PHYSICS

Paper 9702/11
Multiple Choice

There were too few candidates for a meaningful report to be produced.

PHYSICS

Paper 9702/12
Multiple Choice

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

General comments

It is important to carefully read the text of the question before considering the four options presented. Candidates should be familiar with the definitions of physical quantities in the syllabus and would benefit from being able to recognise common misconceptions of definitions, for example confusing definitions for units and quantities.

In numerical questions, candidates should be careful to consider SI prefixes and powers of ten and should be encouraged to apply a common-sense check to their answers to ensure they are a sensible magnitude.

In general, candidates found **Questions 10**, **13**, **20**, **24** and **34** relatively difficult. Candidates found **Questions 5**, **11**, **15**, **35**, **36** and **38** relatively easy.

Comments on specific questions

Question 2

Around half of candidates correctly selected option **A**. Option **B** was also a popular choice. This kinetic energy (5×10^7 J) is consistent with a car of mass close to 10^6 kg travelling at 10 m s^{-1}, or a car of mass 1000 kg travelling at 320 m s^{-1}. Candidates should practice making order of magnitude estimates for quantities in the syllabus.

Question 6

Only half of candidates correctly identified that the acceleration of the ball is constant (option **C**). The options were all selected roughly equally, suggesting that candidates were guessing. As the majority of candidates correctly solved **Question 5** involving an object falling with constant acceleration, this suggests that candidates do not recognise the equivalence of these situations. Candidates should be encouraged to consider the conditions under which physical models and equations can be applied in addition to calculating values from those models.

Question 8

Many candidates correctly selected option **B**. A significant number of candidates chose option **A** suggesting that the term 'terminal velocity' is not well understood.

Question 9

Option **A** was nearly as popular as the correct option **D**. Candidates selecting **A** had found the change in the magnitude of the speed ($4.0\,m\,s^{-1} - 2.8\,m\,s^{-1}$) to determine the change of momentum, as opposed to the change in the velocity ($4.0\,m\,s^{-1} + 2.8\,m\,s^{-1}$). This is a common error, and candidates should be reminded to consider the directions of the object or objects involved in momentum problems.

Question 10

Only a small number of candidates correctly found the lost kinetic energy (option **C**) by subtracting the total kinetic energy after from the total kinetic energy before the collision. Nearly half of the candidates chose option **B**, which is the difference between the kinetic energies of the two carriages before the collision. Candidates should practice problems involving elastic and inelastic collisions, finding momenta, velocities and energies.

Question 13

This was a difficult question, and most candidates selected the incorrect option **B**. These candidates had used the principle of moments to set up an equation for the moment due to each force such as $6.0 \times 7.0 + 6.0 \times 3.0 = 5.0 \times XP + 5.0 \times PY$ and solved for XP + PY. This method is not valid since the forces applied at X and Y are not perpendicular to the line XY. The correct equation is $6.0 \times 7.0 + 6.0 \times 3.0 = 5.0 \times XP\sin60 + 5.0 \times PY\sin60$.

Candidates might find it helpful to draw the lines of actions of the forces on the diagram to identify the perpendicular distance to the pivot.

Question 18

Stronger candidates found this straightforward, with the majority selecting option **C**. Amongst weaker candidates, options **B** and **D** were common choices. These candidates had attempted to determine work done using a force of either 50 N (neglecting *g*) or 490 N and the distance moved along the ramp, as opposed to the vertical distance moved. Weaker candidates are not confident with the definition of work as force × distance moved **in the direction of the force**.

Question 20

This was challenging for many candidates. Option **D** was the least popular, suggesting candidates are confident in recognising that Hooke's law corresponds to a straight-line region on a stress-strain graph. Candidates would benefit from practice analysing graphs of stress against strain for different materials to identify features such as Young modulus, elastic limit and limit of proportionality.

Question 22

Only half of candidates correctly selected option **A**. Option **C** was popular, suggesting that most candidates recognise that the area under a force-extension graph represents work done, but many did not realise the graph presented was force against length. Candidates need to pay close attention to the axis labels and scales given in graphs.

Question 24

This was challenging for candidates. Most candidates selected the correct option **C** or option **D**, recognising that the distance PQ represented a whole wavelength. Candidates could improve by practicing analysing graphical representations of longitudinal waves.

Question 28

Only half of candidates correctly selected option **B**. Option **A** was selected nearly as often. Candidates should understand the difference between amplitude and displacement as this is a common misunderstanding.

Question 32

Fewer than half of the candidates correctly chose option **A**, suggesting that the concept of the quantisation of charge is not well understood. A large number of candidates selected option **D**. Candidates should learn the definitions of key quantities.

Question 34

This was a difficult question, requiring candidates to use $I = nAvq$ and the definition of the number density of charge carriers, to determine the total number of free electrons.

The total number of free electrons, N = n / (cross-sectional area × length), can be substituted into $I = nAvq$ then rearranged to give N = $(IAL) / (Avq) = (IL) / (vq) = 5.3 \times 10^{22}$ which is option **B**.

Options **C** and **D** were chosen as frequently as option **B**, suggesting many candidates, especially weaker ones, may have eliminated option **A**, and then guessed. Stronger candidates were more likely to correctly choose **B**. Candidates could improve by practicing multi-step problems such as this one in addition to more straightforward applications.

Question 39

This was straightforward for stronger candidates, who correctly chose option **D**. Many candidates selected options **A** and **B**, suggesting that the quark composition of protons and neutrons is not well known, or that there is some confusion between quarks, nucleons, neutrons and protons. Candidates should know the meanings of all of these key terms, and how to interpret the nuclear notation $^{3}_{1}H$.

PHYSICS

Paper 9702/13
Multiple Choice

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

General comments

It is important to carefully read the text of the question before considering the four options presented. Candidates should be familiar with the definitions of physical quantities in the syllabus and would benefit from being able to recognise common misconceptions of definitions, for example confusing definitions for units and quantities.

In numerical questions, candidates should be careful to consider SI prefixes and powers of ten and should be encouraged to apply a common-sense check to their answers to ensure they are a sensible magnitude.

Candidates struggled on the circuits questions in particular and would benefit from more practical experience constructing and taking measurements from a variety of circuits.

In general, candidates found **Questions 2, 33 ,34, 35** and **38** relatively difficult. Candidates found questions **8, 15, 18, 24** and **31** relatively easy.

Comments on specific questions

Question 2

More candidates selected option **B** than the correct option **C**. Candidates are required to make reasonable estimates of quantities within the syllabus, so could have estimated the density of copper and then calculated the mass, or they could have estimated the mass directly. Candidates could improve by practicing order of magnitude estimates as part of their studies.

Question 5

A little over half of the candidates correctly selected option **A**, recognising that the upthrust is independent of the density of the cuboids. Amongst weaker candidates, option **B** was the most popular choice, demonstrating a common error in thinking the density of the submerged object determines the upthrust.

Question 7

Approximately half of the candidates correctly selected option **A**. The majority of the other candidates selected option **B**, perhaps reasoning that as X experiences no air resistance, it will travel faster. Candidates should consider that as the initial velocities are the same for X and Y, the **acceleration** of X will be less (due to the absence of air resistance) so it will take a longer time before its velocity is reduced to zero.

Question 12

Around half of the candidates selected the correct option **A**. The four options were chosen roughly equally, suggesting that the variation of resultant force in this situation is not well understood. Candidates are expected to understand that the drag force varies with velocity, and so can reason that the highest drag will occur when the ball is moving fastest, at the point of release. Candidates might benefit from drawing a sketch of the forces acting on the tennis ball to help them visualise the resultant force.

Question 13

Less than two thirds of candidates correctly selected option **D** for this simple definition. Candidates should learn the definitions of key quantities in the syllabus.

Question 14

The incorrect option **C** and the correct option **D** accounted for the majority of responses to this question. This suggests that candidates were largely successful in setting up an equation based on the principle of moments for the beam in equilibrium. Those candidates whose moment expressions were based incorrectly on the mass × distance to the pivot (as opposed to the weight × distance to the pivot) chose option **C**. Candidates are reminded to pay attention to the units given in the question.

Question 19

Stronger candidates found this straightforward, with the majority selecting the correct option **C**. Amongst weaker candidates, options **B** and **D** were common choices. These candidates are not confident with the definition of work as force × distance moved **in the direction of the force**.

Question 23

Stronger candidates found this straightforward and correctly selected option **B**. Weaker candidates typically selected option **A**, recognising that the area under a force-extension curve is equal to the work done, but not realising that the question asked for the shaded area only. The difference between the area under the stretching curve and the area under the contraction curve must represent an energy loss, and the cord starts and ends with no elastic potential energy, so the correct answer must be option **B**.

Question 26

The correct option **C** was chosen by a little under half of candidates. Candidates can determine the period of the wave (1 / 15 = 0.067 s) and then determine the number of complete cycles in 0.5 s (0.5 / 0.067 = 7.5 cycles). Many candidates then multiplied this by 8.0 mm to get a total distance of 60 mm (option **B**) not realising that the particle travels 4 × amplitude in a single oscillation. Some candidates instead determined the wave speed (15 × 0.12 = 1.8 m s^{-1}) and then determined the distance travelled by a wavefront in 0.5 s (1.8 × 0.5 = 0.90 m) rather than particle P and so selected option **D**.

Question 27

Whilst most candidates correctly selected option **C**, a significant minority chose option **D**. Candidates commonly confuse period and wavelength in graphical representations of waves, and this should be practiced frequently. Candidates are reminded to check the axes on the graphs presented, as this can be an easy way to check the units of a measured distance on a graph, and so determine the quantity.

Question 33

This question proved challenging. All four options were selected frequently suggesting that many candidates were guessing. Even amongst the strongest candidates only half correctly selected option **A**. Candidates could solve this problem by combining their knowledge of the IV characteristics of fixed resistors and diodes. In series the current will be the same in both components, so no current will be present until the threshold voltage of the diode is reached.

Candidates could improve by constructing circuits or practicing problems involving combinations of components beyond resistors, thermistors and LDRs.

Question 34

This question was challenging with half of the candidates selecting the incorrect option **D**. Stronger candidates were able to determine the new power using power = work done / time (45.0 / 2.25 = 20W). They could then use power is proportional to (p.d.)^2 as the resistance is constant to determine the new p.d. using 20 / 5 = new (p.d.)^2 / V^2.

Many candidates correctly determined the ratio of power after and before the change to be 4:1 and so selected option **D**, forgetting that this is the ratio of the potential differences squared.

Question 35

The strongest candidates correctly identified that for this null method the current I_2 had to be zero. Many candidates selected options **C** and **D**, suggesting that null methods are not well understood. Candidates would benefit from practical experience of constructing circuits to demonstrate null methods.

Question 38

This factual recall question was answered correctly by fewer than half of candidates. Options **A**, **C** and **D** were selected roughly equally suggesting that candidates do not have a sufficient knowledge of these key quantities. A significant minority of candidates believed that the rest mass of a beta-particle is zero (option **A**).

Candidates should be able to recall the masses and charges of protons, neutrons and electrons.

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Paper 9702/21
AS Level Structured Questions 21

Key messages

- Candidates should pay attention to the instructions given in the question, particularly in explanatory questions. If the question asks candidates to refer to a particular physical quantity, then not doing so is unlikely to lead to full credit. Candidates should also be careful not to contradict statements given in the question stem. For example, if intensity is stated to remain constant, then candidates who state that it changes and rely on this in an explanation will not be awarded full credit.

- Candidates should avoid rounding intermediate answers in a numerical calculation as this can lead to an incorrect final answer. Candidates should keep intermediate values in their calculators or record them to several more significant figures than the final answer. Only once the final answer has been calculated should this value be rounded to an appropriate number of significant figures.

- 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 rearranged. In some questions, credit can be awarded for correct statements of physical equations, but only where the whole equation is clearly known. Candidate should not rely on the examiner to infer a subject for an expression given in the working.

- Candidates should pay attention to the units in which information is presented and take note of any SI prefixes.

General comments

The definitions of basic physical quantities within the syllabus were often not well known. Even where candidates' responses indicated that they recognised the correct quantity, the definition given often needed to be given with more precision to gain credit.

Many candidates could improve by showing more working to support their answers to numerical questions and presenting it more clearly. Correct working, where present, allows marks to be awarded for good methods even where errors then occur.

A significant number of candidates omitted large parts of the paper.

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

Comments on specific questions

Question 1

(a) The definition of density was generally well known, but some weaker candidates confused density with weight or mass.

(b) (i) Stronger candidates found the calculation of the density straightforward. Errors in converting the dimensions of the block from cm to m were common. Amongst weaker candidates, this proved challenging with many adding the three given lengths, indicating that calculation of the volume of a cuboid is not well known. Many candidates correctly defined density in **(a)** but were not able to calculate density in **(b)(i)**, and vice versa.

(ii) This was a challenging question for many candidates. Only stronger candidates were able to calculate the percentage uncertainty in the density by addition of the percentage uncertainties in the given quantities. Many candidates were unable to calculate the percentage uncertainty in any of the individual quantities, suggesting that the concept of percentage uncertainty is not well understood. A significant number of candidates attempted to add the absolute uncertainties in all four quantities.

(c) Stronger candidates correctly identified a systematic error that could be present in this experiment. Weaker candidates often gave responses such as 'parallax' or 'human error', confusing random and systematic errors.

Question 2

(a) There were a wide range of answers to this question. Candidates are reminded to learn the definitions of quantities used in the syllabus. Candidates are also reminded to be precise in their language when describing mathematical relationships. Phrases such as 'mass into velocity' and 'mass by velocity' are ambiguous, whereas 'the product of mass and velocity' or 'mass multiplied by velocity' are clear.

(b) (i) This question required candidates to read a value of momentum from the diagram and then divide this by the given mass, which many candidates were able to do successfully. Several candidates simply gave the maximum momentum instead. Candidates are reminded to carefully read the labels on the axes of the graphs given in the question paper.

(ii) This question was generally well answered, and candidates were often able to receive full credit here using their value of velocity from **(b)(i)**.

(iii) This 'show that' question could be approached in many ways. The most popular methods were to calculate a velocity at time t = 4.0 s and from there determine acceleration using $a = \Delta v / t$, or to find the resultant force acting at t = 4.0 s and calculate acceleration using $F = ma$. Many candidates' working was poorly presented in this question, making it difficult to follow the reasoning. It is especially important in 'show that' questions that the quantities being calculated are identified, as it is the physical reasoning, rather than the answer, that is being assessed in these questions.

(iv) Stronger candidates were able to calculate the correct distance by separately determining the distances travelled between t = 0 and t = 8.0 s and between t = 8.0 s and t = 12 s. Weaker candidates attempted to calculate a distance assuming the car was accelerating constantly over the whole 12 s period. Candidates who assumed that the speed was constant throughout were unable to be given credit.

(c) This question was difficult for the majority of the candidates, suggesting that candidates found it difficult to relate the gradient of the momentum–time graph to acceleration.

Question 3

(a) This definition was not well known. Many candidates spoke vaguely about an amount of energy or an amount of force. Stronger candidates were able to describe the product of force and distance, but very few correctly described the product of force and displacement *in the direction* of the force.

(b) This question required candidates to derive the formula for gravitational potential energy. Most candidates simply stated the formula from memory. A significant number did follow the instruction to state the meaning of symbols, but many described g as simply 'gravity' rather than the acceleration of free fall or the gravitational field strength, which prevented some candidates from receiving credit for identifying the weight as mg. Very few candidates explicitly linked the concept of work done by the weight to the change in gravitational potential energy.

(c) (i) This was generally well answered, though was often omitted by the weaker candidates.

(ii) This was also generally well answered, though was often omitted by the weaker candidates.

(iii) This was well answered by most candidates. Weaker candidates often omitted this question. Although the question asked for efficiency, most candidates gave their answer as a percentage efficiency with a percentage symbol, which was acceptable for full credit.

(iv) This question was answered correctly by many candidates. Some of the weaker candidates found it difficult to connect a power equation to the resistivity equation. However, many candidates who were not successful in earlier parts of **(c)** were able to gain full credit on this question.

Question 4

(a) Of all the definitions questions in the paper, this one was answered correctly most often. A few candidates confused Young modulus with tensile strength.

(b) (i) Most candidates correctly drew a straight line through the origin. Candidates are reminded of the importance of using a ruler to draw straight lines on diagrams. A few candidates ignored that the wire was stretched within its limit of proportionality and drew a line with a non-proportional region at the end. This could not be given credit.

(ii) Some candidates correctly identified the gradient of a force–extension graph as the spring constant. A significant number confused the graph with a stress–strain graph and so gave their answer as Young modulus. There were also a number of answers of stress, strain or elastic potential energy, suggesting that these graphs are not well understood.

(iii) A correct answer here generally correlated with a correct answer to **(b)(ii)**. There were again a number of answers suggesting stress, strain or Young modulus. Some candidates said 'work done' but did not specify that it was the work done on (or by) the wire and so this was not credited.

(c) This was a difficult question. Many candidates were able to identify the effect of one of the differences between wires P and Q on the extension, but very few candidates were able to correctly account for the overall effect of all of the differences. Many candidates were also able to qualitatively state that the extension of Q would be less than that of P, but did not give a quantitative answer using the given quantitative information.

Candidates who attempted to discuss this problem using stress and strain generally were able to perform better than those who attempted to make use of $E = FL / Ax$.

Question 5

(a) (i) This was straightforward for most candidates. A common error was to neglect the minus sign on S. Several candidates gave incorrect answers where $P + R = 40$ and $Q + S = 19$, showing that the conservation of nucleon number and proton number was generally understood, even though the nature of β^- decay was not.

(ii) This was not generally well answered, with only a minority of candidates correctly identifying Z as an antineutrino.

(iii) Many candidates were able to identify the particles as leptons. The answers to **(a)(ii)** showed that candidates often did not know that Z was an antineutrino, but they were at least confident in identifying the β^- particle as a lepton.

(b) Many candidates could identify the nucleon composition of an alpha particle and the quark composition of both protons and neutrons, and so arrived at the correct answer. Very few candidates made arithmetic mistakes in determining the total number of each type of quark. A number of candidates misunderstood the question and gave answers in terms of charge. Candidates are reminded that the quarks are named 'up' and 'down', and these are better answers than using shorthand such as '↑' and '↓'.

Question 6

(a) (i) This was another challenging question. Many candidates recognised that the 90° phase difference of the waves at the source was significant, but very few were able to state clearly that this led to a 90° phase difference *at point O*. Most responses tended to be vague, and few candidates explained that the greatest intensity would occur at a point where the waves were in phase. Many weaker candidates offered general descriptions of interference, or suggested that interference would either not occur at O, or else would be totally destructive.

(ii) Many candidates correctly located point B on the line below O, and a similar number correctly located it the same distance from O as OA. A common error was to place B at the same point as O, suggesting that O was assumed to be a point of minimum intensity.

(b) (i) The very weakest candidates tended to omit this question entirely. It was well answered by most other candidates.

(ii) This was difficult for many candidates. It was common for candidates of all abilities to omit this question. Many who attempted to solve it tried to make use of the double slit formula, rather than considering the path difference as a quarter of the wavelength determined in **(b)(i)**.

(iii) This question was also often omitted by the weaker candidates. Those who attempted it usually followed the instruction to use the double slit formula and were able to obtain the correct answer, though a significant number incorrectly used the diffraction grating equation with an angle of 90°.

Question 7

(a) (i) Nearly all candidates gave an answer of 0.50 A, but somewhat fewer gave a valid set of working to justify that answer. Candidates are reminded that, in ‘show that’ questions, the answer must be shown, but that it is the working that is being assessed. Many candidates were able to use the e.m.f. and the terminal p.d. to calculate a value for ‘lost volts’ that could be then used with the internal resistance to calculate the correct current.

Some candidates attempted to calculate the external resistance in the circuit, setting up correct equations in terms of the unknown *R*, but could not make further progress.

(ii) This question was generally straightforward. Some candidates incorrectly added the internal resistance to the resistance of 1.0 Ω.

(iii) This question was generally well answered.

(b) (i) Most candidates correctly drew two resistors connected in parallel. A small number of candidates drew the resistors in series but located on wires running vertically on the page rather than horizontally. Many candidates’ diagrams could have been improved by careful drawing, with small gaps between components and wires being common. Candidates are reminded that accuracy in the drawing of diagrams is as important as accuracy in presenting calculations.

(ii) The majority of the candidates recognised that the terminal p.d. would be less. Many also realised that the parallel combination of resistors would give a lower resistance than the series combination. It was much less common for candidates to link these two facts by considering the effect on the current in the cell and the effect on the p.d. across the internal resistance. Many candidates stated that the p.d. was proportional to the resistance, without considering that the current is not constant when the external resistance is changed.

PHYSICS

Paper 9702/22
AS Level Structured Questions 22

Key messages

- Candidates should pay attention to the instructions given in the question, particularly in explanatory questions. If the question asks candidates to refer to a particular physical quantity, then not doing so is unlikely to lead to full credit. Candidates should also be careful not to contradict statements given in the question stem. For example, if intensity is stated to remain constant, then candidates who state that it changes and rely on this in an explanation will not be awarded full credit.

- Candidates should avoid rounding intermediate answers in a numerical calculation as this can lead to an incorrect final answer. Candidates should keep intermediate values in their calculators or record them to several more significant figures than the final answer. Only once the final answer has been calculated should this value be rounded to an appropriate number of significant figures.

- 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 rearranged. In some questions, credit can be awarded for correct statements of physical equations, but only where the whole equation is clearly known. Candidate should not rely on the examiner to infer a subject for an expression given in the working.

- Candidates should pay attention to the units in which information is presented and take note of any SI prefixes.

General comments

Most candidates answered questions involving the recall and use of formulae well. Definitions were well known by most candidates, but candidates who were not awarded full credit often either missed out key words or used wording which changed the meaning of the definition.

Many candidates could improve by showing more working to support their answers to numerical questions and presenting it more clearly. Correct working, where present, allows marks to be awarded for good methods even where errors then occur.

A significant number of weaker candidates omitted large parts of **Question 5**, suggesting that the analysis of circuits was not well understood.

There were several questions on the paper that required candidates to draw on diagrams provided. A significant number did not use a ruler to help them draw straight lines, making it difficult to judge if the line was intended to be straight. Candidates should be aware that accuracy in drawing diagrams is as important as accuracy in calculations or in written answers.

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

Comments on specific questions

Question 1

(a) The definition given for a vector quantity was usually good.

(b) (i) Most candidates knew the SI base units for force, radius and velocity. Occasionally, candidates gave the unit of force as N, confusing an SI unit with an SI base unit. Some candidates gave the units of v as m^3, confusing velocity with volume. Weaker candidates sometimes gave the units of D as kg m^{-3}, incorrectly assuming that D represented density. Arithmetic errors were common especially when dealing with seconds, leading to kg m^{-1} s^{-3}.

(ii) Stronger candidates were able to correctly account for the directions of the three forces and so gave a valid equation. Weaker candidates often got the sign of one of the forces incorrect. Some stronger candidates tried to include a resultant force term, but rarely made clear that the resultant force was equal to zero as the sphere was moving with terminal velocity, and so could not be awarded credit.

(iii) Many candidates correctly applied the upthrust formula and formula for the volume of a sphere. Power-of-ten errors in converting the radius to m were common, but could be awarded credit on the principle of error carried forward. A large number of candidates did not connect the weight of the sphere to the equation in **(ii)** and so simply stated the weight of the sphere as equal to the weight of the displaced liquid. Some candidates incorrectly equated the upthrust to the drag force, and tried to determine a new volume or density for the sphere.

Question 2

(a) Most candidates recalled the definition of momentum, and most candidates correctly described a product of mass and velocity rather than giving the vague answer 'mass into velocity'. Weaker candidates sometimes confused moment and momentum, or described ways to calculate an impulse such as 'force times time'.

(b) This was generally well answered, with candidates using either $F = \Delta p / t$ or finding acceleration and then using $F = ma$. Those candidates who first found acceleration were more prone to rounding their acceleration before finding the force, leading to a common incorrect answer of 8.6 N. Candidates are reminded that they should keep intermediate values in their calculator, or write them down to several more significant figures than their intended final answer, to avoid early rounding errors.

(c) This straightforward question was answered well by most candidates. Common errors included assuming that the initial velocity at A was 0, or neglecting to square the second time term in $s = ut + ½at^2$. Very weak candidates sometimes calculated the distance by using the wrong equation of 'initial speed × time'.

(d) (i) This was straightforward for most candidates.

(ii) There were a wide variety of lines drawn on the graph. Only the strongest candidates were awarded full credit, with a majority of candidates assuming that the kinetic energy began at 0, and neglecting the speed given at A in the question. Candidates are reminded to carefully read the axes on printed graphs and to consider this information in the context of the question.

Many candidates drew curved lines between distance = 0 and distance = x, perhaps confusing a speed against distance graph with an energy against distance graph. Many candidates also drew a line with a negative gradient from distance = x to distance = x + 18 m, neglecting that the question states that the velocity is constant over this distance. For those candidates who attempted to draw a horizontal line over this range, the lines were frequently freehand and very wobbly. Candidates are reminded to make use of a ruler when drawing straight lines on graphs.

Question 3

(a) (i) Nearly all candidates correctly stated E = stress / strain and so could be awarded at least partial credit.

A small number of candidates jumped straight to a substitution without stating the equation they were using. It was not always clear that these candidates were using a stress divided by a strain, and so partial credit could not always be awarded. Candidates are reminded to state the equations they are using before making a substitution.

Power-of-ten errors were very common in this question, especially in reading the percentage strain from the graph. Many candidates used 1.0 for the strain instead of 0.01 and arrived at an answer of 2.4×10^8 Pa. Another common error was to use the stress and strain at E, rather than a pair of values from the linear region.

(ii) Many candidates correctly placed Q at 1.0% strain. Some candidates found it difficult to locate the end of the linear region of the graph and placed Q at slightly higher values of strain. Stronger candidates often made use of a ruler and extrapolated the straight line region, making the location of Q easy to identify at the point where their straight line and the printed line diverged.

Weaker candidates sometimes confused the limit of proportionality with the ultimate tensile stress, or possibly with a failure point and so located Q beyond E on the diagram.

(b) Most candidates correctly recalled one of the conditions for equilibrium, with the stronger candidates recalling both. The most common error was for candidates to describe force or moment being zero, without referring to the *resultant* force or moment.

Occasionally candidates confused moment and momentum. Many weaker candidates also referred to a constant acceleration or velocity, or stated that an object must be stationary. As these conditions may be true but are not necessary, these references were ignored.

(c) (i) This question proved challenging, with only the strongest candidates receiving full credit. Many candidates were able to give an expression for a single correct moment. It was common for candidates to correctly determine the distance of one of the forces from point A, but then incorrectly determine the distance for one of the other forces, resulting in very few correct moment equations. Other common errors included neglecting the moment of one of the forces entirely or forgetting to include the distance of T from the pivot.

(ii) This was generally well answered with error carried forward from **(i)**. Most candidates explicitly stated stress = force / area and so could receive some credit even in the case of subsequent errors. Some weaker candidates gave the area as their final answer for the radius, or attempted to use an incorrect area formula such as the area of a sphere or a cylinder, but this was rare.

(iii) Candidates found this question difficult. Some candidates were able to identify that the stress (or more rarely strain) remained relatively small, but the majority of candidates compared this stress to the limit of proportionality rather than the elastic limit. The difference between the elastic limit and the limit of proportionality was clearly not well understood.

Many weaker candidates incorrectly stated that the elastic limit or limit of proportionality had already been exceeded in the initial situation in **(c)**, demonstrating that they did not understand what is being shown in Fig. 3.1. Another common misconception amongst weaker candidates was that doubling the stress would cause the Young modulus to double.

Question 4

(a) There were many very good, concise responses to this question. Candidates who read the question carefully and made use of the terminology presented typically found this straightforward.

Many responses were vague, especially in their description of directions. Candidates frequently referenced ‘the wave’ or ‘the direction of the wave’ or ‘the direction of motion’ or ‘the direction of propagation of the wave’. These ambiguous responses were not credited as the question specifically asked for candidates to refer to ‘the direction of transfer of energy’.

Candidates often compared the direction of transfer of energy with the direction of propagation, perhaps confusing propagation and oscillation.

Some weaker candidates did not mention oscillations at all, and gave meaningless responses such as ‘the wave travels parallel to the energy’ or ‘the wave moves perpendicular to the wave’.

(b) (i) Most candidates correctly located an antinode at the open end of the pipe.

(ii) Nearly all candidates stated $v = f\lambda$. Stronger candidates correctly determined the wavelength and found this straightforward. The most common error was to use the length of the pipe of 4.5 cm as the wavelength. Some candidates used double the length as the wavelength, perhaps treating the pipe as having two open ends.

Some candidates jumped straight into a substitution using 4.5 cm, without first stating the wave equation. Typically this meant that they could not be awarded credit, as using the length of 4.5 cm did not imply a wavelength.

A significant minority attempted to use the Doppler effect equation, confusing the new position of the piston with a constantly moving source.

(iii) This question was generally well answered by stronger candidates. It was challenging to explain the causality of the changes to frequency and wavelength correctly, but the connection between a lower frequency and a longer wavelength or a longer node–antinode distance was usually made correctly. Weaker candidates frequently appeared to guess at the answer and made little effort to justify their choice.

Question 5

(a) This was the least well answered of the three definition questions on this paper. Candidates frequently gave ambiguous or incorrect responses that did not make clear that potential difference is a ratio between energy transferred and charge. Common incorrect answers included ‘energy transferred by a charge’ or ‘energy transferred when unit charge passes’. Both of these definitions describe an energy rather than a ratio between energy and charge and so are not correct.

It was also common for candidates to include units, which are not required in the definition of physical quantities and may prevent a candidate from giving a correct answer. ‘Work done per coulomb’, for example, cannot be awarded credit as it is a mixture of quantities and units.

A few candidates confused the definition of electromotive force and potential difference.

Very weak candidates often stated ‘current × resistance’ which is an equation for calculating electric potential difference and does not define it.

(b) (i) This was a straightforward question for those candidates who had learned the circuit symbols. The most common incorrect answers were ‘variable resistor’ and ‘thermistor’.

(ii) This was a straightforward question for nearly all candidates.

(iii) Stronger candidates found this easy. Many candidates attempted to calculate I_2, but ignored the 6.0 V potential difference across the 0.86 Ω resistor despite having just shown this quantity in **(ii)**.

Weaker candidates often used the 6.0 V and divided by the 2.4 Ω resistance to get a current of 2.5 A. This approach uses wrong physics and could not be awarded credit, and frequently this same misconception meant that few marks could be awarded in **(iv)**. Candidates are encouraged to annotate the electrical circuit with the known or calculated quantities to help them keep track of the different potential differences and currents throughout the circuit.

Some candidates attempted to determine the parallel combination of resistances. This was difficult due to the unknown resistance of X and only the very strongest candidates made progress with this method.

(iv) Stronger candidates were able to use their current from **(iii)** to determine the pd across X. Many candidates again did not account for the 6.0 V potential difference across the 0.86 Ω resistor and so could not correctly determine the potential difference across X. Very weak candidates often calculated the potential difference across the 2.4 Ω resistor instead of across component X. Some candidates attempted to use the parallel combination of resistances, or carried through a value of the resistance of X from **(iii)**. Again, only the strongest candidates were successful.

(v) Most candidates could be awarded credit for a correct power equation, and many were able to use their values of current and potential difference from **(iii)** and **(iv)** to gain credit for power with an error (or two) carried forward. Candidates who used a resistance calculated while answering previous questions often did not show how that resistance was calculated in this question. As the resistance of X was not required in either **(iii)** or **(iv)**, it was often unclear how candidates had found the value.

(vi) Very few candidates gave a fully correct equation for the efficiency of the circuit. Many stated a truncated formula such as 'out / in' without being explicit that they meant the **useful power** out and **total power** in. Candidates are reminded to be careful and precise in presenting their work. Some candidates incorrectly inverted the equation, or gave statements that would evaluate to 100% if taken at face value.

Many candidates received partial credit by implication from a correct substitution, and many who had found earlier parts of the question difficult were still awarded full credit here with error carried forward.

A common error was to assume that current was the same in X as in the power source and so the efficiency was (p.d. in X) / 230 V.

Nearly all candidates gave the final answer as a percentage.

(vii) No reasoning was required for this question, so most candidates gave a one-word answer, which was either correct or incorrect. Those candidates that did give reasons often demonstrated misconceptions that the current must always remain the same based on incorrect application of Kirchhoff's first law, or that the total resistance would decrease due to the removal of the 170 Ω resistor, and so the current must increase.

Question 6

(a) This was challenging for many candidates. Many candidates gave the nuclear notation for alpha- and beta-plus particles, but did not explain what this represented. Some candidates did go on to explain the number of nucleons and protons in an alpha particle, but did not relate this explicitly to mass or charge. It was very common for weaker candidates to incorrectly state that a beta-plus particle was a proton.

Candidates often correctly stated that the mass of the alpha particle was greater than that of the beta-plus particle, but very few stated that it was *much* greater or attempted to quantify the difference. A large number of stronger candidates went on to correctly give the masses of both the alpha and beta particles, usually in terms of u. A large number of candidates correctly gave the mass of the alpha particle, but then incorrectly stated that the mass of the beta particle was zero, suggesting a confusion between the nucleon number of a beta particle and its actual mass.

Many candidates correctly identified the magnitudes of the charges of both particles, usually by explicitly stating them in terms of e. Candidates who gave the charges explicitly as $+1e$ and $+2e$ were also credited with identifying both charges as being positive. Some weaker candidates did not make clear that both charges were positive.

(b) (i) This question was generally well answered. A common incorrect answer was to locate Q at (86, 220), implying an alpha particle had been absorbed by P. It was also common for very weak candidates to locate Q half-way between P and R at (83.5, 214), suggesting that these candidates did not have a good grasp of nuclear concepts.

(ii) This was straightforward for many candidates. Weaker candidates confused beta-plus and beta-minus decay. Many also included an alpha particle, suggesting that they had not carefully read the question.

Candidates should be reminded to be careful with their terminology, as many gave the ambiguous particle 'anti-electron neutrino'. An electron antineutrino is correct, but an anti-electron is a positron.

(c) (i) This question proved to be difficult for most candidates. The strongest candidates were able to form a correct conservation of momentum equation for the components of momentum perpendicular to the original path of P. Candidates in the middle of the ability range were often confused by the directions and tried to form an equation for the components parallel to the original path of P. Typically these candidates assumed incorrectly that the initial velocity of P was zero and so could make no progress.

Many candidates started with a symbol formula for conservation of momentum such as $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$, but then jumped to a substitution that entirely neglected any masses, and so worked exclusively in terms of velocity.

(ii) Nearly all candidates correctly gave an expression for kinetic energy. Weaker candidates typically did not convert the mass of the alpha particle into kg, or used the mass of another particle. It was common also for candidates to forget to square the velocity.

PHYSICS

Paper 9702/23
AS Level Structured Questions 23

Key messages

- Candidates should pay attention to the instructions given in the question, particularly in explanatory questions. If the question asks candidates to refer to a particular physical quantity, then not doing so is unlikely to lead to full credit. Candidates should also be careful not to contradict statements given in the question stem. For example, if intensity is stated to remain constant, then candidates who state that it changes and rely on this in an explanation will not be awarded full credit.

- Candidates should avoid rounding intermediate answers in a numerical calculation as this can lead to an incorrect final answer. Candidates should keep intermediate values in their calculators or record them to several more significant figures than the final answer. Only once the final answer has been calculated should this value be rounded to an appropriate number of significant figures.

- 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 rearranged. In some questions, credit can be awarded for correct statements of physical equations, but only where the whole equation is clearly known. Candidate should not rely on the examiner to infer a subject for an expression given in the working.

- Candidates should pay attention to the units in which information is presented and take note of any SI prefixes.

General comments

Most candidates answered questions involving the recall and use of formulae well. Definitions were well known by most, but many weaker candidates either missed out key words or used wording which changed the meaning of the definition.

In **Question 3(b)(ii)** and **Question 5(b)(i)**, many candidates used the formula given on the question paper but a significant number substituted inappropriate values from the data provided. Practice selecting the relevant data to use with the given formula is essential.

There was no evidence that candidates were short of time on this paper.

Comments on specific questions

Question 1

There were many candidates who were unable to determine correct answers to this question as they seemed to be unaware that the motion of the parcel could be treated as constant acceleration in the vertical direction and constant speed in the horizontal direction.

(a) The majority of the candidates gave the correct definition of velocity. A few candidates gave just 'velocity over time' rather than 'change in velocity over time' and so could not be given credit. Some gave 'the rate of change of velocity per unit time' which is a rate of a rate and so also incorrect.

(b) (i) Only the strongest candidates started the line horizontally from the base of the aircraft to indicate that the parcel started with zero vertical velocity. Many candidates gave a parabola with a vertical final section even though the question stated that there was no air resistance. There were many straight diagonal and vertical lines indicating a lack of understanding of two-dimensional motion. There were many other lines drawn from incorrect starting points such as the propeller of the aircraft or lines that started with too steep an angle.

(ii) The majority of the candidates used the concept that the vertical motion was at constant acceleration due to free fall and correctly obtained the time for the parcel to reach the ground. A significant number ignored the vertical acceleration and used speed = distance / time, combining the horizontal speed with the vertical distance.

(iii) The majority of the candidates used an equation of constant acceleration to determine the vertical component of velocity. A significant number of candidates again attempted to obtain a value for the final vertical velocity assuming no acceleration in the vertical direction.

(iv) This question was only answered well by the more able candidates. A significant number obtained the correct value by combining the horizontal and vertical components of velocity. There were many candidates that did not realise that the final vertical and horizontal components of velocity needed to be combined to obtain the speed of the parcel.

Question 2

(a) The majority of candidates were able to give the idea of conservation of the total momentum. A smaller number gave the correct condition that the conservation applies to an isolated system or where there is no resultant external force. A significant number omitted the concept of the 'sum of' or 'total' initial and final momentum.

(b)(i) This was very well done and generally well presented by the majority of the candidates.

(ii) The majority of the candidates calculated the change in kinetic energy. A small minority did not convert the mass values given into kilograms. A small number calculated the total kinetic energy of the two masses instead of the change in kinetic energy.

(c)(i) The stronger candidates calculated the rate of change of momentum of ball X to determine the force on ball X. A significant number used the kinetic energy change incorrectly. A common error was to forget to convert the time given in ms into seconds. There were a number of ambiguous answers given for the direction, such as 'forwards' or 'east', and a significant number of candidates thought that the force acted to the left.

(ii) This question was answered well by the majority of the candidates. A small number of candidates stated that the force would increase because of the larger mass of ball Y.

Question 3

(a) A significant number of candidates omitted the concept of 'total' or 'sum of' the moments. A common error was to give the definition of the moment of a force rather than to state the principle of moments. Candidates are reminded to read the question carefully.

(b)(i) The majority of the candidates gave at least one correct moment for the three forces acting. A small number gave an answer using the values of the forces given in the question rather than using the principle of moments.

(ii) The majority of the candidates calculated the area of the cylinder using the equation upthrust = ρgV. A small number used an incorrect value for the upthrust or were unable to link a calculated volume to the cross-sectional area of the cylinder. A small number considered the volume to be that of a sphere.

(c) This was a challenging question for many candidates. The majority drew a line starting from the point (0.10, 0.40) given as the starting point in the question. The strongest candidates gave a straight line with negative gradient ending with the correct h value. Many candidates appeared not to fully understand the physics of the situation (as the water was added, the upthrust increased and a smaller moment was required from the load to achieve equilibrium, therefore x decreased). There were many straight lines with positive gradient, curves or lines that ended outside the possible range for *h*.

Question 4

(a) (i) Many candidates were not specific and did not state that the force needed to be applied on the *cross-sectional* area.

(ii) The majority of the candidates gave the definition of strain. A significant number omitted ‘original’ from ‘original length’, giving only ‘extension over length’ which was not acceptable. There were alternatives given for extension that were ambiguous such as ‘extension length’ which were also not accepted. A small number gave the definitions for stress and strain the opposite way round. Candidates are reminded to learn the definitions of key quantities within the syllabus.

(b) (i) Most candidates started with the equation for Young modulus. Many candidates used the full load for the force causing the extension of wire X, instead of only half the value of the load. A small number of candidates did not convert the extension given in mm into m.

(ii) Most candidates explained that the cross-sectional area of wire Y would be larger and then concluded that this meant a lower Young modulus for wire Y. Only the strongest candidates stated that the force, extension and original length were the same for both wires to justify their conclusion of a lower Young modulus for Y. A common response was for candidates to state that the Young modulus was inversely proportional to the cross-sectional area. This was not sufficient as an explanation. A number of candidates stated that ‘other factors’ remained constant in addition to the Young modulus being inversely proportional to the cross-sectional area, but this again was not specific enough to be awarded credit for the reasoning.

Question 5

(a) (i) The majority of the candidates knew the correct location for a node and an antinode. Some candidates drew their crosses clearly away from the line of the stationary wave. A few candidates gave no labels to their crosses or reversed the positions of the antinode and node.

(ii) The majority of the candidates recognised that the stationary wave showed one and a half wavelengths.

(iii) The majority of the candidates correctly calculated the frequency. A significant number could not recall the wave equation correctly, or substituted an incorrect velocity or wavelength.

(b) (i) Most candidates were able to calculate the frequency using the Doppler equation given on the data page of the question paper. A significant number calculated the minimum frequency instead of the maximum frequency. It was clear that many weaker candidates did not know what the symbols in the given equation represented.

(ii) The very strongest candidates gave a frequency variation that started at the source frequency then continuously decreased to a minimum as the source moved away and continuously increased to a maximum as it approached the observer, before returning to the source frequency as the source returned.

Most candidates gave a steady decrease in the frequency to a minimum and no increase to a maximum as the source approached the observer. The majority drew graphs that showed a variation for half a rotation only and many were an incorrect shape.

Question 6

(a) The majority of the candidates gave the correct definition of resistance. A common error was to give a definition that involved units such as ‘volt per current’ or ‘volt per ampere’, which could not be given credit. Candidates are reminded that definitions of quantities should be given in terms of other quantities.

(b) (i) Most candidates were able to correctly determine the value for the resistivity.

(ii) The majority of the candidates correctly determined the value for the charge. A common error was to forget to convert the time from minutes to seconds.

(iii) This was challenging for many candidates. The most common error was to use the charge calculated in **(ii)** instead of the elementary charge *e*. A small number forgot to convert the speed from mm s^{-1} to m s^{-1}.

(c) (i) Many candidates could not give the correct symbol for a thermistor. A small number gave the correct symbol for the thermistor, but omitted the fixed resistor.

(ii) Stronger candidates gave a clear reasoning for the power increasing in the fixed resistor. Candidates often stated that 'the resistance' would decrease but it was not clear whether this meant the resistance of the thermistor or the fixed resistor or the total resistance of the circuit. Many candidates stated correctly stated that the current increased in the circuit but then concluded that the power in the fixed resistor decreased because the resistance had decreased.

Candidates' responses indicated that they were often describing the changes to power dissipated in other components of the circuit. Candidates are reminded to carefully read the question in order to ensure that their answers are relevant.

Question 7

(a) This was straightforward for the majority of the candidates. Some candidates did not know the charges on quarks, especially the strange quark.

(b) (i) This question was well answered by the majority of the candidates. The spelling of 'hadron' by a number of candidates was often such that it was difficult to recognise. A common incorrect answer was lepton.

(ii) This question was well answered by many candidates. It was common for some answers to lack sufficient clarity, such as 'the meson consists of two quarks' and 'baryons consist of three quarks and three antiquarks'. Candidates are reminded to be precise in their descriptions.

(c) There were very few complete answers to this question. As the question asks for a description, the names of the fundamental particles involved in β^+ decay were required, rather than just their symbols. Many candidates gave answers that involved protons and neutrons, but did not mention the fundamental particles and so could not be given credit. The positron was rarely named as a fundamental particle emitted with a neutrino.

PHYSICS

Paper 9702/31
Advanced Practical Skills 31

Key messages

- If a raw value is out of trend to that expected, candidates should be encouraged to check the readings again with the equipment provided in the early stages of data collection.
- Candidates should consider carefully whether it would be advantageous to repeat their measurements.
- In the table work, the number of significant figures in the calculated quantity should relate to the number of significant figures in the raw data with the least number of significant figures. Each calculated quantity should be checked row by row. It is unnecessary, and often incorrect, to force the number of significant figures to be constant down a column of calculated values.
- When justifying a number of significant figures in a calculated quantity, candidates should relate the number of significant figures in the quantity to the raw readings used in the calculation. Candidates should not use the phrase 'raw readings' without explaining what those readings are, or attempt to use intermediate calculated quantities to justify the number of significant figures.
- To be successful answering **Question 2**, candidates should be reminded that their identified limitations and suggestions for improvement must be focused on the particular experiment being carried out. General points such as 'measurements were difficult' or 'use more precise measuring instruments' will not usually gain credit without further detail.

General comments

Most centres did not have difficulties in providing the equipment requested. Any deviation between the requested equipment and that provided to the candidates should be written down in the supervisor's report, and this report must be sent with the scripts to Cambridge so that the examiners can take this into consideration when marking. No additional equipment should be available to the candidates. In some cases, this may disadvantage candidates.

Any help given to a candidate should be noted on the supervisor's report. Supervisors are reminded that help should **not** be given with the recording of results, graphical work or analysis.

The general standard of the work done by the candidates was good, and there were many excellent scripts. Candidates did not seem to be short of time and both questions were attempted by almost all the candidates. They demonstrated good skills in the generation and handling of data but can improve by giving more thought to the analysis and evaluation of experiments.

Comments on specific questions

Question 1

(a) Most candidates stated θ in the accepted range and with an appropriate unit. A small number of candidates stated a value of θ that was out of range, suggesting that they had either misread the protractor or not set up the apparatus correctly.

(b) Most candidates stated m in the accepted range, with an appropriate unit and to the correct precision.

(c) Most candidates correctly calculated *e*.

(d) Most candidates were able to collect six sets of values of *M* and θ without assistance from the supervisor and with the correct trend. Candidates are encouraged to check their results if any values are out of trend with the rest.

Many candidates did not extend their range of *M* low enough and/or high enough. Candidates are encouraged to use the whole range available to them.

Many candidates gave both the quantity and correct unit for each heading, separated by a solidus or with brackets around the unit. Candidates are encouraged to remember to include a separating mark between the quantity and unit. Some candidates gave the unit of sin θ as ° (degree) instead of leaving this calculated quantity without a unit.

Most candidates calculated values for sin θ correctly. Candidates are encouraged not to truncate the value without rounding.

Many candidates correctly stated their calculated values of sin θ based on the number of significant figures used for θ. Others gave too few or too many significant figures.

(e) (i) Many candidates plotted the correct graph and labelled the quantities, and used sensible and regular scales such that the data occupied over half the graph grid available. Plotting and reading of points is then an easy task to carry out. Awkward or irregular scales were often the reason for not awarding credit for the axes.

Many points were drawn as neat crosses such that the point centre was no more than half a square thick, and were plotted correctly so that the position is within half a small square in both the *x* and *y* directions. Common reasons for not awarding credit here were 'blobs' (points with diameter greater than half a small square) and points plotted more than half a square from the correct position.

(ii) Stronger candidates were able to draw a carefully considered line of best fit with a balanced distribution of points either side of the line along the entire length. Common reasons for not awarding this mark included lines needing a rotation or a shift to get a better fit and lines that were kinked (two or more smaller lines joined up).

If a point appears to be anomalous on the graph, candidates are encouraged to check their plotting first, then check their reading with the equipment available. If the candidate still has one anomalous point, they can identify this point as such by ringing it or stating the point as 'anomalous'.

(iii) Some candidates correctly used a large triangle to calculate the gradient, used correct read-offs and substituted into $\Delta y / \Delta x$ correctly. Stronger candidates read off from the graph at $x = 0$ or used a correct read off into $y = mx + c$ to find the *y*-intercept.

Common mistakes with the gradient were using too small a gradient triangle, substitution into $\Delta x / \Delta y$, values incorrectly read off and points used from the table which were not on the line of best fit. For the *y*-intercept, common mistakes were reading the *y*-intercept from the graph when there was a false origin and substitution into a wrongly arranged equation e.g. $c = y / mx$.

(f) Stronger candidates recognised that *P* and *Q* were equal to the gradient and the *y*-intercept respectively and stated correct units. Some candidates omitted units or used different units to those used in the experiment without any evidence of converting correctly. Candidates who inverted their axes on their graph (from the orientation requested in the question) generally did not go on to rearrange the equation to be consistent.

Question 2

(a) Most candidates measured values of *w* and *x* in the accepted range and with a correct unit.

(b) (i) Many candidates correctly stated *d* in the accepted range and to the same precision as the ruler. Some candidates incorrectly stated *d* to the nearest cm instead of mm, or their value was out of range.

(ii) Some candidates, having repeated their readings, correctly showed the uncertainty working as half the range and then went on to calculate the percentage uncertainty with the correct method. Others made a realistic estimate of the uncertainty in *d*, taking into account the difficult nature of this reading. Many candidates made too small an estimate of the absolute uncertainty in the value of *d*, typically 0.1 cm.

(c) Many candidates recorded a value of *T* in the accepted range and some candidates repeated their readings to gain maximum credit. Other candidates stated a period value that was out of range, either because they did not divide by the number of oscillations they were measuring or they read off from the stopwatch incorrectly.

(d) The majority of the candidates stated a second value of *d* and *T* with the second *T* smaller than the first value.

(e) (i) Most candidates were able to calculate *k* correctly. A minority rearranged the equation incorrectly.

(ii) Many candidates correctly justified the number of significant figures they had given for the value of *k* with reference to the number of significant figures used in *T* or time and *d*. Where candidates were not successful, it was often because their answers were insufficiently detailed, e.g. 'raw readings', 'previous measurements' or 'values used in calculation' without detailing the quantities involved.

(f) Some candidates calculated the percentage difference between their values of *k*, tested it against the stated 10% criterion and provided a valid statement. Some candidates omitted a percentage difference calculation, gave a different criterion e.g. 15% or 20%, or gave an invalid statement inconsistent with their findings.

(g) (i) Candidates need to identify problems associated with setting up and obtaining readings. They can do this by writing about the different measurements taken or chronologically going through the experiment systematically and identifying each difficulty. Candidates should then try think of solutions that address each problem.

Problems commonly awarded were 'two sets of data were not enough to draw a valid conclusion', 'difficult to measure *d* as ruler not horizontal and 'spring repeatedly rolled off the board'. Many candidates wasted options discussing the non-critical approximate measurements in the set-up and/or measurements that were not difficult.

(ii) Improvements that were commonly seen were 'take more readings and plot a graph' and 'use video with a timer in the shot'. A solution, like the problem, needs detail to gain credit. Candidates are encouraged to explain *how* a problem will be solved, detailing what additional equipment is necessary.

Credit is not given for suggested improvements that could have been carried out in the original experiment, e.g. 'repeat readings' or 'view the ruler at right angles'.

PHYSICS

Paper 9702/33
Advanced Practical Skills 33

Key messages

- If a raw value is out of trend to that expected, candidates should be encouraged to check the readings again with the equipment provided in the early stages of data collection.
- Candidates should consider carefully whether it would be advantageous to repeat their measurements.
- In the table work, the number of significant figures in the calculated quantity should relate to the number of significant figures in the raw data with the least number of significant figures. Each calculated quantity should be checked row by row. It is unnecessary, and often incorrect, to force the number of significant figures to be constant down a column of calculated values.
- When justifying a number of significant figures in a calculated quantity, candidates should relate the number of significant figures in the quantity to the raw readings used in the calculation. Candidates should not use the phrase 'raw readings' without explaining what those readings are, or attempt to use intermediate calculated quantities to justify the number of significant figures.
- To be successful answering **Question 2**, candidates should be reminded that their identified limitations and suggestions for improvement must be focused on the particular experiment being carried out. General points such as 'measurements were difficult' or 'use more precise measuring instruments' will not usually gain credit without further detail.

General comments

Most centres did not have difficulties in providing the equipment requested. Any deviation between the requested equipment and that provided to the candidates should be written down in the supervisor's report, and this report must be sent with the scripts to Cambridge so that the examiners can take this into consideration when marking. No additional equipment should be available to the candidates. In some cases, this may disadvantage candidates.

Any help given to a candidate should be noted on the supervisor's report. Supervisors are reminded that help should **not** be given with the recording of results, graphical work or analysis.

The general standard of the work done by the candidates was good, and there were many excellent scripts. Candidates did not seem to be short of time and both questions were attempted by almost all the candidates. They demonstrated good skills in the generation and handling of data but can improve by giving more thought to the analysis and evaluation of experiments.

Comments on specific questions

Question 1

(a) Most candidates stated *L* and *V* in the accepted range and with an appropriate unit. Some candidates stated a value of *V* that was out of range because they read the number as volts instead of millivolts, e.g. 404 V instead of 0.404 V or 404 mV.

(b) Most candidates were able to collect six sets of values of *L* and *V* without assistance from the supervisor and with the correct trend. Candidates are encouraged to check their results if one value is out of trend with the rest.

Many candidates did not extend their range of *L* values low enough and/or high enough. Candidates are encouraged to use the whole range available to them.

Many candidates gave both the quantity and correct unit for each heading, separated by a solidus or with brackets around the unit. Candidates are encouraged to remember to include a separating mark between the quantity and unit. Some candidates omitted the unit or gave the unit of 1 / *L* as m instead of m^{-1} (and similarly for 1 / *V*).

Most candidates calculated values for 1 / *V* correctly. Candidates are encouraged not to truncate the value without rounding.

Many candidates correctly stated their calculated values of 1 / *V* with a number of significant figures consistent with those used for *V*. Others gave too few or too many significant figures.

The table work was done well by candidates in general. The most common mistakes were to use too small a range and to use an incorrect number of significant figures for 1 / *V*.

(c) (i) Many candidates plotted the correct graph with quantities labelled, and used sensible and regular scales such that the data occupied over half the graph grid available. Plotting and reading of points is then an easy task to carry out. Awkward or irregular scales were often the reason for not awarding credit for the axes.

Many points were drawn as neat crosses such that the point centre was no more than half a square thick, and were plotted correctly so that the position is within half a small square in both the *x* and *y* direction. Common reasons for not awarding credit here were ‘blobs’ (points with diameter greater than half a small square) and points plotted more than half a square from the correct position.

(ii) Stronger candidates were able to draw a carefully considered line of best fit with a balanced distribution of points either side of the line along the entire length. Common reasons for not awarding this mark included lines needing a rotation or a shift to get a better fit and lines that were kinked (two or more smaller lines joined up).

If a point appears to be anomalous on the graph, candidates are encouraged to check their plotting first, then check their reading with the equipment available. If the candidate still has one anomalous point, they can identify this point as such by ringing it or stating the point as ‘anomalous’.

Candidates found drawing the line of best fit to be the most difficult part of the question, and in general would benefit from more practice of this skill.

(iii) Some candidates correctly used a large triangle to calculate the gradient, used correct read-offs and substituted into $\Delta y / \Delta x$ correctly. Stronger candidates read off from the graph at $x = 0$ or used a correct read off into $y = mx + c$ to find the *y*-intercept.

Common mistakes with the gradient were using too small a gradient triangle, substitution into $\Delta x / \Delta y$, values incorrectly read off and points used from the table which were not on the line of best fit. For the *y*-intercept, common mistakes were reading the *y*-intercept from the graph when there was a false origin and substitution into a wrongly arranged equation e.g. $c = y / mx$.

(d) Most candidates recognised that *J* and *W* were equal to the gradient and the *y*-intercept respectively and stated correct units. Some candidates omitted units or used different units to those used in the experiment without any evidence of converting correctly. Candidates who inverted their axes on their graph (from the orientation requested in the question) generally did not go on to rearrange the equation to be consistent.

(e) (i) Stronger candidates correctly read the micrometer scale with due regard to the precision and stated correct units. Some candidates repeated their values of *d* to gain maximum credit. Many candidates’ values were far from the expected value (and the supervisor’s value), suggesting difficulty with using the micrometer.

(ii) The strongest candidates rearranged for a correct calculation of ρ with correct powers of ten. Many weaker candidates did not convert to metres for *d* and/or to metres in the unit for *J* so that their answer had a power-of-ten error.

Question 2

(a) Most candidates measured values of *m* to the nearest 0.1 g or better.

(b) (i) Stronger candidates correctly stated *b* and *d* to the same precision as the ruler and in the correct range. Some candidates calculated $\sqrt{(d-b)}$ with the correct unit. A common mistake was to omit the unit or to give cm instead of $cm^{0.5}$ or √m.

(ii) Many candidates correctly justified the number of significant figures they had given for the value of $\sqrt{(d-b)}$ with reference to the number of significant figures used in *d* and *b* or ($d-b$). Where candidates were not successful, it was often because their answers were insufficiently detailed, e.g. 'raw readings', 'previous measurements' or 'values used in calculation' without detailing the quantities involved.

(iii) Many candidates stated *H* in the accepted range and the strongest candidates repeated their readings to gain maximum credit.

(iv) Some candidates, having repeated their readings, correctly showed the uncertainty working as half the range and then went on to calculate the percentage uncertainty with the correct method. Others correctly estimated the uncertainty in *H* to be in the accepted range, taking into account the difficult nature of this reading. Many candidates made too small an estimate of the absolute uncertainty in the value of *H*, typically 0.1 cm or 0.2 cm.

(v) Many candidates calculated the value correctly.

(c) The majority of the candidates stated a second value of *H* and *L* with the second *H* greater than the first value.

(d) Many candidates were able to calculate *k* for the two sets of data, showing their working clearly. Some candidates had different values of *M* and *m* for the first *k* value when these should have been the same. A small number of candidates incorrectly stated their values to one significant figure.

(e) Stronger candidates calculated the percentage difference between their values of *k*, tested it against the stated 15% criterion and provided a valid statement of conclusion. Some candidates omitted a percentage difference calculation, gave a different criterion e.g. 10% or 20%, or gave an invalid statement inconsistent with their findings.

(f) (i) Candidates need to identify problems associated with setting up and obtaining readings. They can do this by writing about the different measurements taken or chronologically going through the experiment systematically and identifying each difficulty. Candidates should then try think of solutions that address each problem.

Problems commonly awarded were 'two sets of data were not enough to draw a valid conclusion', 'difficult to measure *b* as difficult to identify the centre of the ball, '*H* difficult to measure as difficult to know when reaches maximum height'. Many candidates wasted options discussing the non-critical approximate measurements in the experimental set-up such as the 50 cm and 1.5 cm lengths and/or measurements that were not at all difficult, such as *d*.

(ii) Improvements that were commonly seen were 'take more readings and plot a graph' and 'use video and a ruler in the shot to measure the maximum height *H*'. A solution, like the problem, needs detail to gain credit. Candidates are encouraged to explain *how* a problem will be solved, detailing what additional equipment is necessary.

Credit is not given for suggested improvements that could have been carried out in the original experiment, e.g. 'repeat readings' or 'view the ruler at right angles'.

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Key messages

- If a raw value is out of trend to that expected, candidates should be encouraged to check the readings again with the equipment provided in the early stages of data collection.
- Candidates should consider carefully whether it would be advantageous to repeat their measurements.
- In the table work, the number of significant figures in the calculated quantity should relate to the number of significant figures in the raw data with the least number of significant figures. Each calculated quantity should be checked row by row. It is unnecessary, and often incorrect, to force the number of significant figures to be constant down a column of calculated values.
- When justifying a number of significant figures in a calculated quantity, candidates should relate the number of significant figures in the quantity to the raw readings used in the calculation. Candidates should not use the phrase 'raw readings' without explaining what those readings are, or attempt to use intermediate calculated quantities to justify the number of significant figures.
- To be successful answering **Question 2**, candidates should be reminded that their identified limitations and suggestions for improvement must be focused on the particular experiment being carried out. General points such as 'measurements were difficult' or 'use more precise measuring instruments' will not usually gain credit without further detail.

General comments

Most centres did not have difficulties in providing the equipment requested. Any deviation between the requested equipment and that provided to the candidates should be written down in the supervisor's report, and this report must be sent with the scripts to Cambridge so that the examiners can take this into consideration when marking. No additional equipment should be available to the candidates. In some cases, this may disadvantage candidates.

Any help given to a candidate should be noted on the supervisor's report. Supervisors are reminded that help should **not** be given with the recording of results, graphical work or analysis.

The general standard of work carried out by the candidates was good, with some producing excellent scripts. Where candidates performed less well, this was often due to improper presentation of data, e.g. the omission of units with values.

Working was usually clear and legible, but some candidates should be reminded to draw tables carefully using ruled lines and, where possible, record data systematically. Candidates are also advised to leave a small gap between a value of time and the unit 's'. Some wrote the unit in such a way that it was difficult to determine whether a unit had been stated or if '5' was the final digit of their value.

The independent variable for the experiment in **Question 1** was the height above the bench of a scale marking on the syringe. Candidates should be aware that the examiners will check that the values of the independent variable differ from each other. Duplicated values will only count as one reading.

For graph work, candidates should be encouraged to use a 30 cm ruler to draw lines of best fit and to provide legible, sensible scale markings on axes. Candidates selecting sensible scales are much less likely to make errors when plotting points and taking read-offs for the gradient and intercept calculations.

Comments on specific questions

Question 1

(a) (i) The majority of the candidates provided values of h_t and h_b that were in the accepted range and with an appropriate unit (e.g. cm). Some candidates had values outside of range but within tolerance of the supervisor's value and so were still able to gain credit. Some candidates did not provide a unit.

(ii) A significant number of candidates misread stopwatches. Some, after taking a sensible measurement of time, divided their value by, for example, 10. This was possibly to account for the number of intervals between the scale markings. This action was incorrect and always resulted in a final answer outside of the accepted range, so the candidate did not gain credit.

Credit was available for repeated readings. When measuring time, especially where timings are short, it is good practice to take multiple readings. Most candidates did this.

(b) The majority of the candidates successfully followed the instructions and recorded six sets of values of h_t, h_b and T. The most successful candidates presented their data sequentially and ensured that the full range of possible h_t values was included in their data.

Credit for the range of values was awarded if the difference between the candidate's maximum and minimum values of h_t was greater than 5 cm. Many candidates achieved this.

Column headings in the table were usually correct and included a suitable separator between the quantity and unit. Candidates who were not awarded credit often found it difficult to provide a suitable unit for the 1 / T value.

When recording the heights h_t and h_b, candidates were expected to present their data using appropriate and consistent precision. Many did this by recording all values to the nearest mm.

The calculation of 1 / T was correct in most cases. A small number of candidates gave a value that was incorrectly rounded.

Most candidates recognised the need to present 1 / T values to the same number of significant figures as (or one more than) than the number of significant figures in the corresponding raw T values.

(c) (i) Candidates producing successful graphs did so by choosing sensible scales that allowed plotted points to occupy at least 4 large squares horizontally and 6 large squares vertically. Scale markings were generally clear, and values were usually written one large square apart.

Some candidates selected unsuitable scales, e.g. labelling axes using fractions or by calculating the difference between their minimum and maximum table values and dividing by the number of squares available on the grid. Awkward scales, including the examples mentioned, should be heavily discouraged as candidates often make subsequent errors when taking read-offs and may be unable to gain credit in multiple different places as a result.

Whilst the plotting of points was generally accurate, some candidates used large circles as points making it impossible to judge whether the points were accurate to within half a small square. These are not given credit.

(ii) When drawing the straight line of best fit, many candidates produced thin lines that had an even distribution of points either side of the line along the full length. Common reasons for lines not being given credit were broken or kinked lines, possibly as a result of using short rulers, or lines requiring a rotation.

Candidates should be made aware that, if they identify a point as anomalous and decide to ignore it when drawing the line, they need to indicate this by either circling the point or labelling it. Only one anomaly can be ignored. If a candidate circles two or more points, the examiner will consider all points when judging the line.

(iii) Most candidates correctly read off two points from their line that were at least half the length of the line apart and then substituted points into the equation Δy / Δx or equivalent. Some candidates incorrectly used Δx / Δy or used points in their equation that were not on the line of best fit.

For the *y*-intercept, most candidates correctly substituted values into $y = mx + c$ or equivalent. A common error made by candidates was in taking a direct read-off from the graph as the *y*-intercept despite the *x*-axis having a false origin.

(d) Most candidates recognised that *p* was equivalent to their gradient value and *q* was equivalent to their *y*-intercept value. Units were often provided, but these were not always consistent with the readings, e.g. candidates working in cm but giving the unit s^{-1} m^{-1} for *p*.

Question 2

(a) (i) Most candidates stated a value for *r* within the expected range and measured to the nearest mm. Some candidates had values outside the accepted range, were still awarded credit if the unexpected *r* value was within tolerance of the supervisor's value of *r*.

(ii) The value of *x* stated by most candidates was smaller than 15 cm.

Credit was available for the taking of repeated readings. Many candidates did not choose to repeat their measurements. Candidates should be advised to take repeated readings where appropriate, e.g. when taking measurements of a dynamic system such as this.

(iii) When asked to estimate the percentage uncertainty in *x*, successful candidates chose an absolute uncertainty in the range 0.3–1.0 cm. They then divided the absolute uncertainty by their *x* value before multiplying the result by 100. Others derived the absolute uncertainty from half the range of their repeated readings. This was credited when the working was clearly shown.

Many of the candidates who did not gain credit simply stated the resolution of the rule (0.1 cm) as their absolute uncertainty. Given the nature of the experiment (*x* was measured while the magnet was moving and at a significant distance above the rule), this was deemed an unrealistic estimate of the absolute uncertainty. Candidates should be encouraged to think about the inherent difficulty in taking the measurement as well as the precision of the measuring instrument.

(iv) Most candidates were able to correctly calculate *h*.

(b) Almost all candidates provided second values of *x* and *h*. Some candidates found that the second value of *x* (heavier nut) was not smaller than the first value of *x*, suggesting that they had not set up the apparatus correctly.

(c) (i) Most candidates were able to correctly calculate two values of *k*. A small number of candidates inappropriately rounded their final value(s) to one significant figure.

(ii) Some candidates successfully linked the significant figures in *k* with those in ($M + m$) and *h*. A significant number referred only to 'raw data' or made a partial reference to the correct quantities.

Candidates should not make a general statement such as 'the quantity with the least significant figures'. Candidates are expected to state all quantities that should be considered when deciding on the suitable number of significant figures.

(d) Candidates were provided with a numerical criterion of 15% to test against. To be successful, they needed to carry out a correct percentage difference calculation, a comparison with 15%, and then give a correct conclusion linking both. The strongest candidates were able to correctly carry out a suitable percentage difference calculation, but many weaker candidates were not. A small number of candidates made incorrect conclusions, e.g. 'my values do not support the suggested relationship as the percentage difference between the values of *k* is only 3% which is not close to 15%'.

A small number of candidates tested against their own criterion, e.g. 10%, and were not credited.

(e) (i) Most candidates recognised that there were too few data to draw a conclusion and that there were sometimes problems with the magnet picking up the nut. Other marking points were, in general, less well addressed.

Centres should encourage candidates to follow the instructions and always state the quantity being measured along with the reason for the uncertainty, e.g. 'it was difficult to measure *r* because…'. Many candidates recognised limitations but did not link these to the correct quantity. For example, some candidates stated that the centre of the magnet was hard to determine but they did not link this to the measurement of *r*.

(ii) Most candidates recognised the need for more data so that a graph could be plotted. Other common correct suggestions were clamping the rule (when measuring *r*), using stronger magnets (to increase the chances of picking up the nut) and using a vertical reference at the 15 cm mark (to ensure a consistent starting point).

Although many candidates referenced the use of video to capture the measurement of *x*, many did not include a ruler in view. Instead, many referred incorrectly to including a timer or watching frame-by-frame.

Candidates should be aware that the examiners do not look for links between responses in the limitations section and those in the improvements section. As such, candidates should state any apparatus/quantity in **(ii)** and avoid using phrases such as 'clamp it' assuming that the examiner knows what 'it' is because of working from **(i)**.

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Key messages

- If a raw value is out of trend to that expected, candidates should be encouraged to check the readings again with the equipment provided in the early stages of data collection.
- Candidates should consider carefully whether it would be advantageous to repeat their measurements.
- In the table work, the number of significant figures in the calculated quantity should relate to the number of significant figures in the raw data with the least number of significant figures. Each calculated quantity should be checked row by row. It is unnecessary, and often incorrect, to force the number of significant figures to be constant down a column of calculated values.
- When justifying a number of significant figures in a calculated quantity, candidates should relate the number of significant figures in the quantity to the raw readings used in the calculation. Candidates should not use the phrase 'raw readings' without explaining what those readings are, or attempt to use intermediate calculated quantities to justify the number of significant figures.
- To be successful answering **Question 2**, candidates should be reminded that their identified limitations and suggestions for improvement must be focused on the particular experiment being carried out. General points such as 'measurements were difficult' or 'use more precise measuring instruments' will not usually gain credit without further detail.

General comments

Most centres did not have difficulties in providing the equipment requested. In **Question 1** there was some variation in the mass of the rulers provided to candidates which affected the balance point. These variations were accommodated within the marking process to allow all candidates fair access to the marks for this part of the experiment.

Any deviation between the requested equipment and that provided to the candidates should be written down in the supervisor's report, and this report must be sent with the scripts to Cambridge so that the examiners can take this into consideration when marking. No additional equipment should be available to the candidates. In some cases, this may disadvantage candidates.

Any help given to a candidate should be noted on the supervisor's report. Supervisors are reminded that help should **not** be given with the recording of results, graphical work or analysis.

The general standard of the work done by the candidates was good, and there were many excellent scripts. Candidates did not seem to be short of time and both questions were attempted by almost all the candidates. They demonstrated good skills in the generation and handling of data but could improve in two main areas: firstly by ensuring that the presentation of their work is legible and conforms to scientific convention (for example, the layout of the table in **Question 1** using ruled lines and clear headings) and secondly, in the last part of **Question 2**, by being more specific about how their limitations and improvements relate to the quantities being measured.

Comments on specific questions

Question 1

(a) Most candidates had appropriate values for *a* and *s* and with *s* greater in value than *a*.

(b) Most candidates were able to collect six sets of values of *a* and *s* without assistance from the supervisor and obtained the correct trend. Candidates are encouraged to check their results if one value is out of trend with the rest and to repeat the collection of that data set.

Some candidates did not extend their range to a value that was low enough and/or high enough. Candidates are encouraged to use the whole range available to them.

Many candidates gave both the quantity and correct unit for each heading, separated by a solidus or with brackets around the unit. Candidates are encouraged to remember to use a separating mark between the quantity and unit. Some candidates incorrectly gave the unit of *s* / *a* as m or m^{-1}.

Many candidates correctly wrote their calculated values of *s* / *a* to a suitable number of significant figures based on their values of *a* and *s*. Candidates are encouraged to be aware that changes in the number of significant figures in their raw (collected) data can have an effect on the number of significant figures in their calculated values. This occurs when the collected data spans both single-digit and double-digit numbers.

Most candidates calculated values for *s* / *a* correctly. Candidates are encouraged not to truncate a value without correct rounding.

Overall, the table work was done well by candidates, but many candidates could have improved by having clearer presentation. Candidates are encouraged to take the time to construct a clear, well laid out table in which to record their data.

(c) Many candidates plotted the correct graph with quantities labelled, and used sensible and regular scales such that the data occupied over half the graph grid available. Plotting and reading of points is then an easy task to carry out. Awkward or irregular scales were often the reason for not awarding credit for the axes.

Many points were drawn as neat crosses such that the point centre was no more than half a square thick, and were plotted correctly so that the position is within half a small square in both the *x* and *y* direction. Common reasons for not awarding credit here were 'blobs' (points with diameter greater than half a small square) and points plotted more than half a square from the correct position. Candidates are encouraged to use a sharpened pencil for the graph work.

(ii) Stronger candidates were able to draw a carefully considered line of best fit with a balanced distribution of points either side of the line along the entire length. Common reasons for not awarding this mark included lines needing a rotation or a shift to get a better fit and lines that were kinked (two or more smaller lines joined up, sometimes made using a damaged straight edge).

If a point appears to be anomalous on the graph, candidates are encouraged to check their plotting first, then check their reading with the equipment available. If the candidate still has one anomalous point, they can identify this point as such by ringing it or stating the point as 'anomalous'.

(iii) Some candidates correctly used a large triangle to calculate the gradient, used correct read-offs and substituted into $\Delta y / \Delta x$ correctly. Stronger candidates read off from the graph at $x = 0$ or used a correct read off into $y = mx + c$ to find the *y*-intercept.

Common mistakes with the gradient were using too small a gradient triangle, substitution into $\Delta x / \Delta y$, values incorrectly read off and points used from the table which were not on the line of best fit. For the *y*-intercept, common mistakes were reading the *y*-intercept from the graph when there was a false origin and substitution into a wrongly arranged equation e.g. $c = y / mx$.

(d) (i) The majority of the candidates correctly identified *P* as being the gradient and *Q* the *y*-intercept. A significant number of candidates did not give a unit with the value of *P*.

(ii) Stronger candidates correctly rearranged the equation and found a value for *R*. Many candidates identified the correct unit for *R* (g) but weaker candidates often either had no unit or some combination of g and cm (e.g. g cm^{-2}).

Question 2

(a) (i) Many candidates correctly measured values of *L* and *d* and did so to an appropriate precision. Weaker candidates did not use the micrometer to measure *d* or, in some cases, misread the micrometer. Stronger candidates measured multiple values of *d* along the rod and calculated an average value. In general, candidates need to be mindful that repeating readings is appropriate for measured quantities in which variation of values might be obtained if doing the experiment again or if done by another experimenter.

(ii) Stronger candidates correctly justified the number of significant figures they had given for the value of *V* with reference to the number of significant figures used in *d* and *L*. A common reason for credit not being awarded was undetailed reference to 'raw readings', 'previous measurements' or 'values used in the calculation' without giving the individual raw quantities concerned. Some candidates incorrectly focused on the number of decimal places involved in the data.

(b) (i) Most values of S_0 were in the accepted range. Some weaker candidates did not convert correctly from a measurement in cm to a value in m.

(ii) Some candidates, having repeated their readings, correctly showed the uncertainty working as half the range and then went on to calculate the percentage uncertainty using a correct method. Others correctly estimated an uncertainty in S_0 that was reasonable, taking into account the difficulties of taking this reading using a (long) ruler. Weaker responses had a vague or unclear use of a half-range calculation (e.g. not showing the data on which this was based), or had power-of-ten errors in the absolute uncertainties (e.g. 0.02/0.050 instead of 0.002/0.050).

(iii) This was done correctly by the majority of the candidates.

(c) Candidates were expected to record the time taken for at least 5 oscillations, and to do this at least twice before using their measurements to determine an average for their final value. Many candidates did this clearly and accurately. Candidates who did not gain credit typically measured the time for one oscillation three or four times before averaging, or measured a single value of, for example, 10*T* only. Some candidates correctly measured, for example, three values of 10*T*, but then only divided their total value by 3, and did not also divide by 10. This was not able to gain credit. A minority of candidates also calculated *n* / *nT* rather than *nT* / *n*, which was also unable to gain credit, as was misreading the stopwatch to give times such as 0.0004 s.

(d) The majority of the candidates successfully made two further readings of *M* and *T* and also showed good experimental technique in obtaining a second value of *T* that was larger than the first.

(e) Many candidates were able to calculate ρ for their two sets of data, showing their working clearly. Weaker candidates rearranged the equation incorrectly (e.g. $\rho = kT^2 / 4\pi^2V - M$) and so obtained an incorrect value for ρ. A minority of candidates incorrectly stated their values of ρ to only one significant figure.

(f) Stronger candidates calculated the percentage difference between their values of ρ, tested it against the stated 15% criterion and provided a valid statement of conclusion. Some candidates omitted a percentage difference calculation, gave a different criterion (e.g. 10%, 20% or the uncertainty from **(b)(ii)**) or gave a statement that was inconsistent with their findings. Some candidates also confused 'percentage difference' with 'percentage uncertainty' meaning their conclusion was unclear. A minority of candidates were not awarded credit because they attempted to calculate their own percentage uncertainty using estimates of the uncertainty in *V*, *T* or *M*.

(g) (i) Candidates need to identify difficulties associated with setting up and obtaining readings. They can do this by writing about the different measurements taken or chronologically going through the experiment systematically. Candidates should then think of corresponding solutions that address each difficulty.

Problems commonly awarded credit were: ‘two sets of data were not enough to draw a valid conclusion’, ‘difficult to measure T as it is difficult to identify the start (or end) of an oscillation’ and ‘S_0 was difficult to measure because of parallax error (from the curvature of the rods)’.

(ii) Improvements that were commonly credited included ‘take more readings and plot a graph’ and ‘clamp the ruler when measuring S_0’.

In general, with both limitations and improvements, candidates should be encouraged to state what the problem is and give a reason for it, e.g. ‘it is difficult to measure T because it is difficult to judge the start/end of an oscillation’. For improvements, candidates should state the solution and say how this helps solve a specific problem, e.g. ‘take a video with a timer in view to help obtain a more accurate value of T’.

Credit is not given for suggested improvements that could have been carried out in the original experiment, e.g. ‘repeat readings’ or ‘view the ruler at right angles’.

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Key messages

- If a raw value is out of trend to that expected, candidates should be encouraged to check the readings again with the equipment provided in the early stages of data collection.
- Candidates should consider carefully whether it would be advantageous to repeat their measurements.
- In the table work, the number of significant figures in the calculated quantity should relate to the number of significant figures in the raw data with the least number of significant figures. Each calculated quantity should be checked row by row. It is unnecessary, and often incorrect, to force the number of significant figures to be constant down a column of calculated values.
- When justifying a number of significant figures in a calculated quantity, candidates should relate the number of significant figures in the quantity to the raw readings used in the calculation. Candidates should not use the phrase 'raw readings' without explaining what those readings are, or attempt to use intermediate calculated quantities to justify the number of significant figures.
- To be successful answering **Question 2**, candidates should be reminded that their identified limitations and suggestions for improvement must be focused on the particular experiment being carried out. General points such as 'measurements were difficult' or 'use more precise measuring instruments' will not usually gain credit without further detail.

General comments

Most centres did not have difficulties in providing the equipment requested. Any deviation between the requested equipment and that provided to the candidates should be written down in the supervisor's report, and this report must be sent with the scripts to Cambridge so that the examiners can take this into consideration when marking. No additional equipment should be available to the candidates. In some cases, this may disadvantage candidates.

Any help given to a candidate should be noted on the supervisor's report. Supervisors are reminded that help should **not** be given with the recording of results, graphical work or analysis.

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 can improve by giving more thought to the analysis and evaluation of experiments.

Working was usually clear and legible, but some candidates should be reminded to draw tables carefully using ruled lines and, where possible, record data systematically. Candidates are also advised to leave a small gap between a value of time and the unit 's'. Some wrote the unit in such a way that it was difficult to determine whether a unit had been stated or if '5' was the final digit of their value.

Candidates did not seem to be short of time and both questions were attempted by almost all the candidates. Candidates should be reminded that they are only allowed access to apparatus for each question for one hour and should allocate their time within each question accordingly.

Comments on specific questions

Question 1

(a) Some candidates did not provide a unit for the length *x*. The metre rule can be read to the nearest 0.1 cm. The protractor can only be read to the nearest degree.

(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 in **(a)** and so did not cover the full range of values that was available to them. 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 26 cm but allowance was made for difficulties making the holes in the card.

Some candidates improved the quality of their results by taking repeated values of θ for each value of *x* and calculating a mean value; this should be recognised as good practice.

The most common errors in table headings were giving a unit for 1 / tan θ or missing a separating mark between θ and °.

Recording values of *x* to the nearest mm was usual, with many candidates having all zeros in the mm place. This is acceptable in this case as candidates are choosing their values of *x*, but measurements of length in other contexts are unlikely to all end in .0 cm. Some candidates added an extra 0 after the decimal point for *x* values less than 10 cm, presumably to give these values to 3 significant figures. This is incorrect as these are measured, not calculated, values.

Values of 1 / tan θ were usually calculated correctly and given to an acceptable number of significant figures. Candidates with values of θ less than 10° (1 significant figure) should not give values of 1 / tan θ to 3 significant figures. This was a case where candidates need to check significant figures in calculated quantities for each row of their table, rather than down a column.

(c) (i) Most 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.

With typical *x* values in the range 4–28 cm, some candidates were tempted to use a scale based on 3 for each large square. Although this appears to give a good spread of points, it is not acceptable as the scale is very difficult to use. Errors in plotting or reading values from the graph were very common with awkward scales.

If candidates identify an anomalous point, they should first check the plotting of that point, then the calculation and then, if possible, to 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. A large number of lines required rotation to give a good spread of points along the line. Some lines seemed to have been drawn so that the maximum number of plotted points were on the line and points not on the line were ignored. A significant number of lines were drawn in two sections, or distorted at one end, 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, these points should not be indicated with the same type of crosses as the plotted points.

There were cases of incorrect read-offs substituted into the gradient calculation, particularly when awkward scales were used. Candidates should be encouraged to use one of the gradient read-offs substituted into the equation for intercept, rather than using another point which creates a further chance of reading error. A common mistake was to use values from the table for a point that was not on the line.

(d) The majority of the candidates transferred their gradient and *y*-intercept values as *a* and *b* respectively. In general, candidates should be advised that they should not present their final answers to only one significant figure.

Candidates who considered the units for the gradient and *y*-intercept were able to give the correct unit for *a*. Otherwise, candidates can ensure that each term in the equation has a consistent unit – in this case *ax* must have no unit so *a* must be in cm^{-1} if *x* is given in cm.

Question 2

(a) A small number of candidates recorded the circle radius rather than diameter. Candidates should be advised that it is good practice to repeat and average diameter measurements, although in this case it was not critical as the centre of the circle was known. The use of a 30 cm ruler means that all values should be to the nearest millimetre and the average value should have the same number of significant figures.

(b) (i) Some candidates gave their value of *p* to the nearest centimetre, despite using a ruler with a millimetre scale.

(ii) Candidates who took repeated readings for *p* in **(i)** were usually able to successfully determine a percentage uncertainty using the half-range method. Otherwise, absolute uncertainties of 1 mm or 1 cm were common, neither of which were reasonable estimates.

(c) (i) Despite the unfamiliar motion, many candidates were able to obtain a suitable value for the period of rotation. Units were omitted by some candidates. A significant number of candidates recorded only a single value of *T*, or repeated values for one rotation. It is good practice to repeat any timing measurement and to determine the time for multiple cycles. Stronger candidates measured the time for 10 rotations three times, giving a total time of about 25 s.

(ii) The calculation caused little difficulty and there were very few rounding errors.

(d) Almost all candidates were able to determine a shorter period for the shorter conical pendulum, as expected. There were some answers where the period was only given to one significant figure.

(e) (i) 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.

(ii) The justification for the number of significant figures needs to be based on the raw data used to determine that value. It is insufficient to state 'raw data' or 'raw readings', and this was seen in many answers. In this experiment, the values of *D* and *p* were the raw data used to calculate Φ and measured times were used to calculate *T*. These need to be stated explicitly, such as 'the diameter *D* and length of pendulum *p* were determined to 3 significant figures, the times were measured to only 2 significant figures so the value of *k* can be given to 2 significant figures, the lowest of these'. Other options were also given credit in this case, including Φ, *p* and *T*.

(f) Candidates should calculate the percentage difference between their *k* values and compare this to the suggested percentage uncertainty. There was a large number of clear answers but some vague statements such as, 'the percentage uncertainty was less than the percentage uncertainty, so the results support the relationship'. Candidates should make a numerical comparison with the suggested uncertainty given, in this case 15%. Some weaker candidates mistakenly suggested that the relationship was supported if the percentage difference was equal to 15%.

(g) (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 bob needed to be linked to the measurement of *p*, for example.

A large number of responses referred to the difficulty measuring or maintaining the 5 mm above the cross, although this is irrelevant once the bob is in its circular motion. In this experiment, it is necessary to move the knot in small circles to maintain the circular motion, so problems stating about the difficulty of holding the knot stationary were not relevant.

Many candidates recognised that two sets of data were insufficient to draw a valid conclusion. There were some clear statements regarding difficulty in timing where candidates used their experience of other oscillatory motion.

(ii) Most candidates described four improvements but, as with the problems in **(i)**, there were many incomplete 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 are standard practice and are not given 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.

The key to this section is for candidates to identify genuine problems associated with setting up the experiment and in obtaining measured values. Candidates are then encouraged to suggest practical solutions that either improve technique or give more reliable data. More successful candidates will select relevant problems and describe them clearly, linking to relevant measurements and will suggest improvements that are workable and expressed clearly.

PHYSICS

Paper 9702/41
A Level Structured Questions 41

There were too few candidates for a meaningful report to be produced.

PHYSICS

Paper 9702/42
A Level Structured Questions 42

Key messages

- 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 a definition if the symbols used are identified.

- 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. It is not uncommon to find candidates giving 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.

- 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 partial credit even when the final answer is incorrect. Incorrect answers that are not supported by working cannot be awarded credit.

- 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; 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 answers to an inappropriate number of significant figures, or that are inaccurate as a result of rounding intermediate values prematurely, can both lead to full credit not being awarded.

General comments

The question paper contained questions of a variety of levels of difficulty, enabling candidates at different levels of ability to show what they know. Candidates who knew the 'bookwork', read the questions carefully, took care over their use of technical language and answered the questions asked were able to perform well.

Some candidates use up more than half of the space provided for the answer by starting their response with essentially a re-write of the question. Candidates should be advised not to do this, as it wastes time and uses up answer space, and cannot lead to any credit being awarded.

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. If multiple answers are provided that are contradictory, the candidate cannot be awarded credit for a correct answer.

There was no evidence that candidates had insufficient time in which to complete the paper.

Comments on specific questions

Question 1

(a) (i) This question and **(ii)** were generally well answered by candidates that knew the basic equations for centripetal acceleration.

(ii) Some candidates who calculated the correct acceleration made an arithmetic error in rounding, to get a final answer of 1.6×10^4 m s^{-2}.

(b) (i) Lenz's law was only well known by the strongest candidates. To be awarded credit, candidates first needed to make it clear that Lenz's law is to do with the direction of the induced e.m.f. Confusion with Faraday's law was common, with many candidates giving responses in terms of the magnitude of the induced e.m.f.

(ii) This question was generally well answered, with most candidates able to show successfully that the period is 45 ms.

(iii) Many candidates knew the defining equation for magnetic flux. Some candidates did not know the correct formula for the area of a circle. Other candidates incorrectly included a factor of $\times$ 8 in the calculation.

(iv) Many candidates were awarded credit for realising that the magnitude of the e.m.f. is given by Faraday's law, but $\times$ 8 factors were common here too. Candidates should realise that the spokes are effectively in parallel, not in series, and so the $\times$ 8 factor is not applicable. Some candidates made a mistake with the unit conversion in the value of the time.

(v) This was a difficult question, with only the very strongest candidates demonstrating an ability to use Lenz's law correctly. The application of Lenz's law lay in realising that the cause of the induced e.m.f. is the rotation of the wheel. If current flows in the spokes, then it will cause a force on the wheel in the opposite direction to the rotation. Applying the left-hand rule then leads to a deduction that any current that flows will be from A to X. Finally, because current flows from low potential to high potential inside an e.m.f. source (and high to low potential around any external circuit), end X must be at the higher potential. A common misconception was that X is at the higher potential because it cuts more flux.

Question 2

(a) A significant minority of candidates did not give a definition of a quantity, but those that did answer the question were mostly able to correctly define the vector quantity gravitational field as force per unit mass (placed in the field).

(b) (i) There was some confusion among weaker candidates between the equations for gravitational force between point masses and the scalar quantity gravitational field strength due to a point mass. The more able candidates generally used the correct equation, but some did not appreciate that the precision of the data provided in the question warranted a three significant figure answer.

(ii) Most candidates were able to substitute the correct values into the equation for gravitational potential energy. Some candidates gave answers that did not reflect the precision of the data and others forgot that gravitational potential energy is always negative.

(c) (i) Many candidates were able to put together the equation for radiant flux intensity and the equation for gravitational field strength, and to eliminate x between them to arrive at the correct equation. Candidates that used letters other than x from the question sometimes struggled with the elimination if the distances they used in the two equations were not the same. Candidates should be advised that it is always better to use the symbols defined for them in the question.

(ii) This question was well answered by many candidates. Of those that correctly read a pair of values of g and L from the graph and substituted them together with the other relevant data into the given equation, the common reasons for not going on to achieve full credit were either making a mistake with the powers of ten in those values from the graph, or forgetting that luminosity is a power and giving the answer with an incorrect unit.

(iii) Many candidates answered correctly. Some struggled with the use of the Stefan–Boltzmann law, with use of the permittivity of free space for the Stefan–Boltzmann constant not unusual, and various arithmetic errors such as forgetting to raise the temperature to the power 4 or forgetting to take the square root of r^2 at the end. Some weaker candidates attempted to use the radiant flux intensity formula.

Question 3

(a) Full credit for this question was rare, indicating that the definition of specific latent heat is not well known by candidates. Many definitions seen were dimensionally incorrect, defining specific latent heat as an energy rather than as thermal energy per unit mass. The aspect that it is to do with energy needed to change state at constant temperature was more successfully articulated.

(b) (i) This question was generally well answered, with the majority of candidates achieving full credit.

(ii) Most candidates realised the need to apply the first law of thermodynamics, but were then unable to arrive at the correct answer because they did not appreciate that the gas is doing work and so the work done on the gas is negative.

(iii) Full credit by error carried forward from the answer to **(b)(ii)** was common. Weaker candidates found it difficult to work out the mass of the substance, with use of the volume of the gas with the density of the liquid being the common incorrect starting point.

(c) Only the strongest candidates were able to give a response to this question that went beyond IGCSE level physics. These stronger candidates were able to discuss the three terms involved in the first law and how they differ between the processes of fusion and vaporisation.

Question 4

(a) Candidates who knew their 'bookwork' were generally able to correctly state three of the assumptions of the kinetic theory. Weaker candidates often gave responses in terms of 'gases' rather than the molecules that make up the gas. A common misconception was that the assumption dealing with the negligible volume of the molecules related to a single molecule rather than to all of the molecules in the gas.

(b) Many candidates answered a different question from the one asked, and discussed why pressure increases with temperature. Of the candidates that did address the question asked, most observed that there are molecular collisions with the walls of the container, but only the strongest candidates discussed the application of Newton's laws to those collisions to explain the origin of the force on the walls.

(c) Many candidates offered descriptions of the graphs rather than drew conclusions about the gases and their samples. Responses that treated quantities that vary as if they were properties of the samples were common. There were many different points that candidates could make by way of conclusions about the gases and their samples, and stronger candidates frequently achieved full credit.

Question 5

(a) A large number of candidates thought that the resultant force on the sphere was horizontal rather than perpendicular to the string.

(b) (i) This question was generally well answered, with most candidates correctly deducing the amplitude from the graph.

(ii) This question was also generally well answered. Some of the weaker candidates were confused between angular frequency and frequency.

(iii) Candidates that knew the syllabus equation for the energy of the oscillations were usually able to use their values in **(b)(i)** and **(b)(ii)** to calculate the energy correctly.

(c) This was a well answered question by candidates that understood this part of the syllabus, with many achieving full credit.

Question 6

(a) Coulomb's law was generally well known, and many candidates achieved full credit.

(b) Most candidates appreciated that the electric field is radially outwards, though care was needed over the diagram to gain full credit. Radial lines are straight, so candidates should be advised to use a ruler to draw them. The + symbols around the sphere were a useful guide to candidates to help them to ensure that their field lines were evenly distributed.

(c) (i) Most candidates deduced the radius correctly from the graph.

(ii) Candidates generally knew the correct equation for the electric field strength due to a point charge, but care was needed over the powers of ten when substituting a pair of values correctly read from the curved part of the graph. Some candidates chose to use the value on the data page for $1 / 4\pi\varepsilon_0$ and substituted it into the denominator rather than the numerator; candidates that used the value of the permittivity of free space generally substituted correctly.

(iii) Most candidates found it difficult to offer a plausible explanation, with many cyclic arguments presented such as 'there are no field lines inside the sphere, so the electric field is zero'. There was a variety of ways in which candidates could approach the answer, and stronger candidates generally were awarded credit.

Question 7

(a) Most candidates knew that, in general, capacitance is defined as charge per unit potential. Fewer candidates were able to give the extra detail of how these quantities apply to the particular scenario of the parallel-plate capacitor.

(b) (i) Many candidates achieved full credit for drawing a straight line from (0, 0) to (V, Q). Some did not appreciate that charge is proportional to p.d. and drew a curved line.

(ii) This question was generally well answered, with many candidates knowing that the energy stored in a capacitor is given by the area under the charge–p.d. graph, leading to $W = \frac{1}{2}QV$.

(c) (i) This was a challenging question that required a good understanding of which quantities are conserved during the process of connecting the capacitors. The mark scheme was structured in such a way that candidates could gain partial credit for getting different aspects of the task right.

It was notable that many candidates gave responses that they must have known could not be correct, because they were dimensionally incorrect. The p.d.s had to have been in terms of V, and the charges had to be in terms of Q, and it is reasonable to expect A Level candidates to realise that answers that were not in terms of V and Q, respectively, could not possibly be correct. Many of the strongest candidates did give a completely correct response.

(ii) Some candidates went to the trouble of actually calculating the energies, but this was not necessary. Candidates were expected to realise that the only possible answer is that the final energy stored must less than the original energy stored, because some energy is dissipated during the charge redistribution.

Question 8

(a) Candidates found it difficult to define frequency correctly. Common incorrect answers included discussing the number of 'waves' rather than the number of cycles/oscillations, attempting to define a quantity in terms of units, and defining frequency as the reciprocal of period.

(b) (i) This question was generally well answered.

(ii) This was also a well answered question, with many candidates achieving full credit.

(iii) This question was generally well answered.

(c) This was a more demanding question. The aim of the question was to show separately the calculation of the mean and peak powers, from the r.m.s. and peak currents respectively, and then to use them to prove that the mean power is half the peak power. It was common for weaker candidates to take the relationship to be proved as the starting point, and to calculate one of the powers using it. This was not what they were asked to do and could not achieve full credit.

Question 9

(a) Many candidates needed to pay closer attention to the command word for this question. 'Explain' requires more than just a statement. Candidates needed to do two things to gain credit; firstly, to establish that diffraction and interference are characteristic behaviour associated only with waves, and secondly, to conclude from that that the observation provides evidence for the wave nature of moving electrons. Many candidates did the second of these but not the first. Some candidates gave contradictory responses by suggesting that the observation provides evidence for both the wave nature and the particle nature of electrons.

(b) Most candidates were able to obtain credit for the equation $p = mv$. Fewer candidates gave the correct conservation of energy equation $qV = ½mv^2$. The strongest candidates correctly completed the algebra by eliminating v between the two equations to arrive at the correct final answer.

(c) Many candidates realised that the increased momentum of the electrons decreases their de Broglie wavelength, though some found it difficult to make the link. The strongest candidates were able to articulate that the effect of this change on the interference pattern is that the fringe spacing decreases.

(d) Both parts of this question were generally well answered, with many candidates achieving full credit.

Question 10

(a) The meaning of 'spontaneous' was generally better understood than the meaning of 'random'. Many responses to the latter were too vague to be awarded credit, with weaker candidates appearing to think that all aspects of radioactive decay are unpredictable. Candidates are expected to realise that the unpredictability is only on the level of individual nuclei, and that on the macroscopic scale the process is highly predictable. Understanding of the experimental evidence for the random nature of decay was generally not well articulated.

(b) (i) To give a creditworthy account of the differences between nuclear fission and nuclear fusion, candidates needed to be very clear when they were referring to a single nucleus and when they were referring to multiple nuclei. Only a minority of candidates explained that fission involves a single nucleus splitting into multiple nuclei, with many describing processes that are more akin to radioactive decay. Explanations of fusion often relied on the word 'fuse', which is part of the term that the question is asking about, and so candidates needed to make clear that this involves two nuclei joining together to make a single nucleus.

(ii) Many responses were seen that were not incorrect in what they said, but that did not answer the question asked. There were many discussions, for example, of mass defect, but the question asked for a discussion of the variation of binding energy per nucleon with nucleon number. A space was provided for candidates to draw a sketch graph of this variation, and candidates that did this (provided the graph was correctly labelled) were generally more successful in answering the question than those that did not.

PHYSICS

Paper 9702/43
A Level Structured Questions 43

Key messages

- 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 a definition if the symbols used are identified.

- 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. It is not uncommon to find candidates giving 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.

- 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 partial credit even when the final answer is incorrect. Incorrect answers that are not supported by working cannot be awarded credit.

- 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; 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 answers to an inappropriate number of significant figures, or that are inaccurate as a result of rounding intermediate values prematurely, can both lead to full credit not being awarded.

General comments

The question paper contained questions of a variety of levels of difficulty, enabling candidates at different levels of ability to show what they know. Candidates who knew the 'bookwork', read the questions carefully, took care over their use of technical language and answered the questions asked were able to perform well.

Questions asking for an explanation or reason were often answered in a way that just described the information that was given in the question, diagram or graph. Candidates should be advised not to do this, as it wastes time and uses up answer space, and cannot lead to any credit being awarded.

Several questions required drawing of lines, including sinusoidal waves, curves and straight lines. Many candidates would have achieved more credit by the appropriate use of a pencil, ruler and eraser, thereby allowing them to easily and clearly correct or clarify their work. Statements written next to diagrams describing how the drawing should look do not compensate for inaccurate drawing.

There was no evidence that candidates had insufficient time in which to complete the paper.

Comments on specific questions

Question 1

(a) Most candidates understood that stating Newton's law of gravitation involved two separate proportionalities. The most common errors occurred with regard to the separation of the masses, either through the use of the non-specific term 'distance', or by not identifying that the separation term was a squared one.

(b) (i) Stronger candidates identified that it was the gravitational force that caused centripetal acceleration, and that the force acted perpendicular to the direction of satellite motion (or its velocity). Weaker candidates implied that centripetal force was a separate force to that of gravitation.

(ii) Candidates were expected to start with Newton's gravitational equation and relate that force to circular motion. Most candidates appreciated that this was a 'show that' question, and so they laid out their derivation and substitutions clearly. Stronger candidates explained in words what the two constants A and B represented.

(iii) This was a question in which the ability to set working out clearly was of significant benefit to the candidate, as credit was available for stages in the process of getting to the final answer. In comparison to **(ii)** above, many candidates were not able to explain their series of calculations and expressions. Stronger candidates realised that the quantities on the axes of the graph did not immediately match the expression given in **(ii)**. Therefore, some reorganisation was required before the gradient given in the straight-line equation $y = mx + c$ could be equated with the calculated value of the gradient taken from two points on the graph. Most candidates realised that taking well separated points yielded a more precise value for the gradient, although it was common to see the power of ten for height h being overlooked in this calculation.

Question 2

(a) Most candidates understood the need to provide a ratio with regard to thermal energy and mass (for example, by using the word 'per'). Fewer candidates repeated the process for the temperature change. Instead, there were often incorrect inclusions of specific units of temperature, or references to a single unit of temperature change.

(b) (i) This question was generally well answered. When weaknesses were shown, they related to thermal equilibrium and thermal isolation, where the blocks needed to be identified as being the system considered.

(ii) Some candidates were not able to appreciate that the change in temperature for the two blocks was not equal, and that those different temperature changes needed to be included in the calculation.

Question 3

(a) (i) This question was generally well answered, the mixing up of the terms 'number' and 'amount' with reference to particles being the only significant area of confusion. Where a meaning for the Avogadro constant was given in terms of carbon-12, it was essential for candidates to appreciate that it was specifically the number of atoms being considered.

(ii) The majority of the candidates equated the three constants correctly.

(b) (i) In this question, stronger candidates appreciated that the terms in the question needed to be included in their expressions rather than numerical values or other terms.

(ii) Most candidates appreciated that the line needed to pass through the origin. Stronger candidates drew a curve with a positive, decreasing gradient that did not have a peak.

Question 4

(a) The proportionality between acceleration and displacement was well understood, but the opposite direction of the two quantities was less clearly explained by some candidates. This question provided an example where quoted equations gained no credit without an explanation of each term used.

(b) (i) The use of a velocity–height graph did not appear to be problematic for most candidates in either **(i)** or **(ii)**.

(ii) As a ‘show that’ question, candidates were expected to indicate a pathway from values to the final answer. Where the starting equation of $\omega = v_0 / x_0$ was used, candidates did not always distinguish the maximum values for v and x using subscripts.

(iii) The majority of the candidates correctly used the given values of angular frequency to calculate the period to two significant figures, as required. Weaker candidates often gave their answer to only one significant figure.

(iv) Candidates found it difficult to sketch the sinusoidal curve without error, although some tolerance was given for freehand drawing. Stronger candidates marked intermediate points on their graph to aid their drawing of the curves. Many candidates were not able to identify that the curve should start at $t = 0$ with h at its lowest value. Apart from this, the most common errors involved a start and finish to the curve at $t = 0$ s and $t = 6$ s that was too sharp, and lines that were wrongly or insufficiently curved between the peaks and troughs. The ability to draw a correct sinusoidal shape is one that would have been applied to good effect in this question. Credit was gained where care was taken with the position and height of the peaks and troughs.

Question 5

(a) Stronger candidates were aware of both the proportionality between electric field and electric potential gradient, and the negative relationship between them. Identifying the first part of the relationship was a prerequisite for achieving credit for the second part. Weaker candidates described the field and potential as being proportional to each other.

(b) Two approaches were possible for this question. Most candidates considered the two scenarios with either like or unlike charges, and explained how that would affect the electric field and electric potential. There was also the possibility of considering the constituent contributions from X and Y to the resultant of the two quantities, one a scalar and one a vector. Weaker candidates discussed only one field and referred to the situation at infinity as a point where both quantities are zero, rather than consider the situation given in the question. The fact that potential is a scalar quantity and electric field a vector was not considered very often.

(c) (i) In this ‘show that’ question, the individual potential contributions of X and Y needed to be shown and then equated to achieve the final relationship between distances y and x. Most candidates achieved this, but in a small number of cases the working was compressed in such a way that the required full working was not shown.

(ii) Most candidates were able to provide the correct expression.

(iii) Many candidates were able to derive a correct expression for the electric field strength due to Y. Fewer candidates appreciated that, because X and Y were opposite charges, the electric fields would be in the same direction and therefore their magnitudes needed to be added.

Question 6

(a) (i) Most candidates correctly indicated a conversion or change of the current or voltage to d.c.

(ii) Candidates found the task of describing the process of both types of rectification challenging. Many chose to describe the mechanics of the conversion in terms of the number of diodes used, or the different power outputs. Other candidates attempted to describe what happened to a sinusoidal wave, in words or via unlabelled sketch graphs. Neither approach specifically addressed the question. Better answers referred directly to what was happening to the voltage (or current) during each half-cycle.

(b) (i) Sketches were generally drawn sufficiently accurately to achieve full credit.

(ii) The use of the capacitor in this particular circuit was understood by most candidates.

(c) (i) This question was generally well answered. Where answers were given in farads rather than microfarads, there was a requirement that the correct units were also shown to achieve full credit.

(ii) Many candidates were able to follow through the substitution of values into the exponential equation to calculate a correct final answer. Weaker candidates did not realise that the time period to be taken was a maximum of 0.01 s. Some candidates took points for a small portion of the decay period (i.e. less than 0.01 s). Whilst this was a perfectly valid approach mathematically, a small time period made it more likely that inaccuracy in reading the value would occur. Candidates should therefore be encouraged to take as large a time period as they can for such measurements.

Question 7

(a) As with **Question 2(a)**, candidates needed to clearly identify the two ratios in their definition. They needed to make clear that they were referring to the length of wire (or the current) being perpendicular to the field, rather than discussing the direction of the force.

(b) Many candidates could not be awarded credit for their sketch drawing because of poor accuracy. Avoidable errors included non-circular 'circles', significant gaps between the start and finish of circles and missing direction arrows. Candidates who made their first circle small were more likely to be able to clearly show an increase in spacing with distance from the wire.

(c) (i) The key to achieving full credit in this question was to consistently identify that the interaction was between the current in one wire and the magnetic field due to the other wire. Weaker candidates talked imprecisely about fields and currents, or simply referenced Newton's third law without explanation.

(ii) After the more difficult part of identifying the direction of force F, a significant number of candidates drew a line of action whose direction missed wire Y.

(iii) Stronger candidates clearly compared magnitudes and directions of the forces, using those words in many cases. Weaker candidates referred to forces being 'the same', which was insufficiently precise.

(iv) Many answers needed to be given with more precision to gain full credit. As in **(c)(i)**, explaining that the current in one wire (X) and the field in the other wire (Y) had both changed direction avoided any ambiguity.

Question 8

(a) Most candidates identified the name of the effect in question.

(b) (i) This question was generally well answered, with candidates knowing how to calculate the work function value.

(ii) Some candidates who achieved full credit in **(b)(i)** did not appreciate that the work function energy needed to be included in the energy equation.

(c) This question tested candidates' understanding of the earlier parts of **(b)**. A correct use of the scales on the graph was also required. Most candidates correctly identified both the threshold frequency and drew the correct line for frequencies above that.

Question 9

(a) (i) Most candidates were able to correctly recall the particle name.

(ii) As a 'show that' question, both working and answer were required, although a unit was not required as it was given in the stem of the question. Weaker candidates often did not clearly show the conversion of the half-life to seconds.

(iii) Most candidates correctly gave the equation linking activity and the number of undecayed nuclei. However, it was common to see candidates mixing up the two methods of calculating that number of undecayed nuclei. Weaker candidates often gave a wrong power of ten in their answer because they were not able to correctly assess whether the mass should be in grams or kilograms, depending on the method used.

(b) (i) A broad range of responses were produced in this question. Some candidates gave good answers and made more than the required number of creditworthy points for full credit. Identification of pair annihilation was the marking point most commonly seen. Weaker candidates referred to either mass being converted to energy, or to the production of gamma rays in a general sense. Stronger candidates identified the total conversion of the pair mass and described the production of a pair of gamma photons for each annihilation, going on to describe what happened to those two photons after production. One aspect that candidates could benefit from having reinforced is that it is the difference in photon arrival times at the detector that is used to identify the tracer position.

(ii) Candidates who took a consistent approach in their explanation avoided the pitfall of contradicting themselves. Stronger candidates focused firstly on the importance of a long enough half-life to allow there to be sufficient activity at the point the sample was inside the body. They then identified that too long a half-life meant that the patient was exposed to harmful radiation unnecessarily. Weaker candidates either regarded the half-life of 110 minutes as being a time during which the procedure had to be completed, or discussed that time period as being without risk to the patient.

Question 10

(a) Some candidates would have benefited from re-reading their answer to this question before moving on. Often answers gave a general picture of the topic without focusing on what this question was actually asking. It was common to see answers that did not mention redshift at all, which reduced the credit available. Weaker candidates were not able to move on from writing about an observer on Earth, whilst stronger candidates discussed the implication of those observations for the more general movement of galaxies in relation to each other.

(b) (i) Many candidates were familiar with the method, starting with a correct equation to link luminosity, radiant flux intensity and distance, to then calculate the value of the distance of the galaxy from the Earth. All data was provided to three significant figures, so answers also needed to be given in that way. Most candidates successfully noted this.

(ii) As in **(b)(i)**, the majority of the candidates successfully answered this question. The most common error was to use the wrong wavelength as the denominator.

(c) (i) This question was also well answered. It was not necessary for the line drawn to physically pass through the origin for full credit to be obtained, as long as the extrapolation was clear and the line was straight.

(ii) Whilst minor spelling errors in Hubble's name were condoned, candidates who described the quantity as a law did not gain credit.

PHYSICS

Paper 9702/51
Planning, Analysis and Evaluation 51

There were too few candidates for a meaningful report to be produced.

PHYSICS

Paper 9702/52
Planning, Analysis and Evaluation 52

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.
- 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.
- Candidates need to understand how to use logarithms (both logarithms to base ten and natural logarithms) correctly, including calculating their uncertainties.
- 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. Some weaker candidates were unsure of the independent and dependent variables in the experiment, while other candidates gave a vague quantity of 'temperature', which could not gain credit. Many candidates were successful in the analysis section, with clear identification of how the constant could be determined. Weaker candidates often suggested a suitable graph, but were not explicit in how the relationship could be proved or how to determine the constants K and Z. To be awarded credit for additional detail, 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 uncertainties, and with finding the gradient and y-intercept of a graph. For some candidates, credit was not awarded because the plotted points were not balanced about the line best fit, 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. Another source of difficulty was determining the percentage uncertainty in n.

In question parts requiring mathematical manipulation, stronger candidates clearly stated the equation used with correct substitution of numbers, and then calculated the answer and included an appropriate 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. A significant number of candidates did not gain credit because they stated that the dependent variable was temperature as opposed to *change* in temperature or $\Delta\theta$. Some candidates also incorrectly stated that $\Delta\theta$ was the independent variable and L was the dependent variable. 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 t would be kept constant. There was additional credit for also stating that A, m and V would be kept constant. Credit is not given for simply stating 'control' t since this is just repeating the stem of the question and does not indicate what is meant by 'control'.

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 that the coil of wire was totally submerged in the oil with a thermometer placed in the oil to measure the temperature. Some weaker candidates incorrectly suggested the use of water baths or Bunsen burners, which could not be given credit.

Candidates needed to explain how the potential difference V was determined. Stronger candidates drew a circuit diagram showing a power supply connected to the wire with a voltmeter in parallel with the wire. A common mistake was to place the voltmeter in series with the power supply and wire. Another error was to place a variable resistor in the circuit and then measure the potential difference across the variable resistor and the wire.

Credit was given for describing how $\Delta\theta$ was determined by measuring the initial temperature of the oil, measuring the final temperature of the oil and then finding the difference between the two temperatures. Additional credit was awarded to candidates who suggested stirring the oil to ensure that the oil was at a uniform temperature or for keeping the initial temperature of the oil constant.

Candidates also gained credit for stating the measuring instruments to measure t and L. Apparatus drawn on its own with no indication of how it will be used, e.g. a drawing of a stopwatch, cannot gain credit. A common error by some candidates was to measure the length of the coil as opposed to the length of the wire. Some candidates gained additional credit for suggesting that the coil should be unwound to measure L. A small number of candidates also gained credit for a description of how the circumference of the coil could be measured and the length calculated by multiplying by the number of turns.

Candidates also needed to state suitable methods to collect values of A and m. Often a micrometer or calipers were suggested to measure the diameter of the wire and then an appropriate equation was given to determine A which included the diameter. Some weaker candidates did not gain credit because they stated '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. There was additional credit 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. A statement of 'repeat measurements of diameter' on its own was not considered sufficient. Many candidates suggested a balance to measure m but did not then describe the method of measuring the mass of an empty container, adding oil to the container, measuring the mass of the container and oil and finding the difference. Candidates should be advised not to write 'a scale' (which can have several meanings) if they intend to refer to a balance.

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. For this experiment, credit was not given for stating that the straight line would pass through the origin (since there would be a y-intercept). Stronger candidates often gave an expression for the y-intercept.

Candidates needed to explain how they would determine a value for the constants K and Z from the experimental results using the gradient and y-intercept. To gain credit, the constants K and Z had to be the subject of the relevant equations. 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, precautions could be taken that were relevant to the potentially hot oil, hot beaker or hot wire, or the potential spillage of the oil. As a precaution against spillage, it was expected that candidates would suggest placing the experiment in a tray or container.

Question 2

(a) Candidates who were mathematically confident were able to work through the algebra and achieve credit. 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 the candidates calculated d^2 correctly. Many candidates also correctly calculated the uncertainty in d^2. A significant minority of candidates incorrectly calculated the uncertainty as 0.4, multiplying the absolute uncertainty in d by 2 (i.e. 2 × 0.2).

(c) (i) The data points were straightforward to plot. It is expected that the data points plotted should be clearly represented. The plotting needed to be within half a small square. This meant that plotting (3.28, 458) on the gridline (3.25, 455), for example, was incorrect since it is more than half a small square out in both the *x*-direction and the *y*-direction. When plotting points, the diameter of each point should be less than half a small square. Candidates need to take greater care over the accuracy of the error bars and 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 stronger candidates drew a line that 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. points that are on grid lines.

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 weaker candidates incorrectly read off the *y*-intercept where the *x*-axis reading was 1.0. Other errors seen included incorrectly dividing the *y* value by mx, inconsistent use of powers of ten between the gradient and the *y*-axis value used, or calculating $mx - y$ to give a positive value.

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 by adding fractional uncertainties.

(d) (i) Credit was not gained for substituting data values from the table. Most candidates realised that the constant *B* was equal to –*y*-intercept. Some candidates did not gain credit since they did not give their values of *B* and *n* to an appropriate number of significant figures, often giving *n* to one significant figure (too few) or sometimes writing five significant figures (too many). Most candidates were able to calculate a value for *n* using the gradient and either the *y*-intercept or *B*. Some candidates who were confused about the negative *y*-intercept corrected their error at this stage but did not then return to **(c)(iv)** to correct the original error. The common error in this question was the determination of units. Most candidates realised that *B* had the unit cm^2, but many candidates did not understand that *n* did not have a unit.

(ii) To gain credit, candidates needed to show their method. Many candidates realised that the percentage uncertainty in the gradient needed to be added to the percentage uncertainty in the *y*-intercept. Only the stronger candidates correctly multiplied their answer by 0.5 to allow for the square root in determining *n*. Some candidates used a maximum or a minimum method – clear working showing how each of the maximum or minimum values was obtained was needed for credit. Where *B* was used, a clear method needed to be shown as to how the maximum or minimum value of *B* was calculated.

(e) It was essential that candidates showed their method of working. Stronger candidates wrote down the equation and clearly substituted in their values. Some weaker candidates were challenged by the negative sign from the *y*-intercept. Weaker candidates often found the final determination of θ from $\sin^2 \theta$ challenging.

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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.
- 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.
- Candidates need to understand how to use logarithms (both logarithms to base ten and natural logarithms) correctly, including calculating their uncertainties.
- 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. Weaker candidates often suggested a suitable graph, but were not explicit in how the relationship could be proved or how to determine the constants *K* and *Q*. To be awarded credit for additional detail, 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 uncertainties, and with finding the gradient and *y*-intercept of a graph. For some candidates, credit was not awarded because the plotted points were not balanced about the line of best fit, 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. Candidates found it difficult to determine the absolute uncertainty in *E*.

In question parts requiring mathematical manipulation, stronger candidates clearly stated the equation used with correct substitution of numbers, and then calculated the answer and included an appropriate 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 *D* would be kept constant. There was additional credit for also stating that *A*, *B*, *L* and *m* would be kept constant. Credit was not given for stating 'control' *D* since this is just repeating the stem of the question and does not indicate what is meant by 'control'.

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 point P, labelled on a bench, with a light gate positioned at P connected to a data logger. Ideally the trolley is drawn with an interrupt card attached so that the speed of the trolley can be measured by the light gate at point P. Some candidates also were given credit here for showing how the block would be held stationary, for example by using a G-clamp. Stronger candidates also thought about the use of a reference marker for the accurate measurement of *s* or *D* and indicated this on the diagram.

Candidates needed to explain how the velocity *v* was determined at point P. A common error was to describe the determination of the average velocity over distance *D*. Candidates should be encouraged to avoid this mistake by carefully reading the question and noting down the meaning of each variable before starting **Question 1**. Many candidates did not gain credit since their descriptions did not contain detail of how *v* is determined. Stronger candidates described an interrupt card (with a measured length) passing through the light gate at P and then stated that *v* = length of card / time measured on data logger.

Candidates also gained credit for suggesting measuring *s*, *L* and *D* with the correct instruments. Apparatus drawn on its own with no indication of how it will be used, e.g. a drawing of calipers, does not gain credit. Candidates should carefully consider which measuring instrument is suitable for the measurement of a length. A micrometer should only be suggested if the measurement is likely to be very small; a micrometer was not appropriate to determine *s* in this experiment.

Candidates also needed to state suitable methods to collect values of *A* and *m*. Some candidates incorrectly assumed that the magnet was cuboid, although the question stated that it was a cylinder. Often a micrometer or calipers were suggested to determine the diameter of the cylindrical magnet and then an appropriate equation was given to determine *A,* including the diameter. Some weaker candidates did not gain credit because they stated 'use a micrometer to determine *A*' or 'use a micrometer to measure the radius of the magnet'. Credit was also not given if the diameter was measured with just $A = \pi r^2$ given, since a description of how *r* is obtained is also required if using that equation for *A*. The physical measurement to determine the radius and/or area is the diameter. Most candidates suggested a balance to measure *m*.

Many candidates stated the use of a Hall probe 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 described, discussing the rotation of the probe so that a maximum reading was obtained or repeating the measurement by reversing the probe and measuring in it in the opposite direction and determining the mean.

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 experiment, credit was not given for stating that the straight line would pass through the origin (since there would be a *y*-intercept). Stronger candidates often gave an expression for the *y*-intercept.

Candidates needed to explain how they would determine a value for the constants *K* and *Q* from the experimental results using the gradient and *y*-intercept. To gain credit, the constants *K* and *Q* had to be the subject of the relevant equations. 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, precautions could be taken to stop the trolley rolling off the bench. Suggestions that were credited included a barrier at the end of the bench or a cushion positioned after point P on the diagram. The suggestion of sand trays on the floor did not gain credit since this was a solution to the trolley falling; it would be better to take precautions to prevent this in the first place.

Question 2

(a) Candidates who were mathematically confident were able to work through the algebra and achieve credit. 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 the candidates calculated $1/I$ correctly. Many candidates also correctly calculated the uncertainty in $1/I$. A minority of candidates incorrectly gave one or more of the $1/I$ values to more than 4 or less than 3 significant figures.

(c) (i) The data points were straightforward to plot. It is expected that the data points plotted should be clearly represented. The plotting needed to be within half a small square. This meant that, for example, plotting (2.22, 6250) on the horizontal gridline (2.22, 6260) was incorrect since it is more than half a small square out in the *y*-direction. When plotting points, the diameter of each point should be less than half a small square. Candidates need to take greater care over the accuracy of the error bars and 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 stronger 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. points that are on grid lines.

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 weaker candidates incorrectly read off the *y*-intercept when the *x*-axis reading was 1.4. Other errors seen included incorrectly dividing the *y* value by *mx* and inconsistent use of powers of ten between the gradient and the *y*-axis value used.

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 by adding fractional uncertainties.

(d) (i) Credit was not gained for substituting data values from the table. Most candidates were able to calculate a value for *E* using the gradient and *Z* using the *y*-intercept. A common error in this question was a power-of-ten error from the gradient, which comes from the candidate not correctly converting the kΩ from the *x*-axis of the graph. Another common error was in the determination of units. Candidates should be encouraged to re-read the beginning of **Question 2** at this point to help them check that their units are correct. The question stated that *E* represented e.m.f and *Z* represented a resistance, therefore the correct units are V and Ω respectively.

(ii) To gain credit in this part, candidates needed to show a clear method. The strongest candidates gained credit here for showing that the absolute uncertainty in *E* is equal to the absolute uncertainty in the gradient plus the 1 / 3 of the absolute uncertainty in E_s. Other strong candidates gained credit by calculating the maximum *E* or minimum *E* and calculating the difference between that and their *E* value to obtain the absolute uncertainty. For this method to be given credit, full substitution of numbers is required including the use of the correct maximum or minimum E_s value within the calculation.

(e) It was essential that candidates showed their method of working. Strong candidates wrote down the equation and clearly substituted in their values. Candidates could gain credit here by error carried forward, and they should be encouraged to continue through to an answer even if they feel that a mistake has been made earlier in the question.