General Certificate of Education (A-level)
June 2013

Physics A PHA5D

(Specification 2450)

Unit 5D: Nuclear and Thermal Physics

Turning Points in Physics

Final

Mark Scheme

Mark schemes are prepared by the Principal Examiner 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 examiners 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 examiner understands and applies it in the same correct way. As preparation for standardisation each examiner 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, examiners encounter unusual answers which have not been raised they are required to refer these to the Principal Examiner.

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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^+, $^{0}_{1}\beta$, $^{0}_{1}e$) 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* × 4190 × 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 – Turning Points in Physics

Question	Part	Sub-part	Marking guidance	Mark	Comment
1	(a)	(i)	(at terminal velocity *v*), weight of droplet (or *mg*) = viscous drag (or $6\pi\eta r v$) ✓ mass (*m*) of droplet = $(4\pi r^3 / 3) \times \rho$, (where *r* is the droplet radius) ✓ (therefore) $(4\pi r^3 / 3) \times \rho g = 6\pi\eta r v$ (or rearranged) ✓ (hence) r (= $(9\eta v / 2\rho g)^{1/2}$ $= \frac{9\times1.8\times10^{-5}\times1.1\times10^{-4}}{2\times880\times9.8}$) gives $r = 1.0(3)\times10^{-6}$ m ✓ note; some evidence of calculation needed to give final mark	4	*Backward working 3 marks max*; viscous force (= $6\pi\eta r v$) = $6\pi \times 1.8 \times 10^{-5} \times 1.0\times 10^{-6} \times 1.1 \times 10^{-4}$ = 3.7×10^{-14} N ✓ weight = mg = $\frac{4}{3}\pi(1.0\times10^{-6})^3\times880\times9.8 = 3.6\times10^{-14}$ N ✓ (allow 3.7) (therefore) viscous force = weight as required for constant velocity ✓ Allow final answer for *r* in the range 1 to 1.05×10^{-6} to any number of sig figs
1	(a)	(ii)	***m*** = $((4\pi r^3/3) \times\rho) = \frac{4}{3}\pi(1.0\times10^{-6})^3\times880$) = 3.7×10^{-15} kg ✓ (or correct calculation of $6\pi\eta r v/g$)	1	Allow ecf for *r* from a(i) in a correct calculation that gives *m* in the range 3.6 to 4.0 x 10^{-15} kg

1	(a)	(iii)	electric force (or *QV*/*d*) = droplet weight (or *mg*) ✓ $Q = \left(\frac{mgd}{V} \right) = \frac{3.7\times10^{-15}\times9.8\times6.0\times10^{-3}}{680}$ ✓ [or *Q* (= viscous force × *d* /*V* $= 6\pi \times 1.8\times10^{-5}\times 1.0\times10^{-6}\times1.1\times10^{-4}\times6.0\times10^{-4} / 680$ ✓] $Q = 3.2\times10^{-19}$ C ✓	3	Allow ecf *m* (or *r*) from a(ii) (or a(i)). Accept values in 1st mark line Use of *e* instead of *Q or q* = 2 marks max For the 2nd mark, allow use of viscous force calculation. Use of viscous force method does not get 1st mark. If both methods are given and only one method gives Q = *ne* (where *n* = integer >1), ignore other method for 2nd mark and 3rd mark. For the final mark, Q must be within $n\,e \pm 0.2\times10^{-19}$ from a correct calculation.

1	(b)		The weight of the second droplet is greater than the maximum electric force on it ✓ Alternative for 1st mark ; weight = drag force + elec force (owtte) **Scheme using V for next 5 marks ;** If *n* =1 for the second droplet , pd to hold it = 1580 V (= *mgd /e*) ✓ which is not possible as *V* max = 1000 *V* ✓ If *n* = 2 , it would be held at rest by a pd of 790 V (= 1580 /2 or 680 × 4.3 / 3.7 V) ✓ if *n* > 2 , it would be held at rest by a pd of less than 790 V (or 790 / *n* V) ✓ So n =1(*e*) must be the droplet charge ✓	Max 4	**Alternative schemes for last 5 marks** **Q scheme** Using *QV/d = mg* for a stationary droplet gives *Q = mgd/V* = 2.53×10^{-19} C ✓ which is not possible as *Q* = *integer x e* ✓ (so) *Q* (=ne) < 2.53×10^{-19} C ✓ owtte) Calculation to show *Q*= 1*e* fits above condition ✓ *Q*= 2*e* does not fit above condition ✓ **F scheme**;- Calc of mg to give 4.2 ($\pm$0.2)x10^{-14} N✓ Calc for Q = 1e of QV/d to give 2.6($\pm$0.2) x 10^{-14} N✓ Calc for Q =2e of QV/d to give 5.3 ($\pm$0.2)x 10^{-14}N ✓ mg> elec force for Q =1e or <2e for Q=2e✓ So n =1(*e*) must be the droplet charge ✓

2	(a)		(Matter) particles have wave-like properties (owtte) ✓ and an associated wavelength = *h* / *p* where *p* is the momentum of the particles ✓.	2	Accept *mv* or mass x velocity in place of *p* Accept ‘inversely proportional to momentum (or *mv*)’ after ‘wavelength’

2	(b)		E_K (= 0.021 eV) = $0.021 \times 1.60 \times 10^{-19}$ or 3.36×10^{-21} J ✓ (Using $E_K = ½ m v^2$ gives) $mv = (2 m E_K)^{1/2} = (2 \times 1.67(5)\times10^{-27} \times 3.36 \times 10^{-21})^{1/2}$ (= 3.35×10^{-24} kg m s^{-1}) ✓ [OR $v = (2 E_K/ m)^{1/2} = (2 \times 3.36 \times 10^{-21}/ \times 1.67(5)\times10^{-27})^{1/2}$ (= 2.0×10^3 m s^{-1}) $mv = (1.67(5)\times10^{-27} \times 2.0 \times 10^3$ (= 3.35×10^{-24} kg m s^{-1})] $\lambda = \frac{h}{mv} (= \frac{6.63\times10^{-34}}{3.35\times10^{-24}})$ = 1.88×10^{-10} m ✓ = 2.0×10^{-10} m to 2 sf ✓	4	For 2nd mark, allow individual values of *e* and *V* in place of E_K value in data substitution For 3rd mark, allow individual values of *m* and *v* in denominator **Alternative** ; Correct use of 0.021 eV in $\lambda = h/ (2meV)^{1/2}$ ✓ $= \frac{6.63\times10^{-34}}{(2\times1.67(5)\times10^{-27}\times0.021\times1.6\times10^{-19})^{0.5}}$ ✓ = 1.88×10^{-10} m ✓ = 2.0×10^{-10} m to 2 sf ✓ Final sf mark - need to see some valid working

2	(c)		electron's momentum (*p*) is the same (as that of the neutron)and its mass is (much) smaller than neutron mass ✓ kinetic energy = $p^2 / 2m$ so kinetic energy of electron is (much) greater ✓ *<u>Alternative</u> for 2nd mark* ;- (so) electron's speed is (much) greater and as kinetic energy = $½ mv^2$, the electron's kinetic energy is (much) greater as v^2 is more significant than *m* (here)(owtte)	2	*<u>2nd alternative</u> for 2nd mark using* $\lambda = h / (2 mE_K)^{1/2}$ $\lambda = h / (2 mE_K)^{1/2}$ so (same λ means) mE_K (in equation) is the same for electron as for the neutron) . So E_K is (much) greater as electron mass is (much) smaller than neutron mass (owtte) Note ; allow use of *eV* in place of E_K *if eV* is identified as E_K .

3	(a)		**Quality of written communication:** **Good – Excellent (5-6 marks)** The candidate provides a comprehensive, coherent and logical explanation which recognises what a stationary wave is and that the conditions for the formation of a stationary wave are present. They should know that nodes and antinodes are formed at alternate positions along XY which are equally spaced with nodes every half wavelength. They should know how the detector is used to locate the position of each node or antinode and how the wavelength is determined from the distance between two such positions. They may know that the nodes can be located more accurately than the antinodes and that their chosen two positions should be as far apart as possible. Their answer should be well-presented in terms of spelling, punctuation and grammar. **Modest – Adequate (3-4 marks)** The candidate provides a logical explanation which recognises what a stationary wave is and what some of the conditions for the formation of a stationary wave are. They may know that nodes and antinodes are formed at alternate positions along XY with nodes every half- wavelength. They may know how the detector is used to locate the position of each node or antinode and how the wavelength is determined from the distance between two such positions. They may know that the nodes can be located more accurately than the antinodes and that their chosen two positions should be as far apart as possible. Their answer should be well-presented in terms of spelling, punctuation and grammar. **Poor to Limited (1-2 marks)** The candidate may recognise that the reflector reflects radio waves which then form a stationary wave pattern with the	6	**For top band ,** explanation = at least b and e description = at least f, g,h ***Explanation of stationary wave formation ;-*** a. radio waves from the transmitter are reflected back towards the transmitter✓ b. reflected and incident waves pass through each other ✓ c. both waves have same frequency (and speed) and amplitude✓ d. superposition (of reflected and incident waves) occurs to form a stationary wave (as above) ✓ e. (equally spaced) nodes and antinodes formed along XY✓ ***Description* of measurement of wavelength ;-** f. Detector signal is zero (or least) along XY at nodes ✓ g. distance between adjacent nodes is ½ λ ✓ h. move detector along XY to measure distance between adjacent nodes and double to give the wavelength ✓ i. measure distance over n nodes and divide by n-1 to give distance between adjacent nodes ✓

			incident waves. They may be unaware what the conditions for the formation of a stationary wave are and their understanding of nodes and antinodes may be poor. They may have some awareness that the stationary wave causes the detector signal to vary with position along XY and that the wavelength can be determined from this variation although they might not be able to link the wavelength to the changes of detector position correctly. Their answer may lack coherence and may contain a significant number of errors in terms of spelling and punctuation. **The explanations expected in a good answer should include most of the following physics ideas** ***Explanation of stationary wave formation ;-*** a. radio waves from the transmitter are reflected back towards the transmitter✓ b. reflected and incident waves pass through each other ✓ c. both waves have same frequency (and speed) and amplitude✓ d. superposition (of reflected and incident waves) occurs to form a stationary wave (as above) ✓ e. equally spaced nodes and antinodes formed along XY✓ ***Description* of measurement of wavelength ;-** f. Detector signal is zero (or least) along XY at nodes ✓ g. distance between adjacent nodes is ½ λ ✓ h. move detector along XY to measure distance between adjacent nodes and double to give the wavelength ✓ i. measure distance over n nodes and divide by n-1 to give distance between adjacent nodes ✓		**For middle band ,** explanation = at least any two of a-e description = at least any two of f-i **For lowest band ,** Any 2 points ,must be 1 of each for 2 marks ***Explanation of stationary wave formation ;-*** a. radio waves from the transmitter are reflected back towards the transmitter✓ b. reflected and incident waves pass through each other ✓ c. both waves have same frequency (and speed) and amplitude✓ d. superposition (of reflected and incident waves) occurs to form a stationary wave (as above) ✓ e. (equally spaced) nodes and antinodes formed along XY✓ ***Description* of measurement of wavelength ;-** f. Detector signal is zero (or least) along XY at nodes ✓ g. distance between adjacent nodes is ½ λ ✓ h. move detector along XY to measure

					distance between adjacent nodes and double to give the wavelength ✓ i. measure distance over n nodes and divide by n-1 to give distance between adjacent nodes ✓

3	(b)		Speed of radio waves (obtained by Hertz) is the same as the speed of light ✓ Speed of electromagnetic waves (calculated or predicted by Maxwell) is the same as the speed of light (or of radio waves) so radio waves are electromagnetic waves ✓	2	

4	(a)		(Using $m = \frac{m_o}{\sqrt{1 - \frac{v^2}{c^2}}}$ gives) $2 = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$ or $\sqrt{1 - \frac{v^2}{c^2}} = 0.5$ ✓ (Rearranging gives) v ($= \sqrt{1 - 0.5^2}\, c$) = 0.866 c or 2.6×10^8 m s^{-1} ✓	2	Accept either answer.

4	(b)		curve starts at v=0 , $m = m_o$ and rises smoothly ✓ curve passes through $2m_o$ at $v = 0.87\ c$ (± 0.03c or in 2nd half of x-scale div containing 0.87c) ✓ curve is asymptotic at $v = c$ (and does not cross or touch $v = c$ or curve back) ✓	3	2nd mark ; ecf from 4a if plotted correctly 3rd mark ; There must be visible white space between the curve and the v = c line; also, the curve must reach $7m_o$ at least.

4	(c)		Energy = mc^2 so (as v -> c) energy of particle increases as mass increases ✓ mass -> infinity as v -> c so energy -> infinity which is (physically) impossible ✓ [OR for one mark only force = ma so force increases as mass increases Mass -> infinity as v->c so force -> infinity which is (physically) impossible✓]	2	Alternative scheme for 1 mark only ; mass infinite at $v = c$ which is (physically) impossible ✓