68	a)	A is the equilibrium position / (resultant) force at A is zero; separation between two neutrons / diameter of a neutron;	1 1 [2]
	(b)	gradient of line $= \frac{[+20 - (-20)] \times 10^3}{(-1.5 + 1.3)\,10^{-15}} = (-)2.0 \times 10^{20}$ (N m^{-1}) minus sign / magnitude accept -2.0×10^{17} kN m^{-1}) no units but minus sign accept -200 kN fm^{-1}) given can get 1/2	1 1 [2]
	(c)	$F_E = \frac{Q^2}{4\pi\varepsilon_0 x^2}$ $= \frac{(1.6 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12}(1.4 \times 10^{-15})^2} = 117$ N accept $1/(4\pi \times 8.85 \times 10^{-12}) = 9 \times 10^9$ gives 117.6 accept ans. = 118 N	1 1 [2]
	(d)(i)	*either* strong force + electrostatic force = 0 *or* attractive strong force = repulsive electrostatic force *or* they are equal and opposite	1 [1]
	(ii)	at equilibrium, strong force = 117 N (1) so separation of B from A $= \frac{117}{2.0 \times 10^{20}} = 5.9 \times 10^{-19}$ m $(= 5.9 \times 10^{-4}$ fm)	1 (+1)
		B is greater than / to the right of A (on graph) (1) because electrostatic force is repulsive (1) (slight) increase in strong (attractive) force to compensate for electrostatic force (1) any 2	2 [3] **10**

Question	Answer	Marks	Total
69 (a)	reaction 1 $^{238}_{92}U + ^{1}_{0}n \;\tau\; ^{239}_{92}U$ reaction 2 $^{239}_{92}U \;\tau\; ^{0}_{-1}e + ^{239}_{93}Np + \overline{\nu}$ reaction 3 $^{239}_{93}Np \;\tau\; ^{0}_{-1}e + ^{239}_{94}Pu + \overline{\nu}$ no neutrino gets 1 + 1 + 0 = 2/4 max. wrong neutrino(s) gets 1 + 1 + 1 = 3/4 incorrect symbol for beta i.e. e^- or β^- –1 once	1 2 1	[4]
(b) (i)	measured from graph $T_{½}$ = 2.36 days (accept 2.3 - 2.4) so $T_{½}$ = 2.36 × 24 × 3600 = 2.04 × 10^5 s accept (1.98 - 2.10) × 10^5	1 1	[2]
(ii)	$\lambda = \frac{\ln 2}{T_{½}} = \frac{0.693}{2.04 \times 10^5}$ (= 3.4 × 10^{-6} s^{-1})	1	[1]
(iii)	$A = \lambda N$ from graph A = 2.77 × 10^{12} s^{-1} accept (2.75 - 2.80) × 10^{12} so $N = \frac{2.77 \times 10^{12}}{3.4 \times 10^{-6}}$ = 8.15 × 10^{17} accept (8.05 - 8.24) × 10^{17} *alternative* finds A by calculation from A_0 = 5.0 × 10^{12} Bq etc. can score 3/3	1 1 1	[3]
(c)(i)	24000 y	1	[1]
(ii)	horizontal line	1	[1]
			12
70 (a)	mass = 1.67 × 10^{-27} kg <u>not</u> 1.66 × 10^{-27} kg charge = -1.60 × 10^{-19} C minus sign essential	1 1	[2]
(b)	in particle accelerator / near high-energy particle collision *or* AW / in cosmic rays / in Sun;	1	[1]
(c)(i)	two γ-photons are produced;) with equal energy / frequency;) *or* from sketch in **(iii)** travelling in opposite directions;)	1 1 1	[3]
(ii)	total energy of a proton = (rest energy + k.e.) = $mc^2 + ½mv^2$ equation so total energy = 2 × 1.67 × 10^{-27} × (3.00 × 10^8)^2 + 2 × 8.00 × 10^{-11} subs. (= 3.00 × 10^{-10} + 1.60 × 10^{-10} = 4.60 × 10^{-10} J) for two photons, total energy = 4.60 × 10^{-10} J energy of one photon = hf i.e. $2hf$ for two photons so 2 × 6.63 × 10^{-34} f = 4.60 × 10^{-10} and f = 3.47 × 10^{23} Hz ans. ignores rest mass and gets f = 1.2 × 10^{23} Hz can get 2/4 ignores k.e. and gets 2.3 × 10^{23} Hz can get 2/4 factor 2 omission: -1	1 1 1 1	[4]
(iii)	photons in **(ii)** would be of higher frequency; sketch to show approximate relation between velocity of particles and directions of photons;	1 2	[3]
			13

71				
	(a)	${}^{2}_{1}H + {}^{3}_{1}H \; \tau \; {}^{4}_{2}He + {}^{1}_{0}n$	1	[1]
	(b)	reactants mass: 2.0141 + 3.0160 = 5.0301 u products mass: 4.0026 + 1.0086 = 5.0112 u so mass defect = 5.0301 - 5.0112 = 0.0189 u = $0.0189 \times 1.66 \times 10^{-27}$ kg (= 3.14×10^{-29} kg) energy = mc^2 = $3.14 \times 10^{-29} \times (3.00 \times 10^{8})^2$ = 2.82×10^{-12} J ans. *or* $E = 0.0189 \times 932$ (= 17.6 MeV) = 2.82×10^{-12} J	 1 1 1 1	 [4]
	(c)	mean neutron k.e. = $\frac{80}{100} \times 2.83 \times 10^{-12}$ = 2.26×10^{-12} J	1	[1]
	(d)	neutron has smaller ($^{1}/_{4}$ ×) mass than ${}^{4}_{2}$He ; (1) because of conservation of mtm. it has larger (4 ×) speed than ${}^{4}_{2}$He ; (1) k.e. = ½mv^2 *or* k.e. proportional to v^2 ; (1) deduces that faster moving neutron carries more energy (than ${}^{4}_{2}$He); (1) because k.e. proportional to v^2, this outweighs greater mass of ${}^{4}_{2}$He ; (1) any 3 remaining energy absorbed by / becomes k.e. of ${}^{4}_{2}$He nucleus;	 3 1	 [4]

72 (a)	${}^{14}_{6}\mathrm{C}$ ${}^{14}_{8}\mathrm{O}$ ${}^{14}_{7}\mathrm{N}$ 2/3 correct gets 1/2	2	[2]
(b)	${}^{14}_{6}\mathrm{C}\ \tau\ {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\mathrm{e} + \overline{\nu}$ first equation (1) ${}^{14}_{8}\mathrm{O}\ \tau\ {}^{14}_{7}\mathrm{N} + {}^{0}_{1}\mathrm{e} + \nu$ second equation (1) incorrect beta particle symbol (i.e. e^- or β^-) loses -1 once ${}^{0}_{-1}\mathrm{e}$ or ${}^{0}_{1}\mathrm{e}$ omitted gets 0/1 for relevant equation neutrino incorrectly shown loses -1 once neutrino omitted from an equation 0/1 omitted altogether 0/2	2	[2]
(c)	$n\ \tau\ p + e^- + \overline{\nu}$ and $p\ \tau\ n + e^+ + \nu$; n is udd, p is uud; $udd\ \tau\ uud + e^- + \overline{\nu}$ and **uud** $\tau\ udd + e^+ + \nu$ gets first two marks then deduces that: $d\ \tau\ u + e^- + \overline{\nu}$ $u\ \tau\ d + e^+ + \nu$ allow neutrino ecf from **(b)**	1 1 1 1	 [4]
(d)	C N and O points shown and labelled with N as the smallest mass; when decay occurs there is (always) a loss of (rest) mass;	1 1	 [2] **10**

73				
	1	uranium-235 is the (main) fissile material;	1	
	2	thermal neutron is *either* a slow-moving (neutron) *or* has k.e. ⊄ mean k.e. of atoms / molecules due to thermal agitation;	1	
	3	(fissile) nucleus absorbs a neutron;	1	
	4	only / mainly thermal neutrons cause (further) fission	1	
	5	nucleus splits / fissions into two nuclei / parts;	1	
	6	emitted neutrons can cause further fissions / cause chain reaction;	1	
	7	(most neutrons) need slowing down / moderating; (1)		
	8	reference to delayed neutrons or AW; (1)		
	9	importance of delayed neutrons in relation to controlling rate of reaction; (1)		
	10	*either* product nuclei 'bunched' around two mass numbers *or* graph showing peaks, sensibly symmetrical	1	
	11	symmetry of graph about nuclide whose mass ⊄ ½ mass of $^{235}_{92}U$;		
	12	(1)		
	13	fission generates (kinetic) energy; (1)		
	14	hence temperature of uranium rises; (1)		
	15	coolant carries heat from uranium / reactor core; (1)	1	
	16	heat used to change water to steam; *either* steam drives turbines linked to (electrical) generators *or* steam drives turbines and generates electricity;	1 3	[12]
		any 3		**12**

74					
	a	**i**	choose two from: penetrations; ionisation; charge; nature; mass; speed; monoenergetic v continuous spectrum of energy/speed	**2**	
			some qualification/detail for each	**2**	
		ii	choose two from: source; energy range/ wavelength or frequency range; penetrating power	**2**	
			some qualification/detail for each	**2**	**8**
	b	**i**	$I = I_0/r^2$ or $I = kr^{-2}$	**1**	
			k = 40 so $I = 40/(0.25)^2 = 40 \times 16 = 640$	**1**	
		ii 1	1280	**1**	
		2	$1280 = 40/r^2$;so $r = \sqrt{(40/1280)} = 0.18$ (m)	**2**	**5**
			Total		**13**

75				
	(a) (i)	number of nucleons = 27 so mass of nucleus = 27 × 1.67 × 10^{-27} = 4.5(1) × 10^{-26} kg	1	[1]
	(ii)	volume of nucleus $V = {}^4/_3\,\pi\, r^3$ r = $27^{1/3}$ × 1.40 × 10^{-15} (= 4.20 × 10^{-15} m) arith. $V = {}^4/_3\,\pi\,(4.20 \times 10^{-15})^3$ = 3.1(0) × 10^{-43} m^3 ans. *alternative answer* $V = {}^4/_3\,\pi\,(A^{1/3}\,r_0)^3 = {}^4/_3\,\pi\,A\,r_0^{\,3}$ $= {}^4/_3\,\pi \times 27 \times (1.40 \times 10^{-15})^3$ = 3.1(0) × 10^{-43} m^3 (at least 2 sf)	1 1 1	[3]
	(iii)	density of nucleus = $\dfrac{4.51 \times 10^{-26}}{3.10 \times 10^{-43}}$ = 1.45 × 10^{17} kg m^{-3} must show substitution and *calculated* answer (not just 1.5 x 10^{17})	1	[1]
	(b)	*either* density of gold nucleus = 1.45 × 10^{17} kg m^{-3} / 1.5 x 10^{17} *or* density of gold nucleus = density of aluminium nucleus; because spacing of nucleons is same inside both nuclei; (1) proton and neutron have approx. same mass (so proportions of neutrons and protons make no difference); (1) the volume of a nucleus is proportional to number of nucleons; (1) any (1)	1 1	[2]
	(c) (i)	$\dfrac{197 \times (1.67 \times 10^{-27})}{27 \times (1.67 \times 10^{-27})}$ = 7.3 $\dfrac{19.3 \times (10^3)}{2.70 \times (10^3)}$ = 7.1; *either* have assumed that mass of *atom* = mass of *nucleus* *or* have assumed that electrons (in atom) have negligible mass;	1 1 [2]	
	(ii)	(average) space occupied by gold <u>atom</u> =/~ (average) space occupied by aluminium <u>atom</u>; allow: volume of gold <u>atom</u> =/~ volume of aluminium <u>atom</u> not 'size' do not allow mass of atom(s) proportional to density	1 **10**	[1]

Question		Expected Answers	Marks	
76	(a)	in nuclear fission, nucleus splits into two parts / nuclei / fragments (of comparable / roughly equal size); (1) in radioactive decay α or β or photon is emitted; (1) nuclear fission is triggered / induced / caused by an (incoming) neutron; (1) radioactive decay is spontaneous; (1) any (2)	2	[2]
	(b) (i)	sum of nucleon numbers / masses of products is constant / equal to 236; so for every small nucleus there is a (corresponding) large nucleus *or* AW;	1 1	[2]
	(ii)	proton number = 46 nucleon number = 118;	1	[1]
	(c)	proton number = 39 nucleon number = 94;	1	[1]
	(d) (i)	$^{140}_{53}I \rightarrow {}^{1}_{0}n + {}^{139}_{53}I$ $^{140}_{53}I \rightarrow {}^{0}_{-1}e + {}^{140}_{54}Xe + \bar{\nu}$ omits $\bar{\nu}$ gets 1/2 ν instead of $\bar{\nu}$ gets 2/2	1 2	 [3]
	(ii)	idea that fission products have too many neutrons /neutron rich (to be stable) *or* AW; idea that β^- emission reduces number of neutrons / increases number of protons / reduces neutron/proton ratio;	1 1	 [2]
	(iii)	neutron decay: reactant mass: 139.9019 product mass: 138.8969 + 1.0087 = 139.9056 u product mass / energy > reactant mass / energy, so reaction cannot occur beta decay: reactant mass: 139.9019 product mass: 139.8919 + 0.0006 = 139.8925 u product mass / energy < reactant mass / energy, so reaction can occur	 1 1 1 1	 [4] **15**
77	(a) (i)	$E_p = \dfrac{(1.6 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12} \times 2.0 \times 10^{-15}}$ $= 1.15 \times 10^{-13}$ J allow 1.1×10^{-13} or 1.2×10^{-13} but not 1×10^{-13}	1 1	 [2]

(ii)	$E_p = 2E_k$	1	[1]
(iii)	$E_k = \frac{1.15 \times 10^{-13}}{2}$ (= 5.75×10^{-14}) J subs. $5.75 \times 10^{-14} = 2.1 \times 10^{-23} T$ $T = 2.7 \times 10^9$ K ans. allow ecf form (a)(ii) eg $E_K = E_P$ gives $T = 5.48 \times 10^9$	1 1	 [2]
(iv)	*either* ^1_1H nuclei have a range of speeds / energies *or* 5.75×10^{-14} J is only an average k.e; (1) some of them have enough energy to fuse; (1) quantum tunnelling can occur; (1) any 2	2	[2]
(b)	*either* ^1_1H consists of a single proton, so no binding has occurred *or* only one nucleon / proton so no further splitting possible;	1	[1]
(c)(i)	$4\,^1_1H \rightarrow \,^4_2He + 2\,^0_1e + 2\nu$ omits neutrinos altogether 0/1 allow 1 neutrino instead of 2 allow either neutrino or anti-neutrino	1	[1]
(ii)	binding energy of ^4_2He nucleus = 4×7.2 MeV (= 28.8 MeV) so energy released = $28.8 \times 10^6 \times 1.6 \times 10^{-19}$ = 4.61×10^{-12} J	1 1	 [2] **11**

78					
1	strong force	short range;		1	
2	electrostatic	long range;			
(3)	gravitational force	long range;	(1)	1	
4	strong force	sketch graph;			
5	electrostatic	*F* proportional to $1 / r^2$ *or* sketch graph;		1	
(6)	gravitational force	*F* proportional to $1 / r^2$ *or* sketch graph;	(1)	1	
7	strong force	holds nucleus together (against repulsion between protons);			
8		acts on all nucleons / protons and neutrons;			
9	electrostatic	acts only on protons / not on neutrons;		1	
10		always repulsive (in nucleus);		1	
11	gravitational force	(very) weak / negligible (inside nucleus);		1	
(12)		attractive only;	(1)	1	
(13)		acts on protons and neutrons;	(1)	1	
			any (1)	1	**[10]**
					10

79

a)	hadrons / baryons / nucleons;	1	[1]
(b) (i)	the proton is (totally) stable (inside the nucleus);	1	[1]
(ii)	free protons are stable	1	[1]
(c)	*either* $N = N_0 e^{-\lambda t}$ $\lambda = \frac{\ln 2}{613} = \frac{0.693}{613} = 1.13 \times 10^{-3}\ s^{-1}$ $N = 500 \times e^{-1.13 \times 10exp(-3) \times 200}$ subs. $= 500 \times 0.798$ $= 399$ ans. *or* $N = N_0 (0.5)^x$ where $x = t / T_{½}$ $x = \frac{200}{613} = 0.326$ half lives $N = 500\ (0.5)^{0.326}$ $= 500 \times 0.798$ $= 399$ allow 398 allow 2sf	1 1 1	 [3]
(d) (i)	charge / baryon number down quark: $-^1/_3$ / $^1/_3$ neutron: 0 / 1	1	[1]
(ii)	charge: 2/3 - 1/3 - 1/3 = 0 baryon number: 1/3 + 1/3 + 1/3 = 1	1 1	 [2]
			9

80

a		a nucleus (of a chosen element)	1	
		a particle/constituent of a nucleus, i.e. proton or neutron	1	2
b	i	A is at (81;208)	2	
	ii	B is at (84,212)	1	
	iii	There is no change in nucleon and proton number/ the emission is pure energy/e-m radiation/AW	1	4
c	i	a few cm/3 to 10 cm; about 1 m/0.3 – 2 m/several m; 1 to 5 mm Al/1 mm Pb 1 – 10 cm of Pb/several m of concrete *2 correct 1 mark, 4 correct 2 marks*	2	
	ii	source, absorbers placed in front of suitable detector on diagram	1	
		how results identify source; allowance for background	2	
		allow up to 2 marks for distance experiment		5
		Total		**11**

81			
(a)	readings of r and A and calculation of r_0 answer in range $(1.41 - 1.45)10^{-15}$ m ; misreads graph, gets 0/2	1 1	[2]
(b) (i)	radius $r = 1.43 \times 10^{-15} \times 235^{1/3}$ (= 8.82×10^{-15} m)	1	[1]
(ii)	mass of $^{235}_{92}U = 235 \times 1.67 \times 10^{-27} = 3.92 \times 10^{-25}$ (kg)	1	[1]
(iii)	density $\rho = m/V$ $= (3.92 \times 10^{-25}) / (^4/_3\, \pi\, [8.82 \times 10^{-15}]^3)$ $= 1.4 \times 10^{17}$ kg m^{-3}	1 1 1	[3]
(iv)	$X = 152$ $Y = 58$	2	[2]
(v)	$r_1 = r_0 A_1^{1/3}$ $r_2 = r_0 A_2^{1/3}$ so $r_1 / r_2 = (A_1 / A_2)^{1/3}$ $= (152 / 83)^{1/3} = 1.2(2)$ *or* calculates $r_1 = 7.63 \times 10^{-15}$ m $r_2 = 6.24 \times 10^{-15}$ m etc.	1 1	[2]
(vi)	*either* nucleons / protons and neutrons all equally spaced; *or* neutrons and protons have same size and are touching; (1) proton and neutron have (approx.) same mass; (1) spacing constant because strong force is short range (and much greater than electrostatic force); (1) any 2	2 **13**	[2]

82

(a)	because they cannot have less energy (on average) than the mean k.e. of the uranium atoms they collide with *or* AW; *or* (for zero k.e.) would need to move through material at absolute zero;	1	[1]
(b) (i)	processes: $\beta^{(-)}$ decays; *or* Pu-239 emits alpha-radiation; nuclides: uranium/U-239; (1) plutonium/Pu-239; (1) neptunium/Np-239; (1) any 1	1 1	 [2]
(ii)	otherwise, greater chance of absorption by U-238 ; this absorption does not produce a fission;	1 1	 [2]
(c)(i)	binding energies per nucleus: $^{235}_{92}U$ 7.6 × 235 (= 1786 MeV) $^{141}_{56}Ba$ 8.4 × 141 (= 1184 MeV) $^{92}_{36}Kr$ 8.6 × 92 (= 791 MeV) so energy released = (1184 + 791) - 1786 = 189 MeV fails to multiply by nucleon number: 8.4+8.6-7.6 = 9.4 gets (0,1,0) = 1/3	 1 1 1	 [3]
(ii)	number of U-235 atoms in 1.00 kg = 1.00 / (235 × 1.67 × 10^{-27}) = 2.55 × 10^{24} *or* 6.02 × 10^{23} / (0.235) = 2.56 × 10^{24} so energy released by fission of 1.00 kg of U-235 = 2.55 × 10^{24} ×200 × 1.6 × 10^{-19} × 10^{6} = 8.2 × 10^{13} J accept 8 × 10^{13} *or* 2.55 × 10^{24} × 189 × 1.6 × 10^{-19} × 10^{6} = 7.7 × 10^{13} J	 1 1 1	 [3]
(d)	idea that more / bigger proportion of neutrons escape from smaller mass; idea that chain reaction accelerates / more neutrons produced in each generation *or* AW; *or* alternative answer in terms of smaller bodies (with greater surface area/volume) cool more quickly (than larger bodies); can get 1/2	1 1	 [2] **13**

83 (a)	particles (to be fused) have positive / like charges, so repel / cause coulomb barrier; they have to be brought (very) close together for fusion / strong force to be attractive; so work has to be done / p.e. of system has to increase; (1) this work / p.e. has to come from k.e. of particles *or* AW; (1) any 1 for particles to have high k.e., (plasma) must have high temperature;	1 1 1 1	[4]
(b)(i)	**reaction 2** reactant mass = 2.01410 + 3.01605 (= 5.03015) product mass = 4.00260 + 1.00866 (= 5.01126) arith. mass defect = 0.01889 u ans. reaction 2 is more suitable because it generates more energy (per fusion reaction);	1 1 1	[3]
(ii)	(accuracy would not / could not be improved) because same number of electrons on both sides (of equation);	1	[1]
(iii)	all reactant nuclei have same charge / number of protons; so Coulomb barrier / repulsion / p.e. gained is same in both cases;	1 1	[2] **10**
84 (a)	$E = mc^2$ proton mass = 1.67×10^{-27} kg proton energy = $1.67 \times 10^{-27} \times (3.0 \times 10^8)^2$ (= 1.503×10^{-10} J) 1 GeV = $1.60 \times 10^{-19} \times 10^9$ (= 1.60×10^{-10} J) so proton mass = $\frac{1.503 \times 10^{-10}}{1.60 \times 10^{-10}}$ = 0.939 GeV	1 1 1 1	[4]
(b)	percentage increase = $\frac{6.00}{0.939} \times 100$ = 640 %	1	[1]
(c)(i)	proton mass = antiproton mass *or* figures make this clear energy required = 2×0.939 = 1.88 GeV	1 1	[2]
(ii)	incoming proton has momentum so products must have momentum *or* aware conservation of momentum for 1/2 so products have k.e.	1 1 1	[3]
(iii)	collide protons head-on, with equal speeds in opposite directions; (incoming protons have) no overall initial mtm so products have no mtm ;	1 1 **12**	[2]