Question			Expected Answers	Marks	Additional Guidance
1	a	(i)	mass of uranium is greater than (the sum of) the mass of the products $E = \Delta mc^2$ OR binding energy of the products is greater than that of uranium energy available is the difference between the binding energies of uranium and the sum of the products	**M1** **A1** **M1** **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 binding energy of products = 141 x 8.3 + 92 x 8.7 = 1170.3 + 800.4 energy available = 184.7 (MeV)	 **C1** **A1**	An answer of 9.4 (not using the number of nucleons) scores zero Allow ≥ 2 sf (180, 185, 184.7) Penalise 184 as an AE
			Total	**[6]**	

Question			Expected Answers	Marks	Additional Guidance
2	**a**		$F = Q_1Q_2 / 4\pi\varepsilon_0 r^2$ $= (1.6 \times 10^{-19} \times 1.6 \times 10^{-19}) / 4\pi\varepsilon_0 (2 \times 10^{-15})^2$ $= 57.5$ (N)	**C1** **A1**	Allow use of 9×10^9 instead of $1 / 4\pi\varepsilon_0$ (using this gives 57.6) Allow ≥ 2sf (58) If correct formula quoted and then AE (e.g. not squaring r <u>or</u> not squaring Q) then allow ecf in final answer for 2/3
	b		<u>attractive</u> strong (nuclear force)	**B1**	Do not it holds them together
	c		as the proton travels towards the stationary proton it experiences a repulsive force that slows it down. (It needs a high velocity) to get close enough (to the proton) / for the (attractive) <u>short range</u> force to have any effect	**B1** **B1**	
			Total	**[5]**	

Question			Answer	Marks	Guidance
3	(a)	(i)	momentum / mass-energy / charge / proton number / baryon number / nucleon number	B1	**Not**: 'energy' on its own
		(ii)	Some basic labelling of neutron(s), Xe and Sr Correct extension of diagram showing at least one of the neutrons interacting with U-235 nucleus and producing neutron(s) and 'fragments'	B1 B1	
	(b)	(i)	initial $m = 6.686 \times 10^{-27}$ (kg) or final $m = 6.681 \times 10^{-27}$ (kg) or $\Delta m = 0.005 \times 10^{-27}$ (kg) $\Delta E = 0.005 \times 10^{-27} \times (3.0 \times 10^{8})^{2}$ energy = 4.5×10^{-13} (J)	C1 C1 A1	
		(ii)	kinetic (energy)	B1	**Not**: heat / sound **Allow**: (gamma) photons / EM radiation
		(iii)	KE = $\frac{3}{2}kT$ KE = $\frac{3}{2} \times 1.38 \times 10^{-23} \times 10^{9}$ KE = 2.1×10^{-14} (J)	C1 A1	**Allow**: 1 sf answer or 10^{-14} (J) because the temperature is given as 10^{9} K
		(iv)	Some nuclei will have KE greater than the mean KE (and hence cause fusion) (AW)	B1	
			Total	**10**	

Question			Answers	Marks	Guidance
4	(a)		Same charge / number of protons	B1	**Not**: 'same chemical property'
	(b)		strong (nuclear force / interaction) gravitational (force)	B1 B1	**Allow**: 'gravity'
	(c)	(i)	$^{15}_{7}\text{N}$	B1	
		(ii)	(u d d) $\rightarrow$ (u u d)	B1	**Allow**: *One down quark becomes up quark* or d $\rightarrow$ u (+ electron + antineutrino)
	(d)	(i)	0.16 MeV = $0.16 \times 10^{6} \times 1.6 \times 10^{-19}$ $\frac{1}{2} \times 9.11 \times 10^{-31} \times v^{2} = 2.56 \times 10^{-14}$ speed = 2.4×10^{8} (m s^{-1}) or 2.37×10^{8} (m s^{-1})	C1 A1	**Allow**: 1 mark for using 9.8 MeV; answer is equal to 1.86×10^{9} (m s^{-1})
		(ii)	The mass of the electron increases / greater than 'rest mass'	B1	
	(e)	(i)	$\lambda = 0.693/T$ $\lambda = 0.693/(5560 \times 3.16 \times 10^{7})$ $\lambda = 3.9 \times 10^{-12}$ (s^{-1}) or 3.94×10^{-12} (s^{-1})	C1 A1	**Allow**: 1 mark for 1.25×10^{-4} (if 5560 y used)
		(ii)	number = $\frac{1.0 \times 10^{-3}}{14} \times 6.02 \times 10^{23}$ number = 4.3×10^{19}	M1 A0	**Note**: This step must be seen to score 1 mark
		(iii)	activity = λN activity = $3.94 \times 10^{-12} \times 4.3 \times 10^{19}$ activity = 1.7×10^{8} (Bq) or 1.69×10^{8} (Bq)	C1 A1	Possible ecf from **(e)(i)** and **(e)(ii)**

Question			Answers	Marks	Guidance
	(f)		Any **three** from: 1. Plants / living things take in carbon(-dioxide) or plants / living things stop taking in carbon after death 2. The ratio of carbon-14 to carbon-12 (nuclei) for the relic sample is determined 3. The current ratio of carbon-14 to carbon-12 nuclei is determined 4. The age of the relic is found using '$x = x_0 e^{-\lambda t}$' Limitation: The ratio of carbon-14 to carbon-12 is assumed to be constant / count(-rate) from relic may be comparable to background count(-rate)	B1×3 B1	**Must use ticks on Scoris to show where the marks are awarded** **Allow**: Any other valid comment for the limitation
			Total	**17**	

Question			Answers	Marks	Guidance
5	(a)		(Minimum) energy to separate (all) nucleons / protons <u>and</u> neutrons (of a nucleus)	M1 A1	**Alternative**: B.E. = mass <u>defect</u> $\times c^2$ M1 mass defect = mass of nucleons – mass of nucleus A1
	(b)	(	BE of $^{2}H = 2 \times 1.8 \times 10^{-13}$ (J) or BE of $^{4}He = 4 \times 1.1 \times 10^{-12}$ (J) energy = $(4 \times 1.1 \times 10^{-12}) - 2 \times (2 \times 1.8 \times 10^{-13})$ energy = 3.68×10^{-12} (J) / 3.7×10^{-12} (J)	C1 C1 A0	**Note**: Ignore signs
		(ii)	total surface area = $4\pi \times (1.5 \times 10^{11})^2$ power = $1400 \times (2.83 \times 10^{23})$ power = 3.96×10^{26} (W) / 4.0×10^{26} (W)	C1 C1 A0	
		(ii)	number = $4.0 \times 10^{26} / 3.7 \times 10^{-12}$ 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**	