AQA

A-level
Physics

PHYA5/1R – Nuclear and Thermal Physics
Mark scheme

2450
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Version 1: Final mark scheme

Mark schemes are prepared by the Lead Assessment Writer and considered, together with the relevant questions, by a panel of subject teachers. This mark scheme includes any amendments made at the standardisation events which all associates participate in and is the scheme which was used by them in this examination. The standardisation process ensures that the mark scheme covers the students' responses to questions and that every associate understands and applies it in the same correct way. As preparation for standardisation each associate analyses a number of students' scripts. Alternative answers not already covered by the mark scheme are discussed and legislated for. If, after the standardisation process, associates encounter unusual answers which have not been raised they are required to refer these to the Lead Assessment Writer.

It must be stressed that a mark scheme is a working document, in many cases further developed and expanded on the basis of students' reactions to a particular paper. Assumptions about future mark schemes on the basis of one year's document should be avoided; whilst the guiding principles of assessment remain constant, details will change, depending on the content of a particular examination paper.

Further copies of this mark scheme are available from aqa.org.uk

Question	Answers	Additional Comments/Guidance	Mark	ID details
1 (a)	A α particles ✓	[auto mark question]	1	
1 (b)(i)	type of radiation / Typical range in air/m α: 0.04 ✓ β: 0.40 ✓	allow students to use their own distance units in the table α allow 0.03 → 0.07 m β allow 0.20 → 3.0 m If a range is given in the table use the larger value. A specific number is required eg not just a few cm.	2	
1 b)(ii)	reference to the inverse square law of (γ radiation) or reference to lowering of the solid angle (subtended by the detector as it moves away) or radiation is spread out (over a larger surface area as the detector is moved away)✓	(owtte) Ignore any references to other types of radiation. Any contradiction loses the mark. For example, follows inverse square law so intensity falls exponentially.	1	
1(c)	dust may be ingested/taken into the body/breathed in ✓ causing (molecules in human tissue/cells) to be made cancerous / killed / damaged by ionisation ✓	first mark for ingestion not just on the body second mark for idea of damage from ionisation	2	

Total			**6**	

Question	Answers	Additional Comments/Guidance	Mark	ID details
2 (a)(i)	electromagnetic/electrostatic/Coulomb (repulsion between the alpha particles and the nuclei) ✓	The interaction must be named not just described.	1	
2 (a)(ii)	the scattering distribution remains the same (because the alpha particles interact with a nucleus) whose charge/proton number/atomic number remains the same or the (repulsive) force remains the same Or the scattering distribution changes/becomes less distinct because there is a mixture of nuclear <u>masses</u> (which gives a mixture of nuclear recoils) ✓ (owtte)	The mark requires a described distribution <u>and the reason</u> for it. A reference must be made to mass and not density or size.	1	
2 (b)(i)	use of graph to find r_0 eg $r_0 = 6.0 \times 10^{-15} / 75^{1/3}$ ✓ (or $8.0 \times 10^{-15} / 175^{1/3}$) ($r_0 = 1.43 \times 10^{-15}$ m)	Substitution and calculation t must be shown. Condone a gradient calculation on <u>R against $A^{1/3}$</u> graph (not graph of Fig 1) as $R \propto A^{1/3}$	1	
2 (b)(ii) Escalate if clip shows $^{27}_{13}$Al in the question giving $R \approx 4 \times 10^{-15}$ m.				
2 (b)(ii)	(using $R = r_0 A^{1/3}$) $R = 1.43 \times 10^{-15} \times 51^{1/3}$ ✓ $R = 5.3 \times 10^{-15}$ (m) ✓ ($R = 5.2 \times 10^{-15}$ m from $r_0 = 1.4 \times 10^{-15}$ m)	first mark for working second mark for evaluation which must be 2 or more sig figs allow CE from b(i) $R = 3.71 \times$ b(i) **Possible escalation**	2	
2 (c) Escalate if clip shows $^{27}_{13}$Al in the question and/or the use of 27 in the working.				
2 (c)	density = mass / volume $m = 51 \times 1.67 \times 10^{-27}$ (= 8.5×10^{-26} kg) $v = 4/3\pi(5.3 \times 10^{-15})^3$ ($6.2(4) \times 10^{-43}$ m^3) Or density = $A \times$ u / $4/3\pi(r_0 A^{1/3})^3$	give the first mark for substitution of data into the top line or bottom line of the calculation of density. In the second alternative the mark for the substitution is only given if the working equation is given as well. $51 \times 1.67 \times 10^{-27}$ would gain a mark on its own but 1.66×10^{-27}	3	

	$= u / 4/3\pi(r_0)^3$ top line = 1.66×10^{-27} bottom line = $4/3\pi(1.43 \times 10^{-15})^3$ ✓ for one substitution density = 1.4×10^{17} ✓ (1.37×10^{17}) kg m^{-3} ✓	would need $u / 4/3\pi(r_0)^3$ as well to gain the mark. Expect a large spread of possible answers. For example If $R = 5 \times 10^{-15}$ $V = 5.24 \times 10^{-43}$ and density = 1.63×10^{17} **Possible escalation**		

			8

Question	Answers	Additional Comments/Guidance	Mark	ID details
3(a)	${}^{239}_{93}\mathrm{Np} \rightarrow {}^{239}_{94}\mathrm{Pu} + {}^{(0)}_{(-1)}\beta^- + {}^{(0)}_{(0)}\bar{\nu}$ ✓✓	First mark for one anti-neutrino or one beta minus particle in any form eg. e^-. If subscript and superscripts are given for these they must be correct but ignore the type of neutrino if indicated. The second mark is for both particles and the rest of the equation. Ignore the full sequence if it is shown but the Np to Pu must be given separately for the mark.	2	
3(b)(i)	$T_{1/2}$ 2.0 → 2.1 × 10^5 s ✓ then substitute and calculate $\lambda = \ln 2 / T_{1/2}$ ✓ Or (substitute two points from the graph into $A = A_o e^{-\lambda t}$) e.g. 0.77×10^{12} $= 4.25 \times 10^{12} \exp(-\lambda \times 5 \times 10^5)$ ✓ then make λ the subject and	$T_{1/2}$ may be determined from graph not starting at zero time. Look for the correct power of 10 in the half-life – possible AE. Allow the rare alternative of using the time constant of the decay $A = A_o \exp(-t/t_{tc})$ from graph t_{tc} = 2.9→3.1 × 10^5 s✓ $\lambda = 1/t_{tc} = 3.4 \times 10^{-6}\ s^{-1}$ ✓	2	

	calculate ✓ (the rearrangement looks like λ = [ln (A_o / A)] / t or λ = – [ln (A / A_o)] / t) both alternatives give λ = 3.3 → 3.5 × 10^{-6} s^{-1} ✓	No CE is allowed within this question. For reference $T_{1/2}$ = 2.0 × 10^5 s gives λ = 3.5 × 10^{-6} s^{-1} and $T_{1/2}$ = 2.1 × 10^5 s gives λ = 3.3 × 10^{-6} s^{-1}		
3(b)(ii)	(using $A = N\lambda$ N = 0.77 × 10^{12} / 3.4 × 10^{-6} = 2.2(6) × 10^{17}) allow 2.2 →2.4 × 10^{17} nuclei ✓	A possible route is find $N_o = A_o/\lambda$ then use $N = N_o e^{-\lambda t}$ condone lone answer	1	
3 (c)(i)	uranium (– 235 captures) a neutron (and splits into 2 smaller nuclei/fission fragments) releasing more neutrons ✓ (at least one of) these neutrons go on to cause further/more splitting/fissioning (of uranium–235) ✓	first mark for uranium + neutron gives more neutrons Ignore which isotope of uranium is used. second mark for released neutron causes more fission The word 'reaction' may replace 'fission' here provided 'fission/splitting of uranium' is given somewhere in the answer.	2	
3 (c)(ii) Escalate if clip shows critical mass in the question.				
3 (c)(ii)	the moderator slows down/reduces the kinetic energy of neutrons ✓ so neutrons are absorbed/react/fission (efficiently) by the uranium/fuel ✓	owtte **Possible escalation**	2	
3 (c)(iii)	neutrons are absorbed/collide with (by the nuclei in the shielding) ✓ converting the nuclei/atoms (of the shielding) into unstable isotopes (owtte) ✓	Second mark is only given if neutrons appear somewhere in the answer. No neutrons = no marks making it neutron rich implies making them unstable.	2	

Total			**11**

Question	Answers	Additional Comments/Guidance	Mark	ID details
4 (a)	(it takes) 130 J/this energy to raise (the temperature of) a mass of 1 kg (of lead) by 1 K / 1 °C (without changing its state) ✓	1 kg can be replaced with unit mass marks for 130J or energy +1 kg or unit mass +1 K or 1 °C Condone the use of 1 °K	1	
4 (b)	(using $Q = mc\Delta T + ml$) $= 0.75 \times 130 \times (327.5 - 21) + 0.75 \times 23000$ ✓ (= 29884 + 17250) = 47134 ✓ $= 4.7 \times 10^4$ (J) ✓	For the first mark the two terms may appear separately ie they do not have to be added. Marks for substitution + answer + 2 sig figs (that can stand alone)	3	

Total			**4**

Question	Answers	Additional Comments/Guidance	Mark	ID details
5 (a)	See below - QWC		6	

The mark scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC).		
Descriptor	**Mark**	
High Level – Good to Excellent An experiment with results and interpretation must be given leading to the measurement of absolute zero. The student refers to 5 or 6 points given below. However each individual point must stand alone and be clear. *The information presented as a whole should be well organised using appropriate specialist vocabulary. There should only be one or two spelling or grammatical errors for this mark.*	5-6	6 clear points = 6 marks 5 clear points = 5 marks
Intermediate Level – Modest to Adequate An experiment must be given and appropriate measurements must be suggested. For 3 marks the type of results expected must be given. 4 marks can only be obtained if the method of obtaining absolute zero is given. *The grammar and spelling may have a few shortcomings but the ideas must be clear.*	3-4	4 clear points = 4 marks 3 clear points = 3 marks
Low Level – Poor to Limited One mark may be given for any of the six points given below. For 2 marks an experiment must be chosen and some appropriate results suggested even if the details are vague. Any 2 of the six points can be given to get the marks. *There may be many grammatical and spelling errors and the information may be poorly organised.*	1 - 2	2 clear points = 2 marks Any one point = 1 mark

The description expected in a competent answer should include:
 	
1. Constant mass of gas (may come from the experiment if it is clear that the gas is trapped) <u>and</u> constant volume (or constant pressure).
 	
2. Record pressure (or volume) for a range of temperatures.
(the experiment must involve changing the temperature with pressure or volume being the dependent variable)
 	
3. How the temperature is maintained/changed/controlled. (The gas must be heated uniformly by a temperature bath or oven – so not an electric fire or lamp)
 	
4. Describe or show a graph of pressure against temperature (or volume against temperature) that is linear. The linear relationship may come from a diagram/graph or a reference to the Pressure Law or Charles' Law
(line of best fit is continued on implies a linear graph)
		for (point 1) amount/quantity/moles of gas is acceptable
		
		for (point 2) no specific details of the apparatus are needed. Also the temperature recording may not be explicitly stated eg. record the pressure at different temperatures is condoned
		
		for (points 4 and 5) the graphs referred to can use a different variable to pressure or volume but its relationship to *V* or *P* <u>must</u> be explicit

5. Use the results in a graph of pressure against temperature (or volume against temperature) which can be extrapolated to lower temperatures which has zero pressure (or volume) at absolute zero, which is at 0 K or -273 °C (a reference to crossing the temperature axis implies zero pressure or volume) 6. Absolute zero is obtained using any gas (providedit is ideal or not at high pressures or close to liquification) **Or** Absolute temperature is the temperature at which the volume (or pressure or mean kinetic energy of molecules) is zero./or when the particles are not moving Discount any point that are vague or unclear		in (point 5) the graph can be described or drawn (second part of point 6) must be stated not just implied from a graph

Question	Answers	Additional Comments/Guidance	Mark	ID details
5 (b)(i)	• The motion of molecules is random. • Collisions between molecules (or molecules and the wall of the container) are elastic. • The time taken for a collision is negligible (compared to the time between collisions) • Newtonian mechanics apply (or the motion is non-relativistic). • The effect of gravity is ignored or molecules move in straight lines (at constant speed) between collisions. ✓✓ any two	If more than 2 answers are given each wrong statement cancels a correct mark.	2	
5 (b)(ii) Escalate if the numbers used are 4000, 5000 and 6000 giving 25666666 or similar.				
5 (b)(ii)	mean square speed (= $(2000^2 + 3000^2 + 7000^2) / 3$ = 20.7×10^6) = 2.1×10^7 ($m^2\ s^{-2}$)	common correct answers 20.7×10^6 21×10^6 2.07×10^7 2.1×10^7 20 700 000 21 000 000 **Possible escalation**	1	

5 (c) Escalate if the question and answer line requires a volume instead of a temperature.				
5 (c)	(using meanKE = $3RT/2N_A$) $T = 2N_A \times$ meanKE / $3R$ $=2\times6.02\times10^{23}\times6.6\times10^{-21}/3\times8.31$ ✓ = 320 (K) ✓ (318.8 K) Or (meanKE = $3kT/2$) $T = 2 \times$ meanKE /$3k$ $=2\times 6.6\times10^{-21} / 3\times1.38\times10^{-23}$ ✓ = 320 (K) ✓ (318.8 K)	first mark for substitution into an equation second mark for answer **Possible escalation** Answer only can gain 2 marks	2	

Total			**11**