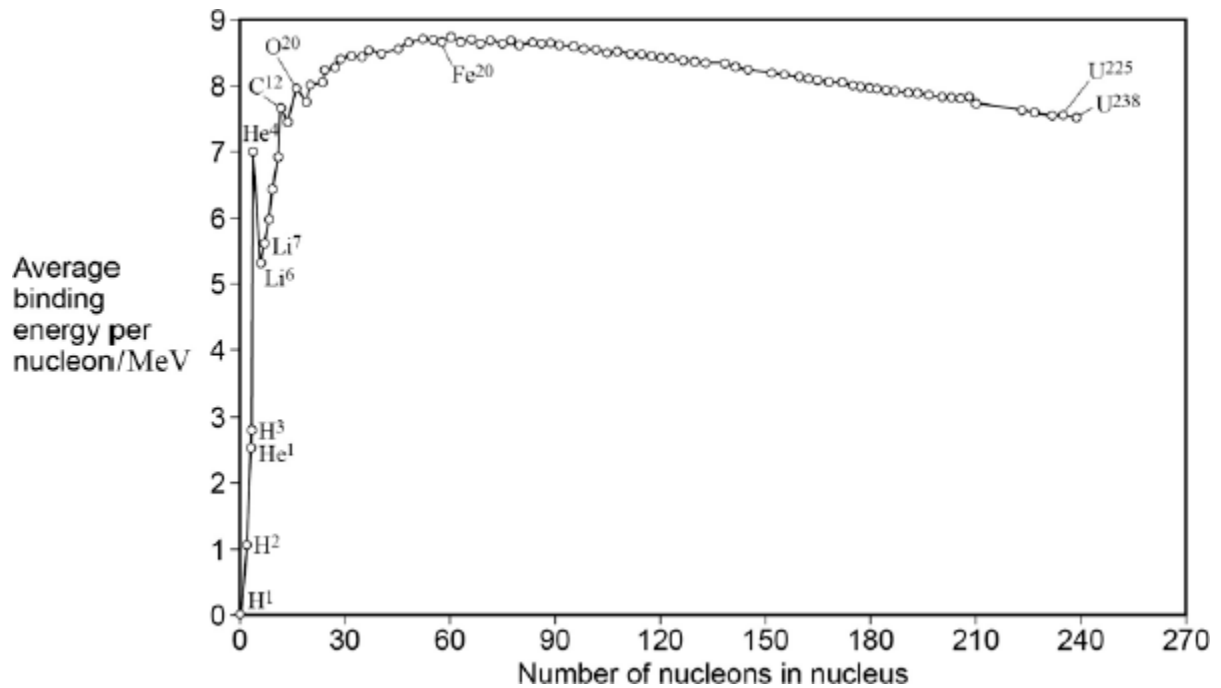


1

The graph shows how the binding energy per nucleon varies with the nucleon number for stable nuclei.



What is the approximate total binding energy for a nucleus of ${}^{184}_{74}\text{W}$?

A 1.28 pJ ☐

B 94.7 pJ ☐

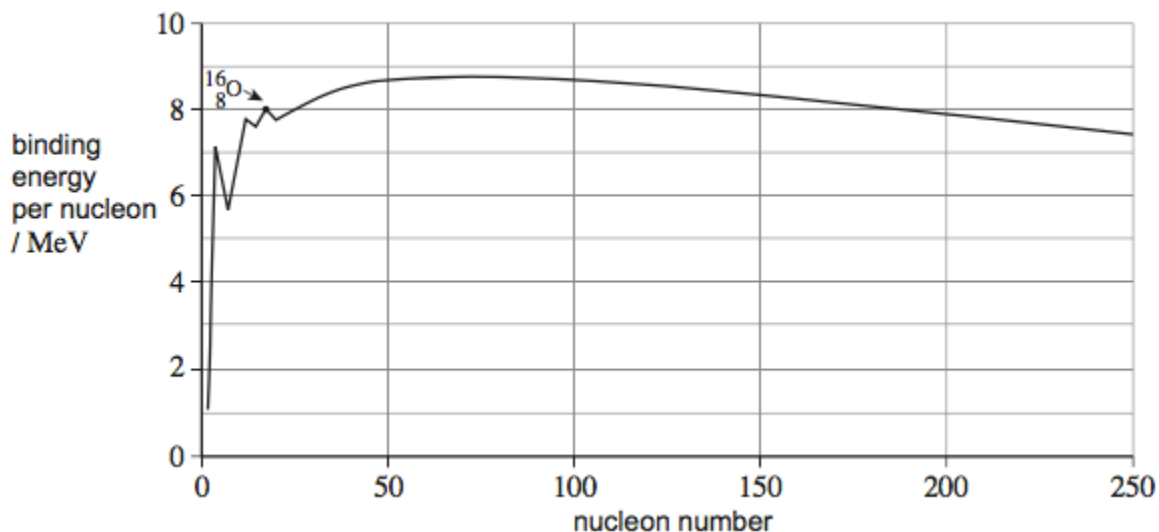
C 103 pJ ☐

D 230 pJ ☐

(Total 1 mark)

2

The diagram shows how the binding energy per nucleon varies with nucleon number.



- (a) (i) Fission and fusion are two nuclear processes in which energy can be released. Explain why nuclei that undergo fission are restricted to a different part of the graph than those that undergo fusion.

(2)

- (ii) Explain, with reference to the diagram, why the energy released per nucleon from fusion is greater than that from fission.

(2)

- (b) (i) Calculate the mass difference, in kg, of the $^{16}_8\text{O}$ nucleus.

mass of $^{16}_8\text{O}$ nucleus = 15.991 u

mass difference = _____ kg

(2)

- (ii) Using your answer to part (b)(i), calculate the binding energy, in MeV, of an oxygen $^{16}_8\text{O}$ nucleus.

binding energy = _____ MeV

(1)

- (iii) Explain how the binding energy of an oxygen $^{16}_8\text{O}$ nucleus can be calculated with information obtained from the diagram.

(1)

(Total 8 marks)

3

In stars, helium-3 and helium-4 are formed by the fusion of hydrogen nuclei. As the temperature rises, a helium-3 nucleus and a helium-4 nucleus can fuse to produce beryllium-7 with the release of energy in the form of gamma radiation.

The table below shows the masses of these nuclei.

Nucleus	Mass / u
Helium-3	3.01493
Helium-4	4.00151
Beryllium-7	7.01473

- (a) (i) Calculate the energy released, in J, when a helium-3 nucleus fuses with a helium-4 nucleus.

energy released _____ J

(4)

- (ii) Assume that in each interaction the energy is released as a single gamma-ray photon.

Calculate the wavelength of the gamma radiation.

wavelength _____ m

(3)

- (b) For a helium-3 nucleus and a helium-4 nucleus to fuse they need to be separated by no more than 3.5×10^{-15} m.
- (i) Calculate the minimum total kinetic energy of the nuclei required for them to reach a separation of 3.5×10^{-15} m.

total kinetic energy _____ J

(3)

- (ii) Calculate the temperature at which two nuclei with the average kinetic energy for that temperature would be able to fuse.
Assume that the two nuclei have equal kinetic energy.

temperature _____ K

(3)

- (c) Scientists continue to try to produce a viable fusion reactor to generate energy on Earth using reactors like the Joint European Torus (JET). The method requires a plasma that has to be raised to a suitable temperature for fusion to take place.

- (i) State **two** nuclei that are most likely to be used to form the plasma of a fusion reactor.

1. _____

2. _____

(2)

- (ii) State **one** method which can be used to raise the temperature of the plasma to a suitable temperature.

(1)

(Total 16 marks)

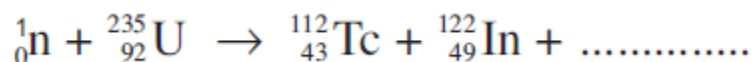
4

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

(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)

- (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 ${}^{235}_{92}\text{U} = 7.59 \text{ MeV}$

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

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

energy released _____ MeV

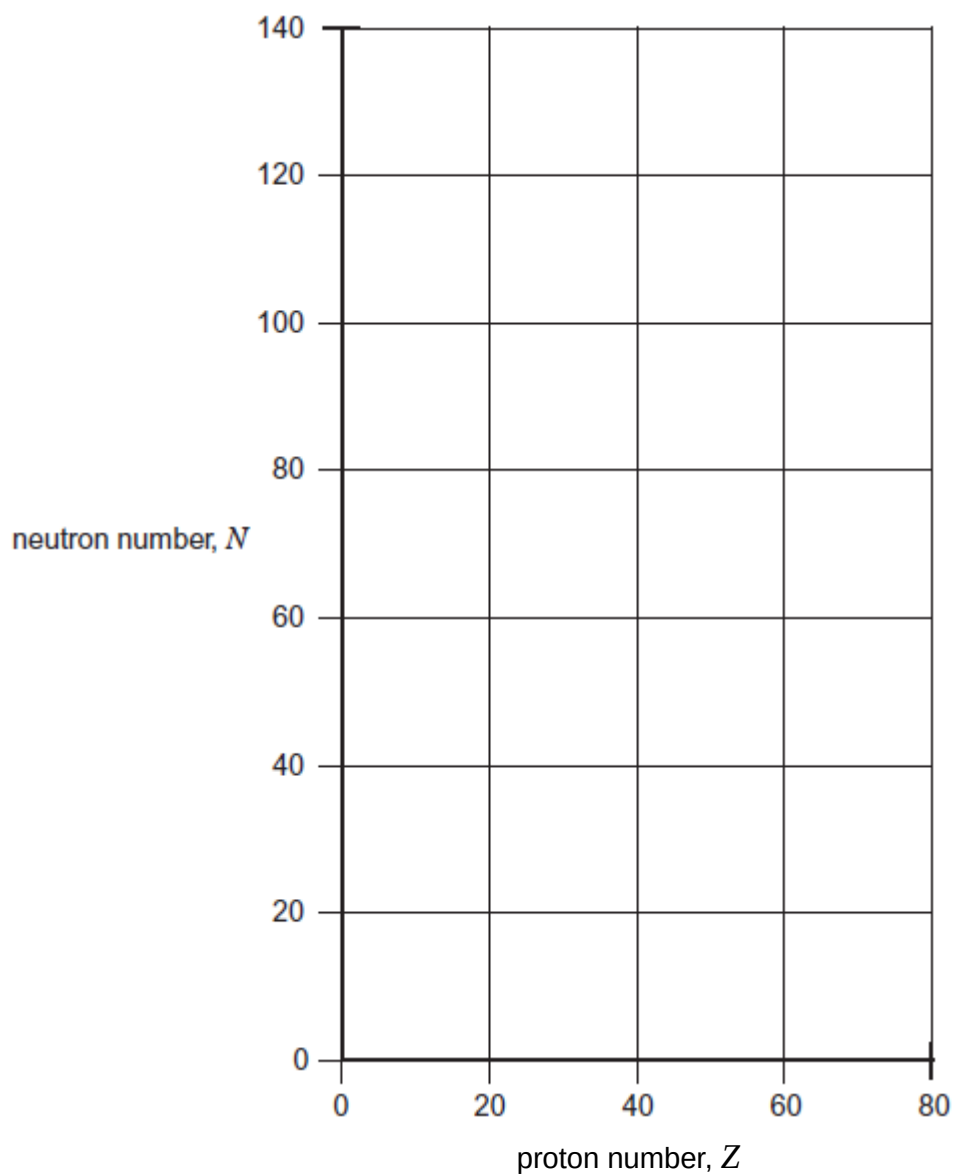
(3)

- (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)

5

The isotope of uranium, ${}_{92}^{238}\text{U}$, decays into a stable isotope of lead, ${}_{82}^{206}\text{Pb}$, by means of a series of α and β^- decays.

- (a) In this series of decays, α decay occurs 8 times and β^- decay occurs n times. Calculate n .

answer = _____

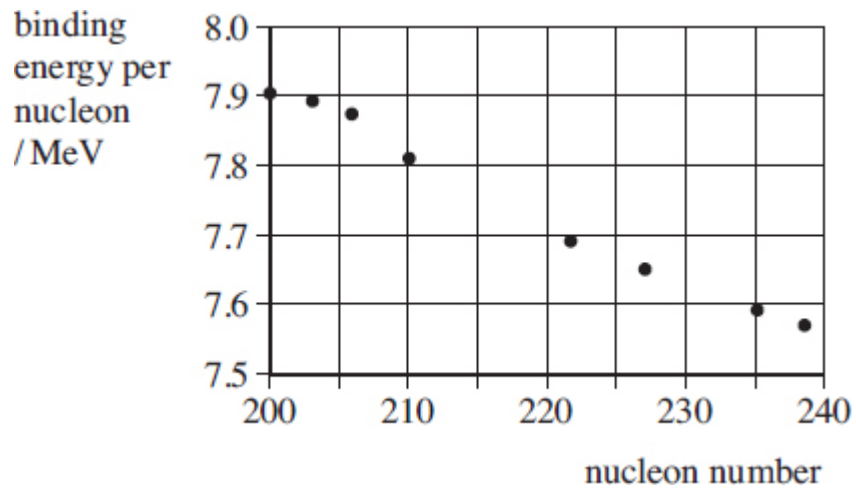
(1)

- (b) (i) Explain what is meant by the binding energy of a nucleus.

(2)

- (ii) **Figure 1** shows the binding energy per nucleon for some stable nuclides.

Figure 1



Use **Figure 1** to estimate the binding energy, in MeV, of the $^{206}_{82}\text{Pb}$ nucleus.

answer = _____ MeV

(1)

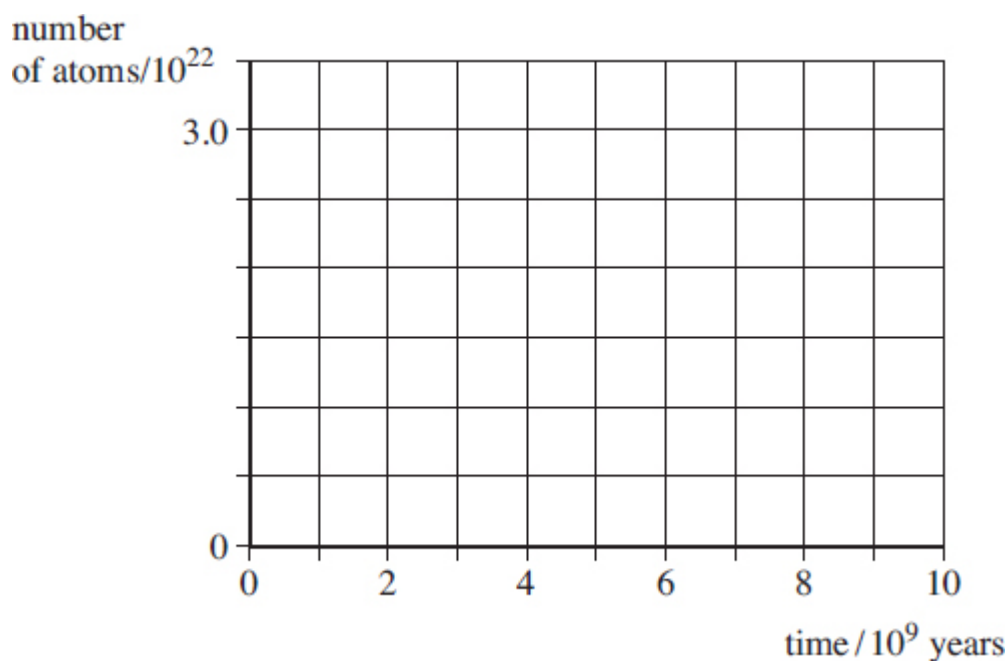
- (c) The half-life of $^{238}_{92}\text{U}$ is 4.5×10^9 years, which is much larger than all the other half-lives of the decays in the series.

A rock sample when formed originally contained 3.0×10^{22} atoms of $^{238}_{92}\text{U}$ and no $^{206}_{82}\text{Pb}$ atoms.

At any given time most of the atoms are either $^{238}_{92}\text{U}$ or $^{206}_{82}\text{Pb}$ with a negligible number of atoms in other forms in the decay series.

- (i) Sketch on **Figure 2** graphs to show how the number of $^{238}_{92}\text{U}$ atoms and the number of $^{206}_{82}\text{Pb}$ atoms in the rock sample vary over a period of 1.0×10^{10} years from its formation.
Label your graphs U and Pb.

Figure 2



(2)

- (ii) A certain time, t , after its formation the sample contained twice as many $^{238}_{92}\text{U}$ atoms as $^{206}_{82}\text{Pb}$ atoms.

Show that the number of $^{238}_{92}\text{U}$ atoms in the rock sample at time t was 2.0×10^{22} .

(1)

(ii) Calculate t in years.

answer = _____ years

(3)

(Total 10 marks)

6

The Sun's energy is produced by the fusion of protons. Near the Sun's surface the protons have a mean kinetic energy of 0.75 eV which is too low for fusion to take place. The core, however, has a temperature of about 1.5×10^6 K and a pressure of about 1.0×10^{16} Pa. This core consists of a plasma of (mainly) protons. Within the core the density, pressure and temperature of the proton plasma are sufficiently high for nuclear fusion to occur.

The energy is thought to be produced mainly by a cycle called the hydrogen cycle. The overall effect in one cycle is that 4 protons fuse to form a helium nucleus. The total mass of hydrogen that fuses each second is 7.0×10^{11} kg of which about 5.0×10^9 kg per second is converted into energy that is radiated.

When answering the following questions assume, where necessary, that the plasma behaves like an ideal gas.

- (a) (i) Use the mean value of the kinetic energy of protons near the Sun's surface to calculate the temperature near its surface.

temperature near the Sun's surface _____ K

(3)

- (ii) Calculate the closest distance of approach for two protons near the Sun's surface.

closest distance of approach _____ m

(3)

- (iii) Explain why fusion cannot occur near the surface.

(3)

- (b) (i) Calculate the number of protons in each cubic metre of the Sun's core.

number of protons _____

(3)

- (ii) Calculate the density of the Sun's core.

density of the Sun's core _____ kg m⁻³

(2)

- (c) (i) Show that the data given in the passage in question (a) suggest that every second, about 4×10^{38} protons fuse to form helium nuclei.

(2)

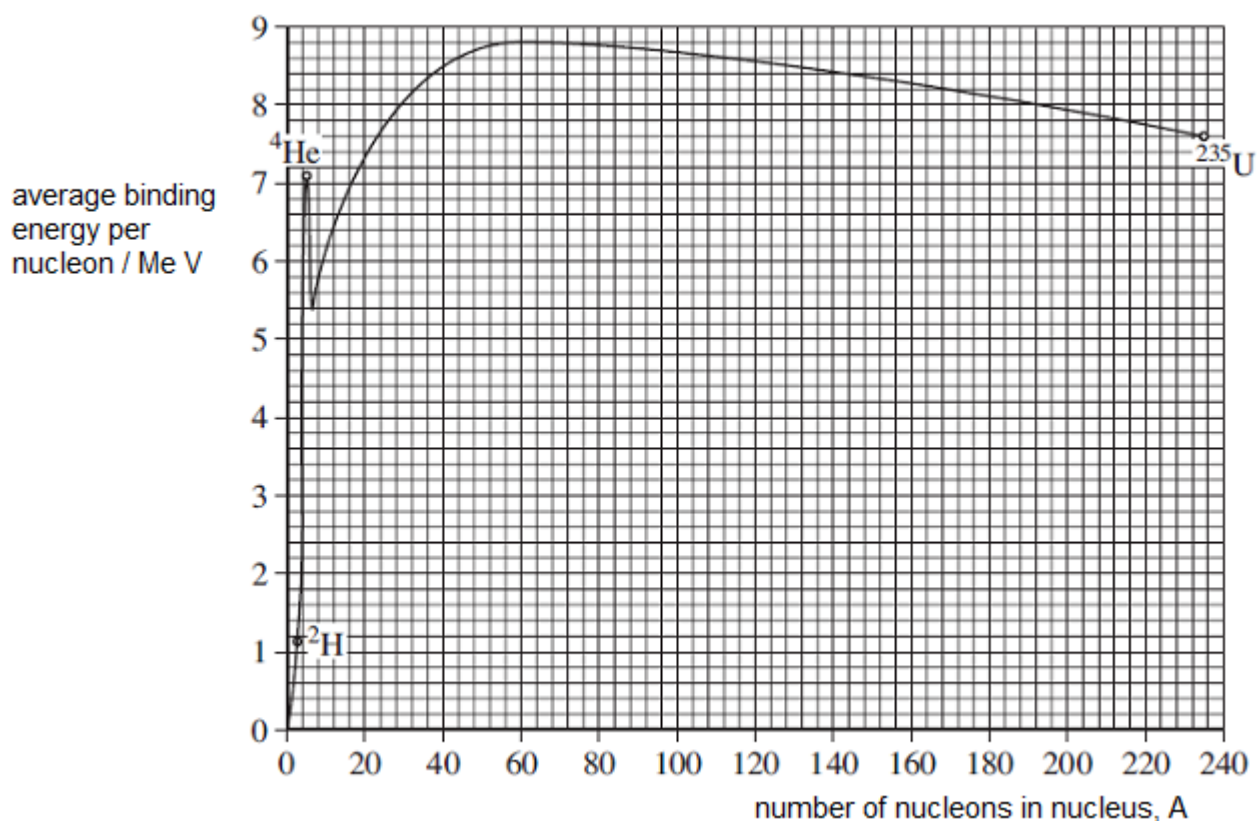
- (ii) The total binding energy of a helium nucleus is 4.5×10^{-12} J.
Determine with an appropriate calculation whether the mass that is converted into radiant energy, stated in the passage, is consistent with this value.

(4)

(Total 20 marks)

7

The figure below shows the variation in binding energy per nucleon with nucleon number.



- (a) A uranium-235, ${}^{235}\text{U}$, nucleus fissions into two approximately equally sized products. Use data from the graph to show that the energy released as a result of the fission is approximately $4 \times 10^{-11}\text{J}$. Show on the graph how you have used the data.

(4)

- (b) Using the data below, show that the energy available from the fusion of two hydrogen-2, ${}^2\text{H}$, nuclei to make a helium-4, ${}^4\text{He}$, nucleus is approximately $3.7 \times 10^{-12} \text{ J}$.

mass of ${}^2\text{H}$ = 2.0135 u

mass of ${}^4\text{He}$ = 4.0026 u

(4)

- (c) Compare the energy available from the complete fission of 1 kg of uranium-235 with the energy available from the fusion of 1 kg of hydrogen-2.

(3)

- (d) Fission and fusion reactions release different amounts of energy. Discuss other reasons why it would be preferable to use fusion rather than fission for the production of electricity, assuming that the technical problems associated with fusion could be overcome.

(2)

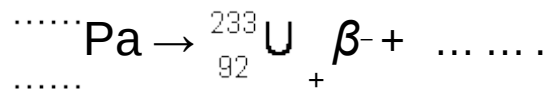
(Total 13 marks)

8

The fissile isotope of uranium, ${}_{92}^{233}\text{U}$, has been used in some nuclear reactors. It is normally produced by neutron irradiation of thorium-232. An irradiated thorium nucleus emits a β^- particle to become an isotope of protactinium.

This isotope of protactinium may undergo β^- decay to become ${}_{92}^{233}\text{U}$.

- (a) Complete the following equation to show the β^- decay of protactinium.



(2)

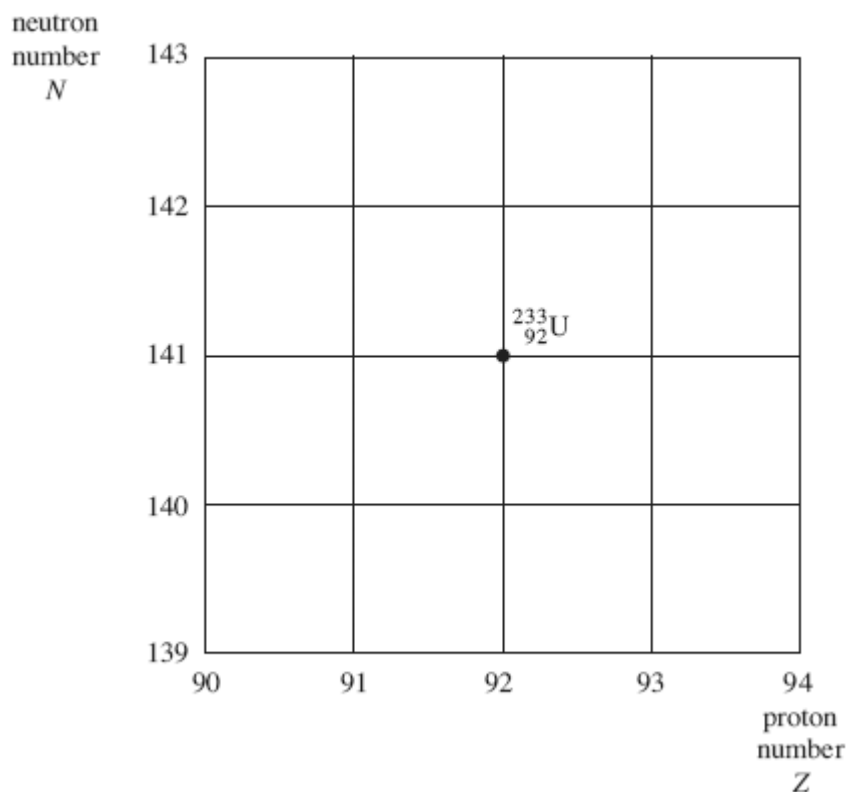
- (b) Two other nuclei, **P** and **Q**, can also decay into ${}_{92}^{233}\text{U}$.

P decays by β^+ decay to produce ${}_{92}^{233}\text{U}$.

Q decays by α emission to produce ${}_{92}^{233}\text{U}$.

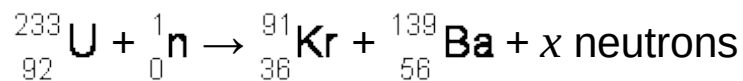
The figure below shows a grid of neutron number against proton number with the position of the ${}_{92}^{233}\text{U}$ isotope shown.

On the grid label the positions of the nuclei **P** and **Q**.



(2)

- (c) A typical fission reaction in the reactor is represented by



- (i) Calculate the number of neutrons, x .

answer = _____ neutrons

(1)

- (ii) Calculate the energy released, in MeV, in the fission reaction above.

mass of neutron = 1.00867 u

mass of ${}_{92}^{233}\text{U}$ nucleus = 232.98915 u

mass of ${}_{36}^{91}\text{Kr}$ nucleus = 90.90368 u

mass of ${}_{56}^{139}\text{Ba}$ nucleus = 138.87810 u

answer = _____ MeV

(3)

(Total 8 marks)

9

The table shows the binding energy per nucleon for two nuclei.

nucleus	binding energy per nucleon/ 10^{-12}J
helium-4	1.1332417
beryllium-8	1.1314027

- (a) (i) Explain what is meant by the total binding energy of a nucleus.

(1)

- (ii) It is more usual to quote binding energies of nucleons in MeV rather than J. Calculate the total binding energy, in MeV, of a beryllium-8 nucleus.

binding energy _____ MeV

(3)

- (b) (i) Calculate the change in mass that occurs when two helium-4 nuclei fuse to form a beryllium-8 nucleus.

mass change _____ kg

(2)

- (ii) Two helium-4 nuclei are initially separated by a large distance and are travelling toward one another. The helium nuclei become influenced by the strong force when their centres are separated by a distance of $3.82 \times 10^{-15} \text{ m}$. Calculate the total initial kinetic energy of the nuclei needed for them to reach this separation.

kinetic energy _____ J

(3)

- (iii) Explain why the kinetic energy calculated in part (b)(ii) will not enable the helium nuclei to fuse and produce a beryllium-8 nucleus.

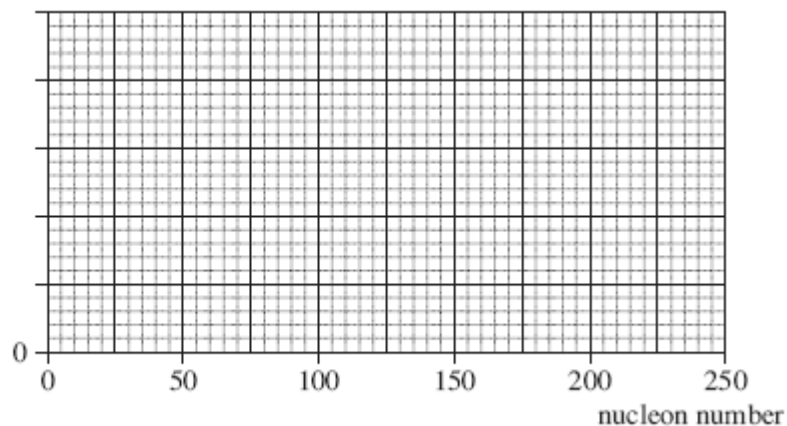
(3)

(Total 12 marks)

10

- (a) Sketch a graph of binding energy per nucleon against nucleon number for the naturally occurring nuclides on the axes given in the figure below. Add values and a unit to the binding energy per nucleon axis.

binding energy
per nucleon



(4)

- (b) Use the graph to explain how energy is released when some nuclides undergo fission and when other nuclides undergo fusion.

(3)

(Total 7 marks)

11

In the reaction shown, a proton and a deuterium nucleus, ${}^2_1\text{H}$, fuse together to form a helium nucleus, ${}^3_2\text{He}$



What is the value of Q, the energy released in this reaction?

mass of a proton = 1.00728 u

mass of a ${}^2_1\text{H}$ nucleus = 2.01355 u

mass of a ${}^3_2\text{He}$ nucleus = 3.01493 u

- A 5.0 MeV
- B 5.5 MeV
- C 6.0 MeV
- D 6.5 MeV

(Total 1 mark)

12

- (a) When a nucleus of uranium -235 fissions into barium -141 and krypton -92, the change in mass is 3.1×10^{-28} kg. Calculate how many nuclei must undergo fission in order to release 1.0 J of energy by this reaction.

(2)

- (b) A nuclear power station produces an electrical output power of 600 MW. If the overall efficiency of the station is 35%, calculate the decrease in the mass of the fuel rods, because of the release of energy, during one week of continuous operation.

(4)**(Total 6 marks)****13**

The mass of the nuclear fuel in a nuclear reactor decreases at a rate of 1.2×10^{-5} kg per hour. Assuming 100% efficiency in the reactor what is the power output of the reactor?

- A** 100 MW
- B** 150 MW
- C** 200 MW
- D** 300 MW

(Total 1 mark)

14

You may be awarded marks for the quality of written communication provided in your answers to part (a)

(a) In the context of an atomic nucleus,

(i) state what is meant by *binding energy*, and explain how it arises,

(ii) state what is meant by *mass difference*,

(iii) state the relationship between binding energy and mass difference.

(4)

- (b) Calculate the average binding energy per nucleon, in MeV nucleon⁻¹, of the zinc nucleus



$$\text{mass of } {}_{30}^{64}\text{Zn atom} = 63.92915 \text{ u}$$

$$\text{mass of proton} = 1.00728 \text{ u}$$

$$\text{mass of neutron} = 1.00867 \text{ u}$$

$$\text{mass of electron} = 0.00055 \text{ u}$$

(5)

- (c) Why would you expect the zinc nucleus to be very stable?

(1)

(Total 10 marks)

15

The fusion of two deuterium nuclei produces a nuclide of helium plus a neutron and liberates 3.27 MeV of energy. How does the mass of the two deuterium nuclei compare with the combined mass of the helium nucleus and neutron?

- A** It is 5.8×10^{-30} kg greater before fusion.
- B** It is 5.8×10^{-30} kg greater after fusion.
- C** It is 5.8×10^{-36} kg greater before fusion.
- D** It is 5.8×10^{-36} kg greater after fusion.

(Total 1 mark)

16

The mass of the beryllium nucleus, ${}^7_4\text{Be}$, is 7.01473 u. What is the binding energy **per nucleon** of this nucleus?

Use the following data:

mass of proton = 1.00728 u
 mass of neutron = 1.00867 u
 1u = 931.3 MeV

- A 1.6 MeV nucleon⁻¹
- B 5.4 MeV nucleon⁻¹
- C 9.4 MeV nucleon⁻¹
- D 12.5 MeV nucleon⁻¹

(Total 1 mark)

17

What is the binding energy of the nucleus ${}^{238}_{92}\text{U}$?

Use the following data:

mass of a proton = 1.00728 u

mass of a neutron = 1.00867 u

mass of a ${}^{238}_{92}\text{U}$ nucleus = 238.05076 u

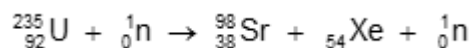
1 u = 931.3 MeV

- A 1685 MeV
- B 1732 MeV
- C 1755 MeV
- D 1802 MeV

(Total 1 mark)

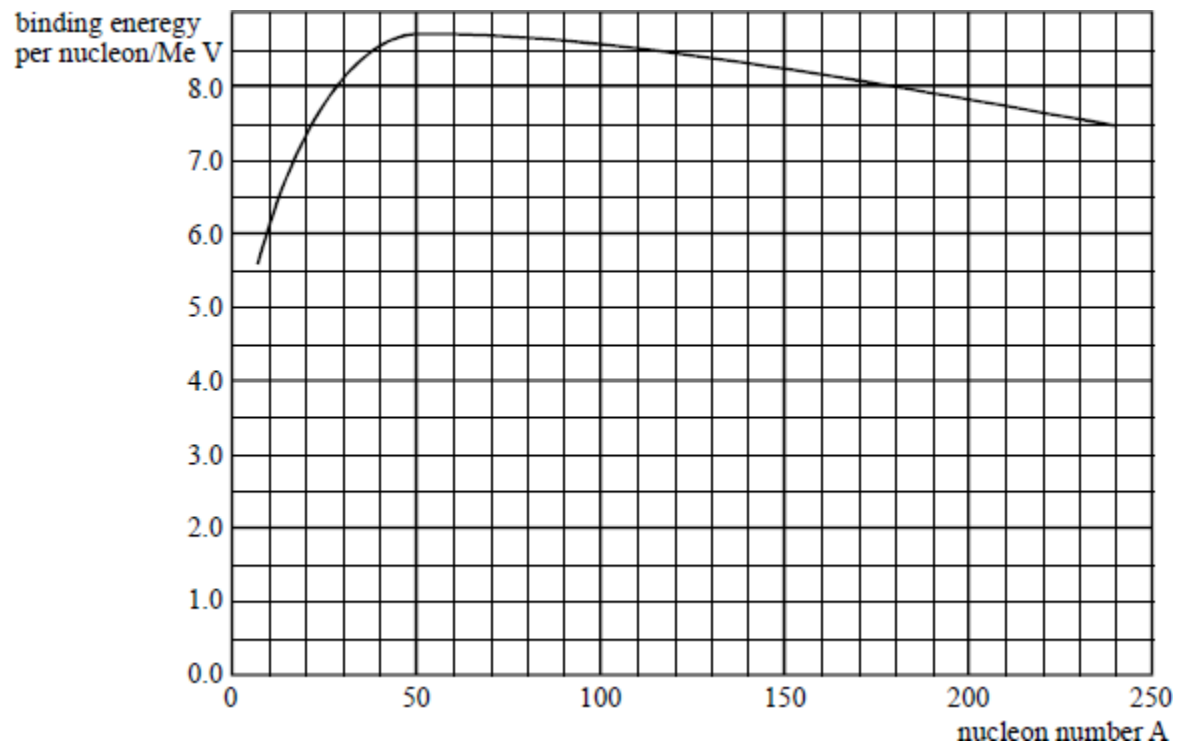
18

(a) (i) Complete the equation below which represents the induced fission of a nucleus of uranium ${}^{235}_{92}\text{U}$.



(ii) The graph shows the binding energy per nucleon plotted against nucleon number A.

Mark on the graph the position of each of the three nuclei in the equation.



(iii) Hence determine the energy released in the fission process represented by the equation.

(6)

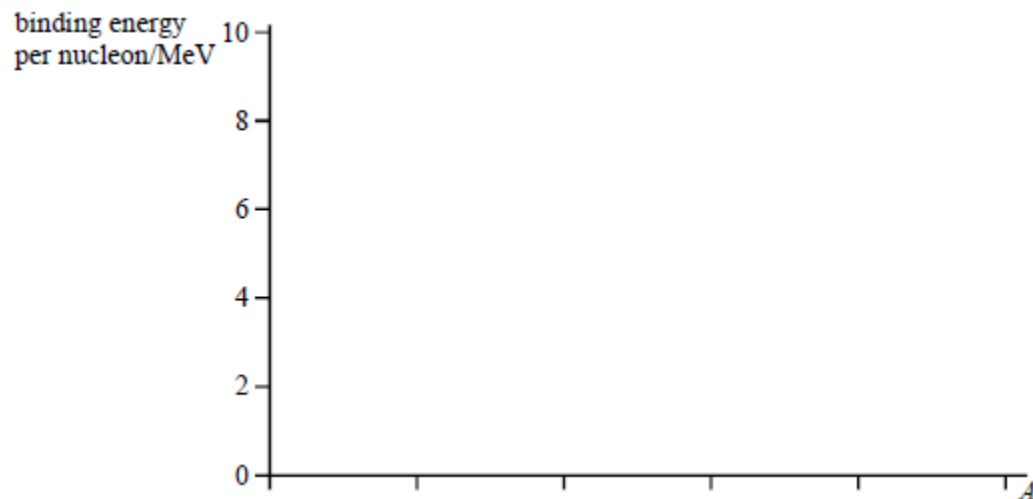
(b) (i) Use your answer to part (a)(iii) to estimate the energy released when 1.0 kg of uranium, containing 3% by mass of $^{235}_{92}\text{U}$, undergoes fission.

- (ii) Oil releases approximately 50 MJ of heat per kg when it is burned in air. State and explain **one** advantage and **one** disadvantage of using nuclear fuel to produce electricity.

advantage _____

disadvantage _____

(6)
(Total 12 marks)



- (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*.

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

(3)

(Total 6 marks)

What is the mass difference of the ${}^7_3\text{Li}$ nucleus?

Use the following data:

mass of a proton = 1.00728 u

mass of a neutron = 1.00867 u

mass of ${}^7_3\text{Li}$ nucleus = 7.01436 u

A 0.93912 u

B 0.04051 u

C 0.04077 u

D 0.04216 u

(Total 1 mark)

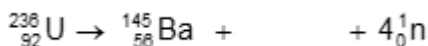
21

(a) The unstable uranium nucleus ${}^{238}_{92}\text{U}$ is produced in a nuclear reactor.

(i) Complete the equation which shows the formation of ${}^{238}_{92}\text{U}$.



(ii) ${}^{238}_{92}\text{U}$ can decay by nuclear fission in many different ways. Complete the equation which shows one possible decay channel.



(2)

(b) Calculate the energy released, in MeV, in the fission reaction.

atomic mass of ${}^{145}_{56}\text{Ba}$ = 144.92694 u

(3)

(Total 5 marks)

22

A small portion of the hydrogen in air is the isotope tritium ${}^3_1\text{H}$. This is continually being formed in the upper atmosphere by cosmic radiation so that the tritium content of air is constant. Tritium is a beta emitter with a half-life of 12.3 years.

(a) (i) Write down the symbols for the **two** isotopes of hydrogen, the atoms of which have lower masses than those of tritium.

(1)

- (ii) Write down the nuclear equation that represents the decay of tritium using the symbol **X** for the daughter nucleus.

(2)

- (iii) Calculate the decay constant for tritium in year^{-1} .

(1)

- (b) When wine is sealed in a bottle no new tritium forms and the activity of the tritium content of the wine gradually decreases with time. At one time the activity of the tritium in an old bottle of wine is found to be 12% of that in a new bottle. Calculate the approximate age of the old wine.

(3)

- (c)
- | | |
|--|---------------------------------------|
| mass of a tritium nucleus | = 3.016050 u |
| mass of a proton | = 1.007277 u |
| mass of a neutron | = 1.008665 u |
| atomic mass unit, u | = 1.660566×10^{-27} kg |
| speed of electromagnetic radiation in free space | = 3.0×10^8 m s ⁻¹ |

Calculate:

- (i) the mass change, in kg, when a tritium nucleus is formed from its component parts,

(2)

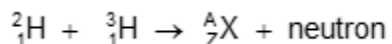
- (ii) the binding energy, in J, of a tritium nucleus.

(2)

(Total 11 marks)

23

Deuterium (${}^2_1\text{H}$) and tritium (${}^3_1\text{H}$) nuclei will fuse together, as illustrated in the equation below.



- (a) State the nucleon number and the proton number for the product of the reaction which has been written as X in the equation.

nucleon number _____

proton number _____

(2)

(b) The masses of the particles involved in the reaction are:

$$\text{mass of } {}^2_1\text{H} = 3.34250 \times 10^{-27} \text{ kg}$$

$$\text{mass of } {}^3_1\text{H} = 5.00573 \times 10^{-27} \text{ kg}$$

$$\text{mass of } {}^A_Z\text{X} = 6.62609 \times 10^{-27} \text{ kg}$$

$$\text{mass of neutron} = 1.67438 \times 10^{-27} \text{ kg}$$

(i) Explain why energy is released during this reaction.

(2)

(ii) Calculate the amount of energy released when a deuterium nucleus fuses with a tritium nucleus.

The speed of electromagnetic radiation, $c = 3.0 \times 10^8 \text{ m s}^{-1}$

(3)

(Total 7 marks)

Mark schemes

1

D

[1]

2

- (a) (i) Fission occurs at A values above the peak / above A of about 56 and fusion occurs at A values below the peak / below A of about 56 ✓

Fission is the splitting of a nucleus (into two smaller ones) *and* fusion is the joining of two nuclei ✓

First mark uses the graph so 'fission occurs in very large nuclei' does not gain a mark. (allow other interpretations that use the graph eg gradients)

2nd Mark splitting into 2 is not required for fission but if the answer implies something different like the separating of all the nucleons the mark may not be given.

2

- (ii) Energy is released when the binding energy (per nucleon) is increased ✓
fusion energy is greater as the increase in BE(/A) for fusion > increase in BE(/A) for fission (owtte) ✓

The last point can be given for a reference to the larger gradient at small values of A (fusion region) compared to the gradient at large values of A (fission region)

2

- (b) (i) $\Delta m = (8m_p + 8m_n) - M_{\text{oxygen}}$
mark for substituting data into the above equation in any workable consistent units

$$= 8(1.00867 + 1.00728) - 15.991 \quad \checkmark$$

$$(\Delta m = 0.1366 \text{ u})$$

$$\Delta m = 0.1366 \times 1.661 \times 10^{-27} = 2.3 \times 10^{-28} \text{ (kg)} \quad \checkmark$$

(range of answers 2.2 - $2.3 \times 10^{-28} \text{ kg}$)

Substitution may take the following form

$$8(1.673 \times 10^{-27}) + 8(1.675 \times 10^{-27}) - (15.991 \times 1.661 \times 10^{-27}) \quad \checkmark$$

$$= 2.23 \times 10^{-28} \text{ (kg)} \quad \checkmark$$

Correct answer gains full marks.

Look out for a physics error in which u is not taken as $1.661 \times 10^{-27} \text{ kg}$

2

- (ii) $E = m \times c^2 = 2.3 \times 10^{-28} \times (3.00 \times 10^8)^2 = 2.07 \times 10^{-11} \text{ J}$
 $BE = 2.07 \times 10^{-11} / 1.6 \times 10^{-13} = 130 \text{ (MeV)} \checkmark (129 \text{ MeV})$
 Or using
 using $\Delta m = 0.1366 \text{ u}$ (this must appear in b(i) for this approach)
 $BE = 0.1366 \times 931.3 = 130 \text{ (MeV)} \checkmark (127 \text{ MeV})$
CE is allowed but only if the calculation is shown
Note answer = b(i) $\times 5.625 \times 10^{29}$
answer only is acceptable for one mark.
(factor may be 931 or 931.5)

1

- (iii) read from the graph the BE/A for $^{16}_8\text{O}$ and multiply by the number of nucleons (or 16)
 $\checkmark$
 Or show the calculation
 $BE = 8(\text{Mev}) \times 16(\text{nucleons}) = 130 \text{ (MeV)} \checkmark (128 \text{ MeV}) \checkmark$
There must be a reference to $^{16}_8\text{O}$ position on the graph.
with the calculation allow $BE = 8.1(\text{Mev}) \times 16(\text{nucleons}) = 130 \text{ (MeV)}$
A calculation may lead to an answer in joule

1

[8]

3

- (a) (i) (Mass change in u) $1.71 \times 10^{-3} \text{ (u)}$
 or (mass Be-7) – (mass He-3) – (mass He-4) seen with numbers

C1

$$2.84 \times 10^{-30} \text{ (kg)}$$

or Converts their mass to kg

Alternative 2nd mark:

*Allow conversion of $1.71 \times 10^{-3} \text{ (u)}$ to MeV by
 multiplying by 931 (=1.59 (MeV)) **seen***

C1

Substitution in $E = mc^2$ *condone their mass difference in
 this sub but must have correct value for c^2 (3×10^8)² or 9×10^{16}*

Alternative 3rd mark:

*Allow their MeV converted to joules ($\times 1.6 \times 10^{-13}$) **seen***

C1

$$2.55 \times 10^{-13} \text{ (J)} \text{ to } 2.6 \times 10^{-13} \text{ (J)}$$

Alternative 4th mark:

Allow $2.5 \times 10^{-13} \text{ (J)}$ for this method

A1

(ii)	Use of $E=hc/\lambda$ ecf	
		C1
	Correct substitution in rearranged equation with λ <i>subject</i> ecf	
		C1
	7.65×10^{-13} (m) to 7.8×10^{-13} (m) ecf	
		A1
		3
(b)	(i) Use of E_p formula:	
		C1
	Correct charges for the nuclei and correct powers of 10	
		C1
	$2.6(3) \times 10^{-13}$ J	
		A1
		3
	(ii) Uses $KE = 3/2 kT$: or halves KE_T , $KE = 1.3 \times 10^{-13}$ (J) seen ecf	
		C1
	Correct substitution of data and makes T subject ecf Or uses KE_T value and divides T by 2	
		C1
	6.35×10^9 (K) or 6.4×10^9 (K) or 6.28×10^9 (K) or 6.3×10^9 (K) ecf	
		A1
		3
(c)	(i) Deuteron / deuterium / hydrogen-2	
		B1
	Triton / tritium / hydrogen-3	
		B1

- (ii) Electrical heating / electrical discharge / inducing a current in plasma / use of e-m radiation / using radio waves (causing charged particles to resonate)

B1

1

[16]

4

- (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) $2\text{}^1_0\text{n}$ or $\text{}^1_0\text{n} + \text{}^1_0\text{n}$ ✓

must see subscript and superscripts

1

- (ii) binding energy of U
= 235×7.59 ✓ (= 1784 (MeV))
binding energy of Tc and In
= $112 \times 8.36 + 122 \times 8.51$ ✓
(= 1975 (MeV))
energy released (= $1975 - 1784$) = 191 (MeV) ✓ (allow 190 MeV)

1st mark is for 235×7.59 seen anywhere

2nd mark for $112 \times 8.36 + 122 \times 8.51$ 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
 $= 191 \times 1.60 \times 10^{-13} \checkmark$
 $(= 3.06 \times 10^{-11} \text{ J})$
 loss of mass $(= E / c^2)$
 $= 2.91 \times 10^{-11} / (3.00 \times 10^8)^2$
 $= 3.4 \times 10^{-28} \text{ (kg)} \checkmark$
 or
 $= 191 / 931.5 \text{ u} \checkmark (= 0.205 \text{ u})$
 $= 0.205 \times 1.66 \times 10^{-27} \text{ (kg)}$
 $= 3.4 \times 10^{-28} \text{ (kg)} \checkmark$

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) $\times 1.78 \times 10^{-30}$

(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
 $Z = 80, N = 110 \rightarrow 130 \checkmark$

initial gradient should be about 1 (ie $Z = 20$; $N = 15 \rightarrow 25$) 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 $\checkmark$
 fission fragments are (likely) to have a larger N / Z ratio than stable nuclei
 or
 fission fragments are neutron rich owtte $\checkmark$
 and become neutron or β^- emitters $\checkmark$

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

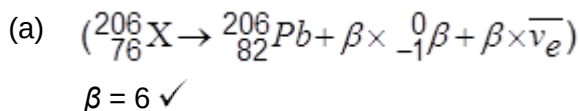
3rd mark beta minus

note not just beta

3

[12]

5



1

- (b) (i) the energy **required** to split up the nucleus ✓
 into its individual neutrons and protons/nucleons ✓
 (or the energy **released** to form/hold the nucleus ✓
 from its individual neutrons and protons/nucleons ✓)
- 2
- (ii) $7.88 \times 206 = 1620 \text{ MeV}$ ✓ (allow 1600-1640 MeV)
- 1
- (c) (i) U, a graph starting at 3×10^{22} showing exponential fall passing through
 0.75×10^{22} near 9×10^9 years ✓
 Pb, inverted graph of the above so that the graphs cross at 1.5×10^{22} near
 4.5×10^9 years ✓
- 2
- (ii) (u represents the number of uranium atoms then)
- $$\frac{u}{3 \times 10^{22} - u} = 2$$
- $$u = 6 \times 10^{22} - 2u \quad \checkmark$$
- $$u = 2 \times 10^{22} \text{ atoms}$$
- 1
- (iii) (use of $N = N_0 e^{-\lambda t}$)
- $$2 \times 10^{22} = 3 \times 10^{22} \times e^{-\lambda t} \quad \checkmark$$
- $$t = \ln 1.5 / \lambda$$
- (use of $\lambda = \ln 2 / t_{1/2}$)
- $$\lambda = \ln 2 / 4.5 \times 10^9 = 1.54 \times 10^{-10} \quad \checkmark$$
- $$t = 2.6 \times 10^9 \text{ years} \quad \checkmark \text{ (or } 2.7 \times 10^9 \text{ years)}$$
- 3

6

- (a) (i) Attempt to use $KE = \frac{3}{2} kT$ expect $0.75 = \frac{3}{2} \times 1.38 \times 10^{-23} T$

C1

Or correct conversion to J $0.75 \times 1.6 \times 10^{-19}$

Correct equations $0.75 \times 1.6 \times 10^{-19} = \frac{3}{2} 1.38 \times 10^{-23} T$

C1

5800 K

A1

3

- (ii) Attempt to use energy = $qQ/4\pi\epsilon_0 r$

C1

arrives at $1.9(2) \times 10^{-9}$ or uses (2×0.75) or twice candidate's energy from (i)

C1

$9.6 \times 10^{-10} \text{ m}$

A1

3

- (iii) For fusion nuclei have to touch or separation has to be nuclear diameter

energy has to be sufficient to overcome the nuclear repulsion (between protons)

B1

Close enough for nuclear strong force to act

B1

answer to 4 a (ii) is much greater than 10^{-15} m

B1

or is greater than atomic radius

or is greater than the range of the strong force

3

(b) (i) Use of $pV=NkT$

C1

(Allow incorrect powers of 10 or rearrangement to make N subject)

$$1 \times 10^{16} \times 1 = N \times 1.38 \times 10^{-23} \times 1.5 \times 10^6$$

C1

$$4.8 (3) \times 10^{32}$$

A1

3

(ii) 1.67×10^{-27} or 1.7×10^{-27} used

C1

$$8.0 - 8.2 \times 10^5 \text{ (kg m}^{-3}\text{)} \text{ Allow ecf for } N \text{ from (b)(i)}$$

A1

2

(c) (i) Number of protons = moles of proton/mass of protons / Mass per second $\times$ Avogadro constant used

B1

Or

$$\text{No of protons} = \text{mass per second} / \text{proton mass}$$

(allow if numerical equation seen with a subject)

$$4.18 \text{ or } 4.19 \text{ or } 4.21 \times 10^{38} \text{ correct to at least 2 sf from correct working}$$

B1

2

(ii) Attempt to use $E = mc^2$ with any mass and substitution for c

C1

Energy radiated = $5 \times 10^9 \times c^2$ energy radiated 4.5×10^{26} J

A1

Number of helium nuclei formed = 1.05×10^{38} (allow 1×10^{39})

B1

Approximate BE per nucleon from article = $4.28(4.5) \times 10^{-12}$ J

B1

(Which is consistent)

4

[20]

7

(a) Draws appropriate triangle on graph or other mark on graph at ~ 118

B1

Change of approx 1 Me V per nucleon is multiplied by 235

B1

Multiplies by 1.6×10^{-13}

B1

Quotes their answer of approx 3.8×10^{-11} to more than 2 sf

B1

4

(b) $(2 \times 2.0135) - 4.0026$ seen or 0.0244 (u)

C1

Multiplies u by 1.7×10^{-27}

C1

$E = mc^2$ seen or multiplies by $(3 \times 10^8)^2$

C1

3.67×10^{-12} J

A1

4

(c) Multiplies 3.8×10^{-11} or their (b) by 6×10^{23}

M1

attempts to convert to energy per kg by multiplying by 1000 / 4 or 1000 / 235

M1

Compares 5.5×10^{14} (J) (Hydrogen) with 9.6×10^{13} (J) (Uranium) in some way eg by stating that the fusion reaction gives more energy (per kg) than the fission or very similar values – must be consequent on some correct analysis

A1

3

(d) Availability of fuel easier for fusion

B1

Doesn't produce radioactive fission products / no waste management problem

B1

2

[13]

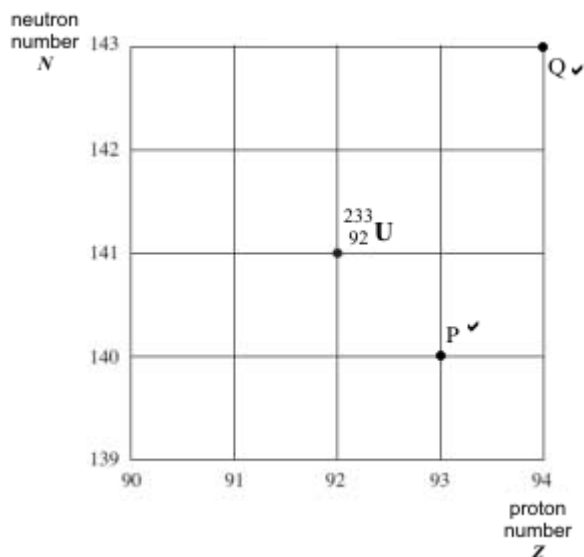
8

(a) ${}_{91}^{231}\text{Pa}$ ✓

anti (electron) neutrino ✓

2

(b)



2

(c) (i) $x = 4$ ✓✓

1

(ii) mass defect = $[(232.98915 + 1.00867) - (90.90368 + 138.87810 + 4 \times 1.00867)] \text{ u}$ ✓✓

= 0.18136 u ✓✓

3

energy released (= 0.18136×931) = 169 (MeV) ✓✓

[8]

9

(a) (i) energy released when the separate nucleons combine to form the nucleus

or energy needed to separate the nucleus into individual nucleons
owtte

B1

1

(ii) BE in J = $8 \times 1.1314027 \times 10^{-12}$ (9.05122×10^{-12})

C1

BE in eV = 5.6570135×10^7 eV or BE/nucleon
= 7.07×10^6 MeV

C1

56.570135 (MeV) (condone 3 sf consistent with electron charge)

A1

3

(b) (i) change in BE = $0.0147120 (\times 10^{-12}) \text{ J}$

C1

use of $E = mc^2$ with their energy $1.635 \times 10^{-31} \text{ kg}$

A1

2

(ii) use of charge on alpha particles = 2 e

C1

attempt to substitute in $PE = \frac{qQ}{4\pi\epsilon_0 r}$

C1

$$2.4(2.39) \times 10^{-13} \text{ J}$$

A1

3

(ii) the mass of Be > mass of 2 He nuclei

B1

explains that when they touch there is zero KE
only mass available is that of the two alpha particles

B1

extra KE provides the increase in mass of the beryllium-8
compared with the 2 He nuclei

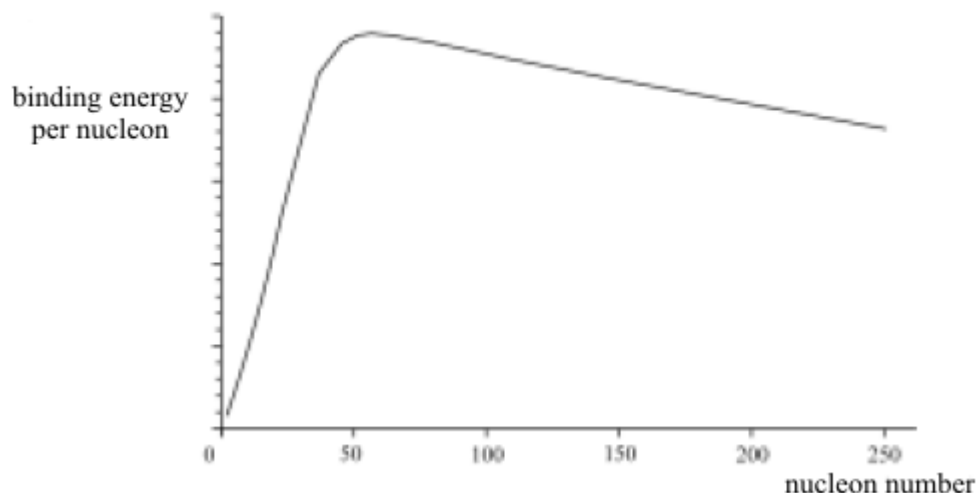
B1

3

[12]

10

(a)



peak 8.7 (accept 8.0 – 9.2)

in MeV ✓

(or peak 1.4×10^{-12} accept $1.3 - 1.5 \times 10^{-12}$ in J ✓)

at nucleon number 50 – 60 ✓ accept 50 – 75

sharp rise from origin and moderate fall not below 2/3 of peak height ✓

4

- (b) energy is released/made available when binding energy **per nucleon** is increased ✓

in fission a (large) nucleus splits and in fusion (small) nuclei join ✓

the most stable nuclei are at a peak

fusion occurs to the left of peak and fission to the right ✓

max 3

[7]

11

B

[1]

12

- (a) for one reaction $\Delta E (= \Delta m c^2) = 3.1 \times 10^{-28} \times (3.00 \times 10^8)^2$ (1)
 $= (2.79 \times 10^{-11} \text{ J})$

$$\text{number of nuclei required} = \frac{1}{2.79 \times 10^{-11}} = 3.5(8) \times 10^{10} \text{ (1)}$$

[or equivalent credit for any other valid method]

2

(b) output power from reactor = $\frac{600}{0.35} = 1700$ (MW) **(1)**
 (1714 MW)

energy output from fuel rods in one week
 = $1.70 \times 10^9 \times 24 \times 7 \times 3600$ **(1)**

(= 1.03×10^{15} J)

$\Delta m \left(= \frac{\Delta E}{c^2} \right) = \frac{1.03 \times 10^{15}}{(3.0 \times 10^8)^2}$ **(1)**

= 1.14×10^{-2} kg **(1)**

[or equivalent credit for any other valid method]

4

[6]

13

D

[1]

14

(a) (i) energy $\left(\begin{array}{l} \text{required to break nucleus up into} \\ \text{released when nucleus is formed from} \end{array} \right)$ separate nucleons **(1)**

$\left(\begin{array}{l} E_p \text{ of nucleons decreases when they come together} \\ \text{work is done on nucleons by the strong force} \end{array} \right)$ **(1)**

energy associated with the strong force **(1)**

(ii) mass of nucleus < total mass of constituent nucleons **(1)**
 Δm is difference between mass of nucleus and total mass of nucleons **(1)**
 $[\Delta m = Zm_p + (A - Z)m_n - m_{\text{nucleus}}$ **(1) (1)**]

$E_b = (\Delta m)c^2$ **(1)**

[or E_b is energy equivalent of mass defect using $E = mc^2$]

max 4
 QWC 1

(b) mass of nucleus = $63.92915 - (30 \times 0.00055) = 63.91265$ (u) **(1)**
 $\Delta m = (30 \times 1.00728) + (34 \times 1.00867) - 63.91265$ **(1)**
 = 0.60053 (u) **(1)**
 $E_b = 0.60053 \times 931.3 = 559.3$ (MeV) **(1)**

$E_b/\text{nucleon} = \frac{559.3}{64} = 8.74$ (MeV/nucleon) **(1)**

(allow C.E. for Δm and E_b)

5

- (c) nucleus has high value of $E_b/\text{nucleon}$
[or is near maximum of $E_b/\text{nucleon}$ vs A curve] **(1)**

1

[10]

15

A

[1]

16

B

[1]

17

C

[1]

18

- (a) (i) ${}^{235}_{92}\text{U} + {}^1_0\text{n} \rightarrow {}^{98}_{38}\text{Sr} + {}^{135}_{54}\text{Xe} + 3{}^1_0\text{n} (+Q)$ **(1)**
- (ii) three correct positions to within ± 2 on x-axis **(1) (1)** (one mark if two correct)
- (iii) *estimate of energy released:*
 binding energy of U-235 nucleus = $(235 \times 7.5) = 1763(\pm 15)(\text{MeV})$ **(1)**
 binding energy of Sr-98 = $(98 \times 8.6) = 843(\pm 15)(\text{MeV})$ **(1)**
 binding energy of Xe-135 = $(135 \times 8.4) = 1134(\pm 15)(\text{MeV})$ **(1)**
 binding energy released = $1134 + 843 - 1763 = 214\text{MeV}$ **(1)**
 $(\pm 40\text{MeV})$

max 6

- (b) (i) 235g of U-235 releases $6 \times 10^{23} \times 214 \times 1.6 \times 10^{-13} \text{ J} = 2.1 \times 10^{13} \text{ (J)}$ **(1)**
 1.0 kg of uranium containing 3% U-235 contains 30g of U-235 **(1)**

energy from 1.0kg of uranium = $\frac{2.1 \times 10^{13} \times 30}{235} = 2.6 \times 10^{12} \text{ J } [[1.6 \times 10^{25} \text{ MeV}]]$
(1)

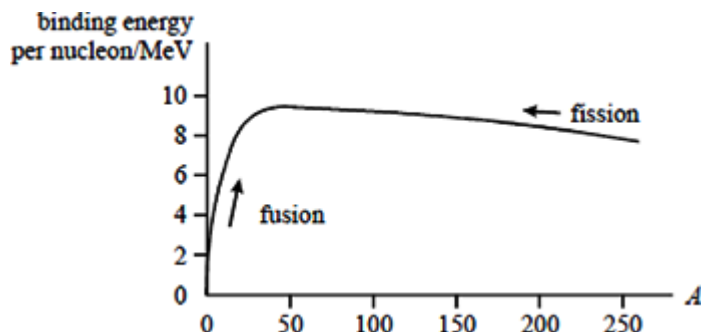
- (ii) *advantage:*
 less mass of fuel used **(1)** because more energy per kilogram **(1)**
 [alternative: less harm to environment **(1)** because does not generate greenhouse gases **(1)**
 or any statement **(1)** argued **(1)**]
disadvantage:
 hazardous waste **(1)** because fission products are radioactive **(1)**
 [alternative: long term responsibility **(1)** because waste needs to be stored for many years **(1)**
 or any statement **(1)** argued **(1)**]

max 6

[12]

19

(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
to this question.

[6]

20

D

[1]

21

- (a) (i) ${}_0^1\text{n} + {}_{92}^{235}\text{U} \rightarrow {}_{92}^{236}\text{U}$ **(1)**

- (ii) ${}_{92}^{235}\text{U} \rightarrow {}_{56}^{145}\text{Ba} + {}_{36}^{87}\text{Kr} + 4{}_0^1\text{n}$ **(1)**

(2)

- (b) ($\Delta m = m_u - m_{\text{Ba}} - m_{\text{Kr}} - 4m_n$, electron masses balance)
 $\Delta m = 236.04573 - 144.92694 - 86.91340 - 4 \times 1.00867$ **(1)**
 $= 0.17071 \text{ u}$ **(1)**
 $Q (= 0.17071 \times 931.3 \text{ MeV}) = 159(\text{MeV})$ **(1)**

(3)

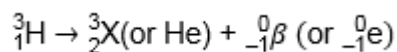
[5]

22

(a) (i) ${}^1_1\text{H}$ and ${}^2_1\text{H}$ **or** ${}^1_1\text{H}$ and ${}^2_1\text{D}$ condone H^1_1 etc

B1
(1)

(ii) ${}^3_1\text{H} \rightarrow \text{X} + \beta$



M0

Z correct throughout

A1

A correct throughout

A1
(2)

(iii) 0.056(4) (no unit penalty)

B1
(1)

(b) $A = A_0 e^{-\lambda t}$

C1

$12 = 100e^{-\lambda t}$ or other progress toward answer

C1

38 (40) y *allow e.c.f. from (iii)*

A1

or evidence of working in half-lives

C1

statement that age is $3 \times T_{\frac{1}{2}}$

C1

age ≈ 37 y

A1

or $A = N_0 e^{-\lambda t}$ (using **incorrect** formula from sheet)

C1

$$\lambda N = N_0 e^{-\lambda t} \text{ and } \frac{N}{N_0} = 0.12 \text{ or } \frac{A}{A_0} = 0.12$$

C1

$t = 89$ y

A1
(3)

- (c) (i) (mass of proton + 2 × mass of neutron – mass of tritium) = 0.0086 u

B1

multiplies any mass in u by 1.660566×10^{-27}

A1

$$1.42 \times 10^{-29} \text{ kg}$$

(no significant figure penalty) (no unit penalty) (condone –ve answer)

(2)

- (ii) $E = mc^2$

C1

$$E = 1.28 \times 10^{-12} \text{ J}$$

(no unit penalty) (allow e.c.f. from (i) for m in kg) (condone –ve answer)

A1

or using recall of $u = 931 \text{ MeV}$

$$\text{energy change in MeV} = 8.557 \times 931 = 7.97 \text{ MeV}$$

C1

$$\text{energy change in J} = 7.97 \times 1.6 \times 10^{-19} = 1.27 \times 10^{-12} \text{ J}$$

A1

(2)

[11]

23

- (a) nucleon number 4

B1

proton number 2

B1

(2)

- (b) (i) mass of products is less than mass of reactants / binding energy per nucleon increases / mass defect increases / 'loss' of mass

B1

change in mass converted to energy

B1

(2)

- (ii) change in mass = $4.8 \times 10^{-29} \text{ kg}$

C1

$$E = mc^2$$

C1

$$4.3 \times 10^{-12} \text{ J} (4.30 \times 10^{-12} \text{ J})$$

(if truncated sig. figs used only 2nd mark available)

A1

(3)

[7]