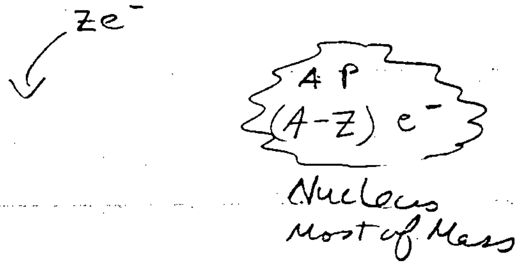
Nuclear Physics

NŪC-LĒ-er NOT NŪCŪ-ler

Rutherford-Bohr ATOM (AT Mass A AT Number Z)



Problems:

- Nucleus should still not be stable (net charge of +Ze)
- electrons confined to nucleus inconsistent with uncertainty principle
- Nuclear spin effect on Atomic electron spectra
  ⇒ hyperfine splitting
  Results not consistent w/ e^- in Nucleus picture

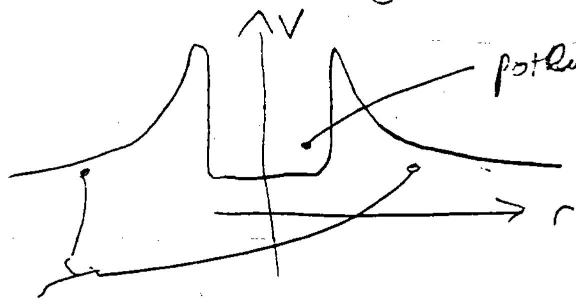
1932 Chadwick discovers Neutron

Nuclear model ⇒ Z protons, A−Z neutrons

	Charge	Mass	Spin
Proton	+e	938.28 MeV/c^2	½
Neutron	0	939.57 MeV/c^2	½
electron	−e	0.511 MeV/c^2	½

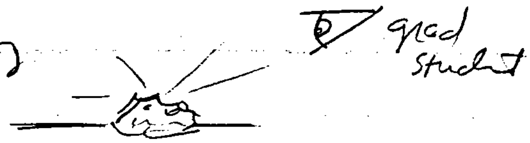
- Model Allows one to explain spin problem in hyperfine splitting of spectra
- Still why does nucleus not blow apart?

Hypothesize existance of Strong Nuclear force



Learn about force two ways:

- Observe Natural radioactivity to Note Stable Nuclei



- bombard nuclei with other particles
  - observe scattered particles
  - observe induced radiation after bombardment

Scattering experiments ⟹

- Nuclear radius ~ 1-10 Fermi (Fm) $(1\times10^{-15}M)$
- Within that radius ... Nuclear density is ~constant!

$$\frac{A}{\frac{4}{3}\pi R^3} \sim \text{constant} \qquad A \sim R^3$$
$$\text{or } R \sim A^{1/3}$$

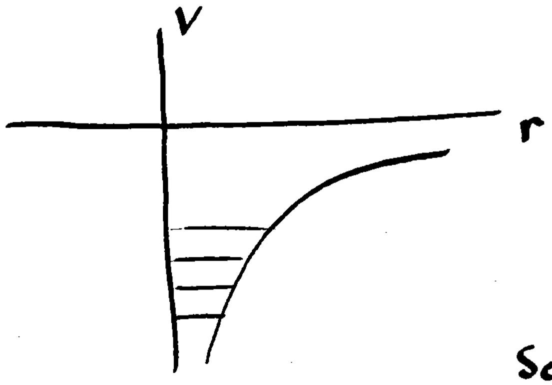
$\rho_{Nuclear} \sim 10^{17}\ kg/M^3$

Ball ~ 140 m in radius = mass of Earth

Very dense!

Another way to look at this

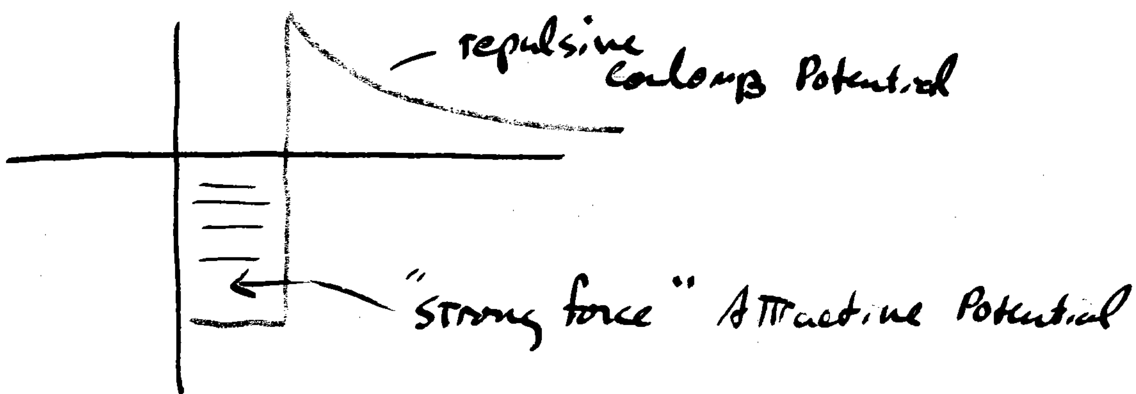
Have Seen



$-1/r$ potential exists for H atom

Schrödinger eqn $\Rightarrow$ bound discrete STATES

for Nucleus

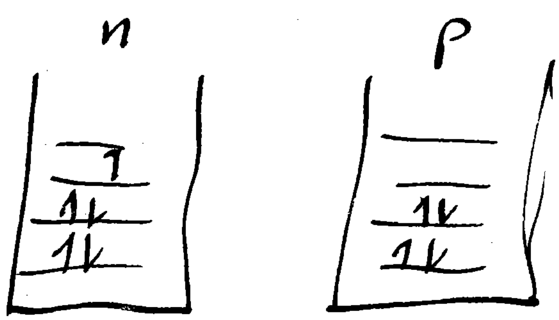


$\Rightarrow$ again get discrete bound energy STATES

n, p $\Rightarrow$ Spin ½

Pauli Exclusion Principle in operation

$\rightsquigarrow$ get "Nuclear Shell Model"



Think of Nucleus in a fashion similar to how you've thought of multi electron ATOMS

⇒ P, n bound in discrete states by "Strong Nuclear force"

⇒ P, n — nucleons exist in allowed state

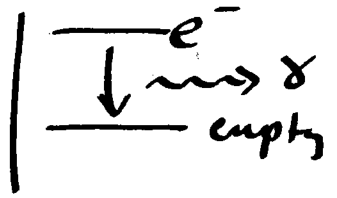
energy — atom n

Angular momentum — ℓ

nucleon spin — s

⇒ ATOM

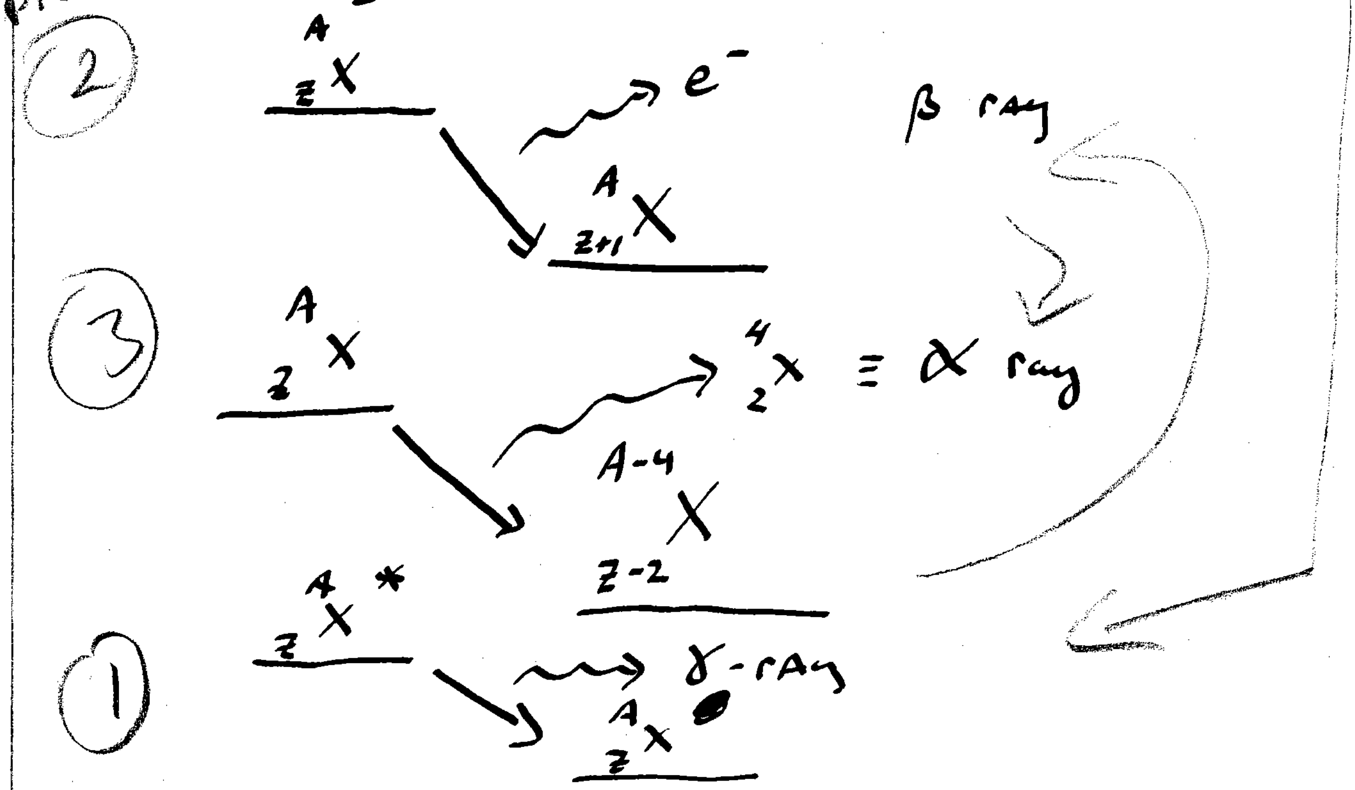
Makes Transitions To More stable STATS



So w/ Nuclei

Natural radiation "Spontaneous"

ORDER of presentation



Nuclear Symbol $^{A}_{Z}X_{N}$

$X \equiv$ Symbol of Element
$Z \equiv$ # protons
AT. #
determines element
$A \equiv$ A. Mass (# $p + n$)
$N \sim A - Z = (\# \; n)$

Sometimes see $_{Z}X^{A}$

Isotopes $\equiv$ Same Z, different A

Binding Energy

know for H atom - Binding energy of e^- to p ~13.6 eV
i.e. energy of H atom is 13.6 eV less than
energy of e^-, p separate

$$M_e c^2 + M_p c^2 = M_H c^2 + 13.6 \text{ eV}$$

↑ known as Binding energy

can do the same thing for Nuclei:

$$(A-Z) M_n c^2 + Z M_p c^2 = M_X c^2 + \text{Total Nuclear BE}$$

↑ nuclear mass

use Atomic Masses

$$(A-Z) M_n c^2 + Z M_H c^2 - Z M_e c^2 = M_X c^2 - Z M_e c^2 + \text{TOT BE}$$

electron terms cancel
∴ can use ATOMIC masses

$$(BE)_X = \left[(A-Z)M_n + Z M_H - M_X\right]c^2$$

example: calc BE & BE/nucleon for ^{56}Fe

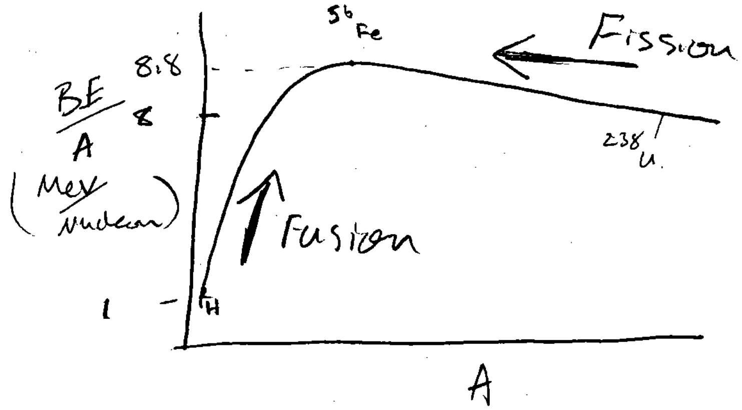
$M(^{56}Fe) = 55.934939$ AMU $\quad M(H) = 938.791 \frac{MeV}{c^2}$ $\quad M(n) = 939.57$ MeV

$= (55.934939)u \times 931.502 \; MeV/c^2/u$

$= 52103.5 \; MeV/c^2$

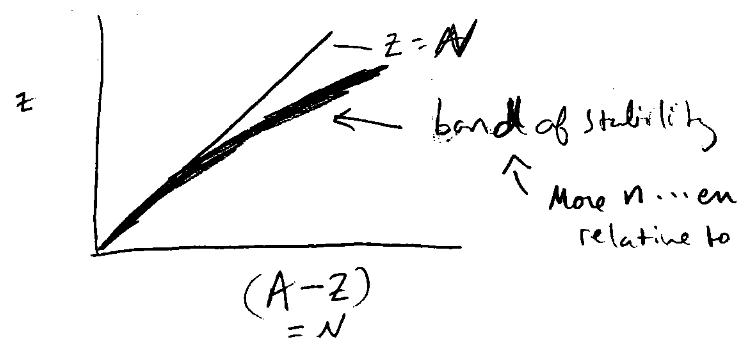
$$(Be)_{^{56}Fe} = \left[(30)(939.57) + (26)(938.791) - 52103.5\right] MeV/c^2 \; c^2 = 492.2 \text{ MeV}$$

$$Be/\text{Nucleon} = \frac{492.2}{56} = 8.79 \text{ MeV/nucleon}$$



- ^{56}Fe nucleus is more tightly bound than any other nucleus
  Most Stable
- Fusion
- Fission
- generally Held that main light elements H, He come from big bang
- heavier elements up to Fe come from fusion in Stars
- heavier elements come from supernovae & "Neutron addition"

NOT all combinations of Z & A are stable



Experimentally Observed

↑ More n ... enhances strong force relative to coulomb repulsion?

If a Nucleus is unstable is TRANSmutes itself to another Nucleus by radioactive decay —

β decay ~~A → A + e⁻~~ → $^{A}_{Z}X \to ^{A}_{Z+1}X + e^-$ ($Z \to Z+1$ $N \to N-1$)

α decay $^{A}_{Z}X \to ^{A-4}_{Z-2}X + ^{4}_{2}H$

γ decay $^{A}_{Z}X^* \to ^{A}_{Z}X + \gamma$