OXFORD

INTERNATIONAL AQA EXAMINATIONS

Topic Test: OxfordAQA International A level Physics

Nuclear Energy

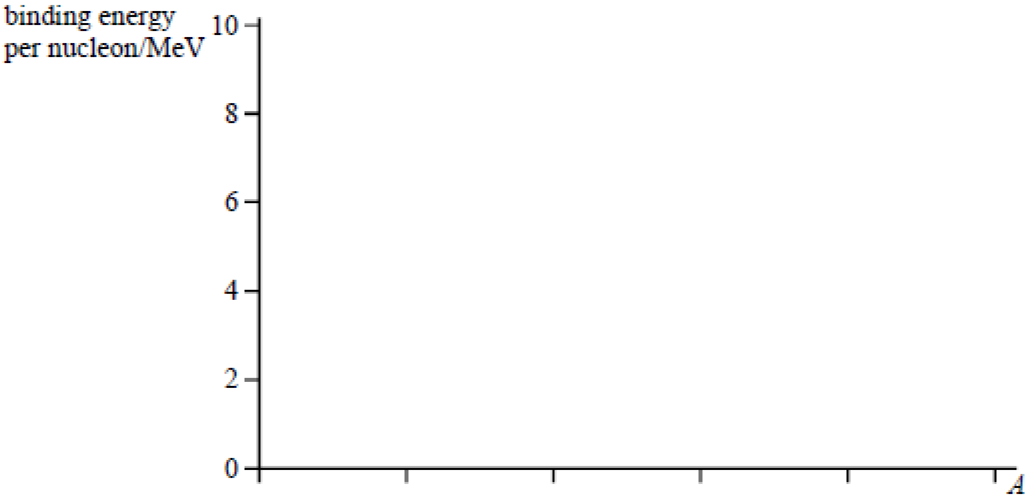
Name: __________

Class: __________

Date: __________

Time:	**58 minutes**
Marks:	**39 marks**
Comments:	

1



(a) On the axes above, sketch a graph to show how the average binding energy per nucleon depends on the nucleon number, A, for the naturally occurring nuclides. Show appropriate values for A on the horizontal axis of the graph.

(3)

(b) (i) Briefly explain what is meant by *nuclear fission* and by *nuclear fusion*.

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(ii) Describe how the graph in part (a) indicates that large amounts of energy are available from both the fission and the fusion processes.

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(3)

(Total 6 marks)

2 (a) State what is meant by the binding energy of a nucleus.

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(2)

(b) (i) When a $^{235}_{92}\text{U}$ nucleus absorbs a slow-moving neutron and undergoes fission one possible pair of fission fragments is technetium $^{112}_{43}\text{Tc}$ and indium $^{122}_{49}\text{In}$.

Complete the following equation to represent this fission process.

$$^{1}_{0}\text{n} + {}^{235}_{92}\text{U} \rightarrow {}^{112}_{43}\text{Tc} + {}^{122}_{49}\text{In} + \ldots\ldots\ldots\ldots$$

(1)

(ii) Calculate the energy released, in MeV, when a single $^{235}_{92}\text{U}$ nucleus undergoes fission in this way.

binding energy per nucleon of $^{235}_{92}\text{U}$ = 7.59 MeV

binding energy per nucleon of $^{112}_{43}\text{Tc}$ = 8.36 MeV

binding energy per nucleon of $^{122}_{49}\text{In}$ = 8.51 MeV

energy released ____________________ MeV

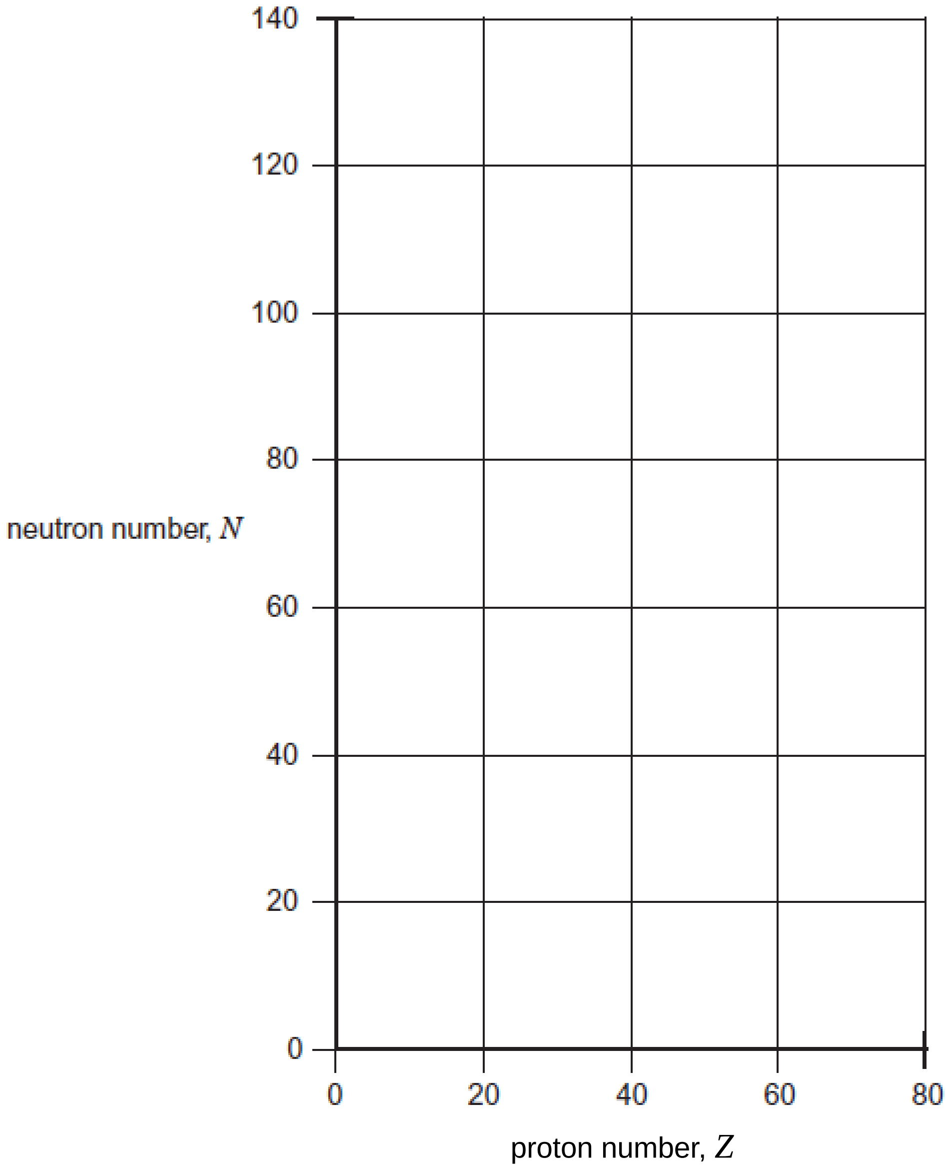
(3)

(iii) Calculate the loss of mass when a $^{235}_{92}\text{U}$ nucleus undergoes fission in this way.

loss of mass ____________________ kg

(2)

(c) (i) On the figure below sketch a graph of neutron number, N, against proton number, Z, for stable nuclei.



(1)

(ii) With reference to the figure, explain why fission fragments are unstable and explain what type of radiation they are likely to emit initially.

(3)

(Total 12 marks)

3 A plasma containing nuclei of two isotopes of hydrogen, ${}^{2}_{1}\mathrm{H}$ and ${}^{3}_{1}\mathrm{H}$, is considered to be a possible fuel for fusion reactors in the future. The plasma must be heated to a high temperature to provide the nuclei with the minimum kinetic energy to enable the fusion reaction to occur.

(a) Explain why the nuclei in the plasma require a minimum kinetic energy for this fusion reaction to occur.

(3)

(b) The radius of a $^{2}_{1}H$ nucleus is 1.51 × 10^{-15} m.

Show that the distance between the centre of a $^{2}_{1}H$ nucleus and the centre of a $^{3}_{1}H$ nucleus is about 3.2 × 10^{-15} m when they are just in contact.

(3)

(c) Assume that the $^{2}_{1}H$ and $^{3}_{1}H$ nuclei fuse when they are just in contact.

Calculate the minimum total kinetic energy that would allow a $^{2}_{1}H$ nucleus and a $^{3}_{1}H$ nucleus to fuse.

minimum total kinetic energy = ____________________ J

(3)

(d) The equation for this fusion reaction is

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

The table shows the mass of each particle involved.

Particle	Mass / u
$^{1}_{0}n$	1.008665
$^{2}_{1}H$	2.013553
$^{3}_{1}H$	3.016049
$^{4}_{2}He$	4.002603

Calculate, in J, the energy released when this fusion reaction takes place.

energy released = ____________________ J

(3)

(e) Plasmas are contained using magnetic fields.

Explain how magnetic containment can be made to be more energy-efficient.

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(2)

(Total 14 marks)

4 A $^{208}_{82}\mathrm{Pb}$ nucleus has a diameter of 1.26×10^{-14} m.

What is the density of a neutron in this nucleus?

A	4.1×10^{16} kg m^{-3}	⬭
B	1.3×10^{17} kg m^{-3}	⬭
C	2.0×10^{17} kg m^{-3}	⬭
D	3.3×10^{17} kg m^{-3}	⬭

(Total 1 mark)

5 The nucleus $^{A}_{Z}X$ has a mass defect Δm.

mass of a proton = m_p

mass of a neutron = m_n

mass of nucleus $^{A}_{Z}X$ = m_x

Which expression is correct?

A $\Delta m = m_x - (Zm_n + (A-Z)m_p)$ ⬭

B $\Delta m = ((A-Z)m_n + Zm_p) - m_x$ ⬭

C $\Delta m = (Am_n + (A-Z)m_p) - m_x$ ⬭

D $\Delta m = m_x - (Am_n + (A-Z)m_p)$ ⬭

(Total 1 mark)

6 A thermal nuclear reactor maintains a steady chain reaction.
The average number of neutrons emitted per fission is 3.

Which row shows possible average numbers of neutrons absorbed by control rods and lost from the reactor without causing fission?

	Average number of neutrons absorbed by control rods	Average number of neutrons lost from the reactor without causing fission	
A	2	1	⬭
B	1	0	⬭
C	1	1	⬭
D	0	1	⬭

(Total 1 mark)

7 Artificial radioactive nuclides are manufactured by placing naturally-occurring nuclides in a nuclear reactor. They are made radioactive in the reactor as a consequence of bombardment by

A α particles.

B β particles.

C protons.

D neutrons.

(Total 1 mark)

8 A thermal nuclear reactor is shut down by inserting the control rods fully into the core. Which line, **A** to **D**, shows correctly the effect of this action on the fission neutrons in the reactor?

	number of fission neutrons	average kinetic energy of fission neutrons
A	reduced	reduced
B	reduced	unchanged
C	unchanged	reduced
D	unchanged	unchanged

(Total 1 mark)

9 Which is **not** a difficulty in a nuclear fusion reactor?

A Confining the plasma.

B Dealing with highly radioactive waste.

C Heating the plasma.

D Sustaining fusion over a period of time.

(Total 1 mark)

10 What does the equation $E = mc^2$ suggest?

A The mass of a substance is increased when it is heated.

B The mass of a nucleus is greater than the mass of its constituent parts.

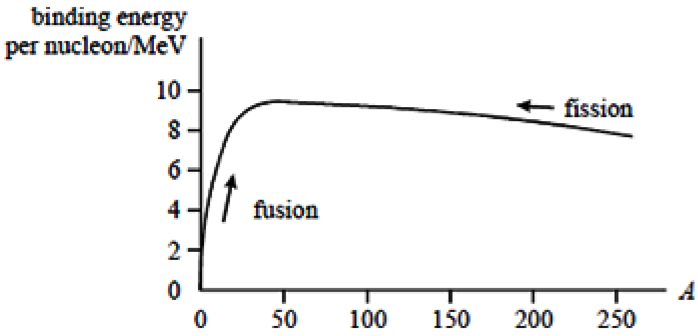
C The total mass of a nucleus is converted into kinetic energy when the nucleus decays.

D Energy is required to initiate proton–antiproton annihilation.

(Total 1 mark)

Mark schemes

1 (a)



graph to show:
steep rise, maximum and gradual fall,
with maximum between 6 MeV and 10 MeV **(1)**
suitable values of A (up to 200 - 250) **(1)**
maximum shown at $A \approx 60$, with fall < 20% of rise **(1)**

3

(b) (i) *fission* when nucleus splits into two nuclei
and
fusion when two nuclei join to form one nucleus **(1)**

(ii) energy released when B.E. / nucleon increases
or when B.E. increases
or when greater stability results
[or by movement towards peak of graph] **(1)**

how fission achieves this **(1)**
how fusion achieves this **(1)**
[if not explained, award **(1)** (one only) if fusion and fission arrows shown correctly on graph]

max 3

The Quality of Written Communication marks are awarded for the quality of answers tothis question.

[6]

2 (a) the amount of energy required to separate a nucleus ✓
into its separate neutrons and protons / nucleons ✓
(or energy released on formation of a nucleus ✓
from its separate neutrons and protons / constituents ✓)

1st mark is for correct energy flow direction

2nd mark is for binding or separating nucleons (nucleus is in the question but a reference to an atom will lose the mark)

ignore discussion of SNF etc

both marks are independent

2

(b) (i) $2\,^1_0n$ or $^1_0n + ^1_0n$ ✓

must see subscript and superscripts

1

(ii) binding energy of U

= 235 × 7.59 ✓ (= 1784 (MeV))

binding energy of Tc and In

= 112 × 8.36 + 122 × 8.51 ✓

(= 1975 (MeV))

energy released (= 1975 – 1784) = 191 (MeV) ✓ (allow 190 MeV)

1st mark is for 235 × 7.59 seen anywhere

2nd mark for 112 × 8.36 + 122 × 8.51 or 1975 is only given if there are no other terms or conversions added to the equation (ignore which way round the subtraction is positioned)

correct final answer can score 3 marks

3

(iii) energy released

= 191 × 1.60 × 10^{-13} ✓

(= 3.06 × 10^{-11} J)

loss of mass (= E / c^2)

= 2.91 × 10^{-11} / (3.00 × $10^8)^2$)

= 3.4 × 10^{-28} (kg) ✓

or

= 191 / 931.5 u ✓ (= 0.205 u)

= 0.205 × 1.66 × 10^{-27} (kg)

= 3.4 × 10^{-28} (kg) ✓

allow CE from (ii)

working must be shown for a CE otherwise full marks can be given for correct answer only

note for CE

answer = (ii) × 1.78 × 10^{-30}

(2.01 × 10^{-27} *is a common answer)*

2

(c) (i) line or band from origin, starting at 45° up to Z approximately = 20 reading Z = 80, N = 110→130 ✓

initial gradient should be about 1 (ie Z = 20 ; N = 15 → 25) and overall must show some concave curvature. (Ignore slight waviness in the line)

if band is shown take middle as the line

if line stops at N > 70 extrapolate line to N = 80 for marking

1

(ii) fission fragments are (likely) to be above / to the left of the line of stability ✓
fission fragments are (likely) to have a larger *N* / *Z* ratio than stable nuclei
or
fission fragments are neutron rich owtte ✓
and become neutron or β^- emitters ✓

ignore any reference to α emission
a candidate must make a choice for the first two marks
stating that there are more neutrons than protons is not enough for a mark

1st mark reference to graph

2nd mark – high N / Z ratio or neutron rich

3rd mark beta *minus*
note not just beta

3

[12]

3 (a) Nuclei are both positively charged
or
Nuclei repel one another ✓

1

Idea that kinetic energy transfers to electrostatic PE as they approach ✓

1

Nuclei need to have high kinetic energy so that the nuclei 'touch' (or become close enough for SNF to act) ✓

Accept statement that nuclei need enough kinetic energy to collide

1

(b) Attempt to use $A^{1/3}$

Accept equivalent method via constant nuclear density

1

$r_0 = 1.12 \times 10^{-15}$ or radius of $^3H = 1.73 \times 10^{-15}$ ✓

Look for 1.73×10^{-15} *m*

1

Adds candidates two radii together ✓

Correct distance between centres = 3.24×10^{-15} *m*

1

(c) Use of $KE = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r}$ ✓

If candidate used $r = 3.2 \times 10^{-15}$ then $KE = 7.2 \times 10^{-14}$ J

1

Correct substitution of charge data in the formula along with their (b) ✓

1

$KE = 7.1 \times 10^{-14}$ J ✓

1

(d) Attempt to calculate mass of (helium + mass of neutron) − (mass of deuterium + mass of tritium) ✓

1

Multiplies by 931.5 MeV ✓

1

Energy released = $2.7(4) \times 10^{-12}$ J ✓

1

or

Attempt to calculate mass of (helium + mass of neutron) − (mass of deuterium + mass of tritium)

1

Multiplies by 1.661×10^{-27} kg OR Multiplies by c^2 ✓

1

energy released = $2.7(4) \times 10^{-12}$ J ✓

(e) Superconducting coils used (to create magnetic fields)

1

I^2R losses are 0 because R is 0

1

[14]

4 D

[1]

5 B

[1]

6 C

[1]

7 D

[1]

8 B

[1]

9 B

[1]

10 A

[1]