Mass defect and Binding Energy

Mass defect

The mass of a nucleus is less than the mass of the protons and neutrons that it is made of.

(mass of protons + mass of neutrons) – mass of nucleus = Δm

Δm is the difference in the masses and is called the ***mass defect***.

Let us look at the nucleus of a Helium atom to see this in action. It is made up of 2 protons and 2 neutrons:

Mass of nucleons = 2 x (mass of proton) + 2 x (mass of neutron)

Mass of nucleons = 2 x (1.673×10^{-27}) + 2 x (1.675×10^{-27})

Mass of nucleons = 6.696×10^{-27} kg   Mass of nucleus = 6.648×10^{-27} kg

Mass defect = mass of nucleons – mass of nucleus

Mass defect = $6.696 \times 10^{-27} – 6.648 \times 10^{-27} = 0.048 \times 10^{-27}$ kg

As we can see, we are dealing with tiny masses. For this reason we will use the **atomic mass unit, u**

1u = 1.661×10^{-27} kg

The mass defect now becomes = 0.029 u

Particle	Mass (kg)	Mass (u)
Proton	1.673×10^{-27}	1.00728
Neutron	1.675×10^{-27}	1.00867
Electron	9.11×10^{-31}	0.00055

Energy and mass

In 1905, Einstein published his theory of special relativity. In this it is stated that:

$E = mc^2$ Energy is equal to the mass multiplied by the speed of light squared.

This means gaining energy means a gain in mass, losing energy means losing mass. The reverse must be true. Gaining mass means a gain in energy, losing mass means a loss in energy.

The energy we are losing is the binding energy.

$E = \Delta mc^2$ where Δm is the mass defect and E is binding energy

Binding Energy

As the protons and neutrons come together the strong nuclear force pulls them closer and they lose potential energy. (Like how an object loses its gravitational potential energy as it falls to the Earth.)

Energy must be done against the s.n.f. to separate the nucleus into the nucleons it is made of. This is called the binding energy (although '*un*binding' energy would be a better way to think of it).

The binding energy of the Helium nucleus from above would be: $E = m c^2$ → $E = (0.048 \times 10^{-27}) \times (3.0 \times 10^8)^2$

$E = 4.32 \times 10^{-12}$ J

The Joule is too big a unit to use at the atomic scale. We will use the electron Volt (see AS Unit 1)

1u = 1.5×10^{-10} J   and   1eV = 1.60×10^{-19} J   →   1u = 931.3 MeV

We can now calculate the binding energy of the Helium nucleus to be: E = 27 MeV (27 million eV)

Binding Energy Graph

The binding energy is the energy required to separate a nucleus into its constituent nucleons. The binding energy per nucleon gives us the energy required to remove one proton or neutron from the nucleus. The graph of binding energy per nucleon against nucleon number looks like this.

There is an increase in the energy required to remove one nucleon up until the peak of 8.8 MeV at Iron 56. The line then gently decreases. This means Iron is the most stable nucleus because it requires the largest amount of energy to remove one nucleon. This will also mean that there is the greatest mass defect.