Binding Energy and Nuclear Forces

Unified Mass Unit

- In nuclear physics it is convenient to use a unit of mass smaller than a kg
  - Unified mass unit, u
  - Defined as 1/12 of the mass of a carbon-12 atom

$$u = 1.661 \times 10^{-27}\ \text{kg}$$

Mass Defect & Binding Energy

- Let's calculate the mass of a helium atom

$${}^{4}_{2}He$$

$$2p: \quad 2(1.007276\,u) = 2.014552\,u$$
$$2n: \quad 2(1.008665\,u) = 2.01733\,u$$
$$2e: \quad 2(0.000549\,u) = 0.001098\,u$$
$$\text{Total mass} = 4.03298\,u$$

- But, the mass of a helium atom is 4.002602 *u*
- This results in a difference of 0.030378 *u*
- This difference is called the ***mass defect***

Where did the extra mass go?

- The answer is given by Einstein's mass-energy equivalence relationship

$$E = mc^2$$

- The mass defect has been converted into energy and is stored in the nucleus
- This energy is called the ***binding energy*** of the nucleus, E_b

- So, how much energy is it?

$$E = mc^2$$
$$E = (1\,u)(2.9979\times10^8\ ms^{-1})^2$$
$$E = (1.661\times10^{-27}\,kg)(2.9979\times10^8\ ms^{-1})^2$$
$$E = 1.4928\times10^{-10}\,J$$

- Converting to electron volts gives us

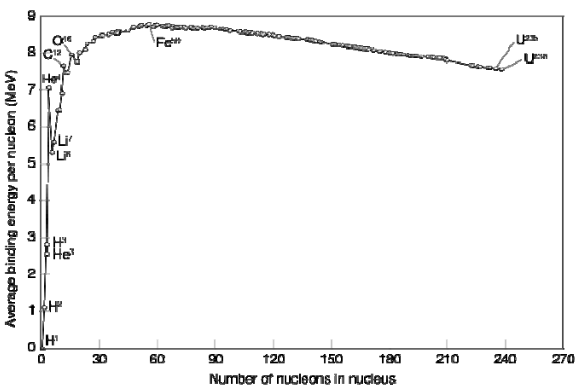
$$E = 9.315\times10^8\,eV = 931.5\,MeV$$

- Therefore $u = 931.5\,MeV$

- For our helium atom, the binding energy is then

$$(0.03038\,u)(931.5\,MeV) = 28.30\,MeV$$

- Most nuclei have a binding energy of approximately 8 *MeV* per nucleon



- The binding energy curve shows a maximum at *A*=62 (nickel)
- When a nucleus decays it releases the binding energy as kinetic energy of the decay particles
- For this to happen, the mass of the nucleus must be less than the mass of the decay particles
- This is true for all particles heavier than nickel (*A*=62)

Forces within the Nucleus

- Protons are positively charged and therefore the nucleus should blow apart due to the electromagnetic force between them
- However, atoms are stable (another force must be present)
  – The strong nuclear force

The Strong Nuclear Force

- An attractive force much stronger than the electromagnetic force if the separation between the particles is very small (10^{-15}m or less)

Weak Nuclear Force

- A weaker force that exists within the nucleus that shows itself in certain types of radioactive decay