



## Q1.

6 (a)	greater binding energy gives rise to release of energy ..... M1 so must be yttrium ..... A1	[2]
(b)	probability of decay ..... M1 of a nucleus per unit time ..... A1	[2]
(c) (i) 1	$A = \lambda N$ ..... C1 $3.7 \times 10^8 \times 365 \times 24 \times 3600 = 0.025N$ ..... C1 $N = 4.67 \times 10^{15}$ ..... A1	[3]
(i) 2	mass = $0.09 \times (4.67 \times 10^{15}) / (6.02 \times 10^{23})$ ..... C1 = $6.98 \times 10^{-10}$ kg ..... A1	[2]
(ii)	$A = A_0 e^{-\lambda t}$ ..... C1 $A/A_0 = e^{-0.025t}$ ..... C1 = 0.88 ..... A1	[2]

## Q2.

8 (a)	S shown at the peak	B1	[1]
(b) (i)	Kr and U on right of peak in correct relative positions	B1	[1]
(ii) 1	binding energy of U-235 = $2.8649 \times 10^{-10}$ J binding energy of Ba-144 = $1.9211 \times 10^{-10}$ J binding energy of Kr-90 = $1.2478 \times 10^{-10}$ J energy release = $3.04 \times 10^{-11}$ J (-1 if 1 or 2 s.f.)	C2	
2	$E = mc^2$ $m = (3.04 \times 10^{-11}) / (3.0 \times 10^8)^2 = 3.38 \times 10^{-28}$ kg (ignore s.f.)	A1	[3]
(iii)	e.g. neutrons are single particles, neutrons have no binding energy per nucleon	C1	
		A1	[2]
		B1	[1]
		Total	[8]

## Q3.

7 (a)	curve levelling out (at 1.4 $\mu$ g) correct shape judged by masses at $nT_{1/2}$ [for second mark, values must be marked on y-axis)	M1	
A1		A1	[2]
(b) (i)	$N_0 = (1.4 \times 10^{-6} \times 6.02 \times 10^{23}) / 56$ = $1.5 \times 10^{16}$	C1	
		A1	[2]
(ii)	$A = \lambda N$ $\lambda = \ln 2 / (2.6 \times 3600)$ (= $7.4 \times 10^{-5}$ s <sup>-1</sup> ) $A = 1.11 \times 10^{12}$ Bq	C1	
		C1	
		A1	[3]
(c)	1/10 of original mass of Manganese remains $0.10 = \exp(-\ln 2 \times t / 2.6)$ $t = 8.63$ hours [use of 1/9, giving answer 8.24 hrs scores 1 mark]	C1	
		A1	[2]

**Q4.**

- 6 (a) probability of decay  
of a nucleus per unit time  
(allow 1 mark for  $A = \lambda N$ , with symbols explained) M1  
A1 [2]
- (b) (i)  $\lambda = \ln 2 / (28 \times 365 \times 24 \times 3600)$   
 $= 7.85 \times 10^{-10} \text{ s}^{-1}$  C1  
A1 [2]
- (ii)  $A = (-)\lambda N$   
 $N = (6.4 \times 10^9) / (7.85 \times 10^{-10})$   
 $= 8.15 \times 10^{18}$   
 $\text{mass} = (8.15 \times 10^{18} \times 90) / (6.02 \times 10^{23})$  (e.c.f. for value of  $N$ )  
 $= 1.22 \times 10^{-3} \text{ g}$  C1  
C1  
C1  
A1 [4]
- (iii) volume =  $(1.22 \times 10^{-3} / 2.54) = 4.8 \times 10^{-4} \text{ cm}^3$  A1 [1]
- (c) either very small volume of Strontium-90 has high activity  
or dust can be highly radioactive  
breathing in dust presents health hazard B1  
B1 [2]

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**Q5.**

- 8 (a) since momentum before combining is zero  
momenta must be equal and opposite after  
equal momenta so photon energies equal B1  
B1  
B1 [3]
- (b)  $E = mc^2$   
 $= 9.1 \times 10^{-31} \times (3.0 \times 10^8)^2$   
 $= 8.19 \times 10^{-14} (\text{J})$   
 $= (8.19 \times 10^{-14}) / (1.6 \times 10^{-13})$   
 $= 0.51 \text{ MeV}$  C1  
C1  
A1 [3]

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**Q6.**

- 9 (a) (i)  $\Delta N / \Delta t$  (ignore any sign) B1 [1]
- (ii)  $\Delta N / N$  (ignore any sign) B1 [1]
- (b) source must decay by 8%  
 $A = A_0 \exp(-\ln 2 t / T_{1/2})$  or  $A/A_0 = 1 / (2^{t/T})$   
 $0.92 = \exp(-\ln 2 \times t / 5.27)$  or  $0.92 = 1 / (2^{t/5.27})$   
 $t = 0.634 \text{ years}$   
 $= 230 \text{ days}$  C1  
C1  
C1  
A1 [4]
- (allow 2 marks for  $A/A_0 = 0.08$ , answer 7010 days  
allow 1 mark for  $A/A_0 = 0.12$ , answer 5880 days)

**Q7.**



8 (a) momentum conservation hence momenta of photons are equal (but opposite) same momentum so same energy	M1 A1 [2]
(b) (i) $(\Delta)E = (\Delta)mc^2$ $= 1.2 \times 10^{-28} \times (3.0 \times 10^8)^2$ $= 1.08 \times 10^{-11} \text{ J}$	C1  A1 [2]
(ii) $E = hc/\lambda$ $\lambda = (6.63 \times 10^{-34} \times 3.0 \times 10^8) / (1.08 \times 10^{-11})$ $= 1.84 \times 10^{-14} \text{ m}$	C1  A1 [2]
(iii) $\lambda = h/p$ $p = (6.63 \times 10^{-34}) / (1.84 \times 10^{-14})$ $= 3.6 \times 10^{-20} \text{ N s}$	C1  A1 [2]

**Q8.**

8 (a) (i) number = $(5.1 \times 10^{-6} \times 6.02 \times 10^{23}) / 241$ $= 1.27 \times 10^{16}$	C1 A1 [2]
(ii) $A = \lambda N$ $5.9 \times 10^5 = \lambda \times 1.27 \times 10^{16}$ $\lambda = 4.65 \times 10^{-11} \text{ s}^{-1}$	C1  A1 [2]
(iii) $4.65 \times 10^{-11} \times t_{1/2} = \ln 2$ $t_{1/2} = 1.49 \times 10^{10} \text{ s}$ $= 470 \text{ years}$	C1  A1 [2]
(b) sample / activity would decay appreciably whilst measurements are being made	B1 [1]

**Q9.**

8 (a) (i) Fe shown near peak	A1 [1]
(ii) Zr shown about half-way along plateau	A1 [1]
(iii) H shown at less than 0.4 of maximum height	A1 [1]
(b) (i) heavy / large nucleus breaks up / splits into two nuclei / fragments of approximately equal mass	M1 A1 [2]
(ii) binding energy of nucleus = $B_E \times A$ binding energy of parent nucleus is less than sum of binding energies of fragments	B1  B1 [2]

**Q10.**



8 (a) energy required to separate nucleons in a <u>nucleus</u> to infinity	M1 A1	[2]
(b) $1u = 1.66 \times 10^{-27} \text{ kg}$ $E = mc^2$ $= 1.66 \times 10^{-27} \times (3.0 \times 10^8)^2$ $= 1.49 \times 10^{-10} \text{ J}$ $= (1.49 \times 10^{-10}) / (1.6 \times 10^{-13})$ $= 930 \text{ MeV}$	C1 M1 M1 A0	[3]
(c) (i) $\Delta m = 2.0141u - (1.0073 + 1.0087)u$ $= -1.9 \times 10^{-3} \text{ u}$ binding energy = $1.9 \times 10^{-3} \times 930$ = 1.8 MeV	C1 A1	[2]
(ii) $\Delta m = (57 \times 1.0087u) + (40 \times 1.0073u) - 97.0980u$ $= (-)0.69 \text{ u}$ binding energy per nucleon = $(0.69 \times 930) / 97$ = 6.61 MeV	C1 C1 A1	[3]

**Q11.**

9 (a) (i) either probability of decay (of a nucleus) per unit time or $\lambda = (-)(dN/dt) / N$ (-)dN/dt and N explained	M1 A1 (M1) (A1)	[2]
(ii) in time $t_{\frac{1}{2}}$ , number of nuclei changes from $N_0$ to $\frac{1}{2}N_0$ $\frac{1}{2} = \exp(-\lambda t_{\frac{1}{2}})$ or $2 = \exp(\lambda t_{\frac{1}{2}})$ $\ln(\frac{1}{2}) = -\lambda t_{\frac{1}{2}}$ and $\ln(\frac{1}{2}) = -0.693$ or $\ln 2 = \lambda t_{\frac{1}{2}}$ and $\ln 2 = 0.693$ $0.693 = \lambda t_{\frac{1}{2}}$	B1 B1 B1 A0	[3]
(b) $228 = 538 \exp(-8\lambda)$ $\lambda = 0.107 \text{ (hours}^{-1}\text{)}$ $t_{\frac{1}{2}} = 6.5 \text{ hours (do not allow 3 or more SF)}$	C1 C1 A1	[3]
(c) e.g. random nature of decay background radiation daughter product is radioactive (any two sensible suggestions, 1 each)	B2	[2]

**Q12.**



- 8 (a) nuclei having same number of protons/proton (atomic) number  
different numbers of neutrons/neutron number  
(allow second mark for nucleons/nucleon number/mass number/atomic mass if made clear that same number of protons/proton number)
- B1  
B1 [2]
- (b) probability of decay per unit time is the decay constant  
 $\lambda = \ln 2 / t_{1/2}$   
 $= 0.693 / (52 \times 24 \times 3600)$   
 $= 1.54 \times 10^{-7} \text{ s}^{-1}$
- C1  
C1  
A1 [3]
- (c) (i)  $A = A_0 \exp(-\lambda t)$   
 $7.4 \times 10^6 = A_0 \exp(-1.54 \times 10^{-7} \times 21 \times 24 \times 3600)$   
 $A_0 = 9.8 \times 10^6 \text{ Bq}$   
(alternative method uses 21 days as 0.404 half-lives)
- C1  
A1 [2]
- (ii)  $A = \lambda N$  and mass =  $N \times 89 / N_A$   
mass =  $(9.8 \times 10^6 \times 89) / (1.54 \times 10^{-7} \times 6.02 \times 10^{23})$   
 $= 9.4 \times 10^{-9} \text{ g}$
- C1  
A1 [2]

**Q13.**

- 8 (a) two (light) nuclei combine  
to form a more massive nucleus
- M1  
A1 [2]
- (b) (i)  $\Delta m = (2.01410 \text{ u} + 1.00728 \text{ u}) - 3.01605 \text{ u}$   
 $= 5.33 \times 10^{-3} \text{ u}$   
energy  $= c^2 \times \Delta m$   
 $= 5.33 \times 10^{-3} \times 1.66 \times 10^{-27} \times (3.00 \times 10^8)^2$   
 $= 8.0 \times 10^{-13} \text{ J}$
- C1  
C1  
A1 [3]
- (ii) speed/kinetic energy of proton and deuterium must be very large  
so that the nuclei can overcome electrostatic repulsion
- B1  
B1 [2]

**Q14.**

- 8 (a) energy is given out / released on formation of the  $\alpha$ -particle (or reverse argument) M1  
either  $E = mc^2$  so mass is less  
or reference to mass-energy equivalence
- A1 [2]
- (b) (i) mass change =  $18.00567 \text{ u} - 18.00641 \text{ u}$   
 $= 7.4 \times 10^{-4} \text{ u}$  (sign not required)
- C1  
A1 [2]
- (ii) energy =  $c^2 \Delta m$   
 $= (3.0 \times 10^8)^2 \times 7.4 \times 10^{-4} \times 1.66 \times 10^{-27}$   
 $= 1.1 \times 10^{-13} \text{ J}$   
(allow use of  $u = 1.67 \times 10^{-27} \text{ kg}$ )  
(allow method based on 1u equivalent to 930 MeV to 933 MeV)
- C1  
A1 [2]
- (iii) either mass of products greater than mass of reactants  
this mass/energy provided as kinetic energy of the helium-4 nucleus  
or both nuclei positively charged  
energy required to overcome electrostatic repulsion
- M1  
A1  
(M1)  
(A1) [2]



## Q15.

- 8 (a) probability of decay of a nucleus ..... M1  
 per unit time ..... A1 [2]
- (b)  $A = \lambda N$  ... (ignore sign) ..... B1 [1]
- (c) (i)  $1 \text{ m}^3$  contains  $1 / 0.024 = 41.7 \text{ mol}$  ..... C1  
 $1 \text{ m}^3$  contains  $41.7 \times N_A = 2.5 \times 10^{25} \text{ molecules}$  ..... A1  
 (ii) number  $= (2.5 \times 10^{25}) / (1.5 \times 10^{21}) = 1.67 \times 10^4$  ..... A1  
 (iii)  $\lambda T_{1/2} = 0.693$   
 $\lambda = 0.693 / 56 = 0.0124 \text{ s}^{-1}$  ..... C1  
 activity  $= 0.0124 \times 1.67 \times 10^4$   
 $= 210 \text{ Bq}$  ..... A1 [5]

## Q16.

- 6 (a) (i) either probability of decay or  $dN/dt = (-)\lambda N$  OR  $A = (-)\lambda N$   
 per unit time with symbols explained 1 1 [2]
- (ii) greater energy of  $\alpha$  particle means 0  
 (parent) nucleus less stable 1  
 nucleus more likely to decay 1  
 hence Radium-224 1 [3]
- (b) (i) either  $\lambda = \ln 2 / 3.6$  or  $\lambda = \ln 2 / 3.6 \times 24 \times 3600$   
 $= 0.193$   $= 2.23 \times 10^{-6}$  1  
 unit day $^{-1}$  s $^{-1}$  1 [2]  
 (one sig.fig., -1, allow  $\lambda$  in hr $^{-1}$ )
- (ii)  $N = \{(2.24 \times 10^{-3})/224\} \times 6.02 \times 10^{23}$  1  
 $= 6.02 \times 10^{18}$  1  
 activity  $= \lambda N$  1  
 $= 2.23 \times 10^{-6} \times 6.02 \times 10^{18}$  1  
 $= 1.3 \times 10^{13} \text{ Bq}$  1 [4]
- (c)  $A = A_0 e^{-\ln 2 \cdot t/T}$   
 $0.1 = \exp(-\ln 2 \cdot n)$  1  
 $n = 3.32$  1 [2]  
 ( $n = 3$  without working scores 1 mark)

## Q17.



7	(a)(i)	energy required to separate the nucleons in a nucleus ..... nucleons separated to infinity / completely .....	M1 A1	[2]
	(ii)	S shown at peak .....	B1	[1]
	(b)(i)	4 .....	A1	[1]
	(ii)	1. idea of energy as product of A and energy per nucleon ..... energy = $(8.37 \times 142 + 8.72 \times 90) - 235 \times 7.59$ = 1189 + 785 - 178 = 190 MeV .....(-1 for each a.e.) .....	C1 A2	[3]
	2.	energy = $mc^2$ ..... 1 MeV = $1.6 \times 10^{-13}$ J ..... energy = $(190 \times 1.6 \times 10^{-13}) / (3.0 \times 10^8)^2$ = $3.4 \times 10^{-28}$ kg .....	C1 C1 A1	[3]

**Q18.**

8	(a)	(i)	either number = $6.02 \times 10^{23} \times (2.65 \times 10^{-6})/234$ or number = $(2.65 \times 10^{-9})/(234 \times 1.66 \times 10^{-27})$ = $6.82 \times 10^{15}$	C1 A1	[2]
		(ii)	$A = \lambda N$ $604 = \lambda \times 6.82 \times 10^{15}$ $\lambda = 8.86 \times 10^{-14} \text{ s}^{-1}$	C1 A1	[2]
		(iii)	$T_{1/2} = \ln 2 / \lambda$ = $7.82 \times 10^{12} \text{ s}$ = $2.48 \times 10^5 \text{ years}$	C1 A1	[2]
		(b)	half-life is (very) long (compared with time of counting)	B1	[1]
		(c)	there would be appreciable decay of source during the taking of measurements	B1	[1]

**Q19.**



- 7 (a) energy required to (completely) separate the nucleons (in a nucleus) ..... B1 [1]
- (b) (i) U labelled near right-hand end of line ..... B1  
 Ba and Kr in approximately correct positions ..... B1 [2]
- (ii) binding energy is  $A \times E_B$  ..... B1  
 either binding energy of U < binding energy of (Ba + Kr)  
 or  $E_B$  of U <  $E_B$  of (Ba + Kr) ..... B1 [2]
- (c) Krypton-92 reduced to 1/8 in 9 s ..... M1  
 in 9 s, very little decay of Barium-141 ..... M1  
 so, approximately 9 s ..... A1 [3]  
 OR  
 $\lambda_{Kr} = 0.231$  or  $\lambda_{Ba} = 6.42 \times 10^{-4}$  ..... (M1)  
 $8 = e^{-\lambda B \times t} / e^{-\lambda K \times t}$  ..... (C1)  
 $t = 9.0$  s ..... (A1)

**Q20.**

- 8 (a) neutron is a single nucleon / particle ..... B1 [1]
- (b) binding energy =  $4 \times 7.07 \times 1.6 \times 10^{-13}$  ..... C1  
 $= 4.52 \times 10^{-12}$  J ..... C1  
 binding energy =  $c^2 \Delta m$  ..... C1  
 $4.52 \times 10^{-12} = (3.0 \times 10^8)^2 \times \Delta m$  ..... C1  
 $\Delta m = 5.03 \times 10^{-29}$  kg ..... A1 [3]
- (c) (i) fusion ..... (do not allow fission) ..... B1 [1]
- (ii)  $(2 \times 1.12) + 3x = 28.28$  ..... C1  
 $\dots -17.7$  ..... C1  
 $x = 2.78$  MeV per nucleon ..... A1 [3]  
 (use of +17.7 gives x = 14.6 MeV, allow 1 mark only)

[Total: 8]

**Q21.**



- 8 (a) (constant) probability of decay ..... M1  
 per unit time ..... A1 [2]  
*(reference to decay of isotope / mass / sample / nuclide, allow max 1 mark)*

- (b) either when time =  $t_{1/2}$ ,  $N = \frac{1}{2}N_0$  ..... M1  
 or  $\frac{1}{2}N_0 = N \exp(-\lambda t_{1/2})$  ..... M1  
 either  $2 = \exp(\lambda t_{1/2})$   
 or  $\frac{1}{2} = \exp(-\lambda t_{1/2})$  ..... M1  
 (taking logs),  $\ln 2 = 0.693 = \lambda t_{1/2}$  ..... A1 [3]

- (c)  $A = \lambda N$   
 $1.8 \times 10^5 = N \times (0.693 / \{1.66 \times 10^8\})$  ..... C1  
 $N = 4.3 \times 10^{13}$  ..... C1  
 mass =  $60 \times (N/N_A)$  or  $60 \times N \times u$  ..... C1  
 $= (60 \times 4.3 \times 10^{11}) / (6.02 \times 10^{23})$   
 $= 4.3 \times 10^{-9}$  g ..... A1 [3]

[Total: 8]

**Q22.**

- 8 (a) splitting of a heavy nucleus (*not atom/nuclide*)  
 into two (lighter) nuclei of approximately same mass ..... M1  
 A1 [2]
- (b)  ${}_0^1n$  ..... M2  
 ${}_2^4He$  (allow  ${}_2^4\alpha$ ) ..... A1 [3]  
 ${}_3^7Li$
- (c) emitted particles have kinetic energy ..... B1  
 range of particles in the control rods is short / particles stopped in rods /  
 lose kinetic energy in rods ..... B1  
 kinetic energy of particles converted to thermal energy ..... B1 [3]

**Q23.**

- 8 (a) (i) time for initial number of nuclei/activity  
 to reduce to one half of its initial value ..... M1  
 A1 [2]
- (ii)  $\lambda = \ln 2 / (24.8 \times 24 \times 3600)$  ..... M1  
 $= 3.23 \times 10^{-7} \text{ s}^{-1}$  ..... A0 [1]
- (b) (i)  $A = \lambda N$  ..... C1  
 $3.76 \times 10^6 = 3.23 \times 10^{-7} \times N$   
 $N = 1.15 \times 10^{13}$  ..... A1 [2]
- (ii)  $N = N_0 e^{-\lambda t}$  ..... C1  
 $= 1.15 \times 10^{13} \times \exp(-\{\ln 2 \times 30\}/24.8)$   
 $= 4.97 \times 10^{12}$  ..... A1 [2]
- (c) ratio =  $(4.97 \times 10^{12}) / (1.15 \times 10^{13} - 4.97 \times 10^{12})$  ..... C1  
 $= 0.76$  ..... A1 [2]

**Q24.**

- 8 (a) (i) probability of decay (of a nucleus)  
per unit time M1  
A1 [2]
- (ii)  $\lambda t_{\frac{1}{2}} = \ln 2$   
 $\lambda = \ln 2 / (3.82 \times 24 \times 3600)$   
 $= 2.1 \times 10^{-6} \text{ s}^{-1}$  M1  
A0 [1]
- (b)  $A = \lambda N$   
 $200 = 2.1 \times 10^{-6} \times N$   
 $N = 9.5 \times 10^7$   
ratio  $= (2.5 \times 10^{25}) / (9.5 \times 10^7)$   
 $= 2.6 \times 10^{17}$  C1  
C1  
A1 [3]

**Q25.**

- 8 (a) (i)  $x = 2$  A1 [1]
- (ii) either beta particle or electron B1 [1]
- (b) (i) mass of separate nucleons  $= \{(92 \times 1.007) + (143 \times 1.009)\} \text{ u}$   
 $= 236.931 \text{ u}$   
binding energy  $= 236.931 \text{ u} - 235.123 \text{ u}$   
 $= 1.808 \text{ u}$  C1  
C1  
A1 [3]
- (ii)  $E = mc^2$   
energy  $= 1.808 \times 1.66 \times 10^{-27} \times (3.0 \times 10^8)^2$   
 $= 2.7 \times 10^{-10} \text{ J}$   
binding energy per nucleon  $= (2.7 \times 10^{-10}) / (235 \times 1.6 \times 10^{-13})$   
 $= 7.18 \text{ MeV}$  C1  
C1  
M1  
A0 [3]
- (c) energy released  $= (95 \times 8.09) + (139 \times 7.92) - (235 \times 7.18)$   
 $= 1869.43 - 1687.3$   
 $= 182 \text{ MeV}$  C1  
A1 [2]  
*(allow calculation using mass difference between products and reactants)*

**Q26.**

- 8 (a) energy to separate nucleons (in a nucleus)  
separate to infinity M1  
A1 [2]
- (b) (i) fission B1 [1]
- (ii) 1. U: near right-hand end of line B1 [1]
2. Mo: to right of peak, less than 1/3 distance from peak to U B1 [1]
3. La:  $0.4 \rightarrow 0.6$  of distance from peak to U B1 [1]



- (iii) 1. right-hand side, mass = 235.922 u  
mass change = 0.210 u C1  
A1 [2]
2. energy =  $mc^2$   
=  $0.210 \times 1.66 \times 10^{-27} \times (3.0 \times 10^8)^2$   
=  $3.1374 \times 10^{-11}$  J C1  
= 196 MeV (need 3 s.f.) A1 [3]  
(use of 1 u = 934 MeV, allow 3/3; use of 1 u = 930 MeV or 932 MeV, allow 2/3)  
(use of  $1.67 \times 10^{-27}$  not  $1.66 \times 10^{-27}$  scores max. 2/3)

**Q27.**

- 8 (a) probability of decay (of a nucleus)/fraction of number of nuclei in sample that decay per unit time M1  
allow  $\lambda = (dN/dt)/N$  with symbols explained – (M1), (A1) A1 [2]
- (b) (i) number =  $(1.2 \times 6.02 \times 10^{23}) / 235$   
=  $3.1 \times 10^{21}$  C1  
A1 [2]

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(ii)  $N = N_0 e^{-\lambda t}$   
negligible activity from the krypton B1  
for barium,  $N = (3.1 \times 10^{21}) \exp(-6.4 \times 10^{-4} \times 3600)$   
=  $3.1 \times 10^{20}$  C1  
activity =  $\lambda N$   
=  $6.4 \times 10^{-4} \times 3.1 \times 10^{20}$   
=  $2.0 \times 10^{17}$  Bq C1  
A1 [4]

**Q28.**



10 (a) energy required to separate the nucleons (in a nucleus) to infinity <i>(allow reverse statement)</i>	M1 A1 [2]
(b) (i) $\Delta m = (2 \times 1.00867) + 1.00728 - 3.01551$ $= 9.11 \times 10^{-3} \text{ u}$ binding energy = $9.11 \times 10^{-3} \times 930$ $= 8.47 \text{ MeV}$ <i>(allow 930 to 934 MeV so answer could be in range 8.47 to 8.51 MeV)</i> <i>(allow 2 s.f.)</i>	C1 C1 A1 [3]
(ii) $\Delta m = 211.70394 - 209.93722$ $= 1.76672 \text{ u}$ binding energy per nucleon = $(1.76672 \times 930)/210$ $= 7.82 \text{ MeV}$ <i>(allow 930 to 934 MeV so answer could be in range 7.82 to 7.86 MeV)</i> <i>(allow 2 s.f.)</i>	C1 C1 A1 [3]
(c) <u>total binding energy of barium and krypton</u> is greater than binding energy of uranium	M1 A1 [2]

**Q29.**

9 (a) time for number of atoms/nuclei/activity (of the isotope) to be reduced to one half (of its initial value)	M1 A1 [2]
(b) (i) $A = \lambda N$ $460 = N \times \ln 2 / (8.1 \times 24 \times 60 \times 60)$ $N = 4.6 \times 10^8$	C1 C1 A1 [3]
(ii) number of water molecules in 1.0 kg = $(6.02 \times 10^{23}) / (18 \times 10^{-3})$ $= 3.3 \times 10^{25}$ ratio = $(3.3 \times 10^{25}) / (4.6 \times 10^8)$ $= 7.2 (7.3) \times 10^{16}$	C1 A1 [2]

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(c) $A = A_0 e^{-\lambda t}$ and $\lambda t_{1/2} = \ln 2$ $170 = 460 \exp(-\{\ln 2 t\}/8.1)$ $t = 11.6 \text{ days}$ (allow 2 s.f.)	C1 C1 A1 [3]
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**Q30.**

- 9 (a) 'light' nuclei combine to form 'heavier' nuclei B1 [1]
- (b) (i) either energy =  $c^2\Delta m$   
 or energy =  $(3.00 \times 10^8)^2 \times 1.66 \times 10^{-27}$   
 energy =  $1.494 \times 10^{-10} \text{ J}$   
 $= (1.494 \times 10^{-10}) / (1.60 \times 10^{-13})$   
 $= 934 \text{ MeV (3 s.f.)}$  C1  
C1  
A1 [3]
- (ii)  $\Delta m = (2.01356 + 3.01551) - (4.00151 + 1.00867)$   
 $= 5.02907 - 5.01018$   
 $= 0.01889 \text{ u}$  C1
- energy =  $0.01889 \times 934$   
 $= 17.6 \text{ MeV (allow 2 s.f.)}$  A1 [2]
- (iii) high temperature means high speeds /kinetic energy of nuclei  
 D and T nuclei collide despite repelling one another B1  
B1 [2]

**Q31.**

- 9 (a) activity =  $(1.7 \times 10^{14}) / (2.5 \times 10^6)$   
 $= 6.8 \times 10^7 \text{ Bq kg}^{-1}$  A1 [1]
- (b) (i) energy released per second in 1.0kg of steel  
 $= 6.8 \times 10^7 \times 0.067 \times 1.6 \times 10^{-13}$   
 $= 7.3 \times 10^{-7} \text{ J}$  B1 [1]

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- (ii) this is a very small quantity of energy so steel will not be warm B1 [1]
- (iii)  $A = A_0 e^{-\lambda t}$  and  $\lambda t_{1/2} = \ln 2$   
 $400 = (6.8 \times 10^7) \exp(-[\ln 2 \times t] / 92)$   
 $t = 1600 \text{ years}$  C1  
C1  
A1
- or
- $A = A_0 / 2^n$  (C1)  
 $n = 17.4$  (C1)  
 $t = 17.4 \times 92 = 1600 \text{ years}$  (A1) [3]

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