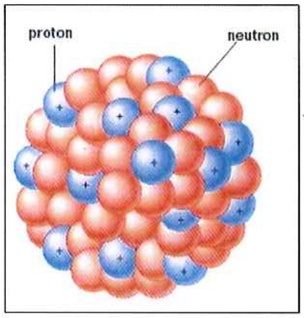
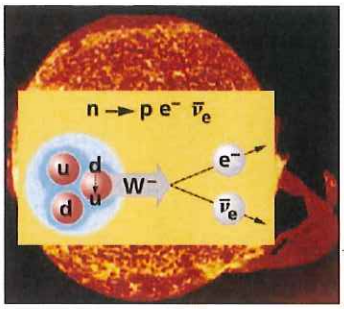
The Four Forces of Nature

STRONG



ELECTRO - MAGNETIC

WEAK



GRAVITY

6

		Strength	Range (m)	Particle
Strong	π, π; (+) (+), (N) (+); Force which holds nucleus togeher	1	10^{-15} (diameter of a medium sized nucleus)	gluons, π(nucleons)
Electro-magnetic	←(+) (+)→; (-)→ ←(+)	$\frac{1}{137}$	Infinite	photon mass = 0 spin = 1
Weak	ν→, W-; e^-; neutrino interaction induces beta decay	10^{-6}	10^{-18} (0.1% of the diameter of a proton)	Intermediate vector bosons W^+, W^-, Z_0, mass > 80 GeV spin =1
Gravity	(m)→ ←(m)	6×10^{-39}	Infinite	graviton ? mass = 0 spin = 2

Nucleons

NEUTRON *n*

The **NEUTRON** is a subatomic particle with no net charge. Along with the proton, it forms the nucleus of an atom. It consists of two down quarks and one up quark. The number of neutrons determines the isotope of an element.

Acrylic felt with poly bead fill for medium mass.

●●●●●●●●○○○○○
LIGHT HEAVY

NEUTRON

The PARTICLE ZOO

PROTON *p*

The **PROTON** is a subatomic particle with a positive charge. Along with the neutron, it forms the nucleus of an atom. It consists of two up quarks and one down quark. The number of protons in the nucleus determines the chemical properties of the atom and which chemical element it is.

Acrylic felt & fleece with poly bead fill for medium mass.

●●●●●●●●○○○○○
LIGHT HEAVY

PROTON

The PARTICLE ZOO

unstable if a free particle
lifetime ~ 15 min

$m_n = 939.6\ MeV/c^2$

electric charge – 0

spin 1/2

radius ~ 0.8 fm

stable

$m_p = 938.3\ MeV/c^2$

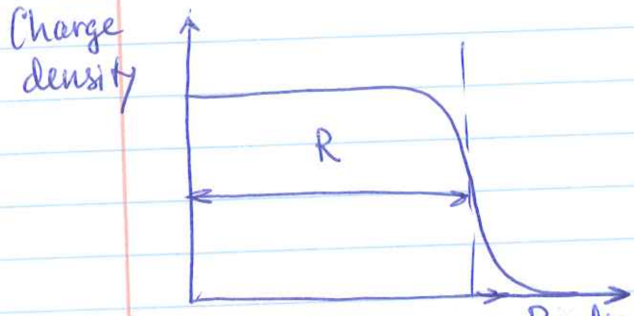
electric charge +e

spin 1/2

radius ~ 0.88 fm ($=10^{-15}$ m)

Atomic nucleous

From first scattering experiments



Radial distance (fm)

$R \sim 10^{-14} - 10^{-15}$ m from early experiments

fm = femtometer $= 10^{-15}$ m (= fermi)

A nucleus consists of protons and neutrons (called nucleons)

Thesarius: Atomic number Z (charge number)
= # of protons (and electrons in atom)
Neutron number N
Mass number $A = Z + N$

Chemical elements are characterize by Z; atomic nuclei with same Z but different N are called isotopes

Carbon $^{11}_{6}C$ | $^{12}_{6}C$, | $^{13}_{6}C$, $^{14}_{6}C$

$^{12}_{6}C$: 98.9% abaudance
$^{14}_{6}C$: unstable

$N=5$ | $N=6$ | $N=7$ $N=8$

Radius of the nucleus $R = r_0 A^{1/3}$, $r_0 = 1.2$ fm

$V_{nucleus} \propto A$ nuclea density is roughly the same

Atomic mass unit $u = \frac{1}{12}$ of atomic mass of ${}^{12}_{6}C$

$m_p = 1.0073u$
$m_n = 1.0087u$
why m_p and m_n are havier than u?!

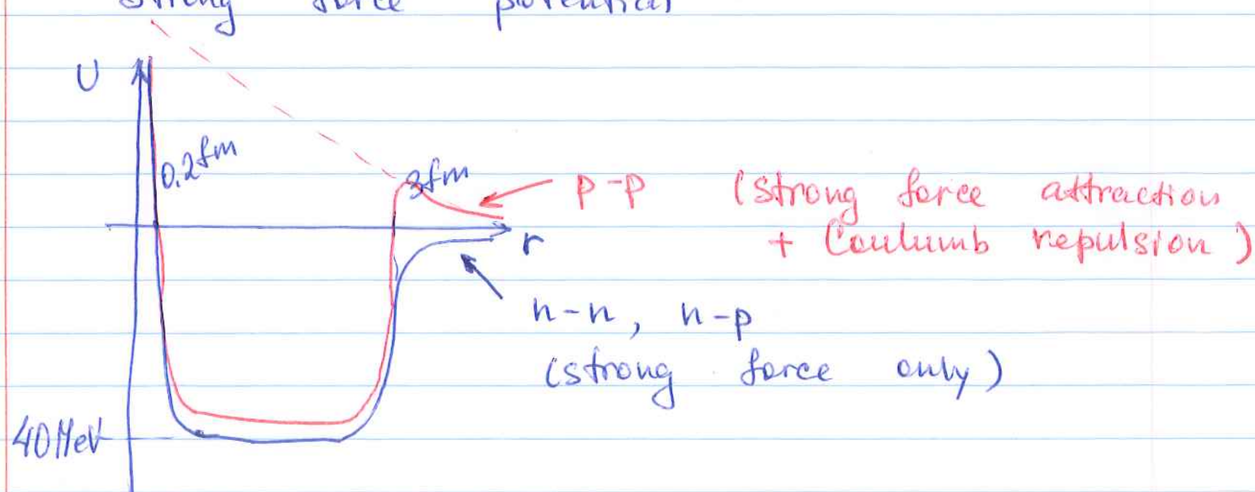
Answer: binding energy: when protons and neutrons are brought together by a strong force, they fall into a potential well, so their energy is reduced. Since $E = mc^2$, the lower energy means lighter particle

Mass of an atom

$$M = Z \cdot m_p + Z m_e + N \cdot m_n - \underbrace{B/c^2}_{\text{binding energy per nucleon}} \cdot A$$

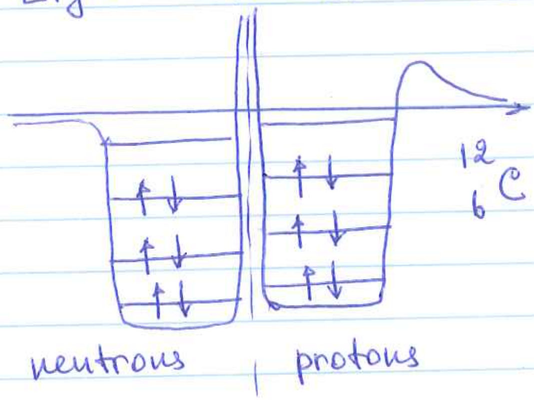
Higher B corresponds to a more stable nucleus (since it will require more energy to release particles from the potential)

Strong force potential

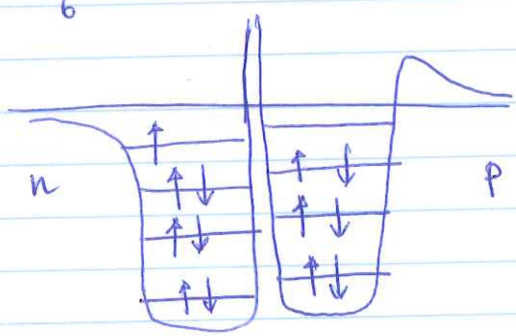


Nuclear model – independent particle model

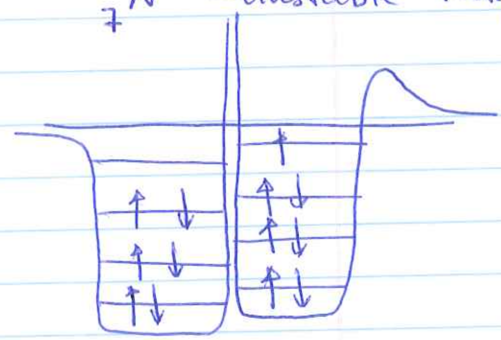
Light nuclei : most stable isotopes $N \approx Z$



$^{13}_{6}C$ – stable isotope



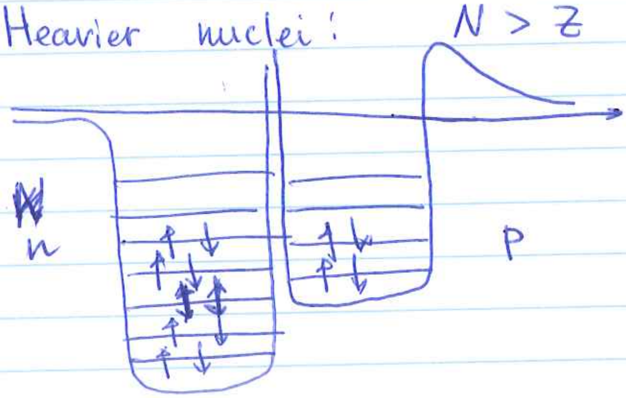
$^{13}_{7}N$ –unstable isotope



Neutron is not a stable particle
Free neutron life time ≈ 15 min

"Magic numbers" Z or N = 2, 8, 20, 28, 50, 82, 126

Heavier nuclei : $N > Z$



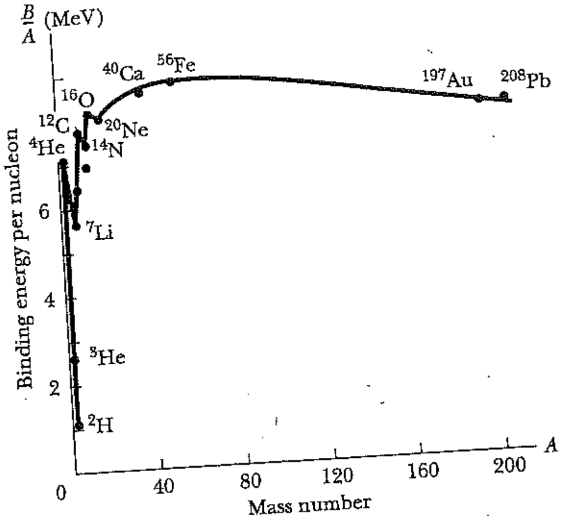


Figure 12.6 The binding energy per nucleon versus the mass number A. Notice the subpeaks at ^{4}He, ^{12}C, and ^{16}O.

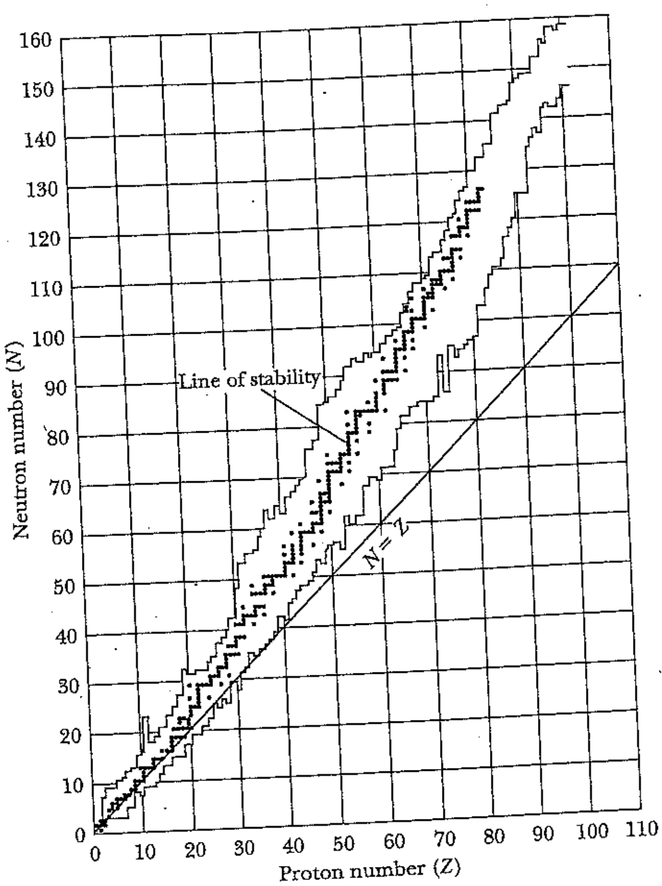
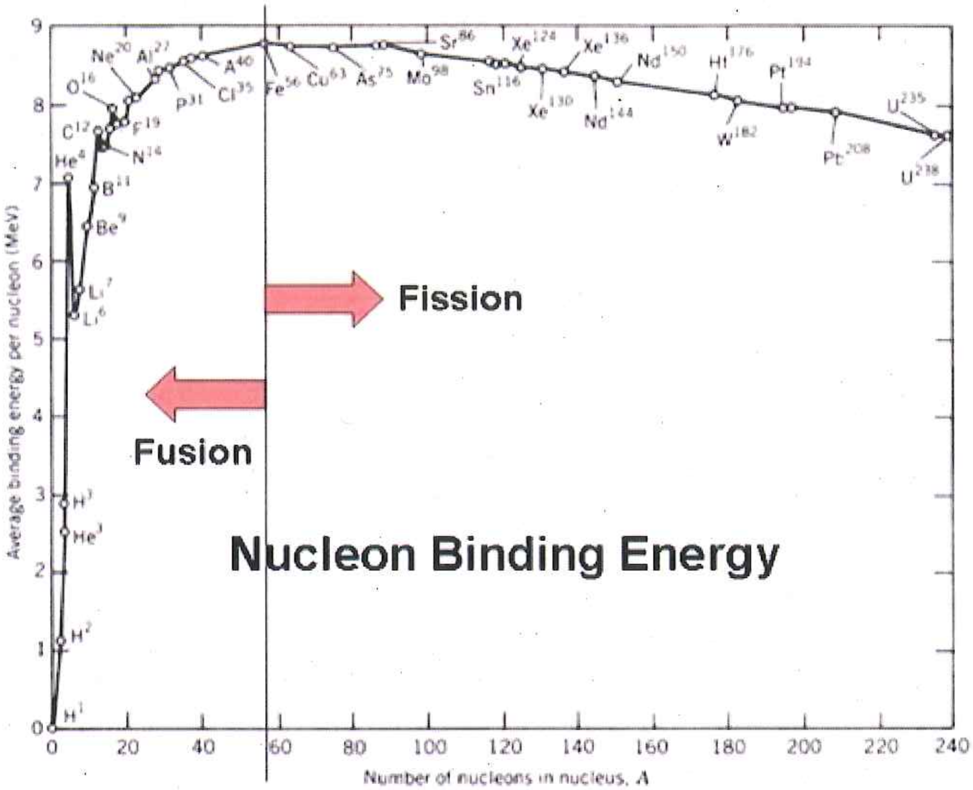


Figure 12.5 A plot of the known nuclides with neutron number N versus proton number Z. The solid points represent stable nuclides, and the shaded area represents unstable nuclei. A smooth line through the solid points would represent the line of stability.


Fission
Fusion
Nucleon Binding Energy
Average binding energy per nucleon (MeV)
Number of nucleons in nucleus, A
H1
H2
He3
H3
Li6
Li7
Be9
B11
He4
N14
C12
F19
O16
Ne20
Al27
P31
Cl35
A40
Fe56
Cu63
As75
Sr86
Mo98
Sn116
Xe124
Xe130
Xe136
Nd144
Nd150
Hf176
W182
Pt194
Pt208
U235
U238