PRESTON
MANOR

A Level Physics Exam Packs

Nuclear Physics

Name:

Form:

Question	Mark

8 **(a)** The following nuclear reaction occurs when a slow-moving neutron is absorbed by an isotope of uranium-235.

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

(i) Explain how this reaction is able to produce energy.

....

....

.... **[2]**

(ii) State in what form the energy is released in such a reaction.

.... **[1]**

(b) The binding energy per nucleon of each isotope in **(a)** is given in Fig. 8.1.

isotope	binding energy per nucleon/MeV
$^{235}_{92}U$	7.6
$^{141}_{56}Ba$	8.3
$^{92}_{36}Kr$	8.7

Fig. 8.1

(i) Explain why the neutron $^{1}_{0}n$ does not appear in the table above.

....

.... **[1]**

(ii) Calculate the energy released in the reaction shown in **(a)**.

energy = ... MeV **[2]**

[Total: 6]

Question			Expected Answers	Marks	Additional Guidance
8	a	(i)	mass of uranium is greater than (the sum of) the mass of the products	M1	
			$E = \Delta mc^2$	A1	
			OR		
			binding energy of the products is greater than that of uranium	M1	
			energy available is the difference between the binding energies of uranium and the sum of the products	A1	
		(ii)	kinetic energy	B1	
	b	(i)	the neutron is a single nucleon / cannot be split further / no binding has occurred	B1	The neutron is not bound to anything
		(ii)	binding energy of uranium = 235 x 7.6 =1786		An answer of 9.4 (not using the number of nucleons) scores zero
			binding energy of products = 141 x 8.3 + 92 x 8.7	C1	
			= 1170.3 + 800.4		
			energy available = 184.7 (MeV)	A1	Allow ≥ 2 sf (180, 185, 184.7) Penalise 184 as an AE
			Total	**[6]**	

6 **(a)** In experiments carried out to determine the nature of atoms, alpha particles were fired at thin metal foils. Describe how the alpha-particle scattering experiments provide evidence for the existence, charge and size of the nucleus.

In your answer, you should make clear how your conclusions link with your observations.

.... [5]

(b) Describe the nature and range of the **three** forces acting on the protons and neutrons in the nucleus.

.... [5]

(c) The radius of a $^{235}_{92}U$ nucleus is 8.8×10^{-15} m. The average mass of a nucleon is 1.7×10^{-27} kg.

(i) Estimate the average density of this nucleus.

density = ... $kg\,m^{-3}$ **[3]**

(ii) State one assumption made in your calculation.

....

.... **[1]**

[Total: 14]

Question			Expected Answers	Marks	Additional guidance
6	(a)		Any <u>four</u> from 1 to 5: 1. Most of the alpha particles went straight through (some deviated through small angles) 2. Hence most of the atom is empty space 3. Some / a very small number of alpha particles were scattered / repelled through large angles / angles more than 90° 4. This showed the existence of (a tiny) positive nucleus 5. The size of the nucleus is about 10^{-14} <u>m</u>	B1×4	**Must use ticks on Scoris to show where the marks are awarded** **Allow**: 10^{-15} <u>m</u>
			✐ QWC: Award a mark for one conclusion correctly linked to an observation	B1	
	(b)		Any <u>five</u> from: Gravitational (force)	M1	**Allow:** gravity
			This force is attractive **AND** is long-ranged / obeys '$1/r^2$ relationship'	A1	**Note**: Do not allow 'inverse square law'; allow 'inverse square law with distance'
			<u>Strong</u> (nuclear force/interaction)	M1	
			This force is attractive (at larger distances) or repulsive at short distances **AND** is short-ranged / ~ 10^{-14} m	A1	
			Electrostatic / electrical (force) / coulomb (force)	M1	**Allow:** Electromagnetic (interaction/force)
			This force is repulsive between protons / zero between neutrons / zero between protons and neutrons **AND** is long-ranged / obeys '$1/r^2$ relationship'	A1	

Question			Expected Answers	Marks	Additional guidance
	(c)	(i)	mass = $235 \times 1.7 \times 10^{-27}$ (= 3.995×10^{-25} kg) volume = $\frac{4}{3}\pi \times (8.8 \times 10^{-15})^3$ (= 2.855×10^{-42} m^3) density = mass/volume density = 1.4×10^{17} (kg m^{-3})	C1 C1 A1	**Allow:** 1.66×10^{-27} kg for mass of nucleon **Allow:** 10^{17} (kg m^{-3}) for this estimation question **Note:** Omitting 235 gives 6.0×10^{14} (kg m^{-3}), allow 2 mark **Allow:** 1 mark if 92 or 143 is used to determine the mass of the nucleus; this gives a density value of 5.5×10^{16} (kg m^{-3}) and 8.5×10^{16} (kg m^{-3}) respectively
		(ii)	The nucleons / neutrons and protons are packed together with little or no empty space (AW)	B1	
			Total	14	

9 **(a)** **(i)** Complete Fig. 9.1 to show the quark composition and charge for neutrons and protons.

	quark composition	charge
neutron		
proton		

Fig. 9.1

[2]

(ii) Complete Fig. 9.2 to show the composition of quarks.

quark	charge	baryon number	strangeness
up		+ 1/3	
down			0

Fig. 9.2

[2]

(b) When a neutron decays it can produce particles that include an electron.

(i) Complete the decay equation below for a neutron.

$^{1}_{0}n \rightarrow$

[2]

(ii) Name the interaction responsible for the decay of the neutron.

.... **[1]**

(iii) Electrons and neutrons belong to different groups of particles. Name the group of particles to which each belongs.

electrons ....

neutrons .... **[1]**

[Total: 8]

10 (a) Describe the process of induced nuclear fission.

....

....

....

....

.... [2]

(b) Explain how nuclear fission can provide energy.

....

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....

.... [2]

(c) Suggest a suitable material which can be used as a moderator in a fission reactor and explain its role.

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.... [3]

[Total: 7]

END OF QUESTION PAPER

Question			Expected Answers	Marks	Additional guidance
10	(a)		A neutron is absorbed by a (massive / uranium) nucleus The nucleus splits into two (smaller/daughter) nuclei and (one or more) neutrons	B1 B1	
	(b)		In a fission reaction there is a decreases in the mass (According to $\Delta E = \Delta mc^2$) mass is converted into energy Or The (total) binding energy of the products / smaller nuclei is greater than the binding energy of the original nucleus The difference in the binding energies is released as energy	M1 A1 M1 A1	 **Allow:** The 'BE increases (in the reaction)'
	(c)		Moderator: water / graphite / carbon It slows down the (fast-moving) neutrons / reduces the (kinetic) energy of neutrons Slow-moving neutrons have greater chance of causing fission (than fast-moving neutrons)	B1 B1 B1	**Note**: If boron is mentioned, then do not award this B1 mark **Allow**: They become thermal neutrons
			Total	**7**	

Question			Expected Answer	Mark	Additional Guidance
9	(a)	(i)	composition for n and p: u d d & u u d charge for n and p: 0 & +1	B1 B1	**Allow**: charge 'e' instead of '+1' or '1'
		(ii)	up +2/3 **(+1/3)** 0 down -1/3 +1/3 **(0)**	B1 B1	**Allow**: charges in terms of 'e'
	(b)	(i)	${}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e + \overline{\nu}$	A2	**Allow**: '→ proton + electron + <u>anti</u>neutrino' **Note**: -1 for any omission or error. Score = 0 if more than one error
		(ii)	weak (nuclear)	B1	
		(iii)	lepton(s) <u>and</u> hadron(s) / baryons(s)	B1	**Not**: Neutrons are mesons
			Total	8	

(f) The isotope of carbon-14 is very useful in determining the age of a relic (e.g. ancient wooden axe) using a technique known as carbon-dating.
Describe carbon-dating and explain one of its major limitations.

.... **[4]**

[Total: 17]

6 **(a)** Explain the term *binding energy* of a nucleus.

.... **[2]**

(b) Nuclear fusion takes place in the core of the Sun. One of the simplest fusion reactions is shown below.

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

(i) The binding energy per nucleon of ${}^{2}_{1}H$ is 1.8×10^{-13} J and the binding energy per nucleon of ${}^{4}_{2}He$ is 1.1×10^{-12} J. Show that the energy released in the reaction is 3.7×10^{-12} J.

[2]

(ii) The Sun radiates its energy uniformly through space. The mean intensity of the Sun's radiation reaching the Earth's atmosphere is about $1400\,\mathrm{W\,m^{-2}}$. The mean radius of the Earth's orbit round the Sun is 1.5×10^{11} m.

1 Show that the mean power radiated from the surface of the Sun is 4.0×10^{26} W.

[2]

2 Assume all the radiated energy from the Sun comes from the fusion reaction shown in **(b)**. Estimate the number of helium-4 nuclei produced every second by the Sun.

number = ... s^{-1} **[2]**

[Total: 8]

Question			Answers	Marks	Guidance
6	(a)		(Minimum) energy to separate (all) nucleons / protons <u>and</u> neutrons (of a nucleus)	M1 A1	**Alternative:** B.E. = mass <u>defect</u> × c^2 M1 mass defect = mass of nucleons – mass of nucleus A1
	(b)	(i)	BE of ^{2}H = 2 × 1.8 × 10^{-13} (J) or BE of ^{4}He = 4 × 1.1 × 10^{-12} (J) energy = (4 × 1.1 × 10^{-12}) – 2 × (2 × 1.8 × 10^{-13}) energy = 3.68 × 10^{-12} (J) / 3.7 × 10^{-12} (J)	C1 C1 A0	**Note**: Ignore signs
		(ii)1	total surface area = 4π × (1.5 × 10^{11})^2 power = 1400 × (2.83× 10^{23}) power = 3.96 × 10^{26} (W) / 4.0 × 10^{26} (W)	C1 C1 A0	
		(ii)2	number = 4.0 × 10^{26}/3.7 × 10^{-12} number = 1.1 × 10^{38} (s^{-1}) or 1.08 × 10^{38} (s^{-1})	C1 A1	**Allow**: 10^{38} (s^{-1}) because the question is about an estimate
			Total	**8**	

6 The nuclear reaction represented by the equation

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{94}_{39}Y + ^{139}_{53}I + 3\,^{1}_{0}n$$

takes place in the core of a nuclear reactor at a power station.

(a) Describe how this reaction can lead to a chain reaction.

....

....

.... [1]

(b) Explain the role of fuel rods, control rods and a moderator in a nuclear reactor.

In your answer you should make clear how chain reactions are controlled in the reactor.

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.... [5]

(c) In the nuclear reactor of a power station, each fission reaction of uranium produces 3.2×10^{-11} J of energy. The electrical power output of the power station is 3.0 GW. The efficiency of the system that transforms nuclear energy into electrical energy is 22%. Calculate

(i) the total power output of the reactor core

power output = ... W **[1]**

(ii) the total energy output of the reactor core in one day

1 day = 8.64×10^4 s

energy output = ... J **[1]**

(iii) the mass of uranium-235 converted in one day. The mass of a uranium-235 nucleus is 3.9×10^{-25} kg.

mass = ... kg **[2]**

(d) Discuss the physical properties of nuclear waste that makes it dangerous.

....

....

....

.... **[2]**

[Total: 12]

Question			Answer	Marks	Guidance
6	(a)		The neutrons interact with other uranium (nuclei) / the neutrons cause further (fission) reactions	B1	**Not**: neutrons interact with uranium atoms / molecules / particles
	(b)		**Fuel rod**: Contain the uranium (nuclei) / fissile material **Control rods**: Absorb (some of the) neutrons *Controlled chain reaction*: The control rods are inserted into the reactor so as to allow (on average) one neutron from previous reaction to cause subsequent fission (AW) **Moderator**: Slows down the (fast-moving) neutrons / lowers the KE of (fast moving) neutrons / makes the (fast moving) neutrons into thermal neutrons Slow moving neutrons have a greater chance of causing fission / of being absorbed (by U-235) / sustaining chain reaction	B1 B1 B1 B1 B1	**Show annotation on Scoris** **Not** 'contains fuel' **QWC mark** **Allow**: Fast moving neutrons are captured (easily) by uranium-238 (nuclei leaving insufficient number of nuclei for fission / chain reaction) for the last B1 mark
	(c)	(i)	power = $3.0 \times 10^9/0.22$ power = 1.36×10^{10} (W) or 1.4×10^{10} (W)	B1	
		(ii)	energy = $1.36 \times 10^{10} \times 8.64 \times 10^4$ energy = 1.18×10^{15} (J) or 1.2×10^{15} (J)	B1	Possible ecf from **(c)(i)**
		(iii)	(number of reactions per day) = $\dfrac{1.18\times10^{15}}{3.2\times10^{-11}}$ mass = $\dfrac{1.18\times10^{15}}{3.2\times10^{-11}}\times3.9\times10^{-25}$ mass = 14.4 (kg) or 14 (kg)	C1 A1	Possible ecf from **(c)(ii)** **Note**: Using 1.2×10^{15} (J) gives an answer of 14.6 (kg); allow 15 (kg)
	(d)		Nuclear waste is (radio)active for a long time (AW) Causes ionisation	B1 B1	**Allow**: '*Nuclear waste can have long* half *life*'
			Total	**12**	

5 **(a)** The diameter of a nucleus is about 10^{-14} m.

(i) Complete the sentence below.

The diameter of a nucleus is .... times smaller than the diameter of an atom. **[1]**

(ii) Very high-energy electrons are diffracted by the nucleus when they have a wavelength similar to the nuclear diameter.

1 Estimate the momentum of an electron with a de Broglie wavelength equal to the diameter of a nucleus.

momentum = ...kg m s^{-1} **[2]**

2 Suggest why the speed of these electrons cannot be calculated by dividing the answer to **(ii)1** by the mass 9.11×10^{-31} kg.

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.... **[1]**

(b) The table of Fig. 5.1 shows some of the isotopes of phosphorus and, where they are unstable, the type of decay.

Isotope	$^{29}_{15}P$	$^{30}_{15}P$	$^{31}_{15}P$	$^{32}_{15}P$	$^{33}_{15}P$
Type of decay	β^+	β^+	stable	β^-	β^-

Fig. 5.1

(i) State the difference between each of the isotopes shown in the table.

....

.... **[1]**

(ii) Describe the structure of the proton in terms of up (u) and down (d) quarks.

.... **[1]**

(iii) Describe what happens in a beta-plus (β^+) decay using a quark model.

....

....

.... **[2]**

(iv) State **two** quantities conserved in a beta decay.

....

.... **[1]**

(v) Examine the table of isotopes in Fig. 5.1 and suggest what determines whether an isotope emits β^+ or β^-.

....

....

.... **[1]**

[Total: 10]

Question			Answer	Marks	Guidance
5	(a)	(i)	Any number in the range: 10^4 to 10^5	B1	
		(ii)1	$10^{-14} = \frac{h}{mv}$ momentum = $\frac{6.63 \times 10^{-34}}{10^{-14}}$ momentum = 6.6×10^{-20} (kg m s^{-1})	C1 A1	**Allow** 1 sf answer of 7×10^{-20} (kg m s^{-1})
		(ii)2	The mass of the electron is greater (than its rest mass / 9.11×10^{-31} kg)	B1	**Allow**: Dividing (momentum) by 9.11×10^{-31} (kg) would give a speed of 7.3×10^{10} (m s^{-1}) which is greater than the speed of light / *c* (this is not possible) (AW)
	(b)	(i)	Different number of <u>neutrons</u>	B1	**Not**: different number of nucleons / different mass number / different A
		(ii)	u u d	B1	
		(iii)	u → d + positron + neutrino	M1 A1	**Allow**: u u d → u d d **Allow**: symbols for positron (e^+ / β^+ / ${}^{0}_{+1}e$) and neutrino (υ) **Allow** full marks for an answer in words **Allow** 1 mark for $p \rightarrow n + e^+ + \upsilon$
		(iv)	Any <u>two</u> from: charge or proton number / momentum / mass-energy / nucleon number / lepton number / strangeness / baryon number / spin	B1	**Not**: <u>mass</u> on its own or <u>energy</u> on its own, but **allow** mass <u>and</u> energy
		(v)	β^+ when there are fewer neutrons / β^+ for lighter nuclei or β^- when there are more neutrons / β^- for heavier nuclei	B1	**Allow**: Alternative correct answers in terms of ratio of protons to neutrons
			Total	**10**	

6 **(a)** Explain what is meant by the statement below.

Radioactivity is a random process.

....

.... **[1]**

(b) Uranium-235 was present during the formation of the Solar System, including the Earth. The percentage of the original quantity of $^{235}_{92}U$ found in rocks today is 1.1%. The half-life of $^{235}_{92}U$ is 7.1×10^8 years. Calculate the age, in years, of the Earth.

age = ... y **[3]**

(c) Fig. 6.1 shows the variation of binding energy per nucleon against nucleon number A.

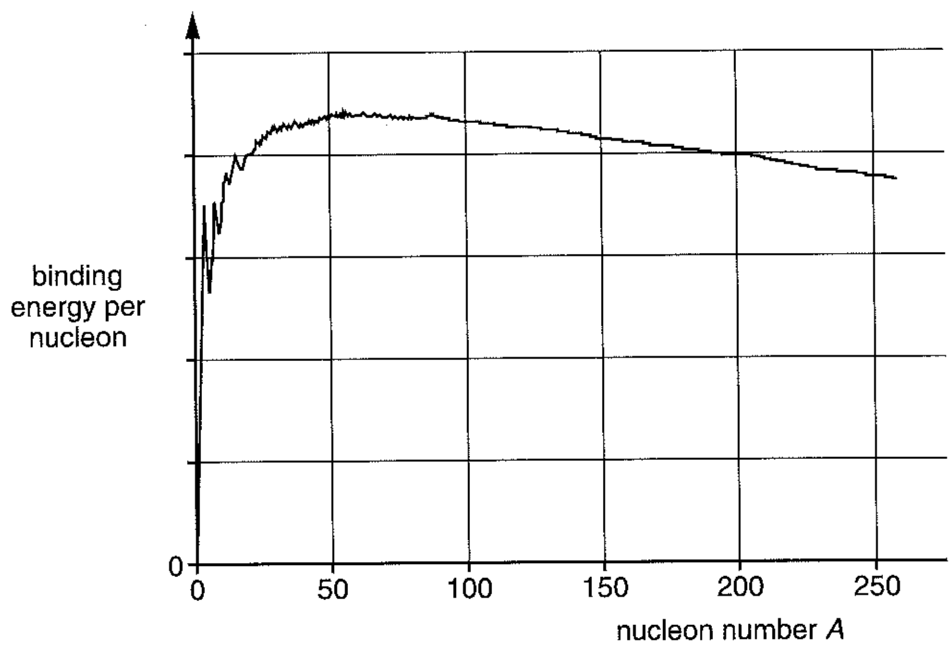

Fig. 6.1

(i) Use Fig. 6.1 to estimate the value of the nucleon number of the most stable isotope.

.... **[1]**

(ii) Use Fig. 6.1 to explain why nuclei of $^{100}_{42}Mo$ cannot produce energy by **fusion**.

....

....

.... **[1]**

(iii) The mass of a $^{8}_{4}Be$ nucleus is 1.329×10^{-26} kg. Use data provided on the second page of the Data, Formulae and Relationships Booklet to determine the binding energy per nucleon for this nucleus.

binding energy per nucleon = ... J **[4]**

[Total: 10]

Question			Answer	Marks	Guidance
6	(a)		Impossible to predict when a <u>nucleus</u> will decay or impossible to predict which <u>nucleus</u> will decay	B1	
	(b)		$N = N_0 e^{-\lambda t}$ (λ =) 0.693/7.1 $\times 10^8$ $\lambda = 9.76 \times 10^{-10}$ y^{-1} $0.011 = e^{-(9.76 \times 10^{-10} \times t)}$ (age =) $\dfrac{\ln(0.011)}{-9.76 \times 10^{-10}}$ age = 4.6×10^9 (y)	C1 C1 A1	**Alternatives:** $N = N_0 e^{-\lambda t}$ (λ =) 0.693/[7.1 $\times 10^8 \times 3.16 \times 10^7$] C1 $\lambda = 3.089 \times 10^{-17}$ s^{-1} $0.011 = e^{-(3.089 \times 10^{-17} \times t)}$ C1 (age =) $\dfrac{\ln(0.011)}{-3.089 \times 10^{-17}}$ age = 1.46... $\times 10^{17}$ (s) age = 4.6×10^9 (y) A1 Or $0.011 = \dfrac{1}{2^n}$ C1 $n = -\dfrac{\ln(0.011)}{\ln 2}$ or $n = 6.5$ C1 age = 6.5 $\times$ 7.1 $\times 10^8$ (y) age = 4.6×10^9 (y) A1
	(c)	(i)	number in the range 50 to 70	B1	
		(ii)	Correct reference to binding energy. Eg: The BE per nucleon will decrease for fusion (which is impossible unless external energy is supplied) (AW)	B1	

Question			Answer	Marks	Guidance
		(iii)	(mass of nucleons =) $4 \times 1.673 \times 10^{-27} + 4 \times 1.675 \times 10^{-27}$ (Δm =) $[4 \times 1.673 \times 10^{-27} + 4 \times 1.675 \times 10^{-27}] - 1.329 \times 10^{-26}$ (mass defect =) 1.020×10^{-28} (kg) BE = mass defect × c^2 (BE =) $1.020 \times 10^{-28} \times (3.0 \times 10^8)^2$ (= 9.180×10^{-12} J) (BE per nucleon) = $9.180 \times 10^{-12}/8$ BE per nucleon = 1.148×10^{-12} (J)	C1 C1 C1 A1	**Allow**, due to misinterpretation of Data, Formulae and Relationship Booklet, the following (though incorrect): (nucleon mass =) $8 \times 1.661 \times 10^{-27}$ (kg) C1 (Δm =) $[8 \times 1.661 \times 10^{-27}] - 1.329 \times 10^{-26}$ (kg) C1 (BE =) (-) $2.0 \times 10^{-30} \times (3.0 \times 10^8)^2$ (= 1.8×10^{-13} J) C1 (BE per nucleon =) $1.8 \times 10^{-13}/8$ BE per nucleon = 2.25×10^{-14} (J) A1 **Allow** 2 sf or 3 sf answer
			Total	**10**	

3 **(a)** Deuterium (^2_1H) and tritium (^3_1H) are isotopes of hydrogen.

(i) State **two** features common to all isotopes of hydrogen.

....

....

....

.... **[1]**

(ii) Explain why the total mass of the individual nucleons of a deuterium nucleus is different from the mass of the deuterium nucleus.

....

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....

.... **[3]**

(b) A fusion reaction between two nuclei is shown below.

$$^2_1H + {}^3_1H \rightarrow {}^4_2He + {}^1_0n$$

A neutron inside a nucleus is stable. However, a 'free' neutron, when outside the nucleus, undergoes beta decay with a half-life of about 11 minutes.

(i) Complete the decay equation below for a free neutron.

$$^1_0n \rightarrow \ldots\ldots\ldots\ldots \; + \; {}^{\;\,0}_{-1}e \; + \; \ldots\ldots\ldots\ldots$$

[2]

(ii) Explain what is meant by the *half-life* of a free neutron.

....

....

....

.... **[1]**

(c) For the fusion reaction to occur the separation between the deuterium and tritium nuclei must be less than 10^{-14} m. This means that the average kinetic energy of these hydrogen nuclei needs to be about 70 keV. The energy released by the fusion reaction is 18 MeV.

(i) Calculate the repulsive electrical force between the deuterium and tritium nuclei at a separation of 10^{-14} m.

force = ... N **[2]**

(ii) Assume that a mixture of these hydrogen nuclei behaves as an ideal gas.

Estimate the temperature of the mixture of nuclei required for this fusion reaction.

temperature = ... K **[3]**

(iii) In practice, fusion occurs at a much lower temperature. Suggest a reason why.

....

....

....

.... **[1]**

(iv) Calculate the change in mass in a single fusion reaction.

change in mass = ... kg **[2]**

(v) Fig. 3.1 shows the variation of probability of fusion reaction with temperature T for deuterium and tritium and for deuterium and helium.

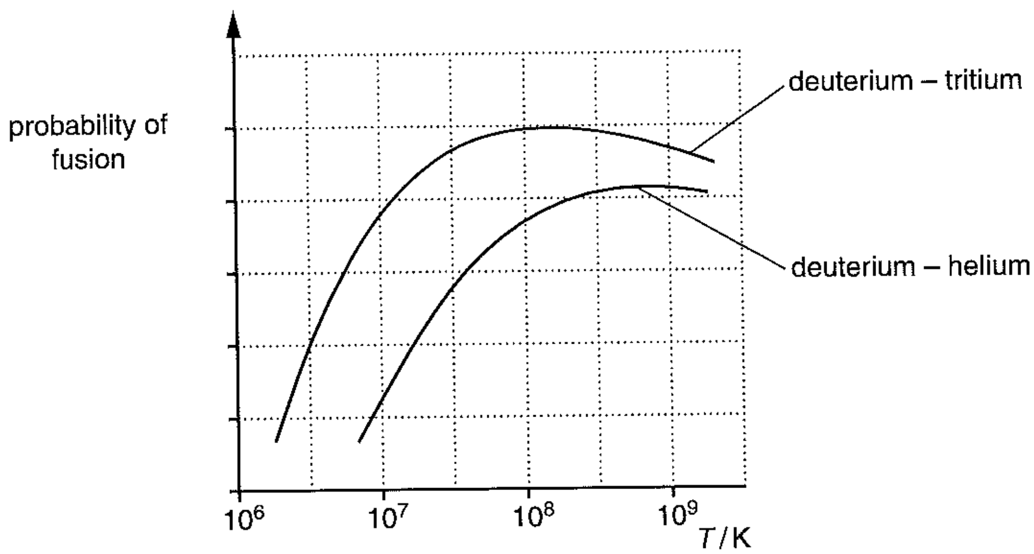

Fig. 3.1

Suggest why the probability of reaction at a given temperature is smaller for deuterium and helium.

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.... **[2]**

[Total: 17]

Question			Answers	Marks	Guidance
3	(a)	(i)	One proton / (same) charge / (same) element and (same) chemical property / one electron	B1	**Allow** (same) number of protons. **Allow** (same) number of electrons.
		(ii)	mass of nucleus < (total) mass of nucleons Energy must be supplied to the nucleus to free the nucleons / energy released when nucleons combine (to form the nucleus). $(\Delta)E = (\Delta)mc^2$ and $(\Delta)E$ is the (binding) energy and $(\Delta)m$ is the mass defect or the difference in mass.	B1 B1 B1	 **Allow** nucleus has binding energy.
	(b)	(i)	${}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e + \overline{\nu}_{(e)}$	B1,B1	**Allow** proton or ${}^{1}_{1}H$ or H^+ or p and (electron) antineutrino.
		(ii)	(Average) time taken for half of the neutrons (in a sample) to decay.	B1	**Note**: Must have reference to 'half' and 'neutrons' **Allow** 'the time taken for the activity of neutrons to halve'.
	(c)	(i)	$F = \dfrac{1.6\times10^{-19}\times1.6\times10^{-19}}{4\pi\varepsilon_0\times(10^{-14})^2}$ force = 2.3 (N)	C1 A1	**Not** $Q = q = 1$
		(ii)	$E = 7.0\times10^4\times1.6\times10^{-19}$ (= 1.12×10^{-14} J) $(E = \frac{3}{2}kT)$; $7.0\times10^4\times1.6\times10^{-19} = \frac{3}{2}\times1.38\times10^{-23}\times T$ temperature = 5.4×10^8 (K)	C1 C1 A1	 **Allow** any subject. Also, allow $E \approx kT$ since it is an estimate. **Allow** 1 sf answer.
		(iii)	Some nuclei will be travelling faster / have greater (kinetic) energy (to overcome electrostatic repulsion and hence cause fusion).	B1	**Allow** the pressures are high (enough to cause fusion). **Not** 'nuclei get close enough'.
		(iv)	$(\Delta E = \Delta mc^2)$; $18\times10^6\times1.6\times10^{-19} = \Delta m\times(3.0\times10^8)^2$ change in mass = 3.2×10^{-29} (kg)	C1 A1	**Allow** any subject **Allow** a maximum of 1 mark for 18MeV ± 70 keV.
		(v)	Helium (nucleus) has greater charge / more protons. The (electrostatic) repulsive force (between the deuterium and helium nuclei) is greater (hence smaller chance of fusion).	B1 B1	 Do **not** award this mark if 'helium nuclei are moving slower' is also given as the reason for smaller probability for fusion.
			Total	**17**	

6 **(a)** Fig. 6.1 shows the quark composition of some particles.

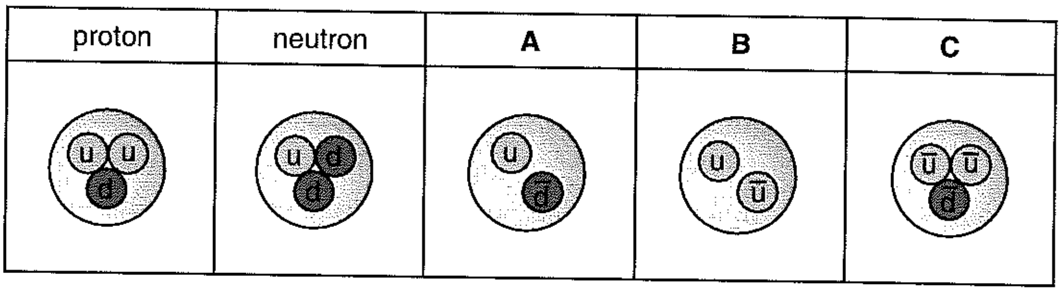

Fig. 6.1

(i) Identify the anti-proton from the table of particles shown in Fig. 6.1.

.... **[1]**

(ii) State the value of the charge of particle **B**.

.... **[1]**

(b) The nuclei of carbon-14 are produced naturally in the upper atmosphere from the reactions of slow-moving neutrons with nitrogen nuclei.

(i) The reaction below shows a nuclear reaction between a neutron and a nitrogen nucleus.

$$^{1}_{0}\mathrm{n} \;+\; ^{14}_{7}\mathrm{N} \;\rightarrow\; ^{14}_{6}\mathrm{C} \;+\; \mathbf{X}$$

Identify the particle **X**.

.... **[1]**

(ii) Carbon-14 has a half-life of 5700 years. The molar mass of carbon-14 is $0.014\,\mathrm{kg\,mol^{-1}}$. The total activity from all the carbon-14 nuclei found on the Earth is estimated to be $1.1 \times 10^{19}\,\mathrm{Bq}$. Estimate the total mass of carbon-14 on the Earth.

mass = ... kg **[3]**

(c) Energy in the core of a nuclear reactor is produced by induced nuclear fission of uranium-235 nuclei. Explain what is meant by *induced nuclear fission*.

....

....

.... **[2]**

(d) Many nuclear reactors use uranium-235 as fuel. Some of these reactors use water as both coolant and moderator. The control rods contain boron-10. Fig. 6.2 shows part of the inside of the core of a nuclear reactor.

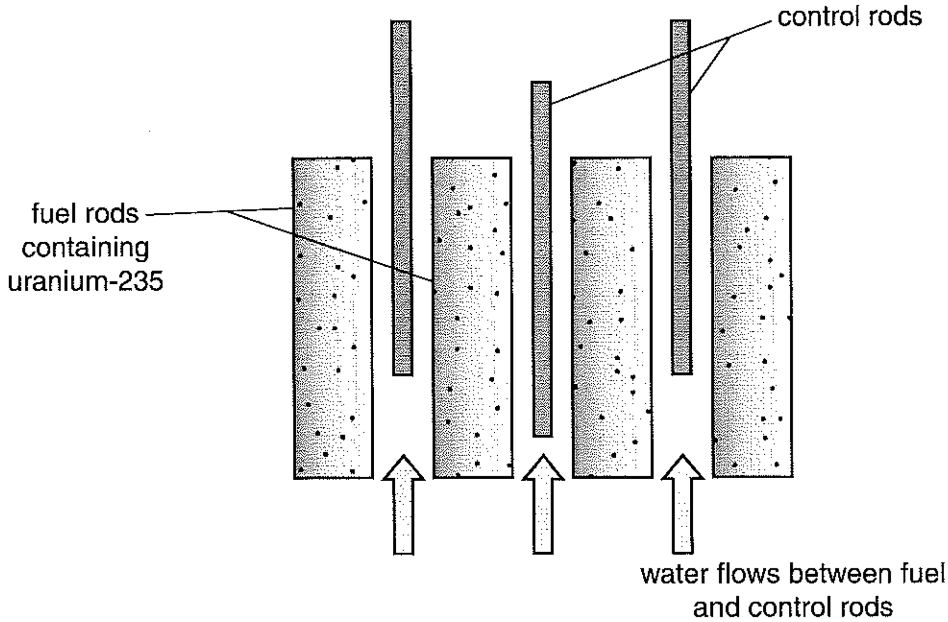

Fig. 6.2

Explain the purpose of using a moderator and control rods in the core of a nuclear reactor.

In your answer you should make clear how a moderator works at a microscopic level.

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....

.... **[4]**

[Total: 12]

Question			Answers	Marks	Guidance
6	(a)	(i)	C	B1	
		(ii)	Zero	B1	
	(b)	(i)	proton / $^1_1$H / $^1_1$p / p	B1	
		(ii)	$\lambda = \dfrac{0.693}{5700 \times 3.16 \times 10^7}$ or λ = 3.847... × 10^{-12} (s^{-1})	C1	
			$(A = \lambda N)$; $N = \dfrac{1.1 \times 10^{19}}{3.847... \times 10^{-12}}$ or N = 2.859.. × 10^{30}	C1	**Allow** any subject **Allow** ecf within the calculation for an incorrect λ.
			mass = $\dfrac{2.859... \times 10^{30}}{6.02 \times 10^{23}} \times 0.014$		
			mass = 6.649... × 10^4 (kg) or 6.6 × 10^4 (kg)	A1	**Allow** 6.7 × 10^4 (kg)
	(c)		A (thermal / slow-moving) neutron splits the <u>nucleus</u> into two (smaller) nuclei	B1	**Allow** 'fast neutron'; **allow** 'decays' instead of 'splits'. **Not** 'splitting the atom'. **Not** 'particles' or 'fragments' in place of '(smaller) nuclei'.
			and (fast-moving) neutron(s).	B1	
	(d)		Any **three** from: 1. Fission reactions produce fast neutrons. 2. The moderator / water slows down (the fast-moving) neutrons. 3. Slow-moving neutrons have a greater chance of causing fission (of U-235). (ora) 4. The control rods absorb (some of the) neutrons. 5. (On average) one neutron survives between successive (fission) reactions.	B1×3	**Allow** boron / cadmium instead of control rods in 4. **Not** graphite for 4.
			QWC: The neutrons make collisions with the (moderator) nuclei <u>and</u> transfer (some of) their (kinetic) energy.	B1	**Allow** atoms / molecules instead of nuclei.
			Total	**12**	

5 **(a)** Explain how the experiments on the scattering of alpha-particles by a metal foil provided evidence for the nuclear model of the atom.

In your answer, you should make clear how your conclusions link with the observations.

....

....

....

....

....

.... **[3]**

(b) Fig. 5.1 shows an alpha-particle ($^4_2$He) of kinetic energy 8.0 MeV moving directly towards a nucleus of aluminium-27 ($^{27}_{13}$Al), initially at rest.

Fig. 5.1

(i) The alpha-particle comes to rest instantaneously a short distance away from the aluminium nucleus. It then reverses its direction of travel. Describe and explain the motion of the aluminium nucleus at the instant the alpha-particle is at rest.

....

....

....

....

.... **[2]**

(ii) Calculate the initial speed of the alpha-particle.

mass of alpha-particle = 6.6×10^{-27} kg

speed = ... $m\,s^{-1}$ **[2]**

(iii) The electric force experienced by the alpha-particle when it is close to the aluminium nucleus is 270 N. Calculate the separation r between the alpha-particle and the aluminium nucleus when the alpha-particle experiences this force.

r = ... m **[3]**

(iv) Consider the situation where the alpha-particle travels much closer to the aluminium nucleus than in **(b)(iii)**.

Discuss how the strong nuclear force may affect the resultant force on the alpha-particle.

....

....

....

.... **[2]**

Question			Answer	Marks	Guidance
5	(a)		Observations: 1. <u>Most</u> of the alpha particles went straight / un-deflected through (the atom(s) / foil) (AW) 2. (Some of the) alpha particles were scattered / repelled / deflected through large angles (AW) Conclusions (QWC mark): • 1 showed that most of the <u>atom</u> is empty space **and** • 2 showed the existence of small / dense / positive nucleus	M1 M1 A1	**Not** 'reflected' **Allow**: The QWC mark even if 'alpha <u>reflected</u> at large angles' is mentioned in 2
	(b)	(i)	The aluminium nucleus has velocity / accelerates / moves to the right There is a repulsive force on the (aluminium) nucleus (to the right) / According to conservation of momentum the (aluminium) nucleus must move (to the right)	B1 B1	**Allow**: Moves away from the alpha particle
		(ii)	$8.0\times10^{6}\times1.6\times10^{-19}=\frac{1}{2}\times6.6\times10^{-27}\times v^{2}$ (Any subject) speed = 2.0×10^{7} (m s^{-1})	C1 A1	**Note**: Answer to 3 sf is 1.97×10^{7} (m s^{-1}) **Allow** 1 sf answer 2×10^{7} (m s^{-1})
		(iii)	$Q = 13e$ or $q = 2e$ or $F=\frac{Qq}{4\pi\varepsilon_0 r^2}$ $270=\frac{13\times1.6\times10^{-19}\times2\times1.6\times10^{-19}}{4\pi\times8.85\times10^{-12}\times r^{2}}$ (Any subject) distance = 4.7×10^{-15} (m)	C1 C1 A1	**Allow**: $F=k\frac{Qq}{r^2}$, where $k = 9\times10^{9}$ **Note**: No credit for using Q and q as 13 and 2

Question			Answer	Marks	Guidance
		(iv)	The strong force is attractive Correct explanation of size / direction of resultant force	M1 A1	**Allow:** The strong force is repulsive M1 Correct explanation of size / direction of resultant force A1
			Total	**12**	

6 **(a)** Explain what is meant by the *binding energy* of a nucleus.

....

.... **[1]**

(b) The fusion of protons occurs in a star when the temperature within the core is greater than about 10^7 K. It takes the fusion of 4 protons to form a helium-4 ($^4_2$He) nucleus. In this process, known as the proton–proton cycle, energy is released.

The net energy released in producing a single helium-4 nucleus is 4.53×10^{-12} J.
Calculate the binding energy per nucleon of the helium-4 nucleus.

binding energy per nucleon = ... J **[1]**

(c) The fusion of helium nuclei to make heavier elements occurs in red giants at temperatures above 10^8 K.

Explain why fusion of helium requires higher temperatures than the fusion of hydrogen (protons).

....

....

.... **[2]**

(d) Estimate the mean speed of helium nuclei at a temperature of 10^8 K.

mass of helium nucleus = 6.6×10^{-27} kg

speed = ... m s^{-1} **[2]**

Question			Answer	Marks	Guidance
6	(a)		The (minimum) energy needed to separate / remove all the nucleons / protons <u>and</u> neutrons (to infinity)	B1	**Allow**: The energy released when (stationary) nucleons combine to form the nucleus **Allow**: The (minimum) energy required to break the nucleus into its (separate) nucleons **Allow**: binding energy = mass <u>defect</u> × speed of light^2 **Allow**: 'Work (done)' in place of 'energy'
	(b)		BE per nucleon = $4.53 \times 10^{-12}/4$ BE per nucleon = 1.13×10^{-12} (J)	B1	**Allow** 2 sf answer of 1.1×10^{-12} (J)
	(c)		The helium nucleus has greater charge / The helium nucleus experience greater repulsive force Helium nuclei need to get <u>close</u> together (for the strong force to initiate fusion)	B1 B1	
	(d)		$(\frac{1}{2} m v^2 = \frac{3}{2} kT)$ $\frac{1}{2} \times 6.6 \times 10^{-27} \times v^2 = \frac{3}{2} \times 1.38 \times 10^{-23} \times 10^8$ speed = 7.9×10^5 (m s^{-1})	C1 A1	**Allow**: KE ≈ kT; this gives an answer of 6.47×10^5 (m s^{-1})
			Total	**6**	