9(a)	difference between mass of nucleus and mass of (constituent) nucleons	**M1**
	when nucleons are separated to infinity	**A1**

9(b)	$\Delta m = (2 \times 2.013553) - (4.001505)$ (u) (= 0.025601 u)	**C1**
	$E = c^2\Delta m$	**C1**
	energy from one He-4 nucleus= $0.025601 \times 1.66 \times 10^{-27} \times (3.00 \times 10^8)^2$ (= 3.82×10^{-12} J)	**C1**
	energy to form 1.00 mol= $3.82 \times 10^{-12} \times 6.02 \times 10^{23}$ = 2.30×10^{12} J	**A1**

9(c)(i)	$L = 1.09 \times 10^{11} \times (3.00 \times 10^8)^2$	**C1**
	= 9.81×10^{27} W	**A1**

9(c)(ii)	$L = 4\pi\sigma r^2 T^4$ $9.81 \times 10^{27} = 4\pi \times 5.67 \times 10^{-8} \times (1.19 \times 10^9)^2 \times T^4$	**C1**
	T = 9930 K	**A1**

9(d)	standard candles have known luminosity	**B1**
	radiant flux intensity (from star) measured (on the Earth)	**B1**
	distance found from $F = L / (4\pi d^2)$	**B1**

Question 9

(a) The definition of mass defect seems to be less well known than other definitions. Some candidates appeared to have the right idea but did not use the terminology correctly (particularly with nucleus/nuclei/nuclide/nucleons/neutrons). Many of the candidates that did identify mass defect as the difference in mass between the nucleus and its constituent nucleons did not make the point that the latter mass is when the nucleons are infinitely separated. Common misconceptions among weaker candidates were either that mass defect is a change in mass during a reaction, or that mass defect is an energy.

(b) Many of the more able candidates obtained credit for determining the energy release from the formation of one nucleus of helium, but then stopped short of extending that to one mole.

(c) (i) Most candidates found this question difficult and attempted to use an equation for which the information was not available. The question was a test of their understanding of what is meant by luminosity (as the rate of emission of energy from the star) and they needed to realise that this could be obtained by applying $E = c^2\Delta m$ to the rate of loss of mass.

(ii) Many candidates were able to obtain full credit here using their value for luminosity from **(c)(i)**.

(d) Most candidates made the point that standard candles have known luminosity. The use of the equation $F = L / 4\pi d^2$ to calculate d was also articulated well by many candidates. Many candidates found it difficult to explain the use of the radiant flux intensity (including naming the quantity correctly).

8(a)	packet / quantum of <u>energy</u>	**M1**
	of electromagnetic radiation	**A1**

8(b)(i)	$E = c^2\Delta m$	**C1**
	$\Delta m = (4.274 \times 10^6 \times 1.60 \times 10^{-19}) / (1.66 \times 10^{-27} \times (3.00 \times 10^8)^2)$ (= 0.00458 u)	**C1**
	$m = 233.915174 + 4.000407 + 0.00458$ = 237.92016 u	**A1**

8(b)(ii)	$E = hc / \lambda$ **or** $E = hf$ **and** $c = f\lambda$	**C1**
	$(4.274 - 4.200) \times 1.60 \times 10^{-13} = (6.63 \times 10^{-34} \times 3.00 \times 10^8) / \lambda$	**C1**
	$\lambda = 1.7 \times 10^{-11}$ m	**A1**

8(b)(iii)	(true) energy of gamma photon is smaller so (true) wavelength is larger	**B1**

8(c)	(anti)neutrinos are emitted during beta decay	**B1**
	particles emitted during beta decay carry varying amounts of energy, so energy of gamma photon is also variable (between decays)	**B1**

Question 8

(a) There was a good understanding of the nature of the photon amongst most candidates.

(b) (i) To successfully answer this question, candidates needed to maintain the use of six decimal places in their calculations to match the data provided. Most candidates attempted to use the equation $E = mc^2$ but only stronger candidates converted the energy released into a mass in u to then be added to the other two masses.

(ii) The correct equation was used by most candidates. Stronger candidates were able to follow through the subtraction of energies that gave the value for the energy of the gamma photon.

(ii) Stronger candidates identified that they should be describing the energy of a gamma photon and its relationship to wavelength.

(c) Candidates who mentioned another product of the decay usually knew the correct product. Weaker candidates were unaware of the impact of the energy sharing between the products on the energy available to each gamma photon. Stronger candidates appreciated that each decay involved a single gamma photon.

11(a)(i)	(nuclear) fusion	**B1**

11(a)(ii)	Δm = [0.030377 – (3 × 0.002388)] u (= 0.023213 u)	**B1**
	$E = \Delta m\, c^2$	**C1**
	$= 0.023213 \times 1.66 \times 10^{-27} \times (3.00 \times 10^8)^2 = 3.47 \times 10^{-12}$ J	**A1**

11(b)(i)	mass of 1 mol of helium-4 = 4 g **or** mass of 1 helium atom = 4 u	**C1**
	N rate = $(6.02 \times 10^{23} \times 7.34 \times 10^{11}) / (4 \times 10^{-3})$ **or** N rate = $(7.34 \times 10^{11}) / (4 \times 1.66 \times 10^{-27})$	**C1**
	luminosity = $1.10 \times 10^{38} \times 3.47 \times 10^{-12}$ = 3.83×10^{26} W	**A1**

11(b)(ii)	$L = 4\pi\sigma r^2 T^4$ $3.83 \times 10^{26} = 4\pi \times 5.67 \times 10^{-8} \times (6.96 \times 10^8)^2 \times T^4$	**C1**
	T = 5770 K	**A1**

Question 11

(a) (i) The correct spelling of the technical term ‘fusion’ was required to ensure that there was no possible ambiguity with ‘fission’. Many candidates either misspelled the term fusion or believed that the nuclear reaction given was fission.

(ii) Most candidates appreciated that this was a ‘show that’ question, and so they laid out their derivation and substitutions clearly. Occasionally, the conversion of the mass defect from atomic mass units to kg was not shown, but most candidates were successful in this question.

(b) (i) Only stronger candidates were able to identify that the mass of helium (whether one atom or one mole) was the quantity to be used in the calculation. Most candidates appreciated that three significant figures were required for their answers. Weaker candidates wrongly attempted to use the Stefan–Boltzmann law.

(ii) Most candidates were able to process the data provided to give the star’s surface temperature to three significant figures. Occasionally the fourth root proved a source of arithmetical error.

10(a)	(decay is) not affected by external / environmental factors	**B1**

10(b)(i)	half-life of X = $2T$ **<u>and</u>** half-life of Y = $3T$	**B1**
	both samples show decay constant, in terms of $1 / T$, equal to ln 2 / half-life (decay constant of X = ln 2 / $2T$ and decay constant of Y = ln 2 / $3T$ if both half-lives correct)	**B1**
	both samples show N_0, in terms of AT, equal to initial activity / decay constant (N_0 for X = $8AT$ / ln 2 and N_0 for Y = $3AT$ / ln 2 if both decay constants correct) (Fully correct table:	**B1**

	half-life	decay constant	A_0	N_0
X	$2T$	ln 2 / $2T$	$4A$	$8AT$ / ln 2
Y	$3T$	ln 2 / $3T$	A	$3AT$ / ln 2

)

10(b)(ii)	correct substitution of A_0 and λ into $A_0 \exp(-\lambda t)$ for sample X or sample Y	**C1**
	$4A \exp(-t \ln 2 / 2T) = A \exp(-t \ln 2 / 3T)$	**C1**
	$t = 12T$	**A1**

10(c)	*Any two points from:* • (radiation) emitted in all directions, not just in direction of detector • some radiation absorbed by air / sample / window of detector • some radiation may not register even though it reaches detector	**B2**

Question 10

(a) Most candidates were able to give the correct meaning of the term spontaneous, although some weaker candidates conflated it with the term random.

(b) (i) Most candidates successfully determined the correct half-lives from the graph, but many of them found it difficult to give dimensionally correct answers for the decay constants and the values of N_0.

(ii) A significant number of candidates determined the correct value of t as $12T$ for full credit. Of those that were not able to determine the correct answer, partial credit was available for correct substitution into $A = A_0 \exp(-\lambda t)$ and then for equating the two expressions for activity. Candidates needed to take care with their use of t and T in the substitution, because t and T have different meanings in this question and both are required in the substitution. Some candidates equated values of N rather than A, which examiners took as an incorrect starting point for the question.

(c) Most candidates realised that the underlying reason for the difference in measured count rate and activity was that the detector does not detect all of the radiation emitted during the radioactive decay process. Weaker candidates often were not able to give reasons why the detector does not detect all the radiation.

9(a)	number of nuclear disintegrations per unit time	**B1**

9(b)	activity is proportional to the number of undecayed nuclei	**B1**
	activity = (–) rate of change of number of undecayed nuclei	**B1**
	N is proportional to the rate of change of N (so exponential variation)	**B1**

9(c)(i)	$120 = 180 \exp(-\lambda \times 8.4)$	**C1**
	$\lambda = 0.048\ \text{min}^{-1}$	**A1**

9(c)(ii)	half-life = ln 2 / 0.048 = 14 min	**A1**

9(c)(iii)	line with negative gradient throughout, starting at (0, 180)	**B1**
	curve with negative gradient passing through (8.4, 120)	**B1**
	curve with decreasing negative gradient, from $t = 0$ to $t = 24$ min, passing through (14, 90)	**B1**

Question 9

(a) A significant proportion of candidates were unable to give a clear and unambiguous definition.

(b) Only strong candidates were able to gain full credit. Most candidates could not explain the nature of an exponential change, for example as a particular fractional change taking the same amount of time or as the rate of change of *N* being proportional to *N*. Some attempts at explanations referring to half-life were incomplete.

(c) (i) The majority of the candidates gave the correct answer

(ii) Most candidates gave the correct answer, some with the benefit of an error carried forward from **(i)**.

(iii) Although many candidates gained full credit, most gained partial credit because the curve was drawn without sufficient care, sometimes resulting in zero gradient or a positive gradient at some times.

9(a)(i)	*either*: cannot predict when a (particular) nucleus will decay *or*: cannot predict which nucleus will decay next	**B1**

9(a)(ii)	not affected by external / environmental factors	**B1**

9(b)	time for activity to halve	**B1**

9(c)	energy = (189 × 7.826) + (4 × 7.074) – (193 × 7.774)	**C1**
	= 7.03 eV	**A1**

9(d)(i)	decay constant	**A1**

9(d)(ii)	decay constant / magnitude of gradient = 1.4 / 0.84	**C1**
	half-life = ln2 / (1.4 / 0.84) = 0.42 ms	**A1**

9(e)(i)	positrons collide with electrons and annihilate	**B1**

9(e)(ii)	long enough to have time to conduct investigation, not so long as to cause patient <u>unnecessary</u> exposure to radiation	**B1**

Question 9

(a) (i) The meaning of the random nature of radioactive decay was not well understood. Many candidates appeared to know that it concerned something being unpredictable but could not articulate that this unpredictability is to do with when individual nuclei decay. Many candidates appeared to think that everything about radioactive decay is unpredictable, which is not correct.

(ii) This was much more successfully answered, with most candidates knowing that the inability of external factors to affect the decay process is the meaning of the term spontaneous.

(b) Many candidates found it difficult to give an accurate definition of half-life. The time taken for the activity of a sample to halve is the simplest definition to articulate. Candidates who went down the number of undecayed nuclei route found it harder to be fully correct in their use of terminology. Responses such as the ‘time for nuclei to halve’ were common.

(c) Generally well-answered by candidates who appreciated that the data in the table is for binding energy <u>per nucleon</u>. Those who thought they were total binding energies made no use of the nucleon number data and just added/subtracted the binding energy per nucleon data. This approach was incorrect physics and could not be awarded credit. Some candidates did correctly calculate the 7.03 eV figure but then gave a negative answer, presumably just because of the way around they performed the subtraction in their calculators. The question did ask for the energy <u>released</u> (not just transferred), and so the sign of the answer has significance, and full credit could not be awarded to candidates who thought there was a negative release of energy.

(d) (i) A variety of responses was seen here, but many candidates did correctly deduce that the gradient of the line represented the magnitude of the decay constant.

(ii) Generally well-answered, with many correct answers seen to this question part.

(e) (i) Generally well-answered, with most candidates able to articulate that upon encounter with an electron, the positron will undergo annihilation.

(ii) Many candidates gave responses to this part that hinted towards some aspect of what examiners are looking for, but responses that only dealt with one half of the full answer were common. To be awarded credit, candidates needed to establish why 2 hours is both not too long and not too short for the half-life of the tracer.

10(a)(i)	cannot predict when a particular <u>nucleus</u> will decay **or** cannot predict which <u>nucleus</u> will decay next	**B1**

10(a)(ii)	(decay is) not affected by external (environmental) factors	**B1**

10(a)(iii)	fluctuations in (measured) count rate	**B1**

10(b)(i)	• large nuclei undergo fission whereas small nuclei undergo fusion • fission involves one nucleus splitting into two (or more) (smaller) nuclei • fusion involves two nuclei joining together to form one (larger) nucleus • fission is (usually) initiated by neutron bombardment • fusion is (usually) initiated by (very) high temperatures *Any three points, 1 mark each*	**B3**

10(b)(ii)	binding energy <u>per nucleon</u> is greatest for intermediate nucleon numbers (may be shown on sketch graph with axes labelled ‘binding energy <u>per nucleon</u>’ and ‘nucleon number’)	**B1**
	both fusion and fission involve an increase in binding energy (per nucleon)	**B1**

Question 10

(a) The meaning of 'spontaneous' was generally better understood than the meaning of 'random'. Many responses to the latter were too vague to be awarded credit, with weaker candidates appearing to think that all aspects of radioactive decay are unpredictable. Candidates are expected to realise that the unpredictability is only on the level of individual nuclei, and that on the macroscopic scale the process is highly predictable. Understanding of the experimental evidence for the random nature of decay was generally not well articulated.

(b)(i) To give a creditworthy account of the differences between nuclear fission and nuclear fusion, candidates needed to be very clear when they were referring to a single nucleus and when they were referring to multiple nuclei. Only a minority of candidates explained that fission involves a single nucleus splitting into multiple nuclei, with many describing processes that are more akin to radioactive decay. Explanations of fusion often relied on the word 'fuse', which is part of the term that the question is asking about, and so candidates needed to make clear that this involves two nuclei joining together to make a single nucleus.

(ii) Many responses were seen that were not incorrect in what they said, but that did not answer the question asked. There were many discussions, for example, of mass defect, but the question asked for a discussion of the variation of binding energy per nucleon with nucleon number. A space was provided for candidates to draw a sketch graph of this variation, and candidates that did this (provided the graph was correctly labelled) were generally more successful in answering the question than those that did not.

9(a)(i)	positron	**B1**

9(a)(ii)	λ = ln 2 / (110 × 60) = 1.05 × 10^{-4} s^{-1}	**A1**

9(a)(iii)	$N = M$ / (18 u) **or** (M in grams × N_A / 18) N = (2.1 × 10^{-12}) / (18 × 1.66 × 10^{-27}) **or** (2.1 × 10^{-9} × 6.02 × 10^{23}) / 18 (= 7.0 × 10^{13})	**C1**
	$A = \lambda N$	**C1**
	= 1.05 × 10^{-4} × 7.0 × 10^{13} = 7.4 × 10^{9} Bq	**A1**

9(b)(i)	• (pair) annihilation occurs • the <u>mass</u> of the two particles is converted into energy • two <u>gamma</u> photons are formed and travel in opposite directions **or** two <u>gamma</u> photons are formed and leave the body • difference in arrival times of photons (at detector) is processed *Any three points, 1 mark each*	**B3**

9(b)(ii)	with a shorter half-life: sample would (almost) fully decay before the test is complete	**B1**
	a longer half-life: exposes patient to harmful/ionising radiation unnecessarily **or** with a longer half-life: a larger dose (of tracer) needed to produce detectable activity	**B1**

NOT FOUND:

9702_w24_qp_41 EXAMINER REPORT (Qu 9)

9(a)	energy required to separate (all) the nucleons (in the nucleus)	**M1**
	to infinity	**A1**

9(b)(i)	Δm = {[(84 × 1.007276) + (128 × 1.008665)] – 211.942749} (u) (= 1.778 u)	**C1**
	= 1.778 × 1.66 × 10^{-27} (kg)	**C1**
	= 2.95 × 10^{-27} kg	**A1**

9(b)(ii)	$E = (\Delta)mc^2$	**C1**
	binding energy = 2.95 × 10^{-27} × (3.00 × 10^8)^2 = 2.66 × 10^{-10} J	**A1**

9(b)(iii)	binding energy per nucleon = (2.66 × 10^{-10}) / 212 = 1.25 × 10^{-12} J	**A1**

9(c)(i)	line rising to a single peak that is to the left of the '9' in the Fig. 9.1 label and then continually decreasing	**B1**
	steep positive gradient on the left of the peak and shallow negative gradient on the right	**B1**

9(c)(ii)	X shown on the line at a value of *A* that is to the right of the left-hand edge of the '*A*' in the axis label, and to the left of '2' in the 250 label	**B1**

9(c)(iii)	nucleus formed (as a result of the decay) has a lower nucleon number	**B1**
	(nucleus formed has a) greater binding energy per nucleon	**B1**

Question 9

(a) The definition of binding energy was not well known by the weaker candidates, and candidates of average ability sometimes found it difficult to get the technical wording right. Nucleus, nuclei, nucleons and neutrons were often confused, and the direction of the energy transfer was sometimes the wrong way around. Some candidates gave contradictory definitions and therefore could not be awarded credit.

(b) (i) Many candidates got as far as calculating the mass defect in u, but then stopped short of converting that mass into kg. Some of those that did go further introduced an error into the third significant figure of their answer, either by premature rounding within the question, or because of the use of the proton mass rather than the unified atomic mass unit.

(ii) The calculation of binding energy from the mass defect, using the mass–energy equation, was generally well done. A common mistake was to forget to square the speed of light when carrying out the calculation.

(iii) The division of the binding energy by the nucleon number to calculate the binding energy per nucleon was also generally well done. The common mistakes here were to use either the proton number or the neutron number rather than the nucleon number.

(c) (i) Most candidates knew the general shape of the curve, but it was common for the peak to be too far to the right or for the line to the right of the peak to descend too steeply.

(ii) Many candidates were able to gain credit. To be awarded credit, candidates needed to judge how far along the axis 212 is compared with 250, and then to mark their X on the line at the appropriate point. It was common for the X to be either too far to the left, or to not be on the line.

(iii) A very large number of candidates did not discuss alpha-decay, but instead talked about the polonium nucleus undergoing a fission reaction. This confusion did not necessarily prevent the candidate from achieving the marking points, but generally this did not happen. Many candidates did not heed the instruction in the question to refer to Fig. 9.1, with reference to the graph often not being made at all. Candidates were expected to explain that the nucleus formed as a result of the alpha-decay has a lower nucleon number than polonium-212, and as a result it has a greater binding energy per nucleon. Only a small minority of candidates made either of these points.

9(a)	time for activity (of sample) to halve	**B1**

9(b)(i)	activity (of X at time *t*)	**B1**

9(b)(ii)	• Y is a stable isotope • total number of nuclei is constant • half-life (of X) is 13.6 s • decay constant (of X) is 0.051 s^{-1} • amount (of X) at $t = 0$ is 0.066 mol • activity (of X) at $t = 0$ is 2.0×10^{21} Bq *Any three points, 1 mark each*	**B3**

9(c)	mass of 1 nucleus = $(7.3 \times 10^{-4}) / (4.0 \times 10^{22})$	**C1**
	nucleon number = mass of nucleus / (1.66×10^{-27})	**C1**
	= $(7.3 \times 10^{-4}) / (4.0 \times 10^{22} \times 1.66 \times 10^{-27})$ = 11 **and** given as an integer	**A1**

Question 9

(a) Many answers used imprecise statements, expressing the half-life in terms of mass or total nuclei rather than activity. Terms such as atom, nucleon and nucleus were often used wrongly in this context.

(b) (i) An understanding that the gradient of the curve was the number of nuclei decaying per unit time meant that the majority of the candidates correctly identified the name of the quantity as ‘activity’.

(ii) A full range of marks was seen on this question. Responses that directly described the graph without drawing a conclusion did not gain credit. Some element of processing or derivation was required. Stronger candidates were able to derive a numerical value for the half-life, or for the activity at some fixed time, and could include an appropriate number of significant figures and the correct unit.

(c) This was a question in which the ability to set working out clearly was of benefit to the candidate, as credit was available for stages in the process of getting to the final answer. Despite the complexity caused by the variety of possible approaches, it was generally well answered. Many candidates understood that the final answer for nucleon number needed to be an integer.

8(a)	(minimum) energy required to separate the nucleons (of a nucleus)	**M1**
	to infinity	**A1**

8(b)(i)	4	**A1**

8(b)(ii)	energy = $(142 \times 8.37) + (90 \times 8.72) - (235 \times 7.59)$	**C1**
	= 190 MeV	**A1**

8(b)(iii)	**either** it has too many neutrons (for the number of protons) **or** its neutron to proton ratio is too high	**B1**

8(b)(iv)	(when $t = 6.0$ s), $N / N_0 = 1 / 32$	**C1**
	either $(1 / 32) = \exp(-\ln 2 \times 6.0 / t_{½})$	**C1**
	$t_{½} = 1.2$ s	**A1**
	or $32 / 2^n = 1$ so $n = 5$ (half-lives)	**(C1)**
	$t_{1/2} = 6.0 / 5$ $= 1.2$ s	**(A1)**

NOT FOUND:

9702_m24_qp_42 EXAMINER REPORT (Qu 8)

9(a)(i)	material introduced into the body **and** (position in body) can be detected **or** absorbed by the tissue (being studied)	**B1**

9(a)(ii)	X = β^+ **or** e^+ **and** $P = 1$	**B1**
	$Q = 0$ **and** $R = 18$	**B1**

9(b)(i)	positrons (emitted in the decay) and electrons annihilate	**B1**
	mass of particles becomes energy of gamma photons	**B1**

9(b)(ii)	arrival times of photons are processed	**B1**
	image built up of tracer concentration in the tissue	**B1**

9(c)(i)	$A = \lambda N$ **and** $\lambda = \ln 2 / T$	**C1**
	$N = n \times N_A$	**C1**
	2 photons produced from each decay, so $R_0 = 2 \times \lambda \times n \times N_A$ $R_0 = (2 \ln 2)\ nN_A / T$ (*allow 0.693 for ln 2*)	**A1**

9(c)(ii)	sketch: exponential decay curve from $t = 0$ to $t = 2T$, starting at $(0, R_0)$ and with a negative gradient of continuously decreasing magnitude	**B1**
	line with negative gradient passing through $(T, R_0 / 2)$ and $(2T, R_0 / 4)$	**B1**

Question 9

(a) (i) Many candidates gave part of the answer but not a full answer as to what is meant by a tracer. A significant minority of weaker candidates attempted to describe how a tracer is used rather than answering the question that was asked.

(ii) This question was a straightforward exercise in balancing a nuclear equation. Some candidates did not know the symbol for a positron, and many others did not know the effect on proton number and nucleon number of beta-plus decay.

(b) (i) Most candidates were able to state that positrons encounter electrons and undergo annihilation. The idea that this involves all of the mass of the particles becoming the energy of the gamma photons was less well articulated by many candidates.

(ii) There was much confusion with other types of medical imaging in responses seen to this question, with image formation in ultrasound scanning and CT scanning being commonly discussed.

(c) (i) Many candidates were able to access either or both of the marks available for use of the correct starting equations. Full credit for a fully correct final expression was only awarded to a small number of candidates who realised that there are two photons produced from each decay.

(ii) Many candidates correctly drew a smooth exponential decay curve or a line passing through the correct points at $t = T$ and $t = 2T$. The number of candidates who demonstrated both of these features was comparatively small.

9(a)	(two small) nuclei join together	**M1**
	to form one larger nucleus	**A1**

9(b)	line with a peak at $A \approx 56$	**B1**
	line with steep initial positive gradient on the left of peak and shallower negative gradient at all points to the right of peak and line does not return to 0 binding energy	**B1**

9(c)(i)	X shown at value of A to the right of the peak	**B1**

9(c)(ii)	Y shown at value of A close to 1	**B1**

9(d)	energy from 1 nucleus = $(1.77 \times 10^{13}) / (6.02 \times 10^{23})$ $(= 2.94 \times 10^{-11}$ J$)$	**C1**
	binding energy of Z = $[(1.25 + 1.81) \times 10^{-10}] - 2.94 \times 10^{-11}$ $(= 2.77 \times 10^{-10}$ J$)$	**C1**
	nucleon number of Z = 93 + 139 + 2 – 1 (= 233)	**C1**
	binding energy per nucleon = $(2.77 \times 10^{-10}) / (233 \times 1.60 \times 10^{-13})$ = 7.43 MeV	**A1**

NOT FOUND:

9702_w23_qp_41 EXAMINER REPORT (Qu 9)

9(a)	difference between mass of nucleus and (total) mass of nucleons	**M1**
	when infinitely separated	**A1**

9(b)(i)	neutron	**B1**

9(b)(ii)	$E = \Delta m\, c^2$	**C1**
	Δm = (0.030377 – 0.002388 – 0.009105)u (= 0.018884u)	**C1**
	energy release = $(0.030377 - 0.002388 - 0.009105) \times 1.66 \times 10^{-27} \times (3.00 \times 10^8)^2 = 2.8 \times 10^{-12}$ J	**A1**

9(c)(i)	number of atoms per unit time = $(1.4 \times 10^{28}) / (2.8 \times 10^{-12})$ (= 5.0×10^{39} s^{-1})	**C1**
	mass of one atom = $4 \times 1.66 \times 10^{-27}$ or $(4 \times 10^{-3}) / (6.02 \times 10^{23})$ (= 6.64×10^{-27} kg)	**C1**
	mass per unit time = $6.64 \times 10^{-27} \times 5.0 \times 10^{39}$ = 3.3×10^{13} kg s^{-1}	**A1**

9(c)(ii)	$L = 4\pi\sigma r^2 T^4$ $1.4 \times 10^{28} = 4\pi \times 5.67 \times 10^{-8} \times (2.3 \times 10^9)^2 \times T^4$	**C1**
	T = 7800 K	**A1**

Question 9

(a) The definition of mass defect appears to be not as well known as most definitions, and many candidates did not give a correct answer. Many candidates tried to suggest that it is an energy, and others described it as a change in mass during a nuclear process. Correct use of technical terms is important, and many responses conflated nucleus, nucleons and neutrons by using them as synonymous terms.

(b) (i) Weaker candidates found it difficult to identify particle X as a neutron, but the stronger candidates generally had little difficulty with this.

(ii) Many candidates answered this question well, and full credit was common. As ever with ‘show that’ questions, candidates should be advised that full credit requires full substitution of all the working. There were some careless errors in transcribing the mass data that resulted in candidates not being awarded credit, and other candidates omitted to show the multiplication by the value of u or the value of c^2.

(c) (i) This was a challenging question. It was not possible to answer just by recalling an equation and plugging numbers into it. The first step required was to appreciate that the luminosity gives the energy released per unit time and the previous question gives the energy released per nucleus. Between these two, the number of nuclei of helium produced per unit time can be determined. The second step was to determine the mass of a helium nucleus in kg. The two steps can then be put together to determine the mass of helium produced per unit time. Weaker candidates found it difficult to know where to start, often just trying to use the Stefan–Boltzmann law inappropriately because the word ‘luminosity’ was in the question. A significant proportion of the more able candidates gave fully correct answers and could be awarded full credit.

(ii) Candidates generally found this to be a much more straightforward question than the previous one, and many of them were able to use the Stefan–Boltzmann law correctly to determine the correct answer. Partial credit was also common for candidates who substituted all the values correctly into the equation but then made a mistake with the arithmetic.

9(a)	time for activity (of sample) to halve	**B1**

9(b)	sketch: line with positive gradient starting at (0,0) and extending to t = 80 min	**B1**
	exponential curve, extending from t = 0 to t = 80 min, with gradient of steadily decreasing magnitude	**B1**
	line passing through (0,0), (20, $0.5N_0$) and (40, 0.75 N_0)	**B1**

9(c)(i)	every (undecayed) nucleus has the same probability of decay	**M1**
	fewer (undecayed) nuclei remaining (with time), so fewer will decay (in a given time interval)	**A1**

9(c)(ii)	• sample emits in all directions but detector only captures emissions in one direction • some emissions are absorbed before reaching detector • some emissions are scattered within the sample • simultaneous arrival of multiple particles only registers once • some particles may reach detector but not cause ionisation *Any two points, 1 mark each*	**B2**
	measured count rate is less than the activity	**B1**

Question 9

(a) Many candidates tried to define half-life in terms of the number of nuclei present. The problem with this definition is that, in many cases, the number of nuclei present does not change. If this is the way that candidates wish to define half-life, then they need to use the words ‘radioactive’ or ‘undecayed’ when referring to the nuclei so that the nuclei of the decay product are not part of the definition. A much simpler definition is the time taken for the activity of a sample to halve.

(b) There were many correct lines that were accurately drawn here. However, there were also many candidates that drew the decay curve for carbon-11 rather than the growth curve for boron-11.

(c) (i) Very few candidates realised the key point here that the probability of decay of a nucleus per unit time is constant, which is why the decay is random.

(ii) Many candidates did not realise that the measured count rate from a sample is always less that its activity. The reasons given by those candidates who correctly stated the count rate would be less than the activity were not always sufficiently detailed to gain credit.

8(a)	234, 92 for the uranium nucleus	**B1**
	4, 2 for the alpha particle	**B1**

8(b)(i)	$N_0 = 0.874 / (238 \times 1.66 \times 10^{-27})$ $= 2.21 \times 10^{24}$	**A1**

8(b)(ii)	$A = \lambda N$	**C1**
	$= \dfrac{\ln 2}{87.7 \times 365 \times 24 \times 3600} \times 2.21 \times 10^{24}$ $= 5.54 \times 10^{14}$ Bq	**A1**

8(b)(iii)	power $= 5.54 \times 10^{14} \times 5.59 \times 10^{6} \times 1.60 \times 10^{-19}$	**C1**
	$= 496$ W	**A1**

8(b)(iv)	$65.3 = 100e^{-\frac{\ln 2}{87.7}t}$	**C1**
	$\ln 0.653 = -(\ln 2 / 87.7)\ t$ $t = 53.9$ years	**A1**

8(c)	advantage: less mass so less energy needed to launch probe	**B1**
	disadvantage: half-life shorter so will not provide power for as long	**B1**

Question 8

(a) This was straightforward for most candidates.

(b) (i) There were a good number of correct calculations, however a common error was to use the mass of the plutonium in kg and the molar mass in $g\,mol^{-1}$ leading to a power of ten error.

(ii) The equation linking activity with number of unstable nuclei was correctly quoted by most candidates. However, there were errors in converting years into seconds and the use of the half-life in years, but the activity stated as being in Bq.

(iii) This calculation was challenging for candidates. Many candidates incorrectly applied $P = E / t$ and used the time as the half-life of the plutonium.

(iv) Candidates should be reminded that intermediate values used in calculations should carry more significant figures than expected in the final answer. Premature rounding of intermediate values leads to incorrect answers in the final significant figure, and this was a common problem in this question. The data justifies a 3 significant figure answer, and candidates who used a value of decay constant prematurely rounded to 3 significant figures often arrived at an answer that was not quite correct to the expected precision. Some candidates did not use the exponential decay formula at all.

(c) Candidates needed to explain why the lower mass is advantageous, and why the shorter half-life is disadvantageous. Most candidates struggled with this. Just stating information given in the question is not sufficient to gain credit.

10(a)(i)	cannot predict when a (particular) nucleus will decay **or** cannot predict which nucleus will decay next	**B1**

10(a)(ii)	not affected by external / environmental factors	**B1**

10(b)(i)	line fluctuates **or** trend is a straight line	**B1**

10(b)(ii)	straight line of best fit drawn on Fig. 10.1	**B1**

10(b)(iii)	$M = M_0 \exp(-\lambda t)$ so $\ln M = \ln M_0 - \lambda t$ so gradient $= -\lambda$ (and magnitude of gradient $= \lambda$)	**B1**

10(b)(iv)	gradient = (–) (8.0 – 4.8) / (11.6 – 0) (*allow any correct pair of values from Fig. 10.1*)	**C1**
	$\lambda = 0.28\ \text{s}^{-1}$	**A1**

10(b)(v)	half-life $= 0.693 / \lambda$ $= 0.693 / 0.28$ $= 2.5$ s	**A1**

10(c)	(for reaction to occur,) energy is released	**B1**
	energy release comes from fall in mass so total mass of products must be less (than mass of carbon-15)	**B1**

Question 10

(a) (i) Radioactive decay is a nuclear process so candidates need to remember to include the word ‘nucleus’ in their answer.

(ii) Most candidates understood the meaning of ‘spontaneous’.

(b) (i) Most candidates realised that the fluctuations on the line were evidence demonstrating that the decay was random.

(ii) A large majority of candidates drew an appropriate line of best fit.

(iv) Many candidates were unable to take natural logarithms of the exponential decay equation and show that the gradient of the line is $-\lambda$. Some candidates who did the majority of the required work missed out the minus sign.

(iv) There were many correct values of the decay constant. However, some candidates do not understand the labelling of axes on a logarithmic graph and included the factor of 10^{-16} in their calculation. Some weaker candidates attempted to take logarithms of the coordinates.

(c) This explanation proved to be challenging. Many candidates did not realise that there is a fall in mass as it is mass–energy that is conserved and not just mass. They also did not realise that energy was released in the reaction.