The unified mass unit is defined as $\frac{1}{12}$th of the mass of a single neutral atom of the isotope carbon-12 in its ground state.

→ needs be in the ground state since any energy is equivalent to mass and the mass is significant at the nuclear level.

Example 50kg object $\Delta h = 3m$ so the potential energy is

$$E_g = mg\Delta h$$
$$E_g = 850J$$

$$E = mc^2$$
$$m = \frac{E}{c^2}$$
$$m = \frac{850J}{(3.00\times10^8 m/s)^2}$$
$$m = 9\times10^{-15} kg$$

this mass equivalence is insignificant compared to the object.

Example What is the mass equivalence for an energy change of 5eV (an energy associated with electrons)

$$m = \frac{E}{c^2}$$
$$m = \frac{(5eV)(1.6\times10^{-19} J eV^{-1})}{(3.0\times10^8 ms^{-1})^2}$$
$$m \approx 10^{-35} kg$$

← not really that significant (compare to mass of an atom)

Example: What is the mass equivalence for 5MeV (nuclear reaction)?

$$m = \frac{(5\times10^6 eV)(1.6\times10^{-19} J eV^{-1})}{(3.0\times10^8 m s^{-1})^2}$$

must more significant → $m \approx 10^{-29} kg$ in a total mass of $\approx 10^{-26} kg$

* ONLY in nuclear reactions that the mass change is large enough to be detectable.

Mass Defect

- energy is required to separate the nucleus into its nucleons
- separated nucleons have more potential energy ⇒ ∴ more mass.
- difference in the mass of the separated nucleons and the bound nucleons (nucleus) is called the mass defect.

mass defect (Δm) → the mass of a nucleus is always less than the total mass of its constituent nucleons and the difference in mass is called the mass defect.

$$\Delta m = Zm_p + Nm_n - m_{nucleus}$$

units: kg more commonly $MeVc^{-2}$

Binding Energy

- add energy to separate the nucleons, and energy is released when the nucleons are brought together to form the nucleus.

The binding energy E_B of a nucleus is the minimum energy to completely separate the nucleus into its component nucleons.

units: MeV

$$E_B = \Delta m\, c^2$$

mass defect

When a nucleus is separated into its component nucleons, an amount of energy, E_B is required and the potential energy of the system increases by E_B

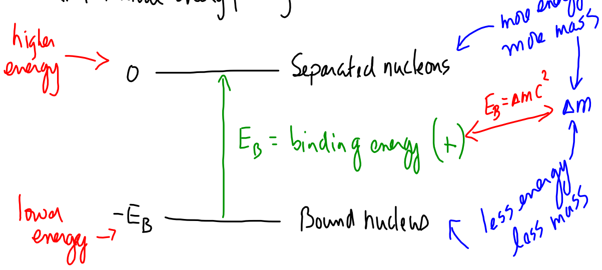
Binding Energy per Nucleon

The binding energy per nucleon of a nucleus is the binding energy of the nucleus divided by the # of nucleons in the nucleus.

$$\frac{E_B}{A}$$ } binding energy per nucleon.

units: "MeV per nucleon"

Nuclear Potential Energy Diagram



Example

$m_p = 1.0073u$
$m_n = 1.0086u$ } ← greater than $\frac{1}{12}$th of C^{12}
$m_e = 0.00055u$

The masses of the individual nucleons are greater than 1u since they are separated and have more potential energy which means more mass.

$\Delta m = 6m_p + 6m_n - 12u$ ← mass of C^{12} is EXACTLY 12u

$\Delta m = 6(1.0073u) + 6(1.0086u) - 12u$

$\Delta m = 6.0438u + 6.0516u - 12u$

$\Delta m = 12.0954u - 12u$

$\Delta m = 0.0954u$

$\Delta m = 0.0954u\left(1.661 \times 10^{-27} \frac{kg}{u}\right)$

$\Delta m = 1.5846 \times 10^{-28} kg$

$E_B = \Delta m c^2$

$E_B = (1.5846 \times 10^{-28} kg)(3.00 \times 10^8 ms^{-1})^2 \left(\frac{1 eV}{1.6 \times 10^{-19} J}\right)$

$E_B = 89.1 MeV$

$\therefore \frac{E_B}{A} = \frac{89.1 MeV}{12 \text{ nucleons}}$

$= 7.43$ MeV per nucleon

Example

$1u = 1.661 \times 10^{-27}\,kg = 931.5\,MeV\,c^{-2}$

$m_p = 1.673 \times 10^{-27}\,kg = 1.007276u = 938\,MeV\,c^{-2}$

$m_n = 1.675 \times 10^{-27}\,kg = 1.008665u = 940\,MeV\,c^{-2}$

Use the data to complete the following chart:

$\Delta m \downarrow$ $E_B \downarrow$

	Nucleus	Nuclear mass	Binding energy per nucleon
Deuteron	H_1^2	$3.345 \times 10^{-27}\,kg$	0.8 MeV
Nitrogen	N_7^{14}	$13.9992u$	7.5 MeV
Iron	Fe_{26}^{56}	$52.09\,GeV c^{-2}$	8.9 MeV
Uranium	U_{92}^{238}	$3.953 \times 10^{-25}\,kg$	7.5 MeV

Example

Consider the following nuclear reaction:

$$H_1^1 + Li_3^7 \rightarrow He_2^4 + He_2^4$$

Use the data to show 17.3 MeV of energy is released in this reaction. (i.e. exothemic)

mass

$H^1 = 1.00728\,u$

$Li^7 = 7.01435\,u$

$He^4 = 4.00151\,u$

$u = 931.5\ MeVc^{-2}$

Example

Consider the following nuclear reaction:

$$H_1^1 + C_6^{13} \rightarrow N_7^{13} + n_0^1$$

Use the data to show that 3.0 MeV of energy is required for the reaction to proceed

mass

$H^1 = 1.00728\,u$

$C^{13} = 13.00006\,u$

$N^{13} = 13.00190\,u$

$n = 1.00866\,u$

$u = 931.5\ MeVc^{-2}$