

PHYSICS

Paper 9702/11
Multiple Choice

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

General comments

Candidates should be advised never to spend a disproportionately long time on any one question. They should also be advised to use the spaces on the question paper for their working. Care with units is essential. Prefix errors are a cause of many wrong answers as are corresponding power-of-ten errors. Some candidates would benefit from taking a moment to think whether a numerical answer has a sensible order of magnitude and to check that it makes basic sense.

The candidates found **Questions 4, 20, 31, 32 and 36** difficult.

Comments on specific questions

Question 4

Many candidates chose **B**, but this graph shows a constant systematic error (the difference between the meter reading and the true value is constant). The correct graph is **A**, because the difference between the meter reading and the true value increases with voltage. Graphs **C** and **D** both show varying systematic errors but the meter readings are smaller than the true values.

Question 12

When answering questions involving Newton's third law, candidates should remember that the two forces in a 'Newton pair' must be the same type of force, e.g. both gravitational or both electrical. In this question, forces Q and S are a pair of gravitational forces: Q is the force of the Earth on the box and S is the force of the box on the Earth. Forces P and R are contact forces: P is the force of the ground on the box and R is the force of the box on the ground.

Candidates who did not choose the correct answer **D** often chose **A** or **C**.

Question 20

This equation applies when a gas expands constant pressure, and relates directly to learning outcome 6.2b on the syllabus. Candidates should be encouraged to learn the conditions under which a particular equation applies, as well as the equation itself. If pressure, volume and temperature are all changing then it is much more difficult to calculate the work done on or by the gas.

Question 28

X and Y do appear to have a phase difference of about 90° , but this is not a travelling wave. Candidates needed to read the question carefully to see that it refers to a stationary wave. In a stationary wave, all of the particles within a 'loop' are vibrating in phase with one another, and there is no phase difference between X and Y.

Question 31

Many candidates chose **A**, particularly weaker candidates. This arrow points directly towards a positive charge. Candidates should be reminded that the field lines at any point show the direction of the force on a positive test charge. Here candidates needed to select an arrow that was parallel to the field lines; the correct answer was **B**.

Question 32

The potential difference between the plates is $(60\,000\text{ V m}^{-1} \cdot 0.004\text{ m}) = 240\text{ V}$. The bottom plate is at a potential of -80 V and the electric field is upwards, so the top plate must be at a lower potential than the bottom plate. Therefore a potential of $(-80 - 240) = -320\text{ V}$ is required on the top plate, giving **A** as the correct answer.

Many candidates chose **C**. These candidates had determined the correct potential difference but had not considered the direction of the field. It may be helpful for candidates to remember that the field gives the direction of the force on a positive charge. For a positive charge to experience a force upwards, the top plate must be at a more negative potential than the bottom plate.

Question 36

Candidates found this question difficult. If the ammeter reading is zero, there must be no potential difference across it. One approach is to consider that the potential difference across the resistor with resistance R_2 must equal the potential difference across the resistor with resistance R_4 . Therefore $R_2/(R_1 + R_2) = R_4/(R_3 + R_4)$. Rearranging this gives $R_1R_4 = R_2R_3$.

PHYSICS

Paper 9702/12
Multiple Choice

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

General comments

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Candidates found **Questions 5, 9, 10, 20** and **24** difficult. **Questions 1, 2, 12, 18** and **28** were relatively easy.

Comments on specific questions

Question 5

Candidates found this question difficult, and many chose the incorrect answers **C** and **D**. The true value lies within the range given by the uncertainty, and therefore the stated value is accurate. However, it is not precise because the uncertainty is large. Some candidates would benefit from further work on the distinction between precision and accuracy.

Question 9

The girl has a constant acceleration when she is in the air, and a rapidly changing acceleration when in contact with the springy floor of the trampoline. This is represented by **D**. Many weaker candidates chose **B**, and these candidates had not considered the motion of the girl in the air.

Question 10

This question required careful thought. The relevant equation of motion is $v^2 = u^2 + 2as$ with $v = 0$. If the acceleration a is constant, then $u^2 \propto s$. The correct answer is then $(1.20x)^2$ which is **C**. Weaker candidates often chose **A** because they incorrectly assumed $u \propto s$.

Question 16

The pressure in the liquid is $(800 \text{ N} / 8 \text{ cm}^2 =) 100 \text{ N cm}^{-2}$. The force on each brake is $(100 \text{ N cm}^{-2} \times 12 \text{ cm}^2 =) 1200 \text{ N}$. Many candidates gave the answer as **A**.

Question 20

Air resistance and friction both cause a dissipation of thermal energy, so the rate at which thermal energy is dissipated is $(2100 \times 25 =) 5.3 \times 10^4 \text{ W}$. A large number of candidates chose **A**. These candidates had noticed that the forces were balanced but they needed to think more carefully about energy. The net change during the motion of the car is from chemical energy in the fuel to gravitational potential energy of the car and thermal energy.

Question 22

Many candidates made mistakes with the powers of ten when answering this question. Candidates also needed to read carefully to see that four rods were involved.

Question 23

Many candidates chose **B** because they thought the distance between a compression and a rarefaction was one wavelength. It is important to emphasise to learners that the wavelength is the distance between points in phase, i.e. between one compression and the next compression.

Question 24

Candidates found this question difficult. Many candidates chose **D**. The value of y is equal to y_1 at these points, but they are not the *next* two points at which y is equal to y_1 . There is another value of x at which $y = y_1$ and that is $x = 3\lambda/8$. Careful reference to the diagram might have helped candidates notice this value.

Question 29

To answer this question successfully, candidates needed to realise that the distance between intensity maxima in a stationary wave pattern is half the wavelength of the wave. Many candidates chose **D** because they thought that the measured distance was equal to the wavelength.

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Paper 9702/13
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PHYSICS

Paper 9702/21
AS Level Structured Questions

Key messages

- Candidates need to be able to recall accurately in precise detail all the definitions and laws referred to in the syllabus. A significant amount of credit can be gained by the straightforward recall of knowledge.
- It is usually appropriate to start a calculation by stating the relevant symbol equation. When appropriate, candidates should be encouraged to represent quantities by using the symbols given in the syllabus.
- It is important not to prematurely round values to two significant figures at intermediate stages within a calculation as this may lead to an incorrect final answer. Candidates should instead wait until they obtain a final answer before rounding to an appropriate number of significant figures.
- Candidates need to present clearly all of their working in extended mathematical questions. Well-presented calculations show all the discrete steps in a logical order. This will often enable marks to be gained for the working even when a mistake has been made with the final answer.

General comments

The paper contained questions which enabled candidates at all levels to show their knowledge. The majority of candidates were able to give the basic formulae required for the calculations on this paper.

The general quality of writing and presentation were usually good. However, in some of the numerical questions many candidates did not state initial equations or give an equation in full, assuming the reader would understand which quantity was being calculated purely from the combination of numbers.

The level of detail was often insufficient, especially in the parts requiring longer responses such **4(c)(ii)** and **7(c)**. A few candidates struggled with how to answer questions with 'define...' or 'state...'. Guidance on the meaning of the command words is given in the syllabus.

There was no indication that candidates had insufficient time, with full answers being given to the last part of the last question by the majority of candidates.

Comments on specific questions

Question 1

- (a) The majority of candidates gave a correct definition for this straightforward opening question.
- (b) (i) The correct answer was calculated by the majority of candidates. A small number of candidates were either unable to transpose the equation or calculated the square root instead of the cube root.
- (ii) A small number of candidates were able to determine the percentage uncertainty and hence the actual uncertainty in the value of the diameter d . The majority of candidates did not add the given percentage uncertainties for the terms in the expression for d and then divide by three. Those who successfully calculated the percentage uncertainty were generally able to calculate the absolute uncertainty. A significant number did not gain the last mark, either because they gave the value of d to too few significant figures (0.12 instead of 0.121) or they gave the absolute uncertainty to too many significant figures (0.0036 instead of 0.004). A significant number used the percentage

uncertainty as the absolute uncertainty and gave an incorrect relationship of $3\Delta d/d = (0.04/7.5 + 0.05/8100)$.

Question 2

- (a) The majority of candidates appreciated that the required answer involved the force on a charge. A significant number of candidates wrote vague statements about an electric field such as 'the region where a charge experiences a force' showing that they have not learned the definition of electric field strength.
- (b) (i) The vast majority of answers were correct. A small minority did not convert the length of the plates into metres or used the vertical distance between the plates.
- (ii) The majority of candidates gave the correct formula for the electric field strength. A minority substituted a wrong value for the distance, the most common being half the correct value, or did not convert the separation between the plates from centimetres to metres.
- (iii) Many candidates completed this part correctly. A few did not gain full credit as they did not state either the charge or the mass of the electron. These were essential as this is a 'show that' question. A number of candidates tried to use equations of motion here without success.
- (iv) The majority of candidates found this part challenging. A significant number used the horizontal velocity as the initial velocity of the electron in the vertical direction. Many of those who calculated the distance travelled by the electron in the vertical direction could not be awarded full credit because they did not subtract the value of 1.4 cm from 2.0 cm to find the distance from the plate.
- (v) Very few candidates gave answers that were a comparison between the gravitational force and the electric force. Most stated only that the gravitational force is negligible. Some candidates wrongly thought that the gravitational force does not act in a vacuum. Others referred to gravitational 'effects' without commenting on either force or acceleration.
- (vi) The majority of candidates gave at least one correct graph. The most common errors were to draw curves for either the horizontal or vertical velocities.

Question 3

- (a) The majority gave a correct statement.
- (b) (i) The majority of candidates were able to give a correct equation for the spring constant. A small minority did not convert the compression given in centimetres into metres. Some candidates used the weight of the block for the force that produced the compression.
- (ii) The majority of candidates gave an adequate solution to explain that the work done to compress the spring is 0.48 J. Some candidates gained no credit for this 'show that' question by producing an unexplained factor of 0.5 conveniently half-way through their working to achieve the required answer. It is important in 'show that' questions for the candidate to make it clear the physics that has been used to arrive at the answer. A few gave answers such as " $12 \times 0.04 = 0.48 \text{ J}$ " without making it clear where the value of 12 had come from. A significant number gave an answer of " $W = F \times d = 24 \times 0.04 = 0.96$ then $0.96/2 = 0.48 \text{ J}$ ". This solution does not make it clear why it is necessary to divide by 2.
- (iii) 1. This question was well answered by the vast majority of candidates.
2. This question was difficult and the correct answer was obtained by a small minority of candidates. Some incorrect answers linked the difference in the kinetic energy or in the potential energy directly with the resistive force. Some candidates attempted to calculate an acceleration by assuming that the acceleration was constant. In some cases the presentation of the answers was difficult to follow because there was a string of numbers with no clear subject to form an equation or no explanation where the subject of an equation was suddenly changed.
- (iv) Most candidates answered question this correctly.

Question 4

- (a) Answers to this question were generally incomplete. A significant number have an idea of the meaning of frequency without being able to express it accurately. A common answer that was not accepted was ‘the number of oscillations per second’. The phrase ‘the number of complete oscillations per unit time’ should be avoided because it implies that the frequency must be an integer value. Very few candidates referred to the fact that the oscillation is at a point or of a particle on the wave.
- (b) There were many references to ‘wavelength’ when the values being used were for a time period. Some candidates wrote down all of the correct figures but with no explanation of the subject being calculated, either in words or symbols. In a ‘show that’ question it is important to justify each step to gain full credit.
- (c) (i) The majority of candidates were able to start with the correct expression from the Formulae page. A significant number of candidates were unable to substitute values into the formula to agree with the situation described in the question. Candidates needed to know that when the source is approaching the observer the denominator of the formula must be $330 - v_s$. Some candidates substituted the speed of sound for v_s and some tried to use $v = f\lambda$.
- (ii) A large number of candidates simply referred to the position of the source relative to the observer affecting the frequency. Statements such as ‘the closer the speaker is to the observer the higher the frequency’ were not given credit. Other statements that were not relevant suggested that the sound would be louder or softer, or else made no reference to how the frequency heard by the observer differed from the frequency of the source.

Question 5

- (a) The majority of candidates were able to gain at least one mark. Many candidates used the word ‘bending’ rather than ‘spreading’ and thus did not distinguish between refraction and diffraction. Another common error was to state ‘when the wave passes through an obstacle’, rather than to mention the edge of an obstacle.
- (b) This was done well by most candidates. Some candidates would have benefited from providing more explanation to accompany their figures. A common error was to confuse line spacing with the number of lines per unit length. Some calculated the former and then gave the latter as their final answer.
- (c) The majority of candidates correctly stated that the wavelength of red light is longer than that of the laser light. A significant number of those who did state that the wavelength of the red light is longer went on to wrongly suggest that there would be more orders due to there being less diffraction.

Question 6

- (a) The correct statement was given by a minority of candidates. Most candidates related potential to work done or energy transfer but then did not write ‘per unit charge’.
- (b) (i) 1. Setting the resistance of R_3 to zero creates a short circuit, but a large number of candidates treated it as an open circuit and therefore incorrectly calculated the resistance to be $18\ \Omega$ rather than $6.0\ \Omega$.
2. The majority were able to combine resistors in parallel and calculate the correct current.
- (ii) The majority calculated the change in power correctly.
- (c) The majority of candidates calculated the correct answer for the ratio of average drift speeds. The inverse ratio was sometimes given as the answer due to errors in manipulating fractions. A common error was to substitute two different values of current for the series resistors.

Question 7

- (a) A minority of candidates were able to give a correct difference. A significant number compared the mass of the two types of particle by comparing a proton with an electron. However, this comparison is not valid for all hadrons and leptons. Some stated that hadrons experience the strong force but then went on to suggest that only leptons experience the weak force.
- (b) (i) This question was generally well answered. Only a very small minority gave the answers the wrong way round.
- (ii) There were many correct answers. The majority of incorrect answers were due either to a lack of knowledge of the constituents of an α -particle or to incorrectly combining the answers in (b)(i) with the number of protons and neutrons in the α -particle.
- (c) (i) A minority of candidates gave the correct response. Very few candidates compared the size of the nucleus with the size of the whole atom. There was a significant number who seemed to have misread the question and gave descriptions or properties of an α -particle.
- (ii) Only a small number of candidates referred correctly to the both the charge and mass of an atom. Very few referred to the nucleus and many described the concentration of the charge and/or mass to be in the 'centre of the atom'. There were again many answers given in terms of the properties of α -particles.

PHYSICS

<p>Paper 9702/22 AS Level Structured Questions</p>
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Key messages

- Candidates need to be able to recall accurately in precise detail all the definitions and laws referred to in the syllabus. A significant amount of credit can be gained by the straightforward recall of knowledge.
- It is usually appropriate to start a calculation by stating the relevant symbol equation. When appropriate, candidates should be encouraged to represent quantities by using the symbols given in the syllabus.
- It is important not to prematurely round values to two significant figures at intermediate stages within a calculation as this may lead to an incorrect final answer. Candidates should instead wait until they obtain a final answer before rounding to an appropriate number of significant figures.
- Candidates need to present clearly all of their working in extended mathematical questions. Well-presented calculations show all the discrete steps in a logical order. This will often enable marks to be gained for the working even when a mistake has been made with the final answer.

General comments

All of the questions had parts that were accessible to weaker candidates as well as other more challenging parts that discriminated between the candidates. There were many high-scoring scripts that showed a good understanding of the topics across the full range of the syllabus.

The candidates who performed best in the examination were able to apply their knowledge and understanding to unfamiliar situations. It is therefore important that candidates practise answering a wide variety of questions as they develop their understanding of the different topics.

In **Question 4**, a significant number of candidates did not seem to fully understand the theory behind the production of a fringe pattern due to double-slit interference. This may indicate that candidates would benefit from further study and work on practice questions when studying topic 15.3 (two-source interference).

There was no evidence that candidates were short of time in the examination.

Comments on specific questions

Question 1

- (a) (i) This was a straightforward introductory part of the question that was usually answered correctly. Weaker candidates sometimes confused pressure and stress and so inappropriately referred to cross-sectional area in their definition. A very small minority wrongly defined pressure as ‘the force on an area’.
- (ii) Most candidates were able to show the correct calculation.
- (b) The manipulation of base units is generally well understood. The strongest candidates clearly listed the base units of each quantity prior to their substitution into the equation. A small minority of candidates squared each side of the equation, but then forgot to take a square root at the end of their calculation to get the final answer. It is essential in this type of calculation to methodically write down each step in order to avoid making simple errors with the indices of the units.

Question 2

- (a) Most candidates were able to recall and apply the formula for a change in gravitational potential energy. A small minority gave their final answer to only one significant figure (two decimal places), perhaps because they did not realise the difference between significant figures and decimal places.
- (b) This was a 'show that' question in which candidates were given the final answer and asked to show that it was correct. In this type of question, it is essential to explicitly show all the intermediate steps leading up to the answer. Only the stronger candidates appreciated that the correct method of calculation was to equate the gain in kinetic energy to the loss of gravitational potential energy. It was inappropriate to use equations of uniform acceleration directly because the acceleration of the ball is not uniform as it moves down the curved track.
- (c) (i) Many answers did not take into account the change in direction of the ball's velocity. The correct change in velocity was determined by adding, not subtracting, the initial speed and the final speed of the ball. The weakest candidates often confused the change in velocity of the ball with its final velocity. Some candidates calculated a final speed of the ball that was greater than its initial speed which should have then made them realise that they had performed an incorrect calculation.
- (ii) There were two possible methods of calculation. The most common approach was to divide the change in momentum of the ball by the contact time. The other approach was to multiply the average acceleration of the ball by its mass.
- (d) Correct answers stated that the collision was inelastic and clearly explained why this was so. Common errors included explaining that the momentum had been reduced or explaining that there was a decrease of energy without reference to kinetic energy.
- (e) This question was challenging, and many candidates wrongly believed that the work done against friction was equal to the increase in kinetic energy of the ball. Others often incorrectly thought the work done against friction was equal to the average frictional force.

Question 3

- (a) Most answers were fully correct. Weaker candidates sometimes thought that an object can only be in equilibrium when there are no forces and no moments acting. It is important that candidates use the correct physics terms in their statements. They should refer to the resultant moment or resultant torque being zero and should avoid phrases such as 'turning effect'. They should also refer to the resultant force being zero rather than saying that 'the forces are balanced' or 'the forces cancel'.
- (b) (i) The great majority of answers were correct. A common mistake was to use the wrong trigonometric function to calculate the vertical component of the force.
- (ii) Most candidates could calculate at least two of the three moments about point A and usually an attempt was made to calculate the answer by equating the sum of the clockwise moments to the anticlockwise moment. A common mistake was to substitute one of the moments into the equation with an incorrect sign.
- (c) (i) The vast majority of candidates found this part of the question straightforward. Candidates should be encouraged to use the quantity symbols listed in the syllabus; in this case the symbol given for the Young modulus is E . If candidates use different, non-standard symbols it is difficult for Examiners to understand the calculation when the subsequent numerical working contains errors.
- (ii) This part of the question discriminated well between the candidates. Stronger candidates found it very straightforward. Candidates of average ability tended to use the total force on the wire in their calculation instead of the increase in force. Weaker candidates were often unable to recall the correct expression for the cross-sectional area of a wire.

Question 4

- (a) Candidates needed to give a precisely worded statement. Diffraction occurs when waves pass through an aperture or pass around an obstacle. It is incorrect to refer to waves passing through an obstacle. The waves should also be described as spreading. The term 'bending' should be avoided as it could be interpreted as referring to refraction rather than diffraction.
- (b) (i) Many candidates did not fully understand the physics behind the production of a fringe pattern due to double-slit interference. It was insufficient to state only that the path difference should be $n\lambda$ or that the phase difference should be $360^\circ n$ because these are the general conditions for any bright fringe rather than for the particular bright fringe at point X.
- (ii) The stated path difference at point Y was rarely correct. Although the question specifically asked for the answer to be in units of nm, some candidates gave their answer in units of m.
- (iii) The correct symbol equation was usually given. The value of the fringe width was often substituted as 2.0 mm which is only half of the correct value. There were a significant number of power-of-ten errors made in this calculation.
- (iv) Candidates needed to be explicit about which fringes they were describing. Simply referring to 'fringes' in this question could mean either dark fringes or bright fringes. Some candidates understood that the bright fringes would get darker, but very few also realised that the dark fringes would get brighter. When candidates are asked to 'compare' they should give any similarities as well as any differences. In this case, credit was given for mentioning that the separation of the fringes would be the same.

Question 5

- (a) A precise statement of the law was needed. Common mistakes included referring to just electromotive force rather than the total electromotive force in a closed circuit and referring to just potential difference rather than the total potential difference in a closed circuit. The weakest candidates sometimes stated Kirchhoff's first law.
- (b) (i) The simplest way to calculate the answer was to obtain, from the graphs, each of the lamp currents at a potential difference of 6.0 V and to then add those two currents. A common error was to obtain each lamp current either at 6.8 V or at 8.0 V. Some candidates calculated the answer by a more indirect method that involved using the graphs to find the individual resistances of the lamps and then using the total external resistance to find the current in the battery.
- (ii) This was a straightforward calculation for well-prepared candidates. Weaker candidates tended to confuse the internal resistance with either the external resistance or the total circuit resistance.
- (iii) This part of the question was well done. A minority of candidates wrongly calculated the resistances of the lamps at a potential difference of either 6.8 V or 8.0 V rather than at the correct potential difference of 6.0 V. A small minority either incorrectly calculated the lamp resistances from the gradients of the graphs or else wrongly expressed the answer to only one significant figure. Although the ratio was expressed as a fraction in the question, it was expected that candidates would fully work out the numerical value of the ratio as 1.9 rather than leaving their answer expressed as a numerical fraction of 13/7.
- (iv) 1. Most candidates could recall an expression for electrical power, although some confused the total power produced by the battery (2.7 W) with the useful output power from the battery (2.4 W).
2. This part of the question discriminated well. Weaker candidates were often able to state a general word equation for efficiency, but were then unable to apply it to the question. Some of the incorrect answers were too small or too large in value to be plausible. Candidates should always be encouraged to quickly check their working for a simple error when their final answer is clearly incorrect.

Question 6

- (a) The candidates could state any one of a variety of points of difference between a hadron and a lepton. A misconception given in some answers was that all leptons have less mass than all hadrons. Some of the weakest candidates listed examples of hadrons and leptons rather than stating a difference between them.
- (b) (i) Many candidates were able to state the correct symbol, nucleon number and proton number for the positron. The remainder of the equation describing a neutrino was often incorrect.
- (ii) This part of the question required only a simple recall of knowledge. The most common error was to just state 'nuclear force' without a reference to 'weak'. Other common incorrect answers included 'beta decay' and 'strong nuclear force'.
- (iii) The most common correct answers were momentum, charge and mass-energy. Many weaker candidates wrongly stated that mass or energy were separately conserved.
- (c) Most candidates could state the correct quark composition of a proton. However, a significant number were unable to recall the charge on each of the quarks. It should be noted that the charge on an up quark is $+\frac{2}{3}e$ (rather than just $+\frac{2}{3}$) and that the charge on a down quark is $-\frac{1}{3}e$ (rather than just $-\frac{1}{3}$).

PHYSICS

Paper 9702/23
AS Level Structured Questions

Key messages

- Candidates need to be able to recall accurately in precise detail all the definitions and laws referred to in the syllabus. A significant amount of credit can be gained by the straightforward recall of knowledge.
- It is usually appropriate to start a calculation by stating the relevant symbol equation. When appropriate, candidates should be encouraged to represent quantities by using the symbols given in the syllabus.
- It is important not to prematurely round values to two significant figures at intermediate stages within a calculation as this may lead to an incorrect final answer. Candidates should instead wait until they obtain a final answer before rounding to an appropriate number of significant figures.
- Candidates need to present clearly all of their working in extended mathematical questions. Well-presented calculations show all the discrete steps in a logical order. This will often enable marks to be gained for the working even when a mistake has been made with the final answer.

General comments

The paper contained questions which enabled candidates at all levels to show their knowledge. The majority of candidates were able to give the basic formulae required for the calculations on this paper.

The general quality of writing and presentation were usually good. However, in some of the numerical questions many candidates did not state initial equations or give an equation in full, assuming the reader would understand which quantity was being calculated purely from the combination of numbers.

The level of detail was often insufficient, especially in the parts requiring longer responses such **4(c)(ii)** and **7(c)**. A few candidates struggled with how to answer questions with 'define...' or 'state...'. Guidance on the meaning of the command words is given in the syllabus.

There was no indication that candidates had insufficient time, with full answers being given to the last part of the last question by the majority of candidates.

Comments on specific questions

Question 1

- (a) The majority of candidates gave a correct definition for this straightforward opening question.
- (b)(i) The correct answer was calculated by the majority of candidates. A small number of candidates were either unable to transpose the equation or calculated the square root instead of the cube root.
- (ii) A small number of candidates were able to determine the percentage uncertainty and hence the actual uncertainty in the value of the diameter d . The majority of candidates did not add the given percentage uncertainties for the terms in the expression for d and then divide by three. Those who successfully calculated the percentage uncertainty were generally able to calculate the absolute uncertainty. A significant number did not gain the last mark, either because they gave the value of d to too few significant figures (0.12 instead of 0.121) or they gave the absolute uncertainty to too many significant figures (0.0036 instead of 0.004). A significant number used the percentage

uncertainty as the absolute uncertainty and gave an incorrect relationship of $3\Delta d/d = (0.04/7.5 + 0.05/8100)$.

Question 2

- (a) The majority of candidates appreciated that the required answer involved the force on a charge. A significant number of candidates wrote vague statements about an electric field such as 'the region where a charge experiences a force' showing that they have not learned the definition of electric field strength.
- (b) (i) The vast majority of answers were correct. A small minority did not convert the length of the plates into metres or used the vertical distance between the plates.
- (ii) The majority of candidates gave the correct formula for the electric field strength. A minority substituted a wrong value for the distance, the most common being half the correct value, or did not convert the separation between the plates from centimetres to metres.
- (iii) Many candidates completed this part correctly. A few did not gain full credit as they did not state either the charge or the mass of the electron. These were essential as this is a 'show that' question. A number of candidates tried to use equations of motion here without success.
- (iv) The majority of candidates found this part challenging. A significant number used the horizontal velocity as the initial velocity of the electron in the vertical direction. Many of those who calculated the distance travelled by the electron in the vertical direction could not be awarded full credit because they did not subtract the value of 1.4 cm from 2.0 cm to find the distance from the plate.
- (v) Very few candidates gave answers that were a comparison between the gravitational force and the electric force. Most stated only that the gravitational force is negligible. Some candidates wrongly thought that the gravitational force does not act in a vacuum. Others referred to gravitational 'effects' without commenting on either force or acceleration.
- (vi) The majority of candidates gave at least one correct graph. The most common errors were to draw curves for either the horizontal or vertical velocities.

Question 3

- (a) The majority gave a correct statement.
- (b) (i) The majority of candidates were able to give a correct equation for the spring constant. A small minority did not convert the compression given in centimetres into metres. Some candidates used the weight of the block for the force that produced the compression.
- (ii) The majority of candidates gave an adequate solution to explain that the work done to compress the spring is 0.48 J. Some candidates gained no credit for this 'show that' question by producing an unexplained factor of 0.5 conveniently half-way through their working to achieve the required answer. It is important in 'show that' questions for the candidate to make it clear the physics that has been used to arrive at the answer. A few gave answers such as " $12 \times 0.04 = 0.48 \text{ J}$ " without making it clear where the value of 12 had come from. A significant number gave an answer of " $W = F \times d = 24 \times 0.04 = 0.96$ then $0.96/2 = 0.48 \text{ J}$ ". This solution does not make it clear why it is necessary to divide by 2.
- (iii) 1. This question was well answered by the vast majority of candidates.
2. This question was difficult and the correct answer was obtained by a small minority of candidates. Some incorrect answers linked the difference in the kinetic energy or in the potential energy directly with the resistive force. Some candidates attempted to calculate an acceleration by assuming that the acceleration was constant. In some cases the presentation of the answers was difficult to follow because there was a string of numbers with no clear subject to form an equation or no explanation where the subject of an equation was suddenly changed.
- (iv) Most candidates answered question this correctly.

Question 4

- (a) Answers to this question were generally incomplete. A significant number have an idea of the meaning of frequency without being able to express it accurately. A common answer that was not accepted was ‘the number of oscillations per second’. The phrase ‘the number of complete oscillations per unit time’ should be avoided because it implies that the frequency must be an integer value. Very few candidates referred to the fact that the oscillation is at a point or of a particle on the wave.
- (b) There were many references to ‘wavelength’ when the values being used were for a time period. Some candidates wrote down all of the correct figures but with no explanation of the subject being calculated, either in words or symbols. In a ‘show that’ question it is important to justify each step to gain full credit.
- (c) (i) The majority of candidates were able to start with the correct expression from the Formulae page. A significant number of candidates were unable to substitute values into the formula to agree with the situation described in the question. Candidates needed to know that when the source is approaching the observer the denominator of the formula must be $330 - v_s$. Some candidates substituted the speed of sound for v_s and some tried to use $v = f\lambda$.
- (ii) A large number of candidates simply referred to the position of the source relative to the observer affecting the frequency. Statements such as ‘the closer the speaker is to the observer the higher the frequency’ were not given credit. Other statements that were not relevant suggested that the sound would be louder or softer, or else made no reference to how the frequency heard by the observer differed from the frequency of the source.

Question 5

- (a) The majority of candidates were able to gain at least one mark. Many candidates used the word ‘bending’ rather than ‘spreading’ and thus did not distinguish between refraction and diffraction. Another common error was to state ‘when the wave passes through an obstacle’, rather than to mention the edge of an obstacle.
- (b) This was done well by most candidates. Some candidates would have benefited from providing more explanation to accompany their figures. A common error was to confuse line spacing with the number of lines per unit length. Some calculated the former and then gave the latter as their final answer.
- (c) The majority of candidates correctly stated that the wavelength of red light is longer than that of the laser light. A significant number of those who did state that the wavelength of the red light is longer went on to wrongly suggest that there would be more orders due to there being less diffraction.

Question 6

- (a) The correct statement was given by a minority of candidates. Most candidates related potential to work done or energy transfer but then did not write ‘per unit charge’.
- (b) (i) 1. Setting the resistance of R_3 to zero creates a short circuit, but a large number of candidates treated it as an open circuit and therefore incorrectly calculated the resistance to be $18\ \Omega$ rather than $6.0\ \Omega$.
2. The majority were able to combine resistors in parallel and calculate the correct current.
- (ii) The majority calculated the change in power correctly.
- (c) The majority of candidates calculated the correct answer for the ratio of average drift speeds. The inverse ratio was sometimes given as the answer due to errors in manipulating fractions. A common error was to substitute two different values of current for the series resistors.

Question 7

- (a) A minority of candidates were able to give a correct difference. A significant number compared the mass of the two types of particle by comparing a proton with an electron. However, this comparison is not valid for all hadrons and leptons. Some stated that hadrons experience the strong force but then went on to suggest that only leptons experience the weak force.
- (b) (i) This question was generally well answered. Only a very small minority gave the answers the wrong way round.
- (ii) There were many correct answers. The majority of incorrect answers were due either to a lack of knowledge of the constituents of an α -particle or to incorrectly combining the answers in (b)(i) with the number of protons and neutrons in the α -particle.
- (c) (i) A minority of candidates gave the correct response. Very few candidates compared the size of the nucleus with the size of the whole atom. There was a significant number who seemed to have misread the question and gave descriptions or properties of an α -particle.
- (ii) Only a small number of candidates referred correctly to the both the charge and mass of an atom. Very few referred to the nucleus and many described the concentration of the charge and/or mass to be in the 'centre of the atom'. There were again many answers given in terms of the properties of α -particles.

PHYSICS

Paper 9702/31
Advanced Practical Skills 1

Key messages

- If a measurement is a static measurement, such as measuring the length of a resistance wire, or the steady reading on an ammeter, there is often little value in repeating the measurement. If the measurement is 'dynamic' (e.g. the height a table-tennis ball bounces) or a degree of judgement is needed in deciding when to take a measurement (e.g. deciding when a mass oscillating on the end of a spring starts or completes an oscillation) then measurements should always be repeated and an average value calculated.
- In order to calculate the percentage (or fractional) uncertainty in a measurement, some judgement has to be made about the absolute uncertainty of the measurement. Candidates often just use the precision of an instrument being used. Estimating the absolute uncertainty should also take into account the effect of extraneous influences (e.g. draughts and changes in temperature), uncertainties in judgement (e.g. when judging the start or finish of an oscillation) and even uncertainties caused by the act of measurement itself (e.g. putting a cold thermometer into a beaker of hot liquid will cool the liquid very slightly).
- Many candidates find it difficult to choose scales that make good use of the graph grid. The aim should be to occupy the majority of the graph grid. If less than half of the grid is occupied in one direction, the range of the corresponding axis can be halved to make better use of the grid.
- To score highly on **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 'avoid parallax error' or 'use more precise measuring instruments' will not usually gain credit without further detail. Candidates should be encouraged to write about four different problems and consequently four different solutions to address these problems, and should not try to state four solutions to the same problem.

General comments

There was no evidence that Centres had any difficulties in providing the equipment required for use by the candidates. 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 'extra' 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.

Comments on specific questions

Question 1

- (b) Many candidates stated a value of time within range and with a unit. Most candidates were able to show their repeated readings and repeated two sets of at least five oscillations. A few candidates were not awarded credit because they either read to the nearest second or omitted the units of seconds.

(c) Most candidates calculated values for k correctly. A few candidates rounded their answers incorrectly. Many candidates recorded their calculated values for k to an appropriate number of significant figures dependent on their raw times. Other candidates generally either stated too many significant figures or gave the calculated value to one significant figure.

(e) Most candidates were able to set up the apparatus without assistance and collect six sets of values of $(h - h_1)$ and T , and in many cases the results showed a correct trend. Some candidates showed an incorrect trend in their tabulated results, most likely because they had read the ruler incorrectly.

Many candidates did not extend their range of $(h - h_1)$ values to over 30 cm, so they did not make the best use of the apparatus available to them.

Some candidates were awarded credit for using the correct column headings in their tables, giving both the quantity recorded and suitable units for each quantity, with the two separated by a solidus, or with the units placed in brackets. Some candidates either omitted the units or the separating mark.

Many candidates recorded their raw values for $(h - h_1)$ to the nearest millimetre. Some candidates incorrectly stated their y values to the nearest centimetre, or presented trailing zeros to a greater precision than 1 mm when the measuring instrument provided (a ruler) can read only to the nearest millimetre.

(f) (i) The size and scale of the graph axes chosen was appropriately chosen by most candidates and the labelling was done correctly. In many cases, the plotted points occupied more than half the graph grid available and the scale was easy to read. Some candidates 'compressed' the axes, particularly the y -axis. A few candidates plotted the wrong graph (e.g. T versus h_1) or, in rare cases, omitted the labels.

Some graphs were drawn with awkward scales (e.g. in multiples of 3). As well as losing credit for the axes, these candidates often go on to plot points incorrectly and make mistakes in the determination of the y -intercept and gradient.

Some candidates plotted their points on the graph grid with great care. Others needed to draw the plotted points so that the diameters of the points were equal to, or less than, half a small square (a small cross is recommended). Many candidates used points with a diameter greater than half a small square. Many points were incorrectly plotted (e.g. 0.606 was plotted as 0.66) or candidates did not take into account the third significant figure of the value to be plotted.

Some candidates can improve by plotting the points more accurately and by ensuring they use a sharp pencil and a straight ruler. If a point seems anomalous, candidates should be encouraged to repeat the measurement to check that an error in recording has not been made. If such a point is ignored in assessing the line of best fit, the anomalous point should be labelled clearly, e.g. by circling the point.

(ii) Many candidates were able to draw a carefully considered line of best fit. There should be a balanced distribution of points either side of the line along the entire length. Some lines needed rotation to give a better fit, or an anomalous point needed to be identified to justify the line drawn. Some candidates lost credit for lines that were kinked in the middle (candidates used too small a ruler), by drawing a double line (broken pencil tip) or by drawing freehand lines without the aid of a ruler.

Candidates are encouraged to use a transparent 30 cm ruler when establishing the position of their line of best fit, and they are encouraged not to join the first and last points on the graph without considering the distribution of the other points.

(iii) Many candidates used a suitably large triangle to calculate the gradient, gaining credit for correct read-offs, and substituted into $\Delta y / \Delta x$ to get a negative numerical answer. Other candidates needed to check that the read-offs used were within half a small square of the line of best fit and show clearly the substitution into $\Delta y / \Delta x$ (not $\Delta x / \Delta y$). The equation $m(x - x_1) = (y - y_1)$ should be shown with substitution of read-offs. Candidates needed also to check that the triangle for calculating the gradient was large enough (the hypotenuse should be greater than half the length of the line drawn).

Some candidates were able to correctly read off the y -intercept at $x = 0$ directly from the graph. Some candidates incorrectly read off the y -intercept when there was a false origin.

Many candidates correctly substituted a read-off into $y = mx + c$ to determine the y -intercept. Others needed to check that the point chosen was actually on the line of best fit and not just a point from the table.

- (g) Many candidates recognised that P was equal to the value of the gradient and Q was equal to the value of the intercept. Many candidates recorded a value with consistent units in range for P (s m^{-1}) and Q (s). Some candidates stated incorrect units, e.g. P in $\text{s}^{-1} \text{m}^{-1}$, while others omitted to give units.

Question 2

- (a) (i) Some candidates measured the diameter of the wire using a micrometer screw gauge so that the D values were stated to the nearest 0.01 mm, with a consistent unit and in range. Many candidates misread the micrometer screw gauge so that their reading was out of range, stated inconsistent units (e.g. 0.15 cm instead of 0.15 mm) or stated the reading to the nearest 0.1 mm.

- (ii) Many candidates were familiar with the equation for calculating percentage uncertainty and stated a suitable absolute uncertainty in the value of D , typically 0.01 mm. This was a static reading and an appropriate uncertainty was equal to the smallest division on the micrometer screw gauge. A few candidates stated the uncertainty to be too large (0.1 mm) because the working and units were unclear, e.g. 0.01/0.015 which was interpreted as 0.01 cm/0.015 cm.

Some candidates repeated their readings and correctly gave the uncertainty in D as half the range. Some candidates did not halve the range.

- (c) (iii) Some candidates correctly recorded the current with a consistent unit. Many candidates stated units that were not consistent with the numerical answer, e.g. 60 A instead of 60 mA, or omitted the unit.

- (iv) Many candidates stated the voltage reading in the appropriate range and with a consistent unit. A few candidates omitted a unit or misread the voltmeter.

- (d) (i) Most candidates correctly measured the wire B-C to be larger in diameter than the initial wire A-B.

- (ii) Many candidates were able to calculate G correctly and give a consistent unit. A few candidates confused the quantities D and d , omitted units or rounded their answer incorrectly.

- (iii) Some candidates correctly justified the significant figures they had given for the value of G , by reference to the number of significant figures used in their raw D and d readings. Many candidates gave reference to just 'raw' readings without stating what the raw readings were. A minority of candidates stated that 'three significant figures were used to give a more accurate value of G ', which does not actually justify the number used.

- (f) (i) The majority of candidates recorded a second value of V and with a value of voltage more than that in the first case.

- (ii) Most candidates recorded a second value of d .

- (g) (i) Many candidates were able to calculate k for the two sets of data, showing their working clearly. The most common error was incorrectly rearranging the equation to calculate k (using G/V instead of V/G).

- (ii) Some candidates calculated the percentage difference between their two values of k , and then tested it against a specified numerical percentage uncertainty. This was accepted as long as the value was a reasonable reflection of the percentage uncertainty of this experiment. Any criterion above 30% needed to be fully justified. Many candidates omitted any sort of criterion. General statements such as 'this is valid because the values are close to each other' were not credited.

- (h) Many candidates recognised that two sets of data were insufficient to draw a valid conclusion. Other commonly stated problems that gained credit included 'difficult to measure the diameter as it was awkward to place the micrometer screw gauge around the wire' and 'difficult to obtain the same value of I because the rheostat movement was not precise enough'.

Credit is not given for suggestions that could be carried out in the original experiment, such as repeating measurements. Vague or generic answers such as 'too few readings', 'difficult to measure d ' (without stating a reason), 'systematic error', 'parallax error', 'air conditioning', 'turn off air con', 'faulty apparatus' or 'use an assistant' are not given credit. Some improvements could not gain credit unless there was detailed clarification. For example, instead of just stating that the crocodile clips should be cleaned, the candidate is encouraged to explain how they would do this (e.g. by using sandpaper).

The key to this section is for candidates to identify genuine problems associated with setting up this experiment and in obtaining readings. Candidates are encouraged to suggest detailed practical solutions that either improve technique or give more reliable data.

PHYSICS

Paper 9702/33
Advanced Practical Skills 1

Key messages

- If a measurement is a static measurement, such as measuring the length of a resistance wire, or the steady reading on an ammeter, there is often little value in repeating the measurement. If the measurement is 'dynamic' (e.g. the height a table-tennis ball bounces) or a degree of judgement is needed in deciding when to take a measurement (e.g. deciding when a mass oscillating on the end of a spring starts or completes an oscillation) then measurements should always be repeated and an average value calculated.
- In order to calculate the percentage (or fractional) uncertainty in a measurement, some judgement has to be made about the absolute uncertainty of the measurement. Candidates often just use the precision of an instrument being used. Estimating the absolute uncertainty should also take into account the effect of extraneous influences (e.g. draughts and changes in temperature), uncertainties in judgement (e.g. when judging the start or finish of an oscillation) and even uncertainties caused by the act of measurement itself (e.g. putting a cold thermometer into a beaker of hot liquid will cool the liquid very slightly).
- Many candidates find it difficult to choose scales that make good use of the graph grid. The aim should be to occupy the majority of the graph grid. If less than half of the grid is occupied in one direction, the range of the corresponding axis can be halved to make better use of the grid.
- To score highly on **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 'avoid parallax error' or 'use more precise measuring instruments' will not usually gain credit without further detail. Candidates should be encouraged to write about four different problems and consequently four different solutions to address these problems, and should not try to state four solutions to the same problem.

General comments

The general standard of the work done by the candidates was good, and there were many excellent scripts.

There was no evidence that Centres had any difficulties in providing the equipment required for use by the candidates. 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 'extra' 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.

Comments on specific questions

Question 1

- (a) (v) Many candidates stated a value of current either with no unit or with a unit which did not correspond to the meter settings, such as 118 A or 0.008 mA. Candidates should check the reading carefully and ensure that any measurements are recorded with the correct power of ten.

- (c) Most candidates were able to collect six sets of values of R and y without any assistance from the Supervisor, and in many cases the results showed a correct trend. Some candidates showed an incorrect trend in their tabulated results. It is likely that these candidates either read the ruler incorrectly or did not take care to ensure that the ammeter reading was adjusted each time so that the same current value was observed.

A large number of candidates extended their range of R values to include $33\ \Omega$. Other candidates increased their values from $R = 10\ \Omega$ without taking full advantage of the resistors made available to them.

Some candidates were awarded credit for using the correct column headings in their tables, giving both the quantity recorded and suitable units for each quantity, with the two separated by a solidus, or with the units in brackets. Some candidates either omitted the units or the separating mark for $1/R$ or $1/y$, or stated a wrong unit (for example $(1/R)/\Omega$).

Many candidates correctly recorded their raw values for y to the nearest mm. Some candidates incorrectly stated their y values to the nearest cm, or presented trailing zeros to a greater precision than 1 mm when the measuring instrument provided (a ruler) can read only to the nearest millimetre.

Most candidates recorded their calculated values for $1/R$ to an appropriate number of significant figures (2 or 3). Many candidates either stated too many significant figures or gave the calculated value to one significant figure.

Most candidates calculated values for $1/y$ correctly. A few candidates rounded their answers incorrectly. A small minority incorrectly worked out $R/100$ or $y/100$.

- (d)(i) A small number of candidates, having gained a reasonable set of results and tabulated them appropriately, did not continue to plot a graph. Candidates should plot a graph even if they do not have confidence in their results, as they can still gain credit for demonstrating the skills of graphical analysis.

The size and scale of the graph axes chosen was appropriately chosen by most candidates and the labelling was done correctly. In many cases, the plotted points occupied more than half the graph grid available and the scale was easy to read. Some candidates 'compressed' the axes, particularly the y -axis. A few candidates plotted the wrong graph ($1/y$ versus R or y versus $1/R$) or, in rare cases, omitted the labels. There were a few cases of candidates using incorrect numerical scales sometimes with a change in power of ten (e.g. 0.07, 0.08, 0.09, 0.10, 0.20, 0.30).

Some graphs were drawn with awkward scales (e.g. in multiples of 3). As well as losing credit for the axes, these candidates often go on to plot points incorrectly and make mistakes in the determination of the y -intercept and gradient.

Some candidates plotted their points on the graph grid with great care. Others needed to draw the plotted points so that the diameters of the points were equal to, or less than, half a small square (a small cross is recommended). In some cases there was an incorrect point, e.g. 0.101 plotted as 0.110, or the candidate did not take into account the third significant figure. Some candidates can improve by plotting the points more accurately and by ensuring they use a sharp pencil and a straight ruler.

If a point seems anomalous, candidates should be encouraged to repeat the measurement to check that an error in recording has not been made. If such a point is ignored in assessing the line of best fit, the anomalous point should be labelled clearly, e.g. by circling the point.

- (ii) Some candidates were able to draw carefully considered lines of best fit, but others joined the first and last points on the graph regardless of the distribution of the other points. There should always be a balanced distribution of points either side of the line along the entire length. Many lines needed rotation to get a better fit, or an anomalous point needed to be identified to justify the line drawn. Some candidates lost credit for lines that were kinked in the middle (candidates used too small a ruler), by drawing a double line (broken pencil tip) or by drawing freehand lines without the aid of a ruler.

- (iii) Many candidates used a suitably large triangle to calculate the gradient, gaining credit for correct read-offs, and substituted into $\Delta y / \Delta x$ to get a negative numerical answer. Other candidates needed to check that the read-offs used were within half a small square of the line of best fit and show clearly the substitution into $\Delta y / \Delta x$ (not $\Delta x / \Delta y$). The equation $m(x - x_1) = (y - y_1)$ should be shown with substitution of read-offs. Candidates needed also to check that the triangle for calculating the gradient was large enough (the hypotenuse should be greater than half the length of the line drawn).

It is worthwhile to carry out a check that the sign of the gradient matches the graph. In this case the gradient was negative and candidates did not gain credit if their gradient value did not match the graph.

Some candidates were able to correctly read off the y -intercept at $x = 0$ directly from the graph. Many candidates incorrectly read off the y -intercept when there was a false origin.

Many candidates correctly substituted a read-off into $y = mx + c$ to determine the y -intercept. Others needed to check that the point chosen was actually on the line of best fit and not just a point from the table.

- (e) Many candidates recognised that P was equal to the negative value of the gradient and Q was equal to the intercept. Many candidates recorded a value in range and with consistent units for P ($\Omega \text{ m}^{-1}$) and Q (m^{-1}). Some candidates stated incorrect units, e.g. P in $\Omega^{-1} \text{ m}^{-1}$, while others omitted to give units or carried forward the negative sign from the gradient.
- (f) (ii) Only the strongest candidates were able to gain an answer within range using their initial current in mA and with correct powers of ten used throughout the calculation.

Question 2

- (b) (iii) Many candidates measured repeated readings of the time for at least five oscillations twice to the nearest 0.1 s, calculated the period to be within range and included a unit. Some candidates were not awarded credit because they stated the time for one set of oscillations with no repeats, omitted units or, in rare cases, stated their time to the nearest second only.
- (c) (i) Most candidates correctly calculated l .
- (ii) Candidates found it difficult to justify the number of significant figures they had given for the value of l by referring to the number of significant figures used in their raw time readings. Many candidates gave reference to just 'raw' readings without stating what the raw readings were, or related the significant figures to those used for T when, in the majority of cases, the period is a calculated quantity derived from the raw time readings, e.g. $10T$. A minority of candidates made a statement such as 'three significant figures were used to give a more accurate value of l and this did not gain credit.
- (d) (ii) Some candidates recorded values of d close to that calculated for l . Many candidates did not make d approximately equal to l as instructed and these candidates could not be awarded credit.
- (iii) Many candidates were familiar with the equation for calculating percentage uncertainty, though some candidates made too small an estimate of the absolute uncertainty in the value of d , typically 1 mm (the smallest reading). It was awkward to place a ruler near to the string because of the masses being in the way, so there was a larger uncertainty than 1 mm.

A few candidates showed an uncertainty that was too large (1 cm or 10 cm) because the working and units were unclear, e.g. $0.2 / 0.450$ which was interpreted as $20 \text{ cm} / 45.0 \text{ cm}$.

Some candidates repeated their readings and correctly gave the uncertainty in d as half the range, but some candidates did not halve the range.

- (e) (ii) Some candidates recorded a value for time t in the required range. Many others found this measurement of time difficult and there were many answers that were a factor of 10 too small, suggesting that these candidates were measuring a different time from the time described in the question.
- (f) The majority of candidates recorded a second value of T .
- Most candidates recorded a second value of t .
- Most candidates recorded a second value of t which was larger than that obtained for the initial 300 g mass.
- (g) (i) Many candidates were able to calculate k for the two sets of data, showing their working clearly. The most common error was incorrectly rearranging the equation to calculate k (using m/t instead of t/m).
- (ii) Some candidates calculated the percentage difference between their two values of k , and then tested it against a specified numerical percentage uncertainty. This was accepted as long as the value was a reasonable reflection of the percentage uncertainty of this experiment. Any criterion above 30% needed to be fully justified. Many candidates omitted any sort of criterion. General statements such as 'this is valid because the values are close to each other' were not credited.
- (h) Many candidates recognised that two sets of data were insufficient to draw a valid conclusion. Other commonly stated problems that gained credit included 'difficult to judge when the separation of the coils was constant' and 'difficult to measure d because there was parallax error'.

Credit is not given for suggestions that could be carried out in the original experiment, such as repeating measurements. Vague or generic answers such as 'too few readings', 'difficult to measure d ' (without stating a reason), 'systematic error', 'parallax error' (on its own without stating what measurement would be affected), 'air conditioning', 'turn off air con', 'faulty apparatus', 'use a set square' (without stating in detail how it is used) or 'use an assistant' cannot be not given credit. Some improvements relied heavily on automatic/robotic devices. Other devices did not gain credit because there was insufficient detail. For example, if suggesting the use of a fiducial marker, its position must be described, and use of a video in this experiment requires reference to some sort of timing device.

The key to this section is for candidates to identify genuine problems associated with setting up this experiment and in obtaining readings. Candidates are encouraged to suggest detailed practical solutions that either improve technique or give more reliable data.

PHYSICS

Paper 9702/34
Advanced Practical Skills 2

Key messages

- If a measurement is a static measurement, such as measuring the length of a resistance wire, or the steady reading on an ammeter, there is often little value in repeating the measurement. If the measurement is 'dynamic' (e.g. the height a table-tennis ball bounces) or a degree of judgement is needed in deciding when to take a measurement (e.g. deciding when a mass oscillating on the end of a spring starts or completes an oscillation) then measurements should always be repeated and an average value calculated.
- In order to calculate the percentage (or fractional) uncertainty in a measurement, some judgement has to be made about the absolute uncertainty of the measurement. Candidates often just use the precision of an instrument being used. Estimating the absolute uncertainty should also take into account the effect of extraneous influences (e.g. draughts and changes in temperature), uncertainties in judgement (e.g. when judging the start or finish of an oscillation) and even uncertainties caused by the act of measurement itself (e.g. putting a cold thermometer into a beaker of hot liquid will cool the liquid very slightly).
- Many candidates find it difficult to choose scales that make good use of the graph grid. The aim should be to occupy the majority of the graph grid. If less than half of the grid is occupied in one direction, the range of the corresponding axis can be halved to make better use of the grid.
- To score highly on **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 'avoid parallax error' or 'use more precise measuring instruments' will not usually gain credit without further detail. Candidates should be encouraged to write about four different problems and consequently four different solutions to address these problems, and should not try to state four solutions to the same problem.

General comments

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.

Any help given to a candidate should be noted on the Supervisor's Report. The type of help given and the details of the candidate must be recorded. Candidates should be encouraged to ask for help from the Supervisor if they are having difficulty assembling the apparatus, or if it does not appear to be working correctly. It is much better for the candidate to lose access to one or two marks after asking for help, but then be able to obtain reliable and accurate results from which to plot graphs, calculate gradients and intercepts and draw conclusions.

Supervisors are reminded that under **no circumstances** should help be given with the recording of results, graphical work or analysis.

Comments on specific questions

Question 1

(b) (ii) Most candidates recorded a value for x in the appropriate range, with a unit. A few candidates did not read the question carefully enough, or interpreted the phrase 'approximately 25 cm' too generously, recording a value for x that was outside the permitted range.

(iv) Most candidates were able to record a value for T in the appropriate range. Some candidates misread the stopwatch, recording values for T less than 0.1 s.

A few candidates measured the time for $10T$ correctly, but omitted to divide by 10 to find T .

To obtain an accurate value for T , the time for 5, 10 or even 20 oscillations should be recorded and this measurement repeated 2 or 3 times. This should enable a candidate to identify any anomalous result (where, for example, the number of oscillations has been miscounted) and to calculate a reliable and accurate mean value for T from the results.

(c) Almost all candidates recorded six values of x and T correctly, showing the correct trend. Very few candidates requested assistance from the Supervisor.

Many candidates needed to make better use of the range of possible values of x , taking particular care to include values of $x \geq 30.0$ cm. In any experiment it is good practice to try to include both the smallest and largest values of the independent variable as possible.

Most candidates were awarded credit for using the correct column headings in their tables, giving both the quantity recorded and suitable units for each quantity, with the two separated by a solidus or with the units in brackets. A few candidates included a column for $1/T^2$ but omitted a unit.

Most candidates recorded all their raw values of x to the nearest mm. A few candidates recorded their values of x only to the nearest cm.

Most candidates recorded the calculated values of $1/T^2$ to an appropriate number of significant figures. The calculated values of $1/T^2$ should be recorded to the same number of significant figures as, or one more than, the number of significant figures in the raw times from which they are calculated.

Almost all candidates calculated the values of $1/T^2$ correctly, though a few only calculated values of $1/T$, or rounded their answers incorrectly.

(d) (i) Most candidates gained credit for drawing appropriate axes, with labels and sensible scales. Others chose extremely awkward scales, making the correct plotting of points much more difficult. As well as losing credit for the axes, these candidates often go on to plot points incorrectly. A few candidates chose nonlinear scales, but this question produced fewer examples of 'compressed' scales as both the x and y scales could start at zero without necessarily producing a compressed scale.

Many candidates gained credit for plotting their tabulated readings correctly. If a point seems anomalous, candidates should repeat the measurement to check that an error in recording the values has not been made. If such a point is ignored in drawing the line of best fit, the anomalous point should be labelled clearly, e.g. by circling the point.

Some candidates needed to draw the plotted points so that the diameters of the points were equal to, or less than, half a small square (a small pencil cross is recommended). Some candidates can improve by plotting the points more accurately, i.e. to within half a small square.

Many candidates were awarded credit for the quality of their data by having all their points either on, or very close to, a straight line. A few candidates obtained an incorrect trend on their graph, or had calculated values of $1/T$ rather than $1/T^2$.

(ii) Some candidates were able to draw carefully considered lines of best fit, but others joined the first and last points on the graph regardless of the distribution of the other points, or drew lines that could clearly be rotated or translated to give a better overall fit to the plotted points. There should

always be a balanced distribution of points either side of the line. The use of a transparent ruler can help with this. A few candidates drew very thick or 'hairy' lines, or a line with an obvious kink.

- (iii) Many candidates used a suitably large triangle to calculate the gradient, gaining credit for correct read-offs, and substituted into $\Delta y/\Delta x$ to find the gradient. Other candidates needed to check that the read-offs used were within half a small square of the line of best fit, show clearly the substitution into $\Delta y/\Delta x$ (not $\Delta x/\Delta y$), and check that the triangle for calculating the gradient is large enough (the hypotenuse should be greater than half the length of the line drawn).

It is important that candidates show their working, making it clear which points they have chosen for the read-offs, e.g. by drawing a small triangle around both of the points chosen, or by drawing a large triangle, with the two chosen points as vertices, on the graph. A value for the gradient without any clear working showing how the value was obtained cannot be awarded credit.

Some candidates used points taken directly from the table to calculate the gradient. This is only valid if the points chosen also lie on the straight line drawn by the candidate.

Some candidates correctly read off the y -intercept at $x = 0$ directly from the graph. Others needed to check that the x -axis started with $x = 0$ (i.e. no false origin) for this method of finding the intercept to be valid.

Many candidates correctly substituted a read-off into $y = mx + c$ to determine the y -intercept. Others needed to check the read-off of the chosen point more carefully. Candidates who had chosen awkward scales on the graph often lost credit for the gradient and intercept calculations because of incorrect read-offs.

- (e) Most candidates recognised that p was equal to the value of the gradient and q was equal to the value of the intercept from (d)(iii). Fewer candidates recorded the correct units for p and q , and many candidates omitted the units.

Question 2

- (b) Most candidates recorded a value for L in the appropriate range successfully, with a consistent unit. A few candidates recorded the value of L for strip B, or omitted the unit.
- (c) (iv) Most candidates were able to measure the value of x_1 and x_2 correctly, though some candidates recorded values to the nearest cm rather than the nearest mm. Very few candidates repeated their measurements and found average values for x_1 and x_2 .
- (v) Almost all candidates were able to calculate the value of X correctly, though a few candidates were not awarded credit because they rounded their value to one significant figure.
- (d) Almost all candidates were familiar with the equation for calculating percentage uncertainty, but many underestimated the absolute uncertainty in the value of X . Many candidates simply used the smallest division in the ruler (1 mm) as the basis for estimating the absolute uncertainty, not taking into account the fact that the accuracy of X depended on the accuracy of two measurements (x_1 and x_2) and that there was potential parallax error in making the measurements. A good estimate of the absolute uncertainty in X would have been 2–10 mm.

Those candidates who had repeated their measurements of x_1 and x_2 in (c)(iv) sometimes calculated the maximum and minimum possible values of X and went on to use half the difference between these values as the absolute uncertainty. Some weaker candidates misunderstood this approach, using half the difference between their values of x_1 and x_2 as the absolute uncertainty.

- (e) Almost all candidates were able to record a second value for L (different from the first value) and recorded second values for x_1 and x_2 .

Most candidates were awarded credit for the quality of data, having obtained a second value for X which was smaller for the larger value of L .

- (f) (i) Most candidates calculated values for k correctly, recording their values to an appropriate number of significant figures. A few candidates lost credit because they recorded one or both of their values to one significant figure on the answer line.
- (ii) Very few candidates based their justification for the significant figures of k explicitly on the significant figures of L , x_1 and x_2 . Many candidates referred only to the 'raw data' (which is too vague to be awarded credit) or stated that the number of significant figures depended on the significant figures of L and X (which is another calculated quantity).
- (iii) Most candidates calculated the percentage difference between their two values of k , and then tested it against a specified percentage uncertainty, either taken from (d) or estimated themselves. Where candidates state a percentage uncertainty value themselves, it is a good idea to try to justify this value in some way, particularly if a very large percentage uncertainty is suggested.

Some candidates gave answers such as 'the difference between the two k values is very large/quite small' which is insufficient – a numerical percentage comparison is required here.

- (g) Candidates found this question to be difficult. Making predictions is assessed as part of 'analysis, conclusions and evaluation'. Many candidates omitted the question.
- (h) (i) Many candidates recognised that two sets of data were insufficient to draw a valid conclusion. Other good answers included the observation that the metre rule tended to rotate (become skewed) as the stands were moved closer together.

Some candidates mentioned aspects of the experiment that were difficult but did not explain why they were difficult, e.g. 'it was difficult to move the stands together' or 'it was difficult to measure x_1 and x_2 '. Much better answers would contain detail such as 'it was difficult to move the stands together because of friction (the bench is rough)' or ' x_1 was difficult to measure because it was difficult to tell where the rod of the clamp touched the ruler'.

Some candidates 'invented' errors such as the rule being 'damaged', 'not accurate' or 'bent', or stated generic answers such as 'systematic errors' or 'parallax error' without any detailed explanation. Others suggested that the wooden blocks fell off, or the Blu-Tack was not sticky enough. In such cases the experiment could have been repeated more carefully, so these were not considered valid sources of difficulty.

- (ii) Valid improvements included taking more readings (for different values of L) and then plotting a suitable graph to test the suggested relationship. Other good answers included:
- using a spirit level to check the metre rule is horizontal (or using a second metre rule and checking the metre rule is the same height above the bench at both ends),
 - making a 'guide' for the stands to follow (e.g. by fixing two metre rules to the bench, one either side of the stands),
 - replacing the rods of the clamps with thinner rods (or 'knife-edge' supports) to make the measurement of x_1 and x_2 more accurate.

There were many answers that required more clarification – for example 'use a smoother bench' or 'make sure the clamps are at the same height'. In each case the candidate should consider how the suggested improvement could actually be made.

Some candidates suggested improvements which should have been carried out in the original experiment, such as repeating measurements and calculating average values, or limiting parallax errors by reading the ruler 'square on'. No credit is given for these suggestions.

PHYSICS

<p>Paper 9702/35 Advanced Practical Skills 1</p>
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Key messages

- If a measurement is a static measurement, such as measuring the length of a resistance wire, or the steady reading on an ammeter, there is often little value in repeating the measurement. If the measurement is 'dynamic' (e.g. the height a table-tennis ball bounces) or a degree of judgement is needed in deciding when to take a measurement (e.g. deciding when a mass oscillating on the end of a spring starts or completes an oscillation) then measurements should always be repeated and an average value calculated.
- In order to calculate the percentage (or fractional) uncertainty in a measurement, some judgement has to be made about the absolute uncertainty of the measurement. Candidates often just use the precision of an instrument being used. Estimating the absolute uncertainty should also take into account the effect of extraneous influences (e.g. draughts and changes in temperature), uncertainties in judgement (e.g. when judging the start or finish of an oscillation) and even uncertainties caused by the act of measurement itself (e.g. putting a cold thermometer into a beaker of hot liquid will cool the liquid very slightly).
- Many candidates find it difficult to choose scales that make good use of the graph grid. The aim should be to occupy the majority of the graph grid. If less than half of the grid is occupied in one direction, the range of the corresponding axis can be halved to make better use of the grid.
- To score highly on **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 'avoid parallax error' or 'use more precise measuring instruments' will not usually gain credit without further detail. Candidates should be encouraged to write about four different problems and consequently four different solutions to address these problems, and should not try to state four solutions to the same problem.

General comments

Many candidates were very successful in taking accurate readings in **Question 1** and in arranging the apparatus for **Question 2**.

The majority of Centres provided the apparatus required as stated in the Confidential Instructions. Any deviation between the requested apparatus and that provided to the candidate should be written in the Supervisor's Report to enable Examiners to consider this while marking. When Examiners are not told of variations, they have to assume that the apparatus has been provided as specified. Candidates may be at a disadvantage if the apparatus is different from that specified and a Supervisor's Report is not received.

Supervisors are reminded that under **no circumstances** should help be given with the recording of results, graphical work or analysis.

Comments on specific questions

Question 1

- (a) (i) Successful candidates used the measuring cylinder provided to measure the maximum volume V_F of water held by the bottle.
- (c) (v) Candidates were given the unit of cm on the answer line and were provided with a metre rule reading to the nearest millimetre, so the reading should have been given to the nearest mm, e.g. 6.0 cm or 6.3 cm. Candidates should be reminded to use the precision of the measuring instrument: a reading of 6 cm would not gain credit.
- (d) (ii) The experiment was straightforward. Successful candidates collected six sets of values for V and y .

Before taking readings, the strongest candidates benefited from considering the total variation in volume that could be achieved with the bottle supplied and made changes to volume V accordingly. Some candidates chose to vary the volume by only a few cm^3 , and could not gain credit for their range. These candidates, using a small range, often had readings with one or more values not fitting in the correct trend.

Most candidates drew neat, well-constructed tables. Candidates should remember to include a separating mark, such as a solidus, between the quantity and unit. The majority of candidates gave V/cm^3 and y/cm but some omitted the unit for V or chose to write " V, cm^3 ". A comma is not accepted as a separator.

The metre rule provided had mm markings and successful candidates used mm when recording their values of y . The measuring cylinder measured to the nearest cm^3 , and successful candidates recorded all measurements to the nearest cm^3 . Some candidates decided to add an extra zero to their readings e.g. 205.0 cm^3 . This precision was not justified by the apparatus provided.

- (e) (i) Candidates gaining credit for the axes labelled them with the appropriate quantities, e.g. y or V . Others omitted the label or wrote units only. Successful candidates had scales that were simple to use, e.g. a volume of 50 cm^3 equivalent to 10 small squares on the graph. Other candidates used 50 cm^3 equivalent to 15 small squares or 30 cm^3 equivalent to 10 small squares. These scales did not gain credit because they are awkward to use.

Before candidates plot their points, they need to consider how much of the grid the points will occupy. For a graph in the portrait orientation, points should occupy six or more large squares in the vertical direction and four or more large squares in the horizontal direction. Some candidates used very compressed scales such that their points spread into just two large squares in the vertical direction. The most successful candidates had access to sharp pencils to draw fine points; any points that have a diameter larger than half a small square are not credited.

- (ii) Successful candidates were able to draw a good line of best fit through their six points, with points well balanced along the whole length of the line.

Candidates could also draw a line through five trend points but identifying one anomalous point. When a point is identified as anomalous for the purposes of drawing the best line, this point should be clearly indicated on the graph by adding a label or by drawing a small circle around the point. Candidates should be advised that, before marking a point as anomalous, they should check that the point is plotted correctly and that the scale is marked regularly, and if possible they should repeat the measurement to check that an error in recording it has not been made.

When a line is drawn, successful candidates look at the balance of points around their whole line. Those candidates who choose to join the first and last points or join up a couple of points often produce a line which is unbalanced and would need to be rotated or shifted. When practising in preparation for this paper, a good method to use for deciding where the best line should be drawn is to take a clear piece of acetate or plastic which has a single line drawn on it. Placing the acetate over the graph grid and moving the line until there is a good balance of points will enable candidates to improve their skills in drawing lines of best fit.

- (iii) Stronger candidates possessed a clear understanding of how to find the gradient and the intercept of a straight line graph. These candidates had the correct trend which generated a graph with a negative gradient and clearly wrote a negative sign before their gradient value. Other candidates sometimes had the negative sign in the working but omitted it when writing their answer, and were not awarded credit.

Many candidates used a suitably large triangle to calculate the gradient, gaining credit for correct read-offs, and substituted into $\Delta y/\Delta x$ to find the gradient. Other candidates needed to check that the read-offs used were within half a small square of the line of best fit, show clearly the substitution into $\Delta y/\Delta x$ (not $\Delta x/\Delta y$), and check that the triangle for calculating the gradient is large enough (the hypotenuse should be greater than half the length of the line drawn).

It is important that candidates show their working, making it clear which points they have chosen for the read-offs, e.g. by drawing a small triangle around both of the points chosen, or by drawing a large triangle, with the two chosen points as vertices, on the graph. A value for the gradient without any clear working showing how the value was obtained cannot be awarded credit.

Successful candidates either read off the y-intercept where $V = 0$ directly from the graph or substituted values from a read-off using a point on the line (not a point from the table) correctly into $y = mx + c$.

When taking the read-off to find the intercept, successful candidates checked that the x-value where the read-off was taken was actually $V = 0$. Often the smallest scale value was not zero. When making the substitution, care needs to be taken that the x-value and y-value are put into the correct places in the equation.

- (f) Candidates who understood how the equation for the graph links to the gradient and intercept were successful. These candidates made a direct transfer of the values in (e)(iii) to (f) and gained full credit. This recognition meant that no calculation was needed to find P and Q . No credit was given for fractions recorded for P or Q ; candidates should be reminded that they must calculate the values.

Correct units were given by stronger candidates, but others omitted the units. Some candidates did write a unit with the gradient and intercept in (e)(iii) but then these units were omitted in (f).

- (g) (i) Successful candidates manipulated the equation correctly and correctly calculated the volume V .
- (ii) The strongest candidates compared their V value with the volume of the bottle V_F . Other candidates were troubled by the negative signs but did not go back through their working to understand where they had made an error. Some candidates correctly found $V > V_F$ but they did not make the link between the volumes to answer the question.

Question 2

- (a) (ii) Most candidates successfully adjusted the wooden strip so that the distance L was correct, and then gave the measurement to the nearest mm with a consistent unit. A few candidates omitted the unit or recorded the length as a whole number of centimetres. Some candidates did not read the question with sufficient care and arranged the strip so that the distance L was outside the required range.
- (iii) Most candidates were familiar with the equation for calculating percentage uncertainty and many made a realistic estimate of the absolute uncertainty in L i.e. 1 mm or 2 mm. Successful candidates realised that the absolute uncertainty in the value of L depended on the precision of the measuring instrument i.e. the rule which read to 1 mm. This was a static measurement and candidates had the opportunity to take their time with the reading, placing their head directly above the scale in line with the end of the wooden strip. There is no reason for the absolute uncertainty to be greater than 2 mm.

When repeat readings were noted, the absolute uncertainty could be calculated as half the range of the repeated values. The half-range calculation needed to be shown so that it was clear how the estimate of absolute uncertainty had been produced.

- (b)(ii) The position of the rule and the edge of the wooden strip made it a challenge to align the eyes to measure d . Successful candidates recorded a value to the nearest mm and gave the correct unit.
- (c)(ii) Successful candidates, using the rule in the correct way, recorded a height with the masses spread along the wooden strip which was greater than the height for the single mass. The majority of candidates were successful here.
- (iii) Most candidates successfully calculated the difference ($d_2 - d_1$). Both values of d_1 and d_2 should have been recorded with the same precision. Some candidates chose to give their final answer to a different precision from their values.
- (iv) Successful candidates correctly calculated a value for M , giving the final value to 2 or 3 significant figures with a correct consistent unit.

The number of significant figures used depended on the number of significant figures used for the values of L and m . A common misconception was that 0.100 kg has 1 significant figure. Some candidates omitted the unit, or used a value of L in cm but gave their unit as kg/m without converting correctly. Others did not use the correct value of L but erroneously substituted ($d_2 - d_1$).

- (d) Successful candidates correctly related the number of significant figures in their values of m and L to the number of significant figures in their value of M . Candidates must refer to m and L (i.e. the quantities relevant to the question) in their answer; 'raw data' or the phrase 'values in the calculation' did not gain credit.
- (e) Most candidates successfully recorded second values for d_1 and d_2 , and successful candidates found that when the mass was reduced the value of ($d_2 - d_1$) was also reduced.
- (f)(i) Most candidates successfully rearranged the equation and calculated $k = (d_2 - d_1)/M$ for both experiments; some candidates misunderstood how to rearrange and used $k = M/(d_2 - d_1)$. Some candidates could give their k values to 1 s.f. when their ($d_2 - d_1$) value was to 1 s.f. (e.g. 5 mm) since the difference in deflection was only a few mm. Some candidates retake their measurements, and when this is done the new values need to be used and taken through into the calculation of k .
- (ii) Successful candidates had three steps in their argument. They first state a criterion to be used for testing the relationship. This could be a percentage uncertainty that they think is a sensible limit for this particular experiment, e.g. 5% or 20%, or could be the percentage uncertainty found in (a)(iii). Next they calculate the percentage difference between their values of k . Finally, they compare the percentage difference between their k values to the percentage uncertainty chosen and decide whether the relationship is supported or not supported. If the percentage difference between the two k values is less than the stated criterion, these successful answers then say that the relationship is supported. If the value of the percentage difference is greater than the value of the percentage uncertainty stated as the criterion, then the relationship is not supported. The candidates should make an explicit statement, e.g. 'the relationship is not supported'.
- (g) The procedure candidates follow to take readings in **Question 2** is designed to have problems in it. Successful candidates thought about problems while doing the experiment and made valid suggestions for improvements. The key to success in this section is for candidates to identify genuine problems associated with taking accurate readings during the experiment.

The ($d_2 - d_1$) values are small, and successful candidates suggested using a travelling microscope or clamped calipers to measure the deflection. Suggesting that a more flexible strip be used was not acceptable. Candidates needed to think about apparatus that would be more suitable than a rule to measure a small deflection more accurately.

It was a challenge to place masses on the strip, but with care this was possible. A statement that 'masses fall off the strip' did not gain credit. Thinking about the distribution of masses was valid. With the unmarked strip it was difficult to ensure the distribution was even. Successful candidates stated 'mark the strip at equal intervals'. Some candidates were distracted by suggesting 'glue masses to the strip', but this would not ensure an even distribution.

Successful candidates appreciated that the position of the rule affected the accuracy of their measurement of d values, and made a statement such as 'it was difficult to measure d because the rule was not vertical'. A statement such as 'it was difficult to measure d ' is not detailed enough to gain credit. Candidates need to give a reason for the difficulty.

Candidates should be encouraged to give detailed limitations and improvements that are specific to this experiment. Statements of general 'errors', 'systematic errors', 'zero errors', 'rules with uneven ends' etc. did not gain credit. Credit was not given for any suggestions that are standard practice, such as repeating measurements and calculating averages. General statements such as 'use an assistant', 'view at eye level' or 'view perpendicular' did not gain credit.

PHYSICS

Paper 9702/36
Advanced Practical Skills 2

Key messages

If a measurement is a static measurement, such as measuring the length of a resistance wire, or the steady reading on an ammeter, there is often little value in repeating the measurement. If the measurement is 'dynamic' (e.g. the height a table-tennis ball bounces) or a degree of judgement is needed in deciding when to take a measurement (e.g. deciding when a mass oscillating on the end of a spring starts or completes an oscillation) then measurements should always be repeated and an average value calculated.

In order to calculate the percentage (or fractional) uncertainty in a measurement, some judgement has to be made about the absolute uncertainty of the measurement. Candidates often just use the precision of an instrument being used. Estimating the absolute uncertainty should also take into account the effect of extraneous influences (e.g. draughts and changes in temperature), uncertainties in judgement (e.g. when judging the start or finish of an oscillation) and even uncertainties caused by the act of measurement itself (e.g. putting a cold thermometer into a beaker of hot liquid will cool the liquid very slightly).

Many candidates find it difficult to choose scales that make good use of the graph grid. The aim should be to occupy the majority of the graph grid. If less than half of the grid is occupied in one direction, the range of the corresponding axis can be halved to make better use of the grid.

To score highly on **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 'avoid parallax error' or 'use more precise measuring instruments' will not usually gain credit without further detail. Candidates should be encouraged to write about four different problems and consequently four different solutions to address these problems, and should not try to state four solutions to the same problem.

General comments

The general standard of the work done by the candidates was good. There were many scripts that were excellent and very few of poor quality. Tables and graphs were particularly clear and accurate, as were most calculations.

The need to provide apparatus exactly as specified in the Confidential Instructions is particularly important for components in an electrical circuit. Changing a resistor value will alter the range of measured values and may disguise a trend, making some marks inaccessible to candidates. Any deviation between the requested apparatus and that provided to the candidate should be written in the Supervisor's Report to enable Examiners to consider this while marking. When Examiners are not told of variations, they have to assume that the apparatus has been provided as specified. Candidates may be at a disadvantage if the apparatus is different from that specified and a Supervisor's Report is not received.

Supervisors are reminded that under **no circumstances** should help be given with the recording of results, graphical work or analysis.

In **Question 2**, the experiment required patient and careful use of the apparatus. Candidates were familiar with the tasks involved and many scored excellent marks in the first sections. The discussion of the experiment in terms of flaws and possible changes proved more demanding.

Candidates did not seem to be short of time and both questions were attempted by almost all the candidates.

Comments on specific questions

Question 1

(b) (i) Most candidates followed the instruction to take the initial reading with the movable contact half-way along the wire.

(iii) Many candidates showed confusion with the unit for their current measurement and, for example, recorded values such as 0.94 A or 940 mA instead of 940 mA. Some candidates omitted the unit.

Some candidates' unit symbols were not clear, and it was not possible to distinguish between mA and A.

(c) The presentation of tables was generally clear and neat. Most candidates were able to provide suitable column headings with their units, giving both the quantity recorded and suitable units for each quantity, with the two separated by a solidus or with the units in brackets.

Nearly all candidates recorded six sets of values of x and I without any assistance from the Supervisor.

Stronger candidates included a sufficiently wide range of x values in their table, but some candidates moved in only one direction after starting in the middle of the wire. This does not make full use of the apparatus provided and so did not receive credit for the range of values.

(d) (i) Graphs were generally drawn to a high standard which included accurate and clear plotting of points. Small crosses are the best way to indicate points as small dots were sometimes obscured by the line of best fit.

Scales were usually chosen well, although a few were awkward (e.g. 3 cm for 0.1 mA). Candidates who use awkward scales make the correct plotting of points very difficult. As well as losing credit for the axes, these candidates often go on to plot the points incorrectly. In a small number of cases the points were compressed into too small an area of the grid.

The quality of the candidates' data was judged by the scatter of points about a straight-line trend, and in the majority of cases this was good.

(ii) Many candidates were able to draw acceptable lines of best fit which accurately indicated the trend of their points.

Some candidates circled an anomalous point (to be ignored when considering the general trend), but in some cases several points were labelled as anomalous. Candidates should not label more than one point as anomalous. Before marking a point as anomalous, candidates should check that the point is plotted correctly and that the scale is marked regularly, and if possible they should repeat the measurement to check that an error in recording it has not been made.

(iii) Determination of the graph gradient and intercept was generally carried out well.

A few candidates lost credit because their working was not shown. It is important that candidates show their working, making it clear which points they have chosen for the read-offs, e.g. by drawing a small triangle around both of the points chosen, or by drawing a large triangle, with the two chosen points as vertices, on the graph. A value for the gradient without any clear working showing how the value was obtained cannot be awarded credit.

In a few cases the coordinates used were not read precisely enough (i.e. they were more than 1 mm from the drawn line).

(e) Nearly all candidates linked the equation to their graph and used their gradient and intercept values for S and T . Most included correct units with their values.

- (f) The calculation of r was usually carried out accurately. Some weaker candidates mixed the units (e.g. Acm^{-1} for S and ∞A for T) and this could lead to a power-of-ten error.

Candidates were asked to give their answer to a suitable number of significant figures and nearly every candidate did so, with very few giving 1 significant figure or more than 3 significant figures.

Question 2

Many candidates recorded sensible values for the various x measurements in (b)(ii), (c), (d)(i) and (d)(ii). A few candidates recorded the scale reading rather than the distance from the pivot to the string.

Some candidates lost credit because they recorded imprecise values. When measuring a distance with a metre rule, the candidate should indicate the precision of the measurement by recording the value to the nearest millimetre, and not round it to the nearest centimetre or half-centimetre.

Another occasional mistake was for a candidate to record all values to three significant figures, so that the smallest value in (d)(ii) had two decimal places and therefore a different precision from the other values (e.g. 6.20 cm).

- (e) (i) The majority of candidates correctly calculated two values of the constant k .
- (ii) Some candidates went on to give good answers explaining that the number of significant figures in their k values was determined by the significant figures in x_1 and x_2 . The most common mistake was to refer only to x or 'raw data', which was not sufficient. Candidates should be encouraged to link their justification to the specific quantities of raw data collected.
- (iii) Candidates generally produced good evaluations based on whether the percentage difference between the two k values fell within a stated tolerance. Weaker answers used expressions such as 'not close enough' which did not include a quantitative comparison.
- (f) (i) Many candidates recorded only a single value for D . When measuring the diameter of a spherical object, random errors can be reduced by repeating the measurement (rotating the sphere between measurements). Candidates should record all measurements, even if equal to a previous value.

Some candidates seemed unfamiliar with the use of a micrometer screw gauge and gave values with a precision of 0.1 mm or 0.001 mm. Other candidates made errors in converting values from millimetres to centimetres.

- (ii) Estimation of the uncertainty in the D value was well done by many candidates.
- (iii) The calculation of the volume of the sphere was carried out accurately by most candidates.

Although an allowance was made for error carried forward, a very large volume (e.g. 2567 cm^3) should have been recognised here as evidence of an error in the measurement of D . Candidates should be encouraged to go back and re-check their measurements if an implausible result is obtained.

- (iv) The mass of the sphere was also calculated accurately by many candidates. Again, some candidates calculated an impossibly large value (e.g. 41 kg) and this could have alerted the candidate to an error in D or k .
- (g) The use of a metre rule on a pivot meant that the system could never be in stable equilibrium, and the best that could be achieved in terms of balance was a very gradual movement away from an initial approximately horizontal position. However, many candidates gave undue importance to having the rule exactly horizontal when the system was balanced, and went on to describe methods of checking whether it was or not.

Credit was gained by many candidates for describing problems with the apparatus, e.g. rule slipping on pivot; empty beaker moving on bench; D not constant for the measured sphere. Descriptions of flaws in the procedure were also credited, e.g. mass of string increasing when wet; assuming a spherical sphere when calculating its volume.

Many candidates recognised that two sets of data were insufficient to draw a valid conclusion, and suggested investigating additional positions for the spheres before considering the variation in k values.

Candidates should be encouraged to give detailed limitations and improvements that are specific to this experiment. Statements of general 'errors', 'systematic errors', 'zero errors', etc. did not gain credit. Credit was not given for any suggestions that are standard practice, such as repeating measurements and calculating averages. General statements such as 'use an assistant', 'view at eye level' or 'view perpendicular' did not gain credit.

PHYSICS

Paper 9702/41
A Level Structured Questions

Key messages

- Candidates often find it difficult to present a logical reasoned explanation. To develop this skill, Centres need to prepare candidates using exercises that involve a range of different explanations. Whilst explanations should be first taught in the context of the topic in which they naturally arise, there is merit to having a session that concentrates on explanations across a range of different topics as part of examination preparation.
- Some questions give an instruction such as “use your answer from...” To be awarded full credit for the answer, it is essential that the instruction is followed. Candidates should be encouraged to read the question carefully and follow any specific instructions relating to the required answer.
- Some questions use earlier parts of the question to guide candidates’ thinking towards the correct approach in subsequent parts. The stronger candidates are aware of this and adopt the approach that they have been guided towards. Weaker candidates often tend to overlook the significance of earlier parts of the question and end up using inefficient or invalid approaches in later parts of the question. They could benefit from considering whether earlier question parts provide any help in the later parts.
- A key part of preparing for any examination is experience of previous papers and mark schemes. This will enable candidates to learn the key words needed in definitions and also the correct use for similar terms such as nucleon, nucleus, nuclei etc.

General comments

Ultimately the sign of a numerical value has physical significance. If a sign is introduced or omitted in error during the working, it is then a second error to simply amend the sign of the final value in the answer line without correcting the error in the working. Having arrived at an inappropriately negative value when it should be positive (or vice versa), it is generally better to include the inappropriate sign and add a comment, if it is not possible to go back and correct the error.

The question stem provides candidates with information and data and then elicits a response. There is no requirement for candidates to repeat any details presented in the stem in their response. However, it is often a feature of weaker candidates’ responses that they tend to repeat wording from the questions which they have been asked to explain, and candidates should be advised that this is not a productive use of time in the examination.

Comments on specific questions

Question 1

- (a) Mentioning that the gravitational force provides the centripetal force was generally a feature of the better candidates’ responses. The majority of candidates started their answers by equating the gravitational force to the centripetal force. Some very weak candidates were unable to introduce the period T into their explanation.
- (b)(i) Candidates generally knew the properties of a geostationary orbit. A common mistake was to describe properties of the satellite, rather than the orbit (e.g. ‘it doesn’t need to be tracked’).

- (ii) The majority of candidates could collate the necessary data from the question stem and from page 2, but weaker candidates tended to make errors during substitution. A common mathematical error was to overlook one or more of the squared or cubed indices.
- (c) This calculation proved challenging. Most candidates were able to use the proportional approach directed in the question paper. There were many errors with powers of ten when working out the radius of the new orbit. Candidates should be encouraged to look at their numerical answers to see if they are sensible in the context of the question.

Question 2

- (a) (i) Most candidates used $pV/T = \text{constant}$. However, as with **Question 1(c)**, some candidates were uneasy with the concept of proportionality, and some used $pV = nRT$, finding n for $T = 300 \text{ K}$ and then using it to find the new thermodynamic temperature T . This approach gives a correct answer but was more prone to errors.
- (ii) This calculation of the amount of gas was well answered. Some candidates showed confusion between R and k and also between N and n . Some weaker candidates used $pV = NkT$ and found N .
- (b) (i) Nearly all candidates could state what the symbols meant, although the weakest candidates either omitted the key words denoting the direction of energy flow or work done, or described the wrong direction.
- (ii) This final part of the question was difficult. Even though candidates could name the symbols, many were then unable to state the numerical values required. Some of the answers given were not logically consistent.

Question 3

- (a) The majority of candidates were able to show the frequency of oscillation of the trolley. Candidates need to practice 'show that' questions and should be encouraged to show all the stages in their algebra and numerical working.
- (b) This calculation was well answered. The most common error was to square the angular frequency. Some of the weakest candidates tried to use equations of uniform acceleration, perhaps not realising that these equations only when the acceleration is constant.
- (c) Most candidates gave these changes to the frequency and maximum speed correctly.

Question 4

- (a) The process of regeneration was not well understood by a large number of candidates. A significant number referred to amplification, which is not the process involved. The key point about digital signals is that noise can be eliminated and this was rarely mentioned.
- (b) (i) This calculation proved to be reasonably straightforward for most of the candidates.
- (ii) Many candidates inverted the ratio and used $\text{attenuation} = (10 / 58) \times \lg [(6.02 \times 10^{-4}) / (9.5 \times 10^{-3})]$, which resulted in an attenuation of -0.21 dB km^{-1} . Candidates who found a negative attenuation tended to then 'lose' the negative sign without comment or correcting the working.

Question 5

- (a) Many candidates could not reason why there is no electric field inside a conductor. There were references to the field lines and potentials, both of which are constructs to help our understanding, but they do not provide a reason for why the spheres behave as they do. It was relatively common for candidates to say that there was no charge, which is not correct. Some candidates answered the question as if it was asking why there was no field *between* the spheres, rather than in the spheres.

- (b) Most candidates realised that the field strengths needed to be subtracted from each other, but generally they did not explain why. Candidates should be reminded that, if a question asks for working to be explained, they should provide some words to do this.
- (c) The most common mistake was to subtract instead of adding the two potentials. Some candidates worked out only one of the two potentials and this does not give a correct answer.
- (d) This was a less structured question requiring several stages. Candidates had to equate the two energies, realise that the charge was 47 times the fundamental charge and realise that the mass was 107 times the atomic mass unit. Then they had to rearrange the equation and calculate v . This proved difficult for many candidates, although most were awarded at least partial credit.

Question 6

- (a) Infinite slew rate is one of the properties of an ideal operational amplifier, but slew rate is not fully understood by candidates. Many candidates correctly made reference to input and output. A smaller number referred to the time delay between a change in the input leading to a change in the output.
- (b) (i) This was a simple potential divider circuit and candidates needed to realise that the voltages at the inverting and non-inverting inputs had to be the same. Some candidates did not realise this. One of the most common mistakes from weaker candidates was to use the 5V supply to the op-amp as the potential divider voltage.
 - (ii) Many candidates did not draw correct symbols for the LEDs. Commonly the arrows were omitted, too many or too few in number, or pointing towards the diode. Many responses showed incorrect logic when establishing which diode would be conducting. Some candidates did not know that the resistance of the thermistor would increase or did not refer to the thermistor at all.

Question 7

- (a) Whilst nearly all candidates had some concept of what is meant by a field, some of the weaker candidates had difficulty in providing a general answer, and instead gave 'mass' or 'charge' rather than 'object' or 'particle'. Some candidates used the word 'field' in their explanation which does not earn credit.
- (b) Whilst the majority of candidates could state that a gravitational field would give rise to a force acting on the moving uncharged particle, it was common for candidates to overlook the possibility of a gravitational field acting on a stationary charged particle or a charged particle moving at an angle to the field or fields.
- (c) (i) Candidates tended to know that the force was magnetic, that it was acting on the particle at right angles to the motion and that it provided the centripetal force. Many candidates did not realise that the force, or the speed of the particle, was constant. A significant number incorrectly stated that the velocity was constant.
 - (ii) Most candidates were able to answer this question. A number of candidates ended their working for the equation with r rather than momentum as the subject, even though they had correctly derived the expression on the previous line.

Question 8

There were some very good answers to this question from candidates who clearly understood the main principles behind NMRI. However, many candidates seemed to be repeating passages remembered from textbooks, which contained a lot of extraneous and irrelevant information. Comprehension is the key to receiving high marks on this type of question.

A common error was to miss the key words such as pulse or nuclei/proton. Some weaker candidates described a magnetic field switching on and off rather than referring to a pulse of RF.

Question 9

- (a) Most candidates had correctly learned Faraday's law of electromagnetic induction. A small number of candidates referred to electromagnetic force in error.
- (b) Most candidates answered correctly. If a mistake was made, it was usually because the candidate did not base the answer on the expression BAN for the flux linkage. These candidates would generally calculate B and stop. A very small number used diameter rather than radius. Some candidates calculated an answer to several significant figures. This is good practice as it indicates to the candidate (and the Examiner) that calculation has been done correctly.
- (c) A common answer was 2.0 mV. Candidates giving this answer did not realise that, if the current changes direction, the flux linkage goes from positive to negative (through zero). The change in flux linkage is therefore 1.2×10^{-3} Wb in a time of 0.30 s.
- (d) The previous question part should have helped the candidates, but the majority of candidates seemed not to have spotted this. Instead many drew graphs that bore no relationship to Faraday's law or the value of the e.m.f. that they had just calculated. Candidates may benefit from further study of Faraday's law and, in particular, it should be emphasised how the induced e.m.f. relates to the gradient of graphs such as the one given.

Question 10

- (a) There were few fully correct answers to this question. Most candidates explained that electrons were emitted from the surface, but fewer candidates mentioned that this occurs when photons are incident on the surface.
- (b) Candidates demonstrated a good ability to calculate photon energy from wavelength.
- (c) Again, candidates demonstrated good ability here in calculating threshold wavelength. Some weaker candidates omitted the conversion from electronvolt to joule, and this cannot give the wavelength in nm.
- (d) These explanations were often insufficient. It was quite common for candidates with correct values for the threshold wavelengths to state that caesium would not give rise to photoelectric emission but that tungsten would. Some candidates gave explanations that did not mention the threshold wavelengths.

Question 11

Many candidates saw the picture of the bands and immediately assumed that this question was about semiconductors. The sentence below **Fig. 11.1** was intended to help candidates realise that it is a generic diagram. The question asked about metals but many candidates, thinking of semiconductors, said that the resistance decreases with increasing temperature. Centres should ensure that candidates are able to explain the conduction of both metals and semiconductors in terms of band theory.

Some stronger candidates stated that in metals at room temperature the valance band and the conduction band overlapped and that this meant that the number of charge carriers would be constant. When it came to explaining interactions of the conduction electrons with the metal lattice, there were several misconceptions. Some candidates stated that conduction electrons got in each other's way and collided with each other, or that increasing the temperature increased the number of conduction electrons and this reduced the space in which conduction electrons can move.

Question 12

- (a) (i) Some answers referred to ambiguous or inappropriate quantities such as the 'amount of the substance' or the 'mass of the sample'. The mass of the sample does not halve during the half-life but the number of active nuclei and the activity of the parent nuclide do. The sample will only be lighter as a result of the radiation that has escaped the sample. There was widespread confusion between the words nuclei, nucleus and nucleon.
- (ii) The weakest candidates either omitted this question or missed out the key statement $A = A_0 e^{-\lambda t}$. Some just rearranged the equation $\lambda t_{1/2} = 0.693$ and this could not be awarded credit. A significant number of candidates demonstrated confusion with the subscripts $\frac{1}{2}$ and 0, and were not able to gain credit.
- (b) This calculation was generally very well done. The most common mistake was to divide by the Avogadro constant *and* multiply by u . Another common error was to use 222 kg as the atomic mass of radon rather than 222 g, which gave an answer incorrect by a factor of 10^3 .

PHYSICS

Paper 9702/42
A Level Structured Questions

Key messages

- Candidates often find it difficult to present a logical reasoned explanation. To develop this skill, Centres need to prepare candidates using exercises that involve a range of different explanations. Whilst explanations should be first taught in the context of the topic in which they naturally arise, there is merit to having a session that concentrates on explanations across a range of different topics as part of examination preparation.
- Some questions give an instruction such as “use your answer from...” To be awarded full credit for the answer, it is essential that the instruction is followed. Candidates should be encouraged to read the question carefully and follow any specific instructions relating to the required answer.
- Some questions use earlier parts of the question to guide candidates’ thinking towards the correct approach in subsequent parts. The stronger candidates are aware of this and adopt the approach that they have been guided towards. Weaker candidates often tend to overlook the significance of earlier parts of the question and end up using inefficient or invalid approaches in later parts of the question. They could benefit from considering whether earlier question parts provide any help in the later parts.
- A key part of preparing for any examination is experience of previous papers and mark schemes. This will enable candidates to learn the key words needed in definitions and also the correct use for similar terms such as nucleon, nucleus, nuclei etc.

General comments

Candidates generally found descriptive questions to be much more challenging than calculations. Candidates should take care to read the question carefully before beginning to answer, as some descriptions were not related to the question being asked (for example, ultrasound being discussed in a question on CT scanning). Some candidates omitted important features of an answer. Candidates could benefit from practice at answering such questions.

There was no evidence to suggest that well-prepared candidates had insufficient time to complete their answers.

Comments on specific questions

Question 1

- (a) This question was generally answered correctly. Candidates should make clear that a ratio is involved, i.e. force per unit mass or force divided by mass, rather than ‘force on a unit mass’.
- (b)(i) Relatively few candidates recognised that the assumption is based on the condition for Newton’s law to be applicable. A common answer was to state that the separation is large.
- (ii) 1. Most candidates successfully carried out this calculation. Some weaker candidates used an incorrect mass or power of ten for the distance.
2. Most candidates did not multiply the answer in **part 1** by the mass of the Sun. Instead, they went back to substituting into the expression for Newton’s law. This gives a correct answer but there are more opportunities to make a mistake.

- (c) Very few answers were based on the answer obtained in **(b)(ii) part 2**. It was expected that candidates would realise that, although the force is very large, the large mass of the Sun would mean any acceleration would be very small.

Question 2

- (a) The symbols were usually identified correctly.
- (b) Most solutions were based on a calculation of n , usually followed by use of the Avogadro constant. A small number of answers were based on use of the expression $pV = NkT$.
- (c) This was a difficult question. Many weaker candidates gave the cube root of the total volume, rather than considering the volume occupied by a molecule. Candidates may benefit from more practice of questions involving interchanging between quantities that relate to the whole gas and quantities that relate to each molecule of the gas.

Question 3

- (a) Most answers included reference to potential energy and kinetic energy. Some did not make a reference to atoms or molecules. The use of the term 'random' was often confused (e.g. 'random systems').
- (b)(i) Many answers did not consider the thermal energy. Candidates should take care, when explaining that work is done, to identify whether it is work done on or by the gas.
- (ii) The question made reference to the change in density. Many candidates were not able to link this to the change in volume and the work involved. Most answers did conclude that the internal energy would increase but the reason for this was not always clear.

Question 4

- (a)(i) Candidates found it difficult to make the link between the graph and the motion of the mass, and many gave times at which the block is not moving with maximum speed.
- (ii) This question was completed successfully by most candidates.
- (iii) It was expected that the relevant expression would be given, together with the substitution and answer. The majority of scripts successfully showed this. Some candidates were unable to determine the amplitude from the graph, confusing amplitude with length.
- (b) The strongest candidates were able to give a correct shape with correct intercepts. Many weaker answers were based on straight lines, perhaps because candidates were more familiar with graphs of the variation of acceleration with displacement.

Question 5

- (a) Some candidates stated that the same transducer could be used as transmitter and receiver. Many answers correctly included a reference to the fact that pulsing meant that the depth of a boundary could be determined.
- (b)(i) This was generally answered correctly. A small minority of weaker candidates made inappropriate reference to the speed of light.
- (ii) Many answers did not contain enough detail. There were many references to both Z_1 and Z_2 being either large or small, but it is the difference between them that is important. Some candidates stated that the ratio could become 'large', without realising that its maximum value is 1.0. Some candidates recalled an expression for the reflection coefficient in terms of Z_1 and Z_2 , but then said that this was the transmission ratio.

Question 6

- (a) Many candidates gave expressions for electric field strength and equated them, but without comment to explain why they had done this. The phrase 'explain your working' is intended to prompt candidates to add some explanation. In this case, making reference to the zero field strength at $x = 11$ cm would have explained why equating the magnitudes of the two electric fields is valid.
- (b) (i) Generally, a correct expression was used. Often the correct change in potential was not substituted. Some weaker candidates gave incorrect values for the charge or mass of the α -particle.
- (ii) Some candidates used the correct value for the change in potential, but a common mistake was to substitute the value of the final potential, rather than any change in value.

Question 7

- (a) (i) A correct ratio was given in most scripts.
- (ii) This was completed successfully in most scripts and with sufficient explanation.
- (b) (i) Candidates should be reminded that they are provided (on page 3) with expressions for the combined capacitance of capacitors, and they should use these rather than relying on memory. A common error was to omit to take the reciprocal when combining capacitances in series.
- (ii) Candidates found this question difficult. Where the candidate quoted a ratio, it was common to find that the ratio had been inverted. This sometimes gave answers that were incorrect by many orders of magnitude, and a quick check whether the answer is reasonable might help candidates to realise that a mistake has been made.
- (iii) Stronger candidates who understood the situation were able to calculate the appropriate potential difference based on the value of 9.0 V together with their answers in (b)(ii).

Question 8

- (a) Most candidates correctly marked the positive connection. Some candidates misread the question, and marked a point elsewhere in the circuit, rather than one of the terminals of the voltmeter.
- (b) (i) This was generally answered correctly by those candidates who attempted the question. Most candidates correctly identified that it is an inverting amplifier and very few incorrectly used the gain formula for a non-inverting amplifier. Power-of-ten errors were quite common.
- (ii) Most candidates who completed (b)(i) successfully then went on to give the correct answer here.
- (c) Stronger candidates recognised that the circuit could be used in a variable-range meter or in the sensitivity control of a c.r.o.

Question 9

- (a) Many candidates incorrectly assumed that there would be a downward force on the wire. The question stated that the force on the magnet was downwards, so application of Newton's third law indicates that the force on the wire must be upwards. Candidates who realised that the force on the wire was upwards were then generally able to complete the remainder of the working to determine the current direction correctly.
- (b) In general, allowance was correctly made for r.m.s. current and the expression $F = BIL$ was used correctly to obtain the maximum force in one direction. In many answers, the final stage to obtain the difference in force was not completed successfully.

Question 10

Most candidates realised that the non-uniform field enabled the location of nuclei/atoms to be determined. Beyond this, many answers did not contain enough detail to be awarded full credit. Many scripts referred to atoms throughout and made no mention of nuclei. A common misconception was that switching off the magnetic field caused the nuclei/atoms to de-excite.

Question 11

- (a) Most answers were correct.
- (b) Many candidates misread this question. Rather than considering the increased magnetic flux due to a stationary core inside the solenoid, candidates wrote about the situation as the core was being inserted. These responses could not be awarded credit because they referred to a different situation from the one described in the question.
- (c) A large number of candidates were able to state two acceptable sources of power loss. Some candidates were not awarded credit because they did not give sufficient detail. For example, the identification of eddy currents required that the location of these currents (the core) would also be given.

Question 12

- (a) (i) A common correct answer was electron diffraction. A significant number of candidates merely referred to diffraction. This could have referred to a wave and so was not awarded credit.
- (ii) Most candidates were able to name the photoelectric effect.
- (b) (i) The correct energy change was identified in most scripts. Many candidates indicated a transition with an incorrect direction, which would have been associated with an absorption spectrum rather than an emission spectrum.
- (ii) The calculation was completed successfully by most candidates who attempted it. Explanation was usually included.
- (c) (i) This proved to be difficult for most candidates. Many did not state that the de Broglie wavelength is the wavelength associated with a moving particle. A common answer was to quote the de Broglie formula and then to explain the meaning of the symbols h and p , without considering λ .
- (ii) For those candidates who were familiar with the formula, the calculation was usually carried out correctly.

Question 13

Some candidates did not attempt this question and a significant number confused CT scanning with NMRI or ultrasound scanning.

Some candidates were familiar with the various stages of the CT scanning process but found it difficult to present these in a logical order. In general, candidates found it particularly difficult to make the distinction between the production of an image of a (2D) 'slice' and the subsequent build-up of a 3D image from a series of 'slices'.

Question 14

- (a) (i) The α -particle was usually identified correctly.
- (ii) Candidates found it much more difficult to identify the neutron. A common error was to describe a proton. Some weaker candidates saw the symbol Φ and incorrectly associated it with work function energy.
- (b) (i) The mass change was determined correctly in most answers.
- (ii) Most candidates correctly obtained the energy by use of the expression $\Delta E = c^2\Delta m$ rather than attempting to recall the energy equivalent of 1.0 u in MeV.
- (c) The strongest candidates made a clear reference to the mass of the products being greater than the mass of the reactants. Many realised, or assumed, that the incident α -particle would need to have energy, but very few stated that this would be in the form of kinetic energy and would be at least the quantity calculated in (b).

PHYSICS

Paper 9702/43
A Level Structured Questions

Key messages

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Question 5

- (a) Many candidates could not reason why there is no electric field inside a conductor. There were references to the field lines and potentials, both of which are constructs to help our understanding, but they do not provide a reason for why the spheres behave as they do. It was relatively common for candidates to say that there was no charge, which is not correct. Some candidates answered the question as if it was asking why there was no field *between* the spheres, rather than in the spheres.

- (b) Most candidates realised that the field strengths needed to be subtracted from each other, but generally they did not explain why. Candidates should be reminded that, if a question asks for working to be explained, they should provide some words to do this.
- (c) The most common mistake was to subtract instead of adding the two potentials. Some candidates worked out only one of the two potentials and this does not give a correct answer.
- (d) This was a less structured question requiring several stages. Candidates had to equate the two energies, realise that the charge was 47 times the fundamental charge and realise that the mass was 107 times the atomic mass unit. Then they had to rearrange the equation and calculate v . This proved difficult for many candidates, although most were awarded at least partial credit.

Question 6

- (a) Infinite slew rate is one of the properties of an ideal operational amplifier, but slew rate is not fully understood by candidates. Many candidates correctly made reference to input and output. A smaller number referred to the time delay between a change in the input leading to a change in the output.
- (b) (i) This was a simple potential divider circuit and candidates needed to realise that the voltages at the inverting and non-inverting inputs had to be the same. Some candidates did not realise this. One of the most common mistakes from weaker candidates was to use the 5V supply to the op-amp as the potential divider voltage.
 - (ii) Many candidates did not draw correct symbols for the LEDs. Commonly the arrows were omitted, too many or too few in number, or pointing towards the diode. Many responses showed incorrect logic when establishing which diode would be conducting. Some candidates did not know that the resistance of the thermistor would increase or did not refer to the thermistor at all.

Question 7

- (a) Whilst nearly all candidates had some concept of what is meant by a field, some of the weaker candidates had difficulty in providing a general answer, and instead gave 'mass' or 'charge' rather than 'object' or 'particle'. Some candidates used the word 'field' in their explanation which does not earn credit.
- (b) Whilst the majority of candidates could state that a gravitational field would give rise to a force acting on the moving uncharged particle, it was common for candidates to overlook the possibility of a gravitational field acting on a stationary charged particle or a charged particle moving at an angle to the field or fields.
- (c) (i) Candidates tended to know that the force was magnetic, that it was acting on the particle at right angles to the motion and that it provided the centripetal force. Many candidates did not realise that the force, or the speed of the particle, was constant. A significant number incorrectly stated that the velocity was constant.
 - (ii) Most candidates were able to answer this question. A number of candidates ended their working for the equation with r rather than momentum as the subject, even though they had correctly derived the expression on the previous line.

Question 8

There were some very good answers to this question from candidates who clearly understood the main principles behind NMRI. However, many candidates seemed to be repeating passages remembered from textbooks, which contained a lot of extraneous and irrelevant information. Comprehension is the key to receiving high marks on this type of question.

A common error was to miss the key words such as pulse or nuclei/proton. Some weaker candidates described a magnetic field switching on and off rather than referring to a pulse of RF.

Question 9

- (a) Most candidates had correctly learned Faraday's law of electromagnetic induction. A small number of candidates referred to electromagnetic force in error.
- (b) Most candidates answered correctly. If a mistake was made, it was usually because the candidate did not base the answer on the expression BAN for the flux linkage. These candidates would generally calculate B and stop. A very small number used diameter rather than radius. Some candidates calculated an answer to several significant figures. This is good practice as it indicates to the candidate (and the Examiner) that calculation has been done correctly.
- (c) A common answer was 2.0 mV. Candidates giving this answer did not realise that, if the current changes direction, the flux linkage goes from positive to negative (through zero). The change in flux linkage is therefore 1.2×10^{-3} Wb in a time of 0.30 s.
- (d) The previous question part should have helped the candidates, but the majority of candidates seemed not to have spotted this. Instead many drew graphs that bore no relationship to Faraday's law or the value of the e.m.f. that they had just calculated. Candidates may benefit from further study of Faraday's law and, in particular, it should be emphasised how the induced e.m.f. relates to the gradient of graphs such as the one given.

Question 10

- (a) There were few fully correct answers to this question. Most candidates explained that electrons were emitted from the surface, but fewer candidates mentioned that this occurs when photons are incident on the surface.
- (b) Candidates demonstrated a good ability to calculate photon energy from wavelength.
- (c) Again, candidates demonstrated good ability here in calculating threshold wavelength. Some weaker candidates omitted the conversion from electronvolt to joule, and this cannot give the wavelength in nm.
- (d) These explanations were often insufficient. It was quite common for candidates with correct values for the threshold wavelengths to state that caesium would not give rise to photoelectric emission but that tungsten would. Some candidates gave explanations that did not mention the threshold wavelengths.

Question 11

Many candidates saw the picture of the bands and immediately assumed that this question was about semiconductors. The sentence below **Fig. 11.1** was intended to help candidates realise that it is a generic diagram. The question asked about metals but many candidates, thinking of semiconductors, said that the resistance decreases with increasing temperature. Centres should ensure that candidates are able to explain the conduction of both metals and semiconductors in terms of band theory.

Some stronger candidates stated that in metals at room temperature the valance band and the conduction band overlapped and that this meant that the number of charge carriers would be constant. When it came to explaining interactions of the conduction electrons with the metal lattice, there were several misconceptions. Some candidates stated that conduction electrons got in each other's way and collided with each other, or that increasing the temperature increased the number of conduction electrons and this reduced the space in which conduction electrons can move.

Question 12

- (a) (i) Some answers referred to ambiguous or inappropriate quantities such as the 'amount of the substance' or the 'mass of the sample'. The mass of the sample does not halve during the half-life but the number of active nuclei and the activity of the parent nuclide do. The sample will only be lighter as a result of the radiation that has escaped the sample. There was widespread confusion between the words nuclei, nucleus and nucleon.
- (ii) The weakest candidates either omitted this question or missed out the key statement $A = A_0 e^{-\lambda t}$. Some just rearranged the equation $\lambda t_{1/2} = 0.693$ and this could not be awarded credit. A significant number of candidates demonstrated confusion with the subscripts $\frac{1}{2}$ and 0, and were not able to gain credit.
- (b) This calculation was generally very well done. The most common mistake was to divide by the Avogadro constant *and* multiply by u . Another common error was to use 222 kg as the atomic mass of radon rather than 222 g, which gave an answer incorrect by a factor of 10^3 .

PHYSICS

Paper 9702/51
Planning, Analysis and Evaluation

Key messages

- In **Question 1**, candidates' responses should include detailed explanations of experimental procedures, such as control of variables, measurements to be taken and analysis of data.
- Candidates should be encouraged to take time initially to read the question slowly and carefully in order to fully understand what is required.
- Graphical work should be carefully attempted and checked. Candidates should use a sharp pencil when plotting data points and use a transparent 30 cm ruler when drawing the line of best fit and the worst acceptable line; care is also needed when reading information from the graph.
- The numerical answers towards the end of **Question 2** require candidates to show all their working particularly when determining uncertainties. A full understanding of significant figures is required.
- The practical skills required for this paper should be developed and practised over a period of time with a 'hands on' approach.

General comments

All candidates completed the paper and there was no evidence of time constraints. The majority of the scripts were clearly written.

In **Question 1**, many candidates misunderstood the requirements of the experiment and did not describe how the velocity of the falling magnet could be determined as it left the pipe. The methods that candidates described often did not contain the necessary amount of detail or mention the appropriate measurements. Some candidates wrote a lot of irrelevant points. It is advisable that candidates think carefully about the experiment following the points given on the question paper, and to imagine how they would perform the experiment in the laboratory.

In **Question 2**, graphs were well drawn with points and error bars easily identifiable. Candidates should be advised that, to gain the highest marks, the presentation of mathematical working requires a clear statement of the equation used with correct substitution of numbers, leading to the correct answer. It is helpful when candidates set out their working in a logical and readable manner.

It is clear that the stronger candidates have experienced a practical course where the skills required for this paper are developed and practised over a period of time with a 'hands on' approach. To assist Centres, Cambridge has produced practical support booklets which are available from the Teacher Support Site.

Comments on specific questions

Question 1

Candidates should be encouraged to take time to read the question carefully before starting their answer. Some candidates use page 2 of the question paper to structure their response.

The question asked the candidates to design an experiment to investigate how the speed v of a magnet as it leaves a copper pipe varies with the magnetic flux density B produced by the magnet. Candidates were also required to test the relationship between v and B and to determine the values of the constants λ and v_0 .

A large number of candidates described a method to measure the average velocity of the magnet falling through the copper tube. This does not give the value of v . A significant number of candidates introduced coils around the copper tube to produce a magnetic field that was not relevant to this investigation. Other candidates suggested winding a coil around the copper tube and measuring the e.m.f. induced by the falling magnet.

Most candidates gained credit for stating that B is the independent variable and v is the dependent variable. Further credit was awarded for either stating that the starting position of the magnet needs to be kept constant or that the magnet needs to be released from rest. It is important to identify quantities that are required to be kept at a constant value in order for the investigation to be valid.

Candidates needed to draw a clearly labelled diagram. Diagrams should include the necessary apparatus, set up as it would be used in the experiment. Copper pipes drawn 'in the air' needed to be supported. For full credit a candidate needed to describe a practical method to ensure that the copper tube was supported vertically.

The next mark for methods of data collection was for describing the how the velocity v of the magnet as it leaves the copper pipe is measured. This was rarely described correctly. To be awarded credit, candidates needed to suggest placing timing devices below the bottom of the tube. Some candidates realised the right placement of light gates but did not mention the need for a timing device. Candidates were able to gain two marks for additional detail if they described other measurements required, e.g. use a ruler to measure the distance between light gates and use an appropriate equation to determine v .

Most candidates knew that a Hall probe measures magnetic flux density. A few candidates tried to calculate B from electromagnetic formulae.

The majority of candidates who gained credit for analysis of the data suggested plotting a graph of $\ln v$ against B . There were two marks for explaining how λ and v_0 could be determined. This required λ and v_0 to be the subject of the equations that included the gradient and y -intercept respectively. There was generally a sound appreciation of the mathematics involved in obtaining a linear equation from the form stated in the question. Some candidates suggested plotting a graph of $\lg v$ against B . Full credit could still be obtained for a correct analysis using this approach, but the use of base 10 makes mistakes more likely to occur in the analysis.

The additional detail section had a maximum of six marks that could be awarded. The marking points allow candidates to broaden their answers. Generally only the strongest candidates were able to obtain more than four of the marks. Candidates should be encouraged to write their plans including appropriate detail; often candidates' answers suggested that they did not have sufficient practical experience. Vague responses were not credited. It is essential that candidates' answers give detail relevant to the experiment in the question rather than general 'textbook' rules for working in a laboratory.

Candidates should be made aware that a statement like "the experiment is repeated and an average is taken" is not awarded credit. More detail is required, such as "for each value of B , the experiment is repeated and v is determined again, and the average value of v is then found".

Question 2

This question required candidates to analyse data given for how the total capacitance X of capacitors in series was related to the potential difference V across the combination.

- (a) This question was generally answered well.
- (b) The table was generally completed well. Most candidates were able to calculate the correct numerical values, but some candidates made errors in the number of significant figures, particularly for the values of $1/V$. Since V was given to three significant figures, it was expected that $1/V$ would be given to three or four significant figures. Candidates must be able to round correctly. The majority of candidates calculated the absolute uncertainties in X correctly.
- (c) (i) Most candidates scored full credit. Some candidates were not awarded credit because the size of their points was too large. Candidates need to take greater care over the accuracy of the error bars. A few candidates incorrectly plotted vertical error bars.

- (ii) The drawing of both the line of best fit and the worst acceptable line was good. Some candidates used shading or drew a line that was discontinuous. Candidates who use a transparent 30 cm ruler will avoid kinks in their lines. Several candidates joined the first plotted point to the last plotted point, and this did not give the line of best fit. Candidates should be encouraged to draw a line which has a good balance of points about the line, and they should clearly indicate the lines drawn.
- (iii) Most candidates clearly demonstrated the points that they used to calculate the gradient. Some candidates lost credit because they misread coordinates, did not use a sensibly sized triangle, or calculated the gradient using $(\text{change in } x)/(\text{change in } y)$. A small number of candidates chose points that were data points from their table but did not lie on the lines. Some candidates did not allow for the 10^{-3} in the x -axis.
- (iv) This part was also well answered, showing good clear working in the calculation of the y -intercept. Common mistakes in calculating the uncertainty in the y -intercept were either to use the same coordinates as the line of best fit (this can only be done if the crossing point is used), or to use the gradient of the line of best fit.
- (d)(i) It is vital that the working for the answers is clearly shown. The equation should be quoted followed by correct substitution of numerical values. To determine E , the value of the y -intercept determined in (c)(iv) needed to be used. To determine Y , the value of the gradient calculated in (c)(iii) was needed.

Most candidates determined E correctly and gave their value to two or three significant figures. Candidates found it more difficult to determine Y with the correct unit. Some candidates could not identify the correct unit for Y or made a power-of-ten error in the gradient calculation. For full credit, candidates needed to have carefully completed the question; the final answer for Y needed to be given within a required range.

- (ii) Candidates needed to demonstrate the method that they used, and clear and logical working was essential for this part. Candidates who used the method of adding percentage uncertainties of the gradient and y -intercept were often successful. The candidates who attempted to calculate the maximum and minimum values for Y tended to make more mistakes by using incorrect combinations of maximum and minimum values. Candidates would benefit from more practice of the addition of percentage uncertainties.

PHYSICS

<p>Paper 9702/52 Planning, Analysis and Evaluation</p>
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Key messages

- In **Question 1**, candidates' responses should include detailed explanations of experimental procedures, such as control of variables, measurements to be taken and analysis of data.
- Candidates should be encouraged to take time initially to read the question slowly and carefully in order to fully understand what is required.
- Graphical work should be carefully attempted and checked. Candidates should use a sharp pencil when plotting data points and use a transparent 30 cm ruler when drawing the line of best fit and the worst acceptable line; care is also needed when reading information from the graph.
- The numerical answers towards the end of **Question 2** require candidates to show all their working particularly when determining uncertainties. A full understanding of significant figures is required.
- The practical skills required for this paper should be developed and practised over a period of time with a 'hands on' approach.

General comments

Most candidates completed the paper and there was no evidence of time constraints. The majority of the scripts were clearly written.

In **Question 1**, candidates did not always describe the method in the necessary detail. Some candidates wrote a lot of irrelevant points. It is advisable that candidates think carefully about the experiment following the points given on the question paper, and to imagine how they would perform the experiment in the laboratory.

In **Question 2**, graphs were well drawn with points and error bars easily identifiable. Candidates should be advised that, to gain the highest marks, the presentation of mathematical working requires a clear statement of the equation used with correct substitution of numbers, leading to the correct answer. It is helpful when candidates set out their working in a logical and readable manner.

It is clear that the stronger candidates have experienced a practical course where the skills required for this paper are developed and practised over a period of time with a 'hands on' approach. To assist Centres, Cambridge has produced practical support booklets which are available from the Teacher Support Site.

Comments on specific questions

Question 1

Candidates were required to investigate the relationship between the magnetic flux density B measured using a Hall probe and the vertical distance p from the poles of an electromagnet, and to explain how their results could be used to determine k and α from a given equation.

Most candidates gained credit for stating that p was the independent variable and B was the dependent variable. To be awarded the second mark for defining the problem, candidates had to state that the current I needed to be kept constant. An additional detail mark was available for stating that the number of turns N needed to be kept constant.

Candidates who drew a correct, labelled diagram indicating how the Hall probe and ruler could be positioned and supported were given credit for the method of data collection. A number of candidates marked distances on the diagram but the start and end points were often vague. A mark was also available for a correct circuit diagram. The last two marks in this section were for measuring p with a rule and for a method to determine p accurately, such as measuring the height of the electromagnet above the bench and subtracting it from the height of P above the bench, or by placing a ruler across the top of the magnet so that a zero could be clearly identified.

The majority of candidates who gained credit for analysis of the data suggested plotting a graph of $\ln B$ against p . There were two marks for explaining how α and k could be determined. This required α and k to be the subject of the equations that included the gradient and y -intercept respectively. A number of candidates found k difficult to determine. There was generally a sound appreciation of the mathematics involved in obtaining a linear equation from the form stated in the question. Some candidates suggested plotting a graph of $\lg B$ against p . Full credit could still be obtained for a correct analysis using this approach, but the use of base 10 makes mistakes more likely to occur in the analysis.

The additional detail section has a maximum of six marks that could be awarded. The marking points allow candidates to broaden their answers and a large number of the stronger candidates obtained several of these marks. Candidates should be encouraged to write their plans including appropriate detail; often candidates' answers suggested that they did not have sufficient practical experience. Vague responses were not credited. It is essential that candidates' answers give detail relevant to the experiment in the question rather than general 'textbook' rules for working in a laboratory.

Candidates should be made aware that a statement like "the experiment is repeated and an average is taken" is not awarded credit. More detail is required, such as "for each value of p , the experiment is repeated (with current or Hall probe reversed) and B is determined again, and the average value of B is then found".

Question 2

This question required candidates to analyse data from an experiment investigating the minimum potential difference V across an LED when it just emits light, and how this varies with the wavelength λ of the light.

- (a) This question was generally answered well.
- (b) The table was generally completed well. Most candidates were able to calculate the correct numerical values, but some candidates made errors in the number of significant figures. Since V was given to two significant figures, then $\lg V$ should be given to two or three decimal places. Candidates must be able to round correctly. The majority of candidates calculated the absolute uncertainties in $\lg(V/V)$ correctly.
- (c) (i) The majority of candidates scored full credit for the plotting of the data points with the corresponding error bars. Some candidates were not awarded credit because the size of their points was too large. Candidates need to take greater care over the accuracy of the error bars.
- (ii) The drawing of both the line of best fit and the worst acceptable line was good. Some candidates used shading or drew a line that was discontinuous. Candidates who use a transparent 30 cm ruler will avoid kinks in their lines. Several candidates joined the first plotted point to the last plotted point, and this did not give the line of best fit. Candidates should be encouraged to draw a line which has a good balance of points about the line, and they should clearly indicate the lines drawn.
- (iii) Most candidates clearly demonstrated the points that they used to calculate the gradient. Candidates should select points that are on the line rather than quoting values from the table. Most candidates were able to choose a sensibly sized triangle. Most candidates realised that the gradient was negative.
- (iv) This part was also well answered, showing good clear working in the calculation of the y -intercept. Common mistakes in calculating the uncertainty in the y -intercept were either to use the same coordinates as the line of best fit (this can only be done if the crossing point is used), or to use the gradient of the line of best fit. Some candidates read off the value from a false origin and could not be awarded either mark.

- (d) It is vital that the working for the answers is clearly shown. Candidates should quote the equation followed by correct substitution of numerical values. To determine p , the value of the y -intercept determined in (c)(iv) needed to be used. To determine q , the value of the gradient calculated in (c)(iii) was needed.

For full credit, candidates needed to have carefully completed the question; the final answer for q needed to be given within a required range and to two or three significant figures.

- (e) The calculated value of V could either be determined using the relationship given on page 5 or the logarithmic equivalent. Again, clear, logical working was required. A large number of candidates did not realise that, for the relationship to work with the values of p and q calculated, λ needed to be measured in nanometres.

PHYSICS

Paper 9702/53
Planning, Analysis and Evaluation

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The majority of candidates who gained credit for analysis of the data suggested plotting a graph of $\ln v$ against B . There were two marks for explaining how λ and v_0 could be determined. This required λ and v_0 to be the subject of the equations that included the gradient and y -intercept respectively. There was generally a sound appreciation of the mathematics involved in obtaining a linear equation from the form stated in the question. Some candidates suggested plotting a graph of $\lg v$ against B . Full credit could still be obtained for a correct analysis using this approach, but the use of base 10 makes mistakes more likely to occur in the analysis.

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- (b) The table was generally completed well. Most candidates were able to calculate the correct numerical values, but some candidates made errors in the number of significant figures, particularly for the values of $1/V$. Since V was given to three significant figures, it was expected that $1/V$ would be given to three or four significant figures. Candidates must be able to round correctly. The majority of candidates calculated the absolute uncertainties in X correctly.
- (c) (i) Most candidates scored full credit. Some candidates were not awarded credit because the size of their points was too large. Candidates need to take greater care over the accuracy of the error bars. A few candidates incorrectly plotted vertical error bars.

- (ii) The drawing of both the line of best fit and the worst acceptable line was good. Some candidates used shading or drew a line that was discontinuous. Candidates who use a transparent 30 cm ruler will avoid kinks in their lines. Several candidates joined the first plotted point to the last plotted point, and this did not give the line of best fit. Candidates should be encouraged to draw a line which has a good balance of points about the line, and they should clearly indicate the lines drawn.
- (iii) Most candidates clearly demonstrated the points that they used to calculate the gradient. Some candidates lost credit because they misread coordinates, did not use a sensibly sized triangle, or calculated the gradient using $(\text{change in } x)/(\text{change in } y)$. A small number of candidates chose points that were data points from their table but did not lie on the lines. Some candidates did not allow for the 10^{-3} in the x -axis.
- (iv) This part was also well answered, showing good clear working in the calculation of the y -intercept. Common mistakes in calculating the uncertainty in the y -intercept were either to use the same coordinates as the line of best fit (this can only be done if the crossing point is used), or to use the gradient of the line of best fit.
- (d)(i) It is vital that the working for the answers is clearly shown. The equation should be quoted followed by correct substitution of numerical values. To determine E , the value of the y -intercept determined in (c)(iv) needed to be used. To determine Y , the value of the gradient calculated in (c)(iii) was needed.

Most candidates determined E correctly and gave their value to two or three significant figures. Candidates found it more difficult to determine Y with the correct unit. Some candidates could not identify the correct unit for Y or made a power-of-ten error in the gradient calculation. For full credit, candidates needed to have carefully completed the question; the final answer for Y needed to be given within a required range.

- (ii) Candidates needed to demonstrate the method that they used, and clear and logical working was essential for this part. Candidates who used the method of adding percentage uncertainties of the gradient and y -intercept were often successful. The candidates who attempted to calculate the maximum and minimum values for Y tended to make more mistakes by using incorrect combinations of maximum and minimum values. Candidates would benefit from more practice of the addition of percentage uncertainties.