1	(a)	(i) (Mean) time for the number of nuclei/activity of a nuclide to halve	1	
		(ii) 6 protons; 8 neutrons	2	[3]
	(b)	(i) ${}^{14}_{7}N(n,p){}^{14}_{6}C$ or $n + {}^{14}_{7}N \rightarrow {}^{14}_{6}C + p$ *-1 mark per error*	2	
		(ii) ${}^{14}_{7}N$ *-1 mark per error*	2	[4]
	(c)	(i) use of $\lambda T = 0.693$	1	
		$\lambda = 0.693/5700 = 1.2 \times 10^{-4}$ *2 marks if correct answer without working*	1	
		(ii) $f (= A/A_o) = \exp(-1.2 \times 10^{-4} \times 4 \times 10^{4}) = e^{-4.8}$	1	
		$= 8.2 \times 10^{-3}$ or 7.7×10^{-3} if sig figs not taken from **c(i)**	1	
		or by half lives: 40000/5700 = 7.02 T giving 1/128 = 7.8×10^{-3}	2	[4]
	(d)	Background count is the random radioactivity/count detected from the surroundings/cosmic rays/building materials, etc	1	
		(The count rate is so low that) no pattern of decay can be seen/the count appears purely random/cannot find half-life/AW	1	[2]

2	(a)	radius of 1 nucleon/proton/neutron/H nucleus	1	[1]
	(b)(i)	$r = 3.8 \times 10^{-15}$ m	1	
	(ii)	$r_0 = r / A^{1/3} = 3.8 \times 10^{-15} / 20^{1/3}$ $= 1.4 \times 10^{-15}$ m	1	[2]
	(c)	$\rho = m/V = m_0 / (\frac{4}{3} \pi r_0^3)$	1	
		$= 1.67 \times 10^{-27} / (\frac{4}{3} \pi [1.4 \times 10^{-15}]^3)$	1	
		$= 1.5 \times 10^{17}$ kg m^{-3} unit penalty	1	[3]
		(allow $1.4\text{-}1.5 \times 10^{5}$ from ecf)		
	(d)	answer to **(c)** is much greater than 70 kg m^{-3}	1	
		mass of atom ≅ mass of nucleus	1	
		so volume of atom >> volume of nucleus	1	
		conclusion eg most of atom is empty space / filled with low density electron (wave)	1	[4]
	(e)(i)	$V \alpha A$ or $V = \frac{4}{3} \pi R^3 = \frac{4}{3} \pi (r_0 A^{1/3})^3 = \frac{4}{3} \pi r_0^3 A$	1	
	(ii)	separation of nuclei constant/always the same	1	[2]

3 (a)		mass = 1.67×10^{-27} kg charge = -1.6×10^{-19} C	1 1	[2]
	(c)(i)	rest mass = $2 \times 1.67 \times 10^{-27}$ = 3.34×10^{-27} kg so energy equivalent = $\Delta m c^2$ = $3.34 \times 10^{-27} \times (3 \times 10^8)^2$ = 3.0×10^{-10} J	1 1 1	
	(ii)	$E = 2hf$ $3 \times 10^{-10} = 2 \times 6.63 \times 10^{-34} f$ $f = 2.3 \times 10^{23}$ Hz unit penalty	1 1	
	(iii)	circumstance: proton and antiproton are at rest/moving with negligible speed initially	1	[6]

4 (a)

	baryon	hadron	lepton	neutrino
neutron	✓	✓		

1 [1]

(b)

	baryon number	charge	strangeness
proton	1	+1	0
neutron	1	0	0
up quark	1/3	(+)2/3	0
down quark	1/3	-1/3	0

one mark per line correctly completed 3 [3]

	(c)(i)	quarks: up + down + down (or udd)	1	
1. 2. 3.	(ii)	baryon number: 1/3 + 1/3 + 1/3 = 1 charge: +2/3 - 1/3 -/1/3 = 0 strangeness: 0 + 0 + 0 = 0	1 1 1	[4]
	(d)(i)	$^1_0n \rightarrow ^1_1p + ^0_{-1}e + ^0_0\nu$ (+ *bar above 'ν' symbol*)	2	
	(ii)	no change to up and one down quark or by implication one down quark changes to up quark + electron + antineutrino	1 1	[4]

Question	Part	Answer	Mark	Total
5	(a)(i)	absorbed neutron causes/initiates/precipitates the reaction fission means splitting	1 1	
	(ii)	(neutron) with k.e./ speed ≈ k.e./ speed of surrounding molecules / in equilibrium with s. m.	1	[3]
	(b)(i)	uranium-236 $^{236}_{92}U$	1	
	(ii)	fissile nucleus has many more neutrons than protons (144:92) stable, smaller nuclei have neutron/proton ratio nearer to 1.0	1 1	[3]
	(c)(i)	$^{239}_{94}Pu \rightarrow {}^{235}_{92}U + {}^{4}_{2}He$	2	
	(ii)	*either* $N = N_0(½)^n$ $N/N_0 = (½)^{1/24}$ $= 0.972$ so decayed percentage = 2.8 % (or 3 %) *or* $N = N_0 e^{-\lambda t}$ where $\lambda = 0.6931 / 24\,000 = 2.89 \times 10^{-5}\,y^{-1}$ $= 0.6931 / (24\,000 \times 365 \times 24 \times 3\,600)$ $= 9.16 \times 10^{-13}\,s^{-1}$ $\ln(N/N_0) = -\lambda t = -2.89 \times 10^{-5} \times 1000 = -2.89 \times 10^{-2}$ so $N / N_0 = 0.97$ and decayed proportion = 3 % (alternatively, $\lambda t = 9.16 \times 10^{-13} \times 1\,000 \times 365 \times 24 \times 3\,600$ $= -2.89 \times 10^{-2}$ etc.)	 1 1 1 1	[6]

6

(a) He nucleus, a few cm/3 to 10 cm
About 1 m / 0.3-2 m /several m, 1 to 10 mm Al / 1 mm Pb
(high energy) e-m radiation, 1-10 cm of Pb/several m of concrete
2 correct 1 mark, 4 correct 2 marks — 3 [3]

(b) Source, absorbers placed in front of detector on diagram — 1
How results identify source) — 2
Allowance for background) to max 2 — 1
Allow for distance expt to max 2 — [3]

(c) (i) ^{235}U decays to $N/2^6$; ^{238}U decays to $N/2$ — 2
$= 1/2^5 = 0.03$ — 1
(ii) Ratio will have reached 0.0075 in a little over two half lives of ^{235}U, another 1.5×10^9 years; ^{238}U will have not halved again so ratio reaches 0.0072 soon after 6×10^9 years / calc for both isotopes / calc based on 235 varying and 238 constant / — 2
basis of suggestion unreliable max 1 — [5]

Total 11

7	(a)	α-particle scattering	1	
		suitable diagram with source, foil, moveable detector	1	
		2 or more trajectories shown	1	
		vacuum (to remove absorption)	1	
		most particles have little if any deflection	1	
		large deflection of very few	1	
		reference to Coulomb's law /elastic scattering	1	
		alphas repelled by nucleus (positive charges)	1	
		monoenergetic;	1	
		............*max 6 marks*		
		OR electron scattering	1	
		high energy	1	
		diagram with source sample, moveable detector/film	1	
		vacuum	1	
		electron accelerator or other detail	1	
		electrons diffracted by nucleus (as obstacle not slit)	1	
		most have zero deflection	1	
		characteristic angular distribution with minimum	1	
		minimum not zero	1	
		de Broglie wavelength	1	
		wavelength comparable to nuclear size hence high energy	1	
		.... *max 6 marks*		**[6]**
	(b)	**(i)** splitting of nuclei, fusing of nuclei/massive, light nuclei/large (200 MeV), small (30 MeV) energy release per reaction	1	
		release of energy/total mass decrease/'increase' in binding energy/ release radiation eg neutrons	1	
		(ii) neutron is absorbed by the nucleus;	1	
		which then splits into two (major) fragments;	1	
		and several/two/three neutrons	1	
		charges on/Coulomb repulsion pushes major fragments apart;	1	
		loss of mass/increased binding energy accounts for k.e. of fragments/release of energy	1	
		reference to $\Delta E = c^2 \Delta m$	1	**[6]**
		.... *max 4 marks* **Total**		**12**
		Quality of Written Communication		**[4]**

8 (a)	1. repulsive 2. attractive 3. attractive	-1 any error	1	[1]
(b) (i)	$F = (Q_1 Q_2)/(4\pi\varepsilon_0 r^2)$		1	
	$= (1.6 \times 10^{-19})^2/(4\pi \times 8.85 \times 10^{-12}[0.8 \times 10^{-15}]^2)$	accept 8.99×10^9	1	
	$= 360$ N or 359.7N	unit penalty once, in (i) or (ii)	1	
(ii)			1	
	$F = m_1 m_2 G/r^2$		1	
	$= (1.67 \times 10^{-27})^2 \times 6.67 \times 10^{-11}/(0.8 \times 10^{-15})^2$		1	[6]
	$= 2.9 \times 10^{-34}$ N	0.8/2 gives 1.16×10^{-33} N for 2/3		
	calculations transposed but otherwise correct, 3/6			
(c)	gravitational force (much) less than electrostatic force	allow ecf for 1/2	1	
	gravitational force is negligible / insignificant / virtually no effect / unimportant / much less / or works out ratio (about 10^{36})		1	[2]
(d)	(so, for protons equilibrium at) separation > x_0	(1)		
	strong force must be attractive	(1)		
	strong force (needs to be attractive to) balance repulsive electrostatic force	(1)		
	only small change in separation needed to produce 360 N, so equilibrium separation still close to x_0	(1)		
		any 3	3	[3]
9 (a)	number of nucleons: Rb 94, Cs 142, U 235	-1 each error	2	[2]
(b)	graph gives BE/nucleon values of: U 7.4 MeV (allow 7.3 - 7.4); Rb 8.6 MeV (allow 8.5 - 8.6); Cs 8.4 MeV	-1 each error	2	
	multiplies BE/nucleon by nucleon number		1	
	so total BE for U = 235 x 7.4 (= 1739 MeV)			
	Rb = 94 x 8.6 (= 808 MeV)		1	
	Cs = 142 x 8.4 (= 1193 MeV)		1	
	so total energy released = 808 + 1193 - 1739 = 262 MeV	process; allow 253 - 286 for ecf	1	
	allow 8.6 + 8.4 - 7.4 = 9.6 MeV for 1/4			[6]
(c) (i)	sketch graph, symmetrical, with equal, smooth peaks and smooth trough	-1 any error	2	
	correct general shape but not symmetrical gets 1/2			
(ii)	two positions, plausibly and symmetrically separated		1	
	correctly labelled		1	[4]
	take into account any numbers which are relevant to symmetry			

10 (a) (i) mixture of (free) ions / fully ionised gas / electrons stripped from atoms 1

1 [2]

detail: consist of nuclei (positive), electrons (negative)

1

(ii) high temperature /hot / but *not* 'heat' 1 [2]

so electrons have enough <u>energy</u> to escape from/break free from atom

(b) (i) nuclei / particles (but *not* atoms) have enough energy to overcome (mutual) repulsion / Coulomb barrier 1

(ii) high density / high pressure / nuclei (or particles) close together / many particles so probability greater / high concentration of particles 1 [2]

(c) (i) 1. ${}^{13}_{7}N \rightarrow {}^{13}_{6}C + {}^{0}_{1}\beta + {}^{(0)}_{(0)}\nu$ 1

nitrogen nucleus decays/splits (*not* fissions) with emission of positron (*not* proton) and neutrino 1

allow ${}^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{1}e + \nu$

and proton decays to neutron, positron and neutrino, for 2/2

2. ${}^{12}_{6}C + {}^{1}_{1}H \rightarrow {}^{13}_{7}N$ 1

carbon nucleus and proton fuse / join together / combine / absorb / capture to form nitrogen 1

(-13) nucleus

no mention of 'nucleus' in 1. or 2. -1 once only

(ii) 1

$4\,{}^{1}_{1}H \rightarrow {}^{4}_{2}He + 2\,{}^{0}_{1}\beta$ (or $2\,{}^{0}_{1}e$) + $2\,{}^{(0)}_{(0)}\nu$

allow ${}^{12}_{6}C$ or other nuclide on both sides 1 [6]

4 protons form a helium <u>nucleus</u>, 2 positrons and 2 neutrinos

11 (a) (i) leptons 1

(ii) hadrons/baryons 1 [2]

(b) ${}^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{(+1)}e$ (or ${}^{0}_{1}\beta$) + ${}^{(0)}_{(0)}\nu$

particle symbols correct throughout ie letters 1

charge and mass numbers correct throughout, (apart from 0,0 for neutrino) 1 [2]

(c) (i) proton up, up, down (or uud) 1

neutron up, down, down (or udd) 1 [2]

(ii) $u \rightarrow d + e + \nu$

allow

u		u	
u	→	d	+ e^+ (or β^+) + ν
d		d	

1 [1]

(iii)

before:	up quark (proton)	baryon number	$\frac{1}{3}$ (1)	
		charge	$\frac{2}{3}$ (1)	
after:	down quark (neutron)	baryon number	$\frac{1}{3}$ (1)	
		charge	$-\frac{1}{3}$ (0)	2
	positron	baryon number	0	
		charge	+1	
	neutrino	baryon number	0	
		charge	0	1

baryon number: $\frac{1}{3} = \frac{1}{3} + 0 + 0$ *or* $\frac{1}{3} + \frac{1}{3} + \frac{1}{3} \rightarrow \frac{1}{3} + \frac{1}{3} + \frac{1}{3} + 0 + 0$ 1

1 [5]

charge $\frac{2}{3} = -\frac{1}{3} + 1 + 0$ *or* $\frac{2}{3} + \frac{2}{3} - \frac{1}{3} \rightarrow \frac{2}{3} - \frac{1}{3} - \frac{1}{3} + 1 + 0$

12	(a)	plots graph: points to within ½ square line to within ½ square of every point -1 each error	2 1	[3]
	(b) (i)	tries to find correct intercept A_0 = 90 x 10^6 Bq value of A_0 87 - 95 unit penalty beware 10^6 omitted	1 1	
	(ii)	half life = 28 years accept 26 - 30	1	[3]
	(c)	$\lambda = 0.693/(t_{1/2}) = 0.693/28$ $= 2.5 \times 10^{-2}\,y^{-1}$	1	[1]
	(d)	$A/A_0 = e^{-\lambda t}$ $0.01 = e^{-0.025t}$ allow A, A_0 values (where A_0 = 100 A), not rearranged $\ln(0.01) = -2.5 \times 10^{-2} t$ $t = \ln(0.01)/(-0.025)$ = 184 years 2/3 for method involving repeated halving A/A_0 = 100/1 can get 1/3 for ln step A/A_0 = 99/100 can get 2/3 (0, 1, 1). This gives 0.40 y	1 1 1	[3]
13	(a) (i)	1 94 2 239 – 94 = 145	1	1
	(ii)	1 92; 2 143 *ecf from a(i) 2*	2	2
	(b)	$\lambda = 0.693/T$ *on page 3* = 0.693/24000 x 3.2 x 10^7 = 9 x 10^{-13} (s^{-1})	1	1
	(c) (i)	n = P/ε ;=2.5/8.2 x 10^{-13} = 3.0(48) x 10^{12}	2	2
	(ii)	A = λN; N = 3 x 10^{12}/9 x 10^{-13} = 3.3 x 10^{24} *ecf from b*	1 1	2
	(iii)	m = N/N_A.M / = (3.3 x 10^{24}/6.02 x 10^{23}) x 0.239 ; =1.3(4) (kg) *ecf (c)(ii)* *aliter* m = AuN / = 239 x 1.66 x 10^{-27} x 3.3 x 10^{24}	2	2
	(d)	advantage: (higher energy per particle/shorter half-life) so smaller mass required/AW disadv.: power does not remain 'constant' for long period/AW safety alternatives: short half-life means fewer disposal/storage problems; higher energy per particle needs more shielding *max 2 marks*	1 1 2	2
		[Total		1:
14	(a)	Nucleus contains most/almost all of mass of atom/detail such as $m_p = m_n$ = 2000 m_e /atom volume almost all empty space/AW; nucleus consists of protons and neutrons; p positively charged, n neutral, e negatively charged; surrounded by cloud of electrons; equal numbers of protons and electrons (to make atom neutral); ratio of p to n; idea of isotope/element; p & n made of quarks, etc. *maximum 4 marks*	1 1 1 1 1 1	4

15 Question	Expected Answers	Marks	
(a) (i)	$F_E \propto 1/r^2$ or $F_E = Q^2/(4\pi\varepsilon_0 r^2)$ or in words	1	
(ii)	$F_G \propto (-)1/r^2$ or $F_G = (-)m^2G/r^2$ or in words	1	[2]
(b)	electrostatic forces (between protons) always repulsive gravitational forces always attractive	1	[1]
(c)	(at equal separations) magnitude of F_E >> magnitude of F_G so F_E scale has bigger range of values than F_G	1 1	[2]
(d)(i)	d_0 is equilibrium separation	1	
(ii)	PQ: repulsive; QR: attractive	1	
(iii)	if neutrons get closer/further apart than Q, they repel/attract ; idea that force acts to restore/return particle to same point/separation	2	[4]
(e)	$\rho = m/V = m_n/[(4/3)\pi r^3]$ $= 1.67\times10^{-27}/[(4/3)\pi(1.4 \times 10^{-15}/2)^3]$ $= 1.16\times10^{18}$ kg m^{-3} ans. + unit uses $r = 1.4\times10^{-15}$ gives 1.45×10^{17} kg m^{-3} allow ecf so 1, 0, 1 = 2/3 $\rho = m/r^3$ ie assumes a cube of side r giving 4.9×10^{18} gets 0 0 1 = 1/3 $\rho = m/(2r^3)$ ie cube of side $2r$ gives 6.1×10^{17} and gets 0 1 1 = 2/3	1 1 + 1	[3]

16 Question	Expected Answers	Marks	
(a)	fission means splitting nucleus into parts caused by absorption/capture of a neutron idea reaction cannot start without neutrons neutrons having ke's comparable with ke of thermal molecular ke /slow moving/low energy	1 1 1 1	[4]
(b)	BE of products = 1210 + 760 = 1970MeV BE of reactant = 1770 MeV so energy released = 1970 - 1770 = 200 MeV energy in joule = $200\times10^6\times1.6\times10^{-19}$ (= 3.2×10^{-11} J)	1 1 1	[3]
(c)(i)	mass of U-235 = 0.03x4.2 = 0.126 (kg) mass of 1 atom = $0.235/(6.02\times10^{23})$ = 3.9×10^{-25} (kg) (so number of atoms = $0.126/(3.9\times10^{-25}) = 3.23\times10^{23}$)	1 1	
(ii)	total energy = $3 \times 10^{23} \times 3.2 \times 10^{-11}$ = 9.6×10^{12}J (3.23×10^{23} gives $1.0(3)\times10^{13}$ for1/1)	 1	
(iii)	power = E/t = $9.6\times10^{12}/(2 \times 3.16 \times 10^7 \times 3) = 5.06\times10^4$ W (=50.6 kW) (1.03×10^{13} gives 5.43×10^4 (W) (= 54.3 kW) for 2/2)	1 1	[5]

17 **stion**

(b)(i)	$^1_1H + ^1_1H \rightarrow ^2_1H + ^0_1\beta$ (+ν)	1	
(ii)	$^2_1H + ^1_1H \rightarrow ^3_2He$	1	
(iii)	$^3_2He + ^3_2He \rightarrow ^4_2He + 2\,^1_1H$	1	
(c)	$^3_2He + ^3_2He \rightarrow ^4_2He + 2\,^1_1H$ $2\,^2_1H + 2\,^1_1H \rightarrow 2\,^3_2He$ $2\,^1_1H + 2\,^1_1H \rightarrow 2\,^2_1H + 2\,^0_1\beta$ (+2ν) allow β^+ *or* ^0_1e add: $6\,^1_1H \rightarrow ^4_2He + 2\,^0_1\beta + 2\,^1_1H$ process cancel two ^1_1H's: $4\,^1_1H \rightarrow ^4_2He + 2\,^0_1\beta$ (+ 2ν) final equation	 1 1	 [5]

Question	Expected Answers	Marks	
18 (a)	strange, charm, top, bottom (any order) 2 quarks per mark: 2/4 or 3/4 gets 1/2	2	[2]
(b)(i) (ii)	ddu duu	1 1	 [2]
(c)(i)	emission of electrons and positrons accept β^+ and β^-	1	
(ii) 1 2	$^{14}_6C \rightarrow ^{14}_7N + ^0_{-1}e$ (+ ν-bar) $^{14}_8O \rightarrow ^{14}_7N + ^0_1e$ (+ ν)	1 1	
(iii) 1 2	(electron) anti-neutrino (electron) neutrino	1 1	
(iv)	neutrons: decrease of 1 (8 to 7) protons: increase of 1 (6 to 7) protons, neutrons correct electrons: increase of 1 (emitted electron) electrons correct	 1 1	
(v)	$d^{(-1/3)} \rightarrow u^{(2/3)} + e^{(-1)}$ *or* down quark decays to up quark and electron	1	[8]

Question	Expected Answers	Marks	
19 (a)	$^{105}_{45}Rh \rightarrow ^{105}_{46}Pd + ^0_{-1}e$ (+ $^0_0$ν-bar)	1	[1]
(b)	mass difference = 104.905 44 - (104.904 83 + 0.000 55) = 0.000 06 u (ignores electron gives 0.00061u gets 0 1 =1/2)	1 1	 [2]
(c)	0.000 06 u = 0.000 06x1.66x10^{-27} *or* E = 0.000 06x931 (= 9.96x10^{-32} kg) $E = \Delta m c^2$ = (0.055 9) MeV = 9.96x10^{-32}x $(3x10^8)^2$ = 0.055 9 x10^6x 1.6 x 10^{-19} = 9.0x10^{-15} J = 9.0x10^{-15} J (omits u → kg step gives 5.4 x 10^{12} J for 0 1 1 = 2/3 ecf from (b): 0.00061 gives 9.1 x 10^{-14} J for 3/3)	1 1 1	 [3]
(d)	9.0x10^{-15} = ½ x 9.11x$10^{-31}v^2$ so v = 1.4 x10^8m s^{-1} (9.1 x 10^{-14} gives 4.47 x 10^8 for 2/2, m_e = 0.00055kg gives 5.7 x 10^{-6} for 1/2)	1 1	 [2]
(e)	(recoiling) nucleus has some energy/ke (1) neutrino takes some energy (1) accept relativistic mass increase means lower speed (for same ke)(1) any 2	2	[2]

20			
(a)	*Activity*:The number of atoms/nuclei which decay/decays per second from/within the sample	1	
	factors affecting activity:the decay constant/the half-life/the nature of the nuclide;	1	
	the number of undecayed nuclei present; which determines how many will decay in the next second as the probability of decay is fixed/AW	2	
	time factor/how old the sample is/the shorter the half-life the more decays per second/other sensible similar statements	1	
	factors not affecting activity: maximum of two sensible suggestions such as pressure, temperature, chemical reaction, etc.	2	
	maximum 6 marks		6
(b)	*similarities*: both release energy in process;	1	
	(rest) mass of fragments less than original;	1	
	conservation of charge/mass-energy, etc. *maximum 2 marks*	1	
	differences:decay into two particles; fission into more particles/4 or 5;	2	
	decay energy release is small compared to fission;	2	
	decay cannot be initiated by any known process/random/spontaneous/ obeys laws of probability/AW; fission can be initiated by incident neutron/fission rate can be varied/controlled/AW;	2	
	energies and masses in decay always the same; fission can be into many different combinations with different energies;	2	
	most of energy in decay carried away by small particle; in fission by massive particles/fragments;	2	
	any other sensible difference with 1 mark for description of each process in comparison (marks must be awarded in pairs) maximum mark 4	2	6
	Quality of Written Communication (see separate sheet)		4
	Total		**16**

Question	Expected Answers	Marks	
21 (a)	graph: curved, in correct sense starts at origin and eventually approaches horizontal (straight line scores zero)	1 1	[2]
(b)	r_0 is radius of 1 proton/ neutron/ nucleon/ hydrogen nucleus (not nucleus/ nuclei/ atom/ molecule)	1	[1]
(c)	$r_0 = r/A^{1/3} = 3.53 \times 10^{-15}/16^{1/3}$ correct subs. $(= 1.4 \times 10^{-15}$)m	1	[1]
(d)	$r = r_0 A^{1/3} = 1.40 \times 10^{-15} \times (79 + 118)^{1/3}$ subs. $= 8.15\times10^{-15}$ m allow 8.1×10^{-15} or 8.2×10^{-15} *omits 79 or 118 can score 1/2*	1 1	[2]
(e)(i)	$V = (4/3)\ \pi r_0^3$ $= (4/3)\ \pi (1.4 \times 10^{-15})^3$ $= 1.149 \times 10^{-44}$ m^3 allow 1 sf (using gold or oxygen radius can score 1/2 only)	1 1	[2]
(ii)	(likely to be) more than16 times as great because of spaces between nucleons (calculated values compared scores zero)	1 1	[2]

22 (a)	similarity: both have same number/ 92 (of) protons/ charge/ are radioactive difference: *either* have different numbers/146 and 143 (of) neutrons *or* ^{235}U fissions but ^{236}U does not (not different mass number/nuceon number)	1 1	
(b)	Reaction 1: $^{238}_{92}U + ^{1}_{0}n \rightarrow ^{239}_{92}U$ Reaction 2: $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U$ (showing only fission products on RHS does not score)	1 1	(
(c)(i)	$^{239}_{92}U \rightarrow ^{239}_{93}Np + ^{0}_{-1}e$ (+v-bar) $^{239}_{93}Np \rightarrow ^{239}_{94}Pu + ^{0}_{-1}e$ (+v-bar) allow $^{0}_{-1}\beta$ or $^{0}_{-1}e$ (if equation not clear but $^{0}_{-1}e$ comes sideways from = sign, allow 1/2 max)	1 1	[
(ii)	(anti)neutrino/ v	1	[
(d)(i)	two nuclei not nuclides/ isotopes/ atoms/ molecules/ elements/ fragments not specific example (several) neutrons	1 1	[
(ii)	0.01%	1	[
(iii)	total mass/number of nucleons of products (from one nucleus) is constant so for every product nucleus which has less than half the mass of the fissile /original nucleus, there is a nucleus which has more than half its mass <u>*or*</u> wtte	1 1	[2
23 a)(i)	strong (interaction)	1	[1]
(ii)	graph: shape - general shape - (asymptotic to force axis) falls to zero against distance axis labels: attraction and repulsion correctly labelled	1 1 1	[3]
(c)	charge: -1 + 1 = 0 + 0 baryon number: 0 + 1 = 1 + 0 strangeness: 0 + 0 = 0 + 0 <u>conclusion</u>: reaction may take place allow ecf (if = sign missing -1 if + sign missing -1)	1 1 1 1	[4]

24	a	i	An element can exist in more than one form, having a different number of neutrons/can have different mass but same proton number/AW		1
		ii	${}^{4}_{2}He$ / ${}^{4}_{2}\alpha$; (-) ${}^{0}_{-1}e$ / ${}^{0}_{-1}\beta$		2
		iii	${}^{238}_{92}U \rightarrow {}^{234}_{92}U + {}^{4}_{2}\alpha + {}^{0}_{-1}\beta + {}^{0}_{-1}\beta$	3	
			or ${}^{238}_{92}U \rightarrow {}^{234}_{90}X + {}^{4}_{2}\alpha$	1	
			${}^{234}_{90}X \rightarrow {}^{234}_{91}Y + {}^{0}_{-1}\beta$	1	
			${}^{234}_{91}Y \rightarrow {}^{234}_{92}U + {}^{0}_{-1}\beta$	1	
			or α followed by two β decays;	1	
			nucleon number =238 – 4 – 0 – 0 = 234;	1	
			proton number = 92 – 2 + 1 + 1 = 92	1	
			or answer in terms of A,p or n,p diagram		3
	b	i	N : the number of undecayed nuclei/nuclei of the original element (remaining)	1	
			N_o : the initial/original number of nuclei present	1	
			λ : the (decay) constant relating the activity to the number of undecayed nuclei/AW/the probability of a given nucleus decaying in the next second	1	3
		ii	$f = N/N_o = e^{-\lambda t}$; = $\exp(-0.693 \times 4.6 \times 10^9/7.1 \times 10^8)$;	2	
			= $\exp(-4.49) = 0.011$	1	
			or time = 6.48 half lives; so $f = 1/2^{6.48}$; = 0.011	3	3
			Total		**12**

	Question	Expected Answers	Marks	
25	(a)	strong /force interaction is zero	1	[1]
	(b)	$F_E = Q_1 Q_2/(4\pi\varepsilon_0 r^2)$; $= (1.6 \times 10^{-19})^2/[4\pi \times 8.85 \times 10^{-12} \times (0.82 \times 10^{-15})^2]$; $= 3.4 \times 10^2$ N ; ans.	1 1 1	[3]
	(c)(i)	indicates slightly larger separation; explanation: protons repel; (1) because they have like charges; (1) hence strong force is attractive; (1) relates to graph eg below axis, *F* is attractive; (1) any 3	1 3	[4]
	(ii)	(approx.) 3.4×10^2 N; reason: because strong force must balance electrostatic / repulsive force;	1 1	[2]

26 (a)	<u>nucleus absorbs / captures a neutron</u> ; meaning of thermal neutron ; (1) <u>new nucleus splits into two (roughly equal) parts</u> ; energy is released in fission ; (1) new nuclei (are unstable and) emit neutrons ; (1) but need moderating / slowing down ; (1) <u>emitted neutrons can cause further nuclear reactions, hence chain / self-sustaining reaction</u> ; suitable equations: eg $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U$ $^{236}_{92}U \rightarrow X + Y$ X (or Y) $\rightarrow$ W + neutrons any equation; (1) any 3	1 1 1 3	

27 a)(i)	$E_k = 2.1 \times 10^{-23} \times 3 \times 10^{8} n = 6.3 \times 10^{-15} n$ J so ke of one particle = 6.3×10^{-15} J	1	[1]
(ii)	(no) idea of random motion / spread of velocities / energies / this value is only an average value	1	[1]
(b)(i)	nuclei both have same (kind of) / positive charge ; so they repel	1 1	[2]
(ii)	graph: negative gradient throughout ; curved correctly and reaches zero ;	1 1	[2]
(iii)	adds ke's ; ke is <u>all</u> converted to pe / states law of energy / states no extra work done ;	1 1	[2]
(iv)	$r = Q_1 Q_2 / (4\pi\varepsilon_0 E_P) = (1.6 \times 10^{-19})^2 / (4\pi \, 8.85 \times 10^{-12} \times 1.3 \times 10^{-14})$; subs. $= 1.8 \times 10^{-14}$ m ; ans.	1 1	[2]
(c)	$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + ^{1}_{0}n$ (+energy)	1	[1]