Section 3 – Nuclear Force

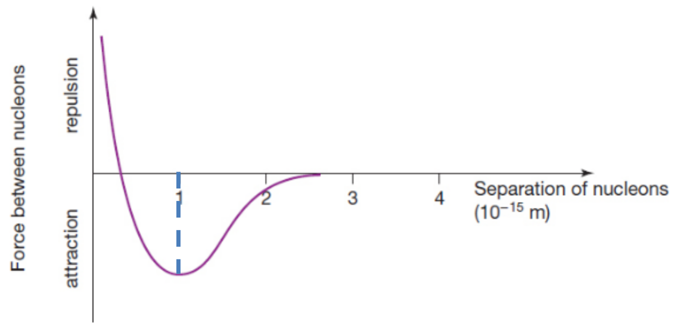
Classification of Forces

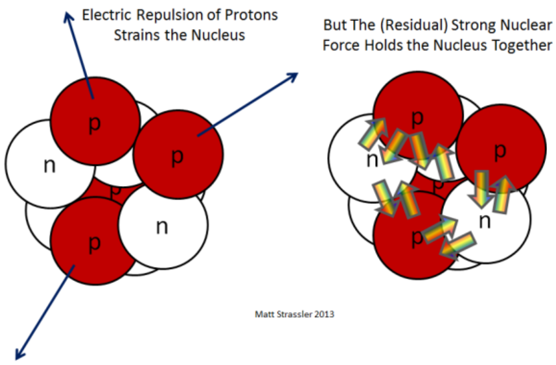
There are only four fundamental forces in nature:

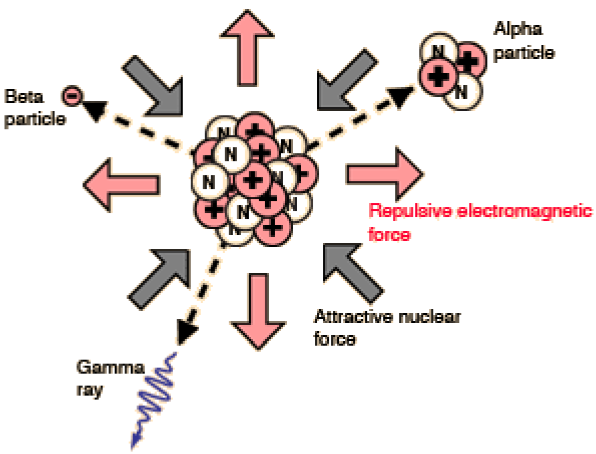
1. The gravitational force
2. The electromagnetic force (electrostatic force)
3. The strong nuclear force
4. The weak nuclear force

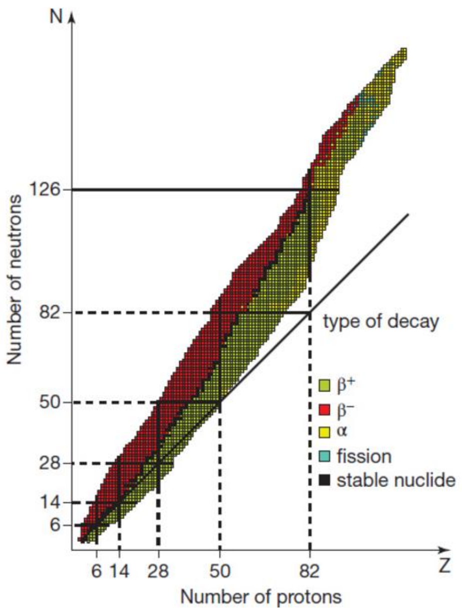
Inside the nucleus of an atom, the **gravitational force** is negligible. However, the other three play important roles.

The **electrostatic force** of repulsion between protons tends to split the nucleus apart. The **weak nuclear force** exerts negligible force on nucleons. It is involved with beta decay. The **strong nuclear** force acts between all nucleons (ie. neutrons and protons) and holds the nucleus together. It is short range over 1 x 10^{-15}m and is much stronger than the electrostatic force.









The graph left shows that:

- Most decay occurs when the nuclei contains more neutrons than protons.
- The vast majority of nuclear decay undergo β decay (both β^+ & β^-)
- Only a small number of nuclei are suitable to undergo fission

Binding Energy

The mass of a nucleus is always very **slightly less** than the mass of the individual nucleons that form it. This difference in mass is referred to as a **mass defect**.

For example, consider the mass of a ^4_2He nucleus and its individual nucleons:

Mass of nucleus	Mass of individual nucleons
Mass (^4_2He) nucleus is: 6.6447 x 10^{-27} kg	Mass of 2 protons is: 2 x (1.6726 x 10^{-27}) kg
	+
	Mass of 2 neutrons is: 2 x (1.6749 x 10^{-27}) kg
	6.6950 x 10^{-27} kg

Therefore the **mass defect (Δm)** = 6.6950 x 10^{-27} - 6.6447 x 10^{-27} = **0.0503 x 10^{-27} kg**

We can now use Einstein's famous equation to calculate the binding energy for a ^4_2He nucleus.

$\boxed{E = mc^2}$ Where E represents the binding energy (J)
m represents mass defect (kg)
c represents the speed of light (3.0 x 10^8 ms^{-1})

So for a mass defect of 0.0503 x 10^{-27} kg, the binding energy for a ^4_2He nucleus is:

E = ?	$E = mc^2$
m = 0.0503 x 10^{-27} kg	= 0.0503 x 10^{-27} x (3.0 x 10^8)^2
c = 3.0 x 10^8 ms^{-1}	= **4.527 x 10^{-12} Joules**

NB: Einstein's famous equations effectively states that mass and energy can be converted!

The Electron Volt (eV)

Whilst the S.I. (Standard International) unit for energy is Joules, in nuclear Physics an alternative unit of energy measurement called the **electron volt** is commonly used.

$$\boxed{1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}}$$

NB: An electron volts is defined by the amount of energy gained (or lost) by the charge of a single **electron** moving across an electric potential difference of **one volt**.

Example

In the previous example we found the binding energy of a ${}^{4}_{2}He$ nucleus to be 4.527 x 10^{-12} J. What is this in electron volts?

$$E \text{ (eV)} = \frac{E\ (J)}{E\ (1\ eV)}$$

$$= \frac{4.527 \times 10^{-12}}{1.60 \times 10^{-19}}$$

= **<u>2.83 x 10^{7} eV (28.3 Mev)</u>**

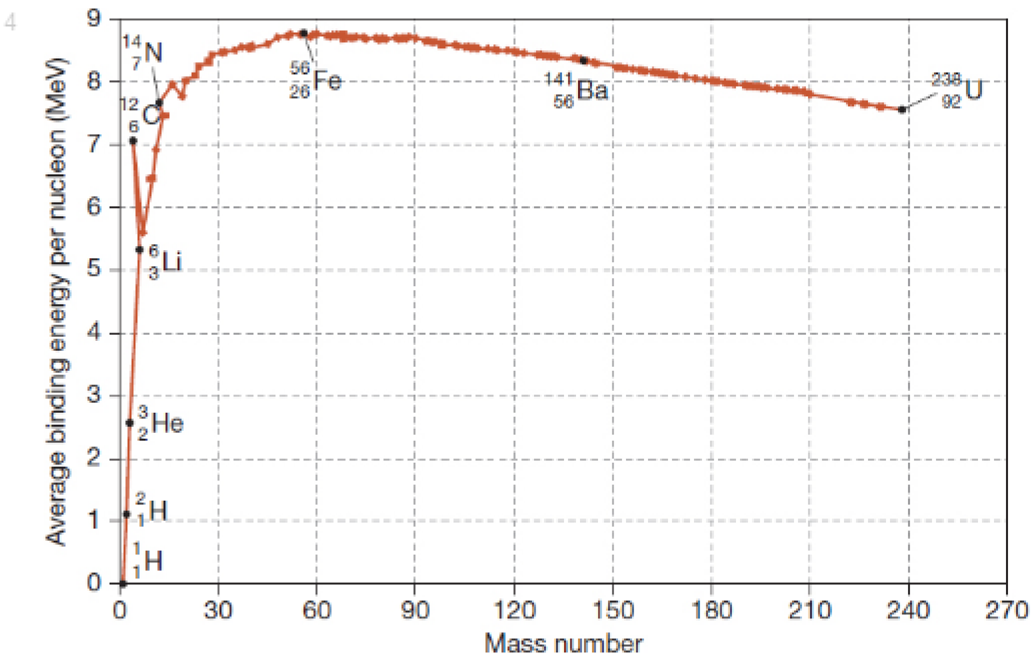
NB: An electron volt (eV) is an extremely small amount of energy

The Binding Energy Per Nucleon

The **binding energy** is the energy required to separate a nucleus into its constituent nucleons. For example, it would take 2.23 MeV of energy to split a 'heavy' hydrogen nucleus into a separate proton and neutron.

Binding energies vary considerably within different nuclei. Nuclei with low binding energies can be split relatively easily. Whereas, nuclei with high binding energies require a lot of energy to split them.

Often it is easier to consider the binding energy per nucleon, rather than the entire binding energy.



The higher the binding energy per nucleon, the greater the nuclei's stability. From the above graph it can be seen that Iron ($^{56}_{26}Fe$) has the highest binding energy per nucleon and it therefore the most stable of nuclei.

Example

In the previous example we found the binding energy of a $^{4}_{2}He$ nucleus to be 28.3 MeV
What would be the binding energy per nucleon for $^{4}_{2}He$?

Binding energy per nucleon = $\dfrac{\text{Total binding energy}}{\text{no.of nucleons}}$

$$= \frac{28.3\ \text{MeV}}{4\ \text{nucleons}}$$

= **<u>7.08 Mev per nucleon</u>**