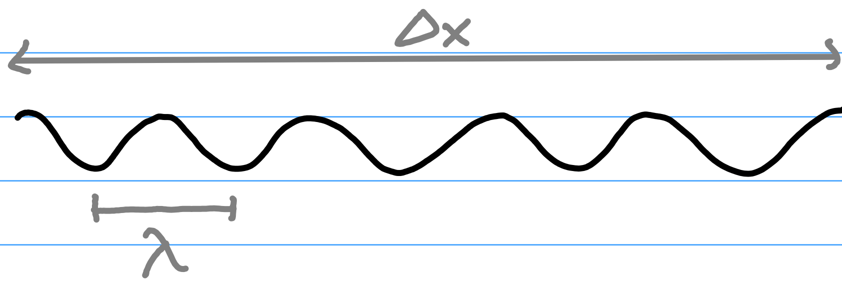
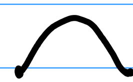
LECTURE 13
CHAPTERS 2,8,15

PHY 100. THE ATOMIC NUCLEUS

RECAP: HEISENBERG'S UNCERTAINTY PRINCIPLE

$$\boxed{\Delta x \, \Delta p \sim h}$$

		CAN YOU SAY WHERE IT IS PRECISELY?	CAN YOU MEASURE λ PRECISELY?
WAVE A:		NO	YES
WAVE B:		YES	NO

DE BROGLIE $\lambda = \frac{h}{mv}$ $\rightarrow$ $\boxed{\Delta x \, \Delta v \sim \frac{h}{m}}$ SAY GOODBYE TO DETERMINISTIC UNIVERSE

$(\lambda \downarrow \Rightarrow v \uparrow)$

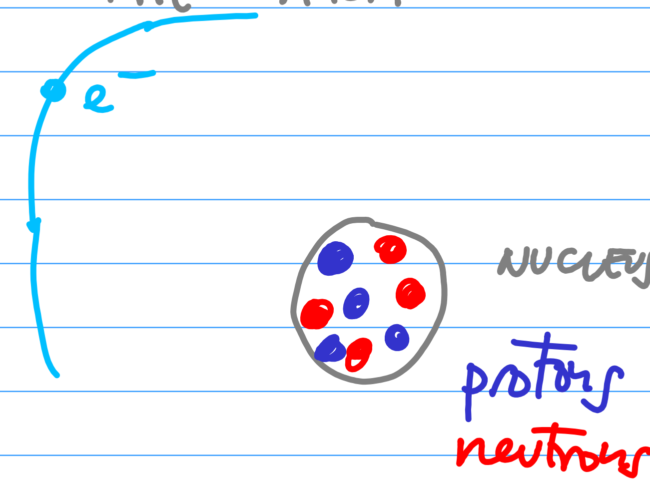
$\boxed{\Delta E \, \Delta t \sim h}$ IS AT THE CORE OF Q.M. $\rightarrow$ IMPLICATIONS IN:

QUANTUM COMPUTING, RADIOACTIVE DECAY, BIG-BANG, LARGE SCALE STRUCTURE, PARTICLE PRODUCTION $\rightarrow$ VACUUM IS NOT VOID!

OUR JOURNEY SO FAR:

- 1m — US (CHUNKS, THINGS)
- 10^{-5}m — hair width / dust
- 10^{-10}m — molecules → CHEMISTRY
  atomic radius → ATOMIC PHYS.
- 10^{-14}m — nucleus → NUCLEAR PHYS.

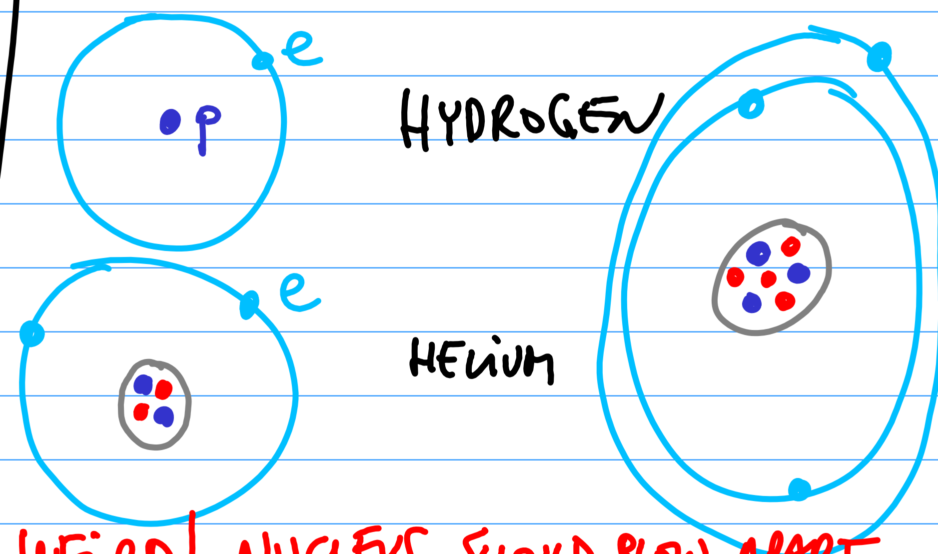
THE ATOM



Z protons (+ charge)

A − Z neutrons (0 charge)

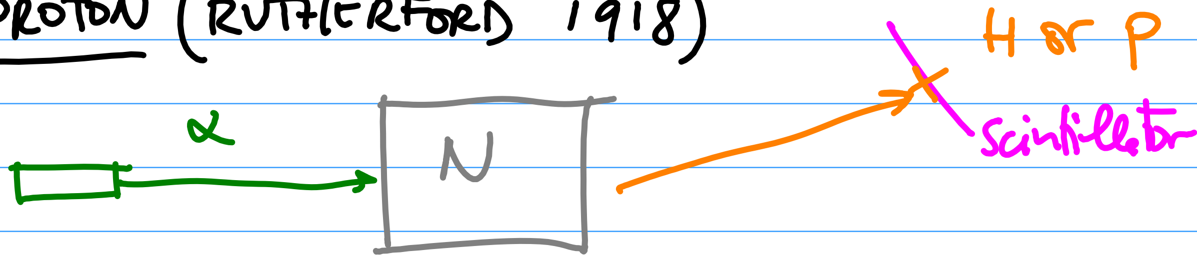
ATOM	Z	A (rounded)	Neutrons
H	1	1	0
He	2	4	2
Li	3	7	4
Be	4	9	5
B	5	11	6
C	6	12	6
N	7	14	7
⋮			
U	92	238	146



WEIRD! NUCLEUS SHOULD BLOW APART WITH ALL THE + CHARGE CRAMMED IN A TINY VOLUME

WHAT'S IN THE NUCLEUS? WHAT HOLDS IT TOGETHER?

PROTON (RUTHERFORD 1918)



EXPECTED ONLY TO SEE α OR N, BUT GOT H.

$\alpha + N \longrightarrow O + p$

A: 4 14 17 1

HE WAS DISINTEGRATING N INTO O AND A PROTON

CENTURIES OLD DREAM: TRANSMUTATION OF ELEMENTS

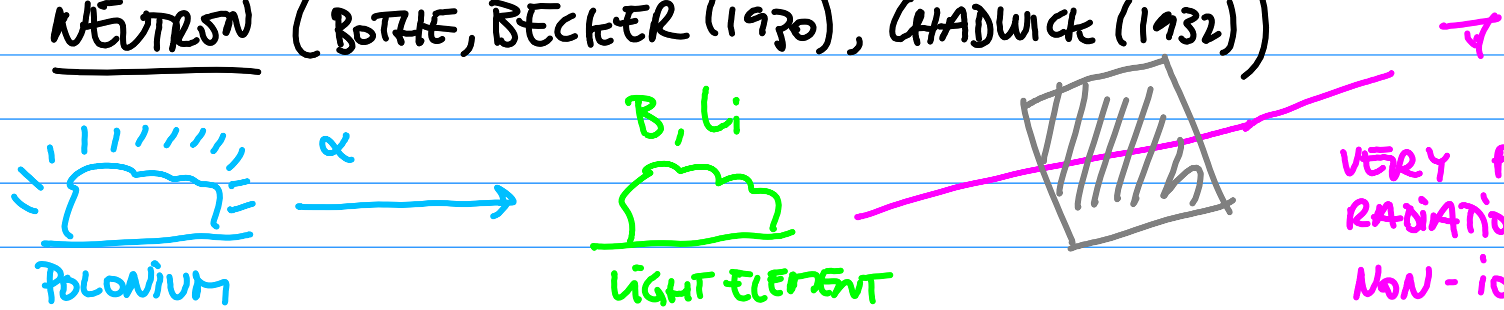
MASS ~ 938 MeV/c^2 = 1 AMU (atomic mass unit)

CHARGE = +1 SPIN = 1/2 (FERMION)

MASS OF ELECTRON ~ 0.511 MeV/c^2

×2000 HEAVIER

NEUTRON (BOTHE, BECKER (1930), CHADWICK (1932))



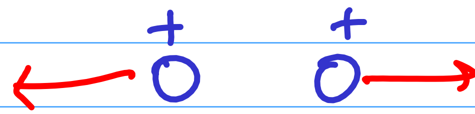
VERY PENETRATING RADIATION: NEUTRAL NON-IONIZING

MASS ~ 940 MeV/c^2

CHARGE ~ 0

SPIN 1/2 (FERMION)

WHY DON'T NUCLEI EXPLODE?

ELECTRIC FORCE: 

NO GOOD

GRAVITY: $F_G/F_E \sim 10^{-46}$ NO WAY!

NEW FORCE (ATTRACTIVE): "STRONG NUCLEAR" FORCE

IMAGINE THAT TWO PROTONS APPROACH EACH OTHER

COULOMB REPULSION UNTIL 10^{-15} m APART

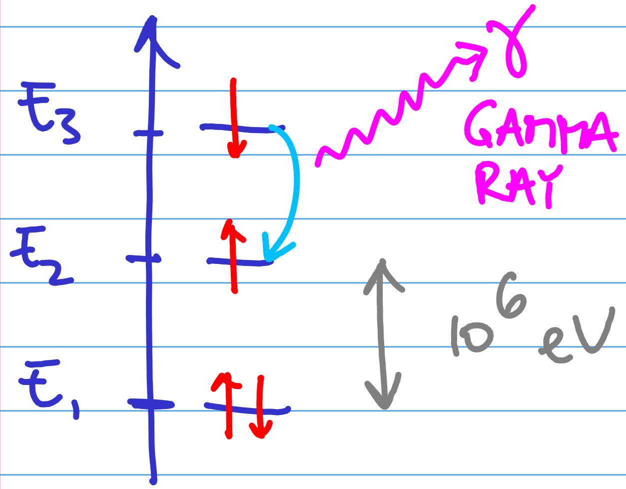
THEN THE STRONG FORCE KICKS IN AND THEY STICK TOGETHER.

PROPERTIES:

- STRONGER THAN E.M. FORCE
- LIMITED IN RANGE TO NO MORE THAN $d \sim 10^{-15}$ m

SOLVE SCHRODINGER EQ. FOR p AND n IN NUCLEUS.

→ DISCRETE AVAILABLE ENERGY LEVELS (JUST LIKE e^-)



ATOM IONIZATION : $E \sim 10$ eV

(TO REMOVE ONE e^- FROM ATOM)

NUCLEUS : $E \sim 10^6$ eV

(TO REMOVE ONE p OR n)

HUGE DIFFERENCE BETWEEN ATOMIC (CHEMICAL) AND NUCLEAR ENERGY!!

NUCLEAR DECAYS : NUCLEUS CAN BE UNSTABLE → TENDS TO DECAY TO LOWER ENERGY (MORE STABLE) STATE

① γ RADIATION (photon)

$$\underbrace{{}^{A}_{Z}X^{*}}_{\text{EXCITED STATE}} \longrightarrow \underbrace{{}^{A}_{Z}X}_{\text{GROUND STATE}} + \gamma$$

GAMMA RAY (EM RADIATION)

② β DECAY

$${}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y$$

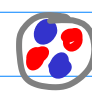
$\longrightarrow e^- \equiv \beta$ ray

A STAYS THE SAME, Z CHANGES

FOURTH FORCE "WEAK FORCE"

$n \rightarrow p^+ + e^-$ $\quad (p^+ \rightarrow n + e^+)$

③ α DECAY : NUCLEUS OF He



$2p$, $2n$ $\equiv \alpha$ PARTICLE

$${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + \alpha$$

NUCLEUS BECOMES MORE STABLE AFTER DECAY

A IS REDUCED BY 4 UNITS (AMU), Z IS REDUCED BY 2 UNITS (protons)