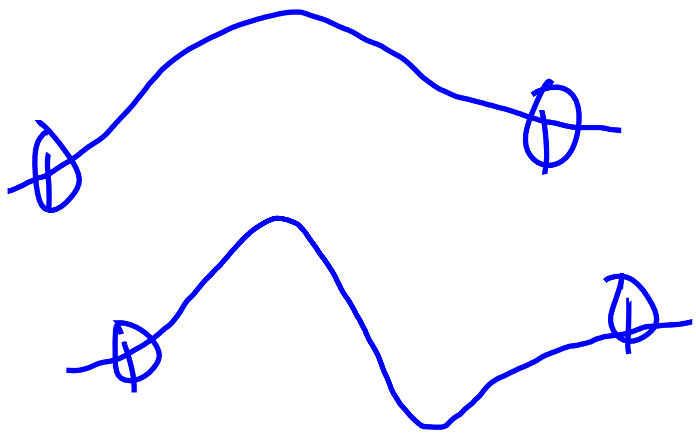
↳ l (angular momentum) becomes important

↳ m (angular momentum projection) becomes important

Lecture 7

ψ

n = 1

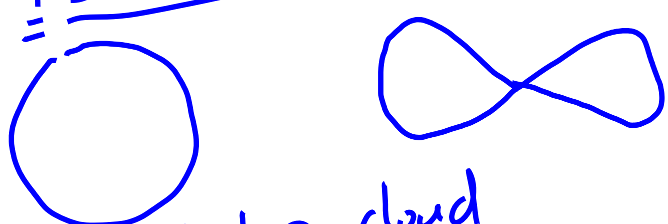


n = 2

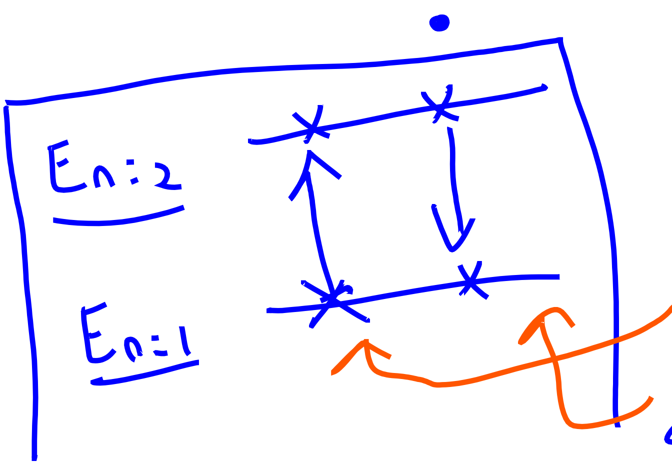
$\leftarrow \lambda_{n=2} < \lambda_{n=1}$

$l=0$ $\uparrow$ $\lambda = \frac{h}{p} \downarrow$

1s-orbital　　2p-orbital ($l=1$)



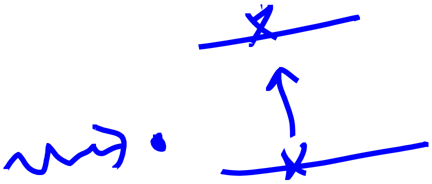
electron cloud



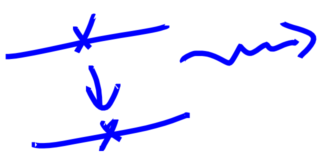
excitation

de-excitation

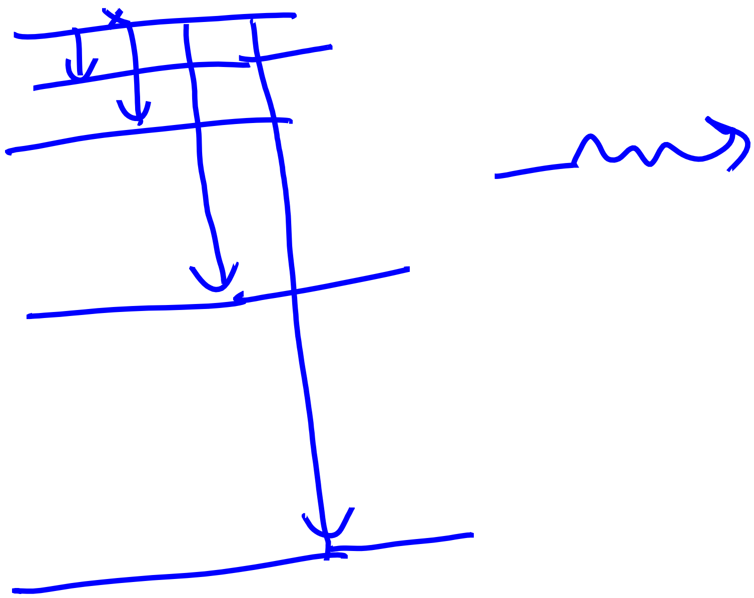
light



excitation



light energy = $E_{n=2} - E_{n=1}$



emitted light from excited Hydrogen atom will have fixed energy

fixed energy → fixed wavelength.

→ characteristic spectrum that Hydrogen atom will have when de-exciting

Different atoms have diff electric field (force fields) → Energy level is diff

→ Wavelength/spectra is different.

In the nucleus, strong nuclear force is several orders of magnitude **stronger** such that the energy level difference is about ~1 million times **more**.

$1\,eV = 1.602 \times 10^{-19}\,J$

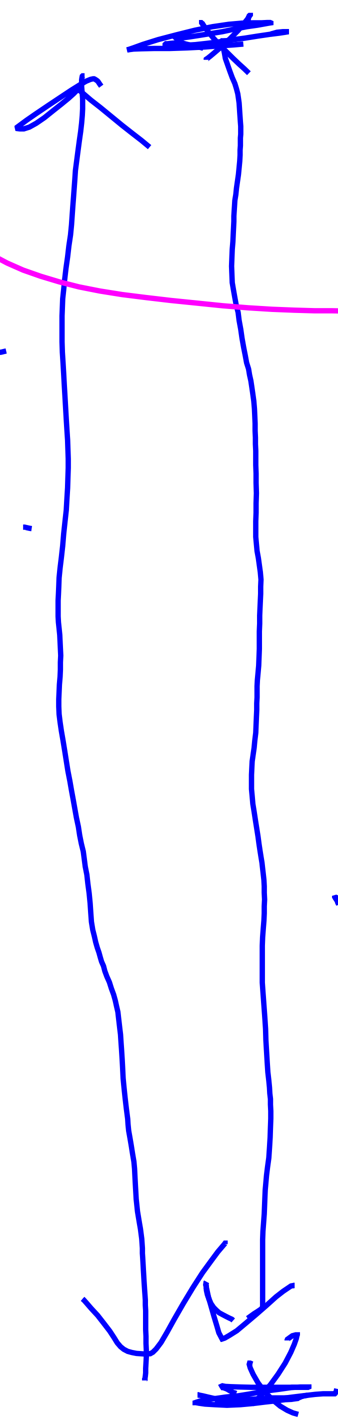
H electron transitions

13.6 $\underline{eV}$ ↕ ≈ 1 nm

nuclear transitions

protons

30 - 100x



keV.

~ MeV.
$= 10^6$

not to scale

γ - decay.

light ⤳ γ-rays

how many pages wld we need to draw this to scale?

100 x $\underline{10,000}$ page

$10^2 \times 10^4$

nuclear energy is 1 million times more dense than $\underline{\text{electron}}$ energy chemical bonds

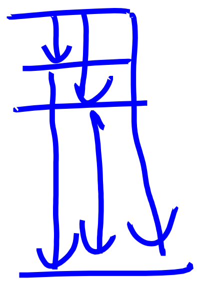
↳ fossil fuel

↳ battery

Nuclear energy is super dense.

Lecture 8

$\text{nucleus}^* \rightarrow \text{nucleus} + \gamma$

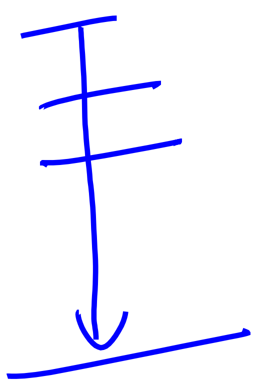


$\boxed{\text{Individual proton transitions}}$

"orbiting"

p $\xrightarrow{\gamma}$

2p
4n



3p
4n ^{7}Li

Main ways for nuclei to have

Excited states (Gamma decay)

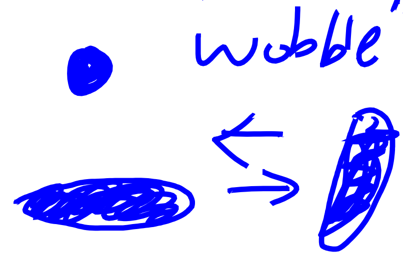
1. • Individual protons excited

2. collective motion.

$$^{238}U \to {}^{238}U^{*}$$

γ p

"nuclear wobble"



"vibration wave"

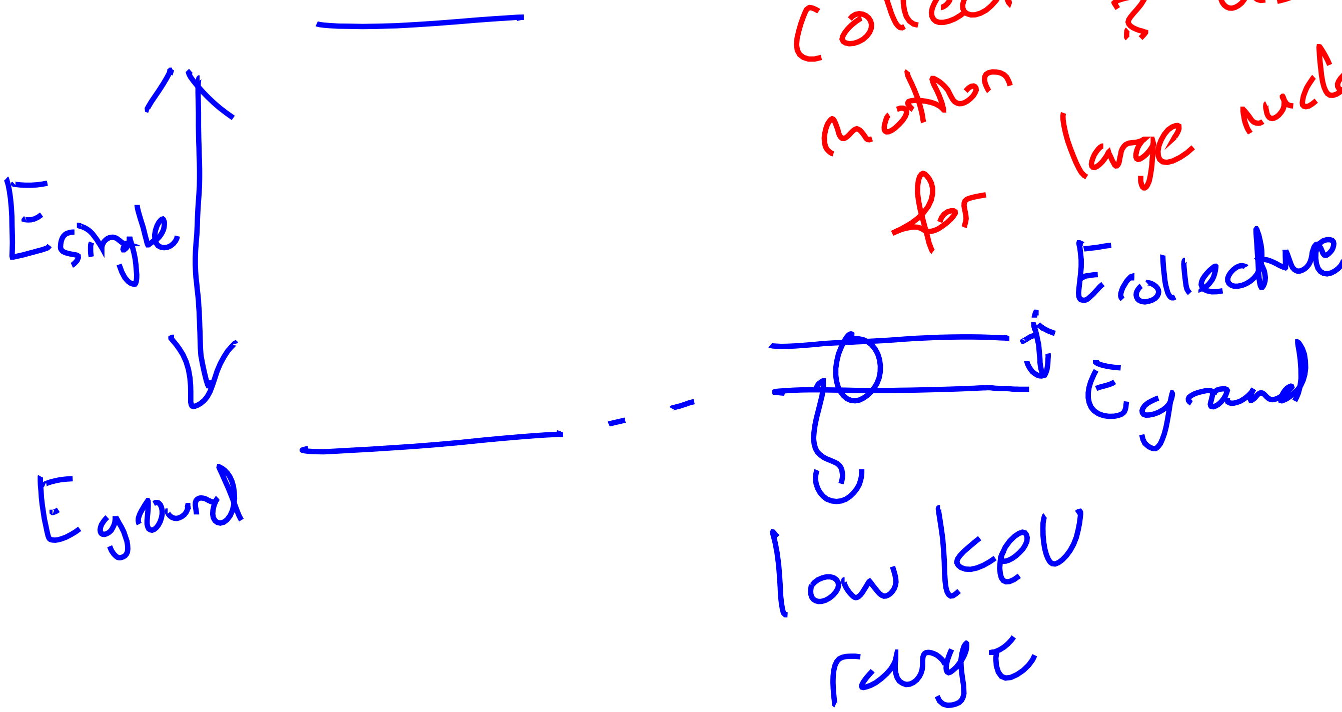
"liquid drop"

→ "shaking"

→ "spinning"

Individual particle excited states energy > collective vibration excited state energy

collective motion usually for large nuclei



How do nuclei get excited?

① photon absorption

② inelastic collision.

$\boxed{\frac{1}{2} m v_1^2}$ v_1 → $p_1 \rightarrow p_2$ (rest)

p_1 (rest) v_1 → p_2 $\boxed{\frac{1}{2} m v_1^2}$

– momentum conserved

– kinetic energy conserved

↓

"no friction"

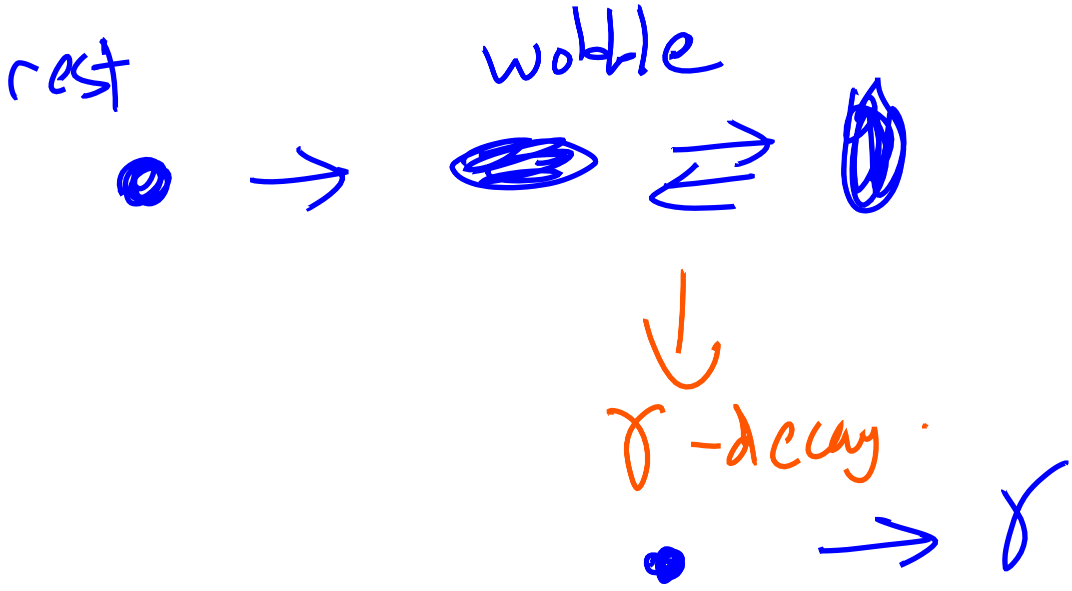
elastic collision

inelastic collision → "friction"

$\boxed{KE_1}$ n → ^{238}U → KE_2, KE_3

$$KE_1 > KE_2 + KE_3$$

where did the energy go?



③ nuclear reactions

$$^{1}_{0}n + {}^{238}U$$

$\Big\downarrow$ "fuse" neutron absorption

$$^{239}U^{*}$$

excited U-239

$$\Big\downarrow$$

$$^{239}U + \gamma$$

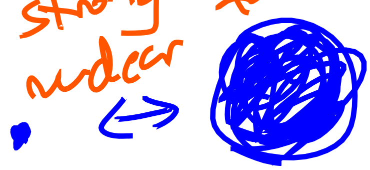
gamma Photon.

(n, γ) reactions → Important

Why did neutron absorption result in excited state?

↳ boils down to forces.

strong nuclear force. → attractive.

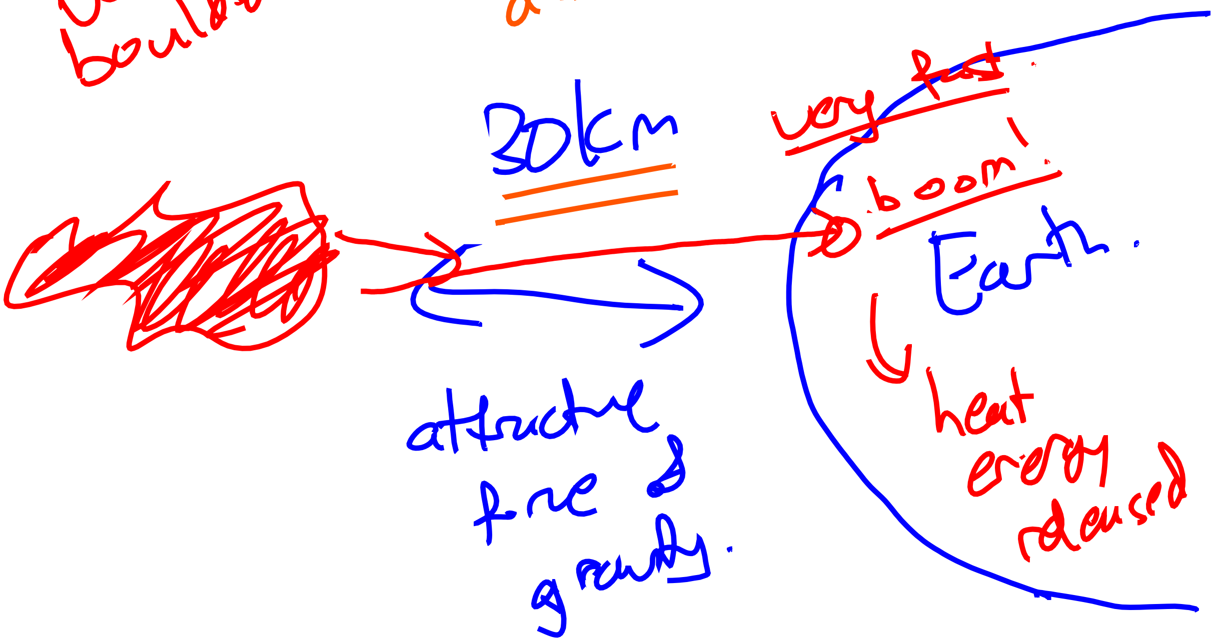


^1_0n $\quad$ ^{238}U

attractive force + separating distance

50 km wide boulder

Separating distance



$^{238}U \rightarrow {}^{4}_{2}He + {}^{234}Th^{*}$

$\boxed{\alpha\text{-decay}}$

^{137m}Ba.

$^{137}Cs \xrightarrow{\beta^-} {}^{137}Ba^{*} \rightarrow \gamma\text{-rays}$

β^-

^{137}Ba.

$\boxed{\alpha\text{-decay}}$ schrodinger's eqⁿ

$^{238}U \to {}^{4}_{2}He\,(\alpha) + {}^{234}Th$.

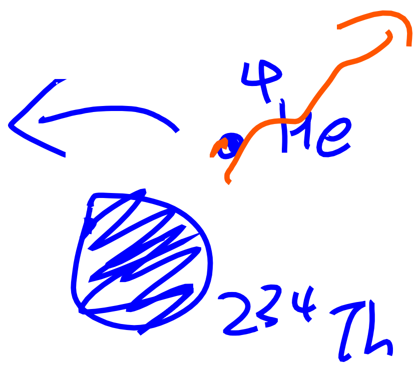
schrodinger's eqⁿ

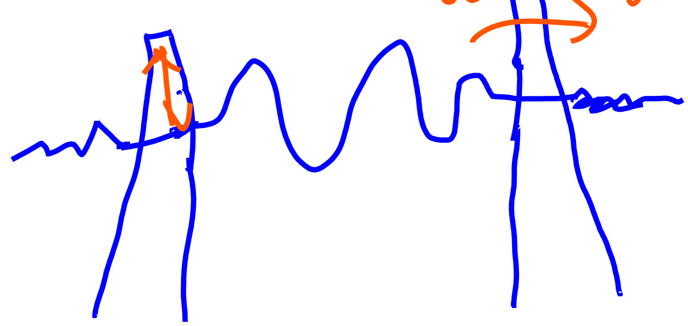
$\boxed{\beta\text{-decay}}$

$\boxed{\gamma\text{-decay}}$

$^{137}Cs \to {}^{137m}Ba^{*} \to {}^{137}Ba + \gamma$

Quantum Tunneling.





Beta decay is special

↳ relies on weak nuclear force.

β - decay & weak nuclear force

$\boxed{\text{Lecture 9}}$

electron cloud.

- electrons ~~Quarks~~ are <u>not</u> affected by attractive force (strong nuclear force) in the nucleus.

  ↳ not all particles are affected by strong nuclear force

  ↳ affected by strong nuclear force = Quarks

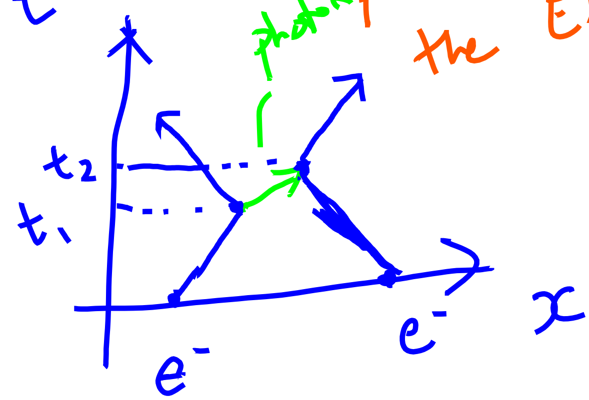
Weak nuclear force

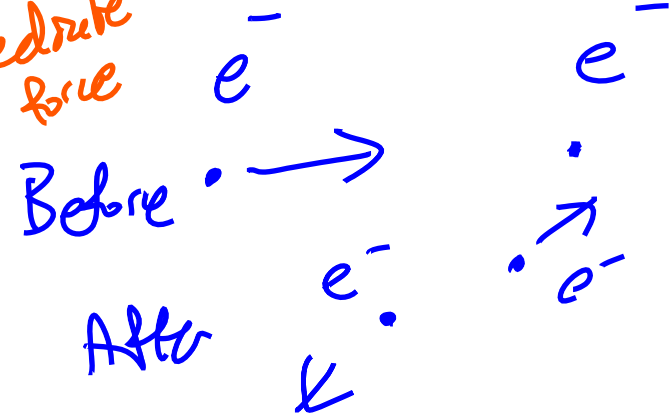
CM $=$ "Centre of mass" frame of

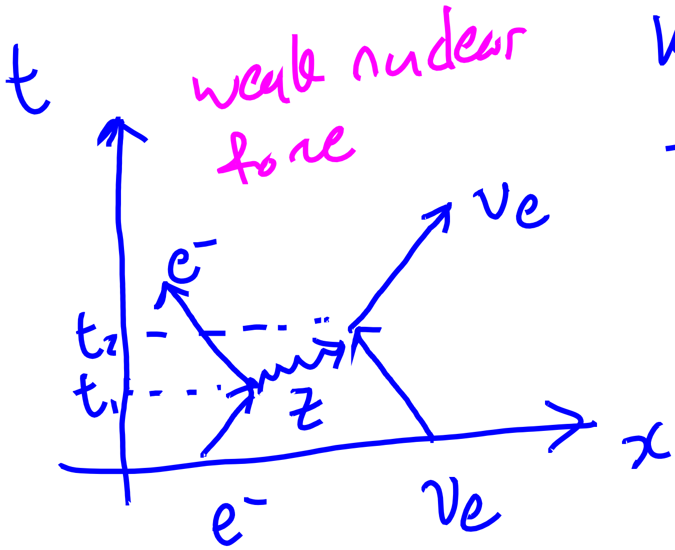
$\circ \rightarrow \quad \leftarrow \bullet$

Feynman Diagram

photons mediate the EM force





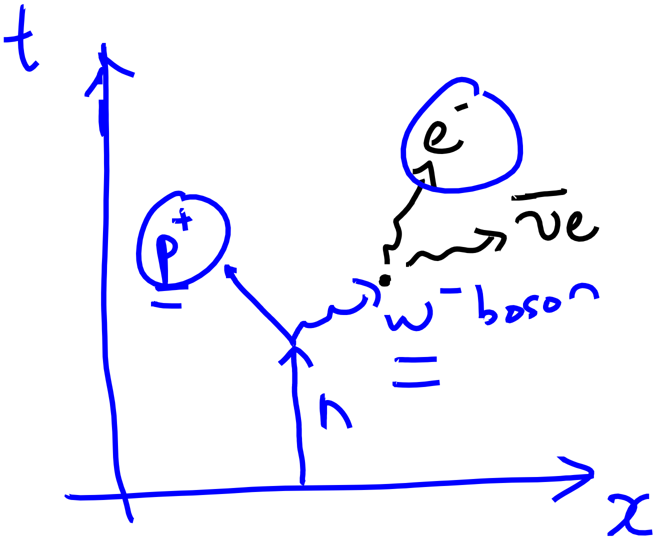


weak nuclear force

- bosons carrying force
- W^-, W^+, Z
- photon is a boson

- neutrinos are ν_e, neutral charge, affected only by gravity & weak nuclear force

- electrons collide w/ neutrons cos of weak nuclear force



W^- boson

(1) neutron splits in two.
→ proton (+)
→ w^- boson (−)

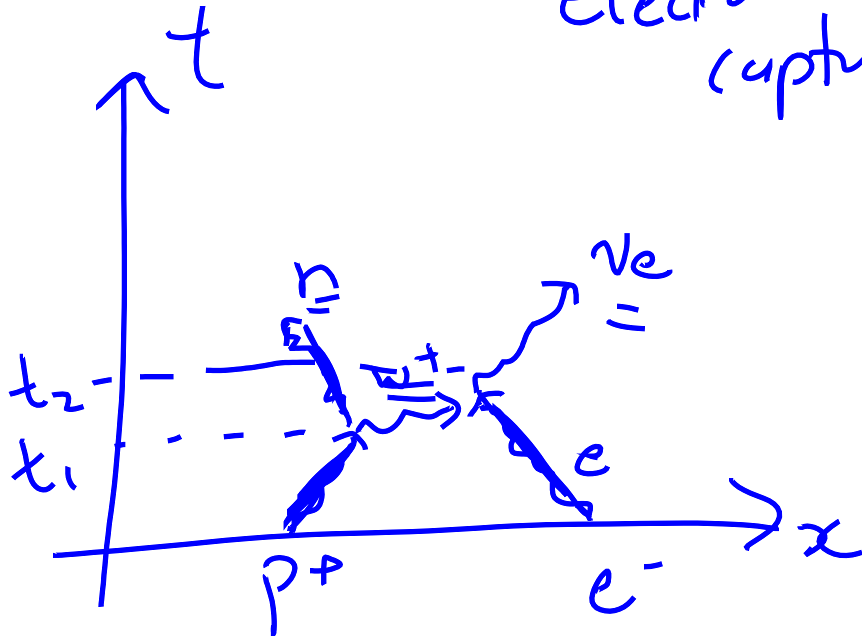
β^--decay

(2) W^- boson decays into e^- & $\bar{\nu}_e$

- lone neutrons are unstable
  ↳ $t_{1/2} \sim 10.5$ mins.

- neutron can also decay in unstable nuclei eg. Cs-137.

electron capture.



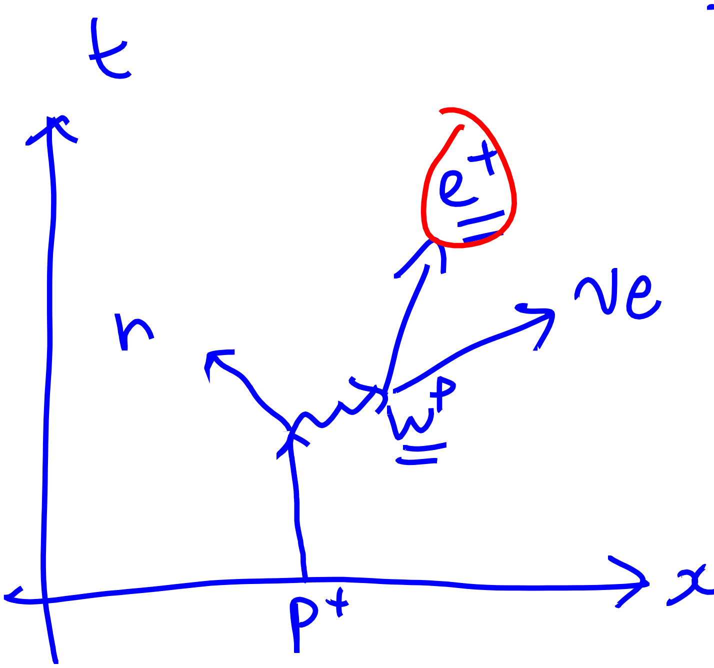
$\underline{\underline{W^+}}$ boson.

e^+ is missing.

β^+ decay.

needs a lot of energy.

<u>β^+ decay.</u>



$e^+ + e^-$

$\downarrow$

2γ rays.

(photons)

<u>511 keV.</u>

positron emission tomography

(PET).

Some unstable nuclei can supply energy for β^+ decay.

binding energy