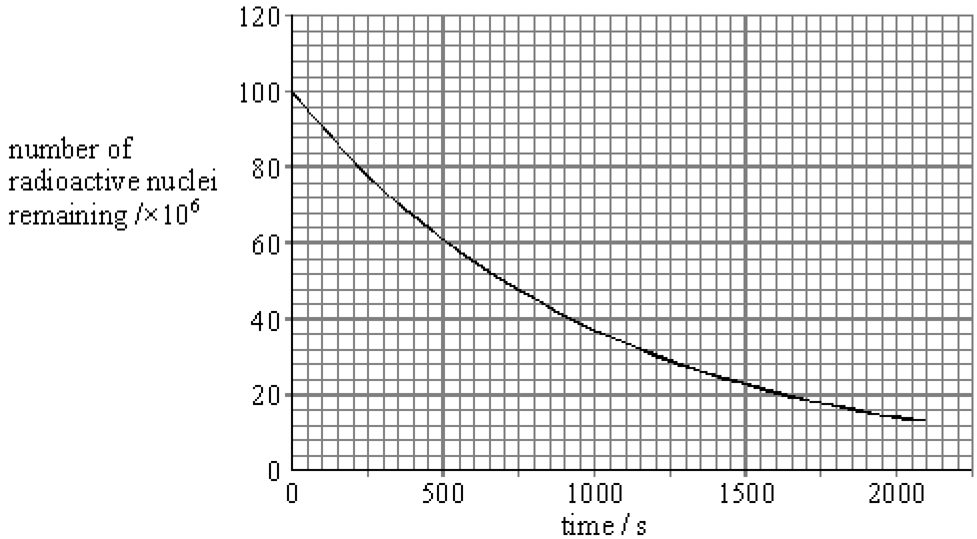
1 The graph below shows the number of radioactive nuclei remaining in a sample of material against time. The radioactive isotope decays to a non-radioactive element.



(a) Use the graph to show that, after a time of 500 s, about 6×10^4 nuclei are decaying every second.

(3)

(b) Calculate the decay probability (decay constant) of a nucleus of the radioactive isotope in the sample.

Decay probability ____________________

(3)

(Total 6 marks)

2 (a) (i) Sketch a graph to show how the neutron number, N, varies with the proton number, Z, for naturally occurring stable nuclei over the range $Z = 0$ to $Z = 90$. Show values of N and Z on the axes of your graph and draw the $N = Z$ line.

(ii) On your graph mark points, one for each, to indicate the position of an unstable nuclide which would be likely to be

an α emitter, labelling it A,

a β^- emitter, labelling it B.

(5)

(b) State the changes in N and Z which are produced in the emission of

(i) an α particle,

____

____

(ii) a β^- particle.

____

____

(2)

(c) The results of electron scattering experiments using different target elements show that

$$R = r_0 A^{\frac{1}{3}}$$

where A is the nucleon number and r_0 is a constant.

Use this equation to show that the density of a nucleus is independent of its mass.

___

___

___

___

(3)

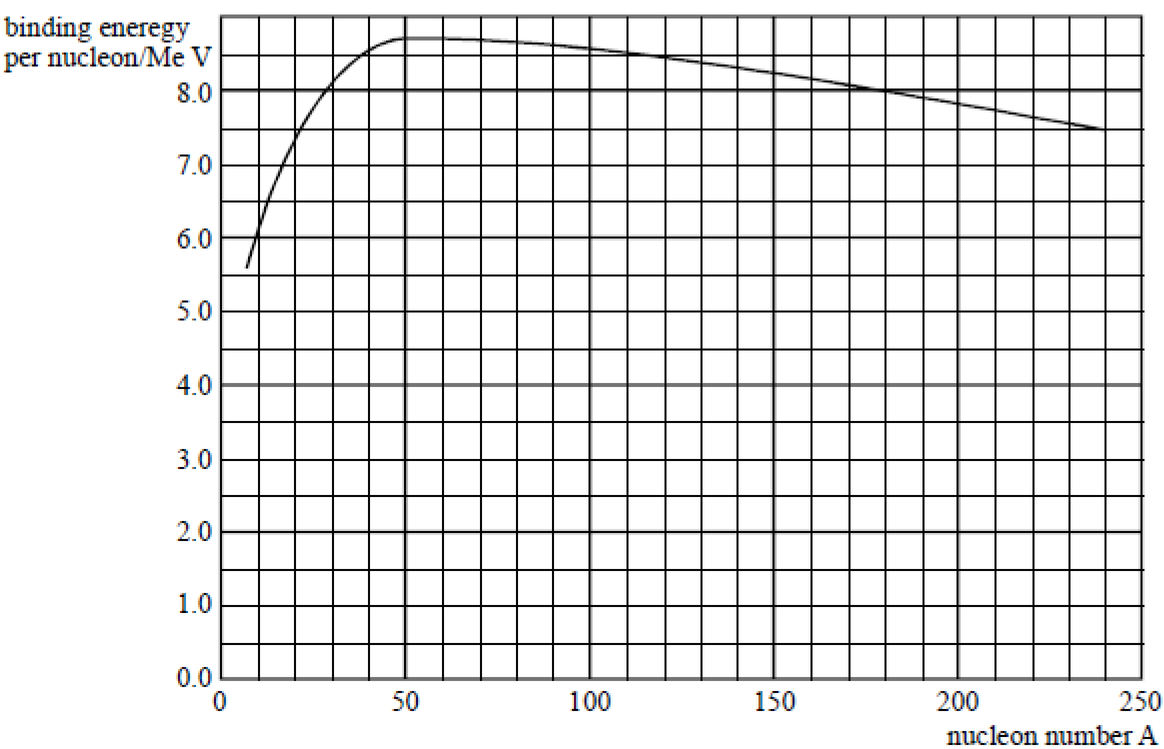
(Total 10 marks)

3 (a) (i) Complete the equation below which represents the induced fission of a nucleus of uranium $^{235}_{92}U$.

$$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{98}_{38}Sr + {}_{54}Xe + {}^{1}_{0}n$$

(ii) The graph shows the binding energy per nucleon plotted against nucleon number A.

Mark on the graph the position of each of the three nuclei in the equation.



(iii) Hence determine the energy released in the fission process represented by the equation.

____

____

____

____

____

____

(6)

(b) (i) Use your answer to part (a)(iii) to estimate the energy released when 1.0 kg of uranium, containing 3% by mass of $^{235}_{92}U$, undergoes fission.

____

____

____

____

____

____

(ii) Oil releases approximately 50 MJ of heat per kg when it is burned in air. State and explain **one** advantage and **one** disadvantage of using nuclear fuel to produce electricity.

advantage ____

____

____

____

disadvantage ____

____

____

____

(6)

(Total 12 marks)

4 Deuterium ($^{2}_{1}H$) and tritium ($^{3}_{1}H$) nuclei will fuse together, as illustrated in the equation below.

$$^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{A}_{Z}X + \text{neutron}$$

(a) State the nucleon number and the proton number for the product of the reaction which has been written as X in the equation.

nucleon number ______________________

proton number ______________________

(2)

(b) The masses of the particles involved in the reaction are:

mass of $^{2}_{1}H$ $= 3.34250 \times 10^{-27}$ kg

mass of $^{3}_{1}H$ $= 5.00573 \times 10^{-27}$ kg

mass of $^{A}_{Z}X$ $= 6.62609 \times 10^{-27}$ kg

mass of neutron $= 1.67438 \times 10^{-27}$ kg

(i) Explain why energy is released during this reaction.

____

____

____

____

(2)

(ii) Calculate the amount of energy released when a deuterium nucleus fuses with a tritium nucleus.

The speed of electromagnetic radiation, $c = 3.0 \times 10^{8}$ m s^{-1}

(3)

(Total 7 marks)

5 A small portion of the hydrogen in air is the isotope tritium $^{3}_{1}H$. This is continually being formed in the upper atmosphere by cosmic radiation so that the tritium content of air is constant. Tritium is a beta emitter with a half-life of 12.3 years.

(a) (i) Write down the symbols for the **two** isotopes of hydrogen, the atoms of which have lower masses than those of tritium.

____

(1)

(ii) Write down the nuclear equation that represents the decay of tritium using the symbol **X** for the daughter nucleus.

____

(2)

(iii) Calculate the decay constant for tritium in year^{-1}.

(1)

(b) When wine is sealed in a bottle no new tritium forms and the activity of the tritium content of the wine gradually decreases with time. At one time the activity of the tritium in an old bottle of wine is found to be 12% of that in a new bottle. Calculate the approximate age of the old wine.

(3)

(c)

mass of a tritium nucleus	= 3.016050 u
mass of a proton	= 1.007277 u
mass of a neutron	= 1.008665 u
atomic mass unit, u	= 1.660566×10^{-27} kg
speed of electromagnetic radiation in free space	= 3.0×10^{8} m s^{-1}

Calculate:

(i) the mass change, in kg, when a tritium nucleus is formed from its component parts,

(2)

(ii) the binding energy, in J, of a tritium nucleus.

(2)

(Total 11 marks)

6 (a) Uranium-238 decays by alpha emission to thorium-234. The table shows the masses in atomic mass units, u, of the nuclei of uranium-238 ($^{238}_{92}U$), thorium-234, and an alpha particle (helium-4).

Element	**Nuclear mass/u**
Uranium-238	238.0002
Thorium-234	233.9941
Helium-4, alpha particle	4.0015

1 atomic mass unit, u	= 1.7×10^{-27} kg
speed of electromagnetic radiation, c	= 3.0×10^{8} m s^{-1}
the Planck constant, h	= 6.6×10^{-34} J s

(i) How many neutrons are there in a uranium-238 nucleus?

____

(1)

(ii) How many protons are there in a nucleus of thorium?

____

(1)

(b) (i) Determine the mass change in kg when a nucleus of uranium-238 decays by alpha emission to thorium-234.

(2)

(ii) Determine the increase in kinetic energy of the system when a uranium-238 nucleus decays by alpha emission to thorium-234.

(2)

(c) Wave particle duality suggests that a moving alpha particle (mass 6.8×10^{-27} kg) has a wavelength associated with it. One alpha particle has an energy of 7.0×10^{-13} J.

Calculate:

(i) the momentum of the alpha particle;

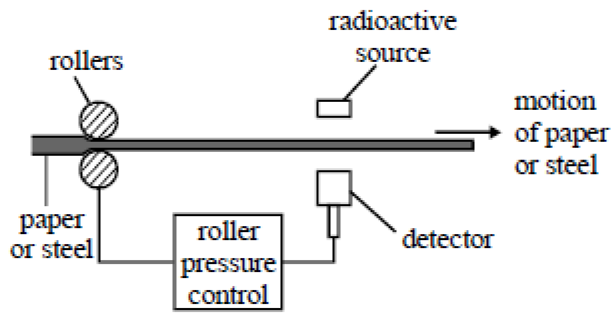
(2)

(ii) the wavelength associated with the alpha particle.

(2)

(Total 10 marks)

7 The diagram below shows an arrangement used to maintain a constant thickness of sheet paper or steel as it is being rolled. A radioactive source and detector are used to monitor the thickness.



(a) Explain briefly how this arrangement works.

____

____

____

____

____

(3)

(b) Alpha, beta or gamma sources could be selected for use in such an arrangement.

State which source should be selected in each case and explain briefly why the others would not be suitable.

Paper:

Source selected ____

Reasons why the others are unsuitable ___________________________

____

____

Steel:

Source selected ____

Reasons why the others are unsuitable ___________________________

____

____

(4)

(c) Cobalt-60 is commonly used as a source in such applications. This has a half-life of 5.3 years. When fresh the source contains 5.0×10^{20} radioactive atoms.

For it to be useful the source has to have an activity of at least 1.5×10^{12} Bq.

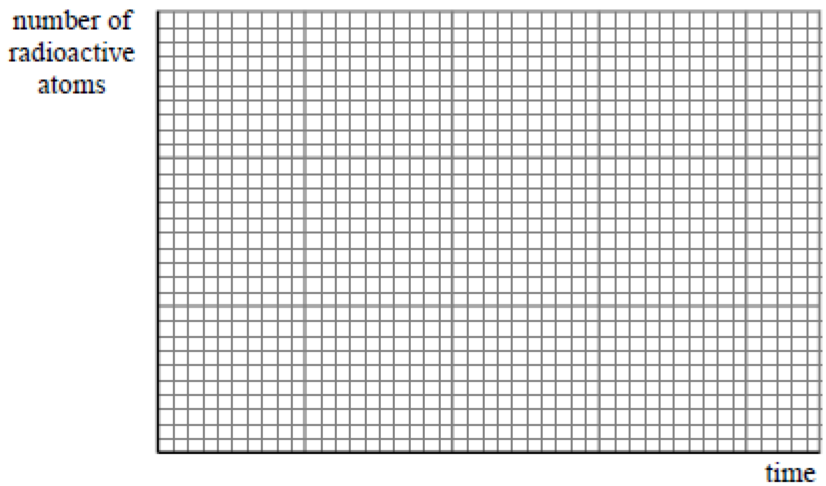
(i) What is meant by an activity of 1 Bq?

____

____

(1)

(ii) Draw a graph showing the number of radioactive atoms in the source over a period of 3 half-lives. Include suitable scales on the axes.



(2)

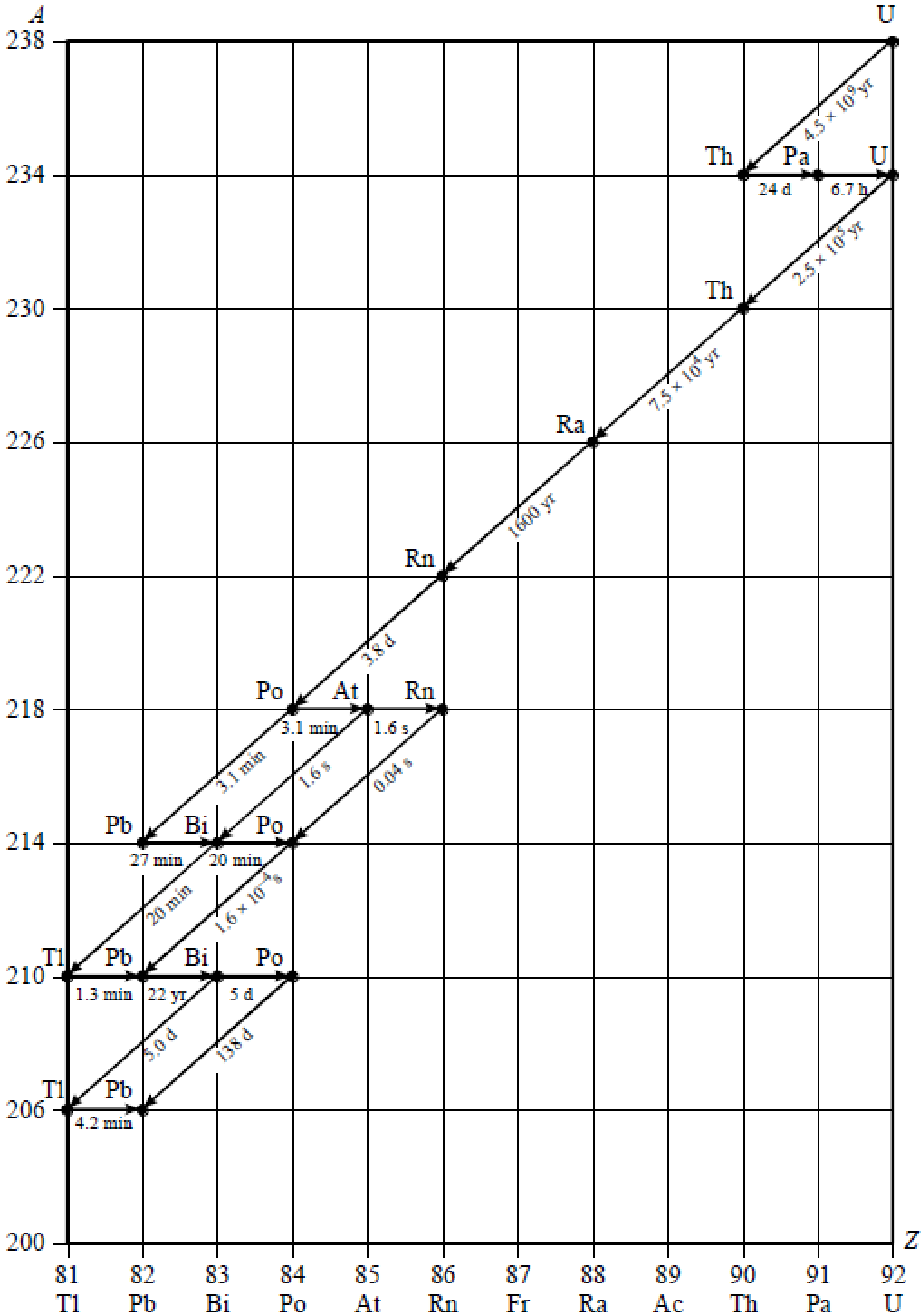
(iii) Determine the decay constant of cobalt-60 in s^{-1}.

(2)

(iv) After what time will it be necessary to replace the source?

(3)
(Total 15 marks)

8 The graph below shows how the nucleon number A changes with proton number Z for the decay series that starts with uranium-238. The half-lives of each decay are also shown.



(a) How many alpha particles and beta particles are emitted when a uranium-238 nucleus decays to radon-222 (^{222}Rn)?

Number of alpha particles ____

Number of beta particles ____

(2)

(b) How many neutrons are there in a nucleus of polonium-210 (^{210}Po)?

____

(1)

(c) Identify the stable isotope that results from this decay chain.

____

(1)

(d) 214 g of bismuth-214 (^{214} Bi) contains 6.0×10^{23} atoms. A sample containing only bismuth-214 has an initial mass of 0.60 g.

(i) After what period of time will the mass of bismuth-214 present in the sample be 0.15 g?

(2)

(ii) Determine the number of bismuth-214 atoms present after this time.

(1)

(iii) Calculate the activity of the bismuth-214 in the sample after this time.

(4)

(iv) Explain how the total activity of the sample will be different from the value calculated in (iii).

____

____

____

____

(2)

(v) The bismuth-214 decays into polonium-214. Explain why you would find very little polonium-214 if you were to analyse the sample.

____

____

(2)

(Total 15 marks)

9 An alpha particle moves at one-tenth the velocity of a beta particle. They both move through the same uniform magnetic field at right angles to their motion.

The magnitude of the ratio $\frac{\text{force on the alpha particle}}{\text{force on the beta particle}}$ is

A $\frac{1}{4}$

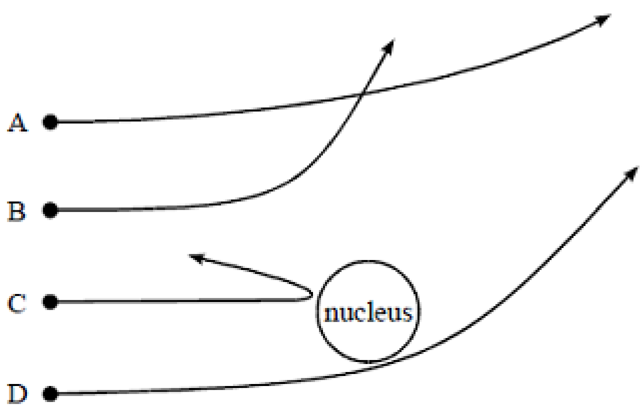
B $\frac{1}{5}$

C $\frac{1}{10}$

D $\frac{1}{20}$

(Total 1 mark)

10 A beam of α particles irradiates a metal foil. The paths of four α particles near the nucleus of a metal atom are shown in the diagram. Which one of the paths must be **incorrect**?



(Total 1 mark)

11 The actinium series of radioactive decays starts with an isotope of uranium, nucleon (mass) number 235, proton (atomic) number 92.

Which line in the table shows the nucleon number and proton number of the isotope after the emission of 5 α particles and 2 β^- particles?

	Nucleon number	proton number
A	213	82
B	215	80
C	215	84
D	227	87

(Total 1 mark)

12 Nuclear binding energy is

A the energy required to overcome the electrostatic force between the protons in the nucleus

B energy equivalent of the mass of the protons in the nucleus

C the energy equivalent of the mass of all the nucleons in the nucleus

D the energy equivalent of the difference between the total mass of the individual nucleons and their mass when they are contained in the nucleus

(Total 1 mark)

13 Which of the following does **not** give a value in seconds?

A capacitance × resistance

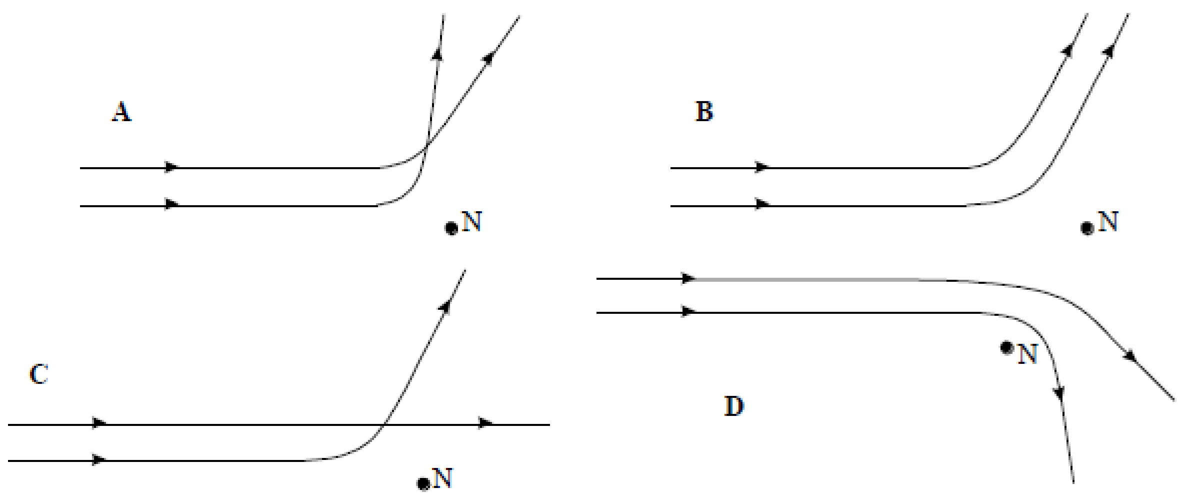
B $\frac{1}{\text{frequency}}$

C half-life

D $\frac{\text{power}}{\text{work}}$

(Total 1 mark)

14 In the Rutherford alpha particle scattering experiment, alpha particles having the same energy were fired at gold nuclei. The diagrams below are intended to represent encounters between two alpha particles and a gold nucleus N, the alpha particles arriving at different times. Which one best represents the possible encounters?



(Total 1 mark)

15 What is the mass difference of the $^{7}_{3}$Li nucleus?

Use the following data:

mass of a proton = 1.00728 u

mass of a neutron = 1.00867 u

mass of $^{7}_{3}$Li nucleus = 7.01436 u

A 0.93912 u

B 0.04051 u

C 0.04077 u

D 0.04216 u

(Total 1 mark)

16 The nuclear fuel, which provides the power output in a nuclear reactor, decreases in mass at a rate of 6.0×10^{-6} kg per hour. What is the maximum possible power output of the reactor?

A 42 kW

B 75 MW

C 150 MW

D 300 MW

(Total 1 mark)

17 Artificial radioactive nuclides are manufactured by placing naturally-occurring nuclides in a nuclear reactor. They are made radioactive in the reactor as a consequence of bombardment by

A α particles.

B β particles.

C protons.

D neutrons.

(Total 1 mark)

Mark schemes

1 (a) Appropriate method

B1

sensible and correct readoffs

B1

correct evaluation from readoffs

B1

3

(b) correct readoff on *y*-axis

B1

use of $\lambda = A/N$

C1

correct evaluation from readoff [condone use of 6.0 here]

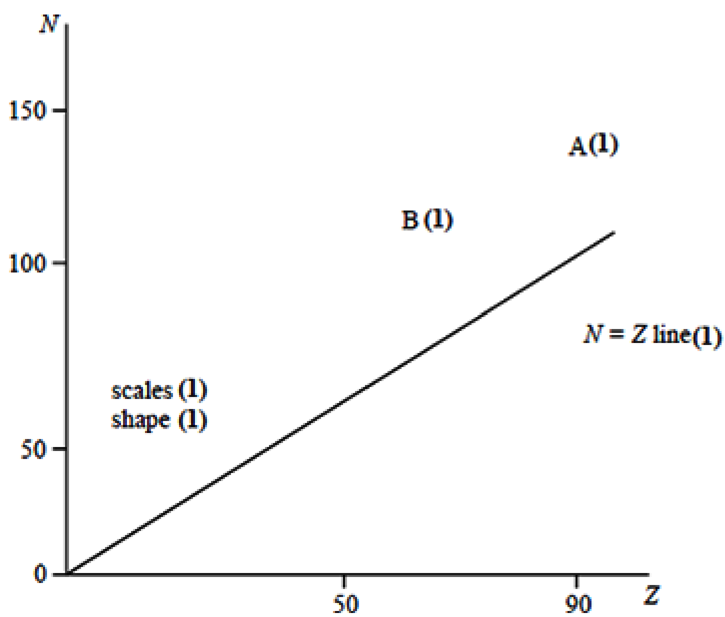
or determines $T_{1/2}$ /uses $T_{1/2}$ =0.69/λ/λ = 0.69/725

A1

3

[6]

2 (a)



(5)

(b) (i) α emitter: $N \downarrow 2$, $Z \downarrow 2$ **(1)**

(ii) β^- emitter: $N \downarrow 1$, $Z \uparrow 1$ **(1)**

(2)

(c) density = $\frac{\text{mass}}{\text{volume}}$ **(1)**

mass $\propto A$

volume $\propto R^3$ and $R \propto A^{\frac{1}{3}}$ hence volume $\propto A$ **(1)**

hence density = $\frac{\text{mass}}{\text{volume}}$ is independent of A **(1)**

(3)

[10]

3 (a) (i) $^{235}_{92}\text{U} + ^{1}_{0}n \rightarrow ^{98}_{38}\text{Sr} + ^{135}_{54}\text{Xe} + 3^{1}_{0}n(+Q)$ **(1)**

(ii) three correct positions to within ±2 on x-axis **(1)** **(1)** (one mark if two correct)

(iii) *estimate of energy released*:
binding energy of U-235 nucleus = (235 × 7.5) = 1763(±15)(MeV) **(1)**
binding energy of Sr-98 = (98 × 8.6) = 843(± 15)(MeV) **(1)**
binding energy of Xe-135 = (135 × 8.4) = 1134(± 15)(MeV) **(1)**
binding energy released = 1134 + 843 – 1763 = 214MeV **(1)**
(±40MeV)

max 6

(b) (i) 235g of U-235 releases 6 × 10^{23} × 214 × 1.6 × 10^{-13} J = 2.1 × 10^{13} (J) **(1)**
1.0 kg of uranium containing 3% U-235 contains 30g of U-235 **(1)**

energy from 1.0kg of uranium = $\frac{2.1 \times 10^{13} \times 30}{235}$ = 2.6 × 10^{12} J [[1.6 × 10^{25} MeV]]
(1)

(ii) *advantage*:
less mass of fuel used **(1)** because more energy per kilogram **(1)**
[alternative: less harm to environment **(1)** because does not generate greenhouse gases **(1)**
or any statement **(1)** argued **(1)**]
disadvantage:
hazardous waste **(1)** because fission products are radioactive **(1)**
[alternative: long term responsibility **(1)** because waste needs to be stored for many years **(1)**
or any statement **(1)** argued **(1)**]

max 6

[12]

4 (a) nucleon number 4 B1

proton number 2 B1 (2)

(b) (i) mass of products is less than mass of reactants / binding energy per nucleon increases / mass defect increases / 'loss' of mass B1

change in mass converted to energy B1 (2)

(ii) change in mass = 4.8×10^{-29} kg C1

$E = mc^2$ C1

4.3×10^{-12} J (4.30×10^{-12} J)

(if truncated sig. figs used only 2nd mark available) A1 (3)

[7]

5 (a) (i) ${}^{1}_{1}H$ and ${}^{2}_{1}H$ **or** ${}^{1}_{1}H$ and ${}^{2}_{1}D$ condone H^{1}_{1} etc B1 (1)

(ii) ${}^{3}_{1}H \rightarrow X + \beta$

${}^{3}_{1}H \rightarrow {}^{3}_{2}X$(or He) + ${}^{0}_{-1}\beta$ (or ${}^{0}_{-1}e$) M0

Z correct throughout A1

A correct throughout A1 (2)

(iii) 0.056(4) (no unit penalty) B1 (1)

(b) $A = A_0 e^{-\lambda t}$ **C1**

$12 = 100e^{-\lambda t}$ or other progress toward answer **C1**

38 (40) y *allow e.c.f. from (iii)* **A1**

or evidence of working in half-lives **C1**

statement that age is $3 \times T_{\frac{1}{2}}$ **C1**

age ≈ 37 y **A1**

or $A = N_0 e^{-\lambda t}$ (using **incorrect** formula from sheet) **C1**

$\lambda N = N_0 e^{-\lambda t}$ and $\frac{N}{N_0} = 0.12$ **or** $\frac{A}{A_0} = 0.12$ **C1**

$t = 89$ y **A1**

(3)

(c) (i) (mass of proton + 2 × mass of neutron – mass of tritium) = 0.0086 u **B1**

multiplies any mass in u by 1.660566×10^{-27} **A1**

1.42×10^{-29} kg
(no significant figure penalty) (no unit penalty) (condone –ve answer)

(2)

(ii) $E = mc^2$ **C1**

$E = 1.28 \times 10^{-12}$ J
(no unit penalty) (allow e.c.f. from (i) for m in kg) (condone –ve answer) **A1**

or using recall of u = 931 MeV
energy change in MeV = 8.557 × 931 = 7.97 MeV **C1**

energy change in J = $7.97 \times 1.6 \times 10^{-19} = 1.27 \times 10^{-12}$ J **A1**

(2)

[11]

6 (a) (i) 146

B1
(1)

(ii) 90

B1
(1)

(b) (i) 0.0046 u **or** 4.0061 u

B1

their mass change in u × 1.7 × 10^{-27} **or**
7.8 × 10^{-30} **or** 6.8 × 10^{-27} kg

B1
(2)

(ii) $E = mc^2$ (**or** recalls 1 u = 931 MeV)

C1

their (i) × 9 × 10^{16}
6.9 – 7.0 × 10^{-13} **or** 4.82 MeV

A1
(2)

(c) (i) speed determined correctly from their (ii)
(1.43 × 10^7 m s^{-1})
or
$p^2 / 2m = E$ or $E = ½mv^2$
and momentum (p) = mv

C1

9.5 – 9.8 × 10^{-20} kg ms^{-1}

A1
(2)

(ii) wavelength = h / mv

C1

their value of h / their (i)
6.6 – 6.9 × 10^{-15} m

A1
(2)
[10]

7 (a) thicker material absorbs more particles **B1**

count rate (number detected) falls if material is thicker **B1**

fall in count rate produces change to adjust process to produce thinner material / restore to original thickness

allow 1 mark for
'change in thickness changes count rate and rollers adjust to compensate' **B1**

(3)

(b) use a beta source **M0**

alphas would be absorbed by paper **A1**

gammas would not be affected **A1**

use a gamma source **M0**

beta would be absorbed completely **A1**

alphas would be absorbed completely

allow beta if candidate includes statement about the steel sheet being thin **A1**

(4)

(c) (i) 1 disintegration / decay / particle emitted per second (per unit time)
not one count per second **B1**

(1)

(ii) correct curvature starting at 5×10^{20};
time scale inserted up to 15 (unit not necessary)
or labelled T1/2, 2T1/2, 3T1/2 **M1**

sensible scales (not multiples of 3);
correct number of atoms at each half-life;
reasonable curve and unit for time **A1**

(2)

(iii) half-life = 0.69 / decay constant **C1**

$4.1 – 4.2 \times 10^{-9}$ (s^{-1}) **A1**

(2)

(iv) $A = (-)\lambda N$ **C1**

number of R / A atoms when activity is 1.5×10^{12} Bq = 3.6×10^{20} **C1**

correct time read from graph **A1**

(2.5 y / 920 days / 8.0×10^{7} s)

or
determines original activity or final number of atoms
2.1×10^{12} Bq or 3.6×10^{20}
allow ecf from (iii) **C1**

$N = N_0 e^{-\lambda t}$ **or** $A = A_0 e^{-\lambda t}$ **C1**

940 d or 2.6 y (answer depends on where rounding off has been done) **A1**

(3)

[15]

8 (a) number of alpha particles = 4 **B1**

number of beta particles = 2 **B1**

(2)

(b) 126 **B1**

(1)

(c) Pb-206 **B1**

(1)

(d) (i) number of half lives = 2

or half life = 20 minutes **C1**

40 minutes **A1**

(2)

(ii) 4.2×10^{20} **B1**

(1)

(iii) decay constant = 0.69 / half life (allow e.c.f. from (i))

or $N_0/2 = N_0 e^{-\lambda t_{1/2}}$ **C1**

5.75×10^{-4} s^{-1} or 5.78×10^{-4} s^{-1} or 0.0345 min^{-1}
(allow if calculation is done in (ii)) **C1**

A = λN **C1**

2.4 (2.42) × 10^{17} Bq (or decays per s)

or 1.5 (1.45) × 10^{19} decays per minute **A1**

(4)

(iv) the (daughter) products are also decaying [**or** are radioactive] **M1**

activity will be greater **A1**

(2)

(v) any 2 of:

polonium-214 has a half life of 1.6 × 10^{-4} s **B1**

decays almost as soon as it is formed or decays very quickly **B1**

only some of the bismuth-214 decays via polonium-214 **B1**

max 2

[15]

9 B **[1]**

10 D **[1]**

11 C **[1]**

12 D **[1]**

13 D **[1]**

14 A **[1]**

15 D

[1]

16 C

[1]

17 D

[1]

Examiner reports

1 (a) There was a widespread inability to carry through this part in any sensible way. Many obviously failed to understand the consequences and implications of this graph. Only rarely did examiners see a clear tangent drawn on the graph and then a serious attempt to evaluate its value, this from candidates who in PHB1 will happily and accurately evaluate the gradient of a distance–time graph to calculate a speed.

(b) This part was better but very frequently marred by misreads from the graph and errors in expressing the unit of decay constant.

3 It was not uncommon for the weaker candidates to score more than 50% of their total marks on this question.

Parts (a)(i) and (a)(ii) were completed correctly by the vast majority of candidates and most heeded the 'hence' in part (a)(iii) and attempted to use the graph, with at least partial success. Frequently, the solution did not extend beyond using the values from the graph and treating them as values of energy rather than energy per nucleon. A few candidates tried the more familiar mass-defect route, which was not a viable option considering the data available in the *Data booklet*.

Answers to part (b)(i), though varied in style, were often successful. Part (b)(ii) was well done, but there were many answers of a vagueness which was not expected at Advanced level.

4 Many candidates demonstrated confused ideas about mass / energy conversion in this question.

(a) The majority of candidates gained full credit here.

(b) (i) Few candidates produced cohesive answers to this part. Although most candidates talked in terms of different masses, mass defects or nuclear binding energies, most answers failed to demonstrate clear understanding of what happens in nuclear fusion. The simplest answers gaining full credit amounted to a statement that the total mass of the fusion products was less than the sum of the masses of the fusing nuclei and that this apparent mass loss had become the kinetic energy of the fusion products.

(ii) The majority of candidates were able to attempt this calculation, although there were frequent errors involving the addition and subtraction of masses or the squaring of the c value. A surprisingly large number of candidates tried to calculate the energy by using the equation for kinetic energy.

5 (a) (i) Most candidates completed this successfully.

(ii) There was a good proportion of correct equations but there were many who were unable to write the symbolic equation correctly using X and β

(iii) Most candidates did this correctly. A minority gave the answer in s^{-1}.

(b) The majority of the candidates used the route of determining the approximate number of half lives and arrived at the correct answer. Although a more difficult route, most others used the decay equation correctly. A common fault by those using the equation was to assume that the activity dropped by 12% rather than to 12%. A very small number quoted the incorrectly printed formula on the formula sheet.

Most of these immediately realised the error and proceeded correctly. A few combined the incorrect formula with $A = \lambda N$ and proceeded correctly to obtain an answer of 89 years. Candidates who proceeded logically in this way gained full credit.

(c) (i) Most candidates gained credit for undertaking the conversion from u to kg correctly. Many failed thereafter because they assumed a tritium nucleus to have either one proton and one neutron or two protons and one neutron. Arithmetic, presumably done using a calculator, presented a problem for some who knew the correct constituents.

(ii) Having obtained the mass change most proceeded correctly in this part. The usual error was to determine the energy equivalent of a tritium nucleus.

6 (a) (i) This was usually correct.

(ii) There were many correct answers to this part but not as many as for part (i) as many misread the question and presumably thought the question was still referring to the uranium nucleus.

(b) (i) There were two reasonable interpretations of this question, both of which were equally rewarded. Some candidates determined the difference in mass between the uranium and the thorium nucleus and others the difference in mass between the parent nucleus and the products of the decay. There were a large number of errors in adding and subtracting the numbers but the majority knew how to convert u to kg.

(ii) Only the total change in mass was appropriate in this part. Many gained a mark for $E = mc^2$ but a large number of candidates seemed unaware of the physics involved here and used ½mv^2 or ½: mc^2.

(c) (i) The use of ½ mc^2 to determine the speed of the alpha particle was correct in this part followed by momentum = my. The common error was to calculate momentum assuming the alpha particle to travel at 3×10^8 m s^{-1}. Some tried to use $p = h / \lambda$.

7 (a) There were many well explained answers to this part. However, the question exposed many misunderstandings. Many candidates wrote that either the source or radioactive particles passed through the material. Some thought that the material itself was radioactive. Although many referred to less radiation reaching the detector, it was disappointing how few referred to the radiation being ‘absorbed’. (Did they think it was reflected?) Many candidates referred to radiation being detected or not detected as thickness changed rather than that there being a variation in count rate.

(b) (i) To gain credit in either part the correct source first had to be identified. There were many who stated that alpha sources should be used for paper although the fact that alpha particles are absorbed by paper and travel only a short distance in air should be well-known.

(ii) A beta source was stated by many to be suitable. This was allowed only if they also stated that the steel would be thin. Many stated or implied in one or other of the two parts that gamma radiation could pass through anything without any change in intensity.

(c) (i) There was a surprising number of incorrect answers to this. Statements such as '1 Bq means that one radioactive atom is radiated from the source per second' or simply that 'it is the activity of a source' were not uncommon. Many associate the value with the count rate of a detector rather than a property of the source.

(ii) Poor graph drawing skills cost many candidates a mark here. To gain the first mark the correct value at $t = 0$ had to be plotted and indicated at 5×10^{20} and the curvature had to be correct though not accurate. For the second mark the scale should have been sensible (e.g. not 5.3, 10.6 etc at the 2 cm grid markings), and the values were expected to be reasonably accurate at times equal to 1, 2 and 3 half lives.

(iii) Most candidates did this correctly. Common faults were giving the answer as 0.13 year^{-1} or as 0.13 s^{-1}.

(iv) Whilst there were many correct answers, many were confused. A common response was $1.5 \times 10^{-2} = 5 \times 10^{20}\ e^{-\lambda t}$. These candidates did not appreciate that they needed to find either the original activity or the final number of radioactive atoms. There were also many instances where units were mixed. Calculation of the number of atoms remaining when the activity is 1.2×10^{12} Bq and reading the time from the graph was an expected, easy route to the answer but this approach was rarely used.