AQA

# A-level
# Physics

PHYA5/1 – Nuclear and Thermal Physics
Mark scheme

2450
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Version: 1.0 Final

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)(i) | momentum (= $E/c$)<br>$= 5.94 \times 10^{-11} / 3.00 \times 10^{8} = 2.0 \times 10^{-19}$ (kg m s$^{-1}$)<br>(= $1.98 \times 10^{-19}$ kg m s$^{-1}$)<br>Or evidence of use of $E = hc / \lambda$ √<br>$\lambda = (h / mv = 6.63 \times 10^{-34} / 1.98 \times 10^{-19}) = 3.35 \times 10^{-15}$ (m) √<br>(allowable range $3.32 \times 10^{-15}$ - $3.37 \times 10^{-15}$ m) | $3.348 \times 10^{-15}$ m alone may score 1 mark<br><br>A completed calculation to at least 3 sf must be seen for 2nd mark | 2 | |
| 1(a)(ii) | nuclear radius = $0.61\ \lambda / \sin\theta = 0.61 \times 3.35 \times 10^{-15} / \sin 42^{o}$<br>$= 3.1 \times 10^{-15}$ (m) √ (allow $2.95 – 3.1 \times 10^{-15}$ m which is a range incorporating $3.32 \times 10^{-15}$ - $3.37 \times 10^{-15}$ m and $42^{o} – 43^{o}$) | (The answer must be to 2 sf or better<br>note $3.3 \times 10^{-15}$ , $42^{o}$ gives $3.008 \times 10^{-15}$ m i.e. $3.0 \times 10^{-15}$) | 1 | |
| 1(b)(i) | diagram to show a labelled $\alpha$ source, foil target and detector (which is not simply a forward facing screen so there must be some indication it can move around the target e.g. a curved arrow/positioned at an angle/or screen curved round target or detectors shown in at least two positions) √<br><br>with evacuated vessel or an item to collimate the beam √<br>(the evacuated vessel does not have to be drawn so a simple label of 'in a vacuum' will gain the mark.)<br>(A tube or a plate(s) must be drawn with a collimator label or a label on an emergent alpha beam from the drawn item (which is distinct from the source) will gain a mark) | 'detector' has alternatives e.g. fluorescent screen/scintillator/zinc sulphide | 2 | |

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| 1(b)(ii) | 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<br>Both observations should be given ie most $\alpha$ particles pass straight through the foil and that some $\alpha$'s are backscattered. Again both of these must be explained. Additionally one approach to finding the upper limit to the radius must be given and interpreted.<br>*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.* | 6 marks = all 3 bullet points covered in full.<br><br>5 marks = Same as 6 marks but one explanation is omitted or poorly expressed | 5 - 6 | |
| | Intermediate Level – Modest to Adequate<br>Both observations should be given ie most $\alpha$ particles pass straight through the foil and that some $\alpha$'s are backscattered. Both of these observations can be explained or one of them explained along with the observation necessary to obtain the upper limit to the nuclear radius but without the explanation of how to use the data. *The grammar and spelling may have a few shortcomings but the ideas must be clear.* | 4 marks = for first two bullet points covered in full.<br>Alternatively both observations given but only one explained along with an observation necessary to find the upper limit to the nuclear radius.<br><br>3 marks = for both observations given but only one explained | 3 - 4 | |
| | Low Level – Poor to Limited<br>Any two observations or interpretations but an interpretation must come with the appropriate observation. *There may be many grammatical and spelling errors and the information may be poorly organised.* | 2 marks for two observations or one observation along with its interpretation.<br>1 mark = Any observation.. | 1 - 2 | |
| | **The description expected in a competent answer should include:**<br>1. most $\alpha$ particles pass straight through<br>2. which suggests an atom is composed of mainly open space | Do not award 'large space between atoms'.<br>The question is a QWC and not all the points | | |

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| | 3. $\alpha$ particles can be backscattered or scattered by more than $90^o$<br>4. which suggests<br>I. they have collided with something more massive than themselves (using momentum considerations)<br>II. they have been repelled by a concentrated positive charge (using coulomb repulsion)<br>these together suggest a 'solar system' configuration for the atom.<br>5. Consider the proportion of $\alpha$'s passing straight through the foil, i.e. how much of the straight through beam is stopped by the foil.<br>Or<br>Appreciate that scattering of $\alpha$'s close to $180^o$ takes place which means the $\alpha$'s have not touched the nuclear surface.<br>6. First alternative data can be related to how much of the beam is intercepted by nuclei. Using the number of atomic layers/thickness of foil and the nuclear cross-sectional area the upper limit to the radius may be found<br>Or If second alternative is used some detail is needed to gain this point.<br>Either a discussion of the loss KE = gain PE to find upper limit to the radius<br>Or the idea that backscattering is not observed/falls off if the alpha comes close the nucleus because the strong nuclear force (SNF) takes over and so provides an upper limit to the radius.<br>(owtte) | are expected to be given as detailed on the left. This check list gives a brief idea of the main parts expected.<br>(note the pairing of 1and 2, 3 and 4, 5 and 6 where the second of each pair cannot be given in isolation but the first of each pair does not have to perfect)<br>If it is obvious the candidate is talking about an alpha particle but calls it something different do not over penalise. E.g. miss out a pairing of marks then mark as if alpha)<br>Quick check list.<br>1. Most alpha's go straight on<br>2. Because an atom has mainly empty space<br>3. A few alpha's are backscattered<br>4. Because of nuclear positive charge or large nuclear mass<br>5. Method suggested to find R (drop in straight on beam Or backscattering means $\alpha$'s have not touched nucleus)<br>6. Some detail such as ref. to (nuclear) area <u>and</u> (foil) thickness Or alpha KE to PE giving r Or if $\alpha$'s touch surface SNF stops scattering. | | |
| **Total** | | | 11 | |

| Question | Answers | Additional Comments/Guidance | Mark | ID details |
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| 2(a) | nuclear fallout/testing/weopons / nuclear accidents / Chernobyl / nuclear waste/ nuclear medicine / X-rays / specific uses of radioactive sources eg medical tracers CT scan etc. / cosmic rays as a result of air travel √<br>(Any source of radiation that an individual may encounter which would not have existed 100 years ago) | No mark for general answers such as 'medical' or Nuclear Power/nuclear plant.<br>If a list is given all must be correct but ignore generalisations such a medical or nuclear power. | 1 | |
| 2(b)(i) | $I_{15CCR}$ = 2050 – 40 = 2010 √<br>Use of inverse square law eg $I_{CCR90} = I_{CCR15}\left(\frac{d_{15}}{d_{90}}\right)^2$ √<br>= 2010 × (0.15 / 0.90)$^2$ = 55.8<br>$I_{90CR}$ = 55.8 + 40<br>$I_{90CR}$ = 96 counts min$^{-1}$ √ | regardless of order:<br>1st mark subtraction of background in original data<br>2nd mark is for using inverse square function<br>3rd mark is for the answer | 3 | |
| 2(b)(ii) | (reduce impact of) random error /decrease the (percentage) uncertainty / improve the statistics (because the percentage error is proportional to the inverse square-root of the count) √ (owtte) | The answer must be an uncertainty related statement and not increases reliability/accuracy or increased chance of a reading (although these ideas can accompany a correct answer) Ignore comparisons with the background count. | 1 | |
| 2(b)(iii) | use (sensible) absorber between source and detector √<br>(sensible absorber means it must have a noticeable effect e.g. 1mm of metal/ aluminium sheet/ 5mm perspex but do not allow metal foil / paper sheets. Also its effect must not be so great that it reduces the gamma rays noticeably)<br><br>(These two marks are independent)<br>β shown by count rate falling when sheet of aluminium | 2nd mark no mark given if count rate falls to zero as γ is still present<br><br>(magnetic deflection is not common but if seen. Use of magnetic deflection √ correct deflection of beta from the beam √)<br><br>(If a cloud chamber is suggested. Observe the | 2 | |

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| | absorber is used √<br>Or (using the existing apparatus)<br>Compare the results (at various distances) in air with the expected inverse square law √<br>Below the range of beta law does not work but above range it does. √ | tracks in a cloud chamber √ beta tracks have varying lengths or they are curly/not straight √<br><br>(The value of the range of beta is not a marking point so accept 15 – 80 cm if a number is given) | | |
| **Total** | | | 7 | |

| Question | Answers | Additional Comments/Guidance | Mark | ID details |
|---|---|---|---|---|
| 3(a)(i) | Fission occurs at *A* values above the peak / above *A* of about 56 <u>and</u> fusion occurs at *A* values below the peak / below *A* of about 56 √<br><br>Fission is the splitting of a nucleus (into two smaller ones) <u>and</u> fusion is the joining of two nuclei √ | First mark uses the graph so 'fission occurs in very large nuclei' does not gain a mark.<br>(allow other interpretations that use the graph eg gradients)<br><br>2nd Mark splitting into 2 is not required for fission but if the answer implies something different like the separating of all the nucleons the mark may not be given. | 2 | |
| 3(a)(ii) | Energy is released when the binding energy (per nucleon) is increased √<br>fusion energy is greater as the increase in BE(/A) for fusion > increase in BE(/A) for fission (owtte) √ | The last point can be given for a reference to the larger gradient at small values of A (fusion region) compared to the gradient at large values of A (fission region) | 2 | |
| 3(b)(i) | $\Delta m = (8m_p + 8m_n) - M_{oxygen}$<br>mark for substituting data into the above equation in any workable consistent units<br><br>= 8(1.00867+1.00728) – 15.991 √<br>($\Delta m$ = 0.1366 u<br>$\Delta m = 0.1366 \times 1.661 \times 10^{-27}$ ) = $2.3 \times 10^{-28}$ (kg) √<br>(range of answers 2.2 - $2.3 \times 10^{-28}$ kg) | Substitution may take the following form<br>$8(1.673 \times 10^{-27})+8(1.675 \times 10^{-27})-(15.991 \times 1.661 \times 10^{-27})$ √<br>= $2.23 \times 10^{-28}$ (kg) √<br><br>Correct answer gains full marks.<br>Look out for a physics error in which u is not taken as $1.661 \times 10^{-27}$ kg | 2 | |
| 3(b)(ii) | $E = m \times c^2 = 2.3 \times 10^{-28} \times (3.00 \times 10^8)^2 = 2.07 \times 10^{-11}$ J<br>BE = $2.07 \times 10^{-11} / 1.6 \times 10^{-13}$ = 130 (MeV) √ (129 MeV)<br>Or using<br>using $\Delta m$ = 0.1366 u (this must appear in b(i) for this approach)<br>BE = 0.1366 × 931.3 = 130 (MeV) √ (127 MeV) | CE is allowed but only if the calculation is shown<br>Note answer = b(i) x $5.625 \times 10^{29}$<br>answer only is acceptable for one mark.<br><br>(factor may be 931 or 931.5) | 1 | |

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| 3(b)(iii) | read from the graph the BE/A for $\left({}^{16}_{8}\mathrm{O}\right)$ and multiply by the number of nucleons(or 16) √<br>Or show the calculation<br>BE = 8(Mev) × 16(nucleons) = 130 (MeV) √ (128 MeV)√ | There must be a reference to $\left({}^{16}_{8}\mathrm{O}\right)$ position on the graph.<br><br>with the calculation allow BE = 8.1(Mev) × 16(nucleons) = 130 (MeV)<br>A calculation may lead to an answer in joule | 1 | |
| **Total** | | | 8 | |

| Question | Answers | Additional Comments/Guidance | Mark | ID details |
|---|---|---|---|---|
| 4(a) | 1. fixed mass or fixed number of molecules/moles √<br>2. constant temperature √ | Allow alternatives to fixed mass such as 'sealed vessel' or 'closed system'.<br>Not amount of gas as this is ambiguous.<br>The temperature must not be specific. | 2 | |
| 4(b)(i) | $(V_2 = \frac{P_1}{P_2} \times V_1 \times \frac{T_2}{T_1})$<br>$V_2 = \frac{1.0 \times 10^5}{4.4 \times 10^5} \times 0.0016 \times \frac{350}{290}$<br>or $(V = \frac{nRT}{P})$<br>$V = 0.067 \times 8.31 \times 350 / (4.4 \times 10^{-4})$ √<br>$= 0.00044$ ($m^3$) √ ($4.39 \times 10^{-4}$ $m^3$) | 1st mark comes from use of valid equation with substitutions.<br><br>In the alternative look out for 0.067 = 1 /15 = (0.0016 / 0.024)<br>And $R = N_A k$<br>Correct answer gains full marks<br>If no other answer is seen then 1 sig fig is wrong. | 2 | |
| 4(b)(ii) | (proportion of a mole of trapped air<br>= volume of cylinder / volume of mole)<br>= 0.0016 / 0.024 = 0.067 (mol) √ (0.0667)<br>or<br>(use of $n = pV/RT$)<br>$= 1.0 \times 10^5 \times 0.0016 / (8.31 \times 290) = 0.066$ (mol) √ (0.0664)<br>or<br>$= 4.4 \times 10^5 \times 0.00044 / (8.31 \times 350) = 0.067$ (mol) √ (0.0666) | Answers range between 0.066 – 0.067 mol depending on the volume carried forward.<br>(answer alone gains mark)<br><br>Working must be shown for a CE<br>Ans = $V_2 \times 151$ | 1 | |
| 4(b)(iii) | (mass = molar mass × number of moles)<br>mass = 0.029 × 0.0667 √ (0.00193 kg)<br>(density = mass / volume)<br>density = 0.00193 / 0.0016 = 1.2(1) kg $m^{-3}$ √<br>(no continuation errors within this question but allow simple powers of 10 arithmetic errors which will lose one mark) | CE mass = 0.029 × (b)(ii)<br><br>CE density = (0.029 × (b)(ii)) / 0.0016<br>or (18.1 × (b)(ii)) | 2 | |
| 4(c) | the (average/mean/mean-square) speed of molecules | | 2 | |

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| | increases (with absolute temperature) √<br>as the mean kinetic energy is proportional to the (absolute) temperature<br>Or<br>Reference to $KE_{mean} = 3/2\ kT$ √ but mean or rms must feature in the answer somewhere. | | | |
| **Total** | | | 9 | |

| Question | Answers | Additional Comments/Guidance | Mark | ID details |
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| 5(a) | Tick in 4th box | | 1 | |
| 5(b)(i) | (using heat energy = $ml$)<br>energy = $0.047 \times 3.3 \times 10^5 = 1.6 \times 10^4$ (J) √ ($1.55 \times 10^4$ J) | answer alone gains mark | 1 | |
| 5(b)(ii) | (heat in from water = heat supplied to melt and raise ice temperature)<br>$1.8 \times 10^4 = 1.6 \times 10^4$ + (energy to raise temp of ice)<br>energy to raise temp of ice = $2 \times 10^3$ (J) √ | answer alone gains mark allow 2, 2.5 or 3 $\times 10^3$ J<br>allow CE if substitution is shown<br>$1.8 \times 10^4$ – (b)(i) | 1 | |
| 5(b)(iii) | (using heat energy = $mc\Delta T$)<br>$c = 2 \times 10^3 / 0.047 \times 25$<br>= $2 \times 10^3$ √ ($1.7 \times 10^3$) (note there is a large range of correct answers)<br>$J\ kg^{-1}\ K^{-1}$ or $J\ kg^{-1}\ {}^oC^{-1}$ √ (allow use of dividing line but don't allow $^oK$ and $^oC^{-1}$ is not the same as $C^{-1}$) | only allow CE if substitutions are seen<br>$c$ = (b)(ii) / 0.047 × 25<br>= b(ii) x 0.851<br>allow 1 sig fig.<br>common answers:<br>for $2.5 \times 10^3$ J gives $2.1 \times 10^3$ or $2 \times 10^3$<br>for $3 \times 10^3$ J gives $2.6 \times 10^3$ or $3 \times 10^3$ | 2 | |
| **Total** | | | 5 | |