**B2. Part 1** Nuclear fission and fusion

(a) (i) the energy released when nuclides form from constituents / energy required to separate nucleus into separate nucleons / *OWTTE*; ***[1]***

(ii) S marked at maximum of curve (on curve/axis); *(judge by eye)* ***[1]***

(iii) highest binding energy per nucleon; ***[1]***

(b) (i) uranium binding energy per nucleon $= 7.6\,(\text{MeV})\ (\pm 0.1)$;
total uranium binding energy $= 7.6 \times 235 = 1786\,(\text{MeV})$;
total Kr + Ba binding energy $= 141 \times 8.4 + 92 \times 8.7 = 1985\,(\text{MeV})$;
energy released $= 1985 - 1786 = 198.8\,(\text{MeV})$;
$\simeq 200\,\text{MeV}$ ***[4]***

(ii) 2; ***[1]***

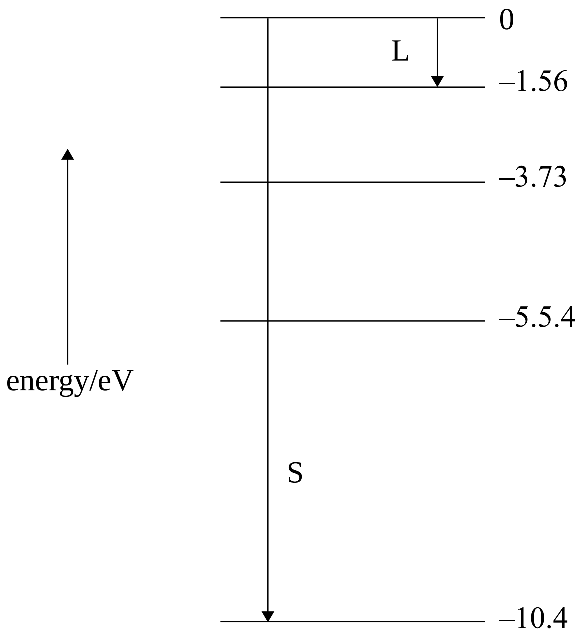
(iii) one reaction: $\Delta E = 3.1 \times 10^{-28} \times \left[3 \times 10^{8}\right]^{2} \left(= 2.8 \times 10^{-11}\,\text{J}\right)$;
number required $= \dfrac{1000}{2.8 \times 10^{-11}} = 3.6 \times 10^{13}$; ***[2]***

(iv) two neutrons produced may cause two further fissions;
producing four neutrons which may produce four further fissions; ***[2]***
*Accept answer in diagram form but it must feature four generated neutrons with **only** two neutrons giving further fission.*

(c) nuclear fusion waste much less active than fission waste;
fusion fuel much more abundant than fission fuel;
fusion fuel has higher energy density than fission;
radiation/pollution from plant lower for fusion; ***[3 max]***

**Part 2** Atomic and nuclear spectra

(a)




(i) as shown; *(allow transition from –1.56 to –3.73)* ***[1]***

(ii) as shown; ***[1]***

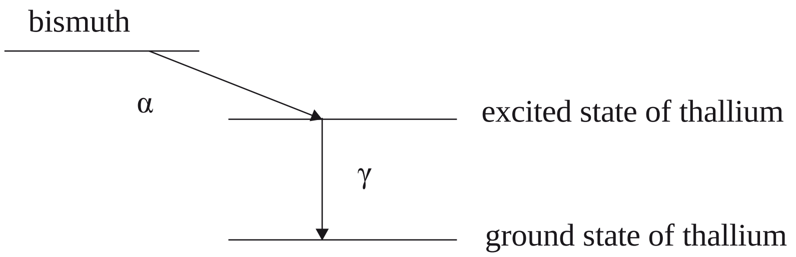
*Award **[1 max]** if (i) and (ii) are labelled the wrong way round or if arrows in wrong direction.*

(b) $E = \frac{hc}{\lambda}$;

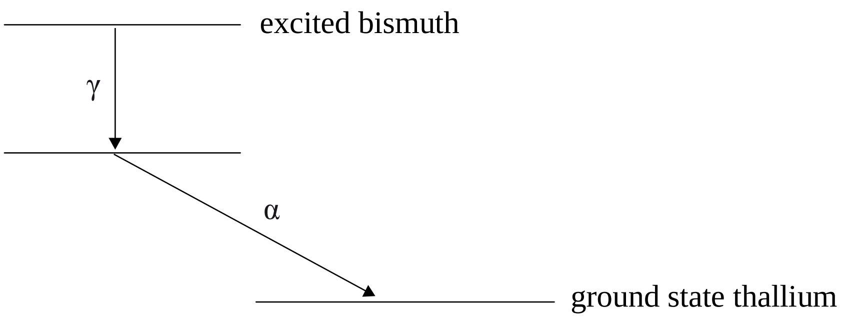
$\lambda = \frac{6.6\times10^{-34}\times3\times10^{8}}{10.4\times1.6\times10^{-19}}$;

$= 1.20\times10^{-7}$ m; ***[3]***

*ECF from (a): if 1.56 eV used,* $\lambda = 7.93\times10^{-7}$ *m*.

(c) 


***or***




labelled bismuth and thallium levels;
α and γ labels; ***[2]***

(d) use of $A = A_0 e^{-\lambda t}$

$\frac{1.13}{2.80} = e^{-80\lambda} = 0.404$;

$\lambda = 0.01134 \ (\text{min}^{-1})$;

$T_{\frac{1}{2}} = \frac{0.693}{0.0113}$;

$\approx 61.1 \text{ min}$; ***[4]***

**B4. Part 1** Decay of radium-226

(a) (i) *proton number*: 86;
*neutron number*: 136; } *need both to award the mark.* **[1]**

(ii) the equation shows a spontaneous change from an unstable state to a more stable state / *OWTTE*;
the less the binding energy per nucleon the more unstable a nucleus so binding energy per nucleon of Ra less than the binding energy per nucleon of Rn / so binding energy per nucleon of Rn greater than binding energy per nucleon of Ra; **[2]**
*Accept answers in terms of negative binding energy per nucleon e.g. the less negative the binding energy per nucleon etc.*
*Award* ***[1]*** *for "number of protons less so (electrostatic) repulsion less and so nucleus more stable".*

(b) $226.0254 = 222.0175 + 4.0026 + Q$;
$Q = 0.0053 \times 931.5$ MeV;
$= 4.94$ MeV **[2]**

(c) (i) mass of $\alpha = \left(4.0026 \times 1.661 \times 10^{-27}\right) = 6.65 \times 10^{-27}$ (kg);

$v = \sqrt{\frac{2E_K}{m}}$;

$= \sqrt{\frac{2 \times 4.94 \times 10^6 \times 1.6 \times 10^{-19}}{6.65 \times 10^{-27}}}$;

$= 1.54 \times 10^7$ m s$^{-1}$ **[3]**

(ii) $F = \frac{\Delta E_K}{d}$; **[1]**

(iii) $\Delta E_K = 7.89 \times 10^{-13}$ (J);
$F = 1.88 \times 10^{-11}$ N; **[2]**

(iv) $a = \frac{F}{m}$ ***or*** $a = \frac{v^2}{2s}$;
$a = 2.82 \times 10^{15}$ (m s$^{-2}$);
$t = \frac{v}{a}$;
$= 5.46 \times 10^{-9}$ s / $\approx 5$ ns; **[4]**

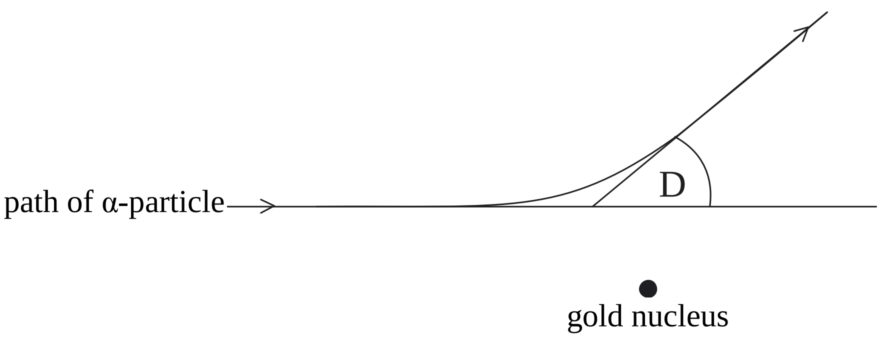
**B4. Part 1** α-particle scattering and nuclear processes

(a) ${}^{222}_{86}\text{Rn}$ ;
${}^{4}_{2}\alpha$ ; ***[2]***

(b) (i) $5.0\times10^{10}$ s ; ***[1]***
*Accept $4.9\times10^{10}$ s if 0.69 used.*

(ii) $N=\left(\dfrac{6.02\times10^{23}}{226}\right)$
$=2.66\times10^{21}$ ;
$A=\left(\dfrac{2.66\times10^{21}\times\ln 2}{5.0\times10^{10}}\right)$ ***or*** use of $A=\lambda N$
$=3.7\times10^{10}$ Bq ;
power $=3.7\times10^{10}\times7.6\times10^{-13}$;
$=28\times10^{-3}$ W ; ***[4]***

(c) (i)




angle shown correctly; ***[1]***
*Horizontal line must be present, angle can be marked to straight portion of deviated path.*

(ii) same number of protons / additional number of neutrons / nuclei are isotopes;
no charge change so deviation unchanged; ***[2]***
*Award **[0]** for bald answer or answer with incorrect explanation.*

(d) $4.0\times10^{6}\times1.6\times10^{-19}$ ;
$\dfrac{79e\times2e}{4\pi\varepsilon_0 r}$ ;
$5.7\times10^{-14}$ m ; ***[3]***
*Award **[3]** for bald correct answer.*

**B2. Part 1** Nuclear fusion

(a) the minimum energy required to (completely) separate the <u>nucleons</u> in a nucleus / the energy released when a nucleus is assembled from its constituent nucleons; ***[1]***

(b) mass defect $= 1\times1.007276 + 2\times1.008665 - 3.016049 = 8.56\times10^{-3}$ u ;
binding energy $= 8.56\times10^{-3}\times931.5 = 7.97$ MeV ;
binding energy per nucleon $= \frac{7.97}{3}$ MeV ;
$= 2.66$ MeV ***[3]***

(c) calculation of binding energies as shown below;
deuterium $^{2}_{1}H$ $1.11\times2 = 2.22$ MeV
tritium $^{3}_{1}H$ $2.66\times3 = 7.97$ MeV
helium $^{4}_{2}He$ $7.20\times4 = 28.8$ MeV
energy released is the difference of binding energies;
and so equals 18.6 MeV; ***[3]***
*Award **[2 max]** for an answer that uses binding energy per nucleon without multiplying by the number of nucleons.*

(d) (i) the electrostatic/Coulomb force; ***[1]***

(ii) total energy initially available is $2E_K$ ;
at closest point potential energy is $E_P = \frac{kq_D q_T}{d}$ ;
reference to energy conservation to equate the two; ***[3]***

(iii) correct identification of charges involved $q_D = q_T = 1.6\times10^{-19}$ C;
substitution to get $E_K = \frac{9\times10^9\times\left(1.6\times10^{-19}\right)^2}{2\times1.2\times10^{-14}}$ ;
$E_K = 9.6\times10^{-15}$ J ***[2]***

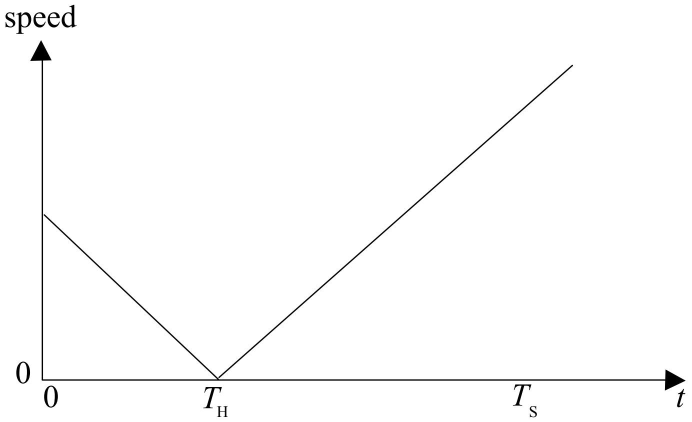
(e) (i) $4.6\times10^8$ K ; ***[1]***

(ii) even at lower temperatures there are nuclei moving sufficiently fast for fusion to occur;
because the formula for energy only refers to the average energy; ***[2]***

(iii) the nuclei have to overcome a Coulomb barrier/the repulsive force between the nuclei;
and so high temperatures are required to make the nuclei come sufficiently close to each other (for the nuclear force to then make them fuse); ***[2]***

(iv) at short distances the dominant force is the strong nuclear force which is attractive;
at large separations the nuclear force is negligible because it has short range leaving the repulsive electric force as the dominant force; ***[2]***

(b)




two lines going in the correct direction as shown;
speed greater at sea than initial speed;
(magnitude of) slopes the same; *(judge by eye)*
zero at $T_H$; ***[4]***
*Award **[2 max]** if lines do not go to zero.*
*Award **[1 max]** if initial speed zero and then going to zero at* $T_H$.

**A3.** (a) (i) an atom or nucleus that is characterized by the constituents of its nucleus / a particular type of atom or nucleus / *OWTTE*;
(in particular) by its proton (atomic) number and its nucleon number / number of protons and number of neutrons; ***[2]***

(ii) nuclides that have the same proton number but different nucleon number / same number of protons different number of neutrons; ***[1]***

(b) (i) $^{24}_{11}\text{Na} \rightarrow {}^{24}_{12}\text{Mg} + \beta^- + \bar{\nu}$
$\beta^-$ / $e^-$ / $^{0}_{-1}e$;
$\bar{\nu}$; ***[2]***

(ii) 5.00216 MeV is equivalent to 0.00537 $u$;
$23.99096 = 23.98504 + 0.00537 + \text{rest mass of particle}$;
rest mass $= 0.00055\,u$; ***[3]***
*No credit given for bald correct answer.*

(c) sodium-24 has more nucleons;
and more nucleons (usually) means greater (magnitude of) binding energy;

***or***

sodium-23 has less nucleons;
and less nucleons (usually) means less (magnitude of) binding energy; ***[2]***

**A4.** (a) product of normal component of magnetic field strength and area that it links / *OWTTE*;
$\phi = BA\cos\theta$; ***[2]***

(b) rate of change of flux $= \left(1.8\times10^{-3}\times5.0\times10^{-2}\right) = 9.0\times10^{-5}\left(\text{Wb s}^{-1}\right)$;
recognize that e.m.f. = rate of change of flux $= 9.0\times10^{-5}\,\text{V}$; ***[2]***
*Ignore any sign.*

## SECTION A

**A1.** (a) (i) $\pm 0.5\,^{\circ}\text{C}$; **[1]**

*Do not accept* $1\,^{\circ}C$.

(ii) actual uncertainty $= \pm 70\,\Omega$;

percentage uncertainty $= \left(\frac{70}{2600}\right) \times 100 = 3\%$; *(do not allow 2.7%)* **[2]**

*Do not apply SD–1 here since the question asks specifically for an estimate.*

(b) (i) *at* $20\,^{\circ}C$: $1800\,\Omega$; **[1]**

*at* $5\,^{\circ}C$: within range $3080\,\Omega \rightarrow 3220\,\Omega$;
within $3120\,\Omega \rightarrow 3180\,\Omega$; **[2]**

(ii) use of tangent at correct position clear;
answer $64\,\Omega\,\text{K}^{-1}$ ***or*** $64\,\Omega\,^{\circ}\text{C}^{-1}$; *(allow* $\pm 2\,\Omega\,K^{-1}$ ***or*** $\pm 2\,\Omega\,^{\circ}C^{-1}$*)*
<u>negative</u> sign; **[3]**

(c) gradient of graph decreases as temperature rises / increases as temperature drops; *accept "gradient not constant".*

so relationship cannot be linear; **[2]**

***or***

straight-line joining extreme points;
does not pass through "error boxes" of all points;

(d) product *RT* calculated correctly for two points;
product calculated correctly for third point;
conclusion: not same value so suggestion not correct; **[3]**
*Award* ***[2 max]*** *if* $^{\circ}C$ *used instead of K.*

**A2.** (a) measure activity *A* of a sample containing the isotope;
determine (chemically) the number *N* of atoms <u>of the isotope</u> (from the measured mass of the isotope);

$A = \lambda N$ <u>and</u> $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$; **[3]**

(b) fraction $= \left(\frac{1}{2}\right)^{1.6}$ ***or*** fraction $= e^{-1.6 \times \ln 2}$;
fraction $= 0.33$; **[2]**

**B3. Part 2 Nuclear decay**

(a) emission of particles and/or e.m. radiation from unstable nucleus;
not affected by temperature/environment / is spontaneous process;
constant probability of decay (per unit time) / is random process;
activity/number of unstable nuclei in sample reduces exponentially;
daughter nucleus is (energetically) more stable; ***[3 max]***

(b) (i) fission; ***[1]***

(ii) **N.B.** *positions may be marked on line or on x-axis.*
U shown near right-hand end of line;
Sr and Xe shown between U and the peak with Sr to the left of Xe; ***[2]***

(iii) total binding energy of uranium $= 1189 + 784.8 - 187.9$;
$= 1785.9\,\text{MeV}$;

binding energy per nucleon $= \left(\dfrac{1785.9}{235} = \right) 7.60\,\text{MeV}$; ***[3]***

*Allow unit as MeV or MeV per nucleon.*
*Accept answer in Joules e.g.* $1.22 \times 10^{-12}\ J$.

(iv) binding energy is zero because neutrons are separate particles; ***[1]***