Worksheet answers

- Large quantities of energy are released during chain reactions and fission when nuclei are destabilised and eventually split into smaller fragments. Fusion is a second process that takes place at a nuclear level and produces large amounts of energy. In fact the quantities are so large that the reactions are yet to be harnessed for commercial energy generation on a large scale.
- Fusion involves the joining of two, relatively light nuclei to form a heavier nucleus. The increase in binding energy of the products of the reaction compared with the reactants results in the production of energy. The equation below shows a typical fusion reaction.

  $^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{1}H + ^{1}_{0}n$

  Two atoms of hydrogen-2 combine to produce hydrogen-3, a neutron and energy. Hydrogen-2 is commonly known as deuterium and hydrogen-3 is known as tritium.
- Extremely high temperatures are necessary for two positively charged nuclei to overcome the potential barrier caused by the electric force, so they can come close enough to fuse. Such a temperature is found in the Sun, where fusion reactions produce the energy that is radiated to Earth.
- The quantity of energy produced in a fusion reaction can be calculated in a similar way to that used in fission reactions.

1. Using the equation above for the fusion of two atoms of deuterium, calculate the mass defect and the energy released in MeV. The table below contains masses of the atoms and particles involved expressed in *unified mass units* (u) where 1 u = 931 MeV.

mass of deuterium	2.014 102 u
mass of tritium	3.016 049 u
mass of a neutron	1.008 665 u
mass of an electron	0.000 549 u

Calculate the mass of the reactants (two deuterium atoms):
Mass of reactants = 2.014 102 x 2 = 4.028 204 u

Calculate the mass of the products (one tritium atom and one neutron):
Mass of products = 3.016 049 + 1.008 665 = 4.024 714 u

Calculate the mass defect (mass of reactants – mass of products):
Mass defect = 4.028 204 - 4.024 714 = 0.003 490 u

Now use the conversion factor of 1 u = 931 MeV to convert mass directly into energy:
Energy released in the fusion reaction = 0.003 490 x 931 = 3.25 MeV

2. The following reaction is one that occurs in the Sun to produce thermal energy.

$^{3}_{2}He + ^{3}_{2}He \rightarrow ^{4}_{2}He + ^{1}_{1}H + ^{1}_{1}H$

Use the following data to calculate the energy produced in the reaction (note: electron masses are not included).

mass of a helium-3 nucleus	3.014 933 u
mass of a helium-4 nucleus	4.001 504 u
mass of a hydrogen-1 nucleus (proton)	1.007 276 u

Calculate the mass of the reactants (two helium-3 nuclei):
Mass of reactants = 3.014 933 x 2 = 6.029 866 u

Calculate the mass of the products (one helium-4 nucleus and two protons):
Mass of products = 4.001 504 + 2 x 1.007 276 = 6.016 056 u

Calculate the mass defect (mass of reactants – mass of products):
Mass defect = 6.029 866 - 6.016 056 = 0.013 810 u

Now use the conversion factor of 1 u = 931 MeV to convert mass directly into energy:
Energy released in the fusion reaction = 0.013 810 x 931 = 12.9 MeV

3. The fission of uranium-235 to form Ba-144 and Kr-90 releases about 200 MeV per atom. How does this compare with the energy produced by the fusion of two atoms of deuterium (see question 1)? Which do you consider to be the most efficient energy producer? Explain your answer.

The amount of energy released per nucleus in the fusion reaction (12.9 MeV) seems small compared to that of U-238 (200 MeV). However this is not small when the mass of the material involved in the reaction is considered.