Energy Released in Nuclear Reactions

The binding energy is equal to the amount of energy released in forming the nucleus and can be calculated using ____________

The daughter nuclei produced as a result of both fission and fusion have a ________ BEpN than the parent nuclei.

Hence energy is ________ as a result of the ________ between the parent and the daughter nuclei.

Mole ratio

Q. ${}^{2}_{1}H + {}^{1}_{1}H \longrightarrow {}^{3}_{2}He$ + energy

Particle	mass/u
${}^{1}_{1}H$	1.00728
${}^{2}_{1}H$	2.0140
${}^{3}_{2}He$	3.01605

i) Calculate energy in joules, released in this reaction.

$\Delta m = 3.01605u - (1.00728u + 2.0140u)$

$= 0.00523u$

$\Delta E = \Delta mc^2$

$= (0.00523 \times 1.66 \times 10^{-27})(3 \times 10^8)^2$

$= 7.8 \times 10^{-13} J$

ii) The temperature in the core of the sun is 1.6×10^7 K. Suggest why such a high temperature is necessary for this reaction.

Since the nuclei are positively charged, they have electrostatic repulsion. To overcome this repulsion, a high kinetic energy is needed.

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(a) **(i)** State what is meant by nuclear binding energy.

Energy required to separate the nucleons in a nucleus to infinity.

.... [2]

(ii) On Fig. 8.1, sketch a line to show the variation with nucleon number *A* of the binding energy per nucleon *E* of a nucleus.

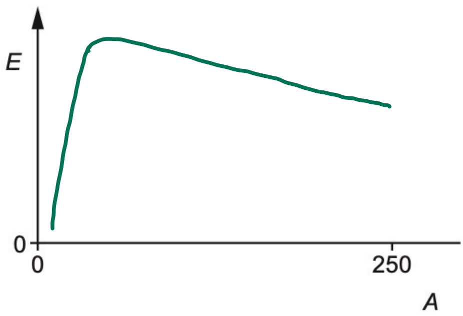

Fig. 8.1

[2]

(b) In one type of nuclear process, deuterium ($^{2}_{1}H$) undergoes the reaction

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{2}He + ^{1}_{0}n.$$

(i) State the name of this type of nuclear process.

nuclear fusion [1]

(ii) Explain, with reference to your line in **(a)(ii)**, why this reaction results in the release of energy.

BEpN of He^{3}_{2} is greater than BEpN of H-2.

Both H-2 particles have low A.

.... [2]

(c) Table 8.1 shows the masses of the particles involved in the reaction in **(b)**.

Table 8.1

particle	mass/u
$^{1}_{0}n$	1.008665
$^{2}_{1}H$	2.014102
$^{3}_{2}He$	3.016029

Calculate the energy released when 1.00 mol of deuterium undergoes the reaction.

$\Delta m = 3.016029u + 1.008665u - (2 \times 2.014102)u$

$= 0.00351u$

$\Delta E = (0.00351 \times 1.66 \times 10^{-27})(3 \times 10^{8})^2$

$= 5.24 \times 10^{-13} J$

Energy released when one He-3 nucleus is formed.

energy = 1.58×10^{11} J [5]

[Total: 12]

2 mol H-2 form 1 mol of He-3

1 mol H-2 forms 0.5 mol of He-3

No. of He-3 nuclei formed $= 0.5 \times 6.02 \times 10^{23} = 3.01 \times 10^{23}$

Energy released $= 3.01 \times 10^{23} \times 5.24 \times 10^{-13}$

$= 1.58 \times 10^{11}$

S-23/42

(a) Define mass defect.

Difference between mass of nucleus and total mass of nucleus when separated to infinity.

[2]

(b) Table 9.1 shows the mass defects of three nuclei.

Table 9.1

nucleus	mass defect / u
$^{2}_{1}H$	0.002 388
$^{3}_{1}H$	0.009 105
$^{4}_{2}He$	0.030 377

The nuclear fusion process in a particular star is described by

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}X$$

where X is a particle that has no mass defect.

(i) State the name of particle X.

neutron

[1]

(ii) Show that the energy released when one nucleus of $^{4}_{2}He$ is formed in this fusion reaction is 2.8×10^{-12} J.

$\Delta m = 0.030377u - (0.002388u + 0.009105u)$

$= 0.018884u$

$\Delta E = \Delta m c^2$

$= (0.018884 \times 1.66 \times 10^{-27})(3 \times 10^8)^2$

$= 2.82 \times 10^{-12}$ J

(c) The star in **(b)** has a radius of 2.3×10^9 m and a luminosity of 1.4×10^{28} W.
All the energy released from the formation of $^4_2$He is radiated away from the star.
All the energy that is radiated from the star has been released in the formation of $^4_2$He.

$P = \frac{E}{t}$

Determine:

(i) the mass of $^4_2$He produced per unit time by the fusion process

1 nucleus of He-4 releases = 2.82×10^{-12} J

Total energy released per second = 1.4×10^{28} J/s

Total # of nuclei formed per second = $\frac{1.4 \times 10^{28}}{2.82 \times 10^{-12}} = 4.96 \times 10^{39}$

Mass of 1 nucleus = 4u = $4 \times 1.66 \times 10^{-27}$ kg = 6.64×10^{-27} kg

Total mass of He-4 produced = $6.64 \times 10^{-27} \times 4.96 \times 10^{39}$

mass per unit time = 3.3×10^{13} kg s^{-1} [3]

(ii) the surface temperature of the star.

temperature = ... K [2]

[Total: 11]

(b) The nuclear fission of uranium-235 can be described by

$$^{1}_{0}n + ^{235}_{92}U \longrightarrow ^{144}_{56}Ba + ^{89}_{36}Kr + 3^{1}_{0}n.$$

Table 6.1 shows the masses of the particles involved in this reaction.

Table 6.1

particle	mass / u
$^{1}_{0}n$	1.008665
$^{89}_{36}Kr$	88.917636
$^{144}_{56}Ba$	143.922953
$^{235}_{92}U$	235.043930

Determine the energy released by the fission of 15.0 kg of uranium-235.

$m_p = 143.922953 + 88.917636 + 3(1.008665)$

$= 235.866584u$

$m_r = 235.043930 + 1.008665 = 236.052595u$

$\Delta m = 0.186011u = 3.0877826 \times 10^{-26}$

$\Delta E = \Delta mc^2 = 2.78 \times 10^{-11}$

energy = ... J [4]

1 particle of U-235 produces 2.78×10^{-11} J

235.043930u produces 2.78×10^{-11} J

3.901×10^{-25} kg — 2.78×10^{-11} J

15 kg — 1.07×10^{15} J