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Physics A PHA5A

(Specification 2450)

Unit 5A: Nuclear and Thermal Physics

Astrophysics

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 <u>added</u> to <u>separate</u> the nucleons or energy is <u>released</u> when a nucleus is <u>formed</u> (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 <u>close together</u> (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* × 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

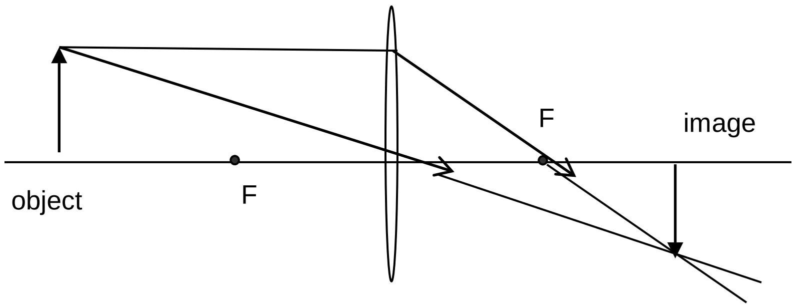
4	(b)	(iii)	($V_2 = P_1 V_1 T_2 / P_2 T_1$) V_2 = 1.6 × 10^6 × .200 × (273 – 50) / 3.6 × 10^4 × (273 + 22) or 6.7(2) (m^3)✓ mass remaining = 5.61 × 0.20 / 6.72 = 0.17 (kg) ✓ (0.167 kg) or *n* = (*PV* / *RT* = 3.6 × 10^4 × 0.200 / (8.31 × (273 - 50)) = 3.88(5) (mol) ✓ mass remaining = 3.885 × 4.3 × 10^{-2} = 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

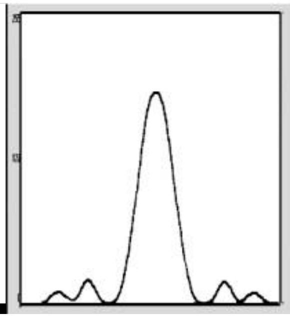
5		The mark scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC).		
	QWC	**Descriptor**	**Mark range**	
	High Level (Good to excellent)	The candidate refers to all the necessary apparatus and records the count-rate at various distances (or 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 – Astrophysics

Question	Part	Sub Part	Marking Guidance	Mark	Comments
1	a		 One construction ray correct ✓ Other construction ray to form diminished image ✓ (The parallel construction ray must pass through a labelled F) Object, image labelled correctly. ✓	3	Arrows are not essential Condone only one focus if it is the one used for the construction ray. Construction ray must have focus labelled to get the mark. Lose the second mark if the image is same size or magnified Image line is needed for second mark.
1	b		u = 128 cm v = 200 -128 = 72 cm ✓ Use of 1/f = 1/u + 1/v To give 1/f = 1/128 + 1/72 f = 46 cm ✓	2	Allow c.e. for incorrect v Condone u and v the wrong way round.
1	c		Objective. As M = fo/fe, for magnification fo > fe ✓ As telescope length = fo + fe, lens must be objective (so that telescope not too long.) ✓	2	No credit for unsupported answer.

2	a	i	central maximum at least twice the height of adjacent maxima ✓ Subsequent narrower maxima. ✓ 	2	Allow graph to be above angle axis Any further maxima should not get bigger.
2	a	ii	Two sources will be (just) resolved if the central maximum of the diffraction pattern of one coincides✓ with the first minimum of the other. ✓	2	Central max and first min may be labelled on diagram in 2ai If they use the term 1st maximum it must be clear that it is the central maximum Second mark is for correct part of the second diffraction pattern. Clearly labelled diagram can get both marks.
2	b		Use of $Rs = 2GM/c^2$ to give $Rs = 2 \times 6.67 \times 10^{-11} \times 4.1 \times 10^6 \times 2 \times 10^{30}/(3 \times 10^8)^2$ ✓ $= 1.2 \times 10^{10}$ m ✓ 2sf ✓	3	Allow ce for **one** from: missing out million; missing out mass of Sun; square in equation, but no square of speed of light in calculation Sf mark stands alone but must be a number (not just stated 2 sf)

2	c	i	use of $\theta = \lambda/D$ to give $\theta = (3 \times 10^8 / 230 \times 10^9)$ ✓ $/ 5000 \times 10^3$ $= 2.6 \times 10^{-10}$ (rad) ✓	2	The first mark is for calculating the wavelength The second mark is for the use of the equation to give the final answer Allow c.e. for an a.e. in the first mark. If frequency used treat as p.e. – no marks
2	c	ii	use of $s = r\theta$ to give $\theta = 5 \times 1.2 \times 10^{10}/(25\ 000 \times 9.46 \times 10^{15})$ ✓ $= 2.5 \times 10^{-10}$ (rad) ✓ which is (approximately) the answer to 2ci	2	First mark is for the angle subtended (5.12×10^{-11}) Second mark is for showing that this is 5 x answer to c(i). Alternatives: Calculate size of object that could just be resolved at this distance, and showing that this is 5 x radius of black hole.
3			The marking scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC). There are no discrete marks for the assessment of written communication but the quality of written communication will be one of the criteria used to assign the answer to one of three levels. **The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.** The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.	6	There are three areas: Structure: silicon chip into pixels Function: photon incident, electron excited, electron trapped in potential well, one electron per photon, no of electrons (and therefore charge) proportional to number of incident photons, after sufficient exposure charge on each pixel measured and image produced Advantage: most will say the QE>70%
			H**igh Level (Good to excellent): 5 or 6 marks** The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.		A 6 mark answer need not be "perfect" but should be substantially complete, correct and free from major errors. One of the above points may be missing. Eg charge integration

			The candidate provides a comprehensive and logical description of the structure of the CCD. The answer includes a clear description of how the light causes a release of charge and why the charge is stored. The answer also includes an explanation of what is meant by quantum efficiency and a correct value for the q.e. of a CCD. Confusion with the photoelectric effect would reduce a 6 mark answer to 5.		5 marks may have 2 missing eg silicon chip and charge integration
			Intermediate Level (Modest to adequate): 3 or 4 marks The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate. The candidate provides a comprehensive and logical description of the CCD. The answer demonstrates some understanding of how the light is used to generate charge. The answer also includes some reference the efficiency of the CCD or other advantage		4 probably has more than 2 missing or no correct advantage
			Low Level (Poor to limited): 1 or 2 marks. The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate. The candidate demonstrates an understanding that an image is formed on the CCD and that this image is transferred to a computer.		
			Zero: Incorrect, inappropriate or no response.		
			Points that can be used to support the explanation: • The CCD is a silicon chip • The chip is divided into picture elements • Each picture element is associated with a potential well in the silicon • Incident photons are focused on the CCD • The photons cause the release of electrons within the semiconductor • The number of electrons liberated is proportional to the intensity of the light. • Electrons are trapped in the potential wells • An electron pattern is built up which is identical to the image formed on the CCD. • When exposure is complete the charge is processed to form an image.		

			Advantages: High quantum efficiency > 70% Light integration – using long exposure times to capture faint images. Device can be directly linked to computer for capture and analysis.		
4	a	i	Similarity both would appear the same <u>brightness</u> As the apparent magnitudes are the same ✓ Difference Kocab would appear orange/red, Polaris yellow/white Due to their spectral classes/ different temperatures ✓	2	Description and explanation needed for mark. Any references to same size gets zero for 1st mark. Allow different colours + ref to spectral class for second mark If colour named, should be correct.
4	a	ii	Polaris is further from Earth: Both stars same size and Polaris is hotter ✓ As $P = \sigma AT^4$ Same A, would mean that Polaris has greater power output. ✓ Polaris must be further from Earth to appear same brightness as Kocab. ✓	3	Alternative: Polaris hotter and same size Hence, Polaris has brighter absolute magnitude/ is intrinsically brighter Same apparent brightness, therefore Polaris is further away.
4	b	i	$v = Hd$ $v = 0.025 \times 3 \times 10^5 = 7.5 \times 10^3$ km s^{-1}✓ $d = 340 \times 10^6$ l yr = 340 / 3.26 Mpc = 104 Mpc✓ $H = 7.5 \times 10^3 / 104 = 72$ kms^{-1} Mpc^{-1}✓	3	1st mark is for calculating v 2nd mark is for working out d in Mpc 3rd mark is for calculating H in the correct unit.
4	b	ii	Age of Universe = 1/H $= 0.014 \times 10^6 \times 3.26 \times 9.5 \times 10^{15} / 1000$ $= 4.3 \times 10^{17}$ seconds (= 13.6 billion years) Unit consistent with calculation.	3	1st mark is for the equation 2nd is for the answer with working 3rd is for a time unit consistent with their answer/working