Question			Answers	Marks	Guidance
1	(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 $\lambda = 3.847... \times 10^{-12}$ (s^{-1}) $(A = \lambda N)$; $N = \dfrac{1.1 \times 10^{19}}{3.847... \times 10^{-12}}$ or $N = 2.859.. \times 10^{30}$ mass = $\dfrac{2.859... \times 10^{30}}{6.02 \times 10^{23}} \times 0.014$ mass = $6.649... \times 10^{4}$ (kg) or 6.6×10^{4} (kg)	C1 C1 A1	**Allow** any subject **Allow** ecf within the calculation for an incorrect λ. **Allow** 6.7×10^{4} (kg)
	(c)		A (thermal / slow-moving) neutron splits the <u>nucleus</u> into two (smaller) nuclei and (fast-moving) neutron(s).	B1 B1	**Allow** 'fast neutron'; **allow** 'decays' instead of 'splits'. **Not** 'splitting the atom'. **Not** 'particles' or 'fragments' in place of '(smaller) nuclei'.
	(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. QWC: The neutrons make collisions with the (moderator) nuclei <u>and</u> transfer (some of) their (kinetic) energy.	B1×3 B1	**Allow** boron / cadmium instead of control rods in 4. **Not** graphite for 4. **Allow** atoms / molecules instead of nuclei.
			Total	**12**	

Question			Answer	Marks	Guidance
2	(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 $\rightarrow$ d + posi ino	M1 A1	**Allow**: u u d $\rightarrow$ 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^+ + υ
		(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**	

Question			Answer	Marks	Guidance
3	**(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} $0.011 = e^{-(9.76\times10^{-10}\times t)}$ (age =) $\dfrac{\ln(0.011)}{-9.76\times10^{-10}}$ 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} $0.011 = e^{-(3.089\times10^{-17}\times t)}$ C1 (age =) $\dfrac{\ln(0.011)}{-3.089\times10^{-17}}$ 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 $n = 6.5$ 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 =) $[4\times1.673 \times 10^{-27} + 4\times1.675 \times 10^{-27}] - 1.329 \times 10^{-26}$ (mass defect =) 1.020×10^{-28} (kg) BE = mass defect $\times$ 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**	

Question			Answer	Marks	Guidance
4	(a)		Any <u>two</u> from: 1. There is a repulsive (electrical) force (between the gold nucleus and the alpha particle) 2. Momentum is conserved (because there are no external forces) / initial momentum of alpha particle = final momentum of gold nucleus (because there are no external forces) 3. KE of alpha particle transformed into (electrical) PE	B1×2	**Allow**: (The gold nucleus and alpha particle experience) forces in opposite directions
	(b)		Correct directions of field shown on lines from **A** and **B** Correct curved field lines from **A** and **B**	B1 B1	
	(c)		$F = \dfrac{Qq}{4\pi\varepsilon_0 r^2}$ $Q = 79e$ and $q = 2e$ force = $\dfrac{79 \times 2 \times (1.60 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12} \times (6.0 \times 10^{-14})^2}$ force = 10.1 (N)	C1 C1 C1 A0	 **All** values must be substituted for this mark
	(d)		Correctly shaped curve with *F* decreasing as *r* increases Value of *F* is between 2 to 3 (N) at $r = 12 \times 10^{-14}$ m	M1 A1	 **Note**: $F \propto 1/r^2$, hence *F* should be about 2.5 (N)
			Total	**9**	

Question			Answer	Marks	Guidance
5	(a)		no: of neutrons = 142	B1	
	(b)	(i)	(5.6 MeV =) $5.6 \times \underline{10^{6}} \times \underline{1.6 \times 10^{-19}}$ energy = 8.96×10^{-13} (J)	M1 A0	**Allow**: $5.6 \times \underline{1.6 \times 10^{-13}}$
		(ii)	$\frac{1}{2} \times 6.65 \times 10^{-27} \times v^2 = 8.96 \times 10^{-13}$ $v = \sqrt{\frac{2 \times 8.96 \times 10^{-13}}{6.65 \times 10^{-27}}}$ speed = 1.6×10^{7} (m s^{-1})	C1 A1	Answer to 3 sf is 1.64×10^{7} (m s^{-1}) **Note**: The answer is 1.65×10^{7} (m s^{-1}) if 9×10^{-13} (J) is used
	(c)	(i)	activity = $\frac{62}{8.96 \times 10^{-13}}$ activity = 6.92×10^{13} (Bq)	C1 A0	**Allow**: activity = $\frac{62}{9 \times 10^{-13}}$ (= 6.89×10^{13} Bq) Possible ecf from **(b)(i)**
		(ii)	$\lambda = \frac{0.693}{T}$ $\lambda = \frac{0.693}{88 \times 3.16 \times 10^{7}}$ decay constant = 2.49×10^{-10} (s^{-1}) or 2.5×10^{-10} (s^{-1})	C1 A1	**Note**: ln2 = 0.693 **Allow**: 1 mark for using 88 years and getting an answer of 7.9×10^{-3}
		(iii)	**1** $A = \lambda N$ $N = \frac{6.92 \times 10^{13}}{2.49 \times 10^{-10}}$ number =2.78×10^{23} or 2.8×10^{23} **2** mass = $\frac{2.78 \times 10^{23}}{6.02 \times 10^{23}} \times 0.24$ mass = 0.11 (kg)	C1 A1 B1	Possible ecf from **(c)(ii)** **Note**: ‘$7 \times 10^{13}/2.5 \times 10^{-10} = 2.8 \times 10^{23}$’ Possible ecf for mass from incorrect value for number of nuclei
			Total	**10**	