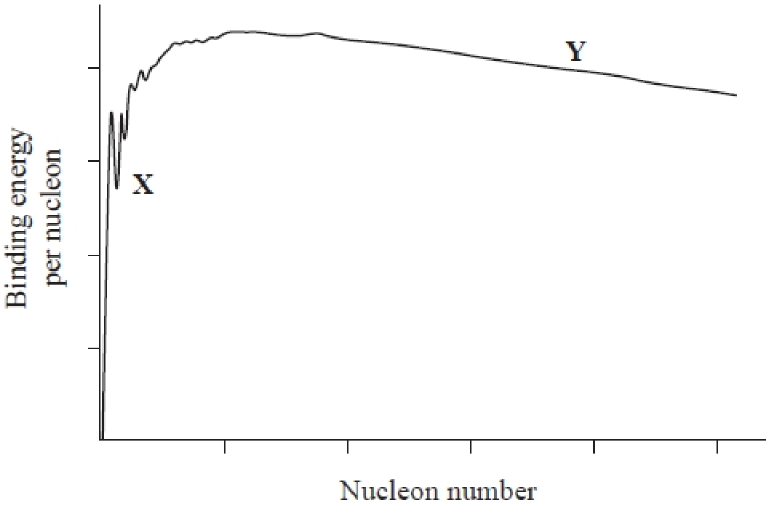
Nuclear Binding Energy, Fission and Fusion

Q1.

The diagram shows binding energy per nucleon against nucleon number for atomic nuclei.



Which line of the table correctly identifies the process that would increase stability for nuclei in the positions indicated by X and Y?

		X	Y
☐	**A**	nuclear fission	nuclear fission
☐	**B**	nuclear fission	nuclear fusion
☐	**C**	nuclear fusion	nuclear fission
☐	**D**	nuclear fusion	nuclear fusion

(Total for question = 1 mark)

Q2.

In both nuclear fission and nuclear fusion there are changes in the binding energy per nucleon. This releases energy.

Which row of the table correctly shows the change in binding energy per nucleon for both processes?

	Nuclear fission	Nuclear fusion
☐ **A**	decrease	decrease
☐ **B**	decrease	increase
☐ **C**	increase	decrease
☐ **D**	increase	increase

(Total for question = 1 mark)

Q3.

In a nuclear fission reaction in power station, a slow-moving neutron is absorbed by a nucleus of U-235
The fission reaction produces nuclei of barium-141 and krypton-92

The equation for the reaction is:

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{141}_{56}\text{Ba} + ^{92}_{36}\text{Kr} + 3 \times ^{1}_{0}\text{n}$$

Use the data in the table to calculate the energy, in joules, released in this fission reaction.

(3)

	Mass/u
neutron	1.008665
uranium-235	235.0439
barium-141	140.9144
krypton-92	91.9262

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Energy = ... J

(Total for question = 5 marks)

Q4.

At the Culham Centre for Fusion Energy (CCFE) experiments are carried out to investigate nuclear fusion and the properties of plasmas. A plasma consists of ionised gas, containing positive ions and electrons.

In a fusion experiment at CCFE, ions of two isotopes of hydrogen fuse to produce helium ions and fast-moving neutrons.

Fusion occurs naturally in the core of stars.

Explain why very high densities of matter and very high temperatures are needed to bring about and maintain nuclear fusion in stars.

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(Total for question = 2 marks)

Q5.

Phosphogypsum is a by-product in the manufacture of fertiliser. It is slightly radioactive because of the presence of radium-226, a radioisotope with a half-life of 1600 years.

It must be stored securely as long as the activity of the radium-226 it contains is greater than 0.4 Bq per gram of phosphogypsum.

Radium-226 decays to radon-222 by alpha emission.

Determine the energy released in MeV in the decay of a single nucleus of radium-226.

(5)

mass of radium-226 nucleus = 225.97713 u
mass of radon-222 nucleus = 221.97040 u
mass of α particle = 4.00151 u

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Energy released = ... MeV

(Total for question = 5 marks)

Q6.

At the Culham Centre for Fusion Energy (CCFE) experiments are carried out to investigate nuclear fusion and the properties of plasmas. A plasma consists of ionised gas, containing positive ions and electrons.

In a fusion experiment at CCFE, ions of two isotopes of hydrogen fuse to produce helium ions and fast-moving neutrons.

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

Show that a single fusion reaction releases about 3×10^{-12} J of energy.

mass of $^{2}_{1}H = 2.013553\,u$

mass of $^{3}_{1}H = 3.015501\,u$

mass of $^{4}_{2}He = 4.001506\,u$

mass of $^{1}_{0}n = 1.008665\,u$

(4)

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(Total for question = 4 marks)

Q7.

Nuclear fusion involves small nuclei joining to make larger nuclei. Nuclear fission involves large nuclei splitting to become smaller nuclei. Both of these processes release energy.

Explain the conditions required to bring about and maintain nuclear fusion.

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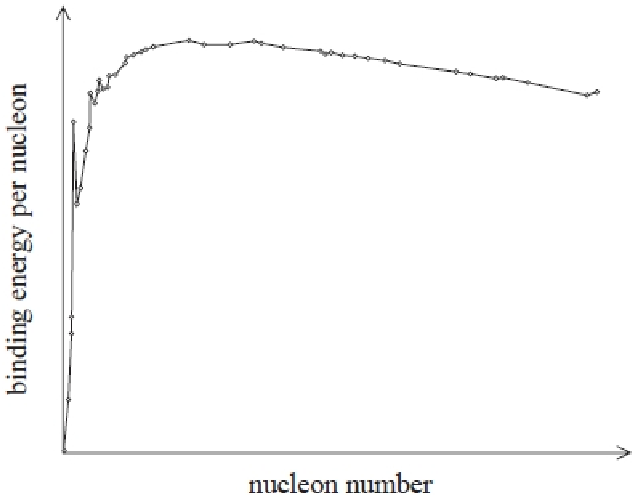
(Total for question = 3 marks)

Q8.

Nuclear fusion involves small nuclei joining to make larger nuclei. Nuclear fission involves large nuclei splitting to become smaller nuclei. Both of these processes release energy.

The graph shows how the binding energy per nucleon varies with nucleon number for a range of isotopes.



Use the binding energy per nucleon curve to explain how fusion and fission both release energy.

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(Total for question = 3 marks)

Q9.

State what is meant by binding energy.

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(Total for question = 2 marks)

Q10.

* The energy radiated by stars is released by nuclear fusion.

Explain the conditions required to bring about and maintain nuclear fusion in stars.

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(Total for question = 6 marks)

Mark Scheme – Nuclear Binding Energy, Fission and Fusion

Q1.

Question Number	Acceptable answer	Additional guidance	Mark
	C	The only correct answer is C because X is a smaller nucleus for which the binding energy per nucleon could increase through a process of fusion and Y is a larger nucleus for which the binding energy per nucleon could increase through a process of fission A I not correct because it states fission for both X and Y B is not correct because the processes are reversed D is not correct because it states fusion for both X and Y	1

Q2.

Question Number	Acceptable answer	Additional guidance	Mark
	D	The only correct answer is **D**: the binding energy per nucleon curve shows an increase for both processes A is not correct because both processes show decreases B is not correct because fission shows a decrease C is not correct because fusion shows a decrease	1

Q3.

Question Number	Acceptable answers	Additional guidance	Mark
	• Calculation of mass difference in kg **(1)** • Use of $E = c^2 \Delta m$ **(1)** • $E = 2.77 \times 10^{-11}$ J **(1)**	Example of calculation: (235.0439 + 1.008665) u – (140.9144 + 91.9262+ (3×1.008665)) u = 0.186u $(0.1860 \text{ u} \times 1.66 \times 10^{-27} \text{ kg}) \times (3 \times 10^8 \text{ m s}^{-1})^2 =$ 2.77×10^{-11} J	3

Q4.

Question Number	Acceptable answers	Additional guidance	Mark
	• High temperature so sufficient (kinetic) energy to overcome the repulsion between (positively charged) ions/nuclei **(1)** • High density to ensure ions close enough to each other to maintain collision rate to maintain fusion **(1)**		2

Q5.

Question Number	Acceptable answers		Additional guidance	Mark
	• attempt to determine mass difference between radium and radon-plus-alpha • conversion to kg • Use of $\Delta E = c^2\Delta m$ • Use of 1.6×10^{-19} factor • Answer = 4.87 (MeV)	(1) (1) (1) (1) (1)	$\Delta m = 225.97713\text{u} - (221.97040\text{u} + 4.00151\text{ u})$ $= 5.22 \times 10^{-3}\text{ u} = 5.22 \times 10^{-3} \times 1.66 \times 10^{-27}\text{ kg} = 8.67 \times 10^{-30}\text{ kg}$ $\Delta E = c^2\Delta m = (3 \times 10^8\text{ m s}^{-1})^2 \times 8.67 \times 10^{-30}\text{ kg} = 7.80 \times 10^{-13}\text{ J}$ ΔE in MeV $= 7.80 \times 10^{-13}\text{ J} \div 1.6 \times 10^{-19}\text{ C}$ = 4.87 MeV	5

Q6.

Question Number	Acceptable answers		Additional guidance	Mark
	• Calculates change in mass • Converts from u to kg • Use of $\Delta E = c^2\Delta m$ • 2.8×10^{-12} J	(1) (1) (1) (1)	<u>Example of calculation</u> $\Delta m = ((2.013553 + 3.015501) - (4.001506 + 1.008665))u$ $= 0.01883 \times 1.66 \times 10^{-27}$ kg $= 3.13 \times 10^{-29}$ kg $\Delta E = (3.00 \times 10^8\text{ m s}^{-1})^2 \times 3.13 \times 10^{-29}$ kg $= 2.8 \times 10^{-12}$ J	4

Q7.

Question Number	Acceptable answers		Additional guidance	Mark
	An explanation that makes reference to: • Identifies (very) high temperature and (very) high density • (Very) high temperature to provide enough energy to overcome the (electrostatic) repulsive force between nuclei • (Very) high density to give big enough collision rate to maintain reaction	 (1) (1) (1)	Accept pressure for density in MP1 Accept correct reference to strong force	3

Q8.

Question Number	Acceptable answers	Additional guidance	Mark
	• Fusion involves an increase in binding energy (per nucleon) as the number of nucleons increases (1) • Fission involves an increase in binding energy (per nucleon) as the number of nucleons decreases (1) • If binding energy per nucleon increases energy is released in the process (1)	Accept reference to larger/smaller nuclei for number of nucleons increases/decreases	3

Q9.

Question Number	Acceptable answers	Additional guidance	Mark
	• The energy equivalent to the mass deficit **(1)** • When nucleons bind together to form an atomic nucleus **(1)**		2

Q10.

Question Number	Acceptable answers	Additional guidance	Mark
	This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content.	The following table shows how the marks should be awarded for structure and lines of reasoning.	6

Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	Max linkage mark available	Max final mark
6	4	2	6
5	3	2	5
4	3	1	4
3	2	1	3
2	2	0	2
1	1	0	1
0	0	0	0

	No. of marks awarded for structure of answer and sustained line of reasoning
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkages between points and is unstructured	0

Guidance on how the mark scheme should be applied:

The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).

	Indicative content: • Requires a (very) high temperature • Nuclei all have positive charge leading to a large repulsive force between nuclei • At high temperature nuclei have high <u>kinetic</u> energy, sufficient to overcome repulsion • Nuclei must get close enough to fuse (accept reference to close enough for strong force) • Requires (very) high density • Collision rate must be high enough to sustain fusion		