7.2 Nuclear Reactions

The nuclide $^{24}_{11}Na$ decays into the stable nuclide $^{24}_{12}Mg$.

a) **(i)** Identify this type of radioactive decay.

(ii) Use the data below to determine the rest mass in unified atomic mass units of the particle emitted in the decay of a sodium-24 nucleus $^{24}_{11}Na$.

rest mass of $^{24}_{11}Na = 23.990\ 96u$

rest mass of $^{24}_{12}Mg = 23.985\ 04u$

energy released in decay = 5.002 160 MeV

a) **(i)** This is an example of negative beta decay since the daughter product has an extra proton (a neutron has decayed into a proton and an electron – with the electron being emitted as a negative beta particle).

(ii) The energy released is equivalent to a mass of 5.002 160 MeV c^{-2}.

1 u is equivalent to 931.5 MeV c^{-2}

So the energy is equivalent to a mass of $\frac{5.002160}{931.5} = 0.005\ 37\text{u}$

The energy mass of the electron must therefore be

$$23.990\ 96\text{u} - (23.985\ 04\text{u} + 0.005\ 37\text{u})$$
$$= 0.000\ 55\text{u}$$

This is consistent with the value for the mass of an electron (given as 0.000 549u in the IB Physics data booklet).

The isotope sodium-24 is radioactive but the isotope sodium-23 is stable. Suggest which of these isotopes has the greater nuclear binding energy.

As sodium-24 has 24 nucleons and sodium-23 has 23 nucleons, the total binding energy for sodium 24 is going to be greater than that of sodium 23.

Compare the process of nuclear fission with nuclear fusion.

Nuclear fusion involves the joining together of light nuclei while nuclear fission involves the splitting up of a heavy nucleus. In each case the total nuclear binding energy of the product(s) is greater than that of the initial nuclei or nucleus. The difference in binding energy is emitted as the kinetic energy of the product(s). In relation to the plot of nuclear binding energy per nucleon against nucleon number, fission moves nuclei from the far right towards the centre whereas fusion moves nuclei from the far left towards the centre – both processes involve a move up the slopes towards higher values.

Helium-4 ($^{4}_{2}He$) and a neutron are the products of a nuclear fusion reaction between deuterium ($^{2}_{1}H$) and tritium ($^{3}_{1}H$).

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + \text{energy}$$

The masses of these nuclides are as follows:

$^{2}_{1}H$	2.014 102u
$^{3}_{1}H$	3.016 050u
$^{4}_{2}He$	4.002 603u

Show that the energy liberated in each reaction is approximately 2.8×10^{-12} J.

To simplify the calculation you should break it down into several steps. Remember to include all of the steps – with so many significant figures, short cuts could cost you marks in an exam.

Total mass on left-hand side of equation = 2.014 102u + 3.016 050u = 5.030 152u

Looking up the mass of the neutron in the data booklet (= 1.008 665u)

Total mass on right-hand side of equation = 4.002 603u + 1.008 665u = 5.011 268u

Thus there is a loss of mass on the right-hand side (as the binding energy of the helium nucleus is higher than that of the deuterium and tritium nuclei)

Mass difference (Δm) = 5.030 152u − 5.011 268u = 0.018 884u

As $u = 931.5$ MeV c^{-2},

$\Delta m = 0.018\,884 \times 931.5$ MeV c^{-2}

$= 17.59$ MeV c^{-2}

$\Delta E = \frac{\Delta m}{c^2} = 17.59$ MeV

$= 17.59 \times 10^6 \times 1.60 \times 10^{-19}$ J

$\Delta E = 2.81 \times 10^{-12}$ J