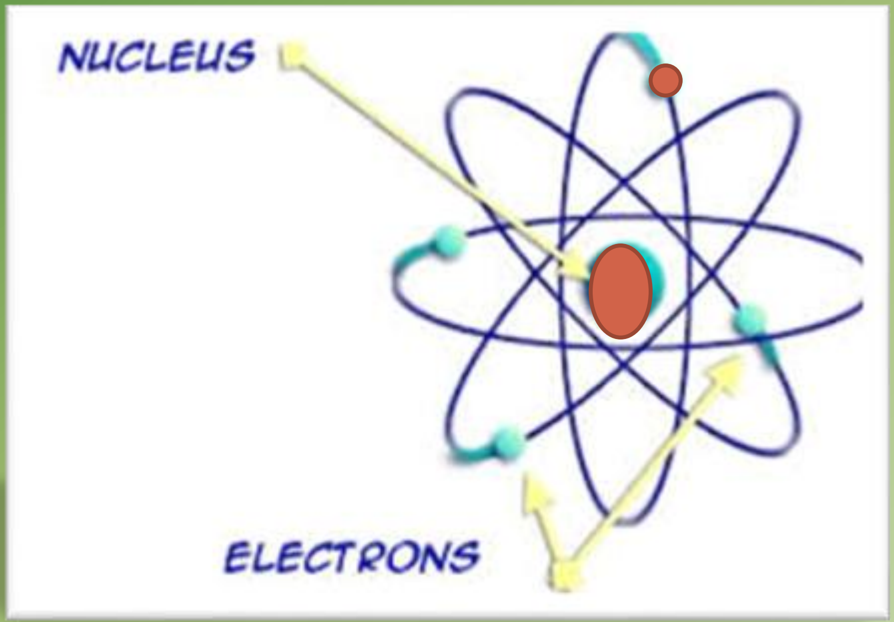
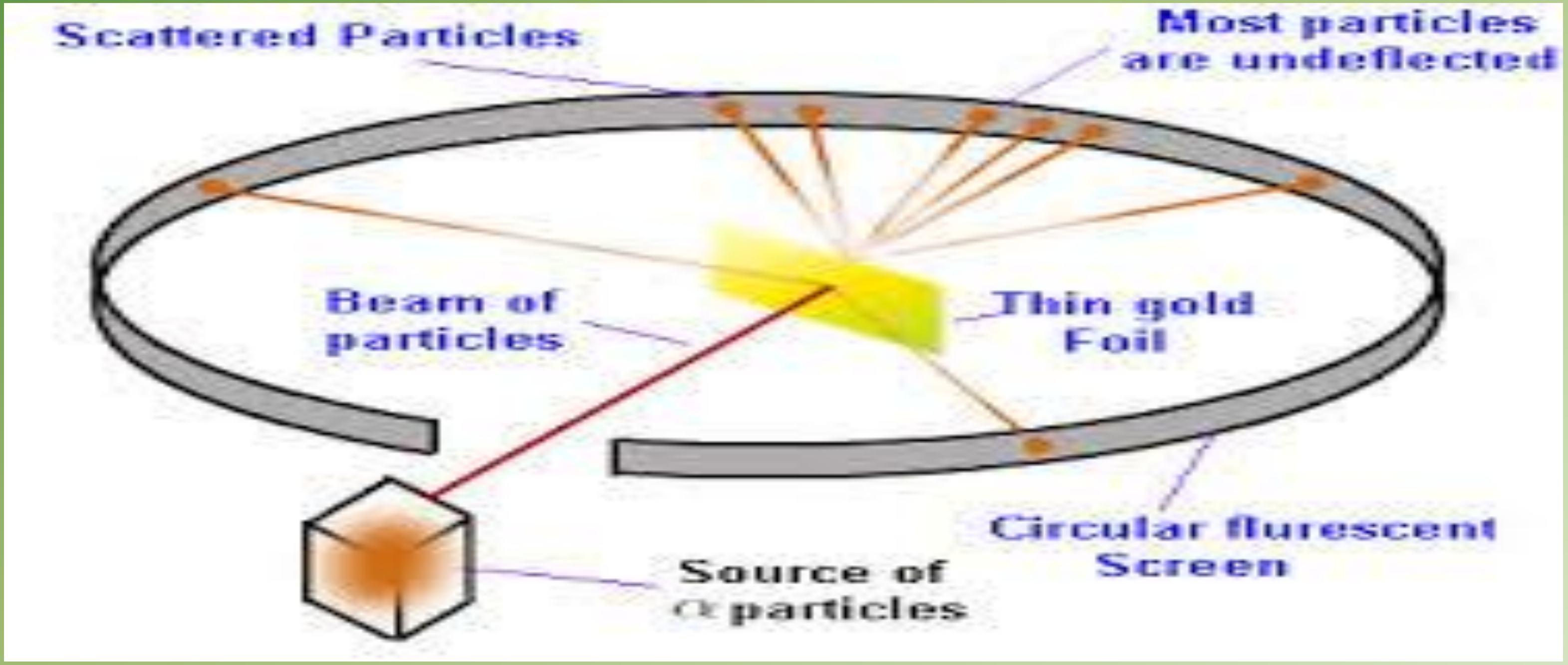
NUCLEAR PHYSICS

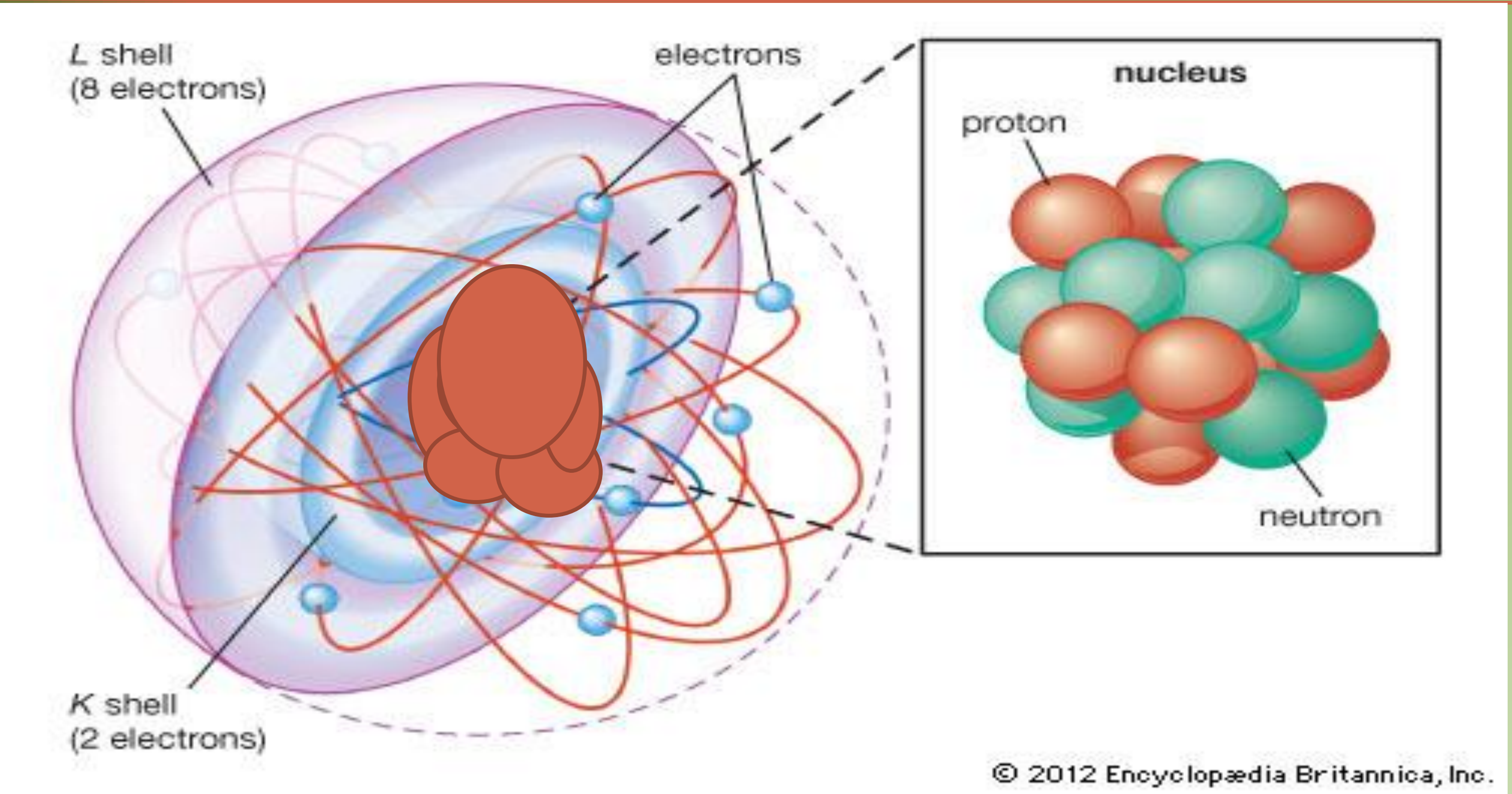


JAMAL BASHA . K . A.
Lec in Physics

NUCLEUS

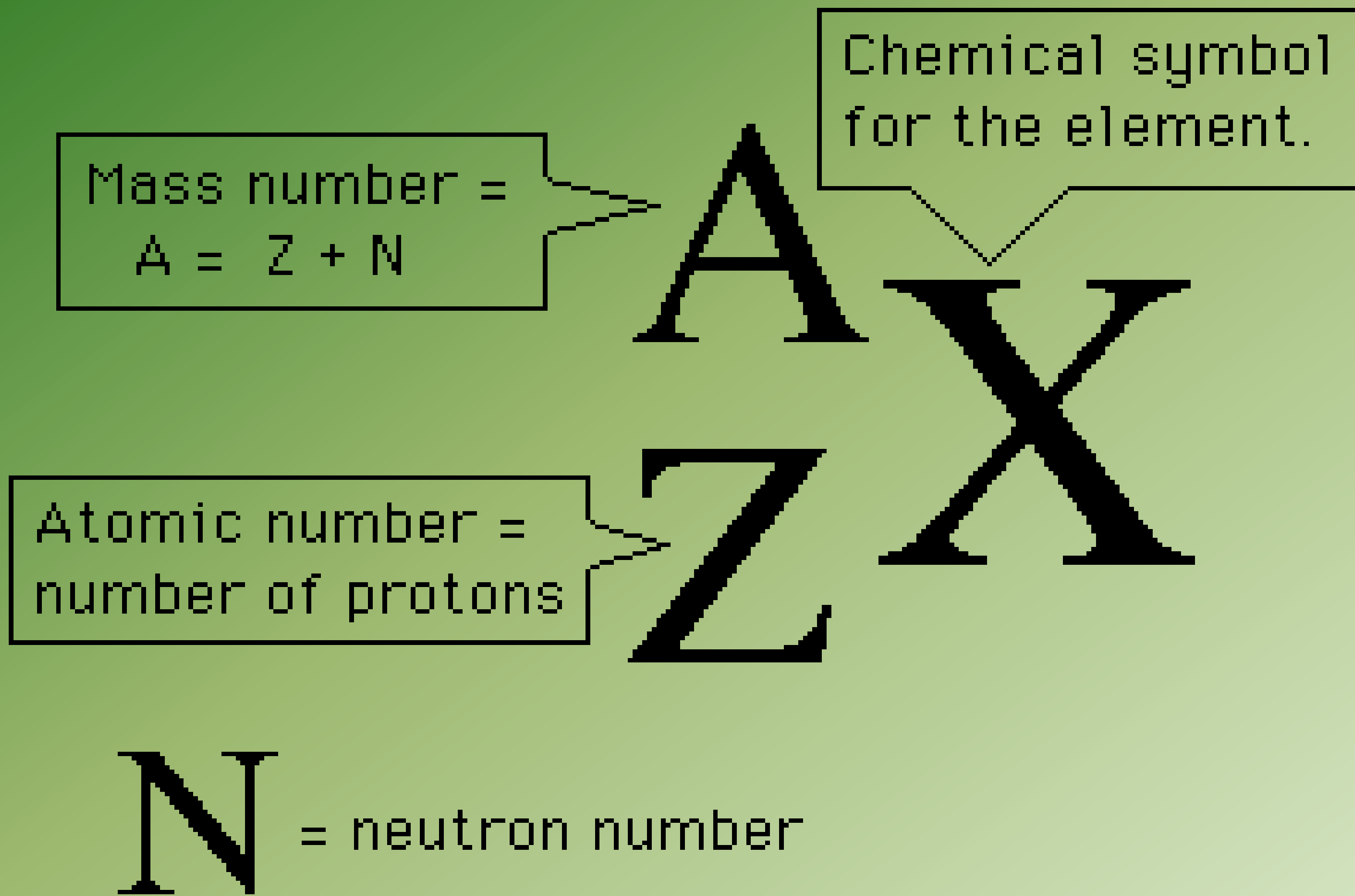
- The atomic nucleus was discovered in 1911 by Rutherford experiments.





According to Rutherford an atom consist of very small nucleus surrounded by orbiting electrons

NOTATION



Mass number =
A = Z + N
Chemical symbol
for the element.
A
X
Z
Atomic number =
number of protons
N
= neutron number

NUCLEONS

- Protons and Neutrons

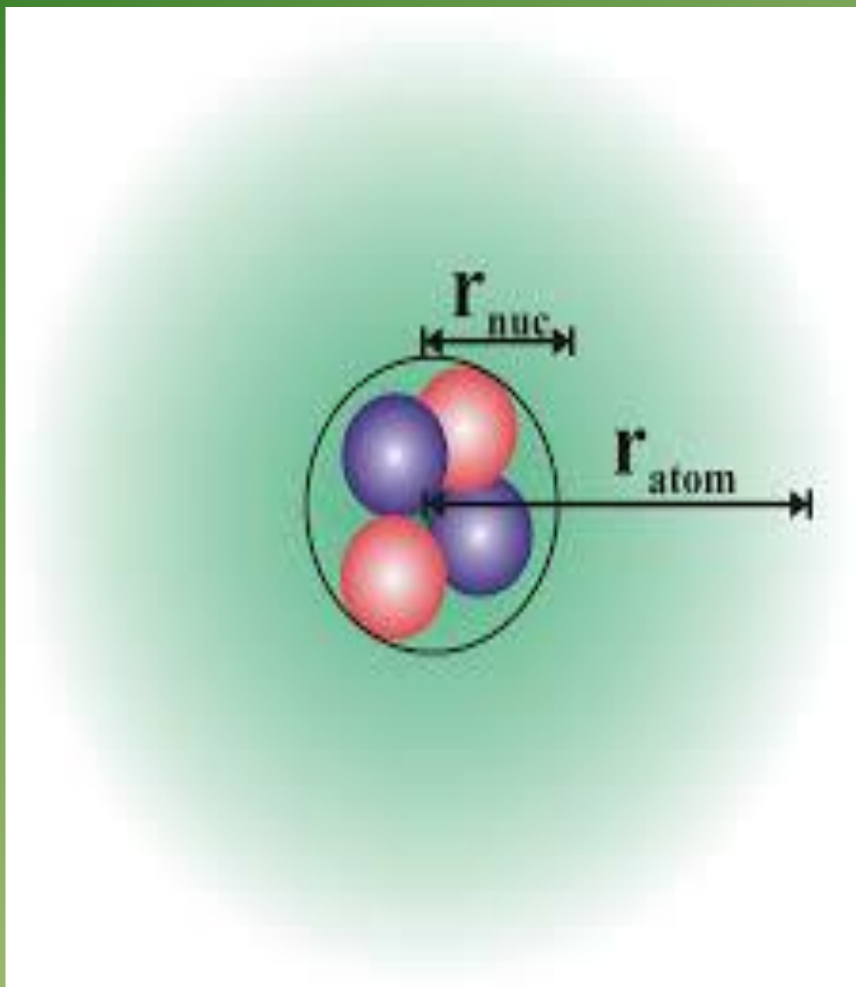
- The nucleons are bound together by the strong force.

NUCLEAR FORCE

BASIC PROPERTIES OF NUCLEUS

- ✓ 1.Nuclear size.
- ✓ 2.Nuclear charge.
- ✓ 3.Nuclear mass.
- ✓ 4.Nuclear density.
- ✓ 5.Nuclear spin.
- ✓ 6.Nuclear magnetic dipolemoment.
- ✓ 7.Electric quadrapole moment (Q).

NUCLEAR SIZE



$$r \propto A^{1/3}$$

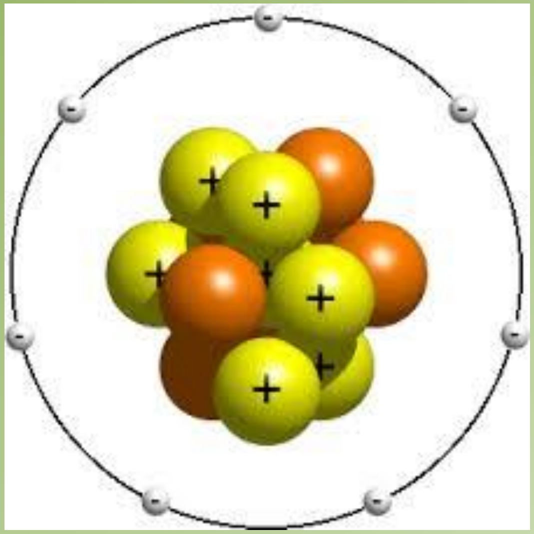
$$r = r_0 A^{1/3}$$

where $r_0 = 1.2 \times 10^{-15}$ m

NUCLEAR CHARGE

NUCLEUS CHARGE IS POSITIVE.

THE CHARGE OF THE NUCLEUS IS DUE TO THE PROTONS CONTAINED IN IT.



NUCLEAR MASS

Nuclear mass $M = Zm(p) + (A-Z)\, m(n)$

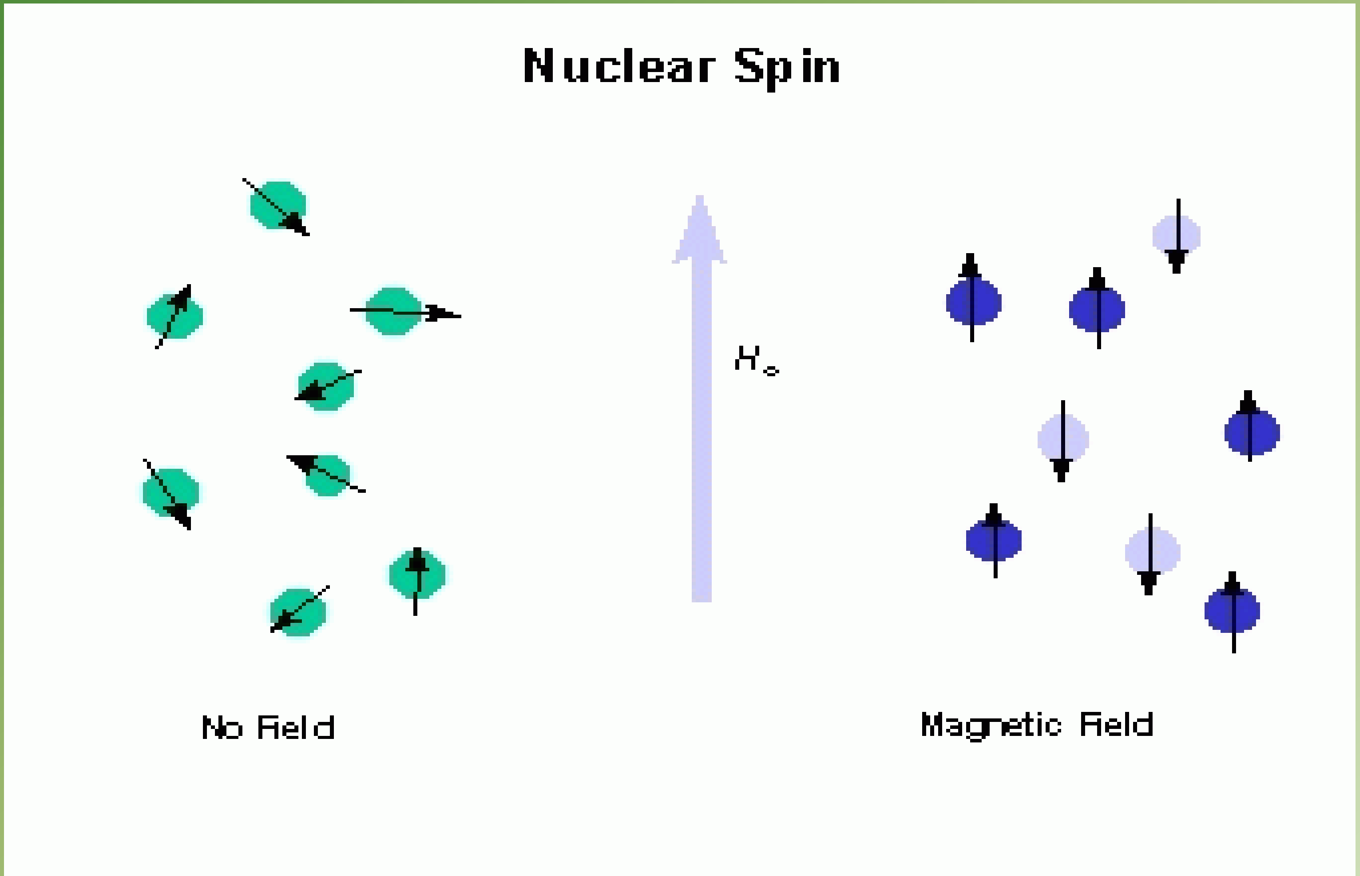
NUCLEAR DENSITY

Density =nuclear mass/nuclear volume

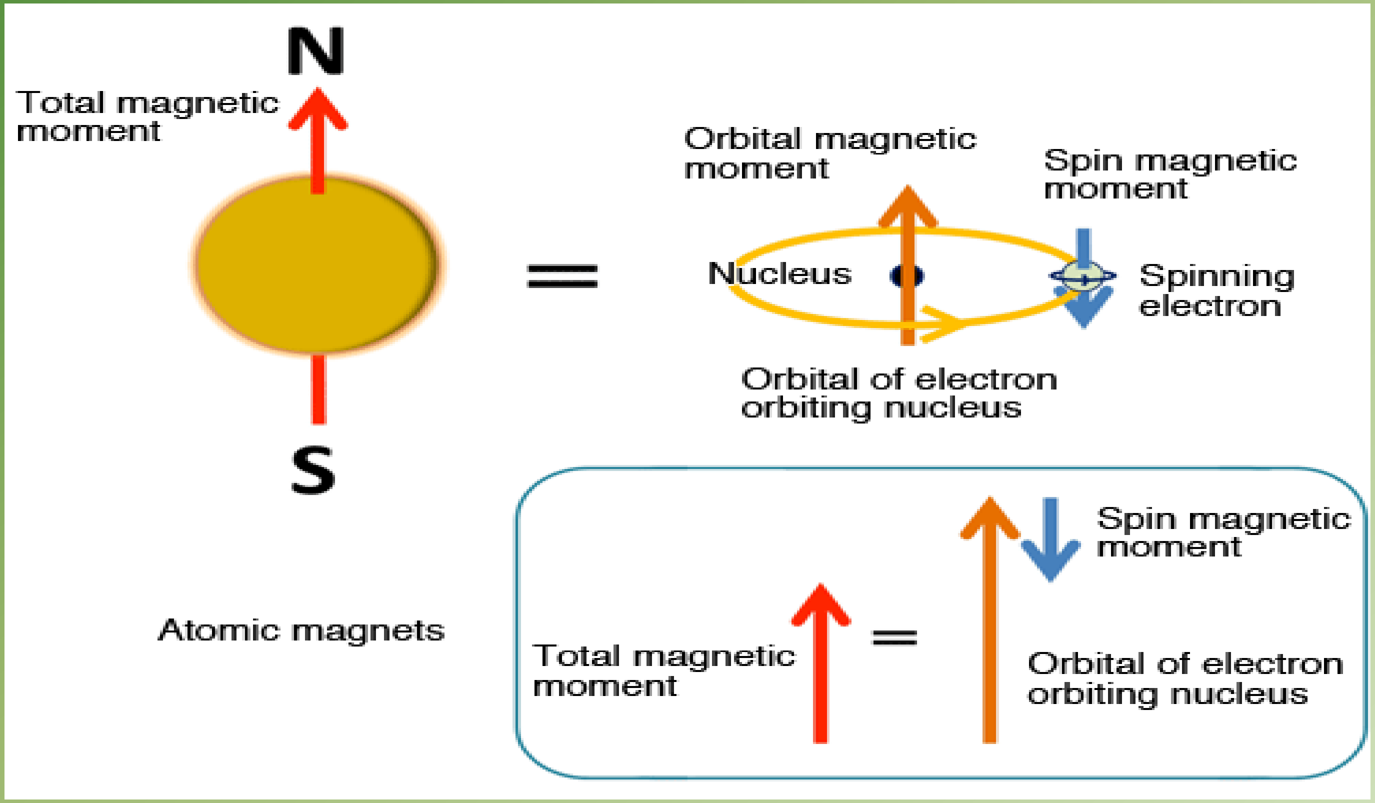
$$n = \frac{A}{\frac{4}{3}\pi R^3}$$

Number of nucleons per c.C =

NUCLEAR SPIN

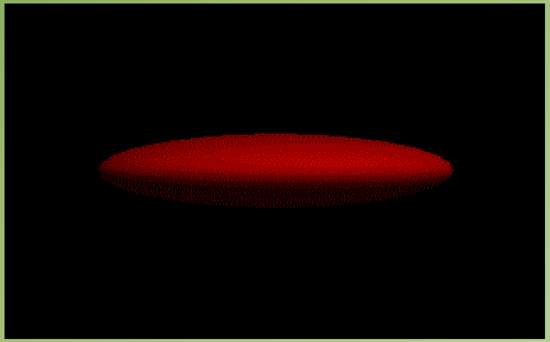


NUCLEAR MAGNETIC DIPOLEMOMENT

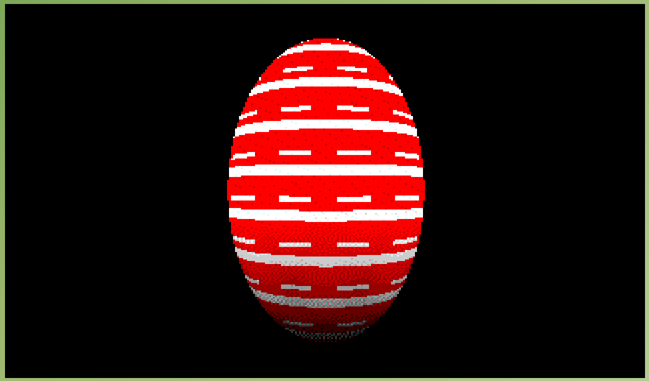


ELECTRIC QUADRAPOLE MOMENT

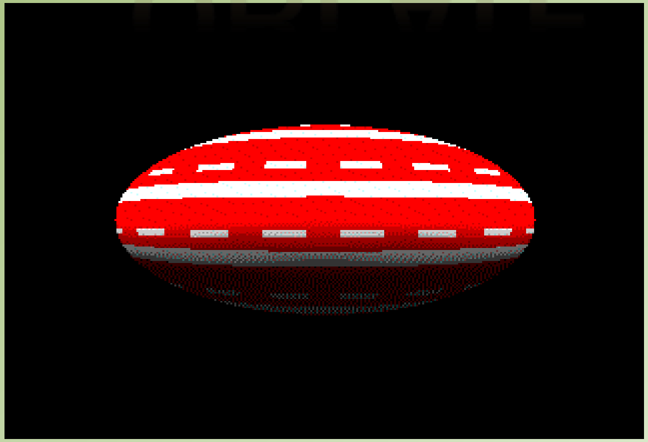
SPHERICAL



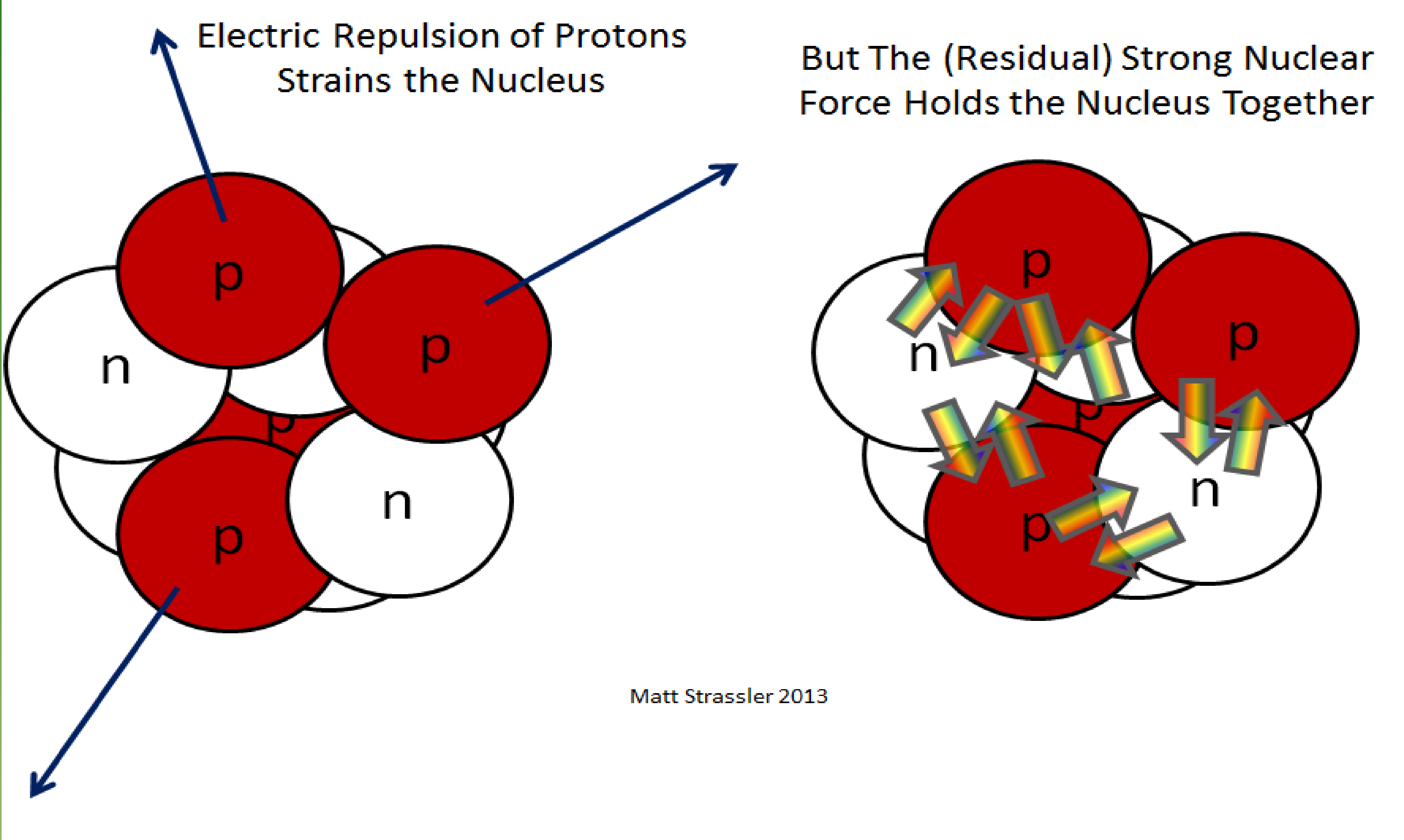
PROLATE

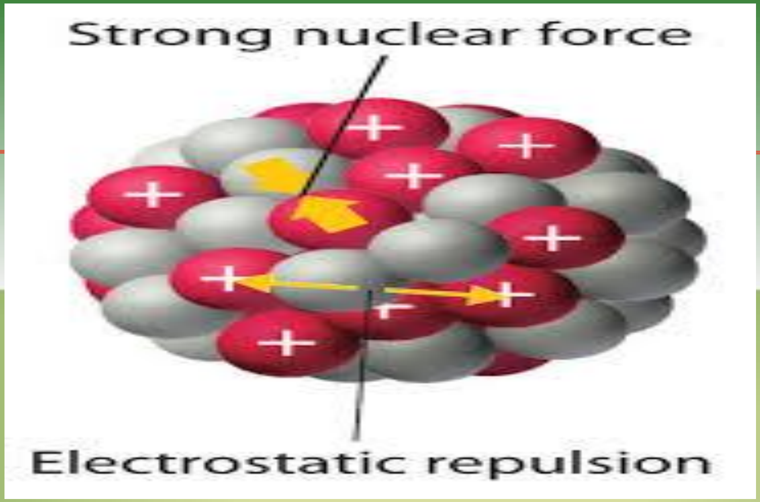


OBLATE



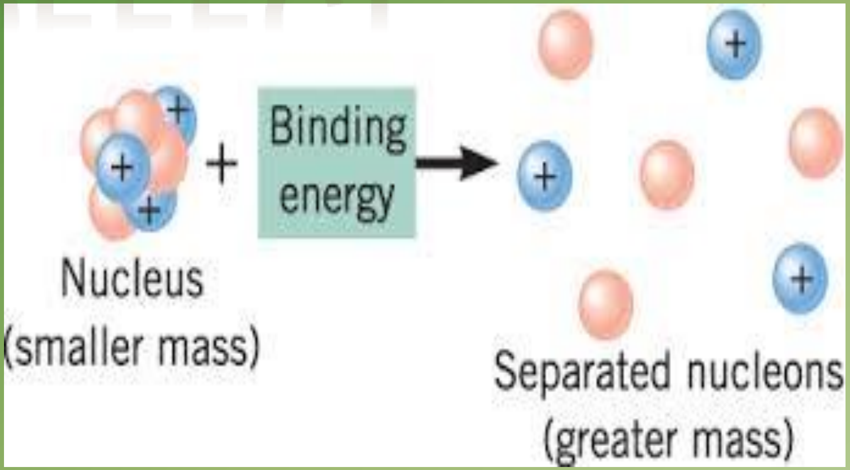
NUCLEAR FORCES



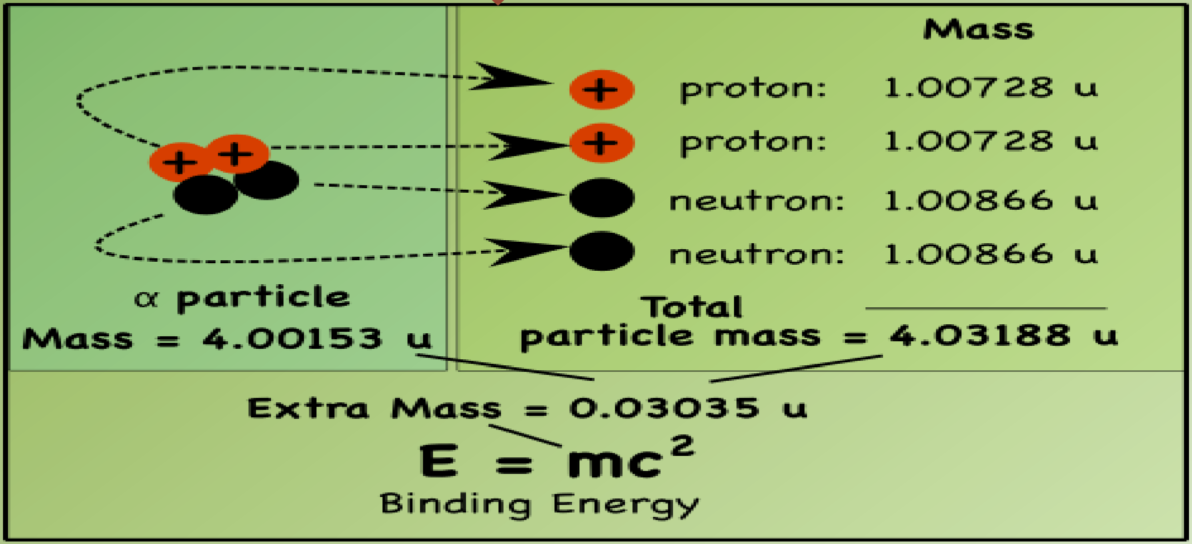


1.SHORT RANGE—ATTRACTIVE
2.CHARGE INDEPENDENCE
3.SATURATION
4.SPIN DEPENDENCE
5.REPULSIVE CORE
6.NON CENTRAL NATURE

MASS DEFECT



B.E



The binding energy of a nucleus:

- the energy available to hold nucleus together

Think of it this way:
- Take bunch of well-separated nucleons: binding energy is zero
- Bring them together: strong force glues them together. However, energy has to come from somewhere: binding energy must come from a **reduction** in nuclear mass

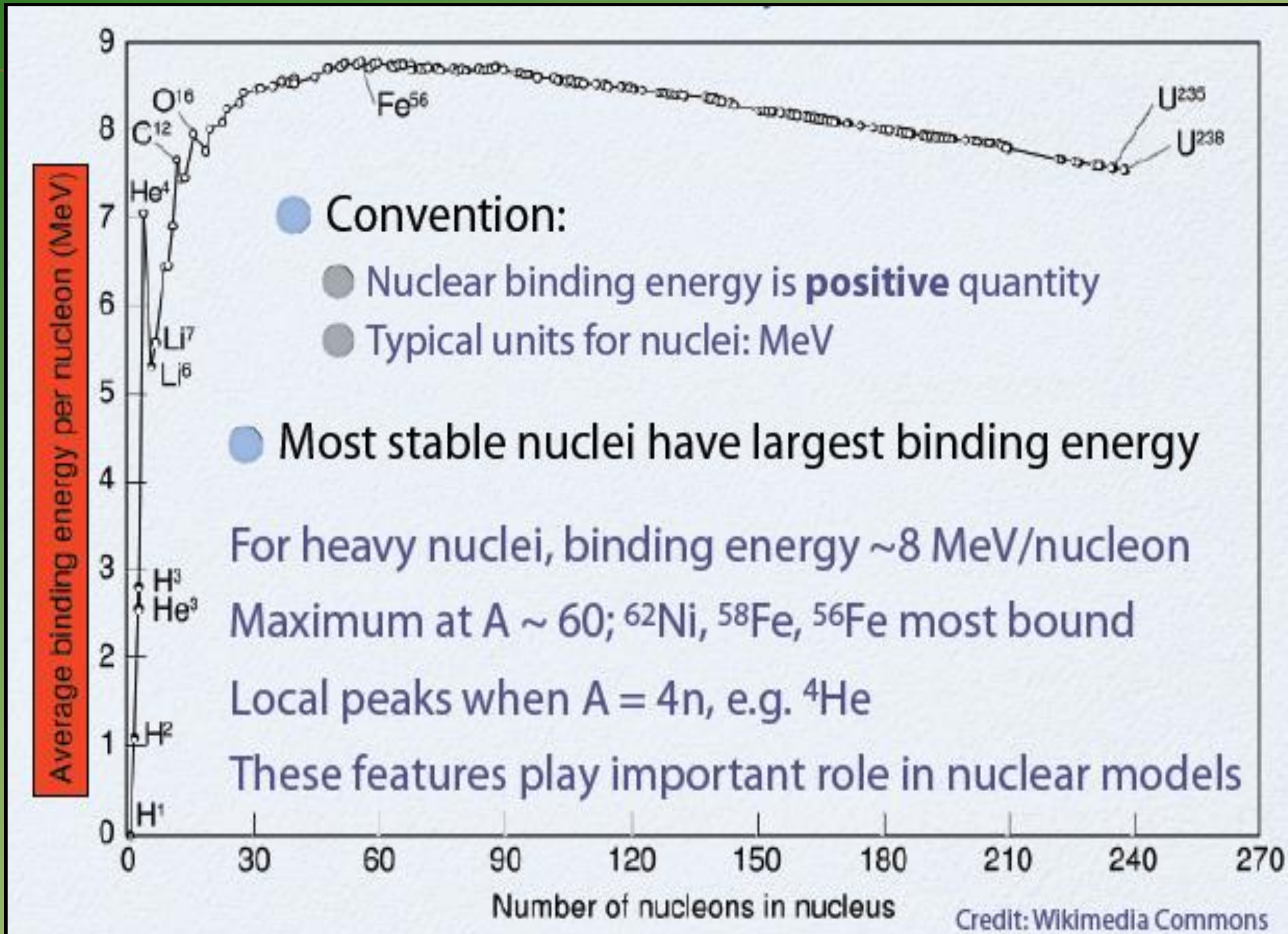
Formally, it is the difference between mass of component protons and neutrons and that of actual nucleus, related through $E = mc^2$:

$$B(A,Z) = Z\, m_p c^2 + N\, m_n c^2 - M(A,Z)\, c^2$$

Binding energy is a **positive quantity**
(don't get confused here - the strong potential in which the nucleons sit is **negative**)

Binding energy per nucleon

→ the average energy state of nucleon is a sum of high energy "surface" nucleons with low energy "bulk" nucleons
→ nucleus minimizes energy by minimizing surface area – a sphere



- Convention:
  - Nuclear binding energy is **positive** quantity
  - Typical units for nuclei: MeV
- Most stable nuclei have largest binding energy

For heavy nuclei, binding energy ~8 MeV/nucleon

Maximum at A ~ 60; ^{62}Ni, ^{58}Fe, ^{56}Fe most bound

Local peaks when A = 4n, e.g. ^{4}He

These features play important role in nuclear models

LIQUID DROP MODEL

-

----BOHR

-

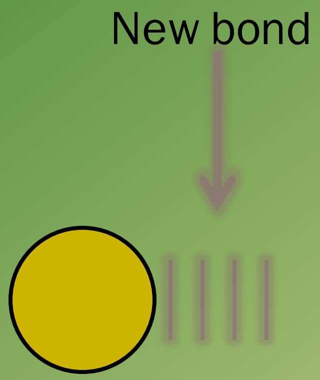
What determines the shape of a nucleus?

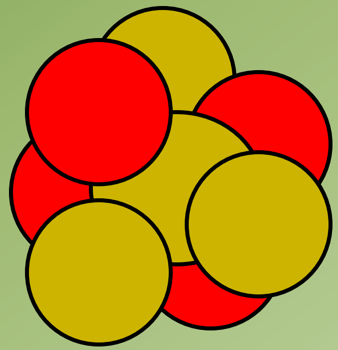
Answer: the attractive interactions between components form a droplet in order to minimize the number of "high energy" components at the surface (similar to the attractive forces between molecules in a droplet of water)

LIQUID DROP MODEL – VOLUME TERM

The liquid drop model is named from the fact that water sticks to itself, but repels itself if pushed too close together (incompressible)

We can consider each new nucleon as having the ability to add one new unit of bond energy to the volume of nucleons. We know the volume increases linearly with A. For larger volume nuclei, there should be proportionally more binding energy.





$$BE = c_1 A + \dots$$

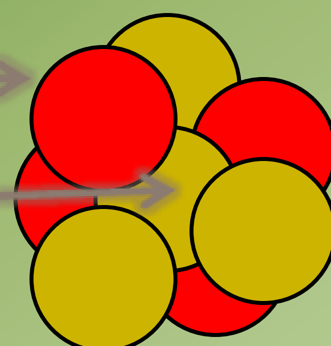
LIQUID DROP MODEL – SURFACE TERM

The liquid drop model is named from the fact that water sticks to itself, but repels itself if pushed too close together (incompressible)

The surface nucleons interact with fewer nucleons because they are separated from the deeper, buried nucleons.

$$V = \frac{4}{3}\pi(A^{1/3}R_o)^3$$

This one can be pulled off easer than this one.



$$SA = 4\pi(A^{1/3}R_o)^2$$

$$\Delta BE = -c_2 A^{2/3}$$

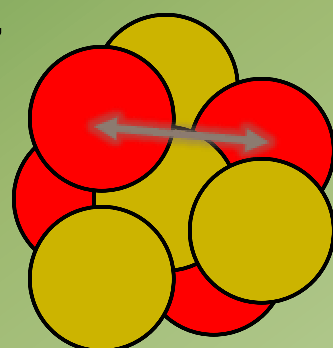
LIQUID DROP MODEL – COULOMB TERM

The liquid drop model is named from the fact that water sticks to itself, but repels itself if pushed too close together (incompressible)

The protons are pushing against each other. The Coulomb force is much lower than the strong force, but it still exists to weaken the binding.

$$U(R) = k\frac{q^2}{R}$$

Some protons are very close and some are $2R$ apart. On average, they are $A^{1/3}R_o$ apart.



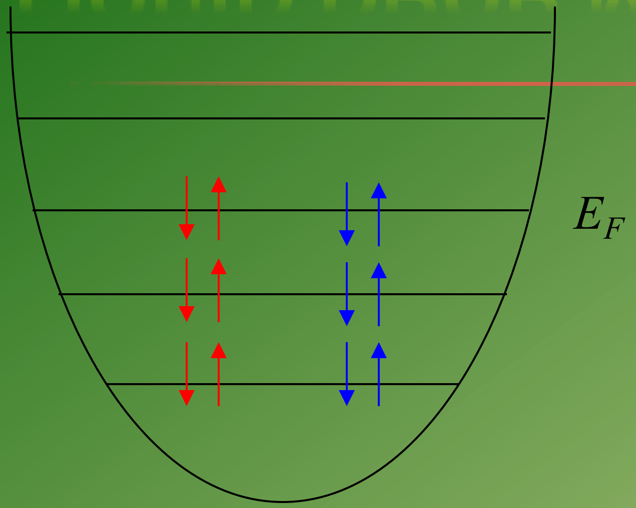
$$U(A^{1/3}R_o) = k\frac{q^2}{A^{1/3}R_o}$$

Z protons feel the other Z-1

$$\Delta BE = -c_3\frac{Z(Z-1)}{A^{1/3}}$$

Each proton feels Z - 1 protons pushing on it. Adding this up for all Z protons.

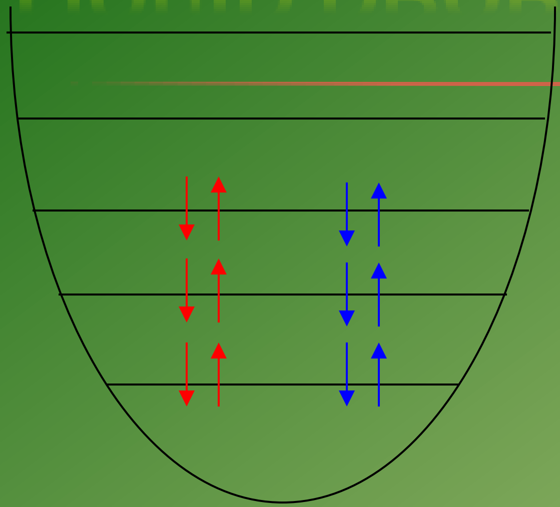
LIQUID DROP MODEL – ASYMMETRY TERM



N = Z (symmetric)

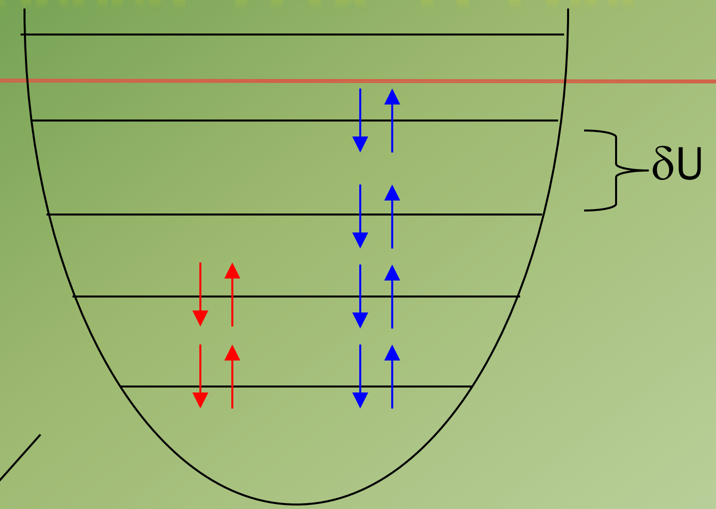
Pauli Exclusion makes $N = Z$ the lowest energy. $N = Z$ allows filling of states in such at way that Pauli Exclusion can be avoided.

LIQUID DROP MODEL – ASYMMETRY TERM



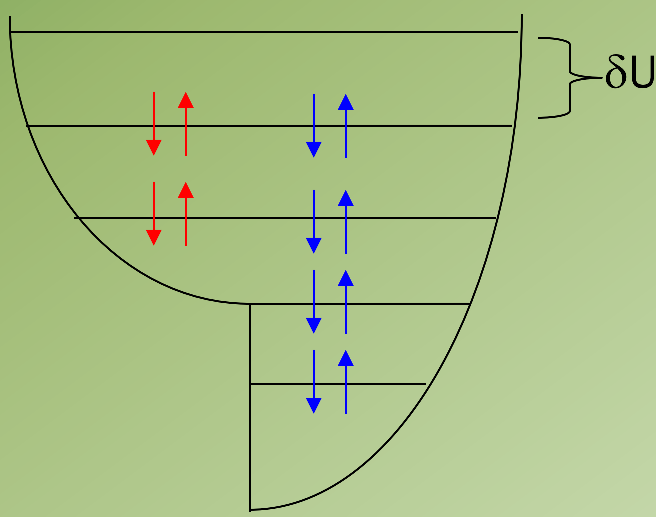
N = Z (symmetric)

Switch two neutrons to protons



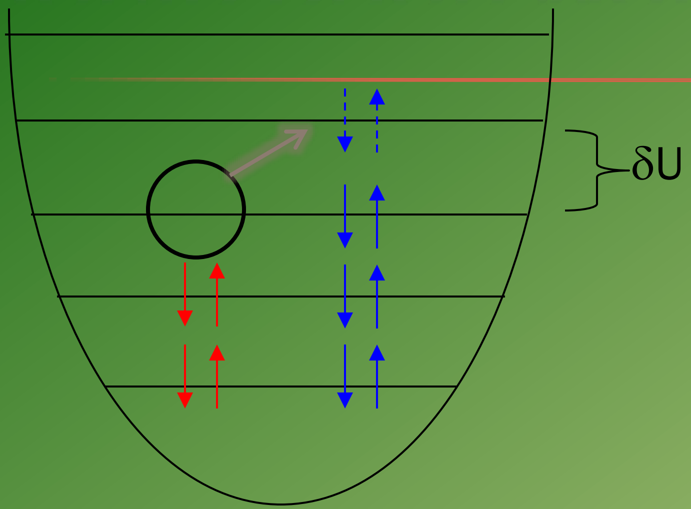
N ≠ Z (asymmetric)

Fermi Energies equilibrate to align for two sets of Fermions in contact



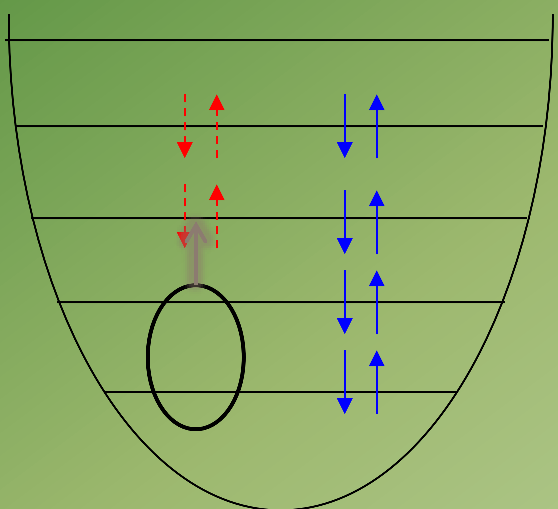
Adjust to equilibrate E_f

LIQUID DROP MODEL – ASYMMETRY TERM



$\delta BE \propto j\,\delta U$

j = number of nucleons being exchanged



$4j\,\delta U$

$$\Delta BE = 4j\delta U \rightarrow j^2\delta U$$

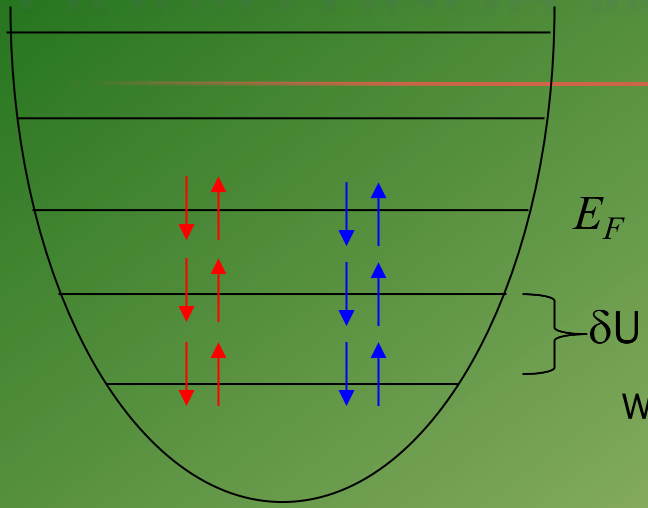
Start with $N = Z$. Take away two from N. Add two to Z

$$N - Z = 2j$$

$$\Delta BE = (N - Z)^2\delta U$$

I ignored the 2 in 2j b/c I'll put a constant in later to take care of it.

LIQUID DROP MODEL – ASYMMETRY TERM



N = Z (symmetric)

$$E_F = X\delta U$$

X is some number of energy steps

When N = Z, we see that the energy levels each have 4 nucleons in them.

$$\delta U \sim \frac{E_F}{A/4}$$

E_F is a constant that can go into C

$$\Delta BE = (N-Z)^2\,\delta U$$

$$\Delta BE = -C_4\frac{(N-Z)^2}{A}$$

LIQUID DROP MODEL

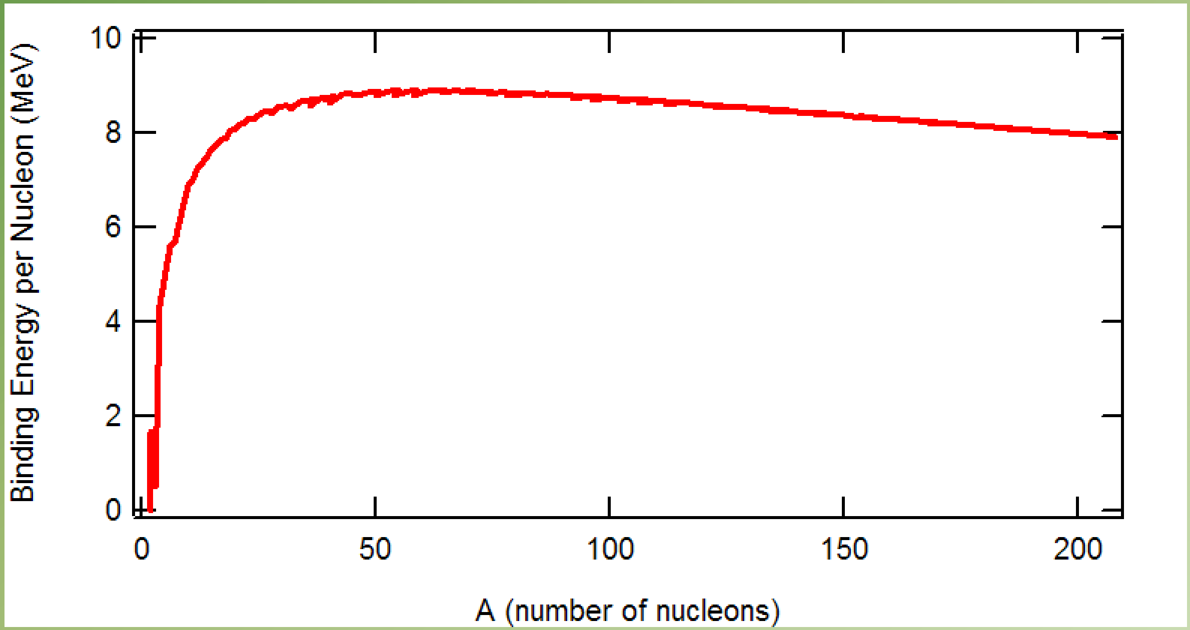
$$BE = C_1 A - C_2 A^{2/3} - C_3 \frac{Z(Z-1)}{A^{1/3}} - C_4 \frac{(N-Z)^2}{A}$$

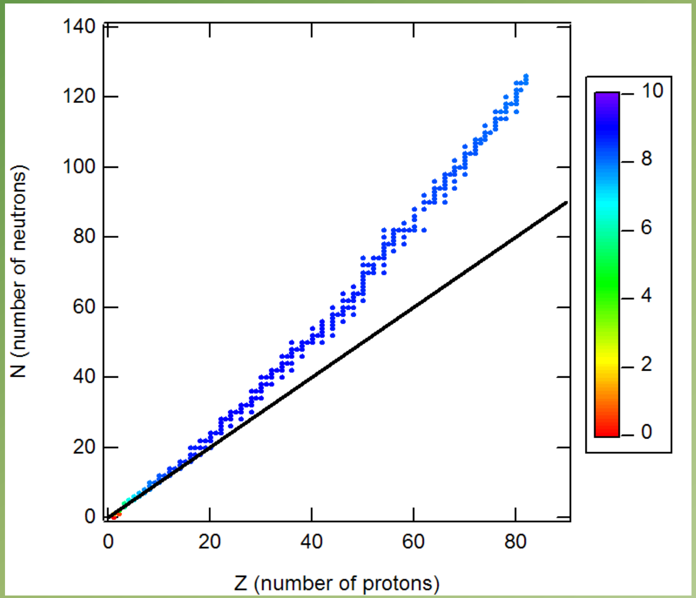
$$C_1 = 15.8$$

$$C_2 = 17.8$$

$$C_3 = 0.71$$

$$C_4 = 23.7$$



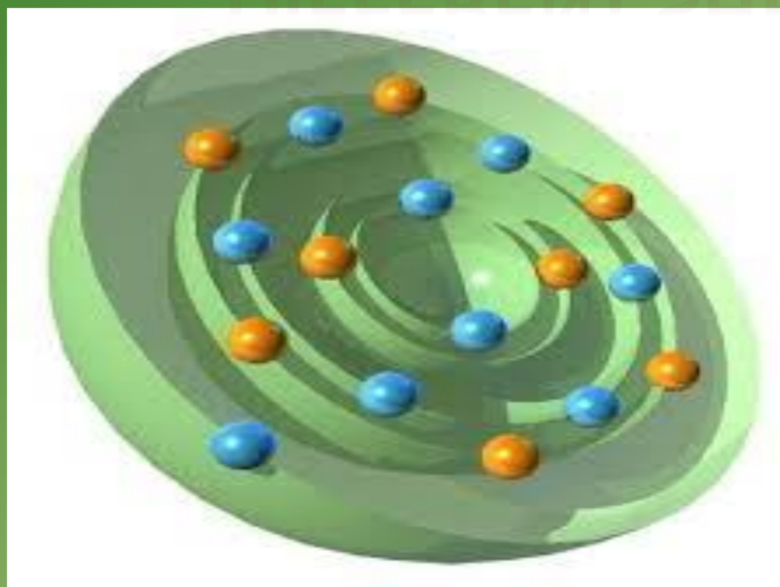


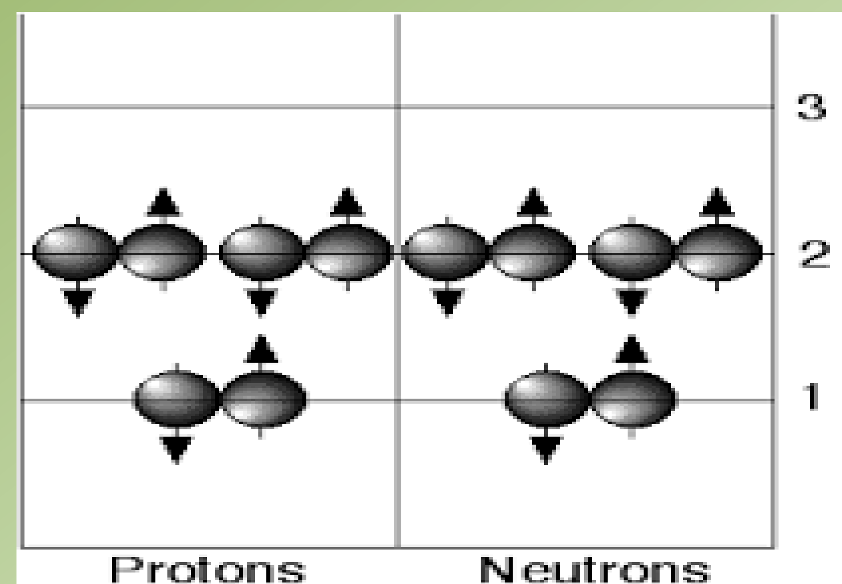
THE SHELL MODEL

- A quantum mechanical model of the nucleus
  - Shell model describes the arrangement of nucleons in different shells of nucleus
  - The concept of magic numbers can only be explained based on shell model
  - Shell model confirms the spin properties of nucleus
  - Spin-Orbit interaction
    - Magic numbers

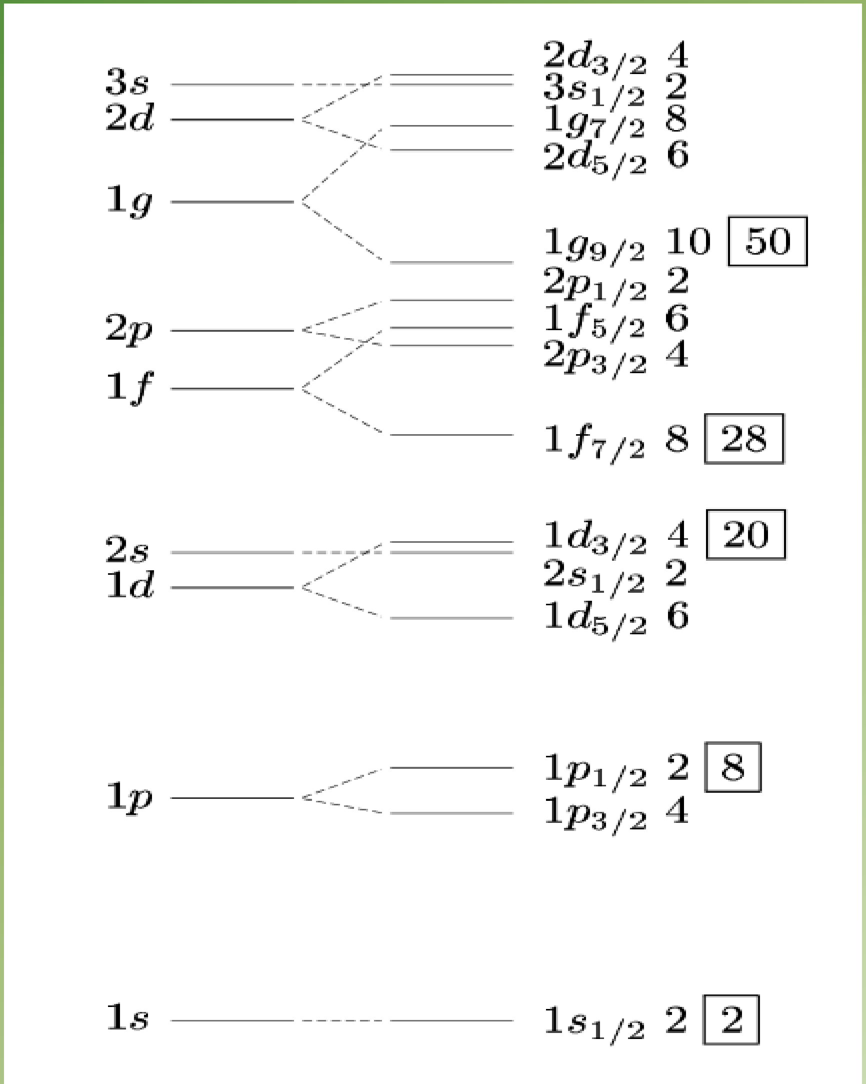
      N, Z, or A
      - 2, 8, 20, 28, 50, 82, 126

DIFFERENT SHELLS IN NUCLEUS





MAGIC NUMBERS



UNITS OF ENERGY

- Mass and energy are interchangeable –

  $E = mc^2$

  where energy usually expressed in MeV
- 1 eV = 1.602×10^{-19} J = 1.60219×10^{-12} erg
- 1 MeV = 1.602×10^{-13} J = 1.60219×10^{-6} erg
- 1 u = 931.5 MeV/c^2

Thank u for your attention

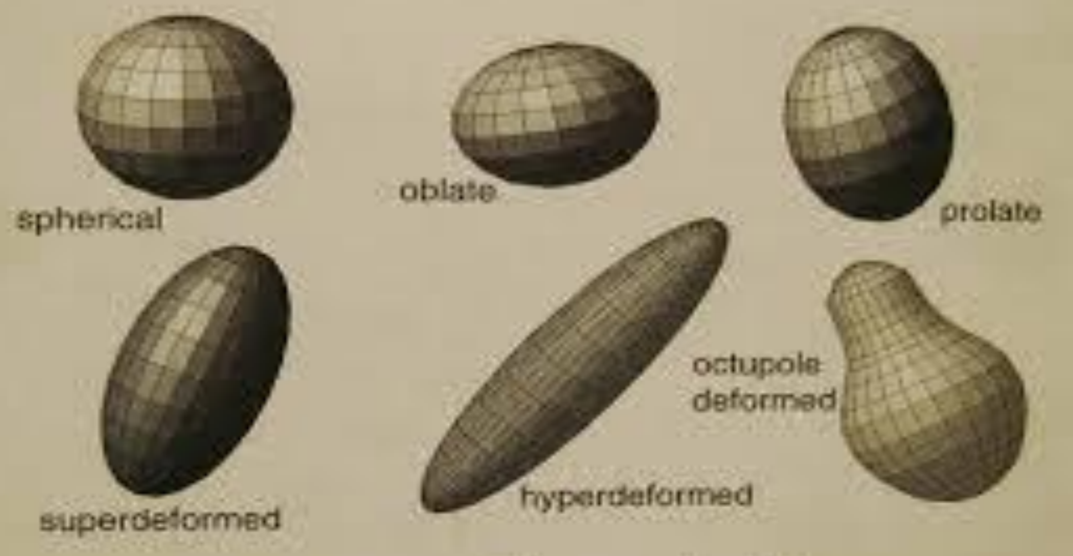
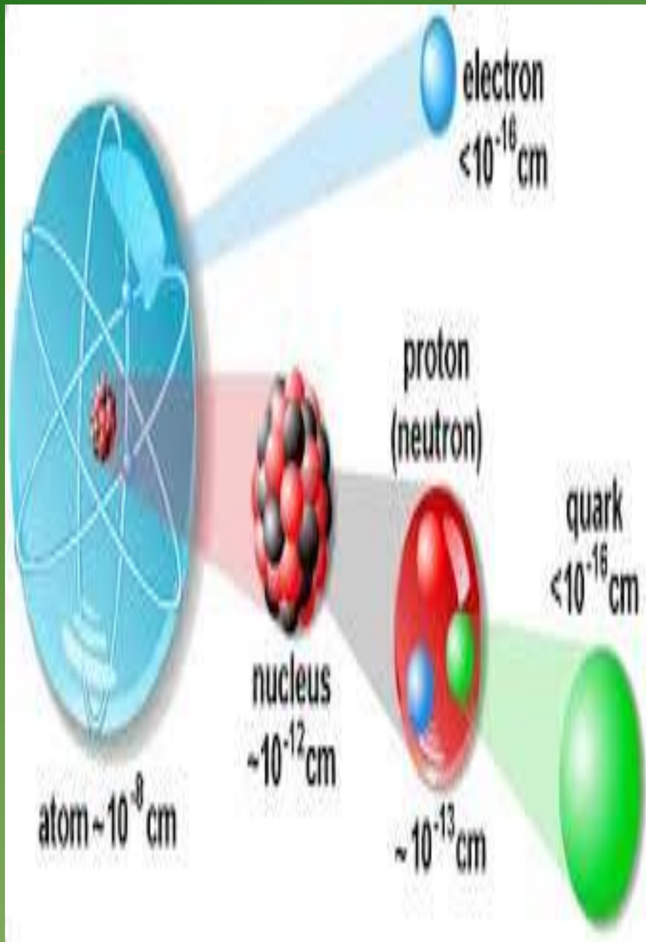
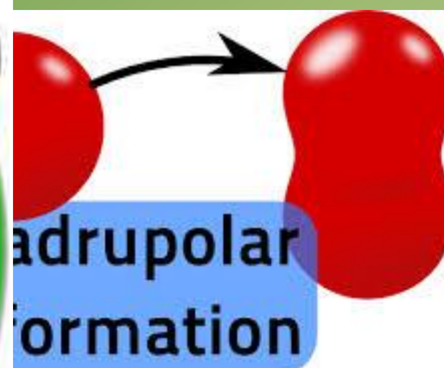
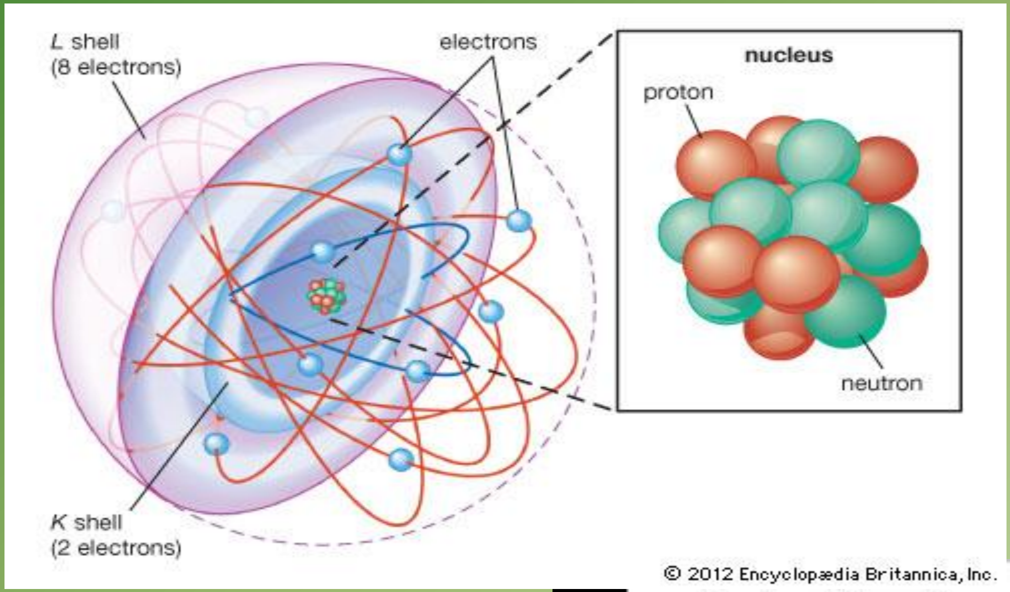


Fig. 20.3. Shapes of nuclei


electron
$<10^{-16}$cm
proton
(neutron)
quark
$<10^{-16}$cm
nucleus
$\sim10^{-12}$cm
atom $\sim10^{-8}$cm
$\sim10^{-13}$cm


adrupolar
formation


L shell
(8 electrons)
electrons
nucleus
proton
neutron
K shell
(2 electrons)
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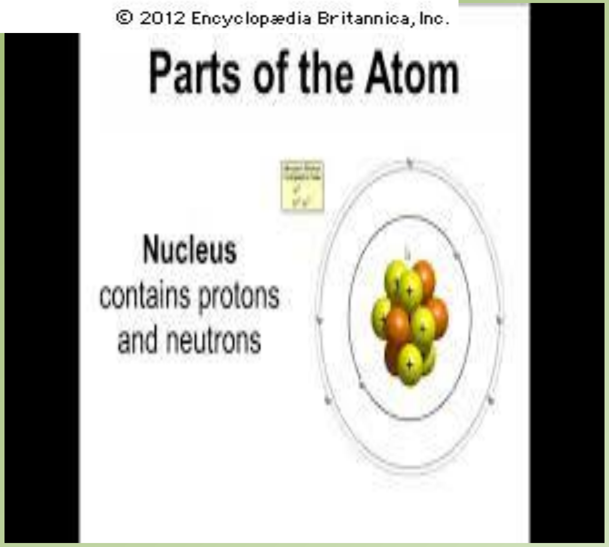
Parts of the Atom
Nucleus
contains protons
and neutrons