GCE Physics Unit 3.6 Nuclear Energy

$E = mc^2$:

A carbon-12 atom contains 6 protons, 6 neutrons and 6 electrons, the sum of the individual mass of each of these is 2.009×10^{-26} kg. The mass of the carbon-12 atom is 1.993×10^{-26} kg. The lost mass has been **turned into energy** when forming the atom.

The amount of energy can be calculated using Einstein's equation, where E is the energy **in J**, m is the mass lost **in kg** and c is the speed of light in a vacuum, 3.00×10^8 m s^{-1}.

$$E = mc^2$$

The information for these questions often involves the use of other units. The mass will often be given in u = unified atomic mass = 1.66×10^{-27} kg. This is useful as a loss of **1u is equivalent to 931MeV** of energy.

Binding energy:

Binding energy is the energy that has to be supplied in order to dissociate a nucleus into its constituent nucleons.

This is the energy released when the nucleons form a nucleus. Separately, having so many charged particles so close together is very unstable and therefore they have a high potential energy, forming a nucleus makes it more stable and the nucleons lose some potential energy. This is released and is equivalent to the mass lost.

Binding energy per nucleon:

Often, you will be asked to calculate the binding energy **per nucleon**. This is a useful way of comparing different nuclei.

Worked example (WJEC Physics Unit 3 2019)

*Calculate the binding energy **per nucleon** for* $^{90}_{38}$Sr

m_{proton} = 1.007 276u

$m_{neutron}$ = 1.008 664u

$m_{electron}$ = 0.000 549u

atomic mass of $^{90}_{38}$Sr = 89.907 738u

1u = 931 MeV

Nucleon mass

38 protons + 52 neutrons

= 38 (1.007 276u) + 52 (1.008 664u)

= 90.727 016u

As the differences in mass can be very small, rounding early can affect your answer. Avoid rounding until the final step.

Mass of the nucleus

atomic mass of $^{90}_{38}$Sr – 38 electrons

= 89.907 738u – 38 (0.000 549u)

= 89.886 876u

Electrons are not part of the nucleus so do not contribute to binding energy.

Mass deficit

90.727 016u – 89.886 876u

= 0.840 140u

Energy

0.840 140u × 931

= 782.170 340 MeV

As 1u = 931MeV is given in the question, no conversion to J or kg is required. However, you would get the same answer if you had converted.

Energy per nucleon

= 782.170 340 ÷ 90

= 8.69 MeV

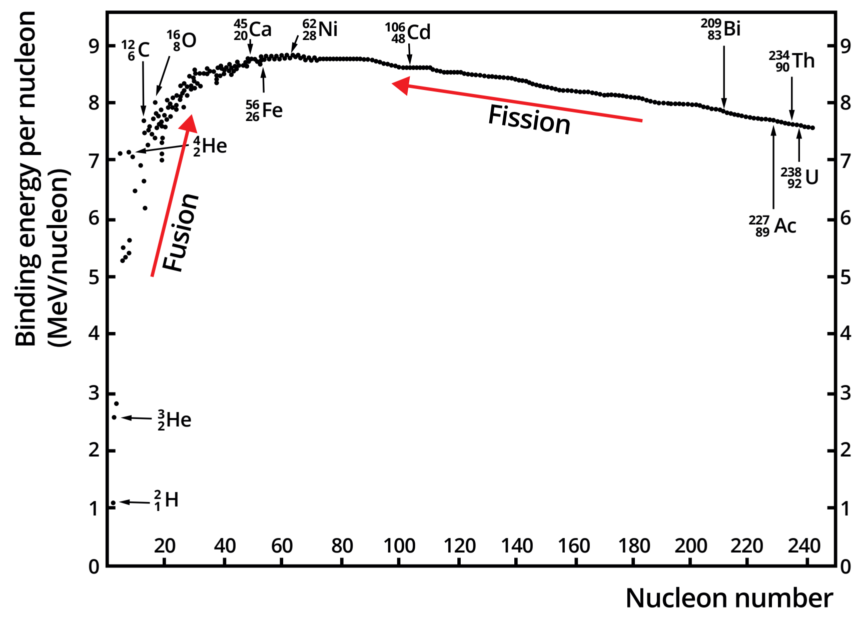
90 nucleons = 38 protons + 52 neutrons

Energy cannot be lost or gained, only transferred from one form to another.

In all nuclear reactions, when new nuclei form, the binding energies are different.

In **fusion** reactions, smaller nucleon number nuclei combine to form larger nuclei with a larger nucleon number.

In **fission** reactions, larger nucleon number nuclei split to form smaller nuclei with a smaller nucleon number.



When nuclei undergo **fission or fusion** reactions, they form more stable nuclei with a **higher binding energy per nucleon**, the extra energy is released as kinetic energy or as photons.

Note that the most stable nuclei are at the peak of the curve, e.g. $^{56}_{26}$Fe, as these have the highest binding energy per nucleon.

E = energy in J or in eV m = mass in kg or u $c^2 = (3.00 \times 10^8)^2$ m^2 s^{-2} $u = 1.66 \times 10^{-27}$ kg u = 931 MeV $eV = 1.6 \times 10^{-19}$ J