Physics 100 - October 24, 2007

Hello from Fermilab

http://www.fnal.gov

Last time Heisenberg's Uncertainty Principle

$$\Delta x \Delta p \sim h$$

$$\Delta E \Delta t \sim h$$

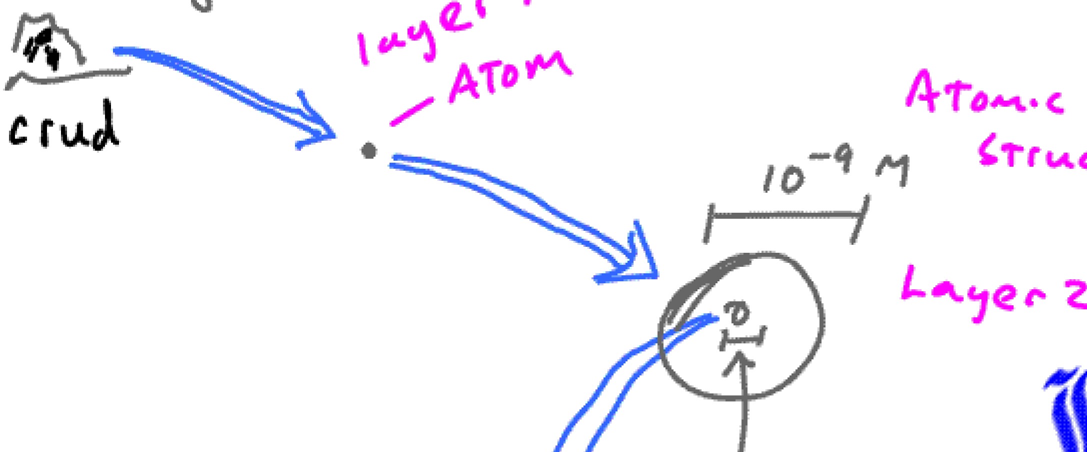
Say Goodbye to the deterministic Universe

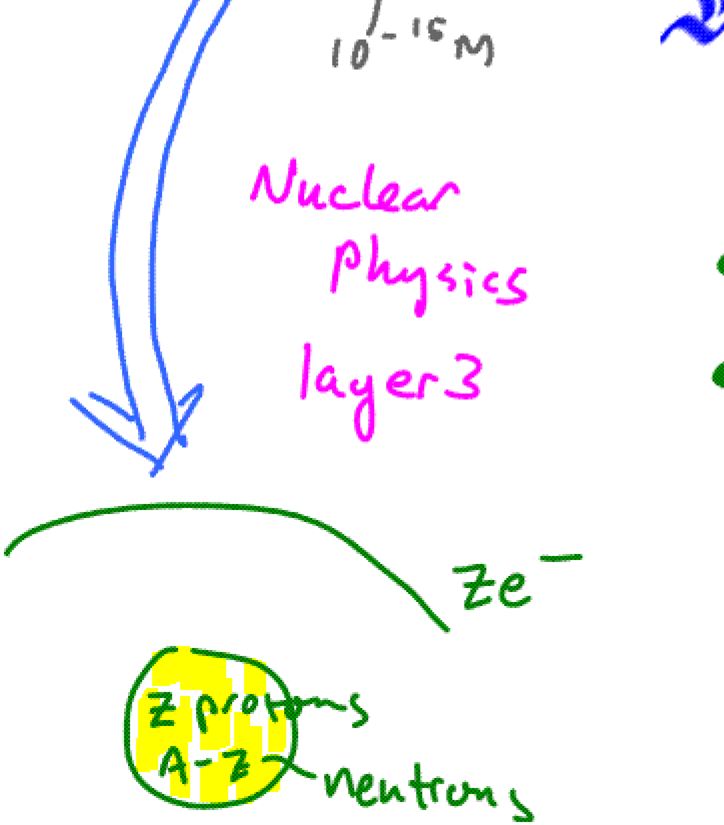
Say Hello to the Harry Potter universe

$\Delta E \Delta t \sim h$ ⟶ gives us a loophole in energy conservation that holds the key to understanding the fundamental essence of forces in Quantum Mechanics

We'll come back to this ...

OUR Journey to date





Journey into Inner Space

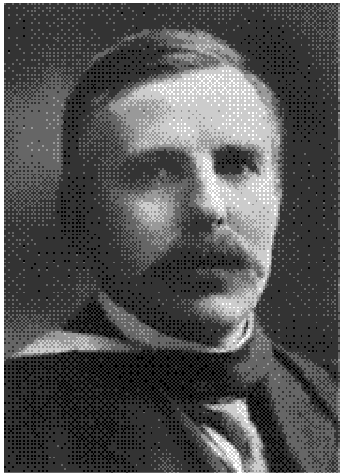
- Protons
- neutrons

Nūk - lē - ər

Nū - kū - lər

Puhlease!! Pronounce the Word Correctly

How did Bohr know to use "nuclear" model of Atom ??



Ernest Rutherford

(1871- 1937)

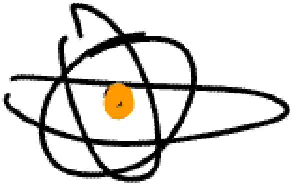
(New Zealand Farmboy → England)

1908 Nobel Prize in chemistry

Established Nuclear Model of Atom

Rutherford (Manchester)

J.J. Thompson (cambridge)

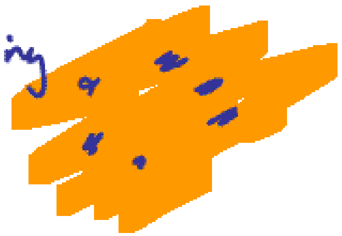


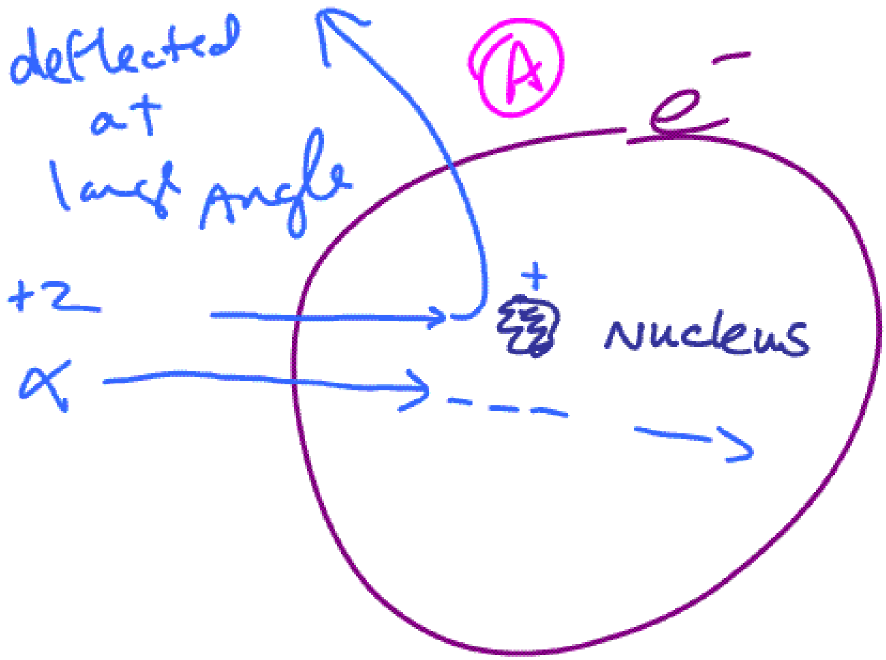
nuclear

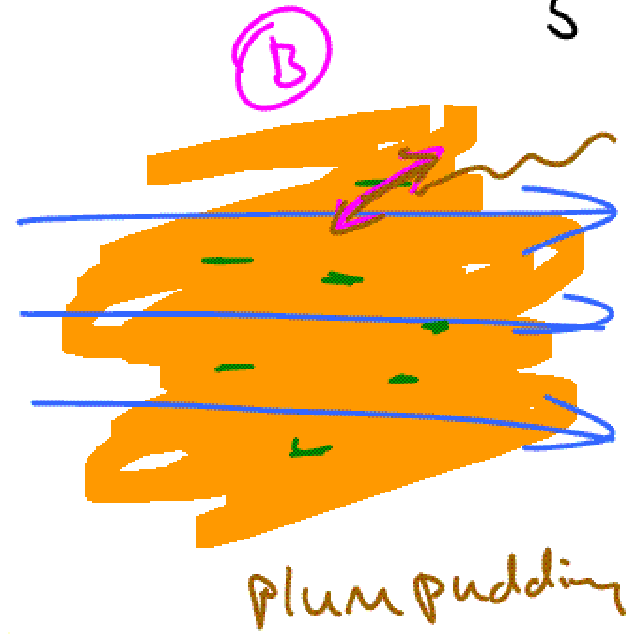
(A)

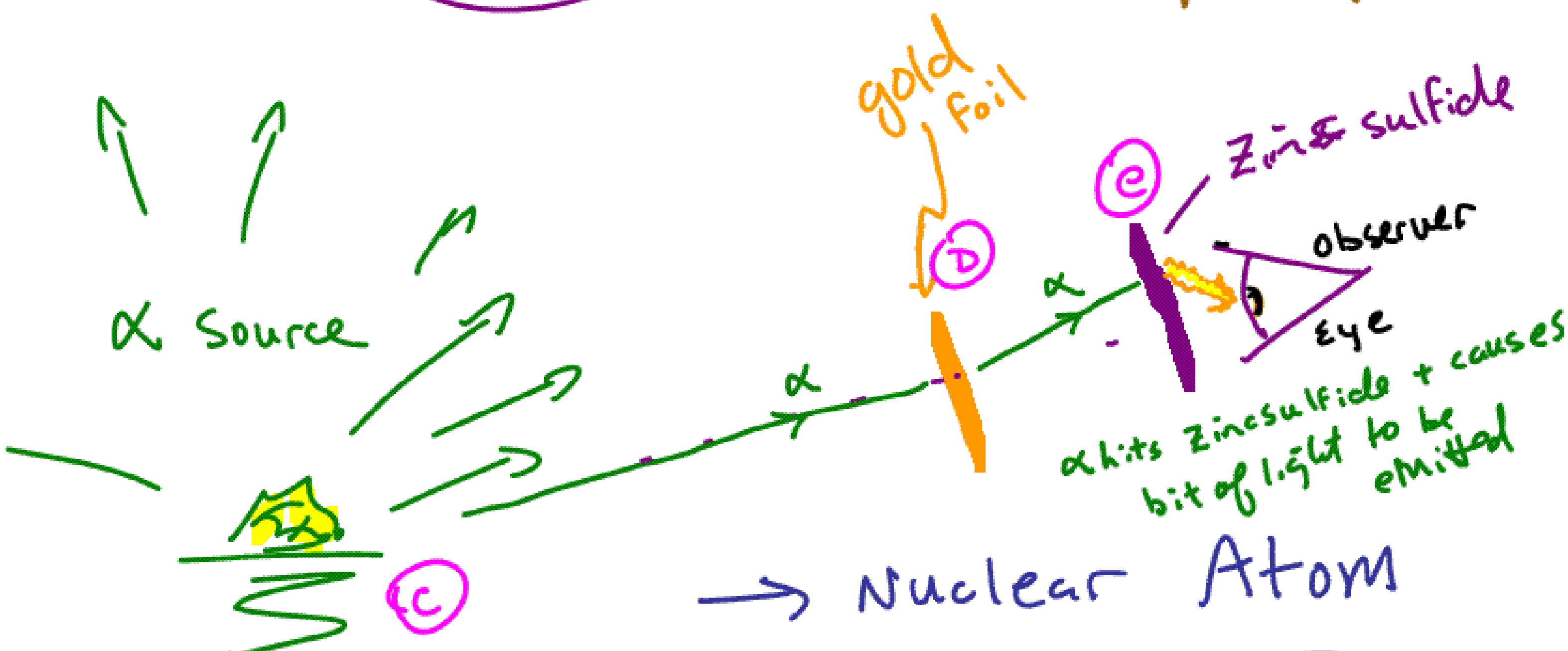
plum Pudding

(B)



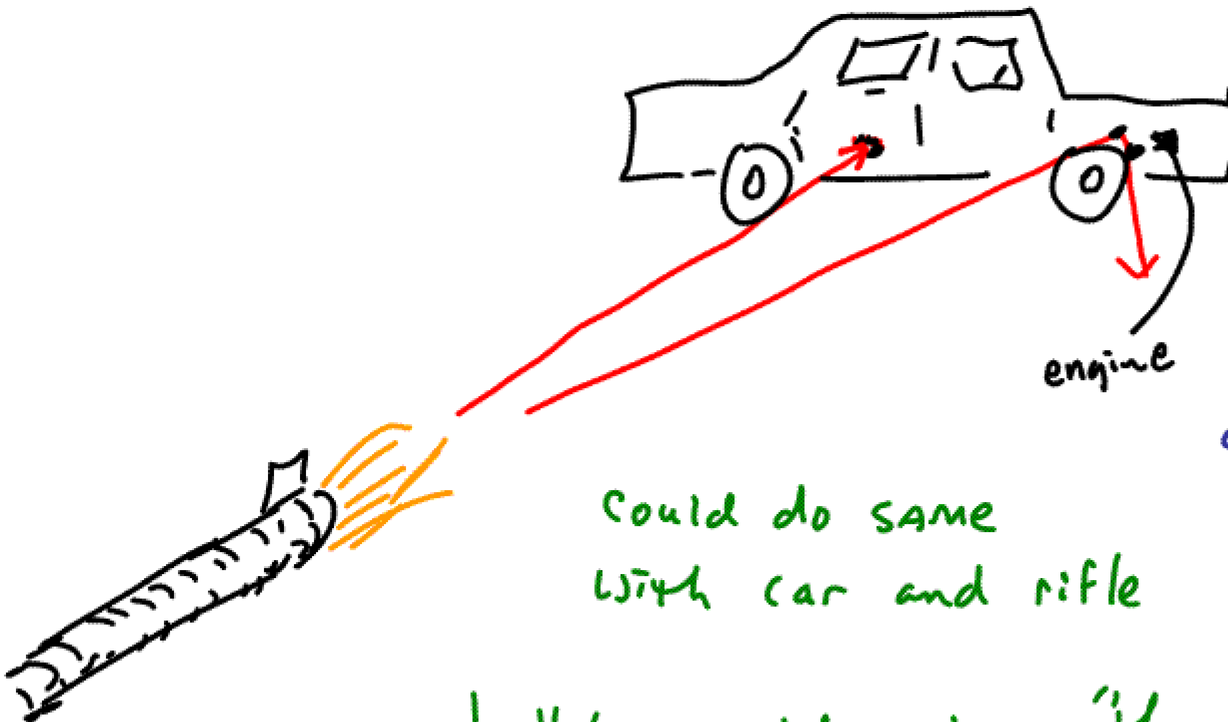






→ Nuclear Atom

Can think of Rutherford expt. as mapping out mass (charge) distribution of atom by probing w/ "bullets" and looking at ricochets



Could do same with car and rifle

bullets would not go "thru" car when hitting engine.

The Modern Atom

The nucleus

Z protons ● (+ charge)

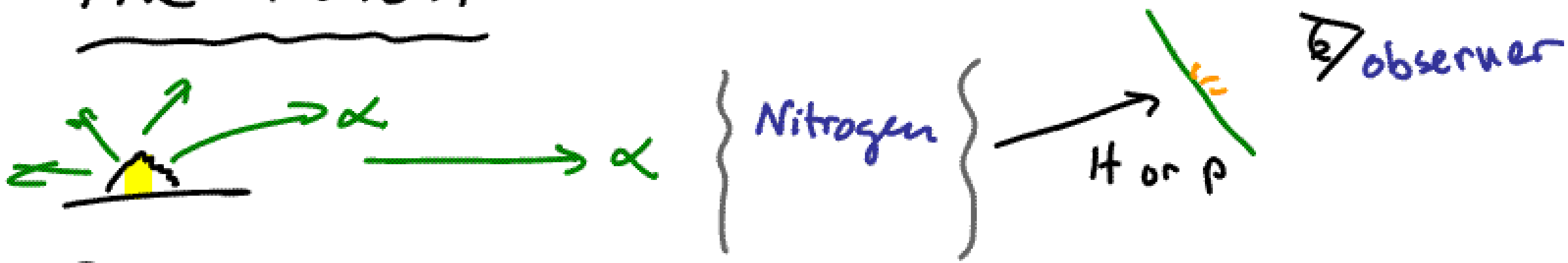
$A - Z$ neutrons ● (neutral)

This is wacked! Why?

nucleus should blow apart with all that + charge crammed into such a small volume

What's in the nucleus? What holds it together?

The Proton



Rutherford 1918

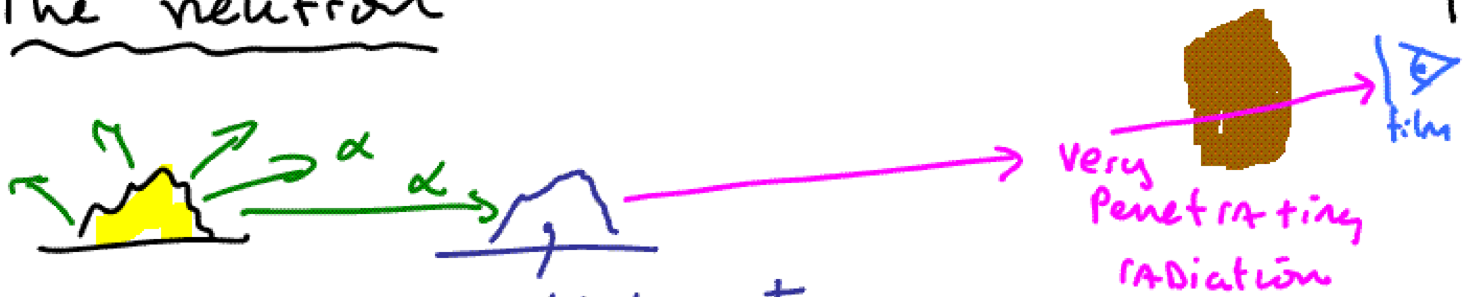
Mass ~ 938 MeV/c^2 = 1 AMU ~ Atomic Mass Unit

Charge = +1

for comparison Mass of electron ~ 0.511 MeV/c^2

Spin = $\frac{1}{2}$ ⟶ Fermion

The neutron



1930 Walther Bothe
H. Becker
(Germany)

1954 Nobel Prize in Physics
"For the coincidence method and his discoveries made therewith"

1932 James Chadwick → 1935 Nobel Prize "For discovery of the neutron"
(England)

Showed this penetrating radiation to NOT be γ-rays
Showed had mass similar to proton and was unchanged

Mass of neutron ~ 940 MeV/c^2

electric chg = 0
Spin = 1/2 fermion

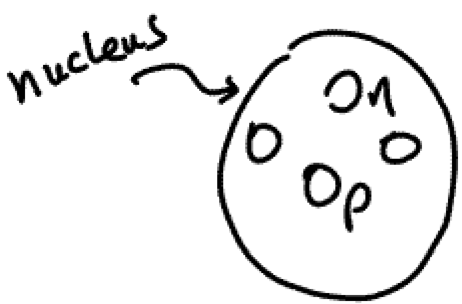
New Attractive force

Strong Nuclear Force

P ⟶ ⟵ P

Two protons approach each other ⟶ Coulomb repulsion until 10^{-15} m distance

then New Attractive force kicks in and they stick together



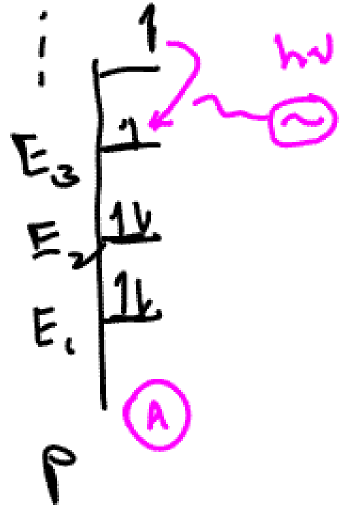
Solve Schrödinger's eqn

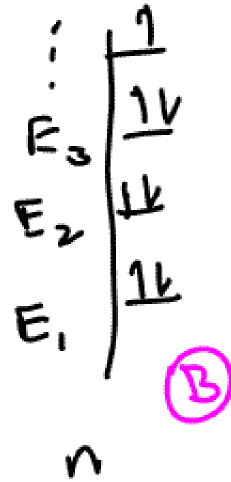
⟶ discrete Available energy levels (just like the atom!)

p, n ≡ collectively called "nuleons"

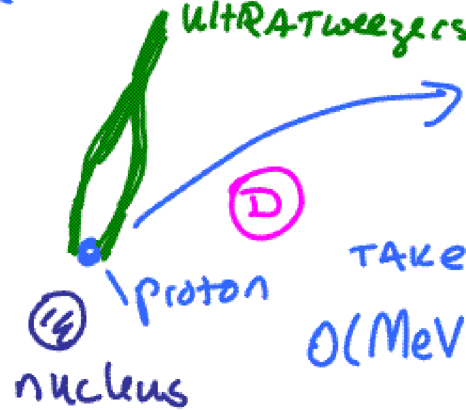
Populate "Nuclear" orbitals w/ n, p

just like e^- in multi-e^- Atom
⋮
fill shells w/ p, n





$\updownarrow \sim O(10^6\, eV)$



TAKES O(MeV) Energy to Remove from nucleus

ionization
O(10)eV to remove

"order"

chemistry Energy Scale

NOTE the Huge difference ....
Nuclear reactions require/release energy 1 million times greater than Atomic Rxns

O(MeV) Means "order of MeV" means Approximately an MeV
~1 - 10 MeV

(I) $^{A}_{Z}X_{N}$ ← nuclei symbolized as

$X \equiv$ Atomic Element symbol
determined by Z

$Z \equiv$ # protons

$A \equiv$ Atomic Mass $=$ # p + # n

$N =$ # neutrons

(II) $^{A}_{Z}X^{*}_{n}$ (* ← Excited STATE) $\xrightarrow{\text{natural decay}}$ $^{A}_{Z}X_{N} + \gamma$

$^{A}_{Z}X_{N}$ ↑ ground STATE

γ ↑ gamma ray

γ-radiation

Naturally radioactive substance - nucleus unstable

Will decay naturally

(A) $E = mc^2$

Beta decay

(B) $^{A}_{Z}X'$ → (D) $^{A}_{Z+1}X$ + e^-

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

β-radiation

(E) $p \rightarrow n + e^+$

$^{A}_{Z}X'$ → $^{A}_{Z-1}X$ + e^+

Positron

anti electron

Alpha decay

(F) $^{A}_{Z}X'$ → (G) $^{A-4}_{Z-2}X$ + α

(I) α = $\begin{matrix} p & n \\ n & p \end{matrix}$ alpha particle

↓

Helium Nucleus

alpha Radiation

Different nuclei → different numbers of p and n
↳ different nuclear shell structures

Stable nuclei
naturally radioactive → characteristic decay times

decay time characterized

(A) $t_{1/2}$ = halflife ≡ time it takes for ½ atoms in a given sample to decay

units of time

(C) $t_{1/2} = \frac{.693}{\lambda}$

(B) activity = $\frac{\Delta N}{\Delta t}$ ≡ # decays in time Δt = λN

λ ← decay constant

N ← # atoms in sample

λ ≡ units of $\frac{1}{s}$