85			
(a)	$R = \frac{0.72}{99.28} = 0.00725$	1	[1]
(b)	uranium/U-235 has a shorter half-life	1	[1]
(c)	uses $R = R_0 (½)^x$ x = no. of half-lives		
	no. of half-lives = $\frac{4.6 \times 10^9}{8.4 \times 10^8}$ (= 5.48)	1	
	$0.00725 = R_0 (½)^{5.48}$	1	
	so R_0 = 0.32(3) ans.	1	[3]
	sensible attempt using repeated doubling can get 1/3		
	or $R = R_0 e^{-\lambda t}$ where $\lambda = \frac{\ln 2}{8.4 \times 10^8} = 8.30 \times 10^{-10}$ y^{-1} (1)		
	$0.00725 = R_0 e^{-8.30 \times \exp.(-10) \times 4.6 \times \exp.(9)}$ (1)		
	$= R_0 e^{-3.82}$		
	R_0 = 0.32(3) (1)		
(d)	N_0 for U-235 approx. 1/3 of N_0 for U-238;	1	
	R clearly decreasing with time;	1	[2]
(e)(i)	proton number = -2 neutron number = -2	1	[1]
(ii)	proton number = +1 neutron number = -1	1	[1]
(iii)	$p = 92 - 7 \times 2 + 4 \times 1 = 82$	1	
	$n = (235 - 92) - 7 \times 2 - 4 \times 1 = 125$	1	[2]
			11

Question	Expected Answers	Marks
86 (a)	lists all quarks: u d s c t b *or* in words ; (1) quarks are fundamental particles *or* AW ; (1) every quark has an antiquark ; (1) every antiquark has opposite values of *Q, B, S* ; (1) quarks are held together by strong force / gluons ; (1) *Q, B, S* are conserved in quark reactions ; (1) any 3	3
	either neutron is udd *or* proton is uud ;	1
	either $Q = {}^2/_3 - {}^1/_3 - {}^1/_3 = 0$ so charge (on neutron) is zero *or* $Q = {}^2/_3 + {}^2/_3 - {}^1/_3 = 1$ so charge (on proton) is 1 ;	1
	$B = {}^1/_3 + {}^1/_3 + {}^1/_3$ so baryon number = 1 *and* $S = 0 + 0 + 0 = 0$ so strangeness = 0 NOT particles / neutron, proton have no strangeness	1 [6]
(b)	electron (1) ; positron (1) ; muon (1) ; tau (1) ; electron neutrino (1) ; muon neutrino (1) ; kaon neutrino (1) ; allow any antiparticle to any of these any 4 -1 each error/omission	2
	weak force ;	1
	$p^+ \rightarrow n^0 + e^+ + \nu$ (2) $n^0 \rightarrow p^+ + e^- + \nu$–bar (2) $u \rightarrow d + e^+ + \nu$ (2) $d \rightarrow u + e^- + \nu$ (2) *or* ${}^{239}_{92}U \rightarrow {}^{239}_{93}Np + {}^{0}_{-1}e + \nu$–bar (2) *or* ${}^{239}_{93}Np \rightarrow {}^{239}_{94}Pu + {}^{0}_{-1}e + \nu$–bar (2) equation omits ν , gets 1/2	2 [5]
		11

87				
	b	α-particle scattering proves existence of a nucleus to the atom:	1	
		suitable diagram **and**/**or** description to illustrate experiment	1	
		most particles have little if any deflection	1	
		large deflection of very few shows nucleus is small	1	
		and very massive/dense	1	
		deflection explained on basis of charged particle interaction (Coulomb's law)	1	
		to estimate nuclear size :		
		of order of 10^{-14} m	1	
		head-on collision/back scattering	1	
		enables distance of closest approach to be calculated	1	
		using conservation of energy argument (by equating distant k.e. to Coulomb potential energy) *max 6*	1	**6**
		Total		**11**
		Quality of Written Communication (see separate sheet)		**4**

88			
	(a)	curve of correct general shape and in correct quadrant; crosses strong force line for [F] << [F_{max}] ;	1 1 [2]
	(b)	strong force (graph) falls to zero / hits x axis ; electrostatic force (graph) does not quite become zero /is asymptotic to x axis	1 1 [2]
	(c)	$F_e \ \alpha \ 1/x^2$ *or* $F_e = Q_1 Q_2 / (4\pi\varepsilon_0 x^2)$ accept relationship is inverse square, in words	1 [1]
	(d)(i) (ii)	$F_E = \frac{Q_1 Q_2}{4\pi\varepsilon_0 x^2}$ Accept $\frac{1}{4\pi\varepsilon_0} = k$ $F_G = \frac{m_1 m_2 G}{x^2}$ Allow direct substitution into expression for R so $\frac{F_E}{F_G} = R = \frac{Q_1 Q_2}{4\pi\varepsilon_0 m_1 m_2 G}$ eliminates x correctly states Q_1 Q_2 m_1 m_2 ε_0 G all constant *or* AW subs. $R = \frac{(1.6 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12} \times (1.67 \times 10^{-27})^2 \times 6.67 \times 10^{-11}}$ ans. $= 1.24 \times 10^{36}$ 8.1×10^{-37} (inverse) gets 1/2	1 1 1 1 1 [5] **10**

89			
	(a)(i)	finds BE / nucleon from graph: U 7.40 MeV Cs 8.15 Rb 8.20 calculates BEs per nucleus : U 7.40×236 = 1746 MeV Cs 8.15×138 = 1125 Rb 8.20×96 = 787 calculates energy released: = 1125 + 787 - 1746 = 166 MeV allow 165 -1 each for graph reading errors but allow ecf wrong BE per nucleon – no ecf doesn't multiply by nucleon number to get 8.95 gets 1, 0, 0, 0 = 1/4	1 1 1 1 [4]
	(ii)	becomes k.e. of neutrons / product nuclei ; (1) energy transferred by collisions with other nuclei ; (1) becomes random k.e. / heat of surrounding nuclei / material ; (1) allow: initially (electrostatic) p.e. of product nuclei; (1) any 3	3 [3]
	(b)	general shape ; symmetry and quality ;	1 1 [2]
	(c)(i)	correct point **P** ; allow **P** marked on *x* axis	1 [1]
	(ii)	$^{236}_{92}U$ -> 2 $^{118}_{46}X$ allow $^{235}_{92}U + ^{1}_{0}n$ on left hand side	1 [1] **11**

90 (a)(i)	24 000 y ans.	1 [1]
(ii)	Pu graph showing exponential decay from N_0 ; falls to about $^1/_4$ of N_0 ; U graph: N sensibly = N_0 - N_{Pu} no labels -1	1 1 1 [3]
(iii)	24 000 y allow ecf	1 [1]
(iv)	*either* because U-235 itself decays (very) slowly *or* because of randomness half-life is an average value or AW	1 [1]
(b)	mass defect = 239.000 58 - (234.993 45 + 4.001 51) = 0.005 62 u so energy released / E = $m c^2$ = $0.005\ 62 \times 1.66 \times 10^{-27} \times (3.00 \times 10^8)^2$ subs. (= 8.4×10^{-13} J) allow use of 1 u = 931 MeV	1 1 1 [3]
(c)(i)	$E_k = ½ m v^2$ $8.4 \times 10^{-13} = ½ \times 4 \times 1.67 \times 10^{-27} v^2$ $v = 1.59 \times 10^7$ m s^{-1} allow 1.6×10^7 (8×10^{-13} gives 1.55×10^7 m s^{-1})	1 1 [2]
(ii)	*either* mass of alpha-particle has increased (slightly) (due to relativity) *or* recoiling U-235 nucleus has (absorbed) some energy/momentum *or* γ-emission which takes some energy	1 [1] **12**

91 (a)(i)		
	LHS RHS reaction 1 Q 0 0+1 (B 1 1 +0) (S 0 -1+0) (No) because Q (and S) do not balance	1
	reaction 2 Q 0 +1-1+0 B 1 1+0+0 S 0 0+0+0 (Yes) because Q B and S / all balance two out of three gets 1/2	2
	reaction 3 Q +1 +1+0 B +1 0+0 (S 0 0+0) (No) because B doesn't balance	1
	reaction 4 Q +1 0+1+0 B +1 +1+0+0 S 0 0+0+0 (Yes) because Q B S / all balance two out of three gets 1/2	2 [6]
(b)	if not, baryon numbers could not balance ; answers involving quarks score zero	1 [1]
(c)	no baryon has mass less than proton mass ; (neutron decay:) ${}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e + \bar{\nu}$ gets 2/2 $n \rightarrow p^{+} + e^{-} + \nu$–bar gets 2/2 $n \rightarrow p + e + \nu$ (–bar) gets 1/2 proton mass + electron mass $<$ neutron mass ;	1 2 1 [4]

(d)	when inside a (stable) nucleus ;	1 [1] **12**	
92 a) 1	(very) high temperature ; not 'very hot'	1	
	(very) high density / no. of nuclei per unit volume *or* AW ; not 'high pressure'	1	
2	matter in plasma state ; (1)		
3	mixture of nuclei/ions and electrons ; (1)		
4	plasma forms because high temperature gives electrons enough energy to break free from atom / nucleus ; (1)		
5	high density because gravity pull / attraction pulls nuclei / particles / plasma together ; not 'confines' (1)		
6	high density means many collisions /per second *or* greater rate of collisions ; (1)	1	
7	high temperature because gravity has caused matter to heat up during star formation *or* AW ; (1)	2	[5]
8	high temperature (not 'heat') means protons (not 'particles') have enough (kinetic) energy ;		
9	-to overcome (electrostatic) repulsion (between them / Coulomb barrier ; (1)	1	
10	any 2		
		1	
	$4\,^{1}_{1}H \rightarrow\ ^{4}_{2}He + 2\,^{0}_{1}e + 2\nu$ -1 each error	1	
(b)	equation without neutrino includes		
11	neutrino (1)		
12	(energy generated because) *either* fusion results in greater BE / nucleon *or* there is a loss of (rest) mass in fusion ;		

13	(few fusions because) mean k.e. (of protons) not enough to overcome repulsion / Coulomb barrier ;	4	[7]
14	nuclei have a range of speeds / energies (at a given temperature) ; (1)	12	
	only a few have enough energy to fuse ; (1)		
15	multistage process which few protons actually complete *or* AW ; (1)		
16	most collisions not head-on (so not all of k.e. available) ; (1)		
	any 4		

93	**(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)	$^{238}_{92}U \rightarrow\ ^{234}_{92}U + ^{4}_{2}\alpha + ^{0}_{-1}\beta + ^{0}_{-1}\beta$ or $^{238}_{92}U \rightarrow\ ^{234}_{90}X + ^{4}_{2}\alpha$ $^{234}_{90}X \rightarrow\ ^{234}_{91}Y + ^{0}_{-1}\beta$ $^{234}_{91}Y \rightarrow\ ^{234}_{92}U + ^{0}_{-1}\beta$ or α followed by two β decays; nucleon number =238 – 4 – 0 – 0 = 234; proton number = 92 – 2 + 1 + 1 = 92	**3** **1** **1** **1** **1** **1** **1**	**3**	**accept** answer in terms of A,p or n,p diagram
	(b)	**(i)**	N : the number of undecayed nuclei/nuclei of the original element (remaining) N_o : the initial/original number of nuclei present 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** **1** **1**	**3**	
		(ii)	$f = N/N_o = e^{-\lambda t}$; = exp(-0.693 x 4.6 x10^9/7.1 x 10^8) ; = exp(-4.49) = 0.011 or time = 6.48 half lives; so f = 1/$2^{6.48}$; = 0.011	**2** **1** **3**	**3**	
			Total		**12**	

Question	Expected Answers	Marks
94 (a)(i)	r : radius of nucleus / nuclei r_0 : radius of nucleon / proton / neutron / hydrogen nucleus; A : number of nucleons / (protons + neutrons) / mass number; each omission (-1)	2 [2]
(ii)	line curves in correct sense from origin but doesn't become horizontal; any part drawn with ruler loses this mark	1 [1]
(b)(i)	$r = r_0 A^{1/3} = 1.41 \times 10^{-15} \times 59^{1/3}$ $= 5.49 \times 10^{-15}$ m do not allow 5.5×10^{-15} m	1 1 [2]
(ii)	$m = V\rho$ or $\rho = m / V$ allow $m = {}^4/_3 \pi r^3 \rho$ $= {}^4/_3 \pi (5.49 \times 10^{-15})^3 \times 1.44 \times 10^{17}$ (= 9.98×10^{-26} kg)	1 1 [2]
(c)(i)	protons: 27, neutrons: 32;	1 [1]
(ii)	mass = $27 \times 1.673 \times 10^{-27} + 32 \times 1.675 \times 10^{-27} = 9.88 \times 10^{-26}$ kg (9.877×10^{-26}) allow ecf from **(c)(i)** allow 2 sf	1 [1]
(d)	difference in mass = $0.1(0) \times 10^{-26} = 1 \times 10^{-27}$ (kg) allow ecf from **(b)(ii)** and **(c)(ii)** $E = (\Delta) m c^2$ $= 1 \times 10^{-27} \times (3 \times 10^8)^2 = 9 \times 10^{-11}$ J	1 1 1 [3] **12**

95 a)(i)	$^{238}_{92}U + ^{1}_{0}n \rightarrow ^{239}_{92}U$	1	
(ii)	$^{239}_{92}U \rightarrow ^{239}_{93}X + ^{0}_{-1}e + ^{(0)}_{(0)}\nu$(–bar)	2	
(iii)	$^{239}_{93}X \rightarrow ^{239}_{94}Pu + ^{0}_{-1}e + ^{(0)}_{(0)}\nu$(–bar)	1	[4]
	wrong neutrinos: 1,1,1 = 3/4		
	omits one neutrino: (1,2,0) or (1,1,1) = 3/4 max.		
	omits both neutrinos (1,1,0) = 2/4 max.		
	use of $^{0}_{+1}e$ gets 0 for equation		
(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.	1	
	$= 9.16 \times 10^{-13}\ s^{-1}$ *or* $< 9.16 \times 10^{-13}\ s^{-1}$ ans.	1	[2]
	1. $\times 10^{-5}\ y^{-1}$ gets 1 / 2		
	$2.89 \times 10^{-5}\ s^{-1}$ gets 0 / 2		
	allow memorised years to seconds conversion factor		
(c)(i)	*either*		
	239 g of Pu contain 6.02×10^{23} atoms		
	$N = (0.05 \times 3.5 / 0.239) \times 6.02 \times 10^{23}$ includes expression for no. of moles	1	
	$= 4.41 \times 10^{23}$ (atoms) answer	1	[2]
	or		
	mass of Pu-239 $= \frac{5 \times 3.5}{100} = 0.175$ kg		
	no. of Pu-239 atoms $= \frac{0.175}{239 \times 1.67 \times 10^{-27}}$ includes expression for atom mass	(1)	
	$= 4.385 \times 10^{23}$ answer	(1)	
(ii)	activity $= \lambda N$		
	$= 9.16 \times 10^{-13} \times 4.41 \times 10^{23}$	1	
	$= 4.04 \times 10^{11}$ ans.	1	
	Bq / s^{-1} unit	1	[3]
			12

96			
(a)	nuclei must overcome (electrostatic) repulsion (to get close enough) to fuse; (1) (gravity) confines / pulls together plasma / nuclei / ions / nucleons / protons; (1) increases density/ concentration / number per unit volume; (1) and increases frequency / number of collisions among nuclei; (1) condensation/collapse under gravity or AW heats plasma / gravitational p.e. changed to heat; (1) any 4	4	[4]
(b)	*either* area is potential / stored energy / work done / energy to overcome coulomb barrier / bring nuclei to their critical separation *or* (minimum) k.e. at infinity or AW; it is minimum energy needed for fusion;	 1 1	 [2]
(c)	$E_k = 2.07 \times 10^{-23} \times 15 \times 10^6 = 3.1 \times 10^{-16}$ J	1	[1]
(d)	combined (mean) k.e. << required p.e. / energy needed for fusion; (1) aware there is a range / spread of (nuclear) k.e.s; (1) (very) small proportion of $^1_1$H nuclei have enough energy to cause fusion;(1) aware (quantum) tunnelling can occur so fusion at distances > x_0 or AW;(1) any 3	3	[3]
(e)(i) (ii)	reactant mass = 2 x 1.007 276 = 2.014 552 u product mass = 2.013 553 + 0.000 549 = 2.014 102 u so $\Delta m = 4.5 \times 10^{-4}$ u $E = \Delta m c^2$ $= 4.5 \times 10^{-4} \times (1.66 \times 10^{-27}) \times (3.0 \times 10^8)^2 = 6.7 \times 10^{-14}$ J allow conversion using 1 u = 931 MeV positron and electron annihilate	 1 1 1	 [2] [1] **13**

97				
	a)	fixed target: beam of accelerated / high speed / high energy particles;	1	
		collide with (stationary) protons / nuclei;	1	
		colliding beam: two beams of accelerated / high speed / high energy particles;	1	
		collide them head-on / from opposite directions;	1	
		'fired at' / 'aimed at' / 'directed at' instead of accelerated etc, (-1) once		
		Advantages:		
		fixed target: high probability of collisions / many collisions because high density of particles in fixed target;	1	
		colliding beam: (total) initial mtm. (can be) zero so final (overall) mtm. (can be) zero;	1	
		either so <u>all</u> k.e. can contribute to making new particles		
		or two beams means twice as much energy available;	1	[7]
		allow any other relevant point up to appropriate max.		
	(b)(i)	$m_e c \approx m_Z c$	1	
		so $m_e \approx m_Z$	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	1	
		positron and ${}^0_0Z$ have different speeds (so masses have changed by different amounts)	1	[2]
	(c)	much / most of input energy goes into k.e. of ${}^0_0Z$ particle (so less energy available to create ${}^0_0Z$)	1	[1]
				13