PHYSICS

Paper 9702/12
Multiple Choice

Question Number	Key	Question Number	Key	Question Number	Key	Question Number	Key
1	D	11	C	21	B	31	C
2	D	12	D	22	A	32	A
3	C	13	D	23	D	33	C
4	A	14	A	24	C	34	B
5	A	15	B	25	B	35	C
6	C	16	A	26	A	36	B
7	B	17	B	27	C	37	B
8	B	18	A	28	C	38	B
9	A	19	D	29	C	39	D
10	A	20	D	30	D	40	D

General comments

It is important to carefully read the text of the question before considering the answer options.

In numerical questions, candidates should be careful to consider SI prefixes and powers of ten, as well as possible unit conversions, and should be encouraged to check to their answers to ensure they are a sensible magnitude.

Candidates had particular difficulty resolving vectors into perpendicular components. Candidates should be able to select the correct trigonometric function for each problem and should be familiar with the inverse trigonometric functions.

In general, candidates found **Questions 5**, **8**, **23** and **36** relatively difficult.

Candidates found **Questions 1**, **22**, **34** and **40** relatively easy.

Comments on specific questions

Question 3

This was answered well by most candidates. A significant number of weaker candidates selected option **A**, neglecting to convert the velocity units from $cm\,s^{-1}$ to $m\,s^{-1}$. Option **B** was also a common incorrect response, suggesting that candidates were not considering the change in velocity of the car. Candidates would benefit from more practice reading velocity-time graphs.

Question 4

Stronger candidates found this straightforward. The most common error among weaker candidates was to use the final velocity of the aircraft as $85\,\text{m}\,\text{s}^{-1}$, rather than converting the $85\,\text{km}\,\text{h}^{-1}$ to $23.6\,\text{m}\,\text{s}^{-1}$ leading to option **C**. A significant minority converted correctly then used the incorrect formula $v^2 = u^2 + as$, neglecting the factor of 2.

Question 5

This proved challenging for candidates, with all 4 options selected roughly equally indicating that the variation of speed in two dimensions without air resistance is not well understood by most candidates. The question is best approached by considering conservation of energy. The projectile's speed must decrease as it rises, as kinetic energy decreases and gravitational potential energy increases. As the projectile is still in motion at its highest point the speed cannot decrease to zero, ruling out options **C** and **D**. The projectile then falls to its original height (ground level) so the speed must return to its original value, as the kinetic energy and gravitational potential energy return to their original values.

Question 7

Stronger candidates found this straightforward. The most common incorrect answer (**D**) was the result of adding the magnitudes of the correct components of momenta, neglecting that momentum is a vector quantity.

Question 8

Many candidates selected the incorrect options **A** and **C** for this question, attempting to find another force acting on the astronaut, despite the question asking for the gravitational force acting on the astronaut. Candidates are encouraged to carefully read the question and not to assume the quantity that they are being asked to find.

Question 11

Stronger candidates found this straightforward. Weaker candidates selected option **B** most frequently, which is the result of swapping sine and cosine when resolving the force in the wire. Candidates should practice resolving forces so they can confidently select the correct trigonometric functions.

Question 13

All candidates found this equilibrium challenging. **A** and **C** were the least popular options, suggesting that most candidates recognised that F would not be zero in either scenario. Option **B** was the most popular incorrect answer, with candidates perhaps considering only the weight of the child and neglecting the weight of the beam.

Question 15

Stronger candidates found this straightforward. The problem is best solved by resolving the acceleration of free fall into a component in the direction of the slope.

Candidates who found this presentation of the problem unfamiliar could still have made progress by recognising $19.6 = 2g$ and relating this to $v^2 = u^2 + 2as$.

Question 18

Less than half of the candidates selected the correct answer **A**. The weakest candidates selected options **B** and **D**. In **D** no energy is lost, suggesting that candidates struggled to visualise this problem. Option **B** resulted from correctly determining the speed of the projectile at the maximum point compared with the initial speed then neglecting that that kinetic energy is proportional to the speed squared.

Question 21

Approximately two thirds of candidates recognised that the elastic potential energy could be determined using values from, or the area under, the graph. Incorrect option **D**, considering a single spring experiencing the whole 160 N force with extension 9.6 mm, was selected almost as often as the correct option **B**. For the correct answer candidates had to recognise that the four springs would share the 160 N force equally, and so each extends only 2.4 mm

Question 23

This question required simple factual recall of the approximate wavelength of infrared radiation in free space. Fewer than half of candidates could recall this information, suggesting that this point on the syllabus is not well known.

Question 25

This was answered correctly by most candidates. The topic of phase difference is often challenging, and here it was also combined with the wave speed equation, suggesting that candidates understood this topic.

Question 29

This difficult question was answered correctly by half of the candidates, suggesting that diffraction grating problems are well understood by stronger candidates. Options **A** (the diffraction angle for the first order maximum) and **B** (the difference between the second and first order maxima) were equally popular. Candidates are encouraged to carefully read the question to ensure they are calculating the correct quantity.

Question 32

Option **B** was a very popular incorrect answer with nearly a third of candidates selecting it. Candidates choosing **B** perhaps confused the resistance against temperature profile of a thermistor with the required power against temperature profile. Candidates can reason that in this circuit the p.d. across the thermistor is constant, and recall that the resistance of the thermistor decreases with temperature. Candidates who therefore considered $P = V^2/R$ could identify option **A** as the correct answer.

Question 36

Candidates found this question challenging. Candidates who recognised that *V* represents the terminal p.d. and that with an open circuit this would be equal to the e.m.f. selected the correct option **B**. Option **D** was the most popular, with candidates confusing the concept of terminal p.d. and e.m.f.. Option **A** was also popular, with candidates perhaps neglecting that the measurement of *V* would include the e.m.f.. Candidates would benefit from practicing problems involving sources with internal resistance, and from practical experience of working with this kind of circuit.

Question 38

This question on conservation of momentum was answered well by most candidates.

Question 39

Around two thirds of candidates correctly answered this factual recall question. The most common incorrect answer was option **B**, indicating that students are not confident distinguishing between β^+ and β^- decay. The weakest candidates selected **B**, **C** and **D** equally, suggesting that the difference between quarks and antiquarks was not well understood.

PHYSICS

Paper 9702/22
AS Level Structured Questions

Key messages

Candidates should explicitly state the subject of any numerical or algebraic equations they use. This is especially important where more than one equation is used in a question, and when equations are stated and then re-arranged. In some questions marks can be scored for correct statements of physical equations, but only where the whole equation is clearly shown. Candidates should not rely on the examiner to infer a subject for an expression given in the working.

Candidates should pay attention to the units and powers of ten in which information is presented, and ensure that they are converting answers into SI base units where appropriate.

Candidates should ensure that reasoning done with equations in the margins of written questions or in diagrams is then transferred to a written answer, rather than relying on the examiner to interpret the working. Candidates are also reminded to present their working within the space provided.

Candidates are reminded to be careful when making comparisons in written questions to be clear what is being referred to. For example when comparing times for two objects R and S, a candidate stating “the time is greater” could be referring to either object and so has not answered the question. Candidates should also be careful when using terms describing change such as ‘decrease’ and ‘increase’ as it is not always clear whether that change is occurring with respect to time or some other variable.

General comments

There was no evidence that candidates were short of time for this examination.

Concepts of uncertainty were not generally well understood. The difference between absolute and percentage uncertainty proved challenging for many, as did the concept of an uncertainty expressing a range of possible values.

Candidates frequently gave answers to 1sf, when data in the question was given to 2sf. Candidates should always consider how many significant figures are appropriate for their answer in the context of the data given.

Most candidates answered questions involving the recall and use of formulae well. Definitions were not always well known, and many either missed out key words or used wording which changed the meaning of the definition.

Many candidates showed little working to support their answers to numerical questions, and the working was often poorly presented. Correct working, where present, allows marks to be scored for good methods even where errors then occur.

Candidates could improve by ensuring they always write a subject for their algebraic or numerical expressions.

Candidates found **1(b)(i)**, **2(b)(i)**, **3(a)**, **6(b)(i)** and **7(a)** relatively easy. They found **1(b)(iii)**, **2(a)**, **3(b)(iii)**, **4(a)**, **5(b)** and **6(c)(i)** difficult.

Comments on specific questions

Question 1

(a) The vast majority of candidates gave an acceptable explanation of accuracy. A small number of candidates inappropriately explained what was meant by the precision of a set of measured values. Very weak candidates sometimes thought that the accuracy was indicated by the number of significant figures or the number decimal places in the measured value.

(b)(i) The majority of candidates gave a correct equation for density, although candidates sometimes used 'd' instead of 'ρ' for density. There was a significant number of candidates that made errors converting the mass in grams into kilograms and the length from centimetres into metres.

(ii) The stronger candidates were able to obtain the correct percentage uncertainty. There were many that did not recognise the need to multiply the percentage uncertainty in the volume by three. Some candidates incorrectly multiplied the percentage uncertainty in mass by three.

The weakest candidates gave an incorrect method, such as treating the absolute uncertainties as percentage uncertainties.

(iii) This was a challenging question. The strongest candidates were able to describe how the uncertainties in the values of density allowed for an overlap between the two ranges, and hence that the cubes could be made from the same material.

Successful candidates typically found the range of densities for one cube, and demonstrated that the given value of density for the other cube fell within this range, but there were other valid explanations given.

Many candidates recognised that the values of density were 'close' or 'similar' to each other but did not explicitly identify an overlap.

Many candidates stated that the cubes could not be made from the same material because the uncertainties for the two cubes were different or that the value quoted for the density was different for the two cubes. This indicates a lack of understanding that a calculated value and its uncertainty shows a range of possible values.

Question 2

(a) There were very few fully correct answers. The candidates usually referred to the total clockwise moments being equal to the total anticlockwise moments. However, many candidates did not explicitly state that these moments are about the same point. It was also common for weaker candidates to omit 'total' from their answer.

Only the stronger candidates stated that this was for an object in rotational equilibrium. Sometimes, reference was made to a 'closed system' or an 'isolated system', possibly due to confusion between the principle of moments and the principle of conservation of momentum. Very weak candidates sometimes stated only what was meant by the moment of a force.

Candidates should be able to recall core principles from the syllabus.

(b)(i) This part was generally well answered with many candidates obtaining the correct answer. Nearly all candidates could correctly determine one or two moments, but a significant number could not give all three moments. A common mistake was to think that the moment of the weight of the beam about end A was either (1700×6.0) N m or (1700×5.0) N m.

(ii) The majority of candidates equated the upthrust with the weight of the cylinder and the force of the beam on the cylinder. Some candidates did not give the required full working for the weight, jumping directly to weight = 100 N without explanation. Weaker candidates tried to use the given equation for the upthrust ($F = \rho g V$) without success.

(iii) The stronger candidates used the expression for the upthrust and a correct expression for the volume of a cylinder to determine the length y. A significant number used the force from the beam

(1300 N) and not the upthrust given (1400 N). Some candidates confused pressure with force and so wrongly stated that $1400 = 990 \times 9.81 \times y$. Others misused the density equation by confusing the mass of the cylinder with the mass of displaced water, stating that $990 = 11 / (p \times 0.39^2 \times y)$.

Many candidates showed a correct calculation, but then inappropriately expressed their final answer to only 1sf. The calculation uses data that has 2sf and so it was expected that the final answer would also be expressed to 2sf.

(iv) It was generally understood that the graph line would have a positive gradient. However, weaker candidates often made the mistake of drawing their graph line from the origin and did not appreciate that the graph would have a non-zero value of depth when the distance from A is zero, as there needs to be an upthrust due to the weight of the beam. Although the question explicitly stated the required range of distance for the graph, a small number of candidates drew lines that ended before 6.0 m.

Question 3

(a) (i) The majority of candidates calculated the acceleration using an appropriate equation of constant acceleration, indicating this subject is generally well understood. Weaker candidates often attempted to find a time using an inappropriate method such as $t = 180/13$ and so could make no progress.

(ii) This proved to be a straightforward calculation for many candidates. Weaker candidates were often able to correctly recall the symbol formula for the kinetic energy of an object. However, a common mistake was to calculate the gain in kinetic energy by using the expression $\frac{1}{2} m(v - u)^2$. A small number of candidates gave a value for kinetic energy at A or at B rather than the difference in energies. Candidates are encouraged to carefully read the question to ensure that they are calculating the required quantity.

(b) (i) The majority of candidates gave the correct definition of force, often using the exact wording from the syllabus ‘rate of change of momentum’. A significant number gave ‘mass times acceleration’ which is a valid way to calculate the resultant force acting on an object, but is not the definition of force. Candidates should be able to recall the definitions of the key quantities within the syllabus.

(ii) There were a significant number of errors made in this ‘show that’ question. Candidates should ensure they begin with an explicit statement of the equation being used, including the subject. Candidates frequently omitted the powers of ten (10^4) in the first step of their working, or incorrectly gave their powers as 10^{-4} instead of 10^4. It was also common for candidates to substitute the values of momenta into their equation the wrong way around, leading to a positive final answer.

Incorrect intermediate answers were often corrected in the final answer.

Candidates are reminded that in a ‘show that’ question, the working must be correct throughout.

(iii) Only a few candidates were able to provide a fully correct explanation. A large number of candidates incorrectly stated that as the force and momentum was the same for both trucks, the time to come to rest for both trucks would also be the same.

Very few candidates explained that truck S and truck R would have the same change in momentum to come to rest.

Many candidates focussed on explaining that a decreasing force acted on truck R whereas a constant force acted on truck S, but did not actually compare the average force acting on truck R to the average force acting on truck S for the trucks to come to rest. Very few candidates tried to determine the value of the average force acting on truck R over the time it took to come to rest.

Many weaker candidates stated that the force on truck S was greater as the force was constant and the force on truck R varied. Some candidates seemed to simply guess that truck S would take less amount of time to come to rest and did not provide a correct supporting explanation. Only a relatively small number of candidates realised that they could determine the value of the time taken for each truck to come to rest, either algebraically or from the graph.

Some candidates annotated the graph but did not make reference to these annotations in their answer, and so it was not clear how this related to the question. Candidates are reminded to present their answer in the space provided.

Question 4

(a) (i) Full explanations were rarely seen, although many candidates were able to give a partial explanation. Some candidates described the reflection of the emitted wave by saying that it 'bounced off' or 'rebounded' from the metal sheet, but did not actually use the verb 'reflect'. Candidates are reminded to use the correct technical terms when describing physical phenomena.

Other candidates explained that a stationary wave is formed by two waves travelling in opposite directions and superposing, but did not make it clear that these two waves were the initial wave moving towards the metal sheet and the wave that is reflected from it.

Many candidates seemed to confuse the production of a stationary wave with the production of a two-source interference pattern. This often led to incorrect comments about the phase difference between the two waves at nodes and antinodes. Many candidates incorrectly referred to maximum displacement instead of maximum amplitude at antinodes. Similarly, it was common to see incorrect references to minimum or zero displacement instead of minimum or zero amplitude at nodes.

(b) (i) The majority of candidates correctly recalled $c = f\lambda$. Power-of-ten errors in the recall of the speed of light or in converting GHz into Hz were common. Very weak candidates occasionally used c = 330 m s^{-1}. Another common error here was to round the correct answer 0.048 m to 0.05 m. As c is given in the data sheet to 3sf and the frequency was given to 2sf, a 2sf value for wavelength was expected.

(ii) Only a minority of candidates understood that the distance between P and Q was equal to a quarter of a wavelength. A common misconception was that this distance was equal to half of a wavelength.

(iii) This was generally well answered. A significant number of candidates explained that the distance would be the same as the wavelength was unchanged. The given fact that the frequency was unchanged meant that other candidates were able to explain that the intensity change was due only to an amplitude change and not a wavelength change. Some candidates stated only that the frequency had not changed (which was given in the question), but did not link this to the wavelength, and so could not score.

Question 5

(a) The stronger candidates were able to calculate the time period from the CRO trace and then evaluate the wavelength of the sound. A significant number were unable to determine the time period using the time-base setting, often mis-reading the graph or failing to convert a correct reading to a period. Candidates frequently introduced a power-of-ten error of 100 when attempting to deal with the cm^{-1}. Another common mistake was to simply use the time-base setting as the period of the wave.

Successful responses generally had clear a presentation and showed all the intermediate steps of the calculation. Candidates are reminded to state the subject of all equations as this made it easier to score some credit when the final numerical answer was incorrect. Poorly presented numerical working often scored no marks when the final answer was wrong. Candidates are reminded that the symbol for the period is T rather than t.

(b) Many candidates recognised that the loudspeaker was moving away. Many also gave correct explanations relating the increase in period to a decrease in frequency, although this was not required as the command for this question was 'describe' not 'explain'. A small minority realised that the continuous increase in the period meant that the speed of the loudspeaker was increasing.

A very small number of candidates misinterpreted the question and thought that they were being asked to describe the motion of a loudspeaker in order to produce a sound wave and so talked about the loudspeaker vibrating or oscillating.

Question 6

(a) The majority of candidates calculated the correct potential difference. Weaker candidates sometimes made a power-of-ten error when trying to convert the units of resistance from mΩ to Ω.

(b)(i) The majority of candidates gave the expression for the area in terms of the resistivity. The most common errors were with the powers of ten or rearranging the equation but generally this was well answered.

(ii) This was generally well answered. The weaker candidates seemed to be unaware of the meaning of the number density of charge carriers. Some candidates attempted to use $v = I/nAq$ but could not make progress as v is not known. Some candidates used this equation with their answer to **6(b)(iii)** but this was not credited, as a 'circular calculation' is not valid in a 'show that' question.

(iii) Stronger candidates found this straightforward. Most candidates realised that they could use $I = nAqv$, but the substitution often proved challenging. The most common mistake was to substitute the total number of charge carriers instead of the number density of charge carriers. Another mistake was to substitute the total charge of all the charge carriers in the wire instead of the charge of a single charge carrier.

(c)(i) This part of the question was challenging. Many candidates focussed on how the resistance of wire Q changes with its length instead of comparing the total resistance of wire Q with the total resistance of wire P. For example, there were many comments about the resistance of wire Q at the end of radius r_1 or at the end of radius r_2 and how those values compared to one another or to the resistance of wire P.

Most candidates commented that the cross-sectional area of Q decreased (along its length).

Stronger candidates realised that the average cross-sectional area of Q is less than P, but very few candidates commented that Q would be longer than P. It was not unusual for candidates to think that the wires had the same length. The relationship of the resistance of a wire to its length and area was generally well known.

(ii) Most candidates realised that the graph line would start from a non-zero value of average drift speed when the distance from X was zero. However, a common misconception was that the average drift speed of the charge carriers would then decrease as the distance from X increased. Although a significant number of candidates realised that the graph line would have a positive gradient, it was usually drawn as a straight line and only the very strong candidates were able to deduce that the graph line would have an increasing positive gradient.

Question 7

(a) The majority of candidates gave the two correct values. The most common incorrect value of the nucleon number of Q was 218 and the most common incorrect value of the proton number of R was 90.

(b) The stronger candidates were able to apply the conservation of momentum to the correct nuclei in this decay. A common error was to use the proton number instead of the mass number for both particles. Many weaker candidates attempted to include particle Q and assigned it a non-zero speed, meaning they could make little progress. A significant number of the weakest candidates seemed unaware of how to apply the conservation of momentum in this situation.

(c) Very few candidates managed to give three quantities that are conserved. 'Momentum' and 'charge' were the most common correct answers. 'Mass' and 'energy' were the most common incorrect answers. A small number of candidates scored a mark for mass-energy.
Very few candidates gave 'nucleon number' or 'proton number' despite having (usually correctly) applied the conservation of both quantities in **7(a)**.

Weak candidates sometimes gave ‘protons’, ‘neutrons’ or ‘electrons’ without stating ‘number’ and so could not score. Very weak candidates offered types of radiation or flavours of quarks.

PHYSICS

Paper 9702/33
Advanced Practical Skills

Key messages

- Where possible, candidates should carry out practice experiments, similar to those examined in previous years. The importance of setting up apparatus in accordance with instructions and diagrams should be emphasised. For experiments of the type in **Question 2**, suitable problems and suggestions for improvement for those experiments can be discussed.

- Candidates should be given opportunities to practice drawing lines of best fit using 30 cm rulers, and should check the appropriateness of the lines they produce.

- Candidates should be given clear advice regarding the resolution of measuring instruments and the correct precision of recorded values, distinguishing this from significant figures in calculated values. The number of decimal places in a measured value should never be forced to give the number of significant figures consistent with a calculated value.

- In **Question 2**, candidates should be advised to concentrate on measured values and should follow the advice in the question, in this case *'state the quantity being measured and a reason for the uncertainty*.' Comments regarding the suitability of apparatus, rather than the method of use, are less likely to get credit.

- Candidates should be encouraged to write clearly and carefully, particularly for numbers and units. Candidates should recognise where units should be included on answer lines.

General comments

The general standard of the work done by the candidates was good, and there were many excellent scripts. Candidates demonstrated good skills in the generation and handling of data but improvements could be made to the analysis and evaluation of experiments.

Candidates did not seem to be short of time and both questions were attempted in full by almost all the candidates. There was a small number of candidates with no response in **Question 1(d)** and **(e)**, but with **Question 2** fully answered; candidates should be reminded that they are only allowed access to apparatus for each question for one hour and should allocate their time to each question accordingly.

In general, centres had little difficulty in providing the specified apparatus. Some centres provided an alternative pipe material in **Question 2** and candidates were not disadvantaged by this. Where a centre has a problem with providing the apparatus required, they should note this in their supervisor's report.

It is important that centres provide measuring apparatus with the correct resolution. Candidates from some centres recorded results consistent with an ammeter reading to 0.01 A in **Question 1**, rather than a milliammeter.

Comments on specific questions

Question 1

Most candidates were able to complete this question and to obtain good quality results, within the ranges expected. For some candidates the scatter of results was greater than to be expected from an electrical experiment and candidates should be advised to check the readings for any points off-trend.

(a) The value of *x* was almost always in range but many candidates did not convert their milliamp readings into amps. Candidates often used the correct unit of mA in their table so should be advised to always check the consistency of units used.

(b) Most candidates were able to obtain the required six sets of values, with the correct trend.

There were some candidates who only increased (or decreased) their *x*-values from the starting value of approximately 0.45 m in **(a)** and so there were many who did not cover the full range of values. Centres were asked to provide one of the connecting leads with a length of 1 m to ensure that the full range was available to candidates. Candidates should be reminded that the widest possible range of the independent variable should be used. In this case, candidates should be able to have *x*-values from close to zero to over 90 cm, but allowance was made to accommodate centres with slightly shorter connecting leads.

It was common for *x* values to be given to the nearest centimetre, as candidates were choosing where to connect their crocodile clips to the wire. Candidates need to be advised to always use the resolution of the measuring instrument used; in this case *x* values can be to the nearest millimetre, as that was the resolution specified in the confidential instructions.

Significant figures and calculations were mainly correct.

Column headings were largely correct. Some candidates either omitted the units for $1/I$ or incorrectly gave them as A. The incorrect expression $1/I$ / A^{-} (a superscript negative sign without any number) was encountered several times from different centres.

(c) (i) Many candidates gained credit for drawing appropriate axes, with labels and sensible scales covering at least half the graph grid, and plotting their six points accurately. There were many graphs with compressed or awkward scales, imprecise points (blobs) and poorly-drawn lines of best fit.

With the *x* values typically used, some candidates used a scale based on 15 cm for each large square. Although this gives a good spread of points, it is not acceptable as the scale is difficult to use. Errors in plotting or reading values from the graph were more common with awkward scales. There were many compressed scales on the *y*-axis, typically due to candidates including the zero value on this scale.

If candidates identify an anomalous point, they should first check the plotting of that point, then the calculation and then, if possible, use the apparatus to repeat the measurements for that point. If necessary, a single anomalous point can be indicated and ignored when drawing the line of best fit.

(ii) Many candidates were able to draw a straight line of best fit. There were many lines requiring rotation to give a good spread of points about the line. Some lines seem to have been drawn so that the maximum number of plotted points were on the line and it appeared that the candidates had ignored the points not on the line. Some lines were drawn to join two points (typically the first and last). A significant number of lines were drawn in two sections so that the line was kinked. Candidates should use a transparent non-folding 30 cm ruler to draw a single clear line.

(iii) Candidates can either draw a triangle on their line or indicate two points on the line used to determine the gradient. To avoid confusion with the plotted points, these points should not be indicated with the same symbol as the plotted points. Typical errors were using a small triangle for the gradient or reading the intercept value from the *y*-axis when a false origin was used on the *x*-axis.

There were cases of incorrect readings substituted into the gradient calculation, particularly when awkward scales were used. A common mistake was to use values from the table for a point that was not on the line.

(d) The majority of candidates transferred their gradient and intercept values as *a* and *b* respectively. Those with one of these values to only one significant figure in **(c)** often did not make the required correction to two significant figures here. Candidates who considered the units for gradient and intercept were usually able to give the correct units. Candidates can ensure that each term in the equation has a consistent unit – in this case ax must have the units A^{-1} so a must be in $A^{-1}\,m^{-1}$ if x is given in m.

(e) The calculation was usually done correctly by those candidates who in **(a)** had used current in amps and *x* in metres. It was rare for candidates who had used mA and cm to convert their calculated value to have correct units.

Question 2

Most candidates were able to complete this question and to obtain results within the ranges expected, despite the difficulties encountered with the small value of the expansion of the pipe and the difficulties of dealing with hot water.

(a) Candidates should be reminded that for answer lines without units they need to consider whether units need to be quoted with their value. Although the metre rule can be read to the nearest 0.1 cm, the thermometer can only be read to the nearest degree but it was common to see temperatures given to 0.1 °C.

(b) (i) A few candidates gave their value of *s* or *d* to the nearest centimetre, despite using a metre rule with a millimetre scale.

(ii) Most *T* values seen were more than the room temperature recorded in **(a)** but the *T* value was well below 50 °C in some cases. The Confidential Instructions asked for ‘access to a supply of boiling water, e.g., electric kettle’; it could be that candidates either took a long time to make their measurements or had not realised that they could re-heat the water in the kettle.

(iii) The common error here was to determine the percentage uncertainty in either H_1 or H_2 rather than $(H_1 - H_2)$. It was rare to see repeated measurements and the half-range method for determination of uncertainty used correctly.

(iv) The calculation of ΔL was usually correct.

(c) (i) It appeared that a small number of candidates used the same pipe for this part and recorded a value of *L* of about 12 cm again.

(ii) The small values of $(H_1 - H_2)$ made it difficult for candidates with low hot water temperatures to be awarded the ‘quality’ mark. Again, it appeared that candidates either took a long time making measurements or had not re-heated the water to ensure they were using ‘very hot water’ as instructed in **(b)(ii)**.

(d) Values of *k* were usually calculated correctly. In a small number of cases, the value was only given to one significant figure, possibly due to rounding of the previous period value. A few candidates used the value of 12 cm for both *k* values but there were only a few re-arrangement errors.

(e) Candidates should calculate the percentage *difference* between their *k* values and compare this to the suggested percentage *uncertainty*. There were many clear answers but some vague statements such as ‘the percentage uncertainty was less than the percentage uncertainty, so the results support the relationship’. There were also answers showing confusion over the requirement, such as: ‘my results do support the relationship as their difference (33%) is close to 30%’, ‘percentage difference does not equal 30% so results do not support the relationship’ or ‘percentage difference is nowhere near the suggested percentage uncertainty of 30% so results do not support the relationship’.

Candidates should give a numerical comparison with the suggested uncertainty given, in this case 30%, and a statement such as 'the percentage difference between my *k* values is less than the suggested percentage uncertainty of 30% so my results support the relationship.'

(f) (i) Most candidates described four sources of uncertainty or problems, but many suggestions were too vague or did not refer to the measurement affected. Difficulty judging the position of the centre of the nail needed to be linked to the measurement of *s* and/or *d*, for example.

Many candidates recognised that two sets of data were insufficient to draw a valid conclusion. There were also good responses that recognised the problem with measuring *L* as the pipe was curved and that there were large percentage uncertainties in $(H_1 - H_2)$ or ΔL due to the small difference between the *H* values.

The key to this section is for candidates to identify genuine problems associated with setting up the experiment and in obtaining measured values.

(ii) Most candidates described four improvements but, as with the problems in **(i)**, there were many vague answers. There were also many suggestions such as 'read the ruler at right angles', 'take repeat measurements and calculate the average' or 'time multiple rotations of the bob' that should be standard practice and so will not get credit.

Stronger candidates were able to suggest taking more sets of readings and plotting a graph and taking a video with a timer in view and replaying frame-by-frame.

Candidates are encouraged to suggest practical solutions that either improve technique or give more reliable data. More successful candidates will select relevant problems in **(f)(i)** and describe them clearly, linking to relevant measurements and will then suggest improvements in **(f)(ii)** that are workable and expressed clearly.

PHYSICS

Paper 9702/42
A Level Structured Questions

Key messages

- Candidates need to take care to ensure that they read the question properly, understand what is being asked and give responses that answer the question that is asked. This is particularly important for questions that require extended writing. Candidates often give answers to questions that were not asked, but that have been asked in recent past papers. Candidates should be advised not to rely heavily on memorising previous mark schemes.

- It is important that candidates use technical language accurately. Examples of words that are often confused by candidates are atom and molecule, nuclide and nucleus, and force and field. Candidates are not able to obtain full credit if they use an inappropriate word that makes the response technically incorrect.

- In defining quantities, candidates need to take care to ensure that the definition they give is dimensionally correct. This often requires use of the phrase ‘per unit’ where the quantity being defined is the ratio between two other quantities, or ‘product’ where the quantity being defined is two other quantities being multiplied together. Examiners will only consider symbol equations to be part of an answer to a question that asks candidates to define a quantity if the symbols in the equation are defined.

- Candidates need to be careful that they do not give more than one answer to a question. This is particularly important when they are answering a question that asks for the definition of a quantity or the meaning of a symbol. These things only have one answer, and if multiple answers are provided that are contradictory, the candidate cannot be awarded credit for a correct answer.

- When answering questions involving calculations, it is important for candidates to show their reasoning clearly. This includes taking care to use the correct conventional symbols for physical quantities. If working is clear, and based on use of correct physics, it is often possible for examiners to award part-credit even when the final answer is incorrect. Whilst correct final answers will usually be awarded full credit, incorrect answers that are not supported by working cannot be awarded any credit.

- Final answers to numerical questions should be given to an appropriate number of significant figures; the precision of the data provided in the question is generally indicative of the appropriate number of significant figures for an answer. When performing intermediate calculations within a question, candidates should take care to avoid premature rounding that changes the answer within the appropriate significant figures; as a general rule, any intermediate calculated values should always carry at least one more significant figure than will be used in the final answer. Candidates should be made aware that giving final answers to too few significant figures, and rounding intermediate answers prematurely so that final answers become incorrect, can both lead to full credit not being awarded.

- It would be helpful for candidates to be advised that there is no need to spend time, or to use up answer space, by repeating the question.

General comments

The question paper contained questions of a variety of levels of difficulty, enabling candidates at different levels of ability to demonstrate their knowledge and understanding of the subject. Candidates who knew the theory, read the questions carefully, took care over their use of technical language and answered the questions asked were able to perform well.

There was no evidence that candidates who were properly prepared for the examination had insufficient time in which to complete the paper. Candidates should be advised that a response should always be attempted, because where there is a response examiners may find opportunities to award credit.

Comments on specific questions

Question 1

(a) A large proportion of candidates thought that centripetal force was one of the two forces acting on the sphere. Correct force diagrams were only seen from a small number of candidates. Some candidates drew diagrams that included more than two forces.

(b) Many candidates answered a different question from the one asked here. The question here was to explain how the two forces acting on the sphere result in the acceleration of the sphere being centripetal. Examiners were expecting to see discussion of horizontal and vertical components of the normal contact force, that the vertical component balances the weight and that the horizontal component is therefore effectively the resultant force that acts towards the centre of the circle. Most responses seen made no reference to the two forces acting at all.

(c) The general equation for acceleration in terms of speed and radius was generally well known. Candidates found it more difficult to use the trigonometry involved in getting to the magnitude of the resultant force from the weight of the sphere.

(d) This was the most successfully answered part of **Question 1**, with many candidates obtaining the correct answer.

(e) A very common misconception was that the angular frequency must remain unchanged, leading to direct proportionality between speed and radius. The candidates who fully appreciated the force analysis of the earlier parts of the question realised that the resultant force, and hence centripetal acceleration, cannot change, and thus the correct relationship is that radius is proportional to the square of speed.

Question 2

(a) Candidates who knew the inverse relationship, understood that gravitational potential is always negative, and took care over their diagrams, were generally able to achieve the marks.

(b) Many candidates realised that, at a constant distance from the Earth's surface, the gravitational potential must be constant.

(c) This question required candidates to realise two things. One, that the potential is zero at the earthed plate and $+V$ at the upper plate. Two, that the electric field between parallel plates is uniform. Candidates who realised both aspects, and took care over the start and end points of their line, were generally able to achieve the marks.

Question 3

(a) (i) Generally well answered by the stronger candidates. However, several misconceptions are worth highlighting. Firstly, many candidates appeared to think that 'constant temperature' and 'equal temperatures' mean the same thing. Secondly, many candidates confused internal energy and thermal energy and gave answers that were contradictory.

(ii) Most candidates knew the general equation for specific heat capacity and were therefore able to achieve the first 'working' mark. However, only the strongest candidates correctly analysed the energy transfers involved to arrive at the correct answer.

(b) (i) Many candidates correctly used the equation for work done on a gas when changing volume at constant temperature. However, only the strongest candidates realised that, because the gas is expanding, the work done on the gas must be negative.

(ii) Generally well-answered. However, one misconception that was common in a minority of candidates, warrants mention. Having correctly stated the starting equation $pV = NkT$, some candidates substituted the change in volume from part **(b)(i)** as the value of V.

(iii) Generally well-answered by the stronger candidates. The common confusion among weaker candidates was the difference between r.m.s. speed and mean-square speed. Many candidates stopped at the mean-square speed and gave this as their answer to the r.m.s. speed.

Question 4

(a) Generally well-answered.

(b) This question was well-answered by the candidates who knew the starting equation.

(c) Many candidates knew the correct equation for total energy, though various errors were seen in its use. These ranged from power-of-ten errors to forgetting which quantities needed to be squared. A common error from some of the weaker candidates was to use the maximum acceleration value from the previous part as the amplitude.

(d) (i) Examiners expected to see reference to an alternating voltage applied across the crystal, making it alternately expand and contract. Many candidates confused the concepts of a voltage being applied (to cause distortion of the crystal) with a voltage being induced in the crystal by mechanical vibrations. Some candidates confused voltage with current.

(ii) Well-answered by many candidates, with full credit being common. Many other candidates calculated the percentage reflected and stopped short of using that value to determine the percentage transmitted.

Question 5

(a) Many candidates were able to correctly reproduce this textbook derivation required by the syllabus. Some, however, were not able to establish the key principles of physics as the starting point (how the p.d.s and charges relate to each other in a series circuit).

(b) Many candidates did not show clarity of presentation in this question, with many conflicting expressions alleged to all be expressions for 'C'. Examiners needed to see a clear expression for the total capacitance in terms of C, and a clear statement that the total capacitance is given by the gradient of the Q-V graph. Some benefit of doubt was given to candidates who started incorrectly but then subsequently arrived at correct physics.

(c) (i) Most candidates knew the equation for time constant, but many then incorrectly substituted 44 μF as the capacitance of the circuit. As a result, 2.4 s was a very common incorrect answer. It was also notable that a significant number of candidates appeared to not know that time constant is a time and therefore struggled with indicating the correct unit.

(ii) Generally well-answered by candidates that had a good understanding of the topic of capacitor discharge. Full credit by the error-carried-forward principle was common for candidates that worked through with their 2.4 s time constant from part **(c)(i)**.

Question 6

(a) Many candidates reproduced the algebra involved in this syllabus derivation correctly. However, only a minority established the core physics behind the derivation as a starting point, the equality between the magnitudes of the electric and magnetic forces.

(b) This question was generally well-answered, with many candidates successfully calculating the correct answer.

(c) Many candidates explained why the particles pass through the field region undeviated, rather than addressing the question asked, which focussed on the expression in part **(a)** and how this expression shows that the speed for undeviated path is independent of the mass and charge of the particle. Many other candidates, who did address the question asked, gave only one of the factors of mass and charge as not appearing in the equation, forgetting that both quantities differ between protons and alpha particles.

(d) Weaker candidates were confused between the current direction and the direction of the electric force on the particles. Many candidates, however, gave a correct analysis of the three terms involved in the left-hand rule, and full credit was common for the more able candidates.

(e) Many candidates were unable to draw the required curve with consistent curvature, and many paths were seen that involved a discontinuity in the path at the point of entry into the field region. Most candidates had the direction of deflection incorrect, with only the strongest candidates able to deduce that with an unchanged electric force but a larger magnetic force, the faster particles will deflect upwards.

Question 7

(a) Faraday's law of electromagnetic induction was generally well-known, and full credit was common.

(b) (i) A large proportion of the weaker candidates missed the point of this question and focussed solely on the trend of Figure 7.2. The candidates who were successful in answering this question spotted that, whilst Figure 7.2 concerns the relationship between E and t, the question was about the relationship between E and v. The starting point for answering correctly required the direct proportionality between v and t to be established from the information that the acceleration of the rod is uniform from rest. A significant minority of weaker candidates thought that v was inversely proportional to t.

(ii) This challenging derivation required candidates to think of the scenario of the rod moving a short distance Δx in a short time Δt. Many candidates conflated t with Δt and were thus unable to produce a derivation based on correct physics.

(iii) Generally well-answered, with many candidates obtaining the correct answer. A common mistake was for candidates to miss the power-of-ten conversion required in the value of E.

Question 8

(a) The identity of a photon, as a quantum of energy of electromagnetic radiation, was generally well-known, although a significant minority of candidates omitted any reference to energy (as the quantity that is quantised) in their answer.

(b) (i) Generally well-answered, with correct answers being deduced by many candidates.

(ii) The stronger candidates generally calculated the number of photons per unit time, from the power and the photon energy, correctly. A common mistake among some of the weaker candidates was to give an answer that is the reciprocal of the number per unit time. Candidates should consider checking whether their numerical answers have a plausible magnitude to identify errors that have been made during the calculation.

(iii) This was a challenging question. Many candidates successfully got as far as deducing that the average force is equivalent to some multiple of the product of the photon energy and the number of photons per unit time. However, many of the candidates were not able to determine that this multiple had to be 3/2 from the information about half of the photons being absorbed and half of them reflected. Some of the stronger candidates did make this connection, and these candidates generally went on to achieve full credit for the question.

Question 9

(a) (i) The meaning of the random nature of radioactive decay was not well understood. Many candidates appeared to know that it concerned something being unpredictable but could not articulate that this unpredictability is to do with when individual nuclei decay. Many candidates appeared to think that everything about radioactive decay is unpredictable, which is not correct.

(ii) This was much more successfully answered, with most candidates knowing that the inability of external factors to affect the decay process is the meaning of the term spontaneous.

(b) Many candidates found it difficult to give an accurate definition of half-life. The time taken for the activity of a sample to halve is the simplest definition to articulate. Candidates who went down the number of undecayed nuclei route found it harder to be fully correct in their use of terminology. Responses such as the 'time for nuclei to halve' were common.

(c) Generally well-answered by candidates who appreciated that the data in the table is for binding energy per nucleon. Those who thought they were total binding energies made no use of the nucleon number data and just added/subtracted the binding energy per nucleon data. This approach was incorrect physics and could not be awarded credit. Some candidates did correctly calculate the 7.03 eV figure but then gave a negative answer, presumably just because of the way around they performed the subtraction in their calculators. The question did ask for the energy released (not just transferred), and so the sign of the answer has significance, and full credit could not be awarded to candidates who thought there was a negative release of energy.

(d)(i) A variety of responses was seen here, but many candidates did correctly deduce that the gradient of the line represented the magnitude of the decay constant.

(ii) Generally well-answered, with many correct answers seen to this question part.

(e)(i) Generally well-answered, with most candidates able to articulate that upon encounter with an electron, the positron will undergo annihilation.

(ii) Many candidates gave responses to this part that hinted towards some aspect of what examiners are looking for, but responses that only dealt with one half of the full answer were common. To be awarded credit, candidates needed to establish why 2 hours is both not too long and not too short for the half-life of the tracer.

Question 10

(a)(i) Candidates who knew the theory were generally able to give a full definition of luminosity, as the total radiant power of the star. Many responses were partial answers.

(ii) Many full and accurate descriptions were seen in response to this question, which directly assesses the syllabus learning outcome concerning the use of standard candles to determine distances to galaxies. For full credit, candidates needed to establish how the information about luminosity and radiant flux intensity is established, and then how the equation linking them can be used to calculate the distance.

(b)(i) For a relatively challenging 'show that' question, that required various topics within the syllabus to be assembled, this question was well-answered. The candidates that did compile all the relevant physics together, establishing the speed of rotation and the relationship between speed, radius and period, generally received two of the three marks available. For the third mark, all elements of the 'show that' working needed to be present, and there were some common reasons for not meeting the requirements for that mark. One was not showing the working leading to the $\Delta\lambda$ value; one was use of the incorrect wavelength in the Doppler equation; one was omission of the speed of light in the working, and the other was not showing how the period is used in the working. Full credit was achieved by many candidates.

(ii) Many candidates incorrectly asserted that the observed wavelength will be larger due to redshift. The stronger candidates realised that point Z on the Sun is moving towards the observer, and hence the observed wavelength in this situation will be less than the emitted wavelength.

(iii) Generally well-answered.

PHYSICS

Paper 9702/52
Planning, Analysis and Evaluation

Key messages

- In **Question 1**, candidates' responses should include detailed explanations of experimental procedures such as how to control variables, how to take measurements and how to analyse the data.
- In **Question 2**, candidates need to understand that the number of decimal places in a logarithmic quantity should correspond to the number of significant figures.
- The numerical answers towards the end of **Question 2** require candidates to show all their working and for the values to be correctly evaluated with appropriate units. A full understanding of significant figures and the treatment of uncertainties is required.
- The practical skills required for this paper should be developed and practised with a 'hands-on' approach throughout the course.

General comments

In **Question 1**, it is advisable that candidates should think carefully about how they would perform the experiment in the laboratory using the bullet points given to aid their answer. Planning a few key points before answering **Question 1** is useful.

Many candidates were successful in the analysis section with clear identification of how the constants could be determined. Lower scoring candidates tended to suggest a suitable graph but were not explicit in how the relationship could be proved or in how the values of Y and Z could be determined. To score the additional detail marks, candidates should take care to describe exactly how each measurement will be obtained, including both the equipment used and the method to take the measurement. It is essential for candidates to have experienced practical work in preparation for answering this question.

In **Question 2**, candidates should be familiar with completing a results table for quantities and their uncertainty, and with finding the gradient and y-intercept of a graph. For several candidates, credit was not awarded because; the plotted points were not balanced about the line of best fit, or the worst acceptable line did not pass through the error bars correctly, or coordinates were wrongly read off when determining the gradient and/or y-intercept.

The recording of the logarithmic quantities in **2(b)** and the determination of the absolute uncertainty in θ_0 in **2(d)(ii)** were challenging for the candidates. Some candidates were confused by the negative value of the gradient.

In question parts requiring mathematical manipulation, higher scoring candidates clearly stated the equation used with correct substitution of numbers and then calculated the answer and unit. Candidates should be encouraged to set out their working logically so that it can be understood.

Comments on specific questions

Question 1

Most candidates correctly identified the independent and dependent variables. Candidates should then consider the control of variables and to explicitly state the quantities that need to be kept constant to make the experiment a fair test. In this experiment it was expected that candidates would state that V would be kept constant. There was an additional credit for also stating that *A, L* and *q* would also be kept constant. Credit was not given for stating 'control' *V* since this is just repeating the stem of the question and does not indicate what is meant by 'control'. Some low scoring candidates incorrectly stated that *B* or *p* should be kept constant.

Candidates were awarded credit for a clearly labelled diagram. Diagrams should be drawn of the workable experiment. In this experiment, it was expected that candidates would show the two cylinders correctly connected to the resistor and power supply and importantly indicate where point X was located. Many candidates did not draw the cylinders in parallel.

Candidates needed to explain how the potential difference *V* was determined. High scoring candidates correctly drew a voltmeter in parallel with the conductors. The common mistake was to place the voltmeter in parallel with the power supply thus measuring the potential difference across the conductors and the resistor. Some high scoring candidates drew a variable resistor in their diagram and then gained an additional credit by describing that the resistance of the variable resistor was adjusted so that *V* was kept constant. Stating 'I will use a variable resistor to keep *V* constant' does not include enough description.

Candidates also gained credit for stating appropriate measuring instruments to measure *L*, *p* and *q*. Apparatus drawn on its own, e.g., a drawing of a rule, did not gain credit.

Many candidates stated the use of a Hall probe to determine *B* but did not give the method of measuring *B*. Some suggested that the probe should be at right angles but did not state how this could be checked. There were some excellent methods describing the rotation of the probe so that a maximum reading was obtained. Additional credit was scored for repeating the measurement by reversing the probe and measuring in it in the opposite direction and determining the mean. Credit was not gained for just stating that the measurement of *B* was repeated and a mean determined.

Many candidates suggested correct axes for a graph. Candidates must explicitly state the quantities to be plotted on each axis either in the text or on drawn axes – credit is not given for just writing $y = mx + c$ under an expression.

Candidates also needed to explain how the graph would confirm the suggested relationship. Candidates need to use the words 'relationship is valid if' and the word 'straight' to describe the line. In this practical credit was not given for stating that the straight line would pass through the origin since there would be a *y*-intercept. High scoring candidates often stated the *y*-intercept that the line would pass through. Credit was not awarded to candidates who did not correctly identify appropriate axes for a graph to plot.

Candidates needed to explain how they would determine a value for the constants *Y* and *Z* from the experimental results using the gradient and *y*-intercept. To gain credit, the constants *Y* and *Z* had to be the subject of the relevant equation. Credit was not awarded to candidates who did not correctly identify appropriate axes for a graph to plot.

The additional detail section had a maximum of six marks that could be awarded. Candidates should be encouraged to write their plans including appropriate detail; some candidates' answers suggested that they did not have sufficient practical experience. Vague responses were not credited. It is essential that candidates' answers are relevant to the planned experiment rather than general 'textbook' rules for working in the laboratory. When describing safety precautions, candidates should be encouraged to explain how the precaution proposed is relevant to the experiment. In this experiment, it was expected that candidates would suggest using gloves or switching off the circuit because of the heating effect of the current in the cylindrical metal conductors – the reason for the precaution was needed to gain credit.

Other additional detail which gained credit included a suitable method to determine *A*, e.g., the use of a micrometer or calipers to measure the diameter of the wire and then an appropriate equation to determine *A*. Some lower scoring candidates did not gain credit for stating that 'use a micrometer to determine *A*' or 'use a micrometer to measure the radius of the wire'. The physical measurement would be the diameter of the wire and then *A* (and the radius) could be determined. There was additional credit awarded for stating that the measurements of the diameter of the wire would be repeated at different positions along the wire and a mean value of diameter would be calculated – just repeating measurements of diameter did not gain credit.

Other additional detail that gained credit included a detailed method to locate the position of X, additional detail of determining *p* and *q* by using the edge of the cylinders and the radius or diameter of the cylinders, detail on checking that P and Q were parallel and the method to fix Q so that distance *q* was kept constant.

Question 2

(a) Candidates who were mathematically confident were able to work through the algebra and achieve credit. Common errors included omitting the '–' sign. A few lower scoring candidates incorrectly wrote 'ln $\theta_0 - \theta_R$' as opposed to 'ln $(\theta_0 - \theta_R)$'. Candidates should use the white space on the question paper to rearrange the equation into an equation of a straight line.

(b) The majority of candidates incorrectly calculated ln $((\theta - \theta_R)\,/\,°C)$ to two decimal places. Since θ and θ_R and $(\theta_0 - \theta_R)$ are all three significant figures, ln $((\theta - \theta_R)\,/\,°C)$ should be recorded to three (or four) decimal places. Many candidates correctly calculated the uncertainty in ln $((\theta - \theta_R)\,/\,°C)$. Where errors occurred, it was often in not identifying that the uncertainty in $(\theta - \theta_R)\,/\,°C$ was ±1. Candidates need to understand that when adding or subtracting quantities, the absolute uncertainties are added.

(c) (i) The data points were straightforward to plot. It is expected that the data point plotted should be clearly represented. The plotting needed to be within half a small square. When plotting points, the diameter of each point should be less than half a small square. Candidates need to ensure that the error bars are symmetrical about their plotted data point.

(ii) Most candidates appear to be using a sharp pencil and a transparent 30 cm ruler. For correctly plotted data, the line of best fit did not pass through both the highest and lowest points. The worst acceptable line was drawn well in general, and many higher candidates drew a line which passed through all error bars. Candidates should clearly label the lines drawn as required by the question. Clear labelling should also assist candidates when they determine the gradient and *y*-intercept. Where a dashed line represents the worst acceptable line, the dashed parts of the line should cross each of the error bars.

(iii) Most candidates clearly demonstrated the points that they used to calculate the gradient. Some candidates misread coordinates or did not use a triangle that covered more than half of the drawn line. A small number of candidates chose data points that did not lie on the lines, often using data from the table that is close to the line instead. Candidates should be encouraged to select two points on the line of best fit which are easy to read, i.e., the points are on grid lines. Some candidates did not realise that the gradient was negative.

When determining the uncertainty in the gradient, candidates need to show their working, including the coordinates that they have used from the worst acceptable line and how the uncertainty is determined from the gradients of the line of best-fit and the worst acceptable line.

(iv) The majority of the candidates who were awarded full credit set out their working clearly. Stronger candidates often substituted data from the gradient calculation in **(c)(iii)** into $y = mx + c$. Some lower scoring candidates incorrectly read-off the *y*-intercept when the *x*-axis reading was 5.0.

When determining the uncertainty in the *y*-intercept, candidates needed to show their working including both the gradient and a data point from the worst acceptable line. In calculating the absolute uncertainty, there must be evidence of subtraction between the *y*-intercept of the line of best fit and the *y*-intercept of the worst acceptable line. Many candidates incorrectly attempted to determine the uncertainty in the *y*-intercept by either assuming that the fractional uncertainty in the gradient was the same as the fractional uncertainty in the *y*-intercept or adding fractional uncertainties.

(d) (i) Credit was not gained for substituting data values from the table. Most candidates realised that the constant K was equal to $-1\,/\,$gradient. Some lower scoring candidates appeared confused by the negative signs. Some candidates did not gain credit since they did not give their values of K and θ_0 to an appropriate number of significant figures. Most candidates were able to calculate a value for θ_0 using the *y*-intercept. The common error in this question was the determination of units. Most candidates realised that θ_0 had the unit °C, but many candidates did not understand that K had the unit of minutes. The common error was to write min $°C^{-1}$. Some candidates converted the time to seconds which gained credit with the correct unit.

(ii) This was a challenging question. To gain credit in this part, a clear method needed to be shown. Many candidates incorrectly calculated an answer using a fractional uncertainty. Some candidates realised that the absolute uncertainty was calculated by using the maximum or minimum values. However, some of these candidates omitted to include the absolute uncertainty of 0.5 in θ_R.

(e) It was essential that candidates showed their method of working. High scoring candidates wrote down the equation that they chose to use and clearly substituted in their values.