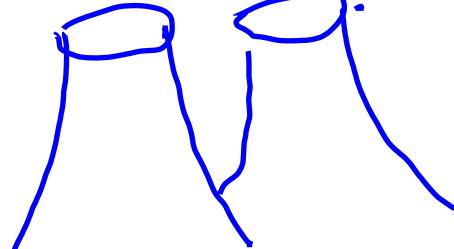


What do you think of when  
you talk about nuclear  
technology?

3 clouds radioactive?



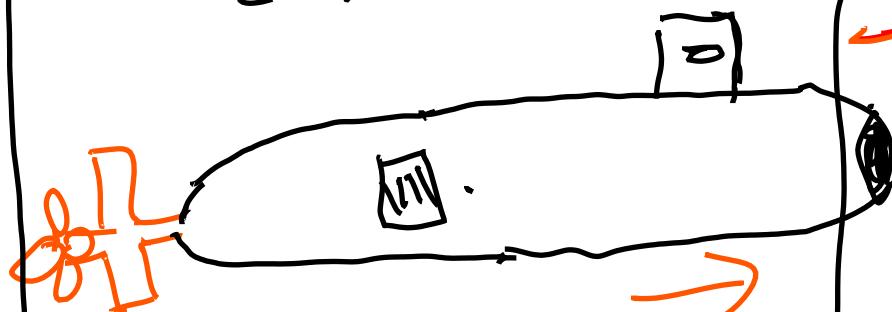
Picture 1



Picture 2

- Gen Y
- Red Alert 2
  - Yuri's Range
  - C & C
    - ↳ Generals
    - ↳ Tiberium Wars

Cold War



Picture 3

- Starcraft II
- Dune Part II
  - ↳ Atomics

))))

Sonar

# What's in the cold war?

## - Nuclear tests

↳ USA

↳ Castle Bravo

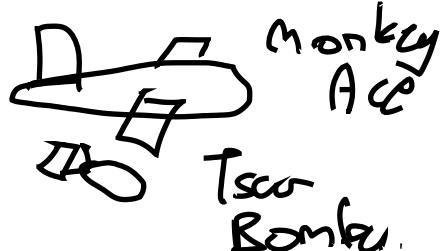
↳ Ivy Mike

↳ ~~Operation~~ Baker (Bikini Atoll)

↳ Russia

↳ Tsar Bomba.

Bloons TDB.



↳ China

↳ India

↳ France

↳ UK.

Submarines

↳ reactors

↳ mobile missile sites (SLBMs)

U-boats.



above  
water  
speed >

Petrol/Diesel

Underwater  
speed.

## Nuclear Submarine mias.

U-571

↳ Hunt for the Red October

↳ Crimson Tide

Pop culture

- Nuclear is dangerous

- Nuclear → 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 → major nuclear power

1949

USSR → explodes 1<sup>st</sup> atomic bomb.



Counter-value  
drop bombs on  
cities

Counter-force

drop bombs to  
kill opponents nuclear  
capability



Red Alert  
Red Alert 2



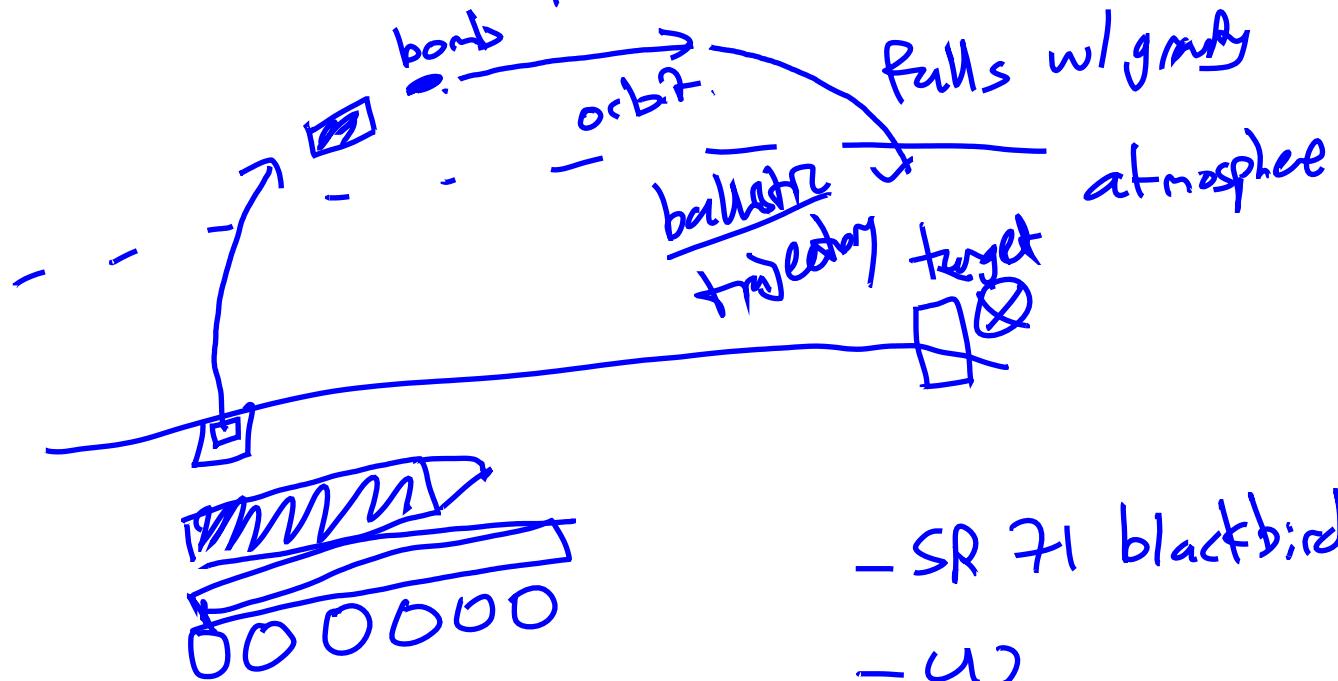
ICBMs



Intercontinental

Ballistic  
missile

(ICBMs)

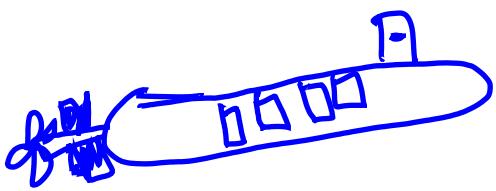


mobile ICBM

nuclear  
deterrence

mutually  
assured  
destruction

MAP



Submarine launched  
ballistic missiles  
(SLBMs)

accuracy  $\rightarrow$  a

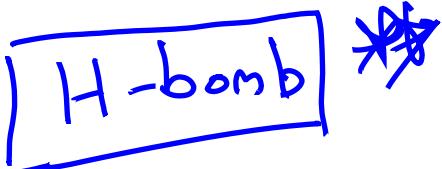
~~big~~ problem

for SLBMs.

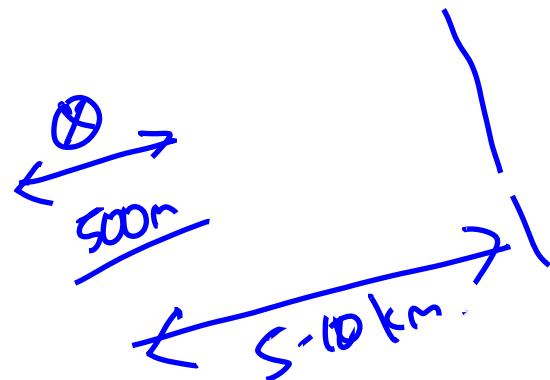
① stay underwater very long



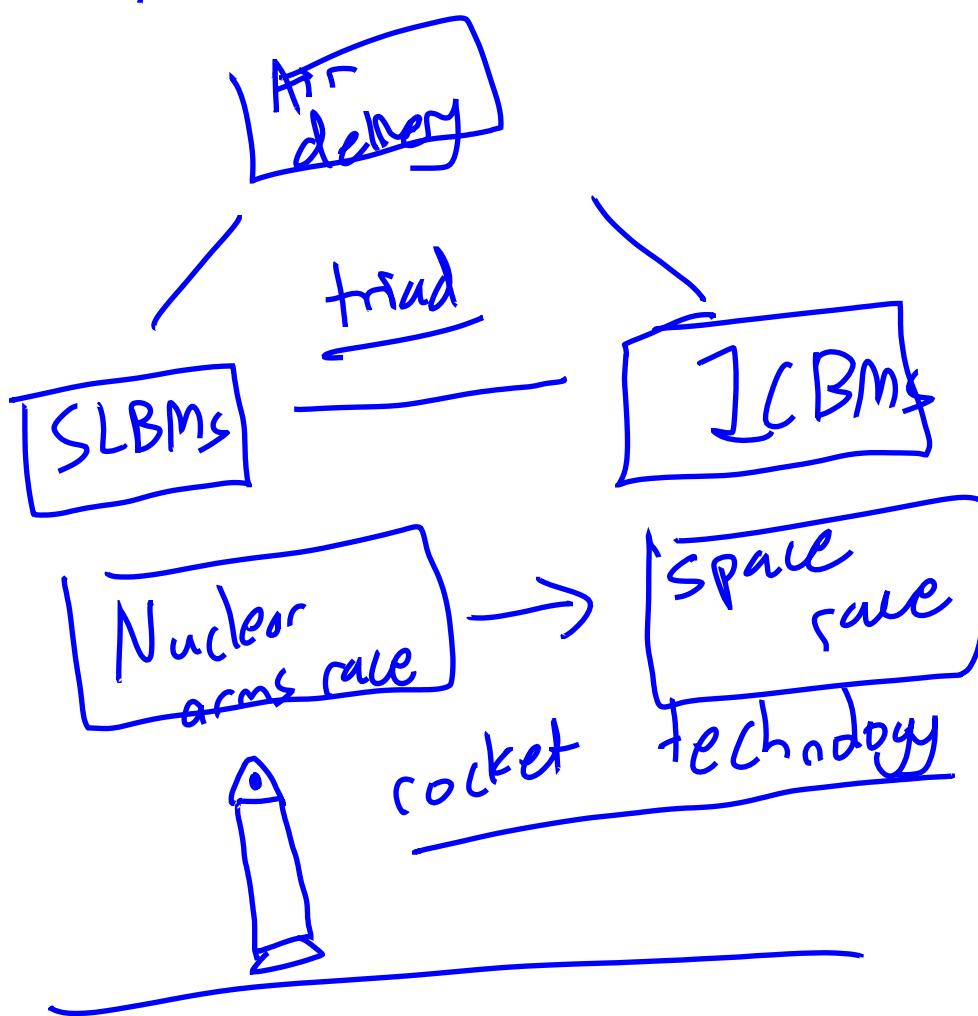
② Big big explosions,  
much bigger than Hiroshima.



↑  
tech.



nuclear triad.



- GPS
- Lunar explorations
- Communications networks → SpaceX
- Telescopes → Hubble space telescope
- Advanced science & technology

# Lecture 3

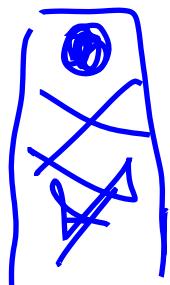
## Manhattan project.

1942

\* Oppenheimer  
cooked

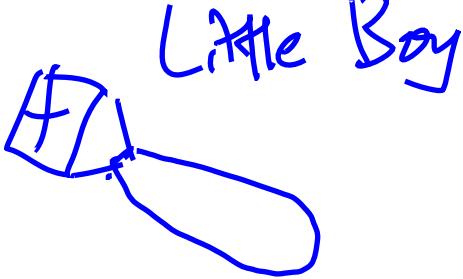
Nazi Germany

trinity



Pu-239

New Mexico



Little Boy

Hiroshima  
Bomb

U-235



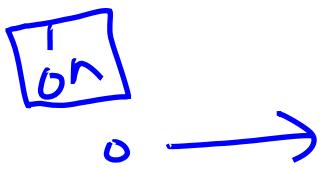
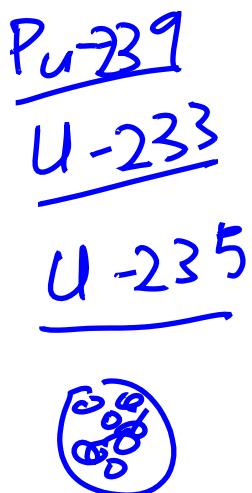
Fat man

Nagasaki:

Pu-239

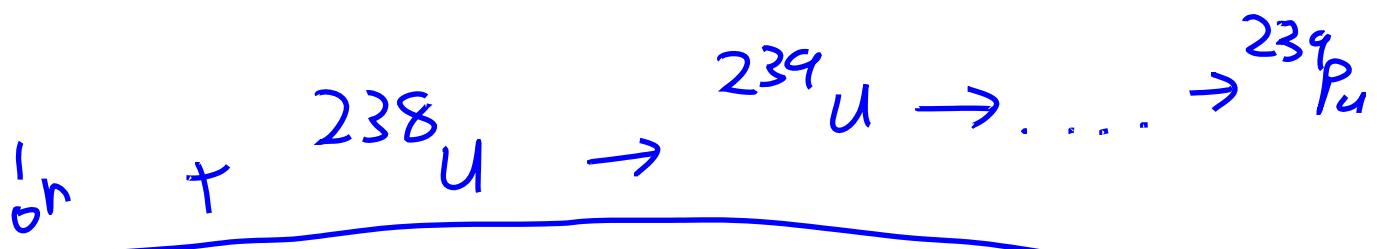
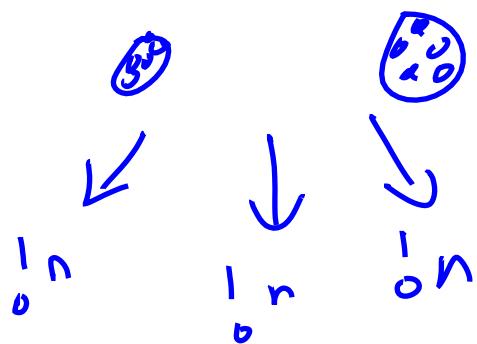
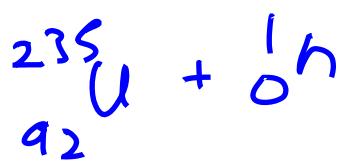
Concepts w/ as little mathematics as possible

Physics



↓ fission

A (total no. of neutrons + protons)  
 $\frac{235}{92} U$   
Z (proton number)



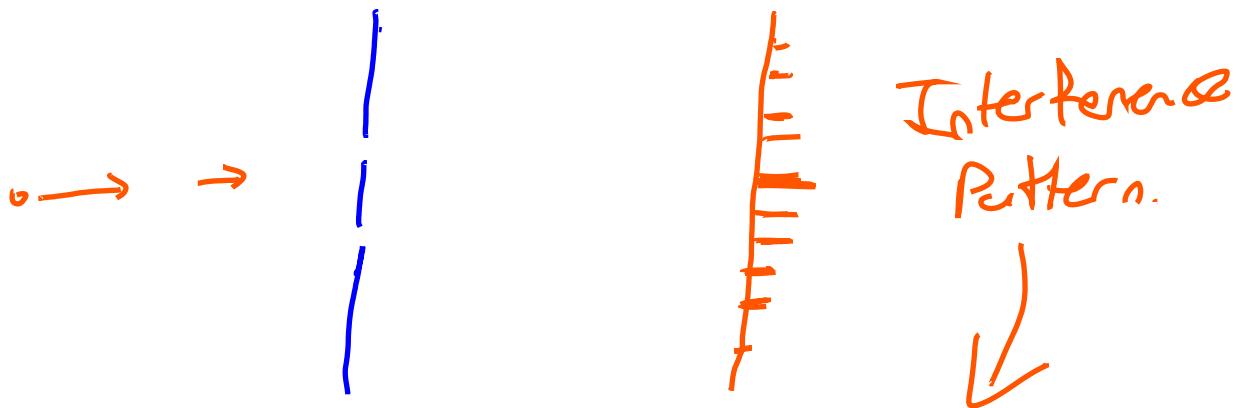
# Quantum Physics

key Idea of Quantum Physics.

matter (protons, neutrons, electrons)

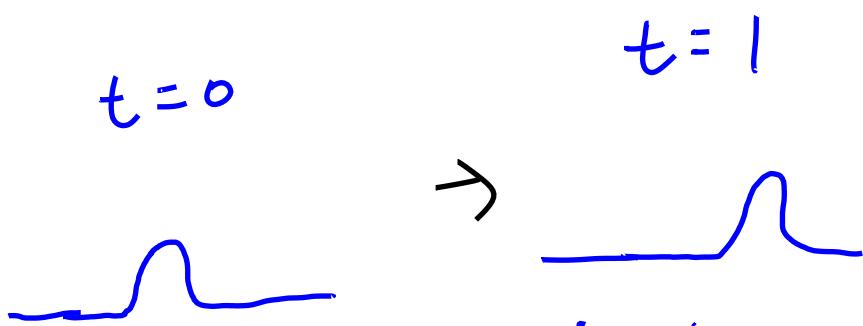
• particle "billiard balls."  
— wave

Young's Double slit experiment.

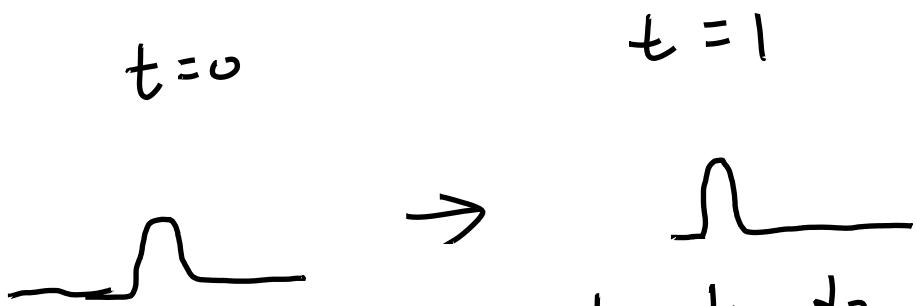


Light  $\rightarrow$  electromagnetic wave

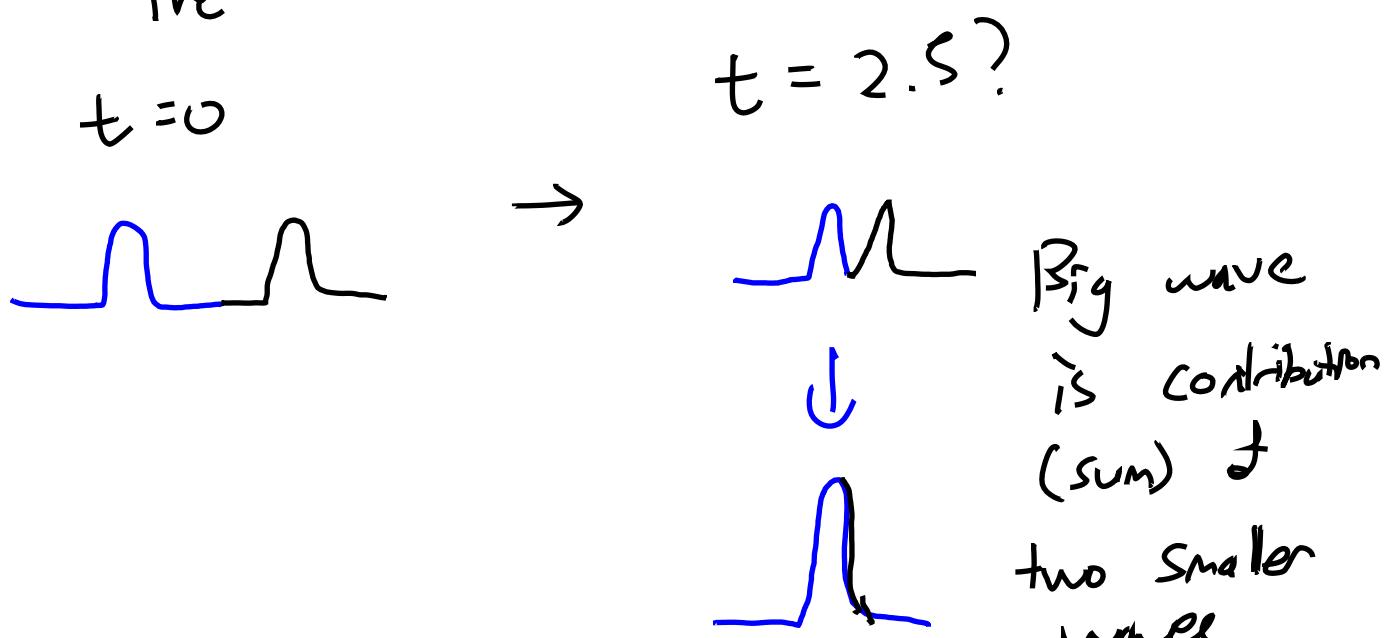
# Waves & Superposition



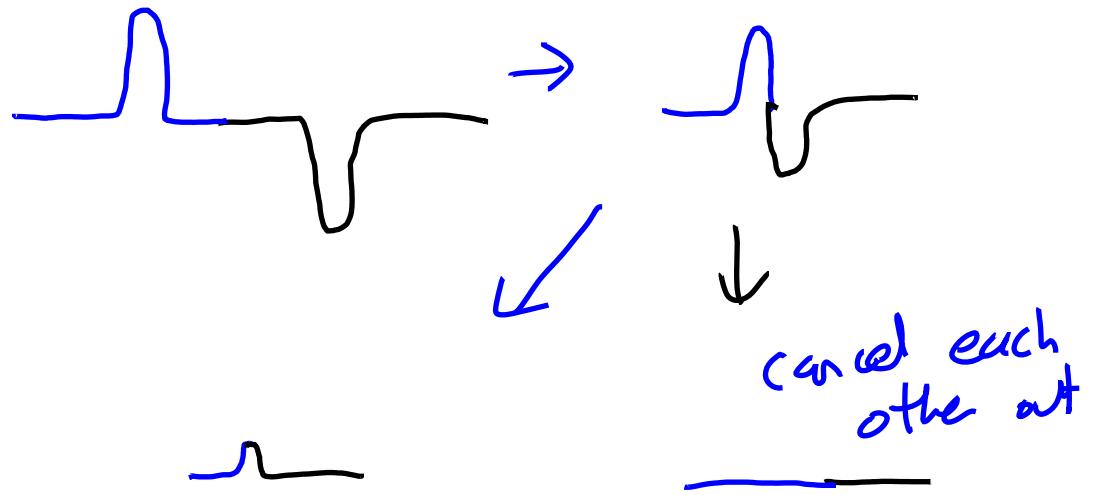
wave is traveling  
to the right.



wave is traveling to  
the left

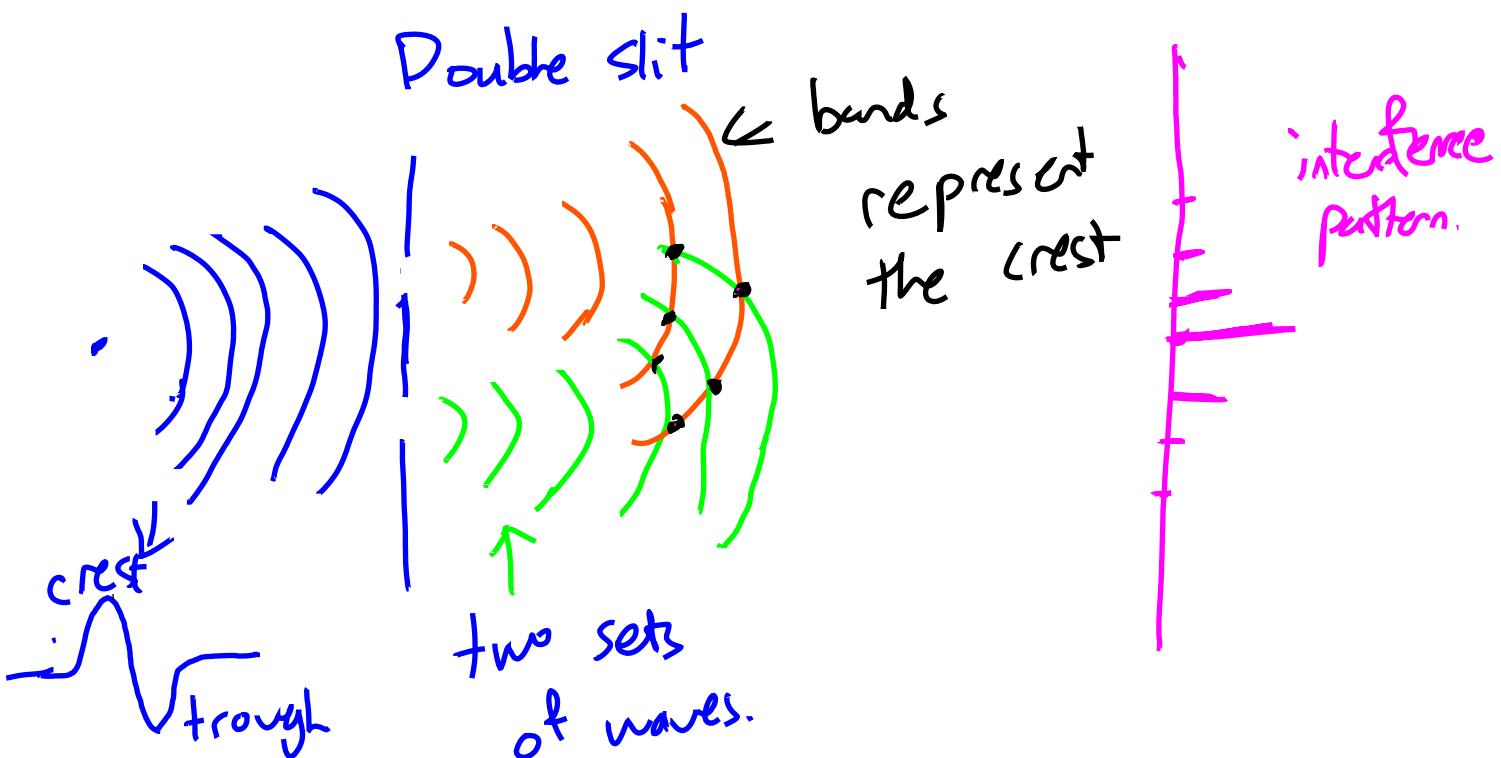


Basic idea of superposition →



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



in quantum physics, the act of observation changes the experimental

results

Discrete Energy levels

wave behaviour  $\rightarrow$  discrete energy levels.

standing waves.

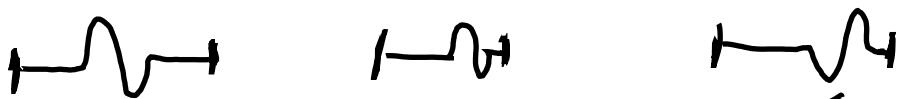
wave on water



"free"

I make the wave "not free"

make the ends "stuck"



wave bounces back & forth &

interferes with itself.

Guitar string



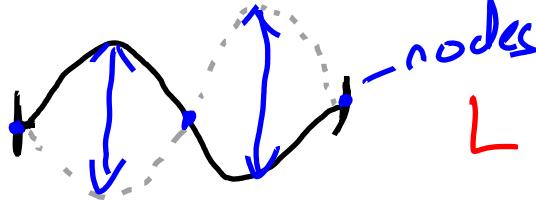
$$n = \underline{\underline{1}}$$



$$2L$$

You can have  
a certain number  
of peaks &  
troughs.

$$n = \underline{\underline{2}}$$



$$L$$

$$n = \underline{\underline{3}}$$

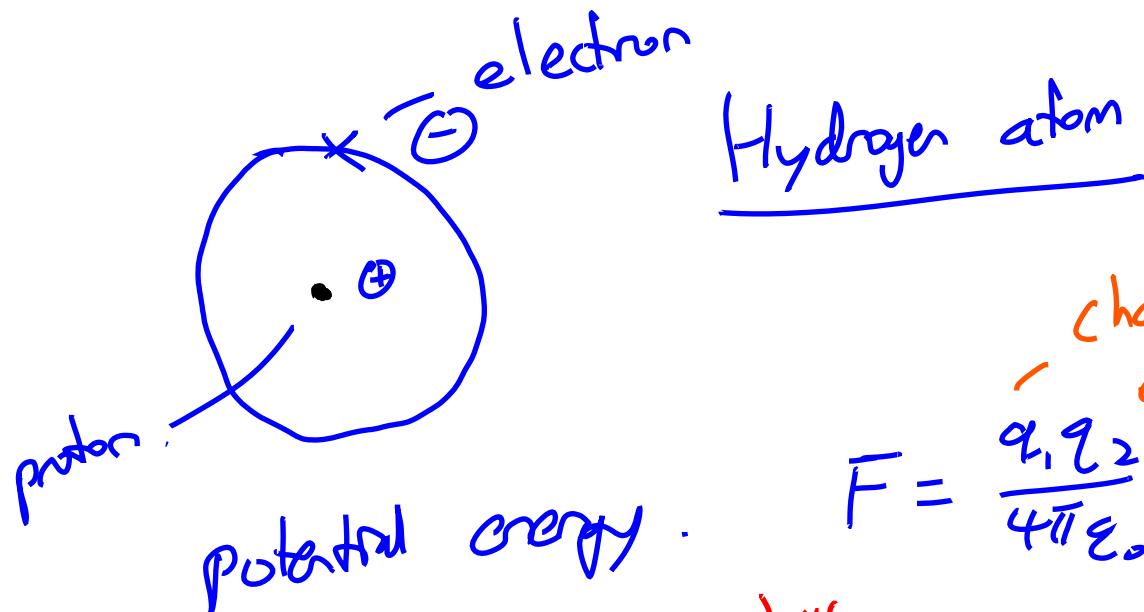


$$\xleftarrow{L}$$

You can store energy at  
different frequencies.

$$V = f\lambda$$

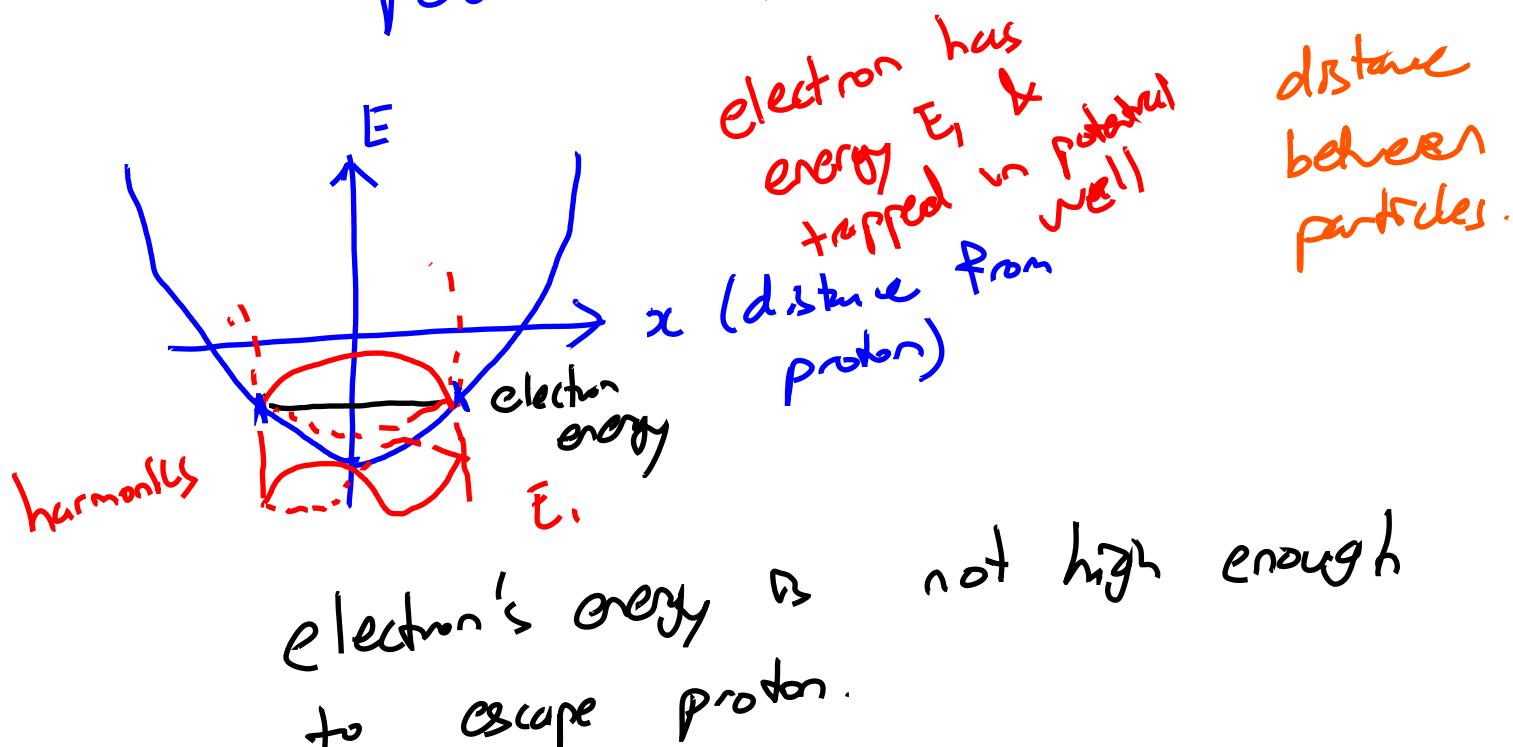
The frequencies (wavelengths) where you can store energy is fixed.



potential energy .

$$F = \frac{q_1 q_2}{4\pi \epsilon_0 r^2} =$$

charge of  
each particle



① Electrons behave as waves

② movement of electron waves is

standing electron

restricted as electron energy < walls.  
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 the of electrons is also  
the of the nucleus.

- ① protons/neutrons behave as waves
- ② movement of proton/neutron waves restricted by attractive forces in nucleus  $\rightarrow$  strong nuclear force

↳ give rise to fixed energy levels with  $\infty$  nucleus.

Energy is "quantized"

↳ fixed energy levels.

If you are interested in the math.

Go read up:

- Schrodinger's equation

- Wave function  $\boxed{\Psi(x)}$   $\Psi = \text{"psi"}$

↳ "probability waves"

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

↳  $\Psi(x) \times \Psi^*(x) \Rightarrow \underline{\text{probability}}$

# Lecture 5

Schrodinger's equation

↳ implications

① Guitar string analogy

↳ Infinite square well.

↳ 1D

↳ "free field" is infinite

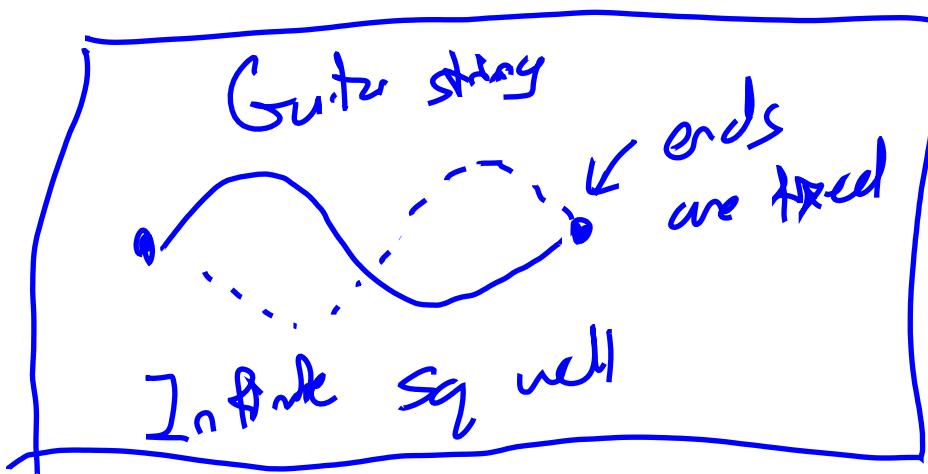
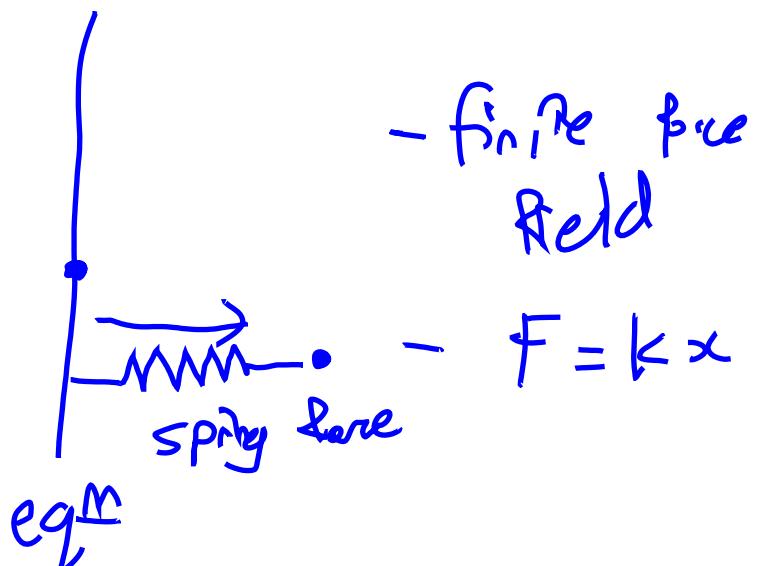
In real life, force fields  
are finite

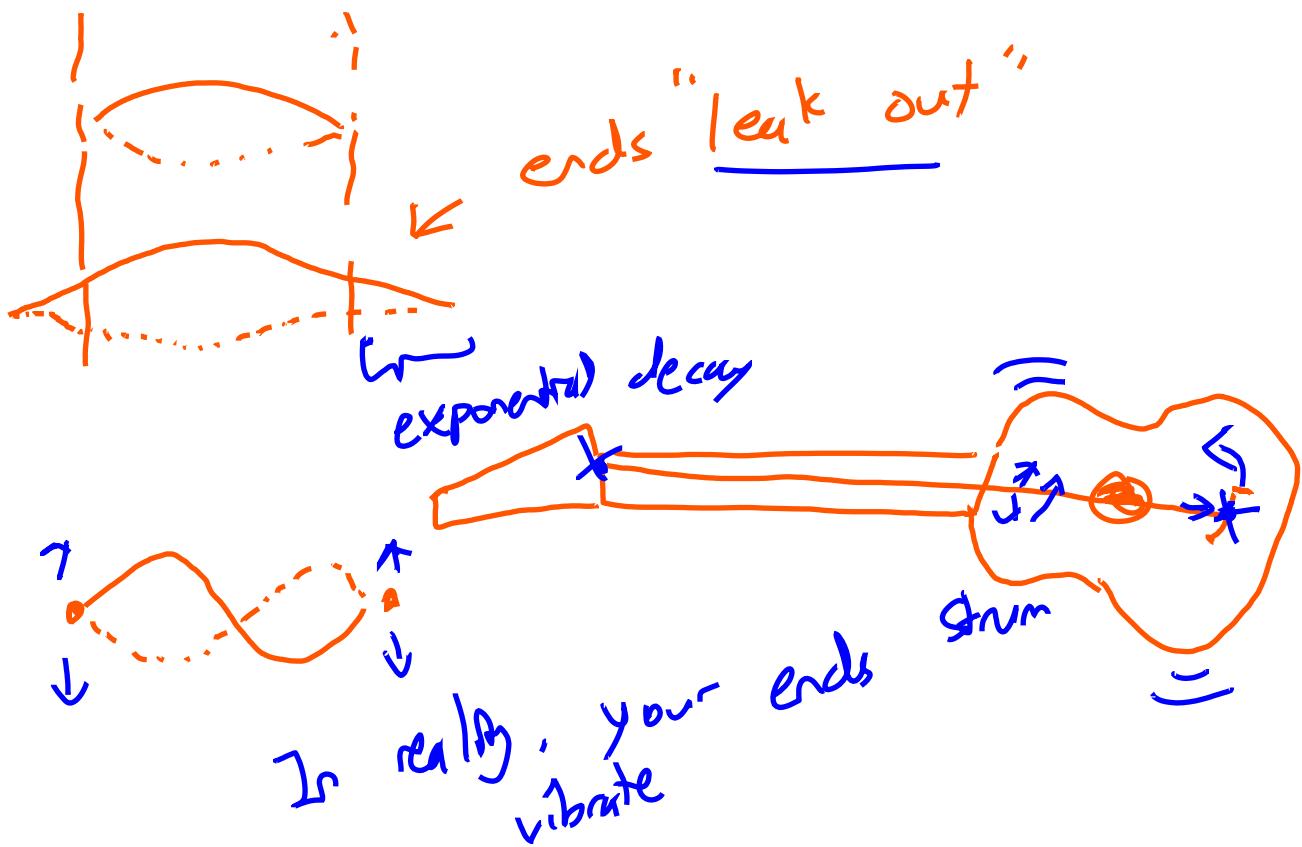
② Finite force fields

↳ 1D

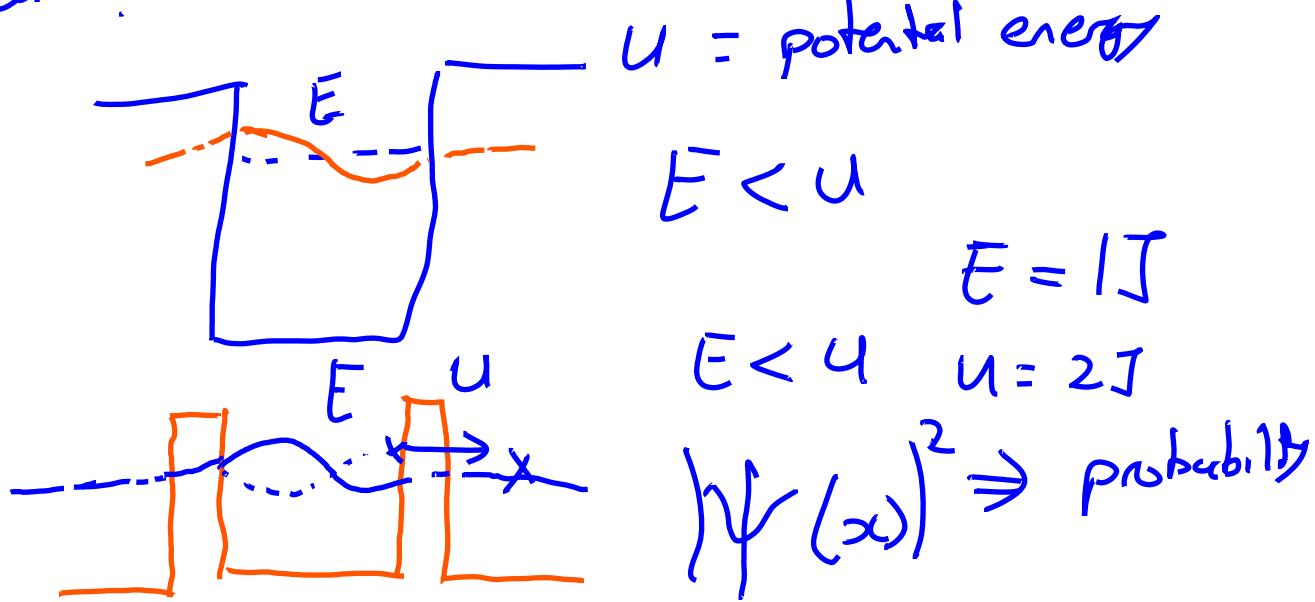
↳ finite force field,  
finite well

↳ simple harmonic oscillator





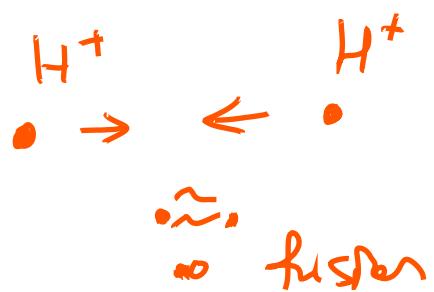
what do waves "leaking out"  
mean?



particles leak through barrier

## ∴ Quantum Tunneling

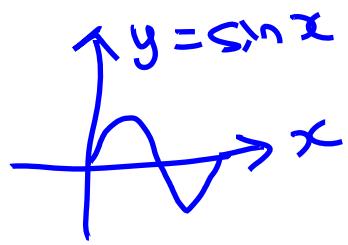
- ↳ Alpha decay
- ↳ Fusion process in the sun.



## Lecture 6

In previous discussion, we  
talked 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 :  $F \propto \frac{1}{4\pi\epsilon_0 r^2}$  ← sphere surf  
are  
 $= 4\pi r^2$

need a  
↳ spherical version of  
the sine wave

## Spherical harmonics

↳ 3D spherical version of sine waves

↳ explored in hydrogen atom

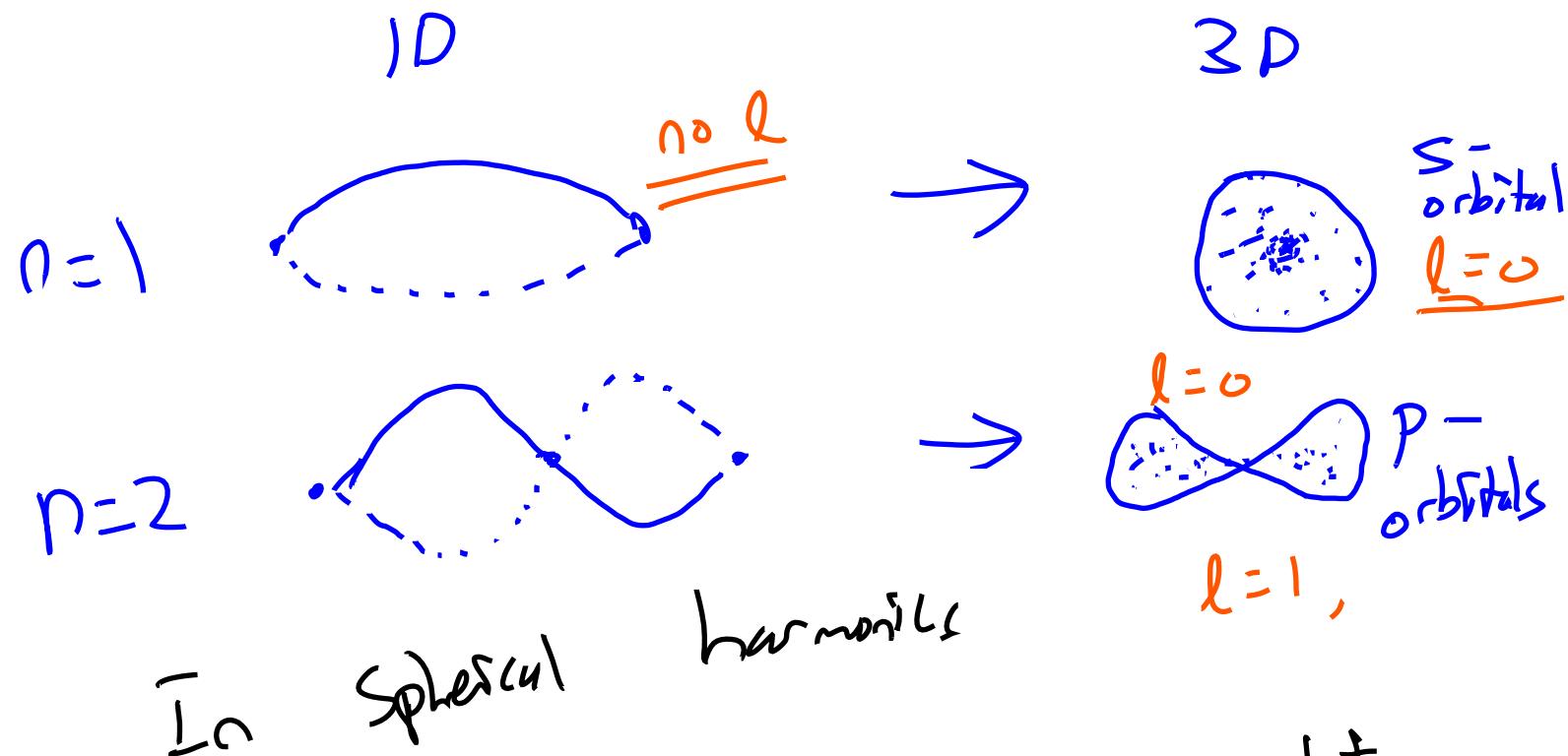


3D matter wave  
electron 'cloud'

↳ implications of spherical harmonics

↳ angular momentum becomes important ( $l$ )

↳ angular momentum projection no. becomes important ( $m$ )



↳  $n, l, m$  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 Schrödinger's equation

① Infinite Sq well

↳ discrete energy levels

② Finite well (Simple harmonic oscillator)

↳ Quantum Tunneling

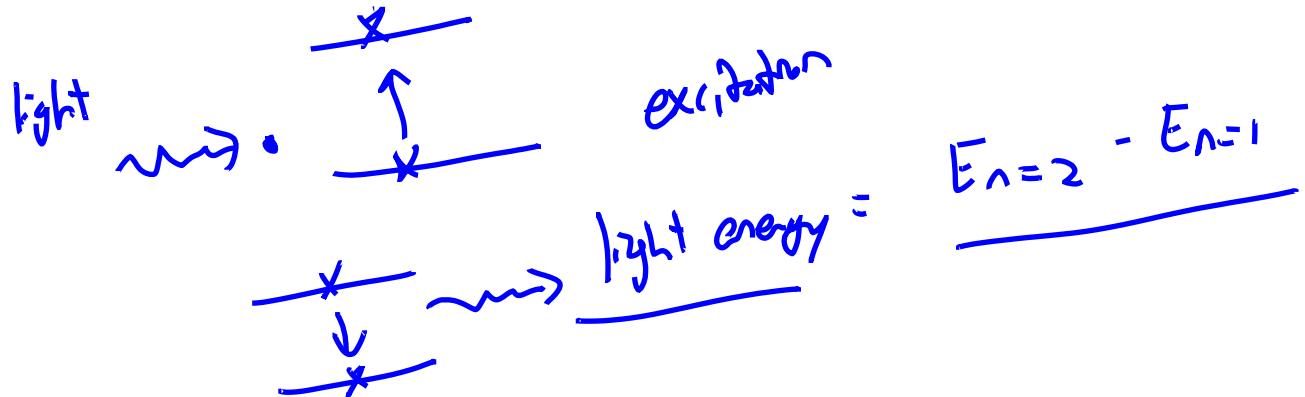
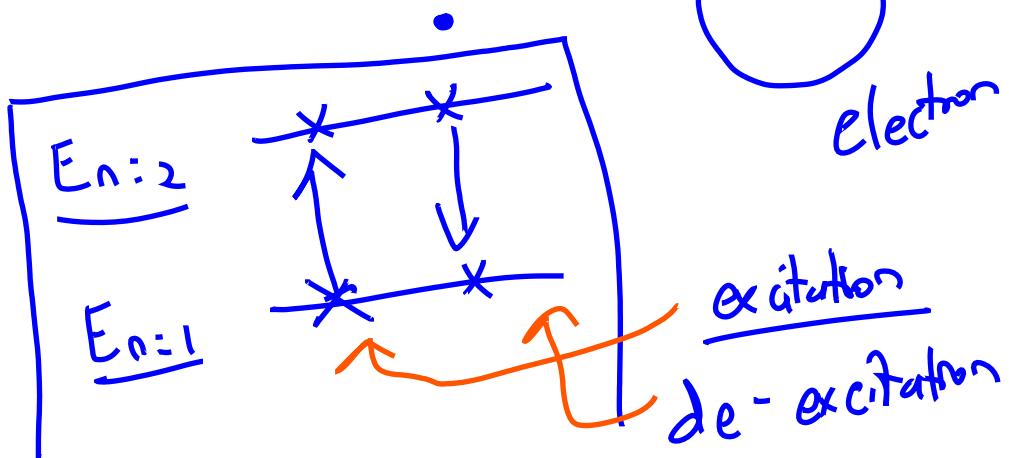
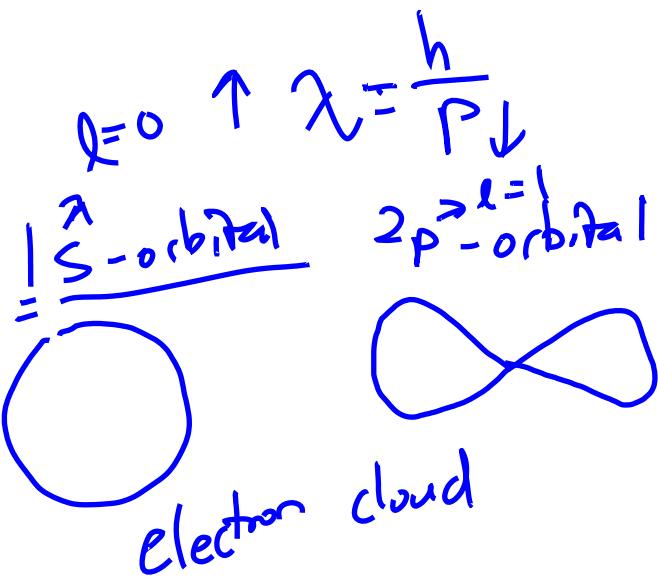
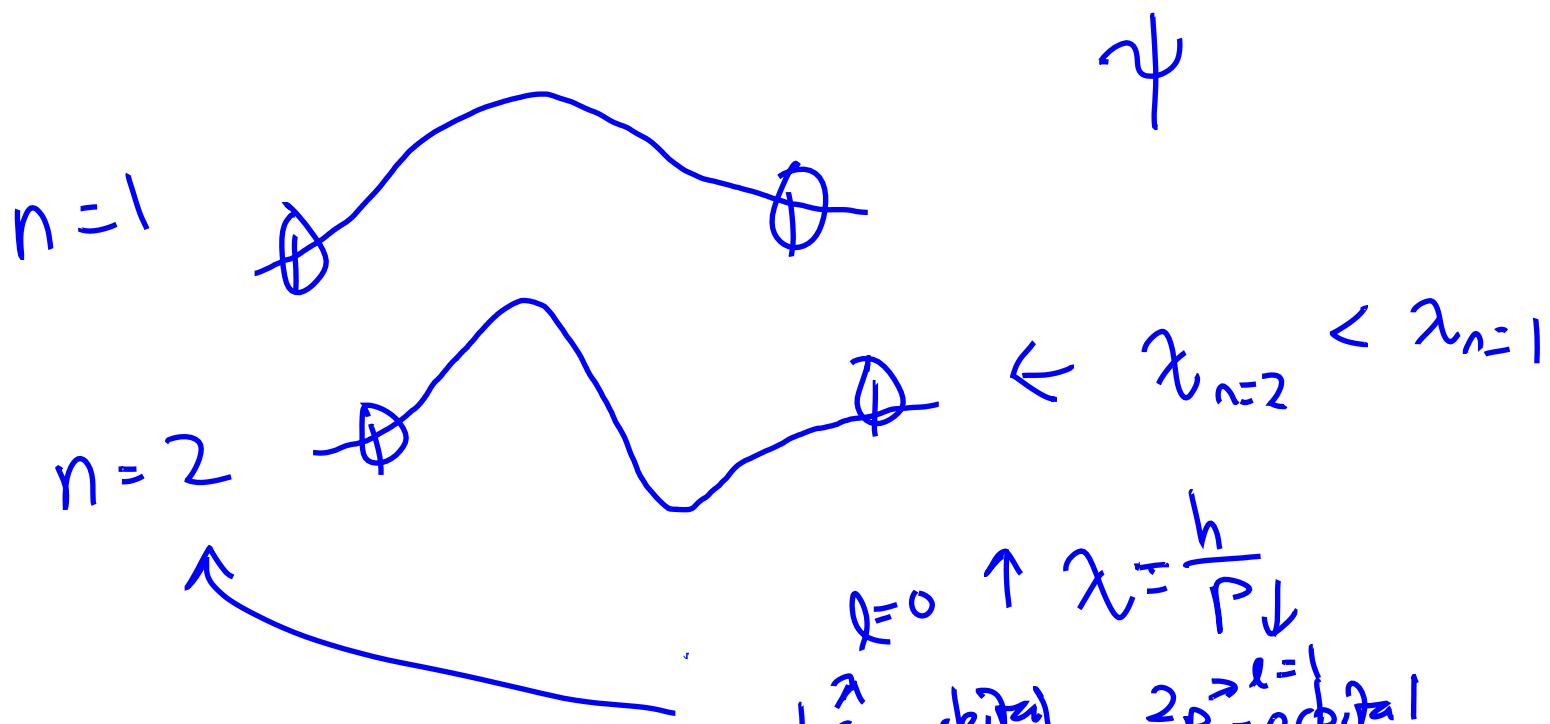
③  $1D \rightarrow 3D$  spherical harmony

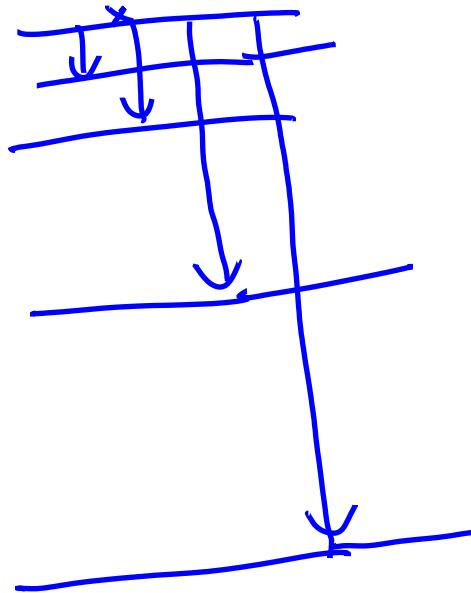
↳  $l$  (angular momentum) becomes important

↳  $m$  (angular momentum projector)

becomes important

# Lecture 7





emitted light  
from excited  
Hydrogen atom  
will have fixed  
energy

fixed energy → fixed wavelength.

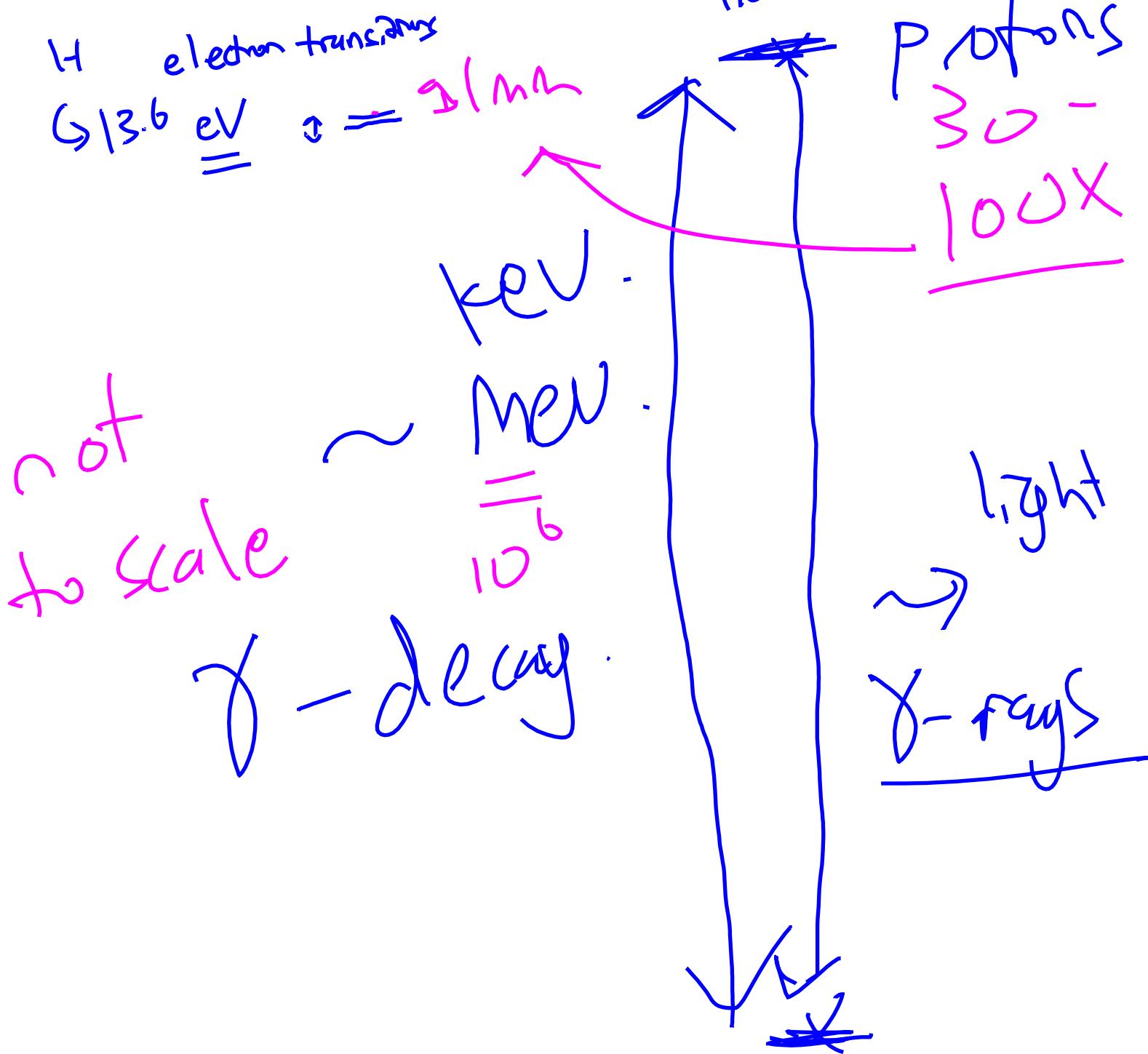
characteristic spectrum that  
Hydrogen atom will have  
when de-exciting

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

→ Wavelength/spectra is different.

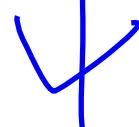
In the nucleus, strong nuclear force  
is several orders of magnitude stronger  
such that the energy level difference  
is about  $\sim 1$  million times more.

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



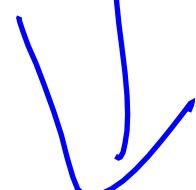
how many pages will we  
need to draw this to  
scale?

$$100 \times \underline{10,000} \text{ page}$$
$$10^2 \times 10^4$$



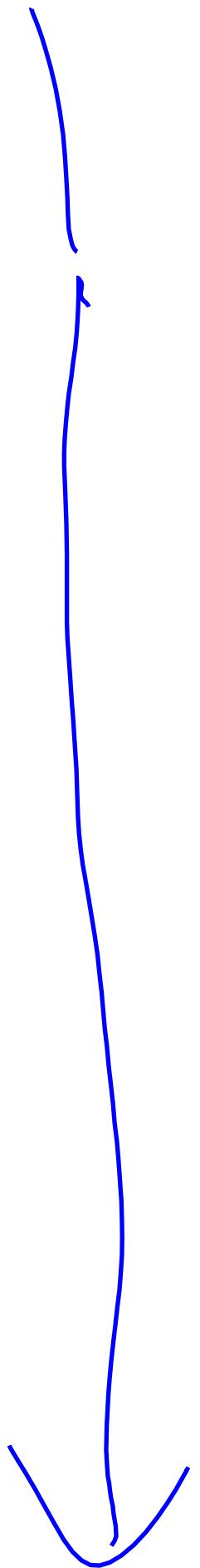
nuclear energy  $\rightarrow$

1 million lines  
more dense than  
electron energy

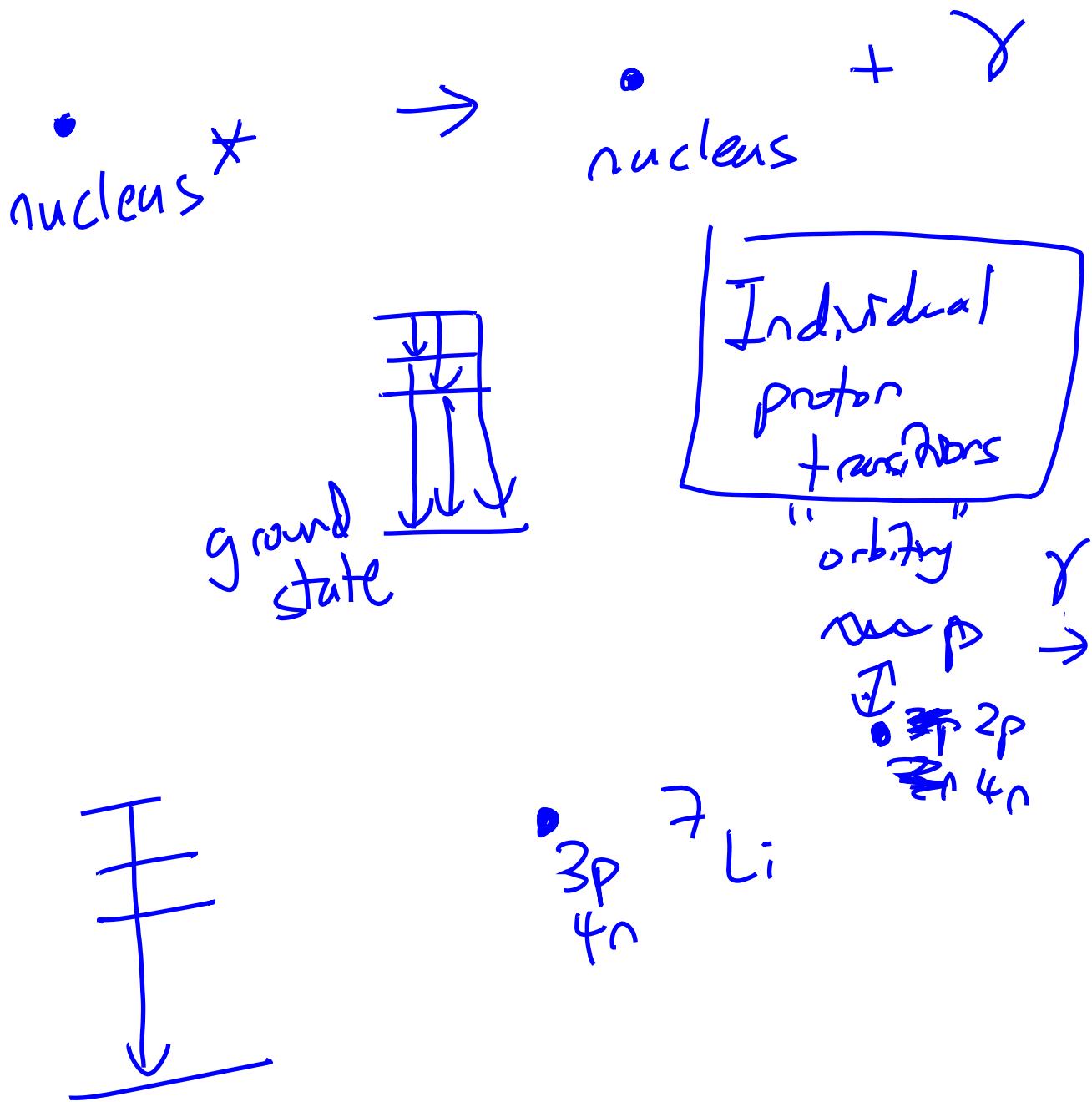


↓  
chemical bonds  
↳ fusion fuel  
↳ battery

Nuclear energy ↗  
super dense.



# Lecture 8



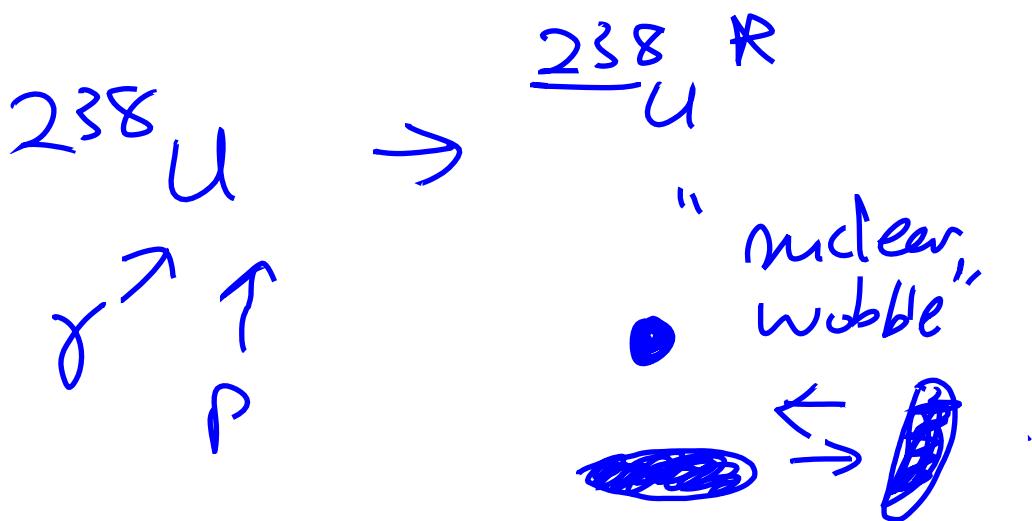
Main ways for nuclei to have Excited states (Gamma decay)

(1)

- Individual protons excited

(2)

collective motion.



"liquid drop"

→ "shaking"

→ "spinning"

"vibration wave"

particle  
Individual "excited" states  
energy > collective  
vibration excited  
state

$E_{\text{single}}$   
 $E_{\text{ground}}$

collective is usually  
motion for large nuclei

$E_{\text{collective}}$   
 $E_{\text{grand}}$   
low keV range

How do nuclei get excited?

① Photon absorption

② inelastic collision.

$$\boxed{\frac{1}{2} m v_1^2}$$

$v_2$

$$P_1 \rightarrow$$

$$\frac{P_2}{\text{rest}}$$

$$P_L$$

$$\frac{P_1}{\text{rest}}$$

$$\boxed{\frac{1}{2} m v_1^2}$$

- momentum conserved

- kinetic energy conserved

"no fraction"  
elastic collision

inelastic collision  $\rightarrow$  "fraction"

$$\boxed{kE_1}$$

$n$

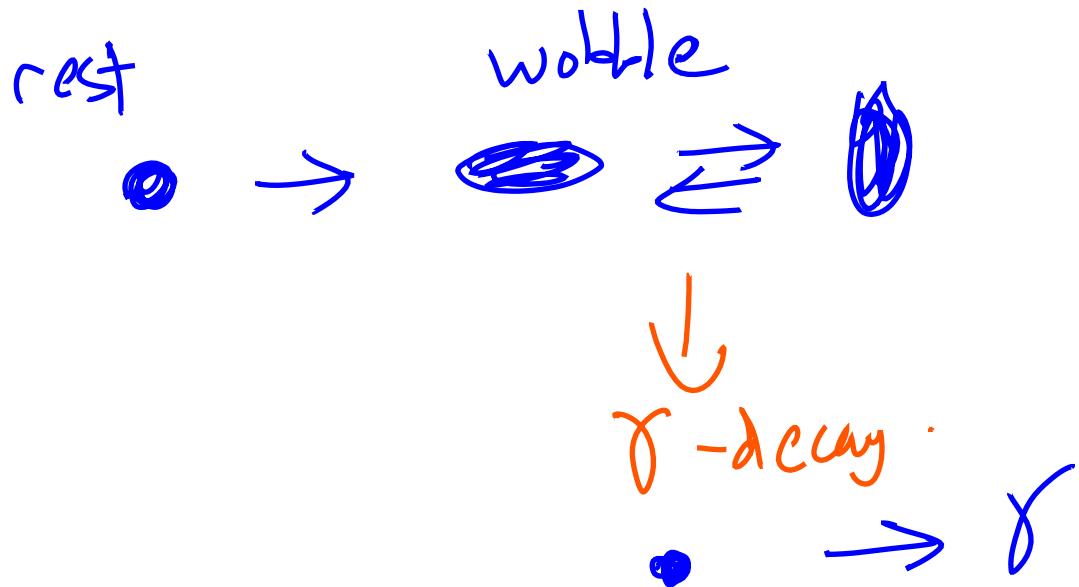
$\rightarrow$

$$kE_2$$

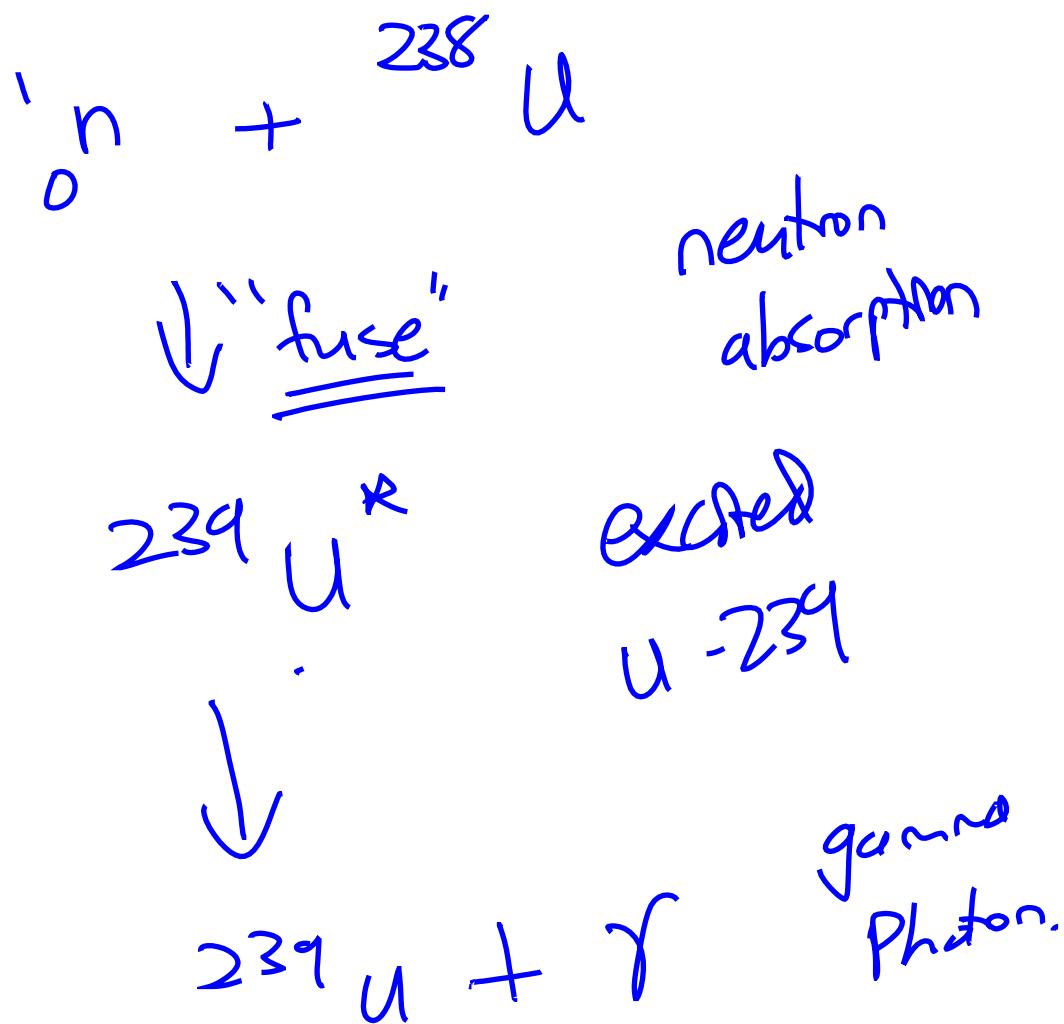
$$^{238}\text{U} \rightarrow kE_3$$

$$kE_1 > \underline{kE_2 + kE_3}$$

Where did the energy go?



### ③ nuclear reactions

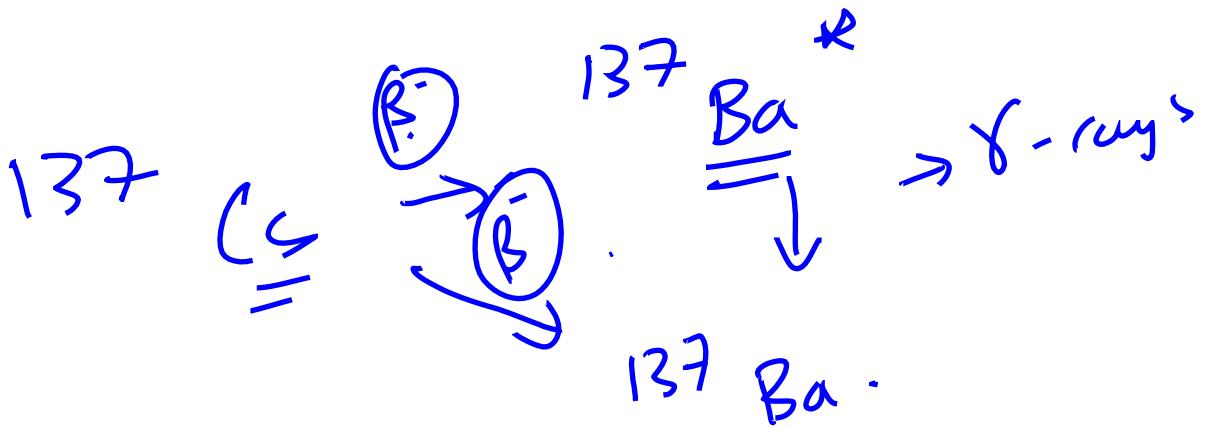
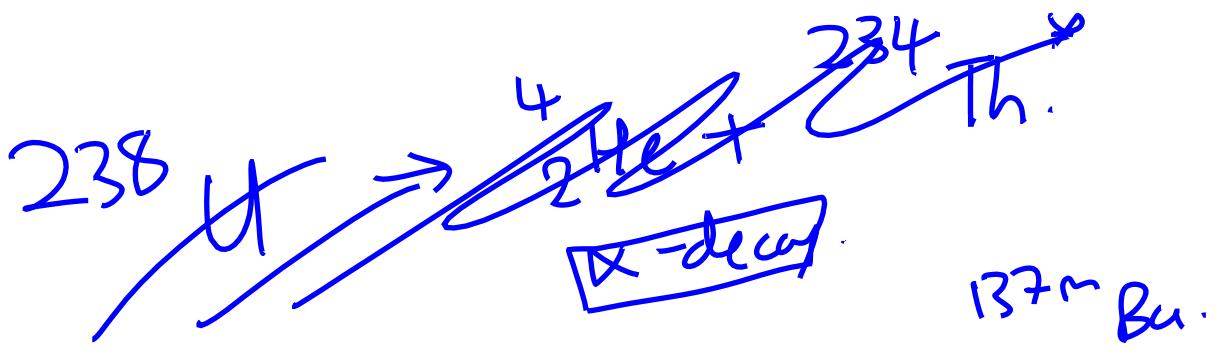
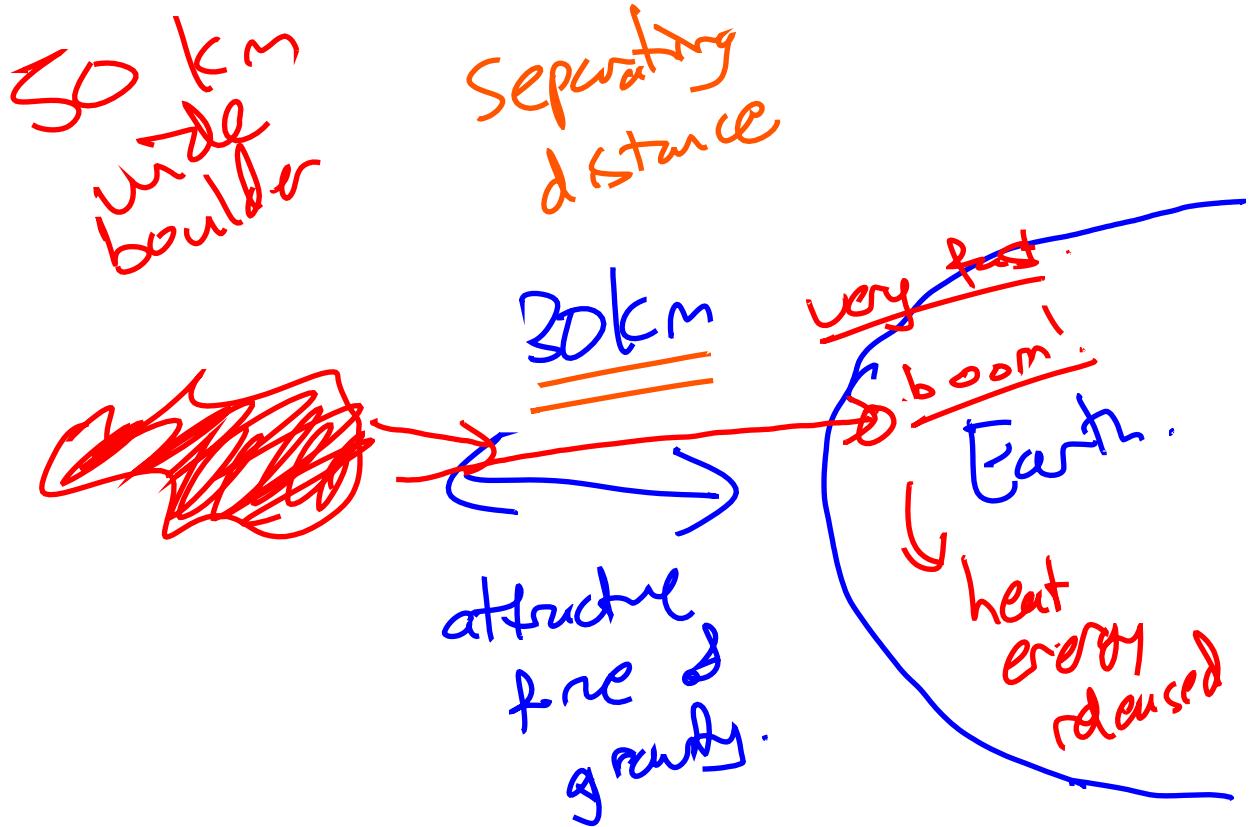


$(n, \gamma)$  reactions  $\rightarrow$  important

Why did neutron absorption result in excited state?

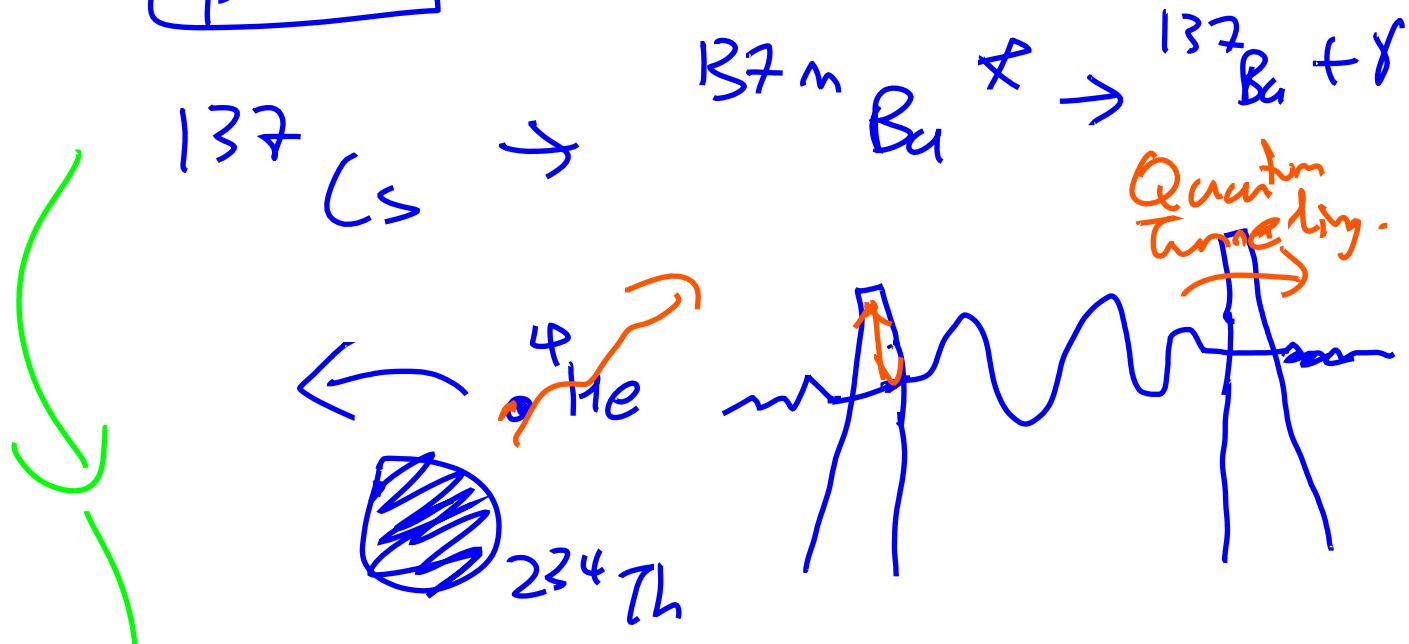
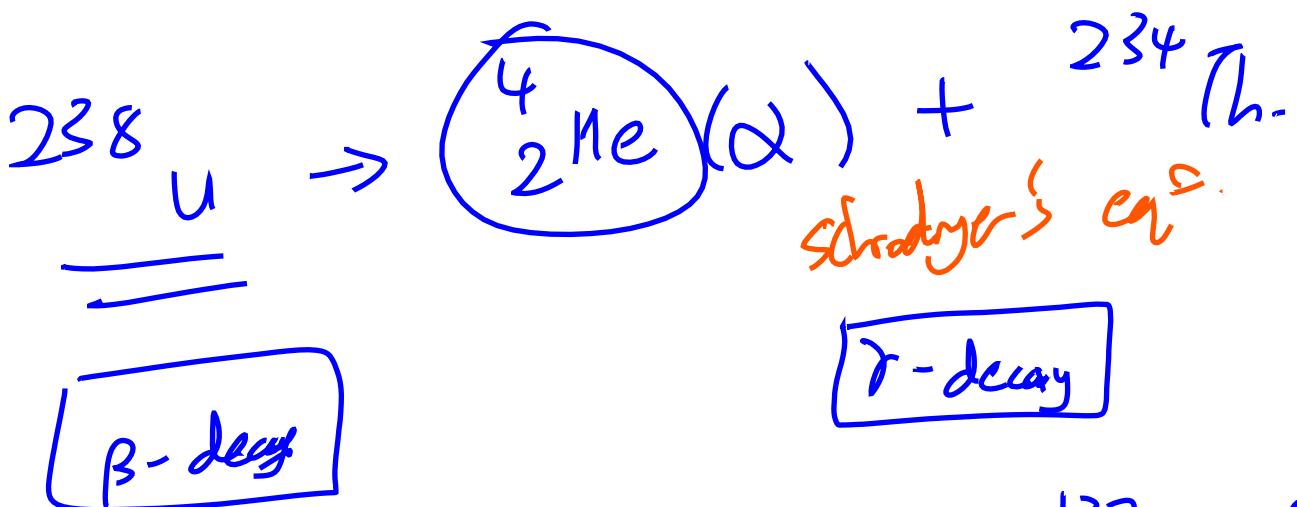
↙ binds Jan to forces.  
strong force.  $\rightarrow$  attractive.  
nuclear  $\leftrightarrow$    
 $^{238}_{\text{U}}$

attractive force +  
separating distance



## $\alpha$ -decay.

Schrodinger's eq:

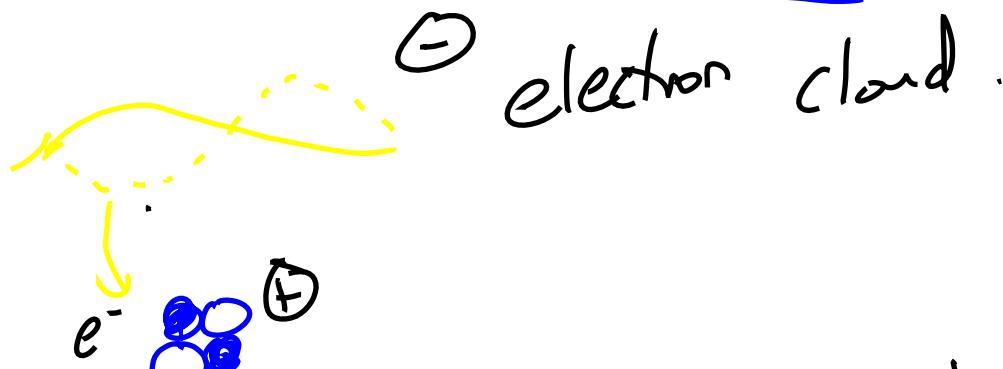


Beta decay is special

↳ relies on weak nuclear force.

# P - decay & weak nuclear force

Leptons q

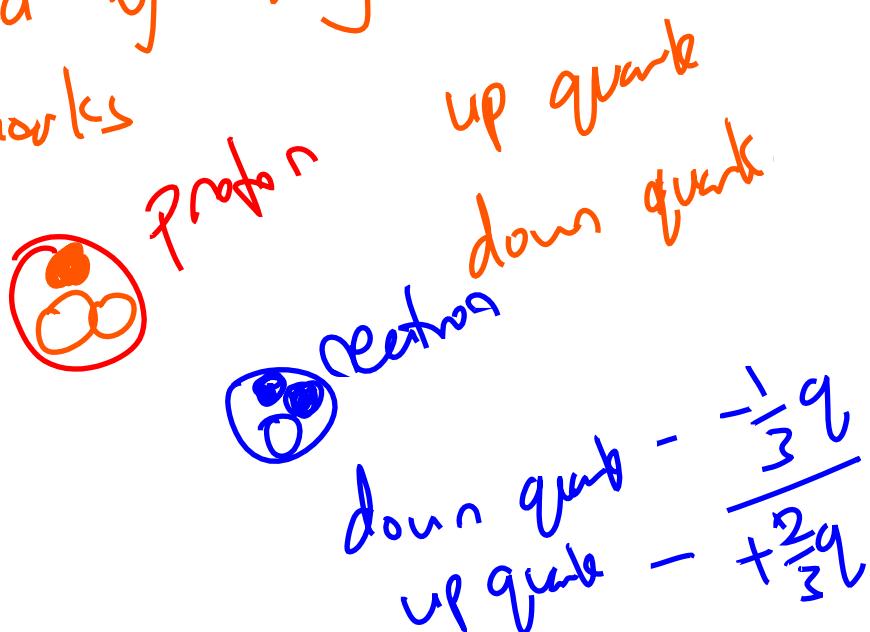


- electrons ~~are~~ Quarks not affected by attractive force (strong nuclear force) in the nucleus.

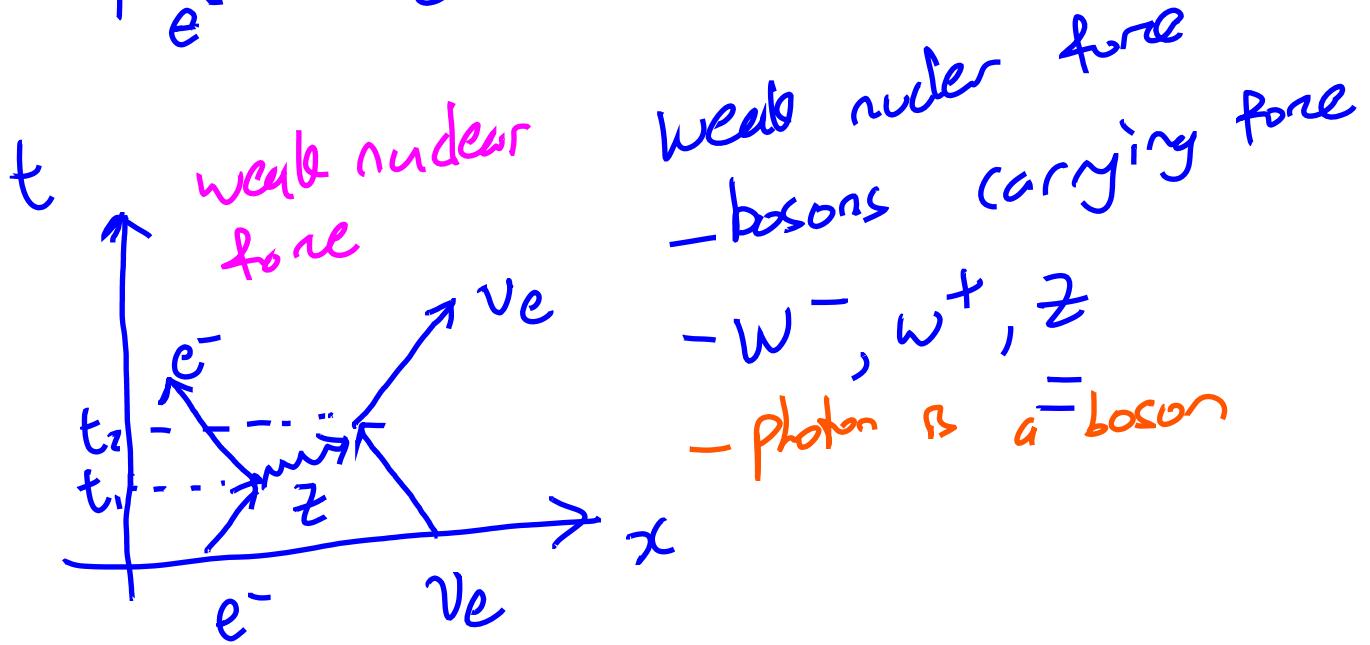
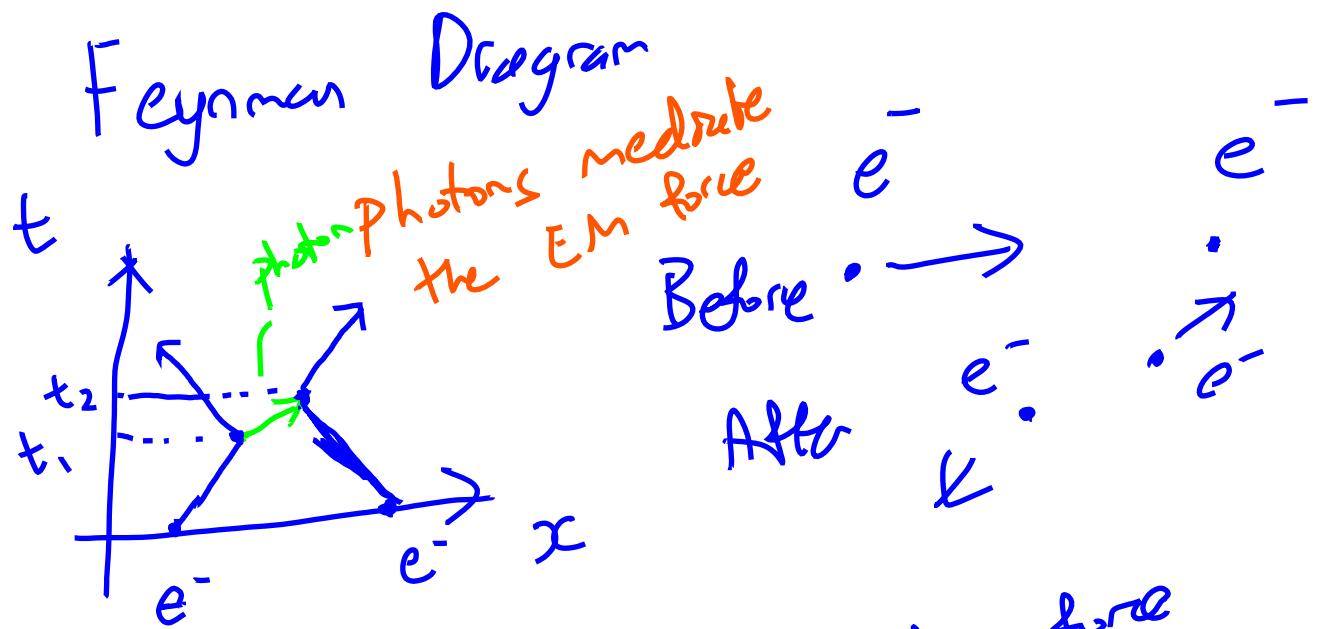
↳ not all particles are affected by strong nuclear force

↳ affected by strong nuclear force

= Quarks

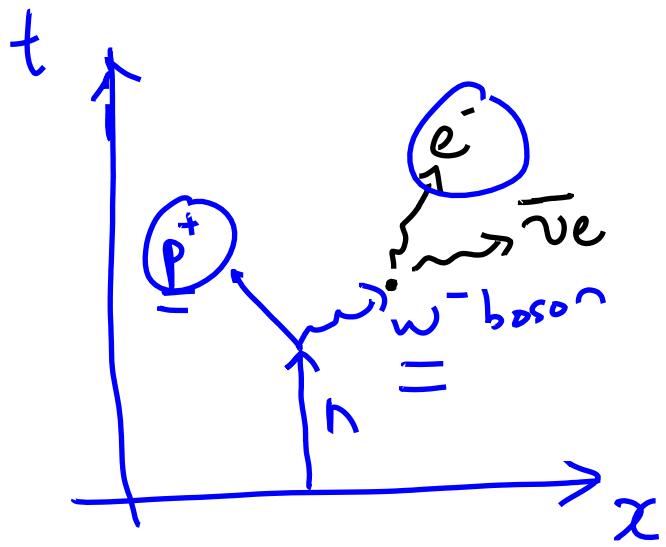


Weak nuclear force  $\equiv$  "CM  
Centre of mass"  
frame of  
 $\bullet \rightarrow \leftarrow \bullet$



- neutrinos are  $\nu_e$ , neutral charge, affected only by gravity & weak nuclear force

- electrons collide w/ neutrons  
cos of weak nuclear force



w<sup>-</sup> boson

- (1) neutron splits into  
two.  
→ proton (+)  
→ w<sup>-</sup> boson (-)

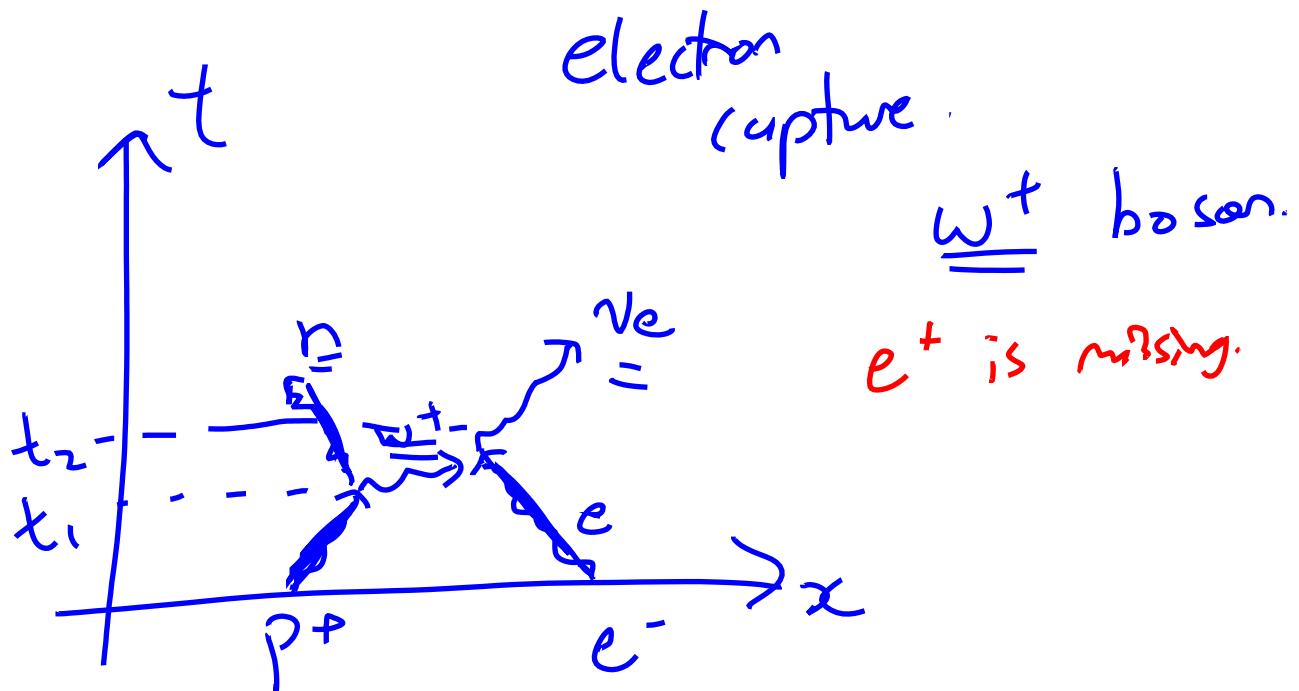
$\beta^-$ -decay

- (2) w<sup>-</sup> boson decays  
into e<sup>-</sup> &  $\bar{\nu}e$

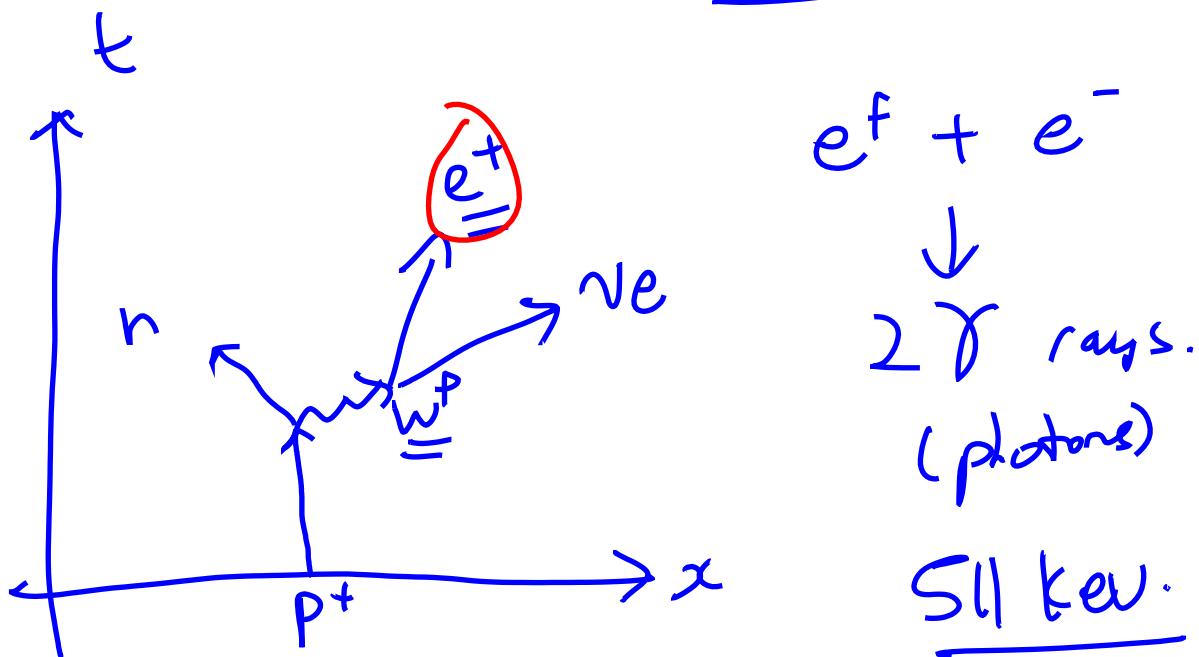
- lone  
neutrons are unstable

$$\hookrightarrow t_{1/2}' \sim 10.5 \text{ min}$$

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



$\beta^+$  decay: needs a lot of energy.  
 $\beta^+$  decay.



position emission tomography  
 (PET).

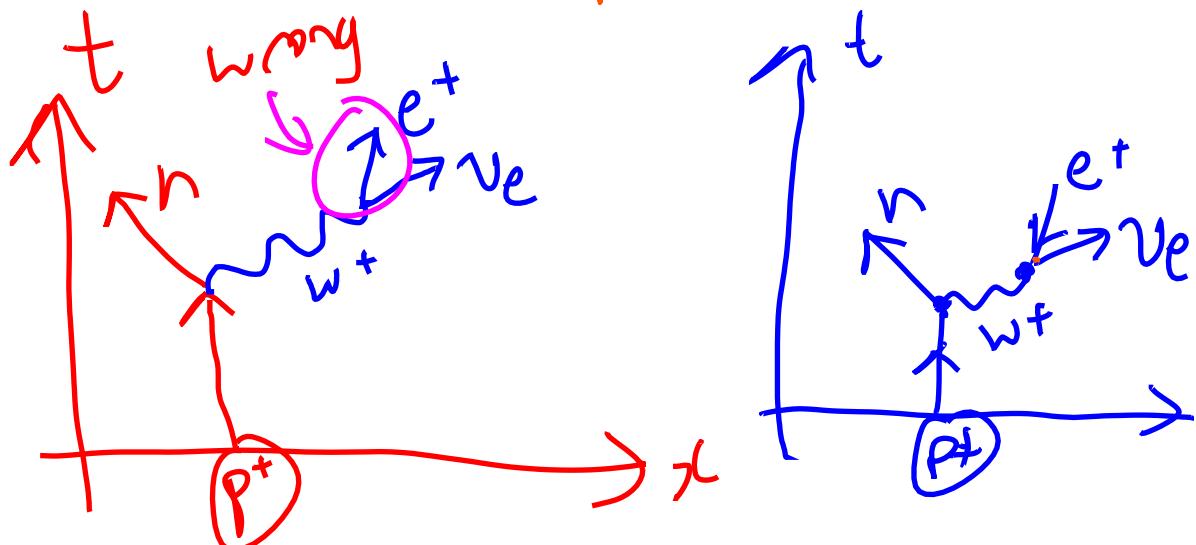
Some unstable nuclei can supply energy for  $B^+$  decay.

binding energy

$\eta_b$  - corrections to lecture

Rumbling:  $\eta$ .

correction # 1  $\Rightarrow$  anti-matter arrows flow opposite time.



Part of correction: no. of arrows in =

no. of arrows out.

Correlation 2:

- fermions must have arrows

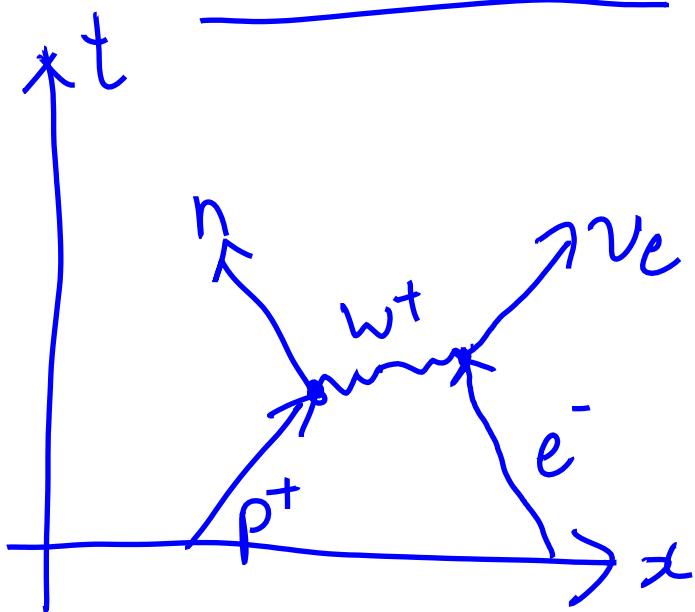
- bosons  $\stackrel{\cong}{\equiv}$  arrows.

↳ photons  $\gamma$

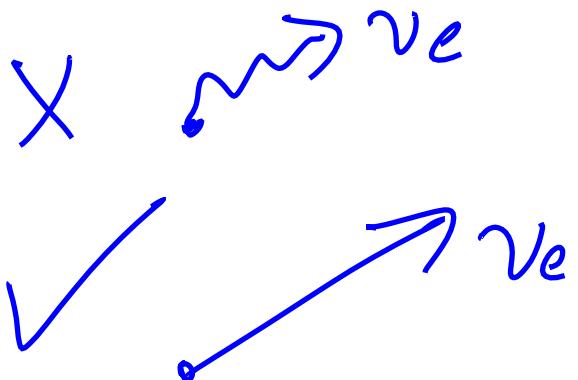
↳  $W^+$ ,  $W^-$ ,  $Z$  bosons.

↳ gluons.

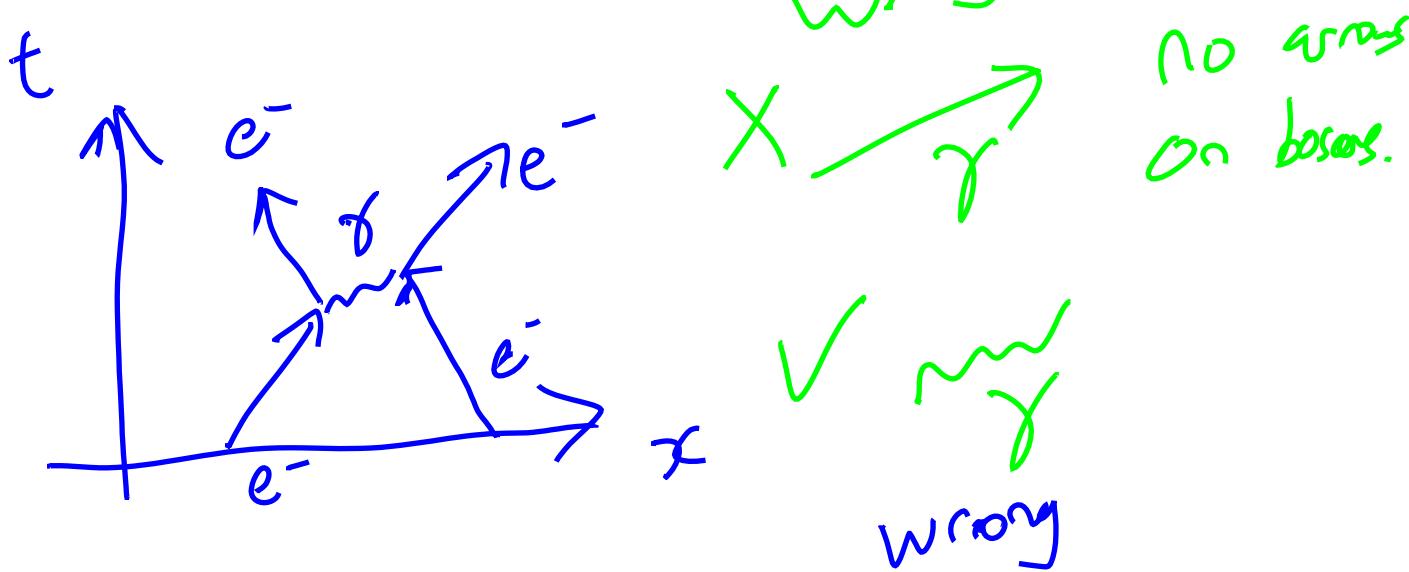
electron capture



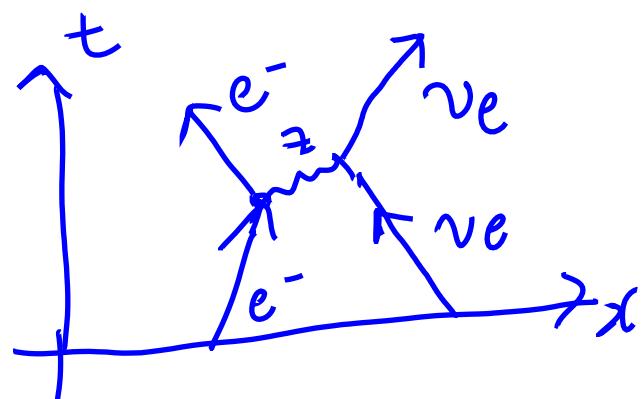
wrong -



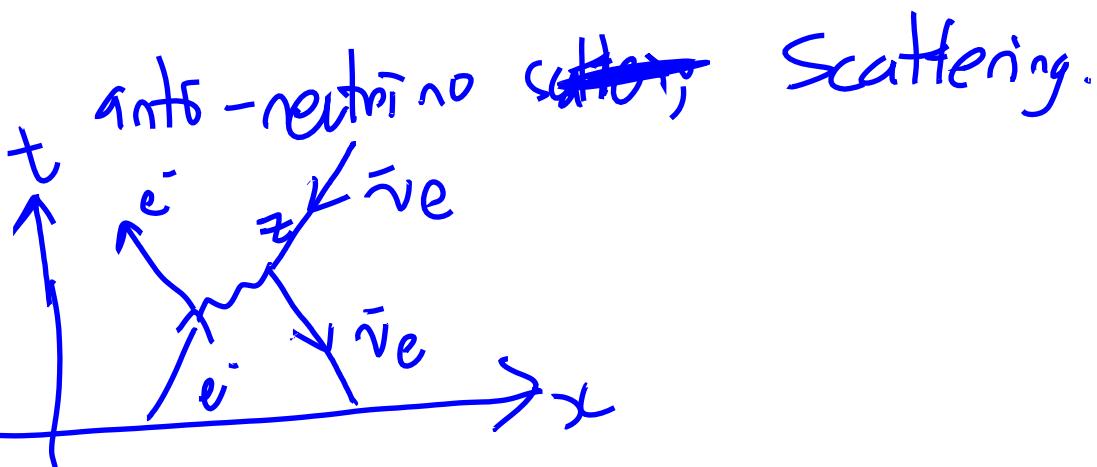
electrostatic repulsion.



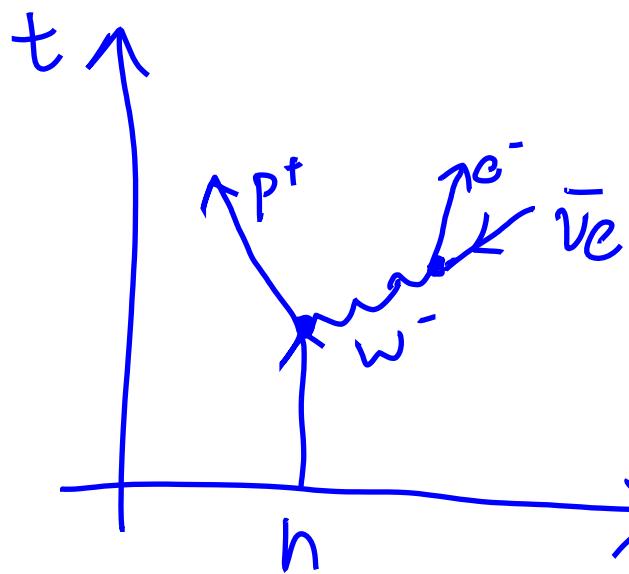
neutrino scattering



$\times \not/e^-$  fermions  
must have arrows.



$\beta^-$  decay.



wavy  
 $x \rightsquigarrow \bar{\nu}_e$

- squiggly line for fermion.

$x$  - wavy arrow direction.

$w^-$   
 $\rightsquigarrow$   
- boson had arrow  
 $x$

$x \rightsquigarrow e^-$

- electron had squiggly line  $x$ .





