FLIPPED around PHYSICS

8.6 Mass and energy

videos

We have already come across mass-energy equivalence in the particle physics unit. The 'rest energy' (E) is proportional to the 'rest mass' (m):

$$E = mc^2$$

where c is a constant = speed of light in a vacuum $= 3 \times 10^8 ms^{-1}$

For example, when an electron and a positron annihilate, two particles with mass produce two massless photons. The rest energy can be calculated using the energy equivalence equation, above. This rest energy then appears as the energy of the two photons ($E = hf, where\ f = frequency\ and\ h\ is\ the\ Planck\ constant$).

(1)✏The rest mass of an electron = $9.11 \times 10^{-31} kg$*. Work out the rest energy of an electron i) in joules, ii) in MeV. (Remember* $1eV \equiv 1.6 \times 10^{-19} J$*)*

(2)✏Work out the frequency of the photons produced when an electron and positron annihilate. (Assume that their initial kinetic energy is zero)

When the potential energy of a system is increased, there is an increase in the mass of the system. For example, when an object is lifted up in the Earth's gravitational field, the potential energy of the system (the Earth and the object) is increased, and there is an equivalent increase in the mass of the system.

The same is true for nucleons in an atom. When nucleons are brought together, the potential energy (due to the strong nuclear force + the electrostatic force) is decreased. This means that the mass of the nucleus is less than the mass of the separate nucleons. This is called the 'mass defect' (Δm) and is equivalent (from $E = \Delta mc^2$) to an energy called the 'binding energy'.

Let us consider an example.

The rest energy of a proton = 938.08MeV. The rest energy of a neutron = 939.37MeV. The rest energy of a helium nucleus = 3727.6MeV.

(3)✏Given that the helium nucleus has two protons and 2 neutrons, work out the rest energy of the separate nucleons added together. Compare this with the rest energy of the helium nucleus.

You should find that the rest energy has decreased. The difference is called the binding energy of the helium nucleus. In constructing the helium nucleus, energy must be released.

Nuclear, mass-energy calculations often involve interchanging between mass and energy! Consider the following:

mass of proton = 1.00728u
mass of neutron = 1.00867u

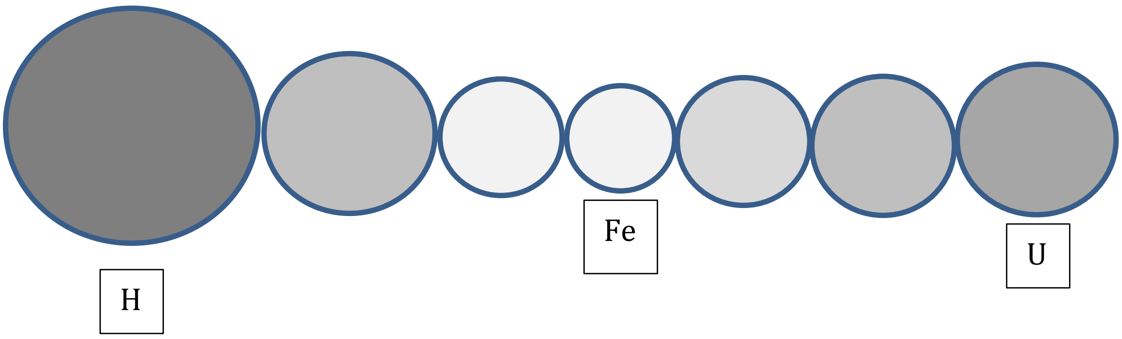
where u is called the 'unified atomic mass unit' and is $\frac{1}{12}$ *of the mass of a carbon-12 atom (at rest).*

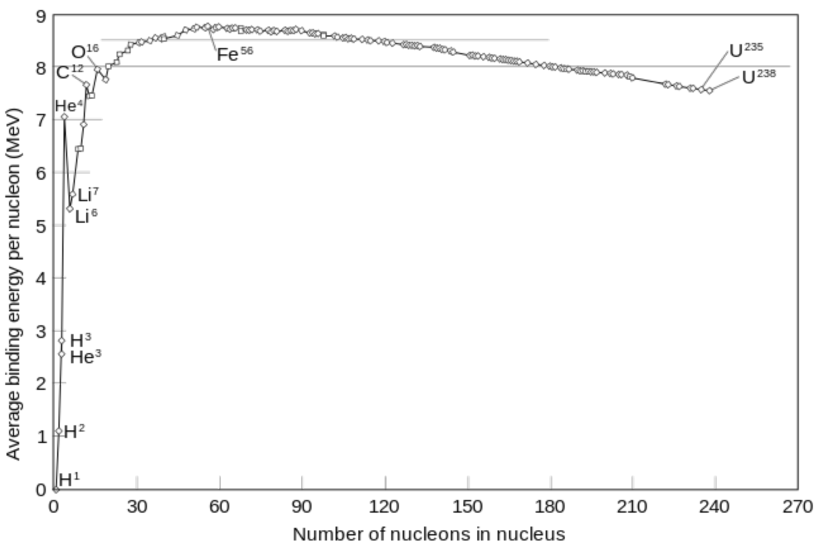
A mass of 1u is equivalent to an energy = 931.3MeV.

(4)✐Krypton-92 has a rest mass of 91.8976u. It has a proton number (atomic number) = 36. Work out the mass defect, in u, of its nucleus. Work out the binding energy, in MeV, of its nucleus.

Binding energy per nucleon

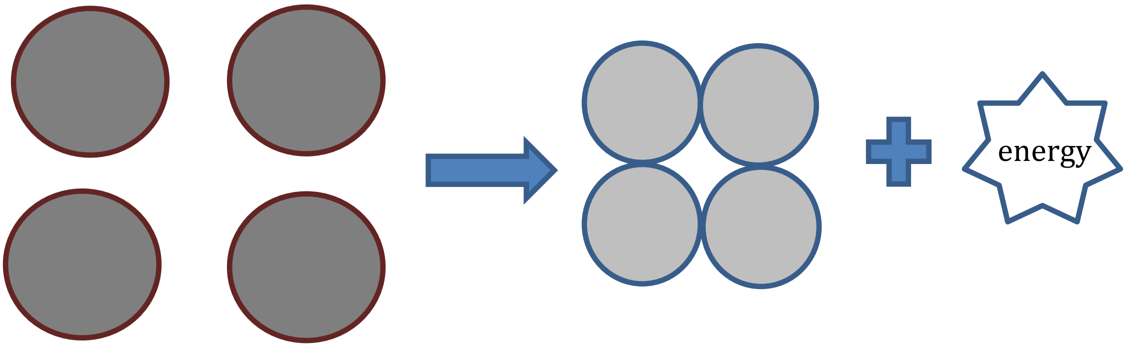
The mass of a nucleon depends on the nucleus it is part of. The images (below) show the relative masses of nucleons in different nuclei. The smaller the mass, the larger the binding energy per nucleon.



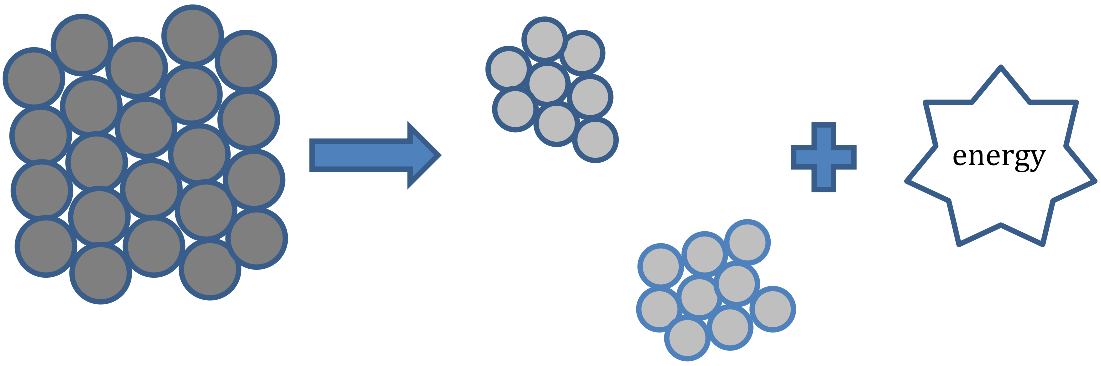


We can see, from the graphic above, that the proton in a hydrogen has the largest mass (because it is not bound to another nucleon). A nucleon in an iron nucleus has the smallest mass (because the binding energy per nucleon is the greatest).

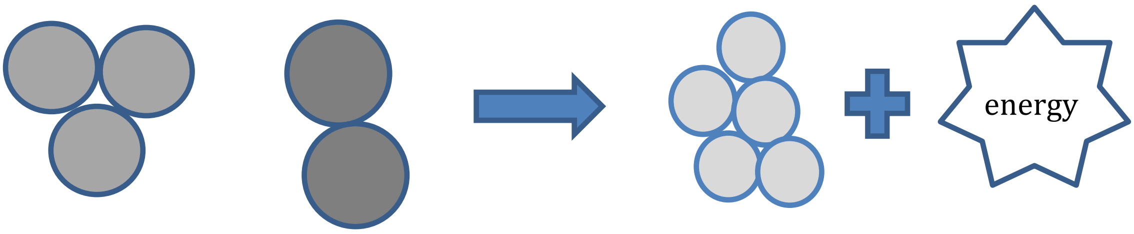
In constructing any nucleus, (binding) energy is released and the mass of the nucleons decreases.



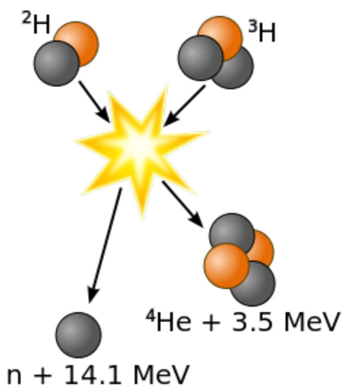
In nuclear <u>fission</u>, a large nucleus is split and the nucleons in the nuclei of the products have a smaller mass. This decrease in mass is accompanied by a release of energy.



In nuclear <u>fusion</u>, smaller nuclei are fused together to form a larger nucleus. The mass of the nucleons decreases. This is accompanied by a release of energy.



(5)✐In a fusion reactor, deuterium (^2_1H) and tritium (^3_1H) are fused together to make ^4_2He and a neutron. Energy is released as the kinetic energy of the products.



Work out the change in mass, and hence the energy released in this process. (mass of ^2_1H = 2.01410u, mass of ^3_1H = 3.01605u, mass of ^4_2He = 4.00260u, mass of neutron = 1.00867u).