# 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 | |
| | | $3.7 \times 10^6 \times 365 \times 24 \times 3600 = 0.025N$ | 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) | $A = A_0 e^{-\lambda t}$ | | |
| | | $A/A_0 = e^{-0.025t}$ | 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 | C2 | |
| | | energy release = $3.04 \times 10^{-11}$ J *(-1 if 1 or 2 s.f.)* | A1 | [3] |
| | 2 | $E = mc^2$ | C1 | |
| | | $m = (3.04 \times 10^{-11})/3.0 \times 10^8)^2 = 3.38 \times 10^{-28}$ kg (ignore s.f.) | A1 | [2] |
| | (iii) | e.g. neutrons are single particles,<br>neutrons have no binding energy per nucleon | B1 | [1] |
| | | **Total** | | **[8]** |

# Q3.

| | | | | |
|---|---|---|---|---|
| 7 (a) | | curve levelling out (at 1.4 μg) | **M1** | |
| | | correct shape judged by masses at $nT_{½}$ | **A1** | **[2]** |
| | | [for second mark, values must be marked on *y*-axis) | | |
| (b) | (i) | $N_0 = (1.4 \times 10^{-6} \times 6.02 \times 10^{23})/56$ | **C1** | |
| | | $= 1.5 \times 10^{16}$ | **A1** | **[2]** |
| | (ii) | $A = \lambda N$ | **C1** | |
| | | $\lambda = \ln 2/(2.6 \times 3600)$ ($= 7.4 \times 10^{-5}$ s$^{-1}$) | **C1** | |
| | | $A = 1.11 \times 10^{12}$ Bq | **A1** | **[3]** |
| (c) | | 1/10 of original mass of Manganese remains | **C1** | |
| | | $0.10 = \exp(-\ln 2 \times t/2.6)$ | | |
| | | $t = 8.63$ hours | **A1** | **[2]** |
| | | [use of 1/9, giving answer 8.24 hrs scores 1 mark] | | |

## Q4.

| | | | | | |
|---|---|---|---|---|---|
| 6 | (a) | | probability of decay | M1 | |
| | | | of a nucleus per unit time | A1 | [2] |
| | | | *(allow 1 mark for $A = \lambda N$, with symbols explained)* | | |
| | (b) | (i) | $\lambda = \ln 2/(28 \times 365 \times 24 \times 3600)$ | C1 | |
| | | | $= 7.85 \times 10^{-10}\ \text{s}^{-1}$ | A1 | [2] |
| | | (ii) | $A = (-)\lambda N$ | | |
| | | | $N = (6.4 \times 10^{9})/(7.85 \times 10^{-10})$ | C1 | |
| | | | $= 8.15 \times 10^{18}$ | C1 | |
| | | | mass $= (8.15 \times 10^{18} \times 90)/(6.02 \times 10^{23})$ (e.c.f. for value of $N$) | C1 | |
| | | | $= 1.22 \times 10^{-3}$ g | 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 | B1 | |
| | | | breathing in dust presents health hazard | B1 | [2] |

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## Q5.

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

## 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% | C1 | |
| | | | $A = A_0 \exp(-\ln 2\ t / T_{½})$ *or* $A/A_0 = 1/(2^{t/T})$ | C1 | |
| | | | $0.92 = \exp(-\ln 2 \times t / 5.27)$ *or* $0.92 = 1/(2^{t/5.27})$ | C1 | |
| | | | $t = 0.634$ years | | |
| | | | $= 230$ days | 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) | M1 | |
| | same momentum so same energy | A1 | [2] |
| **(b)** **(i)** | $(\Delta)E = (\Delta)mc^2$ | C1 | |
| | $= 1.2 \times 10^{-28} \times (3.0 \times 10^{8})^2$ | | |
| | $= 1.08 \times 10^{-11}$ J | A1 | [2] |
| **(ii)** | $E = hc / \lambda$ | | |
| | $\lambda = (6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / (1.08 \times 10^{-11})$ | C1 | |
| | $= 1.84 \times 10^{-14}$ m | A1 | [2] |
| **(iii)** | $\lambda = h / p$ | | |
| | $p = (6.63 \times 10^{-34}) / (1.84 \times 10^{-14})$ | C1 | |
| | $= 3.6 \times 10^{-20}$ N s | A1 | [2] |

## Q8.

| | | | |
|---|---|---|---|
| **8** **(a)** **(i)** | number $= (5.1 \times 10^{-6} \times 6.02 \times 10^{23}) / 241$ | C1 | |
| | $= 1.27 \times 10^{16}$ | A1 | [2] |
| **(ii)** | $A = \lambda N$ | C1 | |
| | $5.9 \times 10^{5} = \lambda \times 1.27 \times 10^{16}$ | | |
| | $\lambda = 4.65 \times 10^{-11}\ \text{s}^{-1}$ | A1 | [2] |
| **(iii)** | $4.65 \times 10^{-11} \times t_{½} = \ln 2$ | C1 | |
| | $t_{½} = 1.49 \times 10^{10}$ s | | |
| | = 470 years | 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 | M1 | |
| | into two nuclei / fragments of approximately equal mass | A1 | [2] |
| **(ii)** | binding energy of nucleus = $B_E \times A$ | B1 | |
| | binding energy of parent nucleus is less than sum of binding energies of fragments | B1 | [2] |

## Q10.

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

## Q11.

| | | | | | |
|---|---|---|---|---|---|
| **9** | **(a)** | **(i)** | *either* probability of decay (of a nucleus) | M1 | |
| | | | per unit time | A1 | [2] |
| | | | *or* $\lambda = (-)(\mathrm{d}N/\mathrm{d}t) / N$ | (M1) | |
| | | | $(-)\mathrm{d}N/\mathrm{d}t$ and $N$ explained | (A1) | |
| | | **(ii)** | in time $t_{½}$, number of nuclei changes from $N_0$ to $½N_0$ | B1 | |
| | | | $½ = \exp(-\lambda\, t_{½})$ *or* $2 = \exp(\lambda\, t_{½})$ | B1 | |
| | | | $\ln(½) = -\lambda\, t_{½}$ and $\ln(½) = -0.693$ *or* $\ln 2 = \lambda\, t_{½}$ and $\ln 2 = 0.693$ | B1 | |
| | | | $0.693 = \lambda\, t_{½}$ | A0 | [3] |
| | **(b)** | | $228 = 538 \exp(-8\lambda)$ | C1 | |
| | | | $\lambda = 0.107$ (hours$^{-1}$) | C1 | |
| | | | $t_{½} = 6.5$ hours *(do not allow 3 or more SF)* | 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)** <u>nuclei</u> having same number of protons/proton (atomic) number B1
different numbers of neutrons/neutron number B1 [2]
(allow second mark for nucleons/nucleon number/mass number/atomic mass if made clear that same number of protons/proton number)

**(b)** probability of decay per unit time is the decay constant C1
$\lambda = \ln 2 / t_{½}$
$= 0.693 / (52 \times 24 \times 3600)$ C1
$= 1.54 \times 10^{-7}\,\text{s}^{-1}$ A1 [3]

**(c)** **(i)** $A = A_0 \exp(-\lambda t)$
$7.4 \times 10^6 = A_0 \exp(-1.54 \times 10^{-7} \times 21 \times 24 \times 3600)$ C1
$A_0 = 9.8 \times 10^6\,\text{Bq}$ A1 [2]
(*alternative method uses 21 days as 0.404 half-lives*)

**(ii)** $A = \lambda N$ and mass $= N \times 89 / N_A$ C1
mass $= (9.8 \times 10^6 \times 89) / (1.54 \times 10^{-7} \times 6.02 \times 10^{23})$
$= 9.4 \times 10^{-9}\,\text{g}$ A1 [2]

## Q13.

8 **(a)** two (light) nuclei combine M1
to form a more massive nucleus A1 [2]

**(b)** **(i)** $\Delta m = (2.01410\,\text{u} + 1.00728\,\text{u}) - 3.01605\,\text{u}$
$= 5.33 \times 10^{-3}\,\text{u}$ C1
energy $= c^2 \times \Delta m$ C1
$= 5.33 \times 10^{-3} \times 1.66 \times 10^{-27} \times (3.00 \times 10^8)^2$
$= 8.0 \times 10^{-13}\,\text{J}$ A1 [3]

**(ii)** speed/kinetic energy of proton and deuterium must be very large B1
so that the nuclei can overcome electrostatic repulsion 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 $= 18.00567\,\text{u} - 18.00641\,\text{u}$ C1
$= 7.4 \times 10^{-4}\,\text{u}$ *(sign not required)* A1 [2]

**(ii)** energy $= c^2 \Delta m$
$= (3.0 \times 10^8)^2 \times 7.4 \times 10^{-4} \times 1.66 \times 10^{-27}$ C1
$= 1.1 \times 10^{-13}\,\text{J}$ A1 [2]
(*allow use of* u $= 1.67 \times 10^{-27}$ kg*)*
(*allow method based on* 1u *equivalent to* 930 MeV *to* 933 MeV*)*

**(iii)** *either* mass of products greater than mass of reactants M1
this mass/energy provided as kinetic energy of the helium-4 nucleus A1
*or* both nuclei positively charged (M1)
energy required to overcome electrostatic repulsion (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 $m^3$ contains 1 / 0.024 = 41.7 mol ........................................ C1
1 $m^3$ contains 41.7 x $N_A$ = $2.5 \times 10^{25}$ molecules ...................... A1
**(ii)** number = $(2.5 \times 10^{25}) / (1.5 \times 10^{21})$ = $1.67 \times 10^4$ .................. A1
**(iii)** $\lambda T_{½} = 0.693$
$\lambda = 0.693 / 56 = 0.0124\ s^{-1}$ ........................................ C1
activity = $0.0124 \times 1.67 \times 10^4$
= 210 Bq ........................................................ A1 [5]

## Q16.

6 (a) (i) *either* probability of decay *or* d*N*/dt = *(-)*$\lambda N$ OR A = *(-)*$\lambda N$ 1
per unit time with symbols explained 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* $\lambda$ = ln2/3.6 or $\lambda$ = ln2/3.6 x 24 x 3 600
= 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} x $6.02 \times 10^{23}$ 1
= $6.02 \times 10^{18}$ 1
activity = $\lambda$N
= $2.23 \times 10^{-6} \times 6.02 \times 10^{18}$ 1
= $1.3 \times 10^{13}$ Bq 1 **[4]**

(c) $A = A_0 e^{-\ln 2 . t/T}$
0.1 = exp(-ln2 . 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 ………………..<br>nucleons separated to infinity / completely ……………………………… | M1<br>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 …………… | C1 | |
| | | energy $= (8.37 \times 142 + 8.72 \times 90) - 235 \times 7.59$<br>$= 1189 + 785 - 178$<br>$= 190$ MeV ………(–1 for each a.e.) ………………………… | A2 | **[3]** |
| | **2.** | energy $= mc^2$ ……………………………………………………………… | C1 | |
| | | 1 MeV $= 1.6 \times 10^{-13}$ J ………………………………………………… | C1 | |
| | | energy $= (190 \times 1.6 \times 10^{-13}) / (3.0 \times 10^8)^2$<br>$= 3.4 \times 10^{-28}$ kg ……………………………………………… | A1 | **[3]** |

## Q18.

| | | | | | |
|---|---|---|---|---|---|
| 8 | (a) | (i) | *either* number $= 6.02 \times 10^{23} \times (\{2.65 \times 10^{-6}\}/234)$<br>*or* number $= (2.65 \times 10^{-9})/(234 \times 1.66 \times 10^{-27})$<br>$= 6.82 \times 10^{15}$ | C1<br>A1 | [2] |
| | | (ii) | $A = \lambda N$<br>$604 = \lambda \times 6.82 \times 10^{15}$<br>$\lambda = 8.86 \times 10^{-14}\ \mathrm{s}^{-1}$ | C1<br>A1 | [2] |
| | | (iii) | $T_{½} = \ln 2/\lambda$<br>$= 7.82 \times 10^{12}$ s<br>$= 2.48 \times 10^5$ years | C1<br>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
binding energy $= c^2 \Delta m$ ..............................................................................................C1
$4.52 \times 10^{-12} = (3.0 \times 10^8)^2 \times \Delta m$
$\Delta m = 5.03 \times 10^{-29}$ kg ..........................................................................................A1 [3]

**(c)** **(i)** fusion ……(*do not allow fussion*) .......................................................................B1 [1]

**(ii)** $(2 \times 1.12) + 3x = 28.28$ ............................................................................................C1
…… –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 = $t_{½}$, $N$ = ½$N_0$
*or* ½$N_0$ = $N \exp(-\lambda t_{½})\ t_{½}$ ........................................ M1
*either* 2 = $\exp(\lambda t_{½})$
*or* ½ = $\exp(-\lambda t_{½})$ ........................................ M1
(taking logs), $\underline{\ln 2 = 0.693 = \lambda t_{½}}$ ........................................ A1 [3]

**(c)** $A = \lambda N$
$1.8 \times 10^5 = N \times (0.693 / \{1.66 \times 10^8\})$ ........................................ C1
$N = 4.3 \times 10^{13}$
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*) M1
into two (lighter) nuclei of <u>approximately same mass</u> A1 [2]

**(b)** ${}^{1}_{0}\text{n}$
${}^{4}_{2}\text{He}$ (*allow* ${}^{4}_{2}\alpha$) M2
${}^{7}_{3}\text{Li}$ A1 [3]

**(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 M1
to reduce to one half of its initial value A1 [2]

**(ii)** $\lambda$ = ln 2/(24.8 × 24 × 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)** $N = N_0\,e^{-\lambda t}$
= $1.15 \times 10^{13} \times \exp(-\{\ln 2 \times 30\}/24.8)$ C1
= $4.97 \times 10^{12}$ 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) | M1 | |
| | per unit time | A1 | [2] |
| (ii) | $\lambda t_{½} = \ln 2$ | | |
| | $\lambda = \ln 2/(3.82 \times 24 \times 3600)$ | M1 | |
| | $= 2.1 \times 10^{-6}\ \text{s}^{-1}$ | A0 | [1] |
| (b) | $A = \lambda N$ | C1 | |
| | $200 = 2.1 \times 10^{-6} \times N$ | C1 | |
| | $N = 9.5 \times 10^{7}$ | | |
| | ratio $= (2.5 \times 10^{25})/(9.5 \times 10^{7})$ | | |
| | $= 2.6 \times 10^{17}$ | 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 × 1.007) + (143 × 1.009)} u | C1 | |
| | = 236.931 u | C1 | |
| | binding energy = 236.931 u – 235.123 u | | |
| | = 1.808 u | A1 | [3] |
| (ii) | $E = mc^2$ | C1 | |
| | energy $= 1.808 \times 1.66 \times 10^{-27} \times (3.0 \times 10^{8})^2$ | | |
| | $= 2.7 \times 10^{-10}$ J | C1 | |
| | binding energy per nucleon $= (2.7 \times 10^{-10}) / (235 \times 1.6 \times 10^{-13})$ | M1 | |
| | = 7.18 MeV | A0 | [3] |
| (c) | energy released = (95 × 8.09) + (139 × 7.92) – (235 × 7.18) | C1 | |
| | = 1869.43 – 1687.3 | | |
| | = 182 MeV | A1 | [2] |
| | (*allow calculation using mass difference between products and reactants*) | | |

## Q26.

| | | | |
|---|---|---|---|
| 8 (a) | energy to separate nucleons (in a nucleus) | M1 | |
| | separate to infinity | 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 → 0.6 of distance from peak to U | B1 | [1] |

(iii) **1.** right-hand side, mass = 235.922 u — C1
mass change = 0.210 u — A1 [2]

**2.** energy = $mc^2$ — C1
$= 0.210 \times 1.66 \times 10^{-27} \times (3.0 \times 10^8)^2$
$= 3.1374 \times 10^{-11}$ J — C1
= 196 MeV (*<u>need 3 s.f.</u>*) — 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 — M1
per unit time — A1 [2]
(*allow $\lambda = (dN/dt)/N$ with symbols explained – (M1), (A1)* )

**(b)** **(i)** number $= (1.2 \times 6.02 \times 10^{23}) / 235$ — C1
$= 3.1 \times 10^{21}$ — 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 $= \lambda N$
$= 6.4 \times 10^{-4} \times 3.1 \times 10^{20}$ — C1
$= 2.0 \times 10^{17}$ Bq — A1 [4]

## Q28.

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

## Q29.

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

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| | | |
|---|---|---|
| **(c)** $A = A_0\,e^{-\lambda t}$ <u>and</u> $\lambda t_{½} = \ln 2$ | C1 | |
| $170 = 460 \exp(-\{\ln 2\ t\}/8.1)$ | C1 | |
| $t = 11.6$ days (*allow 2 s.f.*) | A1 | [3] |

## Q30.

**9** **(a)** 'light' nuclei combine to form 'heavier' nuclei B1 [1]

**(b)** **(i)** *either* energy = $c^2\Delta m$
*or* energy = $(3.00 \times 10^8)^2 \times 1.66 \times 10^{-27}$ C1
energy = $1.494 \times 10^{-10}$ J C1
= $(1.494 \times 10^{-10}) / (1.60 \times 10^{-13})$
= 934 MeV (*3 s.f.*) A1 [3]

**(ii)** $\Delta m$ = (2.01356 + 3.01551) – (4.00151 + 1.00867)
= 5.02907 – 5.01018
= 0.01889 u C1

energy = 0.01889 × 934
= 17.6 MeV (*allow 2 s.f.*) A1 [2]

**(iii)** high temperature means high speeds / <u>kinetic</u> energy of nuclei B1
D and T nuclei collide despite repelling one another B1 [2]

## Q31.

**9** **(a)** activity = $(1.7 \times 10^{14}) / (2.5 \times 10^6)$
= $6.8 \times 10^7$ Bq kg$^{-1}$ A1 [1]

**(b)** **(i)** energy released per second in 1.0 kg of steel
= $6.8 \times 10^7 \times 0.067 \times 1.6 \times 10^{-13}$
= $7.3 \times 10^{-7}$ 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)** $A = A_0 e^{-\lambda t}$ <u>and</u> $\lambda t_{½} = \ln 2$ C1
$400 = (6.8 \times 10^7) \exp(-[\ln 2 \times t] / 92)$ C1
$t$ = 1600 years A1

*or*

$A = A_0 / 2^n$ (C1)
$n$ = 17.4 (C1)
$t$ = 17.4 × 92 = 1600 years (A1) [3]

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