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Physics A PHA5C

(Specification 2450)

Unit 5C: Nuclear and Thermal Physics

Applied Physics

Final

Mark Scheme

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Section A – Nuclear and Thermal Physics

Question	Part	Sub Part	Marking Guidance	Mark	Comments
1	(a)	(i)	1/12 the mass of an (atom) of ${}^{12}_{6}\mathrm{C}$ / carbon-12 / C12✓	1	a reference to a nucleus loses the mark
1	(a)	(ii)	separated nucleons have a greater mass ✓ (than when inside a nucleus) because of the (binding) energy added to separate the nucleons or energy is released when a nucleus is formed (owtte) ✓	2	an answer starting with 'its' implies the nucleus marks are independent direction of energy flow or work done must be explicit
1	(b)		nuclei need to be close together (owtte) for the Strong Nuclear Force to be involved or for fusion to take place✓ but the electrostatic/electromagnetic force is repulsive (and tries to prevent this) ✓ (if the temperature is high then) the nuclei have (high) kinetic energy/speed (to overcome the repulsion) ✓	3	e.g. first mark – within the range of the SNF 3rd mark is for a simple link between temperature and speed/KE
1	(c)	(i)	15 ✓ e^+ ✓ (or β^+, ${}^{0}_{1}\beta$, ${}^{0}_{1}\mathrm{e}$) 12 ✓	3	give the middle mark easily for any e or β with a + in any position

1	(c)	(ii)	Δmass = 4 × 1.00728 – 4.00150 – (2 × 9.11 × 10^{-31}/1.661 × 10^{-27}) or Δmass = {4 × 1.00728 – 4.00150 – 2 × 0.00055}(u) ✓ Δmass = 0.02652(u) ✓ Δbinding energy (= 0.02652 × 931.5) {allow 931.3} Δbinding energy = 24.7 MeV ✓	3	(4×1.00728=4.02912) 1st mark – correct subtractions in any consistent unit. use of m_p = 1.67 × 10^{-27} kg will gain this mark but will not gain the 2nd as it will not produce an accurate enough result 2nd mark – for calculated value 0.02652u 4.405 × 10^{-29} kg 3.364 × 10^{-12} J 3rd mark – conversion to Mev conversion mark stands alone award 3 marks for answer provided some working shown – no working gets 2 marks (2sf expected)

2	(a)		insert control rods (further) into the nuclear core/reactor ✓ which will absorb (more) neutrons (reducing further fission reactions) ✓	2	a change must be implied for 2 marks marks by use of (further) or (more) allow answers that discuss shut down as well as power reduction If a statement is made that is wrong but not asked for limit the score to 1 mark (e.g. wrong reference to moderator)

2	(b)		fission fragments/daughter products or <u>spent/used</u> fuel/uranium rods (allow) plutonium (produced from U-238) ✓	1	not uranium on its own

2	(c)	(i)	γ (electromagnetic radiation is emitted) ✓ as the energy gaps are large (in a nucleus) as the nucleus de-excites down discrete energy levels to allow the nucleus to get to the ground level/state ✓ mark for reason	2	A reference to α or β loses this first mark 2nd mark must imply energy levels or states

2	(c)	(ii)	momentum/<u>kinetic energy</u> is transferred (to the moderator atoms) or a neutron slows down/loses <u>kinetic energy</u> (with each collision) ✓ (eventually) reaching speeds associated with thermal random motion or reaches speeds which can cause fission (owtte)✓	2	

3		(i)	(heat supplied by glass = heat gained by cola) (use of $m_g\, c_g\, \Delta T_g = m_c\, c_c\, \Delta T_c$) $0.250 \times 840 \times (30.0 - T_f) = 0.200 \times 4190 \times (T_f - 3.0)$ ✓ ($210 \times 30 - 210\ t_f = 838\ T_f - 838 \times 3$) $T_f = 8.4(1)$ (°C) ✓	2	1st mark for RHS or LHS of substituted equation 2nd mark for 8.4°C Alternatives: 8°C is substituted into equation (on either side shown will get mark)✓ resulting in 4620J~4190J ✓ or 8°C substituted into LHS ✓ (produces ΔT = 5.5°C and hence) = 8.5°C ~ 8°C ✓ 8°C substituted into RHS✓ (produces ΔT = 20°C and hence) = 10°C ~ 8°C ✓

3		(ii)	(heat gained by ice = heat lost by glass + heat lost by cola) (heat gained by ice = $mc\Delta T + ml$) heat gained by ice = $m \times 4190 \times 3.0 + m \times 3.34 \times 10^5$ ✓ (heat gained by ice = m × 346600) heat lost by glass + heat lost by cola = 0.250 × 840 × (8.41 – 3.0) + 0.200 × 4190 × (8.41 – 3.0) ✓ (= 5670 J) m (=5670/346600) = 0.016 (kg) ✓ or (using cola returning to its original temperature) (heat supplied by glass = heat gained by ice) (heat gained by glass = 0.250 × 840 × (30.0 – 3.0)) heat gained by glass = 5670 (J) ✓ (heat used by ice = $mc\Delta T + ml$) heat used by ice = $m(4190 \times 3.0 + 3.34 \times 10^5)$ ✓ (= m(346600)) m (=5670/346600) = 0.016 (kg) ✓	3	NB correct answer does not necessarily get full marks 3rd mark is only given if the previous 2 marks are awarded (especially look for $m \times 4190 \times 3.0$) the first two marks are given for the formation of the substituted equation not the calculated values if 8°C is used the final answer is 0.015 kg

4	(a)		molecules have negligible volume collisions are elastic the gas cannot be liquified there are no interactions between molecules (except during collisions) the gas obeys the (ideal) gas law / obeys Boyles law etc. at all temperatures/pressures any two lines ✓✓	2	a gas laws may be given as a formula

4	(b)	(i)	n (= PV / RT) = $1.60 \times 10^6 \times 0.200 / (8.31 \times (273 + 22))$ ✓ = 130 or 131 mol ✓ (130.5 mol)	2	

4	(b)	(ii)	mass = 130.5 × 0.043 = 5.6 (kg) ✓ (5.61kg) density (= mass/volume) = 5.61 / 0.200 = 28 ✓ (28.1 kg m^{-3}) kg m^{-3} ✓	3	allow ecf from bi a numerical answer without working can gain the first two marks

4	(b)	(iii)	($V_2 = P_1 V_1 T_2 / P_2 T_1$) V_2 = 1.6 × 10^6 × .200 × (273 – 50) / 3.6 × 10^4 × (273 + 22) or 6.7(2) (m^3)✓ mass remaining = 5.61 × 0.20 / 6.72 = 0.17 (kg) ✓ (0.167 kg) or n = (PV / RT = 3.6 × 10^4 × 0.200 / (8.31 × (273 - 50)) = 3.88(5) (mol) ✓ mass remaining = 3.885 × 4.3 × 10^{-2} = 0.17 (kg) ✓ 2 sig figs ✓	3	allow ecf from bii **[reminder must see bii]** look out for any 2 sf answer gets the mark

5		The mark scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC).		
	QWC	**Descriptor**	**Mark range**	
	High Level (Good to excellent)	The candidate refers to all the necessary apparatus and records the count-rate at various distances (or thicknesses of absorber). The background is accounted for and a safety precaution is taken. The presence of an α source is deduced from the rapid fall in the count rate at 2 – 5 cm in air. The presence of a γ source is deduced from the existence of a count-rate above background beyond 30 -50 cm in air (or a range in any absorber greater than that of beta particles, e.g. 3 – 6 mm in Al) or from the intensity in air falling as an inverse square of distance or from an exponential fall with the thickness of a material e.g. lead. *The information should be well organised using appropriate specialist vocabulary. There should only be one or two spelling or grammatical errors for this mark.*	5-6	If more than one source is used or a different experiment than the question set is answered limit the mark to 4

	Intermediate Level (Modest to adequate)	The candidate refers to all the necessary apparatus and records the count-rate at different distances (or thicknesses of absorber). A safety precaution is stated. The presence of an α source is deduced from the rapid fall in the count rate at 2 – 5 cm in air and the γ source is deduced from the existence of a count-rate beyond 30 -50 cm in air (or appropriate range in any absorber, e.g. 3 -6 mm in Al). Some safety aspect is described. One other aspect of the experiment is given such as the background. *The grammar and spelling may have a few shortcomings but the ideas must be clear.*	3-4	To get an idea of where to place candidate look for 6 items: 1.Background which must be used in some way either for a comparison or subtracted appropriately 2.Recording some data with a named instrument
	Low Level (Poor to limited)	The candidate describes recording some results at different distances (or thicknesses of absorber) and gives some indication of how the presence of α or γ may be deduced from their range. Some attempt is made to cover another aspect of the experiment, which might be safety or background. *There may be many grammatical and spelling errors and the information may be poorly organised.*	1 - 2	3.Safety reference appropriate to a school setting – not lead lined gown for example 4.Record data with more than one absorber or distances 5.α source determined from results taken 6.γ source determined
		The description expected in a competent answer should include a coherent selection of the following points. apparatus: source, lead screen, ruler, γ ray and α particle detector such as a Geiger Muller tube, rate-meter or counter and stopwatch, named absorber of varying thicknesses may be used. safety: examples include, do not have source out of storage longer than necessary, use long tongs, use a lead screen between source and experimenter. measurements: with no source present switch on the counter for a fixed period measured by the stopwatch and record the number of counts or record the rate-meter reading with the source present measure and record the distance between the source and detector (or thickness of absorber) then switch on the counter for a fixed period measured by the stopwatch and record the number of counts or record the rate-meter reading repeat the readings for different distances (or thicknesses of absorber).		from results taken this is a harder mark to achieve it may involve establishing an inverse square fall in intensity in air or an exponential fall using thicknesses of lead if a continuous distribution is not used an absorber or distance in air that would just eliminate β (30-50cm air / 3-6mm Al) must be used with and without the source being present or compared to background

		use of measurements: for each count find the rate by dividing by the time if a rate-meter was not used subtract the background count-rate from each measured count-rate to obtain the corrected count-rate longer recording times may be used at longer distances (or thickness of absorber). plot a graph of (corrected) count-rate against distance (or thickness of absorber) or refer to tabulated values plot a graph of (corrected) count-rate against reciprocal of distance squared or equivalent linear graph to show inverse square relationship in air analysis: the presence of an α source is shown by a rapid fall in the (corrected) count-rate when the source detector distance is between 2 – 5 cm in air the presence of a γ source is shown if the corrected count-rate is still present when the source detector distance is greater than 30 cm in air (or at a range beyond that of beta particles in any other absorber, e.g. 3 mm in Al) the presence of a γ source is best shown by the graph of (corrected) count-rate against reciprocal of distance squared being a straight line through the origin		

Section B – Applied Physics

Question	Part	Sub Part	Marking Guidance	Mark	Comments
1	(a)	(i)	8.3 rev = 8.3 × 2π rad ✓ (= 52 rad) Use of $\omega_2^2 = \omega_1^2 + 2\alpha\theta$ $0 = 6.4^2 + 2 \times \alpha \times 52$ ✓ **OR** use of $\theta = ½(\omega_1 + \omega_2)t$ leading to t = 16.25 s *and* $\omega_2 = \omega_2 + \alpha t$ α = (-) 0.39 ✓ rad s^{-2} ✓	4	If eqtn(s) of motion used correctly with θ = 8.3 (giving α = 2.5), give 2 out of first 3 marks. Accept : s^{-2} Unit mark is an independent mark
1	(a)	(ii)	$T = I\alpha$ $= 8.2 \times 10^{-3} \times 0.39 = 3.2 \times 10^{-3}$ N m ✓	1	Give CE from a i
1	(b)	(i)	($W = T\theta$ or $W = T\omega t$) where $\theta = 0.78 \times 270$ √ (= 210 rad) $= 3.2 \times 10^{-3} \times 210 = 0.67$ J ✓	2	Give CE from a ii
1	(b)	(ii)	ratio = $\frac{900 \times 270}{0.67}$ or $\frac{2.4(3) \times 10^5}{0.67}$ ✓ = 3.6×10^5 ✓	2	CE from b i. Must be in the form: number × 10^5 with number calculated correctly. 900 × 270 or 2.4(3)× 10^5 or equivalent must be seen for 1st mark 1 mark for <u>only</u> writing 3.6×10^5
2	(a)		<u>Use of</u> $I = \Sigma mr^2$ or expressed in words ✓ With legs close to chest, more mass at smaller r, so I smaller ✓	2	
2	(b)	(i)	Angular momentum is conserved/must remain constant **OR** no external torque acts √ as I decreases, ω increases and vice versa to maintain $I\,\omega$ constant ✓ OR as I varies, ω must vary to maintain $I\,\omega$ constant	2	WTTE

2	(b)	(ii)	(Angular velocity increases initially then decreases (as he straightens up to enter the water)). With one detail point e.g. ✓ • Angular velocity when entering water is greater than at time $t = 0$ s. • Angular velocity increases, decreases, increases, decreases • Maximum angular velocity at $t = 0.4$ s • Greatest rate of change of ang. vel. is near the start • Angular velocity will vary as inverse of M of I graph	1	No mark for just ang. vel starts low then increases then decreases, i.e. for describing ω only at positions 1,2 and 3.

2	(c)		angular. momentum = $10.9 \times 4.4 = 48$ (N m s) ✓ (ω_{max} occurs at minimum I) minimum $I = 6.4$ kg m^2 (at 0.4 s) ✓ $6.4 \times \omega_{max} = 48$ leading to $\omega_{max} = 7.5$ rad s^{-1} ✓	3	Allow 6.3 to 6.5. If out of tolerance e.g. 6.2 give AE for final answer

3	(a)		(Adiabatic change requires) no heat transfer / energy transfer / heat to escape / heat loss (to surroundings) ✓ (Compression stroke occurs in short time/very quickly) so no time for heat transfer ✓ (Therefore change can be considered to be adiabatic)	2	Do not accept heat or energy 'change' .

3	(b)	(i)	$P_1 V_1^{\gamma} = p_2 V_2^{\gamma}$ $1.0 \times 10^5 \times (4.5 \times 10^{-4})^{1.4} = 6.2 \times 10^6 \times V_2^{1.4}$ ✓ $V_2 = 2.4 \times 10^{-5}$ m^3 ✓ 2 sig fig ✓	3	Significant figure mark is an independent mark

3	(b)	(ii)	use of $\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$ $T_2 = \frac{p_2 V_2 T_1}{p_1 V_1} = \frac{6.2 \times 10^6 \times 2.4 \times 10^{-5} \times 297}{1.0 \times 10^5 \times 4.5 \times 10^{-4}}$ ✓ OR use of $n = p_1 V_1/RT_1$ and $T_2 = p_2 V_2/nR$ Leading to T_2 = 982 K ✓	2	CE from b i If 2.36×10^{-5} m^3 used for V_2, T_2 = 966 K

3	(b)	(iii)	So that the fuel has partially evaporated/started to burn when piston is at top of stroke (so max pressure obtained when piston is at top of stroke/top dead centre). OR If injected at top dead centre. by the time fuel has started to burn, piston would be on its way down cylinder, (so max possible pressure not obtained).	1	Accept 'diesel' instead of 'fuel'

3	(c)		**Good – Excellent** The information conveyed by the answer is clearly organized, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question. *The candidate gives a comprehensive account of the differences between the two cycles,* ***with reasons****. There are clear statements relating to the need for induction and exhaust processes/strokes in a real engine only, that adiabatic processes are not possible in the real engine, that constant pressure and constant volume processes are impossible, and/or that the corners of the real engine diagram are rounded.* *They will refer to the lower efficiency of the real engine, linking this to the smaller area loop, or the fact that the pumping loop has to be subtracted from the main loop and/or that heat transfers occur during compression and expansion and that in the real engine friction has to be overcome/power has to be expended in driving ancillaries.*	Mark Range 5-6	

			Modest – Adequate The information conveyed in the answer may be less well organized and not fully coherent. There is less use of specialist vocabulary or specialist vocabulary may be used or spelled incorrectly. The form and style of writing is less appropriate. *The candidate's comparisons are less complete but good understanding is shown of some of the major differences between the diagrams, with some reasons given.* *They should be able to give at least one valid reason for the lower efficiency of the real engine cycle.* **Poor – Limited** The information conveyed by the answer is poorly organized and may not be relevant or coherent. There is little correct use of specialist vocabulary. *The candidate is more likely to describe the differences rather than explain them. They are likely to make reference to the rounded corners, and the induction/exhaust strokes in the 'real' diagram, but not be able to say why these do not exist in the theoretical diagram. They may not be able to give a valid reason for the lower efficiency of the real engine cycle, or may give vague reasons in terms of 'heat losses' or 'friction' without further detail.* **The descriptions and explanations expected in a good answer should include several of the following physics ideas** ▪ Real engine needs 'pumping loop' at near atmos. pressure for induction and exhaust ▪ Work needed for induction and exhaust –so efficiency lower than theoretical ▪ Area of pumping loop has to be subtracted from main loop, hence reducing net work and hence efficiency of real engine ▪ Theoretical cycle needs no pumping loop/same air continuously taken through repeated cycles	3-4 2-1	

			▪ Corners rounded on real engine diagram [because valves are needed and take finite time to open/close] ▪ Cooling cannot occur at constant volume in real engine [because piston would have to stop] ▪ Heating does not occur at constant pressure [because impossible to control rate of burning of fuel during injection] ▪ Compression and expansion do not take place infinitely quickly heat is lost; therefore not adiabatic processes, lowering efficiency ▪ Area of loop is smaller for real engine, less work done per cycle so lower efficiency ▪ Friction between moving surfaces has to be overcome /energy expended in driving oil and water pumps, opening and closing valves etc. ▪ Always some exhaust gases present in cylinder. ▪ Theoretical cycle does not make reference to any mechanism ▪ Calorific value of fuel is never fully realised		

4	(a)		(A device in which) an input of work ✓ (causes) heat to transfer from a cold space/reservoir to a hot space/reservoir ✓	2	

4	(b)		Heat transfer to hot space equals work done plus heat transfer from cold space/ $Q_{IN} = W + Q_{OUT}$ so Q_{IN} (is always) > Q_{OUT} *reason must be seen* ✓ $COP_{HP} = \frac{Q_{IN}}{W}$ and $COP_{REF} = \frac{Q_{OUT}}{W}$ So $COP_{HP} > COP_{REF}$ ✓ **OR** $Q_{IN} = W + Q_{OUT}$ ✓ $COP_{HP} \times W = W + COP_{REF} \times W$ *or* $COP_{HP} = \frac{Q_{IN}}{W} = \frac{W + Q_{OUT}}{W}$ So $COP_{HP} = 1 + COP_{REF}$ *So* $COP_{HP} > COP_{REF}$ ✓	2	Either written statement or expressed in symbols The COP formulae are in formulae booklet so no marks for simply quoting them. i.e 2nd mark cannot be awarded without first mark.