Question	Expected Answers	Marks
1 (a)	forces F_S and F_G acting inwards, force F_E acting outwards - all through centre of proton; 3 forces 2/2, 2 forces 1/2, marked and labelled	2 [2]
(b)	$F_E = F_S + F_G$; accept $F_E + F_S + F_G = 0$ allow ecf from **(a)**	1 [1]
(c)(i)	$F_E = Q^2/(4\pi\varepsilon_0 r^2)$ $= (1.6 \times 10^{-19})^2/[4\pi \times 8.85 \times 10^{-12}(2.8 \times 10^{-15})^2] = 29\,N$ use of $r = 1.4 \times 10^{-15}\,m$ (-1) once only	1 1
(ii)	$F_G = m^2 G/r^2$ $= (1.67 \times 10^{-27})^2 \times 6.67 \times 10^{-11}/(2.8 \times 10^{-15})^2 = 2.4 \times 10^{-35}\,N$	1 1
(iii)	F_S = 29 N / same as F_E allow ecf	1 [5]
(d)	$F_E >> F_G$ so F_G negligible / insignificant / can be ignored or AW	1 [1]
(e)(i)	$F_E = 0$ (1)	
(ii)	$F_G = 2.4 \times 10^{-35}\,N$ (approx.) allow ecf (1)	
(iii)	$F_S = 2.4 \times 10^{-35}\,N$ (approx.) (1) comment: F_S now repulsive (not attractive) or AW *or* indicated by minus sign with F_S; (1) any 3	3 [3] **12**
2(a)(i)	$^{238}_{92}U + ^{1}_{0}n \rightarrow ^{239}_{92}U$	1
(ii)	$^{239}_{92}U \rightarrow ^{239}_{93}X + ^{0}_{-1}e + ^{(0)}_{(0)}\nu(\text{–bar})$	2
(iii)	$^{239}_{93}X \rightarrow ^{239}_{94}Pu + ^{0}_{-1}e + ^{(0)}_{(0)}\nu(\text{–bar})$ omits any neutrino (-1) once only electron incorrectly represented (-1) once only	1 [4]

(b)(i)	24 000 year / >24 000 year	1	[1]
(ii)	$\lambda = \ln 2 / T_{½} = \ln 2 / (24000 \times 365 \times 24 \times 3600)$ subs. $= 9.16 \times 10^{-13}\ s^{-1}$ *or* $< 9.16 \times 10^{-13}\ s^{-1}$ ans. failure to convert years to s, giving 2.89×10^{-5}, gets 1/2	1 1	 [2]
(c)(i)	239 g of Pu contain 6.02×10^{23} atoms *or* alternative correct use of N_A $N = (0.05 \times 4.4 / 0.239) \times 6.02 \times 10^{23}$ ie applies % and units correctly (= 5.54×10^{23} (atoms))	1 1	 [2]
(ii)	activity $= \lambda N$ $= 9.16 \times 10^{-13} \times 5.54 \times 10^{23}$ allow ecf $= 5.08 \times 10^{11}$ Bq / s^{-1} ans. + unit	1 2	 [3] **12**
3(a)	p.e. increases k.e. decreases *or* k.e. is converted to p.e. gets 2/2 eventually <u>all</u> k.e. is changed to p.e.	1 1 1	 [3]
(b)	$E_P = (1.6 \times 10^{-19})^2 / (4\pi \times 8.85 \times 10^{-12} \times 2.1 \times 10^{-15})$ (= 1.1×10^{-13} J) so k.e. of <u>each</u> proton = $½ \times 1.1 \times 10^{-13} = 5.5 \times 10^{-14}$ J	1 1	 [2]
(c)	$5.5 \times 10^{-14} = 2.07 \times 10^{-23}\ T$ so $T = 2.7 \times 10^9$ K ans. accept 2.6×10^9 K	1	[1]
(d)	*either:* E_K is the *mean* k.e. of protons (1) protons (in plasma) have a range of k.e.s (1) any 1 so (at any instant) some protons have much greater k.e. than average *or:* protons can fuse for separations > 2.1 fm (1) because of (quantum) tunnelling (effects) (1)	 1 1	 [2]

(e)(i)	$2 \times (2.3 \times 10^{-13}) + 2 \times (8.8 \times 10^{-13}) + (20.6 \times 10^{-13}) = 42.8 \times 10^{-13}$ J adds energies, without $\times 2$ gives 31.7×10^{-13} J for 1/2	2	[2]
(ii)	(2) neutrinos escape from the Sun (and carry away energy)	1	[1]
(f)	*either* T ($\propto E_K$) $\propto Q_1 Q_2$ and $Q_1 Q_2$ is greater for reactions in carbon cycle (eg $1 \times 12 > 1 \times 1$); *or* verbally: repulsion is greater between nuclei in carbon cycle; greater repulsion / Coulomb barrier means more energy needed (so higher temp.)	1 1	[2] **13**
4(a)	fixed target: accelerate one beam of particles / use high velocity / high energy particles; collide with stationary particles / nuclei; colliding beam: accelerate two beams of particles / use high velocity / high energy particles; collide them head-on / from opposite directions; 'fired at' / 'aimed at' / 'directed at' instead of accelerated etc, (-1) once Advantages: fixed target: no steering problems; (1) high probability of collision / many collisions; (1) because high density of particles in fixed target; (1) no problems of recoil in target; (1) any 1 colliding beam: (total) initial mtm. (can be) zero so final (overall) mtm. (can be) zero; *either* so <u>all</u> k.e. can contribute to making new particles *or* two beams means twice as much energy available; allow any other relevant point up to appropriate max.	1 1 1 1 1 1 1	[7]

(b)(i)	$m_e c \approx m_Z c$ so $m_e \approx m_Z$	1 1	[2]
(ii)	ratio = $(1.6 \times 10^{-25})/(9.11 \times 10^{-31}) = 1.8 \times 10^5$	1	[1]
(iii)	mass increases with speed positron and ${}^{(0)}_{(0)}Z$ have different speeds (so masses have changed by different amounts)	1 1	[2]
(c)	much / most of input energy goes into k.e. of ${}^{(0)}_{(0)}Z$ particle (so less energy available to create ${}^{(0)}_{(0)}Z$)	1	[1] **13**
5(a)	β^+ : ${}^{192}_{79}Au \rightarrow {}^{0}_{1}e + {}^{192}_{78}Pt + {}^{0}_{0}\nu$ β^- : ${}^{192}_{79}Au \rightarrow {}^{0}_{-1}e + {}^{192}_{80}Hg + {}^{0}_{0}\nu$ (-bar) omits both neutrinos gets 1/2 max.	1 1	[2]
(b)	β^+ decay: reactant mass = 191.921 47 u product mass = 191.918 24 + 0.000 55 = 191.918 79 u products mass < reactant mass so reaction can occur β^- decay: (reactant mass = 191.921 47 u) product mass = 191.921 41 + 0.000 55 = 191.921 96 u products mass > reactant mass so reaction cannot occur	1 1 1 1 1	[5]

(c)	β^+ mass defect / mass loss = 191.921 47 - 191.918 79 (= 0.002 68 u) then *either*: mass loss in kg = $0.002\ 68 \times 1.66 \times 10^{-27}$ (= 4.45×10^{-30} kg) so energy loss = $\Delta m\, c^2$ $4.45 \times 10^{-30} \times (3.0 \times 10^8)^2$ = 4.00×10^{-13} J *or* : 0.002 68u = 0.002 68 x 932 MeV (2) = (2.50 MeV) = $2.50 \times 10^6 \times 1.6 \times 10^{-19}$ (1) = 4.00×10^{-13} J (1) accept 930 - 934 MeV u^{-1} giving 3.99 - 4.00(5) x 10^{-13} J	1 1 1 1	 [4] **11**
6(a)	all free hadrons (thought to be) (somewhat) unstable; (1) protons and neutrons are (both) hadrons; (1) + (1) protons and neutrons inside a nucleus are stable; (1) free neutrons have half life of 10 - 15 minutes; (1) free protons are stable / have half life of about 10^{32} year; (1) any 5 allow equivalent marks for other hadrons and / or other relevant points	5	[5]
(b)(i) (ii) (iii)	weak (force / interaction); $^3_1H \rightarrow {}^3_2He + {}^0_{-1}e + \bar{\nu}$; d -> u + e + $\bar{\nu}$; d -> u gets 1/2 u d -> u + e / β + $\bar{\nu}$ is not in simplest form, so gets 1/2 d baryon reaction $^1_0n \rightarrow {}^1_1p + {}^0_{-1}e + \bar{\nu}$ gets 1/2	1 1 2	[1] [1] [2] **9**