Principal examiner reports for teachers

Principal examiner reports for teachers summarise what candidates did well and what candidates needed to improve for this examination series only.

This report is to be used in conjunction with the question paper and mark scheme.

For guidance on teaching and learning we provide resources for many of our syllabuses.

Resource	Where to find it
Grade descriptions – Grade descriptions describe the level of performance typically demonstrated by candidates achieving the different grades awarded for a qualification.	School support hub Select: Subject > Resource finder > Syllabus and specimen materials
Schemes of work – Schemes of work are designed to support you in your teaching and lesson planning.	School support hub Select: Subject > Resource finder > Teaching and learning
Lesson planning – Guidance on how to plan a lesson.	Lesson planning
Resource plus – There may be additional resources such as teaching packs containing lesson plans, resources and worksheets and videos for aspects of your syllabus.	School support hub Select: Subject > Resource finder > Teaching and learning
Teaching tools	Teaching Tools
Exemplar candidate responses	School support hub Select: Subject > Resource finder > Teaching and learning
Learner guide – A guide for students to help them understand what the course involves.	School support hub Select: Subject > Resource finder > Teaching and learning
Community forums – Do you have a question or something to share? Our online forums are great way to keep up to date with your subject and the global Cambridge community.	Community forum on the school support hub
Access to scripts for this series.	Access to scripts service
Results analysis is available for some syllabuses.	Results analysis
Test maker is available for some subjects.	Test maker

Other services from Cambridge International Education

- **Digital mocks service**
- **Insight assessments**
- **Professional development**
  - Focus on assessment
  - Online marking workshops

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PHYSICS

Paper 9702/11
Multiple Choice

Key messages

Candidates performed well on **Questions 3, 4, 6, 8, 10, 11, 14, 16, 17, 19, 21, 23, 29, 31, 34, 38, 39** and **40**.

Candidates performed less well on **Questions 1, 2, 5, 7, 9, 12, 13, 15, 18, 20, 22, 24, 25, 26, 27, 28, 30, 32, 33, 35, 36,** and **37.**

Candidates should take care to read the question and all options fully. Options will often include partially correct answers or common misconceptions. Numerical questions will sometimes include common arithmetic errors in applying a correct formula.

Some candidates did not always account for vector addition correctly, often adding or subtracting magnitudes rather than determining the resultant vector.

Some candidates did not always analyse circuit questions successfully, with responses distributed across several distractors in a number of questions.

Candidates generally performed well on the particle physics questions.

Comments on specific questions

Question 1

- Option A was a common incorrect answer.
- Some candidates did not distinguish between base quantities and base units.

Question 2

- Many candidates correctly found the percentage uncertainty in the side length (1.0/2 = 0.5 per cent) and then multiplied this by 3 to get the key B.
- Option C was a common incorrect answer.
- Candidates selecting C had used 3 × percentage uncertainty in the area, rather than 3 × percentage uncertainty in the side length.
- Some candidates chose options A and D, both based on incorrectly treating the percentage uncertainty in the area as the percentage uncertainty in the side length, and incorrectly converting to a percentage uncertainty in volume.

Question 5

- All options were popular, with option A being the most common incorrect answer.
- Candidates selecting A confused velocity with speed.
- Many candidates chose distractors C and D, perhaps confusing the behaviour or velocity and acceleration during the motion of the ball.

Question 7

- Option D was the most common incorrect answer, obtained by adding the magnitudes of the vertical and horizontal components of velocity at t = 3s, rather than finding the resultant magnitude.
- Some candidates added the horizontal and vertical components directly rather than determining the magnitude of the resultant vector.

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- Some candidates chose option A, confusing the horizontal component of the final velocity with the final velocity of the ball.

Question 9

- Many candidates selected option A.
- Many candidates understood that the contact force acting on the book due to the table is both equal and opposite to the weight of the book because the book is in equilibrium, but that this force does not form a third law pair with the weight.
- Some candidates identified forces acting on the same object as a third law pair.

Question 12

- All distractors proved popular.
- Many candidates selected option D, which is the result of adding the magnitudes of the initial velocities, rather than finding the total initial momentum.
- Some candidates selected option A which is the difference between the magnitudes of the initial velocities.
- Few candidates recognised that this was a conservation of momentum problem. Those that did were able to obtain the correct answer of C.

Question 13

- All distractors proved popular.
- Responses indicated that the definition of the torque of a couple was not always recognised.

Question 15

- Some candidates correctly solved the moments problem and selected option B.
- Many candidates selected option C, assuming that F_1 and F_2 were equal, and neglecting the effect of F_3.
- Candidates could solve this problem in several ways, but the simplest was to take moments of the centre of gravity, and form an equilibrium equation in terms of F_1 and F_2.

Question 18

- Many candidates correctly considered the difference in gravitational potential energy for the two objects, and equated this to the kinetic energy as the objects reached the ground to find the correct ratio.
- Many candidates chose the ratio between the gravitational potential energies of the two objects, option D.

Question 20

- Many candidates correctly chose option D, recognising that the Young Modulus is a material property, and does not change as force is increased.
- All distractors were chosen, with option A being the most common incorrect answer. Candidates should realise that if the volume remains constant and the wire is being stretched, then the area must decrease.
- Candidates are encouraged to carefully read the conditions specified in the question.

Question 22

- All options were popular, with all distractors selected approximately equally.
- Responses indicated that effective spring constants for combinations of springs were not always determined correctly.
- Some candidates did not distinguish between springs acting in series and springs acting in parallel when determining the effective spring constant.

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Question 24

- Few candidates realised that as the train moved with a constant velocity, the frequency observed by the stationary observer would be constant (at a value lower than the emitted frequency).
- Most candidates selected option D, indicating that the Doppler effect is not well understood.

Question 25

- Distractors A and C were often selected.
- Responses indicated that the wavelength ranges of the principal regions of the electromagnetic spectrum were not always recognised.

Question 26

- Very few candidates correctly made use of the relationships power = intensity × area and intensity $\propto$ amplitude^2 to arrive at option D.
- Options B and C were commonly chosen, indicating that many candidates were able to recall and apply one of the two relationships, but not both.

Question 27

- Candidates needed to recognise that the next highest frequency would result in a stationary wave with 6 nodes. They also needed to relate the string length to the number of nodes and the wavelength.
- Some candidates were able to do this and selected the correct option A.
- The distractors were chosen evenly, suggesting uncertainty in how to approach the problem.

Question 28

- Most candidates recalled that the wavelength is unchanged during diffraction, with A (the key) or B selected by most candidates.
- Candidates needed to realise that the gap width in the diagram was similar to the wavelength of the waves, and so increasing the width would gradually reduce the observed diffraction angle.

Question 30

- Candidates needed to make use of the diffraction grating equation to determine the key A.
- All three distractors were equally popular, suggesting uncertainty in applying the diffraction grating equation.

Question 32

- Candidates needed to make use of the formula $R = \rho L/A$ to recognise that R is inversely proportional to A.
- Many candidates chose distractor B, indicating that candidates recognised the negative correlation between R and A, but could not correctly recall the shape of an inverse graph.

Question 33

- Candidate responses were distributed across the distractors, with no single incorrect response predominating.
- This question required careful consideration of the circuit. There were several ways to approach this problem, with the most straightforward being to consider the potential difference across each component and then use power = pd^2/resistance, or to consider the current in each component and use power = current^2 × resistance.

Question 35

- Most candidates correctly selected option A.
- Some candidates selected option B, confusing the sum of potential differences in series with those in parallel.
- Some candidates selected option D, confusing Kirchhoff's first and second laws.

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Question 36

- Some candidates correctly compared the resistances in both branches to determine the potential between each pair of resistors, and were then able to determine the potential difference on the voltmeter and select option B.
- Many candidates chose option A, which was the potential difference across the 6.0 Ω resistor.
- Many candidates chose option C which was the potential difference across the 9.0 Ω resistor.

Question 37

- Some candidates were able to correctly identify the changes to the readings on the meters.
- Some candidates chose option B, perhaps confusing the behaviour of the LDR, or else considering the potential difference across the LDR rather than the fixed resistor.
- Some candidates chose option C, which would require the resistance of the LDR to have both increased and decreased.

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Paper 9702/12
Multiple Choice

Key messages

Candidates performed well on **Questions 1, 2, 4, 5, 6, 7, 8, 9, 14, 15, 17, 18, 20, 21, 22, 23, 24, 25, 29, 34, 36, 37, 38, 39** and **40.**

Candidates performed less well on **Questions 3, 10, 11, 12, 13, 16, 19, 26, 27, 28, 30, 31, 32, 33,** and **35.**

Candidates should take care to read the question and all options fully. Options will often include partially correct answers or common misconceptions. Numerical questions will sometimes include common arithmetic errors in applying a correct formula.

Some candidates did not distinguish between the conditions required for an object in equilibrium and the conditions required for Newton's third law.

Candidates generally performed well on the nuclear physics questions.

Comments on specific questions

Question 3

- Very few candidates recognised that a percentage increase in one force required an identical percentage increase in the other two forces.
- Options B and D were popular distractors, indicating that most candidates thought that Q and R would increase by different proportions.
- Many candidates assumed that *Q* would increase by 10 per cent, and then proceeded to determine the absolute increase in *R*, rather than the percentage increase, leading to option C. For example if *P* and *Q* increase from 100 N to 110 N, then Q increases from $\sqrt{20\,000}$ N to $\sqrt{24\,200}$ N. The difference between the new and old values of Q is $10\sqrt{2}$ N.

Question 10

- Many candidates correctly deduced that a solid steel object would have a greater mass and thus a greater weight, and so a greater terminal velocity, as the upthrust force remains unchanged.
- Candidates who thought about an object falling in the absence of air resistance, or who had not recognised that the original object reached terminal velocity chose option B, which was the most popular distractor.
- Option C was more popular than option D, suggesting candidates had not realised that the original object had reached terminal velocity, and so needed more time to reach a higher velocity.

Question 11

- To solve this dynamics problem, candidates needed to consider the resultant force acting on the ball as the vector sum of the force applied on the ball by the sand and the weight of the ball. Candidates who remembered the weight of the ball were able to calculate F = 4.5 × 800 + 4.5 × 9.81 = 3644 N.
- The vast majority of candidates calculated the resultant force acting on the ball (4.5 × 800 = 3600 N) and gave this as the answer, without considering the weight acting on the ball.
- A small proportion of candidates gave the weight of the ball as the answer, perhaps considering an equilibrium situation.

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Question 12

- Many candidates correctly chose option C, recognising that objects need not be in contact.
- The most popular distractor was B, illustrating a common misconception that the forces in a third law pair act on the same object. Candidates often confuse the requirement for forces acting on an object in equilibrium with Newton's third law.

Question 13

- This question assessed candidates' understanding of Archimedes' principle. Candidates needed to recognise that the density of the liquid was the crucial variable in the options presented, and then determine the correct option.
- Most candidates selected options B or D, indicating that the relationship between density and upthrust is generally well understood.
- Candidates who realised that h would decrease if the bulb sat lower in the water, requiring a lower density of liquid, and so a greater displaced volume at equilibrium selected option B.
- Many candidates chose option D, perhaps confusing what distance h was measuring.

Question 16

- Very few candidates chose option A, indicating that most candidates do not hold this common misconception.
- Many candidates chose options C and D, indicating that the conditions for equilibrium are generally recognised, but not realising that both conditions are required for a system in equilibrium.
- Few candidates selected option B, suggesting that the concept of resultant torque may be unfamiliar.

Question 19

- Many candidates correctly determined the extension using an elastic potential energy equation (for example $x = \sqrt{(2 \times 0.010/22.5)} = 0.030$) and then subtracted this from the stretched length to get option B.
- Many candidates determined the extension and then chose this as their answer (option A). Candidates are reminded to carefully read the question.
- Option C was the most popular distractor, a result of missing the factor of ½ in the elastic potential energy equation and determining an extension of 20 mm.
- Candidates who misunderstood the question and confused the original and final lengths chose option D.

Question 26

- Many candidates selected distractor B, suggesting that the relationship between diffraction and gap size was not always understood.
- Many candidates selected distractor B, suggesting that they believe the gap should be larger than the wavelength.

Question 27

- All options were selected frequently, with the distractors chosen quite equally, suggesting uncertainty in applying the diffraction grating equation.
- To solve this problem, candidates needed to set up an equation using the diffraction grating equation and recognise that the line spacing and diffraction angle were constant, for $n_x\lambda_x = n_y\lambda_y$ leading to $\lambda_x/\lambda_y = n_y/n_x$. As $n_x = 2$ and n_y is an integer, only option D (3/2) is possible.

Question 28

- Most candidates chose either option A or B, indicating that candidates can distinguish between nodes and antinodes.
- Many candidates chose distractors B and D, confusing a graph of displacement against L with the graph of amplitude against L.
- Some candidates did not distinguish between scalar and vector quantities when interpreting graphical representations.

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Question 30

- Most candidates correctly selected option C, demonstrating good understanding of the definition of potential difference.
- Option A was the most popular distractor, suggesting confusion between power and energy.

Question 31

- Many candidates correctly selected option B.
- Option C was the most popular distractor, with many candidates realising the equation required time in the denominator.
- Option D was also popular, with candidates perhaps confusing V (volume) with v (average drift speed) when applying the equation.

Question 32

- Many candidates correctly recalled that the resistance of a filament lamp varies with current in the lamp.
- The distractors were all selected evenly, with no single incorrect response proving more popular than the others.

Question 33

- Few candidates were able to make use of the equation $R = \rho L/A$ and the stated constant volume to determine the key D.
- Option C was the most popular choice, with candidates correctly determining that the area would reduce by a factor of 4, increasing the resistance by a factor of 4, but not accounting for the corresponding increase in length and its effect on the resistance.

Question 35

- There were many ways to approach this problem, for example using the ratio of resistances in the original circuit to determine the e.m.f of the battery (4:2 = 12:E, so E = 18 V), then using the ratio of resistances in the new circuit to find the new reading (2:2 = 9:9)
- Few candidates correctly selected option B.
- All three distractors were selected frequently, with option C marginally more popular, suggesting that candidates thought the added resistor had no effect on the terminal p.d.
- Candidates should be familiar with the effect of the internal resistance of a source of e.m.f. on the terminal p.d.

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Paper 9702/13
Multiple Choice

Key messages

Candidates performed well on **Questions 1, 2, 5, 6, 7, 8, 11, 12, 15, 18, 21, 23, 24, 25, 26, 27, 29, 31, 32, 33, 36, 38** and **39.**

Candidates performed less well on **Questions 3, 4, 9, 10, 13, 14, 16, 17, 19, 20, 22, 28, 30, 34, 35, 37** and **40**.

Candidates should take care to read the question and all options fully. Options will often include partially correct answers or common misconceptions. Numerical questions will sometimes include common arithmetic errors in applying a correct formula.

Comments on specific questions

Question 3

- To solve this problem candidates needed to determine the percentage uncertainty in X in terms of the percentage uncertainty in terms of Z (%X = 2 × 2%Z + %Z = 5%Z), leading to option D.
- Many candidates selected option C, managing to correctly determine the effect of Y^2 on the percentage uncertainty in X, but not accounting for the effect of the percentage uncertainty in Z on the percentage uncertainty in X.
- Many candidates chose option B, either neglecting the effect of the power of 2 on Y on the percentage uncertainty in X, or neglecting that the percentage uncertainty in Y was twice that in Z.

Question 4

- Most candidates were able to correctly determine the resultant force by vector addition.
- There were a number of approaches, including resolving the 8.0N force into perpendicular components (4N horizontally, and 6.9N vertically) and then adding this to the 10N horizontal force, followed by either trigonometry or Pythagoras.
- Some candidates gave the horizontal component of the forces as their answer and chose option A.
- Few candidates mixed sine and cosine (which led to option C) or simply added the magnitudes of the two forces (option D).

Question 9

- Most candidates correctly identified the collision as inelastic, and so chose option A.
- Many candidates chose option B, confusing the conservation of energy with the conservation of kinetic energy, or else misidentifying the collision as an elastic collision.

Question 10

- Few candidates correctly chose option D, with both distractors A and B more popular.
- Option A was the result of assuming the moving part had a speed of v after the explosion (or simply recalling the kinetic energy equation in general terms).
- Candidates who used conservation of momentum to realise that the velocity of the moving part after the explosion must be $2v$, but who then cancelled this with the factor of ½ without squaring the velocity selected option B.

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Question 13

- Most candidates recognised that the upthrust would be greatest on the object displacing the largest amount of water and so chose option B.
- Option D was a popular distractor, with candidates perhaps reasoning that B must experience a force less than its weight, whilst D must experience a force equal to its weight, and assuming that the two larger objects had the same weight so D must experience the greater upthrust.

Question 14

- Very few candidates were able to solve this problem.
- Candidates could approach this problem by considering the pressure at the point where the oil and water meet. The pressure due to the oil above the point must equal the pressure due to the water above the point and so candidates could form an equation for example, $850 \times 30 = 1000 \times (30 - x)$.

Question 16

- To solve this problem, candidates needed to use conservation of energy to determine the height of X above Z and then subtract this from 4.0m. Some candidates were able to do this.
- The most popular distractor was C, with candidates successfully finding the height of X above Z and choosing this as their answer.
- Some candidates identified the height of X above Z but did not use this to determine the required height.

Question 17

- A minority of candidates were able to correctly combine the equation for change in kinetic energy with the equation for work done.
- Distractor D was most popular, with candidates correctly substituting F/m for a, but incorrectly handling the sign of this term.
- Distractor A was also popular, with candidates neglecting the factor of ½ in the kinetic energy equation.

Question 19

- This question required candidates to convert energy per unit mass and mass per unit time into a power, which was answered correctly by relatively few candidates. Candidates then needed to determine the wasted power from the calculated total power.
- Some candidates were able to form and solve an equation for the total input power for example, $1.5 \times 10^4 \times 34 \times 10^3/3600 = 142\,\text{kW}$ and use this to determine the wasted power $142\,\text{kW} - 40\,\text{kW} = 102\,\text{kW}$.
- Many candidates correctly determined the total input power and chose this as their answer (option B).
- Some candidates added the total input power to the useful output power to get option C.

Question 20

- Many candidates correctly determined the ratio X:Y.
- Some candidates appeared to think that the force was constant, and so using $W = Fd$, doubling the extension would double the work done. This led to options A (chosen by many candidates) and B (chosen by only a small proportion).

Question 22

- Many candidates correctly selected option A, showing understanding of the definition of the elastic limit.
- Many candidates also selected option D, confusing the limit of proportionality with the elastic limit.
- Candidates should be familiar with both the elastic limit and the limit of proportionality, and how they differ from one another.

Question 28

- Most candidates selected options A or B, indicating that they are familiar with the central white fringe formed in this experiment.
- Slightly more candidates chose A than B, showing understanding that shorter wavelengths experience smaller angles of diffraction.

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- A few candidates chose option C, indicating uncertainty about the outcome of the experiment.

Question 30

- Candidates needed to deduce from the number of nodes (17) that there were 8 complete wavelengths between X and Y. They could then calculate the wavelength using $\lambda = 0.48/8 = 0.06$ m. They then needed to use the wave equation to find the frequency, $f = 3.0 \times 10^8/0.06 = 5.0 \times 10^9$ Hz.
- Candidates that divided XY by 7.5 instead of 8, confusing the number of nodes between X and Y for the total number of nodes, arrived at option A.
- Candidates that divided XY by 15 instead of 8, confusing the number of nodes between X and Y for the number of wavelengths, arrived at option C.
- Candidates that divided XY by 16 instead of 8, confusing the number of half-wavelengths between X and Y for the number of wavelengths, arrived at option C.

Question 34

- Many candidates were able to combine the equations $I = Q/t$ with $I = Anqv$ to determine the average displacement of the free electrons for example, displacement = Q/Anq.
- Distractor B was a popular choice, resulting from candidates using the diameter as the radius when determining the cross-sectional area of the wire.

Question 35

- A few candidates were able to correctly deduce that the decrease in temperature would lead to a higher resistance in the thermistor, and so a greater reading on the voltmeter. To reduce the reading back to its original value the resistance of the variable resistor would need to be increased.
- Many candidates selected incorrect responses across all distractors.

Question 37

- The circuit symbol for an oscilloscope was not widely known.
- The most commonly chosen incorrect answer was a galvanometer.
- Candidates are expected to recognise all the circuit symbols listed in the syllabus.

Question 40

- Many candidates confused neutron number with nucleon number and so selected option A.
- Candidates are reminded to carefully read the question to ensure they are answering what has been asked.
- Candidates are reminded to pay particular attention to the terminology of nuclear physics that has many similar sounding but different terms.

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PHYSICS

Paper 9702/14
Multiple choice

Key messages

Candidates performed well on **Questions 1, 2, 3, 4, 5, 8, 9, 12, 14, 15, 18, 19, 20, 22, 23, 26, 28, 32, 33, 35, 37, 38, 39** and **40.**

Candidates performed less well on **Questions 6, 7, 10, 11, 13, 16, 17, 21, 24, 25, 27, 29, 30, 31, 34** and **36.**

Candidates should take care to read the question and all options fully. Options will often include partially correct answers or common misconceptions. Numerical questions will sometimes include common arithmetic errors in applying a correct formula.

Some candidates did not always interpret graphs with non-linear relationships accurately.

Some candidates did not always interpret the motion of waves from descriptions and diagrams accurately.

Comments on specific questions

Question 6

- Most candidates were able to form a suvat equation correctly accounting for the initial upwards direction of the stone to arrive at option C.
- Many candidates treated the displacement and the acceleration as being in opposite directions and so calculated their initial speed as 20 m s^{-1}.
- A few candidates treated this is a constant velocity problem and used $s = v/t$ to get 3.5 m s^{-1}.

Question 7

- Most candidates selected options B or C.
- Many candidates correctly related the gradient of the graph to the equation $s = ½at^2$ and deduced the answer was option C.
- Many candidates did not account for the factor of ½ and so chose option B.

Question 10

- This question was answered correctly by relatively few candidates.
- Very few candidates chose option B, suggesting that most recognised that *N* and *P* formed a third-law pair and so must be equal.
- Options A, C and D were chosen roughly equally, suggesting that many candidates were guessing from these options.
- Candidates who thought that the ball was in equilibrium were likely to choose A or C.
- Candidates who realised that although the ball is stationary momentarily, it would experience a large upwards acceleration at this instant could reason that *N* must be larger than *W*.

Question 11

- Many candidates correctly determined the magnitude of the resultant momentum of the system. Candidates who are familiar with a 3 – 4 – 5 right angle triangle may have spotted this could be applied here.
- Many candidates chose option D, the result of adding the magnitudes of the initial momentum vectors, rather than finding the magnitude of the resultant vector.

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- Few candidates chose option A (subtracting the magnitude of the initial momenta) or the option that treated the objects as being of equal mass.

Question 13

- Many candidates correctly chose option C.
- Candidates choosing options B and D did not realise that the pressure a point on the object increased with depth.
- Candidates choosing option A confused the upthrust being dependent on the volume of water displaced to the upthrust being equal to the volume of water displaced. Candidates are reminded that two different types of physical quantity cannot be meaningfully equated to one another.

Question 16

- Most candidates correctly determined that the change in energy was simply equal to mgh.
- Many candidates chose option B, not realising that as the object was raised with a constant speed its kinetic energy would not change during time t.
- A few candidates chose option C confusing power with energy.

Question 17

- A majority of candidates correctly related the kinetic energy to time and chose option C.
- Very few candidates chose option D, indicating that most (but not all) realised that the kinetic energy would increase as the object fell.
- Candidates choosing option A may have confused velocity against time with kinetic energy against time, or else did not realise that kinetic energy is proportional to velocity squared.
- Candidates choosing option B may have treated this as a problem where air resistance was significant and so assumed they were looking for an object approaching termina velocity.

Question 21

- Most candidates correctly chose option A.
- Many candidates chose options D, recognising that the curved graph must related extension and elastic potential energy, but getting the axes the wrong way around.
- A few candidates chose B and C, not realising that force and extension are proportional for a wire obeying Hooke's law, which would give a linear graph.

Question 24

- A significant proportion of candidates chose options B and D, even though the question clearly states that the initial intensity of the transmitted light is zero. Candidates are reminded to carefully read the conditions stated in the question.
- Many candidates recalled that the intensity varies with $\cos^2\theta$ and so would go through two cycles over an angle of 360°, with the majority of candidates choosing either A or B.
- Some candidates thought that the intensity would vary with $\cos\theta$ and so chose C or D.

Question 25

- Many candidates correctly chose option A.
- The distractors were all selected equally suggesting that those candidates who did not know that transverse waves can diffract were guessing.

Question 27

- Some candidates correctly recalled that the distance from a peak to a trough is twice the amplitude of the wave, and so the object would travel a vertical distance equal to 4 times the amplitude during a single cycle.
- Many candidates chose option C, confusing the amplitude with the peak-trough distance.
- Some candidates chose option A, confusing the distance travelled horizontally by a wavefront with the vertical distance travelled by the object.

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Question 29

- Many candidates correctly determined that the fringe separation was 22/9 = 2.4 mm. They were then able to use the fringe separation in the double-slit equation to obtain the correct answer ($500 \times 10^{-9} \times 3.5/2.4 = 0.72$ mm).
- Many candidates though that the fringe separation was 22/10 = 2.2 mm and so arrived at option D.
- Many candidates treated the distance between the first and tenth fringes as the fringe separation, and so arrived at option A.

Question 30

- Most candidates incorrectly treated the given wave as a progressive wave, rather than a stationary wave and so chose option B.
- Some candidates correctly realised that all points on a stationary wave between a pair of adjacent nodes move in phase, and so D was the only possible answer.
- Distractors A and C were also chosen by many candidates, with C slightly more popular than A. Neither A nor C correspond to possible motions on the wave.

Question 31

- To solve this question candidates needed to consider the next two waves that can be formed in a tube closed at one end. This can be approached in a number of ways, for example relating the frequency to odd integer multiples of the fundamental frequency.
- Many candidates correctly determined the answer as option D.
- Candidates who thought that the next higher frequencies would be integer multiples of the fundamental frequency chose option B.
- Candidates who thought that the frequencies would double each time chose option C.
- Candidates who thought that the frequencies would be 1.5 and 2 times the fundamental frequency chose option A.

Question 34

- A majority of candidates chose options A and B, possibly recalling sketches of the variation of resistance with light intensity for an LDR.
- Many correctly recognised that as the resistance of the LDR will decrease with light intensity, the value of R must increase in order to maintain a constant total resistance. Candidates that understood this could recognise that only option A was possible.
- Many candidates also chose option B, either confusing the behaviour of the LDR, or possibly misreading the requirements of the question and giving the variation of resistance in the LDR with light intensity as their answer.
- Very few candidates chose option D, realising that the resistance of the LDR must change, and so R must also change.

Question 36

- Very few candidates correctly selected option B, perhaps being unfamiliar with the idea of a circuit with zero current.
- Many candidates chose option A, without realising that the statement is equating a potential difference (work done per unit charge) with an energy (work done). Candidates are reminded to carefully read every option.
- Many candidates chose option C, confusing electromotive force for terminal potential difference, and also not recognising that the option describes a quantity of energy, rather than a ratio of energy to charge.

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PHYSICS

Paper 9702/22
AS Level Structured Questions

Key messages

What candidates did well
- Candidates mainly showed sufficient working in numerical questions to demonstrate a correct method, even when errors occurred.
- Candidates generally answered the circuits question successfully. In particular, many responses included a correct proof of parallel resistance.
- Candidates generally recalled and defined the required concepts in the recall and definition questions.

What candidates needed to improve
- Premature rounding of interim answers sometimes led to an incorrect final answer.
- Use of the multiplication sign (×) rather than a dot (.) was not always seen.
- Final answers were not always fully worked out and expressed as decimal numbers.
- Questions requiring explanation of physical phenomena were less well answered.
- Construction of free-body diagrams was not always evident.
- More complex calculations, such as Questions **4(b)(ii)**, **5(c)(ii)** were less well answered. Responses did not always show a clear approach to multi-step calculations.

Comments on specific questions

Section A

Question 1

(a) Comprehensive responses
- Candidates identified power as a scalar and force as a vector.
- Candidates identified force and momentum as vectors

Limited responses
- Many candidates misidentified amplitude as a scalar.

(b) (i) Comprehensive responses
- Most identified the displacement as being the area under the graph.
- Many candidates restated the time interval of $t = 0$ to $t = 40$ s although this was not required.

Limited responses
- Some candidates gave descriptions of the motion of the car, for example, 'the car speeds up and slows down'.

(ii) Comprehensive responses
- Candidates determined the distance travelled by car as 390 m.
- A variety of methods were seen, including use of the trapezium rule, breaking the area on the graph into rectangular and triangular sections and occasional use of 3 suvat equations to represent each period of constant acceleration.

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Limited responses

- Many candidates often attempted to use a single suvat equation to represent the motion, not recognising that the acceleration was not the same throughout.
- Some candidates attempted to find an average speed. This approach did not always lead to the correct answer.

(iii) Comprehensive responses

- Most candidates correctly stated that the acceleration was the gradient of the graph or gave the symbol formula $a = \Delta v / \Delta t$.
- Some candidates recognised that the greatest magnitude of acceleration of the car occurred between $t = 35$ s and $t = 40$ s, and used this to determine the correct answer.

Limited responses

- Many candidates incorrectly found the magnitude of the greatest positive acceleration (1.2 m s–2).
- Some candidates misread the maximum speed from the graph as 14 ms–1.

(iv) Comprehensive responses

- Most used $v^2 = 2as$ to solve for the correct speed, recognising that initial velocity was 0.
- A few first determined the time at which the car returned to P and then a second suvat equation to find the speed.

Limited responses

- Some candidates attempted to use an initial speed of 12 m s–1 confusing the motion before and after the car reached P.
- Some candidates incorrectly assumed that the car would return to P at $t = 80$ s.

(v) Comprehensive responses

- Most candidates identified that the displacement of the car increased and then decreased.
- Most candidates correctly showed the maximum displacement of the car at $t = 40$ s.
- Some candidates varied the gradient of the line in relation to the acceleration of the car.

Limited responses

- Most candidates identified that the displacement of the car increased and then decreased.
- Many candidates incorrectly showed the maximum displacement of the car at $t = 35$ s.
- Many candidates showed the displacement becoming negative.
- Many candidates showed straight lines throughout, or a line of increasing gradient from $t = 40$ s to $t = 80$ s.
- Some candidates reproduced the velocity-time graph given.

Question 2

(a) Comprehensive responses

- Most candidates gave both correct conditions for equilibrium.
- Explicit statements such as ‘the resultant force is zero and the resultant moment (or torque) is zero’ were seen in some responses.

Limited responses

- Many candidates gave only one of the two conditions for equilibrium.
- Many candidates did not describe resultant moment, for example, ‘clockwise moment = anticlockwise moment’.
- Many candidates described ‘no force’ as opposed to ‘no resultant force’ or said ‘there are no external forces’.
- Some candidates stated that the system must have zero velocity, which is not a required condition.
- Some candidates confused moment with momentum.

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(b) (i) Comprehensive responses

- Many candidates clearly showed separate equations successful candidates clearly showed separate equations for the forces acting on the plank and the forces acting on the block. They were then able to combine these equations to form the required equation.
- Some candidates confused sine with cosine when resolving the tension.

Limited responses

- Many candidates did not consider the block, and the plank separately and so did not include the tension forces.
- Some candidates attempted to use a value for the weight of the block and the plank to verify the equation given, rather than to show how the equation was derived.

(ii) Comprehensive responses

- Most candidates successfully substituted the given masses multiplied by g into the given equation.

Limited responses

- Some candidates incorrectly rearranged the equation or gave the value of $2R$ as their final answer.
- Some candidates used the mass of the objects instead of the weight.

(c) (i) Comprehensive responses

- Candidates stated Hooke's law.

Limited responses

- Most did not state Hooke's law.
- 'Hooke' was often spelled incorrectly.
- Some gave a definition of the spring constant instead.

(ii) Comprehensive responses

- Many gave a description of elastic deformation in terms of an object returning to its original length when the force is removed.
- Some gave a description in terms of 'non-permanent deformation'.

Limited responses

- Many responses omitted to describe the force being removed.
- Many responses described the elastic limit instead of elastic deformation.
- Many responses described plastic deformation.
- Many responses gave imprecise descriptions of an object returning to its original length such as 'original shape' (which could be a different size)/'original state' (which could mean many things)/'original position' (which suggests a translation rather than an extension).

Question 3

(a) Comprehensive responses

- Candidates described a wave which transfers energy.

Limited responses

- Some described a transverse or longitudinal wave instead of or in addition to a progressive wave.
- A few described a stationary wave.

(b) (i) Comprehensive responses

- Candidates correctly determined the period of 0.33 s.

Limited responses

- Many rounded their answer to 1SF or gave their answer as a fraction.

(ii) Comprehensive responses

- Most were able to determine the wavelength from the distances AP and BP and the diagram. They then used this with $v = f\lambda$ to find the correct wave speed.

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Limited responses
- Most were able to state $v = f\lambda$.
- Many were unable to use distance AP and BP to determine the wavelength. Many used λ = 3 m or λ = 1.8 m.
- Many candidates calculated an average of AP and BP (3.2 m) and used this as wavelength.
- Some candidates confused frequency with period.

(c) (i) **Comprehensive responses**
- Most candidates used the equation $\Delta E = mg\Delta h$ and with a Δh of 2×0.15 m to find the correct change in energy.
- Some candidates did not convert from cm to m.

Limited responses
- Most candidates used the equation $\Delta E = mg\Delta h$.
- Most candidates used Δh = 0.15 m.
- Some candidates did not convert from cm to m.
- Some candidates used Δh = 3.9 – 2.4.

(ii) **Comprehensive responses**
- Most candidates stated that the amplitude of oscillation of the ball would decrease.
- Very few candidates were able to explain that this was due point P no longer being a point of maximum amplitude, as the waves from A and B no longer met in phase at P.

Limited responses
- Most candidates stated that the amplitude would remain unchanged as the amplitude is independent of frequency.
- Some candidates stated that the amplitude would increase as it was proportional to frequency.
- Many candidates assumed that the ball's amplitude depended only on the amplitude of the individual waves being produced. They did not recognise that the ball's amplitude was determined by the interference of the waves arriving at point P.
- A few correctly stated that the amplitude would decrease but based this on incorrect physics.

Question 4

(a) **Comprehensive responses**
- Most candidates recalled the formula for kinetic energy and correctly substituted and rearranged it to find the speed of the train.

Limited responses
- Most candidates recalled the formula for kinetic energy.
- Some candidates made an error in rearrangement.
- Some candidates gave v^2 instead of v for their final answer.
- Some candidates used the change in gravitational potential energy instead of the given kinetic energy.

(b) (i) **Comprehensive responses**
- Candidates gave a correct definition.

Limited responses
- Candidates gave an incorrect definition.
- Common errors included defining a ‘rate of change of a rate of change’ such as ‘the rate of change of energy transferred per unit time’.

(ii) **Comprehensive responses**
- Most candidates gave a formula for either work or power that could be applied to this question.
- Some candidates worked in terms of energy and were able to form a correct equation by determining the work done by the driving force and subtracting the change in gravitational potential energy to find the work done by the resistive force.
- Other candidates worked in terms of power and found the power dissipated by the driving force and the power dissipated by the weight to determine the power dissipated by the resistive force.

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Limited responses

- Most candidates gave a formula for either work or power that could be applied to this question.
- A correct equation representing the energy or power transferred to the train between X and Y was not always seen.
- It was common for candidates to use only the change in gravitational potential energy, without considering the work done by the driving force.
- It was common for candidates to include the kinetic energy in the calculation, despite the fact that the train had constant velocity and so no change in kinetic energy.
- Some candidates attempted to determine the acceleration of the train as 4.2 m s^{-1} / 52 s, despite the fact that the train had constant velocity.
- Many candidates equated energy with force, rather than work done by the resistive force.
- A few candidates attempted to solve this problem by resolving forces. This approach did not always lead to a correct solution.

(iii) Comprehensive responses

- Most candidates correctly stated P = IV and a correct word equation for efficiency. They were able to combine the given values to find the correct efficiency.

Limited responses

- Most candidates stated or implied P = IV for the total input power.
- Some candidates did not state an equation for power or efficiency. They proceeded directly to substitution.
- Many candidates stated an incomplete formula for efficiency such as 'power out/power in' or 'total out/total in'.
- Many candidates used the change in gravitational potential energy as the useful output power, despite the question explicitly stating the useful output power as 1.1×10^5 W.

Question 5

(a) Comprehensive responses

- Most candidates began their derivation with a clear statement of Kirchhoff's first law.
- Both alternative methods were commonly seen in candidates' responses.
- Many candidates gave a thorough explanation including an explicit statement of the fact that the potential differences were equal for each component.

Limited responses

- Many candidates began the derivation with a clear statement of Kirchhoff's first law.
- Many candidates then made reference to V_1 V_2 and V_3 without explicitly stating that these were all equal to V.
- Some candidates started their proof from the formula for total resistance in series and typically did not complete the derivation.

(b) (i) Comprehensive responses

- Most candidates made use of the parallel resistance formula to determine the combined resistance of the two resistance wires. With this they then were able to determine the current in the battery.
- Some candidates instead used V = IR to determine the current in each wire and then used Kirchhoff's first law to find the current in the battery.

Limited responses

- Many candidates found the current in one of the resistance wires and gave this as their answer.

(ii) Comprehensive responses

- Most candidates determined that the current in each wire was half their answer to **5(b)(i)** and were able to apply the transport equation correctly.

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Limited responses

- Most candidates recalled the transport equation.
- Most candidates used their answer from **5(b)(i)** (the current in the battery) without halving to find the current in one wire.
- Some candidates did not always rearrange the equation correctly and frequently obtained very high speeds. Calculated values were not always checked for physical reasonableness.

(c) (i) Comprehensive responses

- Candidates were able to name the light-dependent resistor.

Limited responses

- The light-dependent resistor was not always identified correctly.
- The most common incorrect answer was a thermistor.
- Some candidates confused diodes with resistors and gave 'light emitting diode'.

(ii) Comprehensive responses

- Candidates made use of all three methods given.

Limited responses

- Most candidates were able to show a first step towards solving the problem. The majority found the total resistance of the new circuit (2.4 W). Many gave this as their final answer.
- Some candidates determined the total resistance of the top branch. The method was not always completed to find the resistance of X.
- Few candidates approached this problem via current. Those that did often incorrectly assumed that the current would be the same in both parallel branches
- Many candidates incorrectly gave the equation $R = (1 / 2.8) + (1 / X)$ despite having derived the equation for resistors in parallel in part **(a)**.

(iii) Comprehensive responses

- Most candidates stated that the resistance must have increased, and so the light intensity must have decreased.
- Many started by considering the change in the environment and justifying the effect on the circuit.
- Many candidates gave explanations of the changes in the circuit such as 'the total resistance has increased, and the resistance of the wires remains constant, so the resistance of the LDR must have increased'.
- Some candidates stated that the temperature would have decreased, especially those who thought that X was a thermistor.

Limited responses

- Many candidates confused the relationship between the light intensity and the resistance of the LDR and stated that the light intensity must have decreased.
- Some stated that the total resistance of the circuit had increased without specifying that this must mean the resistance of the LDR had increased.

Question 6

(a) Comprehensive responses

- Most candidates gave concise and accurate explanations.

Limited responses

- Many candidates gave incomplete responses such as 'alpha particles pass straight through' or 'most of the particles pass through' that did not contain quite enough detail to answer the question.
- Some candidates described a small number of particles being reflected/deflected, which does not necessarily mean that the remaining particles pass straight through.

(b) (i) Comprehensive responses

- Candidates gave a clear statement of $p=mv$ and a full substitution to achieve the required result.

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Limited responses

- Most candidates stated or implied $p=mv$.
- Many candidates did not show a full substitution of $4u = 4 \times 1.66 \times 10^{-27}$.
- Some candidates used 197u instead of 4u.

(ii) Comprehensive responses

- Most formed a correct equation for the conservation of momentum with all terms substituted.
- Very few omitted u, with most using the result from **6(b)(i)** as one of their terms.

Limited responses

- Many candidates attempted to form a conservation of momentum equation.
- Many candidates did not account for the opposite direction of the velocity of the alpha particle after the collision.
- Many candidates did not make consistent use of u in all their terms.
- Some candidates neglected the momentum of the alpha particle after the collision entirely.

(iii) Comprehensive responses

- Most correctly determined the absolute uncertainty as $5 \times 10^4 + 5 \times 10^4 = 1 \times 10^5$ m s–1and then divided this by the sum of the speeds.
- Some divided the correct absolute uncertainty by the difference in the speeds rather than the difference in velocities.

Limited responses

- Most did not determine the correct absolute uncertainty.
- Many candidates added the percentage uncertainties in both measurements.
- It was possible to get the correct answer via an incorrect method, and some candidates did so.

(c) Comprehensive responses

- Candidates gave the correct answer of 3.

Limited responses

- Some candidates did not give the correct answer of 3.
-

(d) Comprehensive responses

- Candidates stated the correct composition of a meson.

Limited responses

- Many candidates stated a specific combination of quarks, for example is up and antidown, which is not the general composition of a meson.
- Some candidates stated the composition of a hadron.
- Some candidates described a meson as consisting of ‘matter and antimatter’. More specific descriptions were also seen.

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PHYSICS

Paper 9702/23
AS Level Structured Questions

Key messages

What candidates did well
- The quantitative parts on momentum were generally carried out well by candidates.
- The quantitative parts on Young modulus were generally correctly calculated.
- Candidates who attempted question 5 on particle physics often produced good answers.

What candidates needed to improve
- Many candidates did not attempt Question 5 on particle physics. Knowledge of fundamental particles was not always evident.
- Analysis of basic circuits and calculation of electrical quantities were not always successful.
- Application of knowledge to novel situations was not always evident.

Comments on specific questions

Question 1

(a) Comprehensive responses
- Most of the candidates gave the correct definition of momentum.

Limited responses
- Some candidates gave an expression for change in momentum, for example, change in momentum equals force times time.

(b)(i) Comprehensive responses
- Many candidates calculated the acceleration by reading the change in velocity and the time accurately from the graph.

Limited responses
- Some candidates misread the time for the change in velocity.
- Some candidates determined an incorrect value for the change in velocity by ignoring the signs of the initial and final velocities.

(ii) Comprehensive responses
- Many candidates determined the change in the velocity during the collision using the correct sign convention and then the change in momentum during the collision.

Limited responses
- Some candidates did not take account of the different signs for the initial and final velocities of ball X before and after the collision. These calculations determined the change in the magnitudes of the momenta during the collision but did not take account of the change in direction of ball X.

(iii) Comprehensive responses
- Many candidates attempted to calculate the area beneath the line on the graph during the collision.
- A few candidates calculated the area of the triangle as the velocity changed from 1.6 m s^{-1} to zero during the times 0.09 to 0.11 s and then for the velocity change from zero to 0.80 m s^{-1} during the times of 0.11 to 0.12 s.

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Limited responses

- Many candidates determined an incorrect area. For example, the area of the triangle produced by the line showing the collision from (0.09, 1.6 to 0.12, –0.80). The base of this triangle was not along the velocity = 0 axis but along the line from (0.09, –0.80 to 0.12, –0.80).
- Many candidates used an inappropriate equation for constant acceleration applied to the complete collision time.
- A few candidates attempted to calculate the total distance travelled by ball X rather than the distance travelled during the collision.

(c) (i) Comprehensive responses

- Candidates compared the relative speed of approach to the relative speed of separation.

Limited responses

- Many candidates compared the initial and final momentum or the initial and final kinetic energies of the balls and ignored relative speeds.

(ii) Comprehensive responses

- Many candidates drew correct lines for the ball Y on Figure 1.1 before and after the collision.

Limited responses

- Some candidates drew a line along the velocity = 0 axis to an incorrect starting time for the collision or started the velocity of ball Y after the collision at an incorrect time.

(iii) Comprehensive responses

- Many of the candidates were able to calculate the mass of ball Y.
- The equation formed by applying the conservation of momentum was shown clearly by many candidates.

Limited responses

- A significant number omitted the momentum of ball X from the final momentum of the two balls.

Question 2

(a) Comprehensive responses

- Candidates gave the correct definition of Young modulus.

Limited responses

- A significant number of candidates gave an inappropriate definition that did not relate the ratio between stress and strain.
- Some candidates did not give a definition and gave a descriptive explanation of the meaning of Young modulus applied to a material.

(b) (i) Comprehensive responses

- Most candidates were able to show the length of the thread by linking the volume and cross-sectional area.

Limited responses

- A significant number of candidates were unable to link the length of the thread to the information in the question.
- Some candidates tried to use all the information given in the question rather than the relevant details.
- A few candidates determined the volume of the thread and were then unable to link this to the length.
- A significant number gave no response.

(ii) Comprehensive responses

- Candidates showed knowledge of the definition of stress to complete this part.

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Limited responses
- A small number used an incorrect expression for stress using the mass rather than the weight of the thread.
- A significant number gave no response.

(iii) Comprehensive responses
- Successful candidates related the stress at a point in the wire to the weight of the wire below the point.

Limited responses
- This was a very demanding part and candidates were generally unable to explain the shape of the graph.
- Most candidates were unable to apply their knowledge of stress and its dependence on weight to explain the variation shown in Figure 2.1.
- A small number described the variation of the weight with distance from the top of the thread.

(c) (i) Comprehensive responses
- Most candidates were able to use the equation linking Young modulus to the information given in the question.

Limited responses
- A small minority used the value given for the stress as the force and divided by the cross-sectional area.
- A small number gave an incorrect equation for Young modulus.
- A significant number gave no response.

(ii) Comprehensive responses
- Most of the candidates gave an equation for the elastic potential energy.
- A significant number were able to use the information given to calculate a value for this energy.

Limited responses
- A small number confused the value given for the stress with force and omitted the cross-sectional area.
- A small number gave incorrect expressions for elastic potential energy.
- A small number miscalculated the spring constant.
- A significant number gave no response.

(d) Comprehensive responses
- Most of the candidates considered the force or stress were the same in both situations.
- Most candidates compared the initial and final momentum or the initial and final kinetic energies of the balls rather than the relative speeds of approach and separation.

Limited responses
- A very small number gave the correct response with a clear explanation.
- A significant number gave no response.

Question 3

(a) Comprehensive responses
- A few candidates gave a correct statement.

Limited responses
- Many responses were not accurate with waves not described as overlapping or amplitudes rather than displacements being added.

(b) (i) Comprehensive responses
- A minority of candidates gave a correct meaning for coherence.

Limited responses
- There were many descriptions that referred to the same phase or the same frequency.

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(ii) Comprehensive responses

- Most candidates gave the correct description.

Limited responses

- A small minority described the waves as spreading rather than due to diffraction.

(iii) Comprehensive responses

- Many candidates were able to explain that waves overlapped and produced constructive interference.
- Many candidates were unable to explain that the waves had a zero phase difference to produce the central bright fringe.

Limited responses

- A significant number of candidates gave incomplete or inaccurate descriptions of the formation of a bright fringe.

(iv) Comprehensive responses

- A significant number started with the correct expression.
- A limited number of candidates were able to calculate the distance between fringes despite difficulties with substitution of values, conversion of nanometres to metres, or arithmetic.

Limited responses

- A small number realised that the distance asked for was from a bright fringe to a dark fringe.
- A significant number gave no response.

(c) Comprehensive responses

- There were many correct responses.

Limited responses

- A small number did not realise that the distance between bright and dark fringes is half the distance between adjacent bright fringes or gave inaccurate positions for the fringe positions.

(d) Comprehensive responses

- There were many correct answers.

Limited responses

- A few candidates were unable to substitute a value for the speed of the waves.
- A few candidates were unable to convert nanometres into metres.

Question 4

(a) Comprehensive responses

- Many candidates gave a correct series circuit diagram for a cell with a resistor and a voltmeter in parallel.
- Incorrect symbols for an LDR were commonly seen.

Limited responses

- A small number gave the symbol for a battery rather than a cell.
- There were very few candidates that placed the voltmeter in series with the LDR.

(b) (i) Comprehensive responses

- A minority of candidates gave a systematic error.

Limited responses

- A significant number gave a random error or an unrealistic systematic error.

(ii) Comprehensive responses

- Most candidates determined the power.

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Limited responses
- A few gave an answer to one significant figure.
- A significant number were unable to use the information given in the question.

(iii) Comprehensive responses
- Most candidates linked the electromotive force of the cell with the potential difference across the internal resistance and the potential difference across the LDR.

Limited responses
- A significant number were unable to use the information given in the question as they were unable to use a suitable electrical equation.
- A few candidates calculated the current and rounded its value to two significant figures when substituting into the final equation for the internal resistance. This resulted in an inaccurate final answer.
- A significant number gave no response.

(iv) Comprehensive responses
- A small number gave the correct change in the p.d. across the LDR.

Limited responses
- A small number gave the correct change in the p.d. across the LDR.

Question 5

A significant number gave no response to all parts of this question.

(a) Comprehensive responses
- Many candidates gave the correct meaning of a meson.

Limited responses
- A significant number of candidates did not give the correct response.

(b) Comprehensive responses
- This part was well answered by many candidates.

Limited responses
- A significant number were unable to give the charges on the quarks.

(c) (i) Comprehensive responses
- Many of the candidates were familiar with this type of equation and gave correct responses.

Limited responses
- A significant number of candidates did not give the correct response.

(ii) Comprehensive responses
- Most candidates were able to give the correct name of the particle.

Limited responses
- A significant number of candidates did not give the correct response.

(iii) Comprehensive responses
- A minority of candidates were able to give the correct change in the quark composition.

Limited responses
- A significant number of candidates did not describe the quark changes correctly.

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(iv) Comprehensive responses

- Some candidates described the neutrino and beta particles as sharing energy.
- The explanation given by almost all candidates did not include the energy of each decay being constant.

Limited responses

- A significant number of candidates used conservation of energy to explain the continuous range of energies for beta particles in the decay process.

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PHYSICS

Paper 9702/24
AS Level Structured Questions

Key messages

What candidates did well
- Most candidates demonstrated understanding across the topics covered on the question paper.
- Most candidates produced well-presented and accurate answers to the quantitative parts of the questions.

What candidates needed to improve
- Quantitative explanations were not always provided in questions describing numerical changes
- Knowledge of the properties of electrical components and their effects in circuits was not always evident.

Comments on specific questions

Question 1

(a) Comprehensive responses
- Most of the candidates gave the correct three vectors.

Limited responses
- A small number of candidates omitted acceleration or added distance to their list of vectors.

(b) (i) Comprehensive responses
- The majority of candidates determined the kinetic energy of the car.

Limited responses
- A small number of candidates gave the correct equation for kinetic energy and then made an arithmetic error by omitting to square the velocity.
- A very small number started with an incorrect equation. This was usually $\frac{1}{2}\ mv$.

(ii) Comprehensive responses
- Most of the candidates substituted the values given for the car into an appropriate equation for constant acceleration and obtained a negative answer.

Limited responses
- Some candidates substituted the value for the initial velocity into an equation where the symbol represented in the equation is for the final velocity. This resulted in a positive value for the acceleration whereas the car was decelerating.
- A significant number calculated a negative value for the acceleration and then gave a positive value on the answer line.
- A few started with an incorrect equation ($v^2 = u^2 - 2as$) and obtained a positive value for the acceleration.

(iii) Comprehensive responses
- Most candidates determined the force acting on the car using their value determined for the acceleration in the previous part.

Limited responses

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- A small number of candidates added the weight of the car to the decelerating force.

(c) (i) Comprehensive responses

- Most candidates gave the correct statement.

Limited responses

- A significant number omitted in their explanation that the mass of the car remained constant.
- A few candidates considered the acceleration to increase because the speed had increased.

(ii) Comprehensive responses

- Most candidates stated that the stopping distance would increase.
- A small number of candidates quantified the change in distance. This was required as the question stated the new speed of the car and not just that the speed had increased.

Limited responses

- Many explanations did not include sufficient detail.
- A number did not explain that the acceleration was constant, and the final velocity was zero.
- Many quoted the equation $s = u^2 / 2a$ to explain the change in distance without giving the necessary detail.

Question 2

(a) Comprehensive responses

- Most candidates gave Hooke's law.

Limited responses

- A significant number of candidates gave the expression for the spring constant which is a consequence of Hooke's law.

(b) (i) Comprehensive responses

- Most candidates gave the correct extension and uncertainty.

Limited responses

- A significant number of candidates gave the uncertainty as ± 0.1 cm.
- A few rounded the extension up to 12 cm although the uncertainty was given as 0.1 or 0.2 cm.

(ii) Comprehensive responses

- Most candidates used the correct equation for the spring constant.

Limited responses

- Many candidates used the extension in centimetres rather than metres.

(iii) Comprehensive responses

- Most candidates calculated the percentage uncertainty in the mass.
- A significant number added the percentage uncertainty in the extension to give the percentage uncertainty in the spring constant.

Limited responses

- A significant number of candidates determined the percentage uncertainty in each of the lengths rather than the extension.

(c) (i) Comprehensive responses

- Most of the candidates gave a correct response with a valid explanation.

Limited responses

- A small number stated that the length would increase.
- A few gave no explanation for their answer.

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(ii) Comprehensive responses

- Most candidates stated that the extension in Y would be less and therefore the elastic potential in Y is smaller than in X.
- Most candidates used the equation $E = \frac{1}{2} Fx$ in this constant force context to explain their answer.

Limited responses

- Some candidates used $E = \frac{1}{2} kx^2$ to explain their answer. This did not always support a clear conclusion because k increases while x decreases.

Question 3

(a) Comprehensive responses

- Most candidates described two waves travelling in opposite directions overlapping without reference to the apparatus shown in Figure 3.1.

Limited responses

- A few candidates described waves reflecting from the fixed point.
- A few candidates described incident and reflected waves superposing to form the stationary wave.

(b) Comprehensive responses

- The majority gave the correct position of a node.

Limited responses

- A few placed their cross at an antinode position.

(c) Comprehensive responses

- Most candidates determined the correct wavelength and the speed of the wave.

Limited responses

- A small number of candidates calculated an incorrect value for the wavelength. This was usually 0.45 m.

(d) Comprehensive responses

- Most candidates drew a wave of one wavelength.

Limited responses

- Some candidates drew inaccurate waves with varying amplitudes or varying half wavelengths.
- Some responses included waves that were not clearly sinusoidal.
- A number drew more than one wavelength and some half a wavelength.

Question 4

(a) Comprehensive responses

- Most candidates gave the correct responses.

Limited responses

- A few candidates gave the drag force as staying the same during acceleration downwards.
- A few candidates gave the upthrust as increasing during acceleration downwards.

(b) Comprehensive responses

- Most candidates gave the correct relationship.

Limited responses

- A few gave the drag force in the same direction as the weight.

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(c) **Comprehensive responses**

- Most candidates calculated the drag force.
- Some candidates showed clear calculations for upthrust and weight even though they had an incorrect expression in part **(b)**.

Limited responses

- A few candidates used inappropriate formulae for the drag force or the upthrust.
- A few candidates did not identify the forces that they were calculating or used *F* instead of the symbols given in the question.

Question 5

(a) **Comprehensive responses**

- A small number gave the correct electrical component.

Limited responses

- Common incorrect responses included thermistor, filament lamp and semiconductor.

(b) **Comprehensive responses**

- Most of the candidates drew the correct straight line.

Limited responses

- A few lines were drawn inaccurately missing the required points by more than the tolerance allowed.
- A few drew curved lines or lines to an incorrect value of current at a potential difference of 0.80 V.

(c) **Comprehensive responses**

- Most candidates showed correct working to determine the electromotive force of 0.80 V.
- Most determined the potential difference across each component.
- A significant number calculated the resistance of resistor X before calculating the potential difference across X or calculating the total resistance in the circuit.

Limited responses

- A few candidates showed the current as 5 mA instead of 0.005 A as required in this show that question.

(d) **Comprehensive responses**

- Candidates gave the current as zero in the reverse biased arrangement for the diode.

Limited responses

- A significant number gave the same current as that in **5(c)** (before the diode was reversed) showing a misunderstanding of the properties of a diode.

(e) **Comprehensive responses**

- Most of the candidates calculated the current in each component.

Limited responses

- A few candidates assumed the resistance of the diode was constant and used the value determined in part **(c)** for the resistance in this part.

Question 6

(a) **Comprehensive responses**

- Most candidates used a relevant equation for power to show the resistance of the wire.

Limited responses.

- A few candidates did not convert the power in kW into W as required in a show that question.

(b) **Comprehensive responses**

- Most candidates determined the length of wire using the expression for resistivity.

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Limited responses
- A very small number did not use the resistivity formula.

(c) Comprehensive responses
- Most of the candidates were able to substitute the values given in the question into the expression given on the Formulae page and calculate the correct value for the number density.

Limited responses
- A few candidates substituted the value for the potential difference (230 V) into the expression for the velocity of the charge carriers.
- A significant number of the candidates rounded the value for the current to two significant figures early in the calculation and this resulted in an inaccurate value for the number density.

Question 7

(a) (i) Comprehensive responses
- Most candidates gave a clear meaning for the term isotope.

Limited responses
- A few gave no reference to the form their description referred to such the same nuclei, atom or element.
- A few had no reference to the number of neutrons or the number of protons and referred to only protons or neutrons

(ii) Comprehensive responses
- Most candidates correctly gave the number of emissions for each case.

Limited responses
- A significant number gave combinations of proton and neutron numbers and not the number of change/emissions necessary.

(iii) Comprehensive responses
- Most candidates gave the correct atomic number and nucleon number.

Limited responses
- A few candidates did not recognise that the thorium isotope had to have the same proton number as that given in the question.
- A significant number gave the same nucleon number even though the question indicated another thorium isotope.

(b) (i) Comprehensive responses
- Most candidates gave the correct quark composition for the proton.

Limited responses
- A few gave the quark composition for a neutron.

(ii) Comprehensive responses
- Most candidates stated the quark change for beta+ decay.

Limited responses
- A significant number did not give a quark change.

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PHYSICS

Paper 9702/31
Advanced Practical Skills 1

Key messages

Manipulation, measurement and observation

What candidates did well
- Many candidates manipulated and used the apparatus in both questions competently.
- Most candidates demonstrated a clear understanding of the scientific presentation of data.

What candidates needed to improve
- Candidates should consider when it is appropriate to check their experimental readings, for example checking trends in data.
- When drawing graphs candidates should pay careful attention to the setting up of axes to ensure the use of regular, sensible scales on which their data can be plotted accurately without the need to use a calculator.
- Candidates should be mindful of the need to check that written statements contain suitable levels of detail, for example when formulating responses to the final part of **Question 2** ('limitations and improvements').

Presentation of data and observations

What candidates did well
- Most candidates presented their data in neat tables that were clearly laid out and easy to read.
- Many candidates demonstrated the selection of regular and sensible scales for the graph axes.

What candidates needed to improve
- Where a quantity has no unit, candidates should follow scientific convention and present the quantity only.
- Candidates are reminded of the need to use a sharpened pencil for plotting their data on the graph and to use a 30 cm ruler for drawing their line of best fit.
- When plotting their data on the graph, candidates should ensure they are checking their graph scales carefully and that the location of the plotted points is accurate to the nearest half a small square.
- In drawing the line of best fit candidates are advised to consider carefully how to ensure a good balance of points either side of the line along its entire length.
- Candidates should have experience of deciding whether or not to nominate an anomalous point to assist in the drawing of a best fit line.

Analysis, conclusion and evaluation

What candidates did well
- Most candidates demonstrated clear understanding of how to calculate a gradient and a y-intercept from their graph.
- Most candidates ensured they chose a large enough separation for the gradient read offs on their graph.

What candidates needed to improve
- Errors in gradient and y-intercept read offs were sometimes evident, particularly where values were not read to within half a small square on the graph paper.
- In **Question 1(e)** candidates should give due consideration to the precision given in the values of the constants (P and Q) as well as to the units that should accompany each of these quantities.

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- In **Question 2h(i)** candidates should aim to identify a limitation and provide a reason for how or why this limitation affects the accuracy of the experiment.
- In **Question 2h(ii)** candidates should identify an improvement and link this clearly to the limitation it is intended to address.

Comments on specific questions

Question 1

(a) Comprehensive responses

- Most candidates had an appropriate value for V_1 within the range required.
- Most candidates recorded the value of V_1 to match the precision of the voltmeter used.

Limited responses

- Some candidates omitted a unit with their value of voltage.
- A few candidates recorded a value for V_1 that was out of range (for example, did not take account of the unit, 325 V instead of 325 mV).

(b) Comprehensive responses

- Many candidates changed the circuit correctly and obtained a value for V_2 that was greater than V_1.

Limited responses

- Some candidates incorrectly rounded the number of significant figures in their answer to **b(ii)**.

(c) Comprehensive responses

- Most candidates collected six sets of values of R, V_1 and V_2 without assistance from the Supervisor and obtained the correct trend in the data.
- Most candidates used the full range of resistors available to them.
- Candidates took time to construct a clear, well laid-out table in which to enter their data.
- Most candidates correctly identified an appropriate unit for each quantity and presented this using correct scientific notation.

Limited responses

- Some candidates collected six sets of data by simply using the first six resistors and so did not use the full range available to them.
- In a few cases, candidates omitted the separating mark between the quantity and the unit.
- A few candidates obtained a trend that was not consistent with that expected from the experiment.
- Some candidates presented the calculated value of $V_1/(V_2 - V_1)$ to a number of significant figures that did not correctly link to the significant figures in the measured data.

(d)(i) Comprehensive responses

- Most candidates plotted the correct graph, labelling the axes with the correct quantities.
- Many candidates used sensible and regular scales where all the data occupied more than half the graph grid.
- Most candidates demonstrated clear, neat plotting of points using crosses that were accurate to a tolerance of half a small square.

Limited responses

- Some candidates set the 12 large squares of the $V_1/(V_2 - V_1)$ axis by choosing their lowest value for the bottom of the y axis and their largest value for the very top of the y axis. Adopting this approach almost always leads to an awkward scale.
- In some cases, graph scales were chosen to fit the data exactly to the graph grid, resulting in awkward scales and inaccuracies in plotting.
- Some candidates marked their scales every two large squares instead of every large square.
- Candidates who plotted a correct graph but with irregular or awkward scales sometimes plotted points incorrectly or, in later parts of the question, made graph read-offs that were not accurate to within half a small square.

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- A few candidates drew plotted points with a diameter larger than half a small square. A sharp pencil should be used to produce clear and precise graph points as neat crosses.

(ii) Comprehensive responses

- Some candidates drew a good line of best fit with an even spread of points either side of the line along the entire length of the line.

Limited responses

- Many candidates drew a line of best fit that could have been improved by more careful drawing with a 30 cm long ruler and a sharp pencil.
- Some candidates 'forced' their best fit line to go through at least two data points when in fact the best fit line would not have passed directly through any of the points.
- Some candidates drew a line of best fit where rotating or translating the line would have given a more even distribution of points either side of the line along its entire length.
- Some candidates often tried to pass the line through as many points as possible, ignoring the overall distribution.
- Clearly anomalous points were not always identified or labelled appropriately.

(iii) Comprehensive responses

- Many candidates used gradient read offs from a large triangle, clearly showing their substitution into Δy/Δx.
- Many candidates read the graph at $x = 0$ or used a correct read off (often from the gradient calculation) into a correct version of $y = mx + c$ to find the y-intercept.

Limited responses

- Some candidates attempted to calculate the gradient using a triangle that was too small or from incorrectly read off readings.
- A few candidates chose their read offs from the table resulting in points on the graph that were not on the line of best fit.
- A few candidates used the incorrect formula for the gradient, using Δx/Δy instead of Δy/Δx.
- For the y-intercept, some candidates either read off directly at a false origin so x ≠ 0 whilst others substituted into an incorrectly rearranged equation, for example, y/mx = c instead of $y - mx = c$.

(e) Comprehensive responses

- Most candidates correctly identified P as the gradient and Q as the y-intercept with appropriate units for both.

Limited responses

- Some candidates correctly identified P and Q and then omitted the unit or gave an incorrect unit such as Ω instead of Ω^{-1} for P and some other unit such as V or V^{-1} for Q.

(f) Comprehensive responses

- Many candidates interpreted the information provided in the stem of the question to correctly work out how to draw the second line on the graph.

Limited responses

- A significant number of candidates drew a second line that crossed their original line on the graph and thus did not meet the criteria of Q being independent of X.

Question 2

(a) Comprehensive responses

- Many candidates measured a value of l_o using the correct precision of the ruler (to the nearest mm) and giving an appropriate unit with their final value on the answer line.

Limited responses

- Some candidates omitted a unit for their values of l_o either on the answer line and/or with their raw readings of l_o.

(b) Comprehensive responses

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- Many candidates demonstrated good practice by repeating their timing measurements and using a suitable number of oscillations (at least 5) for each timing.
- Many candidates gave resulting values of T_o that were in range.

Limited responses
- Some candidates repeated nT_o and stated this as their final value of T_o without dividing by n to give the true value of T_o.
- Some candidates did not present data to show that they had taken repeated readings of T_o.
- Some candidates incorrectly gave a frequency value rather than a time value for T_o.

(c) (i) Comprehensive responses
- Many candidates measured a suitable value for l and calculated $l - l_o$ correctly.

Limited responses
- A few candidates who had recorded several values for l_o in **part (a)** and crossed out one or more of these values, incorrectly calculated e through using a crossed-out value of l_o instead of their final, presented value.

(ii) Comprehensive responses
- Many candidates stated an absolute uncertainty in e which was in range and showed a correct method of working to calculate the percentage uncertainty.
- Some candidates recorded repeated readings of e, calculated half the range for the absolute uncertainty and showed a correct method to calculate the percentage uncertainty in e.

Limited responses
- Many candidates stated the absolute uncertainty in e to be that of the precision of the ruler without giving due consideration to the issue of needing to take two measurements in order to calculate e.

(d) (i) Comprehensive responses
- Most candidates measured a value of T that was less than their value of T_o.

Limited responses
- A few candidates presented a value of T greater than T_o due to their use of frequency rather than time.

(ii) Comprehensive responses
- The majority of candidates calculated $(T_o - T)$ correctly.

Limited responses
- A few candidates who had a value of T greater than T_o omitted the negative sign when calculating $(T_o - T)$.

(e) Comprehensive responses
- Most candidates were able to record a second m, l and T.
- Many candidates recorded the second value of $(T_o - T)$ to be greater than the first value of $(T_o - T)$.

Limited responses
- A few candidates recorded the second value of l to be the same as the first value of l perhaps due to omitting to add the value of l_o to the additional spring length of 6.5 cm.

(f) Comprehensive responses
- Many candidates correctly calculated two values of C for their two sets of data, showing their working clearly.

Limited responses
- A few candidates rearranged the equation incorrectly.
- A few candidates incorrectly stated one, or both, of their values of C to only one significant figure when the least number of significant figures in the data used to calculate C was at least two.

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(g) Comprehensive responses

- Many candidates successfully carried out the three required steps for this question, correctly showing the calculation of percentage difference between their values of *C,* comparing it against the stated 15 percent criterion and providing a valid statement of conclusion supporting or not supporting the relationship.

Limited responses

- Some candidates omitted to show a valid percentage difference calculation.
- Some candidates made a comparison with a different percentage than that given in the question, for example, 10 percent or 20 percent.
- A few candidates attempted to compute their own percentage uncertainty calculations rather than using the criterion specified in the question.

(h) (i) Comprehensive responses

- Some candidates chronologically and systematically identified limitations associated with setting up the apparatus or with taking specific measurements.
- Some candidates then provided a valid reason to explain how each identified limitation affected the experiment.
- Many candidates identified that ‘two readings are not enough to draw a valid conclusion’.

Limited responses

- Many candidates did not state the limitations of the experiment with sufficient specificity. Comments such as ‘it was difficult to measure the lengths’ did not identify clearly which measurement presented the limitation.
- Many candidates did not provide a sufficiently detailed explanation of how an identified limitation affected the accuracy of the experiment. Reasons such as ‘cannot measure the length accurately due to using a ruler’ did not explain the source of the measurement limitation in sufficient detail.

(ii) Comprehensive responses

- Some candidates demonstrated good practice by linking their solutions or improvements clearly to the identified limitation. For example, ‘the timing of oscillations can be improved by videoing the experiment with a timer that is in view’.
- A few candidates gave clear explanations as to how or why a particular solution would be beneficial. For example, ‘using a rod with grooves cut in to it will help stop the spring from sliding off the rod’.

Limited responses

- Some candidates gave vague ‘technology-related’ suggestions to improve the experiment. For example, ‘use light gates’ without considering whether this equipment was actually a feasible solution for this particular experimental set up.
- Some candidates gave vague, technology-related suggestions such as ‘use a laser timer’ without explaining how the suggestion would address the identified limitation.
- Some candidates gave sensible suggestions for improvements but did not back up their idea with some further detail of exactly how it would be used. For example, ‘use a motion sensor’ but not mentioning where this would be placed in order to help record the required data more accurately.
- Some candidates did not use their work from **h(i)** to guide their thinking for the second part of this question and did not identify solutions to (all of) the problems they had mentioned in the first part.
- Many candidates referred only generally to the limitations identified in **h(i)**, making it difficult to determine which issue the proposed solution or improvement was intended to address. For example, statements such as ‘use a caliper to measure it’.
- Some candidates gave suggested improvements that could have been undertaken anyway, for example, ‘repeat readings’.

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PHYSICS

Paper 9702/32
Advanced Practical Skills 2

Key messages

Manipulation, measurement and observation

What candidates did well
- Candidates were able to set up the apparatus without help and to obtain a set of measurements.
- Most candidates made accurate measurements with suitable precision.

What candidates needed to improve
- Some candidates did not record values that covered the full range of the independent variable available from the apparatus. Equal intervals between values were not required.
- Some candidates did not repeat measurements where the experimental method gave rise to significant measurement uncertainty.

Presentation of data and observations

What candidates did well
- Candidates presented their measured values in a single table, with correct column headings.
- Most candidates presented the different values of each measured quantity in a table column to the same precision.
- Candidates prepared graphs with clearly labelled axes, sensible scales such that the plotted points occupied at least half of the grid in both directions and numerical labels at 2 cm intervals on both axes.
- Most candidates plotted all their data points to within 1 mm of the correct position.
- Some candidates drew lines of best fit which showed an even distribution of plotted points either side of the line towards both ends of their line.

What candidates needed to improve
- When recording measured quantities in their table, some candidates recorded the values in a column to the same number of significant figures. When these values are to be recorded to the same precision, it is more usual that they should be recorded to the same number of decimal places.
- Some plotted points were shown as large dots, filled circles or thick crosses, reducing the precision with which points could be plotted.
- Some candidates drew a line of best fit with an equal number of plotted points either side of the line overall, but with the points at each end predominantly on the same side of the line. A different orientation of the line would have produced a more even distribution of points along its entire length.

Analysis, conclusions and evaluation

What candidates did well
- Most candidates could determine the gradient and intercept from their graph and use $y = mx + c$ to determine the required values.
- Most candidates correctly calculated values of a constant from measured data and a given mathematical expression.

What candidates needed to improve
- Some candidates whose graphs showed a false origin on the axis for m ($m \neq 0$ at the origin) used a read-off from the axis to determine the value of their intercept. For these graphs, the intercept could be obtained using points read from the line and substituted into $y = mx + c$.

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- Some candidates used only the resolution of the metre rule as their estimate of absolute uncertainty when calculating a percentage uncertainty. The estimated uncertainty did not always take account of the difficulty of the measurement.
- Experimental limitations due to measurement difficulties did not always identify the quantity being measured or explain the source of the limitation.
- Some suggested improvements were not relevant to the experiment being carried out.
- When determining whether the results supported a relationship, some candidates used less specific terms such as *experimental accuracy* rather than comparing a *percentage difference* with the given *percentage uncertainty*.

Comments on specific questions

Question 1

(a) Comprehensive responses

- Most candidates recorded final values for L that were in the correct range, presented with a correct unit and presented to the nearest mm. Where candidates recorded raw measurements of L before calculating a final value, the raw values were usually presented to the nearest mm.

Limited responses

- Candidates presented their value of L without a unit.
- Candidates presented their final value of L to the nearest cm instead of to the nearest mm.

(b) Comprehensive responses

- Candidates successfully recorded six sets of values for m, L and h.
- Candidates correctly recorded values of L that increased with increasing m.
- Candidates recorded all their h values to the nearest mm.
- Some candidates recorded their values of L and h in metres. These candidates usually recorded their values, including their h values, to the nearest 0.001 m.
- Candidates correctly calculated the values of T from their recorded values of L and h.
- Candidates provided tables with correctly headed columns. A correct unit and an appropriate separator (usually a solidus or brackets round the unit) were provided.

Limited responses

- Some candidates did not record values across a large enough range of values of m. They might have recorded values at 50g intervals, starting at 100g and ending at 350 g.
- Some candidates gave values of h to the same number of significant figures (for example, 9.80 and 11.2). Values of h were expected to be recorded to the nearest mm (e.g. 9.8 and 11.2), even when this resulted in different numbers of significant figures.
- Some candidates omitted a unit for T in the column heading.
- A few candidates omitted a unit in all their column headings.

(c) (i) Comprehensive responses

- Many candidates prepared axes that were labelled with the correct quantities.
- Many candidates gave a linear scale on both T and m axes, with the markings on each scale spaced by 2 cm (one large square). The scales were chosen so that the points occupied over half the grid in both axes directions.
- Points were plotted clearly and accurately, using a sharp pencil.

Limited responses

- Some candidates marked values on the scales of their axes that were greater than 2 cm apart. These candidates usually marked their scales at 4 cm intervals.
- Candidates used awkward scales to label their axes. This most often involved a multiple of three, or a spacing of 6 cm (1.5 large squares) between successive scale markings.
- A few candidates used axes labelled with the values for the points being plotted rather than labelling the axes at regular intervals.
- A few candidates did not label their axes with a quantity.
- Plotted points were shown as blobs (filled-in circles) or thick crosses from using a blunt pencil or over-writing.

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(ii) Comprehensive responses

- Candidates were able to draw a straight line with points equally spaced either side of the top half of their line, and equally spaced either side of the lower half of their line.

Limited responses

- Although candidates ensured that there were 3 points above and 3 points below the line, there was an imbalance of points, with points above one half of the line and below the other half, such that the line could be rotated to produce a more even distribution of points about the line.

(iii) Comprehensive responses

- Candidates were able to successfully use two read-offs from their straight line to calculate a value for the gradient and for the intercept. These read-offs were substituted into correct calculations for the gradient and intercept.
- The read-off values were taken from points on major gridlines for either m or T.
- Most candidates determined their intercept by a substitution method.

Limited responses

- Some candidates took their read-offs from points on their line that were less than half the length of the line apart.
- Some candidates used a read-off for the intercept from the y-axis to find the intercept value when there was a 'false origin' on the m axis (T value therefore not corresponding to m = 0).

(d) Comprehensive responses

- Candidates transferred their gradient and intercept values as p and q respectively.
- Many candidates used the correct units for their gradient and intercept values from **(c) (iii)** as the units for p and q.

Limited responses

- Candidates omitted units for their values of p and q.
- Some candidates recorded gradient or intercept values to only 1 significant figure before transferring these values to **(d)**.
- A few candidates recorded their gradient values as a fraction, and then transferred the fraction value to **(d)**.
- Some candidates did not use their gradient and intercept values and instead attempted to substitute table values into the equation in order to calculate values of p and q. This approach typically produced values that did not match the gradient and intercept obtained from the graph.

Question 2

(a) Comprehensive responses

- Candidates recorded a suitable value for H, recorded to the nearest mm.

Limited responses

- Some candidates recorded values of H that were less than 40.0 cm. This can result from misusing the metre rule.
- Some candidates recorded a value of H to the nearest cm instead of to the nearest mm.

(b) Comprehensive responses

- Candidates recorded values of H that showed the correct trend (as n increase, H increases).
- A sensible scale was used on the H axis of the graph to that points were well spaced.
- A clear curve was drawn passing close to the points.

Limited responses

- A few candidates recorded values that showed an incorrect trend (as n increased, H decreased). This was likely due to misusing the metre rule.
- The H axis of the graph started at zero, to that points were all in the top section of the graph.
- A thick curve was drawn so that reading values from the graph was difficult.
- A few candidates drew a straight line on the graph that disregarded the plotted points.

(c) (i) Comprehensive responses

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- Candidates recorded two or more raw values for H, and calculated a mean value.
- Candidates recorded final values of H that were greater than the value in **(b)**.

Limited responses

- Many candidates recorded a single value of H (no repeats shown).

(ii) Comprehensive responses

- Candidates considered an uncertainty recognising the variability of the measurement as well as the resolution of the ruler. This is certainly greater than 0.1 cm (the ruler resolution) and, due to the difficulty in correctly identifying the point at which the loop leaves the water, could be as much as 0.6 cm.

Limited responses

- Some candidates used the range of repeated values rather than $\frac{1}{2}$ range – in many of these cases this did give an absolute uncertainty within the limits of 0.2 cm to 0.6 cm.
- Many candidates just used the resolution of the ruler to determine their absolute uncertainty as 0.1 cm or 0.05 cm.
- A few candidates did not multiply by 100 to convert their answer to a percentage.

(iii) Comprehensive responses

- Candidates recorded a value of n to the nearest 0.1, with a correct read-off from the line on their graph.
- Candidates correctly calculated the value of F from their value of n.

Limited responses

- Value of n only given to nearest whole number, or (rarely) to two decimal places.
- Value of n was not consistent with the line drawn on their graph

(d) Comprehensive responses

- Candidates recorded a final value for d that was in the expected range, with a correct unit, and recorded to the nearest mm.
- Candidates who repeated their measurements for d recorded the raw values to the nearest mm. These candidates often also rounded their mean (final) value to the nearest mm.

Limited responses

- Candidates did not give a unit with their value for d.
- Candidates recorded a single value for d, and recorded it to the nearest 0.1 mm. This often involved adding a ‘trailing zero’ in the 0.1 mm place.
- Some candidates recorded final values for d that were out of range. This may have been because they measured a radius, or, possibly a circumference.

(e) Comprehensive responses

- Candidates recorded a second set of results, with both H and d values greater than those for the first loop.

Limited responses

- It was common for this value of H to be less than the value in **(c)(i)**. This may be an indication of the distorted shape of the larger diameter loop.

(f) (i) Comprehensive responses

- Candidates were able to correctly calculate values for k using the relevant measured values at **(c)**, **(d)** and **(e)**.
- Where units were given, the values of k were consistent with units used. A number of candidates correctly converted their values of d into metres and used this in the calculation of k.

Limited responses

- Some candidates calculated incorrect values for k. This often occurred because the expression for k was incorrectly rearranged when k was made the subject of the expression.

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- Some candidates either presented values of k to one significant figure, or incorrectly rounded a correct value to two significant figures on the answer line.
- Some candidates used the same value of F to calculate both of their values of k.

(ii) Comprehensive responses

- A few candidates related their significant figures in k to the significant figures in H and d (that is, to the raw measurements used in the calculation of k). They recognised that F was itself calculated from the measured value of H.
- Candidates generally used a numerical description of numbers of significant figures in the measured quantities to correctly state a corresponding number of significant figures for k, for example, 'I have used 3 significant figures for k as my answers for H and d have all been to 3 significant figures'.

Limited responses

- Many candidates related the significant figures in k to the significant figures in F and d, with no mention of the significant figures in H. This did not recognise that F was a calculated quantity from the measured quantity H.
- Other candidates made very general statements about the least number of significant figures in raw data. For example: 'k has to have the same number of significant figures as the measurement with the least significant figures'. Candidates need to relate the number of significant figures in k explicitly to the number of significant figures in all the raw measured quantities used in the calculation of k.
- Some candidates stated words to the effect of 'd had the least number of significant figures of two, so k is given to two significant figures'. Even if the one quantity referred to does have the least significant figures, they need to show that both measured quantities have been considered.

(g) Comprehensive responses

- Many candidates calculated a percentage difference in their k values and clearly compared this difference to the given percentage uncertainty of 10 per cent. They then drew a correct conclusion based on whether or not their percentage difference was less than or greater than 10 per cent.
- Some candidates used the alternative approach of applying the 10 per cent criterion to their k values and showing an overlap of the ranges to support the relationship.
-

Limited responses

- Some candidates incorrectly calculated the value of their percentage difference.
- Some candidates correctly calculated a percentage difference, and gave a correct conclusion without making an explicit comparison of their percentage difference to 10 per cent.
- Candidates made a comparison with a percentage uncertainty other than the given 10%. This could be their value from **(c)(ii)** or another numerical value.
- Candidates attempted an explanation in terms of unspecified 'experimental accuracy' or other vague term, without reference to the given 10 per cent.
- Some candidates were under the impression that the difference should be equal to 10 per cent in order to support the relationship, with a response such as 'the relationship is not valid since the difference of 23 per cent is not equal to 10 per cent'.
- Candidates who took the route of calculating the 10 per cent ranges of the k values often did not make a sufficient comparison of the overlap of the ranges before asserting a conclusion.

(h) (i) Comprehensive responses

- Many candidates recognised that two values of d, with corresponding values of H, is insufficient to draw a conclusion.
- Candidates considered each of the measured values (H and d) in turn, stating the quantity and describing a difficulty with that measurement. Each response usually began, for example, 'It was difficult to measure d accurately because …'.
- Some candidates described the reason for the difficulty in measuring H as the loop detached from the water.
- Candidates were able to comment on a difficulty with the apparatus.

Limited responses

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- Responses noted a difficulty without stating the quantity being measured. A typical response would be ‘There was parallax error when using the ruler’.
- Responses identified the quantity without describing the difficulty, for example, ‘It was difficult to measure H’.
- Some candidates suggested that wind, or other air movement, would affect the position of the card. Other effects are more significant, such as movement of the card due to contact with the metre rule.
- Candidates did not successfully describe the reason for the difficulty measuring H when the loop of wire detached from the water surface. These candidates usually stated the difficulty without further explanation.

(ii) Comprehensive responses

- Candidates considered each of their identified limitations in turn and suggested relevant improvements to the method or apparatus.
- Candidates stated that the experiment should be repeated for several different values of d in order to give more evidence to support the relationship between d and F. These candidates usually included plotting a relevant graph in their response.
- Candidates' responses were relevant to the experiment, for example, referring to the need for ruler to be in view if a video recording of the experiment was made.

Limited responses

- Some candidates did not recognise the need to plot a graph of their repeated measurements.
- Some candidates described improvements that they would already have been able to carry out using the provided apparatus. One example was ‘measuring d in different directions across the wire loop and finding the average’. A second example was ‘viewing the ruler perpendicularly to avoid parallax’.
- Some candidates suggested a relevant improvement in a way that did not apply to the experiment set. An example was describing the use of a video recording of the experiment with a timer or viewing frame-by-frame. For this experiment, a rule needed to be in view and timing was not required.
- Some candidates offered vague or irrelevant suggestions for improvement. Examples included, ‘Carry out the experiment in a closed environment to eliminate air movement’, or ‘Check that the bench is steady and the equipment works before starting the experiment’.

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PHYSICS

Paper 9702/33
Advanced Practical Skills 1

Key messages

Manipulation, measurement and observation

What candidates did well
- Many candidates often recorded their measurements in range and with a unit.

What candidates needed to improve
- Many candidates should consider the precision of their measuring device when recording their measurements, for example, ± 0.1 cm for a ruler and ± 1° for a protractor.

Presentation of data and observations

What candidates did well
- Most candidates presented their data in neat tables that were logical and easy to read.
- Many candidates carefully considered the selection of regular and sensible scales for the graph axes.

What candidates needed to improve
- Candidates should carefully double check the location of the plotted points and that they are accurate to the nearest half a square, using a sharp pencil.
- Candidates should use a sharp pencil and a 30 cm rule for drawing the line of best fit.
- Candidates should practise drawing the line of best fit to give a balance of points either side of the line along the length of the entire line.

Analysis, conclusion and evaluation

What candidates did well
- Many candidates chose triangles for the gradient that was large enough.

What candidates needed to improve
- When reading off chosen points for the gradient calculation, double check to the nearest half a square.
- When calculating *g* in **Question 1(f)**, consider the units used throughout the whole experiment.
- When reviewing the limitations, specify the quantity and reason.
- When suggesting improvements, detail the method used or the extra equipment needed.

Comments on specific questions

Question 1

(a) **Comprehensive responses**
- Many candidates had an appropriate value for *L* within the range required.
- Many candidates recorded *L* to match the precision of the ruler.
- Most candidates recorded a value for *S* within the range required.

Limited responses
- A few candidates recorded a value for *L* that was either out of range or omitted a unit.
- A few candidates recorded a value for *L* that was to the nearest cm when the ruler can measure to the nearest mm so a precision to the nearest mm is expected.
- A few candidates recorded a value for *S* that was out of range.

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(b) Comprehensive responses

- Many candidates stated their final value for T in range, recording evidence of repeated readings of at least two or more sets of nT where n = 5 or more.

Limited responses

- Some candidates repeated nT and stated this as their final value of T without dividing by n to give T and with no indication shown that they had taken repeated readings.
- Some candidates omitted to repeat their readings of nT.

(c) Comprehensive responses

- Most candidates collected five sets of values of L and T without assistance from the supervisor and obtained the correct trend within a range extended to a low enough and high enough value of L. There is no requirement for the independent variable to be evenly spaced.
- Candidates took time to construct a clear, well laid-out table in which to enter their data.
- Candidates gave both the quantity and the correct unit for each heading in the table.
- T^2 was correctly calculated.

Limited responses

- Some candidates collected five sets of data without extending the range enough.
- Some candidates recorded a quantity in the column heading and omitted the unit or, in rare cases, omitted the separating mark between the quantity and the unit.
- A few candidates collected five sets of data showing the wrong trend to that expected. This suggested that either the rule was reversed or candidates read off the incorrect scale.
- A few candidates calculated T^2 and then rounded incorrectly by truncating their value, for example, stating 1.36 instead of 1.37 for an answer of 1.3689.

(d) (i) Comprehensive responses

- Most candidates plotted the correct graph with labelled axes with the required quantities.
- Many candidates used sensible and regular scales where all the data occupied more than half the graph grid.
- Points were plotted using neat crosses within a tolerance of half a small square.

Limited responses

- Some candidates set their axes so that the step size was inappropriate and caused a compression in the y or x axes.
- Some candidates marked their scales every two large squares instead of every large square.
- Some candidates plotted the correct graph with irregular axes. This often led to incorrect plotting or read-offs later. Scale choices were not always appropriate where data were fitted exactly to the graph grid.
- Some candidates plotted points that were more than half a square out of the expected position on the graph grid.
- A few candidates drew plotted points with a diameter larger than half a small square. A sharp pencil should be used to produce clear and precise graph points as neat crosses.

(ii) Comprehensive responses

- Candidates drew a good line of best fit with an even spread of points either side of the line along the entire length of the line.

Limited responses

- Candidates drew a line of best fit. Use of a 30 cm ruler and a sharp pencil was not always evident.
- Candidates drew a line of best fit. Rotation or translation of the line was not always applied to achieve a balanced distribution of points either side of the line along its entire length.
- Candidates often tried to pass the line through as many points as possible, with the overall distribution of points not always taken into account. Some responses identified anomalous points.

(iii) Comprehensive responses

- Many candidates used a large triangle to calculate the gradient intercept.
- Many candidates read the graph of at x = 0 or substituted a correct read off (often from the gradient calculation) into $y = mx + c$ to find the y-intercept.

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Limited responses

- Some candidates attempted to calculate the gradient using a small triangle or made imprecise read-offs. A few candidates chose their read-offs from the table for points that were not on the line of best fit or were on the line but not precisely plotted.
- A few candidates used the incorrect formula for the gradient, using $\Delta x / \Delta y$ instead of $\Delta y / \Delta x$.
- For the y-intercept, some candidates either read off directly at a false origin so $x \neq 0$ whilst others substituted into an incorrectly rearranged equation, for example, $y / mx = c$ instead of $y - mx = c$.

(e) Comprehensive responses

- Most candidates correctly identified *P* as the gradient and *Q* as the y-intercept with appropriate units for both.

Limited responses

- Some candidates correctly identified *P* and *Q* and then omitted the unit or gave an incorrect unit such as cm / s^2 for *P* instead of s^2 / cm and cm^2 for *S* instead of s^2.

(f) Comprehensive responses

- Some candidates calculated a value for *g* with consistent units.

Limited responses

- Many candidates calculated a value for *g* with inconsistent units, for instance, m / s^2 were stated when throughout the experiment cm were used and no conversion shown at any stage. This meant that the value of *g* was often a factor of 100 out, for instance, 934 m / s^2 instead of 9.34 m / s^2 or 934 cm / s^2.
- A few candidates rearranged the equation incorrectly or forgot to square their π.

Question 2

(a) Comprehensive responses

- Many candidates recorded a final value of *t* in range and with an appropriate unit with any raw values to the nearest mm to reflect the precision of the measuring rule used.

Limited responses

- Some candidates recorded a final value of *t* in range and omitted a unit or recorded the raw readings to either too low a precision, that is to the nearest cm, or too high a precision, that is to the nearest 0.1 mm or even 0.01 mm.

(b) Comprehensive responses

- Many candidates recorded their final value of θ_0 in range and their raw values to the precision of the protractor, that is ± 1°.

Limited responses

- Some candidates recorded their raw values to the nearest ± 0.1°.
- Some candidates recorded θ_0 to be greater than 90° or less than 30°, suggesting that they mis-read their protractor.

(c) (i) Comprehensive responses

- Many candidates recorded a value for θ to be less than θ_0.

Limited responses

- A significant number of candidates, having read their protractor incorrectly, continued to mis-read their protractor here and obtain a value of θ greater than θ_0.

(ii) Comprehensive responses

- Some candidates stated an absolute uncertainty in θ in range and showed a correct method of working to calculate the percentage uncertainty in θ.
- Some candidates recorded repeated readings of θ and calculated half the range for the absolute uncertainty and showed a correct method to calculate θ.

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Limited responses

- Many candidates stated the absolute uncertainty in θ to be that of the precision of the protractor without giving due consideration to the nature of the measurement.

(iii) Comprehensive responses

- Many candidates calculated $\tan\theta / \tan\theta_0$ correctly.

Limited responses

- Some candidates had their calculator set to radians and so their calculation was incorrect.
- A few candidates calculated θ / θ_0.
- A few candidates did not round their answers correctly and truncated them.

(iv) Comprehensive responses

- Many candidates referred specifically to the number of significant figures in θ and θ_0.

Limited responses

- Some candidates referred to the 'raw data' without detailing what the raw data was.
- Some candidates referred to the wrong quantity, for instance, t.
- Some candidates referred to the number of decimal places instead of referring to the number of significant figures.

(d) Comprehensive responses

- Most candidates were able to record a second t, m, θ and θ_0.
- Many candidates recorded the second value of θ to be less than the first value of θ.

Limited responses

- A few candidates recorded the second value of θ to be greater than the first value of θ, perhaps because the protractor was read off incorrectly from the second scale.

(e) Comprehensive responses

- Many candidates correctly calculated two values of k for their two sets of data, showing their working clearly.

Limited responses

- Some candidates rearranged the equation incorrectly.
- A few candidates incorrectly stated their values of k to only one significant figure.

(f) Comprehensive responses

- Many candidates successfully carried out the three required steps for this question, correctly calculating the percentage difference between their values of k, comparing it against the stated 15 % criterion and providing a valid statement of conclusion supporting or not supporting the relationship.

Limited responses

- Some candidates omitted the percentage difference calculation.
- Some candidates made a comparison with a different percentage than that given in the question, for example, 10 per cent or 20 per cent.
- A few candidates attempted to find their own percentage uncertainty.

(g) Comprehensive responses

- Candidates identified limitations associated with setting up and obtaining specific readings. They did this by writing about the different measurements taken, for instance, 'high percentage uncertainty in t' and 'parallax error in θ'.
- Candidates went chronologically and systematically through the experiment detailing limitations in order.
- Candidates explained clearly the sources of uncertainty or limitations of the procedure, for example, 'judging the point of over balance' or 'the block slides along the table'. Then they suggested corresponding improvements that addressed each limitation, for example, 'video the experiment with a protractor in view' or 'use a rubber mat'.
- Many candidates identified that 'two readings are not enough to draw a valid conclusion' and suggested to 'take more readings and plot a graph'.

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Limited responses

- Many candidates did not specify the measurements that are problematic or provide reasons, for example ‘parallax error’ without referring to θ. Expressions such as ‘uncertainty in measuring θ because the protractor was not steady’ provided a clearer description of the measurement limitation.
- Some candidates, having identified the measurements that was problematic, then did not address the solution to improve the measurement of that quantity.
- Many candidates did not explain how a problem will be solved by detailing what additional equipment is necessary. It is often helpful to candidates to think about which quantity they are referencing their improvement to and the nature of that improvement.
- Some candidates gave suggested improvements that could have been undertaken anyway, for example, ‘repeat readings.

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PHYSICS

Paper 9702/34
Advanced Practical Skills 2

Key messages

Manipulation, measurement and observation

What candidates did well
- Many candidates included a correct unit with values.
- Most candidates presented values to an appropriate number of significant figures.

What candidates needed to improve
- The precision of measuring devices was not always reflected in recorded measurements, for example, ± 0.1 cm for a ruler.
- Measured values were not always checked for consistency with reasonable expectations, for example, for the internal diameter of a tube or a measured time interval.

Presentation of data and observations

What candidates did well
- Most candidates presented their data in neat tables with data that were logically sequenced.
- Many candidates carefully considered the selection of regular and sensible scales for the graph axes.

What candidates needed to improve
- Lines of best fit were not always drawn with sufficient precision.
- Lines of best fit did not always provide an even distribution of points either side of the line along its full length.

Analysis, conclusion and evaluation

What candidates did well
- Many candidates correctly processed data, for example, calculating a gradient using a sufficiently large triangle which was clearly shown on the graph grid.

What candidates needed to improve
- Points taken directly from the line of best fit were not always used when calculating the gradient and the y-intercept.
- Descriptions of limitations did not always specify both the quantity affected and the reason for the limitation.
- Suggested improvements did not always identify both the quantity affected and the action required. Additional equipment was not always identified correctly where relevant.

Comments on specific questions

Question 1

(a) Comprehensive responses
- Many candidates recorded appropriate values for d and A with a consistent unit.
- Most candidates recorded a value of B that was in range and with a correct unit.
- Some candidates recorded the value of B to the nearest mm.

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Limited responses

- Some candidates recorded a value of B to the nearest 0.1 mm without providing any raw readings to the nearest mm.
- A few candidates did not include a unit with the values stated.

(b) Comprehensive responses

- Many candidates collected six sets of data (different values of d) and included all the requested quantities in a well-structured table.
- Many candidates recorded measured values to an appropriate precision, for example all values of d recorded to the nearest mm.
- Many candidates correctly calculated values of t (using $B \div A$) and presented their values to an appropriate number of significant figures, for example, using the same significant figures or one more than the least significant figures in the raw values of B and A.

Limited responses

- Many candidates did not use the full range of potential d values. A value of $d \geq 13.0$ cm was often omitted.
- Some candidates omitted a necessary unit alongside the quantity in their column headings.
- Some candidates stated an incorrect unit in their column headings; this was most common when providing a unit for $1 / d$ (often incorrectly given as cm rather than cm^{-1}) or by providing a unit for the quantity t which is dimensionless.
- A few candidates presented their calculated t values with rounding errors or to an inappropriate number of significant figures, for example recording values of B and A to 3 significant figures and t to 2 significant figures.

(c) (i) Comprehensive responses

- Most candidates plotted the correct graph and labelled the axes with the required quantities.
- Many candidates used sensible and regular scales which allowed data to occupy more than half the graph grid in both the x and y directions.
- Many candidates labelled scales using values positioned no more than 1 large square (2 cm) apart.
- Many candidates plotted points using neat crosses to within a tolerance of half a small square.
- Many candidates collected data resulting in plotted points lying sufficiently close to a line of best fit.

Limited responses

- Some candidates used scale markings every 2 large squares (4 cm).
- Some candidates used inappropriate scales. For example, placing the lowest table value for the plotted quantity at the origin and the highest table value at the end of the grid then dividing by the number of large squares to determine the scale interval. This inevitably resulted in awkward scales and increased the chances of error when plotting points or taking read-off values for the gradient and intercept calculations. This often resulted in awkward scales and increased the likelihood of plotting and read-off errors.
- Some candidates used non-linear scales; often because a value was omitted from an otherwise correct sequence or because of a scale jump, for example, 0.8, 0.9, 1.0, 2.0.
- Some candidates used large dots or thick crosses (using a blunt pencil or marker pen) when plotting points. The precision of such points could not be assessed reliably against the accepted tolerance of 1 mm. Large dots or thick crosses reduced the precision with which plotted points could be assessed against the accepted tolerance.

(ii) Comprehensive responses

- Many candidates drew a thin, straight line of best fit with an even spread of points either side of the line along the entire length of the line.

Limited responses

- Some candidates drew a line of best fit that had offset joints or changes of direction. Some lines of best fit contained offset joints or changes of direction.
- Some candidates drew a line of best fit that could have been improved by rotating or translating the line to give a better fit of points either side of the line along the entire length of the line. Some lines of best fit could have been adjusted to provide a more even distribution of

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points either side of the line along its full length. Some lines of best fit could have been adjusted to provide a more even distribution of points either side of the line along its full length.
- Some candidates excluded points when drawing the line of best fit without indicating it as an anomaly. Some candidates excluded points when drawing the line of best fit without identifying them as anomalies.

(iii) Comprehensive responses
- Many candidates used a large triangle to calculate the gradient and used appropriate read-off values to determine the y-intercept.
- Many candidates took a reading from the line at $x = 0$ or substituted correct read-off values into $y = mx + c$ to find the y-intercept.

Limited responses
- Some candidates attempted to calculate the gradient using a small triangle (less than half the length of the drawn line) or incorrectly read off the readings.
- Some candidates used table values that were not on the line of best fit when calculating the gradient and/or y-intercept value.
- Some candidates used the incorrect formula for the gradient, using $\Delta x/\Delta y$ instead of $\Delta y/\Delta x$.
- For the y-intercept, some candidates read off directly at a false origin ($x \neq 0$) whilst others confused x and y values or substituted into an incorrectly rearranged equation, for example, $y/mx = c$ instead of $y - mx = c$.

(d) Comprehensive responses
- Most candidates correctly identified p as the gradient and q as the y-intercept.
- Most candidates stated both values using 2 or more significant figures.
- Some candidates provided a consistent unit for p, for example, cm (derived from $1 \div (1/d)$ where d was in cm) and recognised that q had no unit (since t has no unit).

Limited responses
- Some candidates stated values to only 1 significant figure or presented values as fractions.
- Some candidates gave an incorrect unit for p (often cm^{-1}) or provided a unit for q (often cm).

Question 2

(a) (i) Comprehensive responses
- Most candidates recorded a final value of L with an appropriate unit and recorded any raw values to the nearest mm reflecting the precision of the metre rule used.

Limited responses
- Some candidates recorded a final value of L to the nearest cm while others omitted the unit.
- A few candidates appeared to measure the length of the tube from the wrong end of the metre rule arriving at a value of less than 30 cm. Some candidates recorded values of less than 30 cm, suggesting that the measurement had been taken from an incorrect point on the metre rule.

(ii) Comprehensive responses
- Many candidates recorded their raw value(s) of D to a consistent precision of either 0.1 mm or 0.01 mm.
- Some values of D were outside the expected range but remained close to the Supervisor's value. Supervisor values assisted the assessment of measurements where apparatus differed from that specified in the confidential instructions.

Limited responses
- Many candidates gave a value of D outside of the expected range. In some cases, raw values suggested a misinterpretation of the vernier scale.
- Some candidates, whilst recording raw data to an appropriate precision, then reduced precision on the answer line, for example, a raw reading of 3.0 mm and a final value of 3 mm. Final values were not always stated to the same precision as the raw data.

(b) (i) Comprehensive responses
- Most candidates recorded a value of H that was less than 45.0 cm and gave a compatible unit.

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Limited responses

- A few candidates presented a value of H that was greater than 45.0 cm suggesting that they had either set up the apparatus incorrectly or had measured the wrong height.

(ii) Comprehensive responses

- Some candidates stated a suitable absolute uncertainty in H and showed a correct method of working to calculate the percentage uncertainty in H.
- Some candidates recorded repeated readings of H and calculated half the range for the absolute uncertainty and showed a correct method to calculate H.

Limited responses

- Many candidates stated the absolute uncertainty in H to be that of the precision of the metre rule without increasing the absolute uncertainty to reflect the nature of the measurement.

(iii) Comprehensive responses

- Many candidates took repeated readings for T and recorded all raw readings to an appropriate and consistent precision.
- Many candidates recorded a final value of T that was in range and presented with a unit.

Limited responses

- Some candidates presented repeated readings with inconsistent precision, for example some values to 0.01 s and others to 0.1 s.
- Some candidates did not include a unit with the answer line value of T.

(c) (i) Comprehensive responses

- Almost all candidates recorded a second value of L that was different to the first L value.

Limited responses

- A few candidates did not record a value of L or recorded the same value as the first value of L.

(ii) Comprehensive responses

- Almost all candidates recorded a second T value.
- Many candidates recorded a second value of T that was greater than the first value of T.

Limited responses

- A few candidates recorded a second value of T that was smaller than the first value of T.

(d) (i) Comprehensive responses

- Many candidates correctly calculated two values of k for their two sets of data, showing their working clearly.

Limited responses

- Some candidates remeasured D for the second tube, even though they were not instructed to do so, resulting in an incorrect k value.
- Some candidates rearranged the equation incorrectly.
- A few candidates incorrectly stated their values of k to only one significant figure.

(ii) Comprehensive responses

- Many candidates recognised that the significant figures in k depended upon the significant figures in the quantities T, D, H, and L.
- Many candidates included a correct numerical justification in their response. For example, quoting the number of significant figures used in each of the stated quantities and then suggesting that k should have the same (or one more) significant figures than the least significant figures in the quantities.

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Limited responses

- Some candidates referred to 'raw data' rather than naming the quantities involved in the calculation of *k*.
- Some candidates referred to some and not all the necessary quantities.
- Some candidates referred only to D^4 and not *D*.

(e) Comprehensive responses

- Many candidates correctly calculated the percentage difference between their two values of *k* and showed their working. They then compared this percentage difference to the suggested criterion of 15% and stated whether their *k* values supported the relationship.

Limited responses

- Some candidates performed an incorrect percentage difference calculation; one error was in forgetting to multiply by 100. For example, what should have been a 35% difference was recorded as 0.35% giving rise to an invalid comparison with 15% and an incorrect conclusion.
- Some candidates did not explicitly compare the % difference with the criterion of 15%. For example, 'the percentage difference is 10% and the criterion is 15% so the relationship is supported'. In this example, the response is missing a comparison between the two values, for example, '10% < 15%'.

(f) Comprehensive responses

- Many candidates went chronologically and systematically through the experiment detailing limitations in order.
- Many candidates presented their limitations in the format 'difficulty with 'stated quantity' with reason'. For example, 'difficulty with T because it is not always straightforward to judge when the water passes the syringe graduations' or 'difficult to measure *D* because the tube deforms easily'.
- Many candidates presented their improvements in the format 'stated quantity and improved method or more suitable apparatus'. For example, 'record the experiment with a timer in view to measure *T*' or 'use a clamp to hold the rule when measuring *H*'.
- Most candidates identified that 'two readings are not enough to draw a valid conclusion' and suggested to 'take more readings and plot a graph'.

Limited responses

- Many candidates did not specify the measurements that are problematic or provide reasons, for example 'parallax error' without referring to *H* or 'difficult to measure H' without a reason. Responses did not always identify both the affected quantity and the reason for the limitation.
- Some candidates were not clear in specifying the measurement affected. For example, the use of 'height' instead of *H*. Although, for example, 'internal diameter' was acceptable for '*D*', the use of 'height' for *H* was not. This is because *H* was not the only height measured. The height of the syringe body above the bench and the height of the end of the tube above the bench were also measured. The quantity affected was not always identified unambiguously.
- Some candidates suggested improvements that could have been undertaken anyway, for example, 'repeat readings of *D* in different positions around the tube' or 'view the rule perpendicularly'.

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PHYSICS

Paper 9702/35
Advanced Practical Skills 1

Key messages

Manipulation, measurement and observation

What candidates did well
- Many candidates recorded their measurements in range and with a unit.

What candidates needed to improve
- Many candidates should consider the precision of their measuring device when recording their measurements, for example, ± 0.1 cm for a ruler.

Presentation of data and observations

What candidates did well
- Most candidates presented their data in neat tables that were logical and easy to read.
- Many candidates carefully considered the selection of regular and sensible scales for the graph axes.

What candidates needed to improve
- Candidates should carefully double check the location of the plotted points and that they are plotted accurately to the nearest half a square, using a sharp pencil.
- Candidates should use a sharp pencil and a 30 cm ruler for drawing the line of best fit.
- Candidates should practise drawing the line of best fit to give a balance of points either side of the line along the length of the entire line.

Analysis, conclusion and evaluation

What candidates did well
- Many candidates chose triangles for the gradient that were large enough.

What candidates needed to improve
- When reading off chosen points for the gradient calculation, double check to the nearest half a square.
- When reviewing the limitations, specify the quantity and reason.
- When suggesting improvements, detail the method used or the extra equipment needed.

Comments on specific questions

Question 1

(a) **Comprehensive responses**
- Many candidates had an appropriate value for d within the range required with a unit.

Limited responses
- A few candidates recorded a value for d that was either out of range or omitted a unit.
- A few candidates recorded a value for d that was to the nearest cm when the ruler can measure to the nearest mm so a precision to the nearest mm is expected.

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(b) Comprehensive responses

- Most candidates collected six sets of values of *M*, *n* and *d* without assistance from the supervisor and obtained the correct trend within a range extended to a low enough and high enough value of *M*. There is no requirement for the independent variable to be evenly spaced.
- Candidates took time to construct a clear, well laid-out table in which to enter their data.
- Candidates gave both the quantity and the correct unit for each heading in the table.
- 1 / *d* was correctly calculated and recorded the value to an appropriate number of significant figures.

Limited responses

- Some candidates collected six sets of data without extending the range.
- Some candidates recorded a quantity in the column heading and omitted the unit.
- A few candidates collected six sets of data showing the wrong trend to that expected.
- A few candidates calculated 1 / *d* and then rounded incorrectly by truncating their value.
- Some candidates recorded the calculated value of 1 / *d* to too many or too few significant figures. Reference to the raw value of *d* showed that the calculated 1 / *d* values should contain the same number of significant figures, or one additional significant figure.

(c) (i) Comprehensive responses

- Most candidates plotted the correct graph with labelled axes with the required quantities.
- Many candidates used sensible and regular scales where all the data occupied more than half the graph grid.
- Points were plotted using neat crosses within a tolerance of half a small square.

Limited responses

- Some candidates set their axes so that the step size was inappropriate and caused a compression in the *y* or *x* axes.
- Some candidates marked their scales every two large squares instead of every large square.
- Some candidates plotted the correct graph with irregular axes. This often led to inaccurate plotting or read-offs later. In some responses, data were fitted exactly to the graph grid, resulting in unsuitable scale choices.
- Some candidates plotted points that were more than half a square out of the expected position on the graph grid.
- A few candidates drew plotted points with a diameter larger than half a small square. A sharp pencil should be used to produce clear and precise graph points as neat crosses.

(ii) Comprehensive responses

- Candidates drew a line of best fit with an even spread of points on either side of the line along its entire length.

Limited responses

- Candidates drew a line of best fit using a 30 cm ruler and a sharp pencil.
- Candidates drew a line of best fit. Rotation or translation of the line was not always applied to give a balanced distribution of points either side of the line along its length.
- Candidates often tried to pass the line through as many points as possible, with the overall distribution of points not always taken into account. Some responses identified anomalous points.

(iii) Comprehensive responses

- Many candidates used a large triangle to calculate the gradient and intercept.
- Many candidates read the graph at $x = 0$ or substituted a correct read-off, often from the gradient calculation, into $y = mx + c$ to find the y−intercept.

Limited responses

- Some candidates attempted to calculate the gradient using a small triangle or made imprecise read-offs. A few candidates chose their read-offs from the table for points that were not on the line of best fit or were on the line but not precisely plotted.
- A few candidates used an incorrect formula for the gradient, using $\Delta x / \Delta y$ instead of $\Delta y / \Delta x$.
- For the y−intercept, some candidates either read off directly at a false origin so $x \neq 0$ whilst others substituted into an incorrectly rearranged equation, for example, $y / mx = c$ instead of $y - mx = c$.

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(d) **Comprehensive responses**

- Most candidates correctly identified *P* as the gradient and *Q* as the *y*−intercept with appropriate units for both.

Limited responses

- Some candidates correctly identified *P* and *Q* and then omitted the unit or gave an incorrect unit such as 'cm' for *P* instead of 'cm^{-1}'.

(e) **Comprehensive responses**

- Some candidates calculated a value for *S* with consistent units.

Limited responses

- Many candidates calculated a value for *S* omitting the units.
- A few candidates rearranged the equation for *S* incorrectly.

Question 2

(a) (i) **Comprehensive responses**

- Some candidates stated an absolute uncertainty in *L* in range and showed a correct method of working to calculate the percentage uncertainty in *L*.
- Some candidates recorded repeated readings of *L* and calculated half the range for the absolute uncertainty.

Limited responses

- Many candidates stated the absolute uncertainty in *L* to be that of the precision of the ruler without giving due consideration to the nature of taking this measurement in this experiment.

(ii) **Comprehensive responses**

- Many candidates recorded a final value of D_B and D_C in range, with an appropriate unit and with all raw values to the nearest mm to reflect the precision of the measuring rule used.

Limited responses

- Some candidates recorded a final value of D_B and D_C out of range (over 50.0 cm) or a few omitted a unit or recorded raw readings to the nearest cm without considering the precision of the rule.

(b) (i) **Comprehensive responses**

- Many candidates recorded their final value of *R* to the precision of the ohmmeter, that is ± 0.1 Ω with an appropriate unit.

Limited responses

- Some candidates recorded their raw values to small a precision, for example, to the nearest ± 1 Ω or too high a precision, for example 0.01 Ω, when the ohmmeter can read to the nearest 0.1 Ω.

(ii) **Comprehensive responses**

- Most candidates calculated (D_B − x) and (D_C + x) correctly.

Limited responses

- A few candidates did not round their answers correctly, truncating them.

(iii) **Comprehensive responses**

- Many candidates recorded a value for R_x to be less than *R*.

Limited responses

- Some candidates obtained a value of R_x to be greater than *R*.

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(iv) **Comprehensive responses**

- Many candidates calculated (R / R_X) correctly.

Limited responses

- A few candidates calculated (R / R_X).
- A few candidates did not round their answers correctly, truncating them.

(v) **Comprehensive responses**

- Many candidates referred specifically to the number of significant figures in R_x and R.

Limited responses

- Some candidates referred to the 'raw data' without detailing what the raw data was.
- Some candidates referred to the wrong quantity, for instance, L.
- Some candidates referred to the number of decimal places instead of referring to the number of significant figures.

(c) **Comprehensive responses**

- The majority of candidates were able to record a second ($D_B - x$), ($D_C + x$) and R_x.
- Most candidates recorded the second value of R_x to be less than the first value of R_x.

Limited responses

- A few candidates recorded the second value of R_x to be greater than the first value of R_x suggesting that the candidate mis-read the rule.

(d) **Comprehensive responses**

- Many candidates correctly calculated two values of k for their two sets of data, showing their working clearly.

Limited responses

- Some candidates rearranged the equation incorrectly.
- A few candidates incorrectly stated their values of k to only one significant figure.

(e) **Comprehensive responses**

- Many candidates successfully carried out the three required steps for this question, correctly calculating the percentage difference between their values of k, comparing it against the stated 15% criterion and providing a valid statement of conclusion supporting or not supporting the relationship.

Limited responses

- Some candidates omitted the percentage difference calculation.
- Some candidates made a comparison with a different percentage than that given in the question, for example, 10% or 15%
- A few candidates attempted to find their own percentage uncertainty.

(f) **Comprehensive responses**

- Candidates identified limitations associated with setting up and obtaining specific readings. This was shown through reference to the different measurements taken, for instance, 'measuring L was affected because the wire was not wrapped tightly around the screws at either end', accompanied by a reason.
- Candidates chronologically and systematically went through the experiment detailing limitations as they occur.
- Candidates explained clearly the sources of uncertainty or limitations of the procedure, for example, the precision of the ohmmeter was only 0.1 Ω. Then they suggested corresponding improvements that addressed each limitation.
- Many candidates identified that 'two readings are not enough to draw a valid conclusion' and suggested to 'take more readings and plot a graph'.

Limited responses

- Many candidates did not specify the measurements that are problematic or provide reasons, for example, 'loose wire' without referring to the measurement that is affected, in this case, L.

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Expressions such as ‘uncertainty in measuring *L* because the wire was not taut and was loose’ provided a clearer description of the measurement limitation.

- Some candidates, having identified the measurement that was problematic, then did not address the solution to improve the measurement of that quantity.
- Many candidates did not explain how a problem will be solved by detailing what additional equipment is necessary. It is often helpful to candidates to think about which quantity they are referencing their improvement to and the nature of that improvement.
- Some candidates gave suggested improvements that could have been undertaken anyway, for example, ‘repeat readings’.

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PHYSICS

Paper 9702/37
Advanced Practical Skills 1

Key messages

Manipulation, measurement and observation

What candidates did well
- Many candidates often recorded their measurements in range and with a unit.

What candidates needed to improve
- Many candidates should consider the precision of their measuring device when recording their measurements, for example, ± 0.1 cm for a ruler and ± 1° for a protractor.

Presentation of data and observations

What candidates did well
- Most candidates presented their data in neat tables that were logical and easy to read.
- Many candidates carefully considered the selection of regular and sensible scales for the graph axes.

What candidates needed to improve
- Candidates should carefully double check the location of the plotted points and that they are accurate to the nearest half a square, using a sharp pencil.
- Candidates should use a sharp pencil and a 30 cm rule for drawing the line of best fit.
- Candidates should practise drawing the line of best fit to give a balance of points either side of the line along the length of the entire line.

Analysis, conclusion and evaluation

What candidates did well
- Many candidates chose triangles for the gradient that was large enough.

What candidates needed to improve
- When reading off chosen points for the gradient calculation, double check to the nearest half a square.
- When calculating *g* in **Question 1(f)**, consider the units used throughout the whole experiment.
- When reviewing the limitations, specify the quantity and reason.
- When suggesting improvements, detail the method used or the extra equipment needed.

Comments on specific questions

Question 1

(a) **Comprehensive responses**
- Many candidates had an appropriate value for *L* within the range required.
- Many candidates recorded *L* to match the precision of the ruler.
- Most candidates recorded a value for *S* within the range required.

Limited responses
- A few candidates recorded a value for *L* that was either out of range or omitted a unit.
- A few candidates recorded a value for *L* that was to the nearest cm when the ruler can measure to the nearest mm so a precision to the nearest mm is expected.
- A few candidates recorded a value for *S* that was out of range.

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(b) Comprehensive responses

- Many candidates stated their final value for T in range, recording evidence of repeated readings of at least two or more sets of nT where n = 5 or more.

Limited responses

- Some candidates repeated nT and stated this as their final value of T without dividing by n to give T and with no indication shown that they had taken repeated readings.
- Some candidates omitted to repeat their readings of nT.

(c) Comprehensive responses

- Most candidates collected five sets of values of L and T without assistance from the supervisor and obtained the correct trend within a range extended to a low enough and high enough value of L. There is no requirement for the independent variable to be evenly spaced.
- Candidates took time to construct a clear, well laid-out table in which to enter their data.
- Candidates gave both the quantity and the correct unit for each heading in the table.
- T^2 was correctly calculated.

Limited responses

- Some candidates collected five sets of data without extending the range enough.
- Some candidates recorded a quantity in the column heading and omitted the unit or, in rare cases, omitted the separating mark between the quantity and the unit.
- A few candidates collected five sets of data showing the wrong trend to that expected. This suggested that either the rule was reversed or candidates read off the incorrect scale.
- A few candidates calculated T^2 and then rounded incorrectly by truncating their value, for example, stating 1.36 instead of 1.37 for an answer of 1.3689.

(d) (i) Comprehensive responses

- Most candidates plotted the correct graph with labelled axes with the required quantities.
- Many candidates used sensible and regular scales where all the data occupied more than half the graph grid.
- Points were plotted using neat crosses within a tolerance of half a small square.

Limited responses

- Some candidates set their axes so that the step size was inappropriate and caused a compression in the y or x axes.
- Some candidates marked their scales every two large squares instead of every large square.
- Some candidates plotted the correct graph with irregular axes. This often led to incorrect plotting or read-offs later. Scale choices were not always appropriate where data were fitted exactly to the graph grid.
- Some candidates plotted points that were more than half a square out of the expected position on the graph grid.
- A few candidates drew plotted points with a diameter larger than half a small square. A sharp pencil should be used to produce clear and precise graph points as neat crosses.

(ii) Comprehensive responses

- Candidates drew a good line of best fit with an even spread of points either side of the line along the entire length of the line.

Limited responses

- Candidates drew a line of best fit. Use of a 30 cm ruler and a sharp pencil was not always evident.
- Candidates drew a line of best fit. Rotation or translation of the line was not always applied to achieve a balanced distribution of points either side of the line along its entire length.
- Candidates often tried to pass the line through as many points as possible, with the overall distribution of points not always taken into account. Some responses identified anomalous points.

(iii) Comprehensive responses

- Many candidates used a large triangle to calculate the gradient intercept.
- Many candidates read the graph of at x = 0 or substituted a correct read off (often from the gradient calculation) into $y = mx + c$ to find the y-intercept.

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Limited responses

- Some candidates attempted to calculate the gradient using a small triangle or made imprecise read-offs. A few candidates chose their read-offs from the table for points that were not on the line of best fit or were on the line but not precisely plotted.
- A few candidates used the incorrect formula for the gradient, using $\Delta x / \Delta y$ instead of $\Delta y / \Delta x$.
- For the y-intercept, some candidates either read off directly at a false origin so $x \neq 0$ whilst others substituted into an incorrectly rearranged equation, for example, $y / mx = c$ instead of $y - mx = c$.

(e) Comprehensive responses

- Most candidates correctly identified *P* as the gradient and *Q* as the y-intercept with appropriate units for both.

Limited responses

- Some candidates correctly identified *P* and *Q* and then omitted the unit or gave an incorrect unit such as cm / s^2 for *P* instead of s^2 / cm and cm^2 for *S* instead of s^2.

(f) Comprehensive responses

- Some candidates calculated a value for *g* with consistent units.

Limited responses

- Many candidates calculated a value for *g* with inconsistent units, for instance, m / s^2 were stated when throughout the experiment cm were used and no conversion shown at any stage. This meant that the value of *g* was often a factor of 100 out, for instance, 934 m / s^2 instead of 9.34 m / s^2 or 934 cm / s^2.
- A few candidates rearranged the equation incorrectly or forgot to square their π.

Question 2

(a) Comprehensive responses

- Many candidates recorded a final value of *t* in range and with an appropriate unit with any raw values to the nearest mm to reflect the precision of the measuring rule used.

Limited responses

- Some candidates recorded a final value of *t* in range and omitted a unit or recorded the raw readings to either too low a precision, that is to the nearest cm, or too high a precision, that is to the nearest 0.1 mm or even 0.01 mm.

(b) Comprehensive responses

- Many candidates recorded their final value of θ_0 in range and their raw values to the precision of the protractor, that is ± 1°.

Limited responses

- Some candidates recorded their raw values to the nearest ± 0.1°.
- Some candidates recorded θ_0 to be greater than 90° or less than 30°, suggesting that they mis-read their protractor.

(c) (i) Comprehensive responses

- Many candidates recorded a value for θ to be less than θ_0.

Limited responses

- A significant number of candidates, having read their protractor incorrectly, continued to mis-read their protractor here and obtain a value of θ greater than θ_0.

(ii) Comprehensive responses

- Some candidates stated an absolute uncertainty in θ in range and showed a correct method of working to calculate the percentage uncertainty in θ.
- Some candidates recorded repeated readings of θ and calculated half the range for the absolute uncertainty and showed a correct method to calculate θ.

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Limited responses

- Many candidates stated the absolute uncertainty in θ to be that of the precision of the protractor without giving due consideration to the nature of the measurement.

(iii) Comprehensive responses

- Many candidates calculated $\tan\theta / \tan\theta_0$ correctly.

Limited responses

- Some candidates had their calculator set to radians and so their calculation was incorrect.
- A few candidates calculated θ / θ_0.
- A few candidates did not round their answers correctly and truncated them.

(iv) Comprehensive responses

- Many candidates referred specifically to the number of significant figures in θ and θ_0.

Limited responses

- Some candidates referred to the 'raw data' without detailing what the raw data was.
- Some candidates referred to the wrong quantity, for instance, t.
- Some candidates referred to the number of decimal places instead of referring to the number of significant figures.

(d) Comprehensive responses

- Most candidates were able to record a second t, m, θ and θ_0.
- Many candidates recorded the second value of θ to be less than the first value of θ.

Limited responses

- A few candidates recorded the second value of θ to be greater than the first value of θ, perhaps because the protractor was read off incorrectly from the second scale.

(e) Comprehensive responses

- Many candidates correctly calculated two values of k for their two sets of data, showing their working clearly.

Limited responses

- Some candidates rearranged the equation incorrectly.
- A few candidates incorrectly stated their values of k to only one significant figure.

(f) Comprehensive responses

- Many candidates successfully carried out the three required steps for this question, correctly calculating the percentage difference between their values of k, comparing it against the stated 15 % criterion and providing a valid statement of conclusion supporting or not supporting the relationship.

Limited responses

- Some candidates omitted the percentage difference calculation.
- Some candidates made a comparison with a different percentage than that given in the question, for example, 10 per cent or 20 per cent.
- A few candidates attempted to find their own percentage uncertainty.

(g) Comprehensive responses

- Candidates identified limitations associated with setting up and obtaining specific readings. They did this by writing about the different measurements taken, for instance, 'high percentage uncertainty in t' and 'parallax error in θ'.
- Candidates went chronologically and systematically through the experiment detailing limitations in order.
- Candidates explained clearly the sources of uncertainty or limitations of the procedure, for example, 'judging the point of over balance' or 'the block slides along the table'. Then they suggested corresponding improvements that addressed each limitation, for example, 'video the experiment with a protractor in view' or 'use a rubber mat'.
- Many candidates identified that 'two readings are not enough to draw a valid conclusion' and suggested to 'take more readings and plot a graph'.

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Limited responses

- Many candidates did not specify the measurements that are problematic or provide reasons, for example 'parallax error' without referring to θ. Expressions such as 'uncertainty in measuring θ because the protractor was not steady' provided a clearer description of the measurement limitation.
- Some candidates, having identified the measurements that was problematic, then did not address the solution to improve the measurement of that quantity.
- Many candidates did not explain how a problem will be solved by detailing what additional equipment is necessary. It is often helpful to candidates to think about which quantity they are referencing their improvement to and the nature of that improvement.
- Some candidates gave suggested improvements that could have been undertaken anyway, for example, 'repeat readings'.

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PHYSICS

Paper 9702/38
Advanced Practical Skills 2

Key messages

Manipulation, measurement and observation

What candidates did well
- Many candidates included a correct unit with values.
- Most candidates presented values to an appropriate number of significant figures.

What candidates needed to improve
- The precision of measuring devices was not always reflected in recorded measurements, for example, ± 0.1 cm for a ruler.
- Measured values were not always checked for consistency with reasonable expectations, for example, for the internal diameter of a tube or a measured time interval.

Presentation of data and observations

What candidates did well
- Most candidates presented their data in neat tables with data that were logically sequenced.
- Many candidates carefully considered the selection of regular and sensible scales for the graph axes.

What candidates needed to improve
- Lines of best fit were not always drawn with sufficient precision.
- Lines of best fit did not always provide an even distribution of points either side of the line along its full length.

Analysis, conclusion and evaluation

What candidates did well
- Many candidates correctly processed data, for example, calculating a gradient using a sufficiently large triangle which was clearly shown on the graph grid.

What candidates needed to improve
- Points taken directly from the line of best fit were not always used when calculating the gradient and the y-intercept.
- Descriptions of limitations did not always specify both the quantity affected and the reason for the limitation.
- Suggested improvements did not always identify both the quantity affected and the action required. Additional equipment was not always identified correctly where relevant.

Comments on specific questions

Question 1

(a) Comprehensive responses
- Many candidates recorded appropriate values for d and A with a consistent unit.
- Most candidates recorded a value of B that was in range and with a correct unit.
- Some candidates recorded the value of B to the nearest mm.

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Limited responses

- Some candidates recorded a value of B to the nearest 0.1 mm without providing any raw readings to the nearest mm.
- A few candidates did not include a unit with the values stated.

(b) Comprehensive responses

- Many candidates collected six sets of data (different values of d) and included all the requested quantities in a well-structured table.
- Many candidates recorded measured values to an appropriate precision, for example all values of d recorded to the nearest mm.
- Many candidates correctly calculated values of t (using $B \div A$) and presented their values to an appropriate number of significant figures, for example, using the same significant figures or one more than the least significant figures in the raw values of B and A.

Limited responses

- Many candidates did not use the full range of potential d values. A value of $d \geq 13.0$ cm was often omitted.
- Some candidates omitted a necessary unit alongside the quantity in their column headings.
- Some candidates stated an incorrect unit in their column headings; this was most common when providing a unit for $1 / d$ (often incorrectly given as cm rather than cm^{-1}) or by providing a unit for the quantity t which is dimensionless.
- A few candidates presented their calculated t values with rounding errors or to an inappropriate number of significant figures, for example recording values of B and A to 3 significant figures and t to 2 significant figures.

(c) (i) Comprehensive responses

- Most candidates plotted the correct graph and labelled the axes with the required quantities.
- Many candidates used sensible and regular scales which allowed data to occupy more than half the graph grid in both the x and y directions.
- Many candidates labelled scales using values positioned no more than 1 large square (2 cm) apart.
- Many candidates plotted points using neat crosses to within a tolerance of half a small square.
- Many candidates collected data resulting in plotted points lying sufficiently close to a line of best fit.

Limited responses

- Some candidates used scale markings every 2 large squares (4 cm).
- Some candidates used inappropriate scales. For example, placing the lowest table value for the plotted quantity at the origin and the highest table value at the end of the grid then dividing by the number of large squares to determine the scale interval. This inevitably resulted in awkward scales and increased the chances of error when plotting points or taking read-off values for the gradient and intercept calculations. This often resulted in awkward scales and increased the likelihood of plotting and read-off errors.
- Some candidates used non-linear scales; often because a value was omitted from an otherwise correct sequence or because of a scale jump, for example, 0.8, 0.9, 1.0, 2.0.
- Some candidates used large dots or thick crosses (using a blunt pencil or marker pen) when plotting points. The precision of such points could not be assessed reliably against the accepted tolerance of 1 mm. Large dots or thick crosses reduced the precision with which plotted points could be assessed against the accepted tolerance.

(ii) Comprehensive responses

- Many candidates drew a thin, straight line of best fit with an even spread of points either side of the line along the entire length of the line.

Limited responses

- Some candidates drew a line of best fit that had offset joints or changes of direction. Some lines of best fit contained offset joints or changes of direction.
- Some candidates drew a line of best fit that could have been improved by rotating or translating the line to give a better fit of points either side of the line along the entire length of the line. Some lines of best fit could have been adjusted to provide a more even distribution of

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points either side of the line along its full length. Some lines of best fit could have been adjusted to provide a more even distribution of points either side of the line along its full length.
- Some candidates excluded points when drawing the line of best fit without indicating it as an anomaly. Some candidates excluded points when drawing the line of best fit without identifying them as anomalies.

(iii) Comprehensive responses
- Many candidates used a large triangle to calculate the gradient and used appropriate read-off values to determine the y-intercept.
- Many candidates took a reading from the line at $x = 0$ or substituted correct read-off values into $y = mx + c$ to find the y-intercept.

Limited responses
- Some candidates attempted to calculate the gradient using a small triangle (less than half the length of the drawn line) or incorrectly read off the readings.
- Some candidates used table values that were not on the line of best fit when calculating the gradient and/or y-intercept value.
- Some candidates used the incorrect formula for the gradient, using $\Delta x/\Delta y$ instead of $\Delta y/\Delta x$.
- For the y-intercept, some candidates read off directly at a false origin ($x \neq 0$) whilst others confused x and y values or substituted into an incorrectly rearranged equation, for example, $y/mx = c$ instead of $y - mx = c$.

(d) Comprehensive responses
- Most candidates correctly identified p as the gradient and q as the y-intercept.
- Most candidates stated both values using 2 or more significant figures.
- Some candidates provided a consistent unit for p, for example, cm (derived from $1 \div (1/d)$ where d was in cm) and recognised that q had no unit (since t has no unit).

Limited responses
- Some candidates stated values to only 1 significant figure or presented values as fractions.
- Some candidates gave an incorrect unit for p (often cm^{-1}) or provided a unit for q (often cm).

Question 2

(a) (i) Comprehensive responses
- Most candidates recorded a final value of L with an appropriate unit and recorded any raw values to the nearest mm reflecting the precision of the metre rule used.

Limited responses
- Some candidates recorded a final value of L to the nearest cm while others omitted the unit.
- A few candidates appeared to measure the length of the tube from the wrong end of the metre rule arriving at a value of less than 30 cm. Some candidates recorded values of less than 30 cm, suggesting that the measurement had been taken from an incorrect point on the metre rule.

(ii) Comprehensive responses
- Many candidates recorded their raw value(s) of D to a consistent precision of either 0.1 mm or 0.01 mm.
- Some values of D were outside the expected range but remained close to the Supervisor's value. Supervisor values assisted the assessment of measurements where apparatus differed from that specified in the confidential instructions.

Limited responses
- Many candidates gave a value of D outside of the expected range. In some cases, raw values suggested a misinterpretation of the vernier scale.
- Some candidates, whilst recording raw data to an appropriate precision, then reduced precision on the answer line, for example, a raw reading of 3.0 mm and a final value of 3 mm. Final values were not always stated to the same precision as the raw data.

(b) (i) Comprehensive responses
- Most candidates recorded a value of H that was less than 45.0 cm and gave a compatible unit.

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Limited responses

- A few candidates presented a value of H that was greater than 45.0 cm suggesting that they had either set up the apparatus incorrectly or had measured the wrong height.

(ii) Comprehensive responses

- Some candidates stated a suitable absolute uncertainty in H and showed a correct method of working to calculate the percentage uncertainty in H.
- Some candidates recorded repeated readings of H and calculated half the range for the absolute uncertainty and showed a correct method to calculate H.

Limited responses

- Many candidates stated the absolute uncertainty in H to be that of the precision of the metre rule without increasing the absolute uncertainty to reflect the nature of the measurement.

(iii) Comprehensive responses

- Many candidates took repeated readings for T and recorded all raw readings to an appropriate and consistent precision.
- Many candidates recorded a final value of T that was in range and presented with a unit.

Limited responses

- Some candidates presented repeated readings with inconsistent precision, for example some values to 0.01 s and others to 0.1 s.
- Some candidates did not include a unit with the answer line value of T.

(c) (i) Comprehensive responses

- Almost all candidates recorded a second value of L that was different to the first L value.

Limited responses

- A few candidates did not record a value of L or recorded the same value as the first value of L.

(ii) Comprehensive responses

- Almost all candidates recorded a second T value.
- Many candidates recorded a second value of T that was greater than the first value of T.

Limited responses

- A few candidates recorded a second value of T that was smaller than the first value of T.

(d) (i) Comprehensive responses

- Many candidates correctly calculated two values of k for their two sets of data, showing their working clearly.

Limited responses

- Some candidates remeasured D for the second tube, even though they were not instructed to do so, resulting in an incorrect k value.
- Some candidates rearranged the equation incorrectly.
- A few candidates incorrectly stated their values of k to only one significant figure.

(ii) Comprehensive responses

- Many candidates recognised that the significant figures in k depended upon the significant figures in the quantities T, D, H, and L.
- Many candidates included a correct numerical justification in their response. For example, quoting the number of significant figures used in each of the stated quantities and then suggesting that k should have the same (or one more) significant figures than the least significant figures in the quantities.

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Limited responses

- Some candidates referred to 'raw data' rather than naming the quantities involved in the calculation of *k*.
- Some candidates referred to some and not all the necessary quantities.
- Some candidates referred only to D^4 and not *D*.

(e) Comprehensive responses

- Many candidates correctly calculated the percentage difference between their two values of *k* and showed their working. They then compared this percentage difference to the suggested criterion of 15% and stated whether their *k* values supported the relationship.

Limited responses

- Some candidates performed an incorrect percentage difference calculation; one error was in forgetting to multiply by 100. For example, what should have been a 35% difference was recorded as 0.35% giving rise to an invalid comparison with 15% and an incorrect conclusion.
- Some candidates did not explicitly compare the % difference with the criterion of 15%. For example, 'the percentage difference is 10% and the criterion is 15% so the relationship is supported'. In this example, the response is missing a comparison between the two values, for example, '10% < 15%'.

(f) Comprehensive responses

- Many candidates went chronologically and systematically through the experiment detailing limitations in order.
- Many candidates presented their limitations in the format 'difficulty with 'stated quantity' with reason'. For example, 'difficulty with T because it is not always straightforward to judge when the water passes the syringe graduations' or 'difficult to measure *D* because the tube deforms easily'.
- Many candidates presented their improvements in the format 'stated quantity and improved method or more suitable apparatus'. For example, 'record the experiment with a timer in view to measure *T*' or 'use a clamp to hold the rule when measuring *H*'.
- Most candidates identified that 'two readings are not enough to draw a valid conclusion' and suggested to 'take more readings and plot a graph'.

Limited responses

- Many candidates did not specify the measurements that are problematic or provide reasons, for example 'parallax error' without referring to *H* or 'difficult to measure H' without a reason. Responses did not always identify both the affected quantity and the reason for the limitation.
- Some candidates were not clear in specifying the measurement affected. For example, the use of 'height' instead of *H*. Although, for example, 'internal diameter' was acceptable for '*D*', the use of 'height' for *H* was not. This is because *H* was not the only height measured. The height of the syringe body above the bench and the height of the end of the tube above the bench were also measured. The quantity affected was not always identified unambiguously.
- Some candidates suggested improvements that could have been undertaken anyway, for example, 'repeat readings of *D* in different positions around the tube' or 'view the rule perpendicularly'.

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PHYSICS

Paper 9702/41
A Level Structured Questions

Key messages

What candidates did well
- Many candidates demonstrated expertise with calculations and showed all steps in their working.
- Many candidates were able to recall syllabus definitions accurately.

What candidates needed to improve
- Questions requiring explanations of physical processes (for example, production of X-rays, changes in total mass defect during nuclear radiation) were often not answered well.
- Candidates need to ensure that any graphs drawn are complete and demonstrate the correct physical principles along the whole length of the line.
- Candidates always need to work to an appropriate number of significant figures. The appropriate number of significant figures in calculation is very often three significant figures.

Comments on specific questions

Question 1

(a) Comprehensive responses
- Many candidates gave complete definitions of gravitational potential.

Limited responses
- Some candidates did not make the ratio clear. The statement 'work done on a unit mass' is not sufficient because the ratio between work done and mass is not clear.

(b)(i) Comprehensive responses
- Candidates gave complete explanations of why gravitational potential is negative for all separations, including that work is done on both masses to move them apart from each other.

Limited responses
- Almost all candidates recalled that gravitational potential is zero at infinity.

(ii) Comprehensive responses
- Many candidates wrote the correct equation and defined G as the gravitational constant.

Limited responses
- Some candidates wrote only the correct equation.

(iii) Comprehensive responses
- Many candidates wrote the correct equation in terms of Φ and R on the answer line.

Limited responses
- Some candidates gave answers in terms of other quantities.

(iv) Comprehensive responses
- Candidates drew lines with the correct general shape, correct signs and correct magnitudes.

Limited responses
- Candidates drew lines with the correct general shape only.

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Question 2

(a) **Comprehensive responses**

- Many candidates gave a complete definition of what is meant by an ideal gas.

Limited responses

- Some candidates used symbols that were not defined.

(b) (i) **Comprehensive responses**

- Candidates stated correct advantages of an ideal thermometer over a liquid-in-glass thermometer. The statement that 'an ideal gas thermometer measures absolute temperature' was the most common correct answer.

Limited responses

- Candidates incorrectly stated that ideal gas thermometers are more suitable for rapidly changing temperatures.

(ii) **Comprehensive responses**

- Candidates stated a situation where a thermocouple thermometer would be preferable over an ideal gas thermometer. The statement that 'a thermocouple thermometer can measure rapidly changing temperatures' was the most common correct answer.

Limited responses

- Candidates incorrectly stated that thermocouple thermometers are able to measure over a greater range of temperatures.

(c) **Comprehensive responses**

- Candidates calculated the sum of the squares of the speeds as their first step. This approach resulted in a correct mean square speed and correct root mean square speed (c_0). Most of these candidates gave their answers to the required three significant figures.

Limited responses

- Some candidates calculated the square of the sum of the speeds as their first step. This approach is not correct Physics.

(d) (i) **Comprehensive responses**

- Candidates gave the correct answer to two significant figures as justified by the two significant figure value for the number of molecules.

Limited responses

- Some candidates incorrectly recalled or re-arranged the starting equation.

(ii) **Comprehensive responses**

- Candidates gave the correct answer to three significant figures as justified by the three significant figure values for all the quantities used in the calculation.

Limited responses

- Some candidates did not start with the two correct starting equations.

(iii) **Comprehensive responses**

- Candidates drew lines with the correct starting point and the correct general $\sqrt{T}$ shape.

Limited responses

- Some candidates' lines became horizontal at the end or even decreased in magnitude. Sketch graphs must show the correct physical principles along the whole length of the line.
- Many candidates draw their line starting at $T = 0$. The question required candidates to draw their line showing the change in r.m.s. speed as the temperature is increased from T_0 so a line starting at $T = 0$ was not correct.

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Question 3

(a) Comprehensive responses
- Candidates gave a complete definition of what is meant by the internal energy of the system.

Limited responses
- Some candidates did not make clear that the energy was the energy of molecules. Phrases such as 'energy of the system of molecules' or 'energy in the system of molecules' were commonly used.

(b) (i) Comprehensive responses
- Candidates gave a fully correct answer with the substitution of each quantity shown clearly.

Limited responses
- A few candidates used an incorrect starting equation.

(ii) Comprehensive responses
- Candidates calculated the correct value for the internal energy and some of these candidates also correctly stated that the potential energy of molecules is zero.

Limited responses
- Many candidates calculated the mean kinetic energy of molecules.
- Many candidates stated only that the potential energy is zero.

(c) Comprehensive responses
- Most candidates were able to give at least one correct conclusion about the energy changes.

Limited responses
- Some candidates gave statements relating to changes in other quantities, such as pressure, volume or temperature.

Question 4

(a) (i) Comprehensive responses
- Candidates gave clear statements about the equal magnitudes and same directions of the two fields at point P.

Limited responses
- The statement 'equal and opposite' was not sufficient.
- Some candidates answered only in terms of the forces rather than the fields.

(ii) Comprehensive responses
- Candidates gave clear statements about the equal magnitudes and opposite signs of the two potentials at point P.

Limited responses
- The statement 'equal and opposite' was not sufficient.
- Some candidates answered only in terms of the charges rather than the potentials.

(b) (i) Comprehensive responses
- Candidates gave a fully correct answer with all numerical factors combined to show a factor of 16 in the denominator.

Limited responses
- Some candidates did not combine all numerical factors in their expression.
- Some candidates did not start with a Coulomb's law expression.

(ii) Comprehensive responses
- Candidates gave the correct answer in terms of only F and x.

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Limited responses
- Many candidates did not give an answer in terms of only F and x.

Question 5

(a) Comprehensive responses
- Candidates gave a complete definition of the capacitance of a parallel plate capacitor, in terms of charge per potential difference, with the charge on one plate and the potential difference between the two plates.

Limited responses
- The statement 'charge on a unit potential difference' is not sufficient because the ratio between charge and potential difference is not clear.
- Some candidates used the phrase 'potential difference across the plates'. This phrase is ambiguous as it could be interpreted as the potential difference between one side of a single plate and the other side of the same plate.

(b) Comprehensive responses
- Candidates started with an expression to show that charge was conserved followed by correct working through to the final answer. Some candidates also stated the important assumption that $E = V_x = V_y$.

Limited responses
- Some candidates answered in terms of C_1 and C_2 rather than C_x and C_y.

(c) Comprehensive responses
- Candidates gave a fully correct answer in the correct units to three significant figures.

Limited responses
- Most candidates were able to recall the equation for the energy stored on the capacitor.

Question 6

(a) Comprehensive responses
- Many candidates gave a complete definition for magnetic flux density.

Limited responses
- The statement 'force on a unit length on a unit current' is not sufficient.

(b) (i) Comprehensive responses
- Candidates made clear statements on the direction of the force on the particles and the direction of the current.

Limited responses
- Most candidates identified the charge as positive.

(ii) Comprehensive responses
- Candidates made a clear statement on the direction of the force on the particles (always perpendicular to the velocity) and then explained that the force causes centripetal acceleration.

Limited responses
- Some candidates answered in terms of the field rather than the force.

(c) (i) Comprehensive responses
- Many candidates gave a fully correct answer.

Limited responses
- Some candidates did not convert diameter to radius.

(ii) Comprehensive responses
- Many candidates gave a fully correct answer with the correct unit T.

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Limited responses
- Some candidates did not give the correct unit for magnetic flux density.

(d) Comprehensive responses
- Some candidates drew a circular trajectory in the correct direction with half the radius of the printed semi-circle along the whole length of the line.

Limited responses
- Most candidates drew a trajectory in the correct direction.

Question 7

(a) (i) Comprehensive responses
- Candidates gave a complete explanation of half-wave rectification, in terms of allowing current in one direction and blocking current in the other direction.

Limited responses
- A common incorrect approach was to refer to the sign of the current or potential difference.

(ii) Comprehensive responses
- Many candidates gave a complete response, which was simply a single diode connected into the circuit.

Limited responses
- Some candidates drew circuits with four diodes (full-wave rectification)
- Some candidates drew circuits with additional components and/or wires connecting the terminals. Many of these additional components and wires would prevent the circuit from working as half-wave rectification circuit.

(b) Comprehensive responses
- Candidates demonstrated a clear understanding of the effect of half-wave rectification on sinusoidal and square wave input voltages.

Limited responses
- Most candidates identified the correct r.m.s. value for the unrectified sinusoidal voltage.

Question 8

(a) Comprehensive responses
- Candidates gave a complete definition of a photon: ‘a quantum of energy of electromagnetic radiation’.

Limited responses
- Most candidates defined a photon as a packet or quantum of energy.
- Clear reference to the energy being the energy of electromagnetic radiation was required. Phrases such as ‘energy in electromagnetic radiation’ or ‘energy carried by electromagnetic radiation’ were also seen.

(b) (i) Comprehensive responses
- Most candidates stated the name of the particle correctly.

Limited responses
- Some candidates stated the name of the particle incorrectly.

(ii) Comprehensive responses
- Candidates used physics terminology accurately. Specific keywords required here were ‘deceleration’, ‘kinetic energy’ and ‘photon energy’.

Limited responses
- Some candidates used abbreviations or symbols, which were not sufficient.

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(iii) Comprehensive responses

- Candidates used physics terminology accurately. Specific keywords required here were 'kinetic energy', 'thermal energy' and 'photon energy'.

Limited responses

- This question was about energy changes during X-ray production. Many candidates described other processes in Physics such as the photoelectric effect or absorption spectra.
- Some candidates used abbreviations or symbols, which were not sufficient.

(iv) Comprehensive responses

- Many candidates gave a fully correct answer to three significant figures.

Limited responses

- Some candidates did not convert eV to J.

(c) Comprehensive responses

- Candidates used the correct name of the property (either attenuation or absorption co-efficient) and then linked good contrast to very different transmitted intensities.

Limited responses

- A common incorrect property was density and / or acoustic impedance.
- A common incorrect process was partial reflections at boundaries.

Question 9

(a) Comprehensive responses

- Many candidates gave a complete definition of the mass defect of a nucleus

Limited responses

- The words nucleus, nuclei, nucleons, nucleon, neutron, neutrons, neutrino are similar. Any misspelling introduces ambiguity or contradiction into a candidate's answer.

(b) (i) Comprehensive responses

- Candidates used their knowledge from the relevant AS topic to determine the products of alpha, beta-minus and beta-plus decay of Th-228 and recognised that the total mass defect must increase for a nuclear decay to occur.

Limited responses

- Most candidates identified that alpha decay of Th-228 produces Ra-224.

(ii) Comprehensive responses

- Many candidates used the correct starting equation, values given in the Table 9.1, and values of constants given on the formula sheet, to determine the correct value of the energy in MeV.

Limited responses

- Most candidates identified the correct starting equation.
- Some candidates used values of constants different from those given on the formula sheet.

Question 10

(a) Comprehensive responses

- Candidates gave complete statements of Wien's displacement law, including the additional details required for temperature and wavelength.

Limited responses

- Most candidates stated that wavelength was inversely proportional to temperature.
- Some candidates gave equations without defining symbols.

(b) (i) Comprehensive responses

- Many candidates gave fully correct answers to three significant figures.

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Limited responses

- Some candidates used the distance between the Earth and Sun in their calculations rather than the radius of the Sun.

(ii) Comprehensive responses

- Many candidates gave fully correct answers to three significant figures with unit W m^{-2}.

Limited responses

- Some candidates used the radius of the Sun in their calculations rather than the distance between the Earth and Sun.

(iii) Comprehensive responses

- Candidates recalled the equation of Wien's displacement law, re-arranged the equation correctly and substituted the value of wavelength given. Candidates gave their answer to three significant figures.

Limited responses

- Most candidates could recall the equation for Wien's displacement law.

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PHYSICS

Paper 9702/42
A Level Structured Questions

Key messages

What candidates did well

- Candidates generally read the questions carefully and attempted to provide answers to the questions asked.
- Candidates generally knew the equations of the syllabus well and were often successful in the calculation questions. Even candidates that did not reach the correct final answers were able to demonstrate knowledge of the correct starting equations, by setting out their working clearly.
- Candidates generally answered the questions involving graph work well.

What candidates needed to improve

- Responses were not always provided for every question part.
- When answering questions asking for the definition of a quantity, candidates need to take care to offer a definition that is dimensionally correct and that does not conflate quantities with units.
- When deciding how many significant figures to present a numerical answer to, candidates need to consider carefully the precision of the data in the question and take care to avoid presenting a final answer to a precision that is less than that justified by the data.
- When dealing with quantities where the sign is meaningful, candidates need to take more care over the sign that is used. This is particularly important when dealing with energy transfers in questions involving thermodynamics and questions involving charge and electric potential.
- When providing descriptive answers, candidates need to use the technical language of the syllabus accurately and to take care to avoid contradicting themselves.

Comments on specific questions

Question 1

(a) Comprehensive responses

- Candidates gave clear descriptions of how velocity and acceleration relate to each other in uniform circular motion.
- Candidates used the words ‘magnitude’ and ‘direction’ accurately in describing the aspects of velocity and acceleration that they were considering in the point being made.

Limited responses

- Candidates may have discussed only one of velocity and acceleration and not both.
- Candidates discussing force and speed needed to focus their responses on answering the question asked, about velocity and acceleration.
- Candidates discussing which aspects were changing and which aspects were constant needed to be clearer as to whether they were considering magnitude or direction.

(b) (i) Comprehensive responses

- Candidates gave clear explanations of the role of the horizontal and vertical components of the lift force in order to explain why the lift force needed to be at the angle shown.

Limited responses

- Candidates may have discussed only one component of the lift force.

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- Some candidates thought that a component of the weight of the aircraft causes the centripetal acceleration.
- Some candidates gave responses in terms of the resultant force acting on the aircraft rather than in terms of the two forces acting on the aircraft, the lift and the weight.
- Some candidates thought that there was a normal contact force acting on the aircraft.

(ii) Comprehensive responses

- Candidates drew an arrow from the aircraft in the correct direction.

Limited responses

- Candidates that drew more than one arrow needed to use labelling to make clear which one was the arrow that was the intended answer to this question.

(iii) Comprehensive responses

- Candidates obtained the correct answer.

Limited responses

- Candidates often gave a correct version of the starting equation even if they were unable to complete the calculation correctly.

(iv) Comprehensive responses

- Candidates obtained the correct answer.
- Candidates explained clearly the algebra leading to the equation used to determine the angle.

Limited responses

- Some candidates gave a correct explanation. The algebra was not always correct.
- Some candidates confused the horizontal and vertical components of the weight.

Question 2

(a) (i) Comprehensive responses

- Candidates gave the correct definition of gravitational field.

Limited responses

- Some candidates gave responses that were not the definition of a quantity.
- Some candidates gave definitions that were of a quantity that had dimensions of force rather than of force per unit mass.

(ii) Comprehensive responses

- Candidates drew clear diagrams of four vertical equally spaced lines with arrows pointing downwards.

Limited responses

- Candidates needed to take care over the quality of their diagrams to make sure that the lines were straight, the lines were vertical and that the lines were evenly spaced.
- Candidates that drew diagrams where these features were not clear usually indicated the correct downwards direction.

(b) (i) Comprehensive responses

- Candidates obtained the correct answer and expressed it the three-significant-figure precision required.

Limited responses

- Candidates usually gave the correct starting equation.
- Some candidates used a value for the Earth's gravitational field strength that was to a lower precision than the three significant figure value provided on the data page of the question paper; this was required to produce the correct three significant figure answer.
- Some candidates performed the calculation correctly, with the answer then given to a precision other than that specified in the question.

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(ii) Comprehensive responses

- Candidates obtained the correct value for the gravitational potential and gave it with the correct unit.

Limited responses

- Candidates usually calculated the correct magnitude for the answer or provided working that led to it.
- Some candidates presented their answers to a different precision from the one required in the question.
- Some candidates gave answers that were not negative.
- Some candidates did not give the correct unit for gravitational potential with their answers.

(iii) Comprehensive responses

- Candidates obtained the correct answer.

Limited responses

- Some candidates correctly calculated the magnitude of the answer. The sign of gravitational potential energy was not always included when presenting the answer.
- Many candidates used an incorrect value for the radius of the orbit of the satellite, either the radius of the Earth or the height of the satellite above the surface of the Earth.

Question 3

(a) Comprehensive responses

- Candidates gave the correct definition of specific latent heat capacity.

Limited responses

- Candidates usually realised that specific heat capacity relates to a change of temperature.
- Candidates needed to be clear that the transfer of energy that specific heat capacity relates to is the transfer of thermal energy.
- Candidates needed to be clear that the numerical quantity is a thermal energy per unit mass per unit change in temperature.
- Some candidates gave definitions of a quantity that would have dimensions of energy rather than of energy per unit mass per unit temperature change.
- Some candidates confused the definition of the quantity with its units.

(b) (i) Comprehensive responses

- Candidates correctly used the equation $W = p\Delta V$ and showed the full substitution of the relevant data in the question into this equation to calculate the required answer.

Limited responses

- Candidates usually knew the correct starting equation. Some responses did not include one or more stages in the working required to show the answer.

(ii) Comprehensive responses

- Candidates correctly determined that the work done on the gas is positive and explained this in terms of the volume of the gas decreasing.

Limited responses

- Some candidates correctly stated the sign of the work done on the gas, with the explanation requested in the question not always included.

(iii) Comprehensive responses

- Candidates deduced the correct proportionality link between volume and internal energy and used it to explain quantitatively the increase in internal energy of the gas.

Limited responses

- Some candidates gave a qualitative description of why the internal energy decreases, with explanation of the magnitude of the change requested in the question not always included.

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- Some candidates attempted to use first law ideas to give an explanation in terms of work done on the gas and thermal energy transferred to it. The information provided was not sufficient to consider thermal energy transfer at this stage.

(v) Comprehensive responses

- Candidates obtained the correct answer.

Limited responses

- Some candidates were able to correctly determine the change in temperature in the process even if they then made other mistakes in using the specific heat capacity equation.
- Some candidates used either the mass of one molecule or the number of molecules for the mass of the gas in the specific heat capacity calculation.

(c) Comprehensive responses

- Candidates made the correct points in respect of each of the three terms involved in the first law of thermodynamics leading to the correct conclusion.

Limited responses

- Candidates were usually able to reason that no change of volume meant that the work done on the gas during the re-heating process is zero.
- Candidates needed to realise that the change in internal energy for both processes is the same because the change in temperature is the same.
- Many candidates were confused about the effect of work done during the cooling process on the thermal energy transfer, thinking that it reduced rather than increased the need for transfer of thermal energy.
- Some candidates thought that the specific heat capacity relates to change of internal energy rather than transfer of thermal energy.

Question 4

(a) Comprehensive responses

- Candidates correctly stated the two assumptions of the kinetic theory that relate to collisions of particles.

Limited responses

- Some candidates gave assumptions of the kinetic theory that were not the ones that relate to collisions involving particles.

(b) (i) Comprehensive responses

- Candidates gave the correct expression.

Limited responses

- Some candidates omitted the factor of 2 that comes from the momentum being reversed.
- Some candidates used symbols other than the ones required by the question.

(ii) Comprehensive responses

- Candidates gave the correct expression.

Limited responses

- Some candidates omitted the factor of 2 that comes from the particle needing to transit two side lengths of the cube to get back to the same face.
- Some candidates used symbols other than the ones required by the question.

(iii) Comprehensive responses

- Candidates gave the correct expression.

Limited responses

- Some candidates either did not simplify their expression or used symbols other than the ones required by the question.

(iv) Comprehensive responses

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- Candidates gave the correct expression and correctly explained how they went from considering the force exerted on the particle by the wall to the force exerted on the wall by the particle.

Limited responses

- Some candidates either did not simplify their expression or used symbols other than the ones required by the question.
- Many candidates needed to explain how Newton's third law is involved in progressing from part **(b)(iii)** to part **(b)(iv)**.

(iv) Comprehensive responses

- Candidates gave clear explanations of the three principles of physics involved in going from the single particle moving in one dimension to all the particles moving in all three dimensions.

Limited responses

- Many candidates needed to realise that presenting a list of unexplained algebraic expressions does not constitute an explanation.
- Candidates needed to set out clearly the effects on the equation of moving from a cube of side length L to a gas of volume V, from consideration of one particle to N particles, and from one particle moving with speed u in one dimension to many particles moving at r.m.s. speed $\sqrt{<c2>}$ in three dimensions.
- Candidates needed to use the correct technical terminology in their explanations.

Question 5

(a) (i) Comprehensive responses

- Candidates correctly showed the working substituted into $\omega = 2\pi / T$ to show the required value for angular frequency.

Limited responses

- Candidates that chose to break the reasoning down into multiple stages needed to be careful to make sure they showed the full substitution at each stage of the reasoning.

(ii) Comprehensive responses

- Candidates gave the correct definition of amplitude.

Limited responses

- Some candidates gave responses in terms of distance travelled rather than displacement.
- Some candidates omitted the zero reference for the displacement, from the equilibrium position.

(iii) Comprehensive responses

- Candidates obtained the correct answer.

Limited responses

- Many candidates gave the correct starting equation.
- Some candidates omitted one or both two SI prefix conversions when substituting the values of total energy and mass into the starting equation.

(b) Comprehensive responses

- Candidates drew accurate curves and indicated a consistent scale on the x-axis consistent with the intercepts of the end points of their curves with the x-axis and their amplitude value in **(a)(iii)**.

Limited responses

- Some candidates drew curves with the peaks at the incorrect value of the energy of the oscillations.

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- Many candidates either omitted to add the scale to the *x*-axis or overlooked the 10^{-3} factor included in the unit in the axis label, or omitted the minus signs on one or more of the scale markings in the negative *x* region.

Question 6

(a) Comprehensive responses

- Candidates gave the correct definition of electric potential.

Limited responses

- Candidates needed to make the dimensions of electric potential, as the ratio of work done and charge, clear.
- Candidates needed to correctly establish the sign convention for electric potential in the doing of work to move positive charge from infinity to the point.

(b) (i) Comprehensive responses

- Candidates obtained the correct answer and gave the correct meaning for ε_0.

Limited responses

- Some candidates gave the correct expression. The meaning of ε_0 was not always stated correctly.

(ii) Comprehensive responses

- Candidates drew an accurate curve in the correct part of the graph, with the correct curvature and passing through the correct key points.

Limited responses

- Many candidates realised that the potential due to a positive charge will be positive throughout.
- Many candidates knew that the curve starts at (R, V_0) and shows decreasing potential as distance from the centre increases.
- Candidates needed to be careful to show the potential at $x = 3R$ as $V_0 / 3$ and not $V_0 / 4$.

(c) (i) Comprehensive responses

- Candidates obtained the correct answer and presented it to an appropriate precision.

Limited responses

- Candidates were usually able to substitute the correct values of ε0 and radius into the equation for electric potential.
- Some candidates omitted the unit conversion from cm to m when substituting the radius value.
- Candidates needed to realise, when presenting their answers, that the precision of the data in the question justifies a 3 significant figure answer.
- Candidates needed to realise that the fact that the electric potential is negative means that the charge on the sphere must also be negative.

(ii) Comprehensive responses

- Candidates explained that the fact that the dome stores charge or energy means that it is behaving as a capacitor.

Limited responses

- Some candidates confused the concepts of potential and potential energy.

(iii) Comprehensive responses

- Candidates obtained the correct answer and presented it with a correct unit to an appropriate precision.

Limited responses

- Candidates usually knew the starting equation for capacitance in terms of charge and potential.
- Candidates needed to realise that the precision of the data in the question warrants a 3 significant figure answer.

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(iv) Comprehensive responses

- Candidates obtained the correct answer.

Limited responses

- Many candidates knew the correct equation for energy stored by a capacitor. Some responses referred instead to the potential energy between two-point charges.

Question 7

(a) (i) Comprehensive responses

- Candidates identified the correct two faces.

Limited responses

- Candidates needed to identify faces PSZW and QRYX.

(ii) Comprehensive responses

- Candidates identified the meanings of the three symbols correctly.

Limited responses

- Candidates identified some of the symbols correctly.

(b) (i) Comprehensive responses

- Candidates gave a full explanation of how the Hall voltage is formed.
- Candidates used technical terminology accurately.

Limited responses

- Many candidates were able to explain that charge carriers deflect to one face due to the magnetic field and there is an accumulation of charge on that face.
- Candidates needed to be clearer in their discussion of forces acting as to why the deflection of the charge carriers occurs.
- Candidates needed to be clearer that a charge separation between opposite faces results in a potential difference being created between those faces.
- Some candidates confused the process of the creation of the Hall voltage with electromagnetic induction.

(ii) Comprehensive responses

- Some candidates gave a correct explanation of which face is at the higher potential based on the type of charge carrier being considered.

Limited responses

- Some candidates correctly deduced that the deflection of the charge carriers is towards face QRYX, with a conclusion about whether QRYX or PSZW is at the higher potential, consistent with the sign of the charge carriers being considered, not always included.

Question 8

(a) (i) Comprehensive responses

- Candidates identified the correct component.

Limited responses

- Some candidates identified a type of circuit rather than a circuit component.
- Some candidates mixed up the role of the diode and the role of the capacitor in rectification and smoothing.

(ii) Comprehensive responses

- Candidates identified the correct component.

Limited responses

- Some candidates confused the component capacitor with the quantity capacitance.

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- Some candidates mixed up the role of the diode and the role of the capacitor in rectification and smoothing.

(b) (i) Comprehensive responses

- Candidates obtained the correct answer.

Limited responses

- Some candidates misread the scale to conclude a peak p.d. of 4.0 V.
- Some candidates read off the correct peak p.d. The value was then used to calculate an r.m.s. value.

(ii) Comprehensive responses

- Most candidates obtained the correct answer.

Limited responses

- Some candidates correctly read off the period from the graph. The value was then converted into a frequency or angular frequency.

(c) Comprehensive responses

- Candidates identified three correct conclusions that can be made from the graphs.
- Candidates correctly calculated numerical quantities to an appropriate precision and gave the answer with a correct unit.

Limited responses

- Some candidates gave points that were simply direct read-offs from, or descriptions of, the graphs, without doing something further with that information.
- Some candidates identified quantities from which conclusions could be drawn, with the calculation not always correct or the answer not always presented with the correct unit.
- Some candidates calculated correct values, with the quantity being calculated not always identified sufficiently.

Question 9

(a) Comprehensive responses

- Candidates correctly stated the meaning of the de Broglie wavelength.

Limited responses

- Some candidates gave an equation for calculating de Broglie wavelength, without answering the question about what the term means.

(b) Comprehensive responses

- Candidates correctly identified a piece of experimental evidence for each of the four natures asked for in the question.

Limited responses

- Most candidates identified correct evidence for one or two of the natures asked for. Completion of the full set of four responses was less common.
- Some candidates were confused between identifying the evidence and outlining the theory for each of the four natures.
- Many candidates gave responses that were a vague reference to a phenomenon rather than identifying actual evidence that may be seen (for example, stating merely ‘diffraction’ for either of the wave natures, without clarifying that evidence for the wave nature of matter is electron diffraction whereas evidence for the wave nature of electromagnetic radiation could be diffraction in light).

(c) (i) Comprehensive responses

- Candidates obtained the correct answer.

Limited responses

- Some candidates identified the correct starting equation, with the mass of a proton then used in the calculation rather than the mass of an electron.

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(ii) Comprehensive responses

- Candidates obtained the correct answer.

Limited responses

- Many candidates who did not obtain the correct answer in **(c)(i)** were nevertheless able to answer this question correctly using their value from the previous part.
- Some candidates identified the correct starting equation, with the speed of light then used in the calculation rather than the answer in **(c)(i)**.

Question 10

(a) Comprehensive responses

- Candidates gave the correct definition of binding energy of a nucleus, taking care with their use of the technical terms involved.

Limited responses

- Many candidates knew that binding energy is the energy needed to separate the components of the nucleus. Use of the term ‘nuclei’ instead of ‘nucleons’ was commonly seen when referring to those components.
- Candidates needed to be clearer about the role of ‘infinity’ in the definition, in that the energy required is that to separate the nucleons to infinite separation. Many candidates gave responses that conveyed that the whole process was taking place ‘at infinity’.

(b) (i) Comprehensive responses

- Candidates identified the correct particle.

Limited responses

- Some candidates did identify the correct particle, with an additional particle also identified in the response.

(ii) Comprehensive responses

- Candidates used the equation E = Δmc2 correctly and showed the relevant data from the question paper substituted into it to show the required energy value.

Limited responses

- Many candidates knew the correct starting equation.
- Candidates needed to make sure the value of the unified atomic mass constant was correctly shown in the substitution.
- Some candidates omitted to square the value of the speed of light in the substitution.

(c) (i) Comprehensive responses

- Candidates obtained the correct answer to the appropriate precision.

Limited responses

- Many candidates stated the correct starting equation, with the distance not always squared when carrying out the calculation.
- Some candidates carried out the calculation correctly, with the answer not always given to three significant figures, consistent with the three significant figure data provided in the question.

(ii) Comprehensive responses

- Candidates obtained the correct answer.

Limited responses

- Some candidates broke down their reasoning into clear steps and explained what they were calculating in each step.

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PHYSICS

Paper 9702/43
A Level Structured Questions

Key messages

What candidates did well
- Many candidates showed all steps in calculations.
- Many candidates were able to recall syllabus definitions accurately.

What candidates needed to improve
- Questions requiring explanations of physical processes (for example, production of X-rays, changes in total mass defect during nuclear radiation) were often not answered with the required detail.
- Candidates need to ensure that any graphs drawn are complete and demonstrate the correct physical principles along the whole length of the line.
- Candidates always need to work to an appropriate number of significant figures. The appropriate number of significant figures in calculation is very often three significant figures.

Comments on specific questions

Question 1

(a) Comprehensive responses
- Many candidates gave complete definitions of gravitational potential.

Limited responses
- Some candidates did not make the ratio clear. The statement 'work done on a unit mass' is not sufficient because the ratio between work done and mass is not clear.

(b)(i) Comprehensive responses
- Candidates gave complete explanations of why gravitational potential is negative for all separations, including that work is done on both masses to move them apart from each other.

Limited responses
- Many candidates recalled that gravitational potential is zero at infinity.

(ii) Comprehensive responses
- Many candidates wrote the correct equation and defined G as the gravitational constant.

Limited responses
- Some candidates wrote only the correct equation.

(iii) Comprehensive responses
- Many candidates wrote the correct equation in terms of Φ and R on the answer line.

Limited responses
- Some candidates gave answers in terms of other quantities.

(iv) Comprehensive responses
- Candidates drew lines with the correct general shape, correct signs and correct magnitudes.

Limited responses

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- Candidates drew lines with the correct general shape only.

Question 2

(a) Comprehensive responses

- Many candidates gave a complete definition of what is meant by an ideal gas.

Limited responses

- Some candidates used symbols that were not defined.

(b) (i) Comprehensive responses

- Candidates stated correct advantages of an ideal thermometer over a liquid-in-glass thermometer. The statement that 'an ideal gas thermometer measures absolute temperature' was the most common correct answer.

Limited responses

- Candidates incorrectly stated that ideal gas thermometers are more suitable for rapidly changing temperatures.

(ii) Comprehensive responses

- Candidates stated a situation where a thermocouple thermometer would be preferable over an ideal gas thermometer. The statement that 'a thermocouple thermometer can measure rapidly changing temperatures' was the most common correct answer.

Limited responses

- Candidates incorrectly stated that thermocouple thermometers are able to measure over a greater range of temperatures.

(c) Comprehensive responses

- Candidates calculated the sum of the squares of the speeds as their first step. This approach resulted in a correct mean square speed and correct root mean square speed (c_0). Most of these candidates gave their answers to the required three significant figures.

Limited responses

- Some candidates calculated the square of the sum of the speeds as their first step. This approach is not correct physics.

(d) (i) Comprehensive responses

- Candidates gave the correct answer to two significant figures as justified by the two significant figure value for the number of molecules.

Limited responses

- Some candidates incorrectly recalled or re-arranged the starting equation.

(ii) Comprehensive responses

- Candidates gave the correct answer to three significant figures as justified by the three significant figure values for all the quantities used in the calculation.

Limited responses

- Some candidates did not start with the two correct starting equations.

(iii) Comprehensive responses

- Candidates drew lines with the correct starting point and the correct general $\sqrt{T}$ shape.

Limited responses

- Some candidates' lines became horizontal at the end or even decreased in magnitude. Sketch graphs must show the correct physical principles along the whole length of the line.
- Many candidates drew their line starting at $T = 0$. The question required candidates to draw their line showing the change in r.m.s. speed as the temperature is increased from T_0, so a line starting at $T = 0$ was not correct.

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Question 3

(a) Comprehensive responses
- Candidates gave a complete definition of what is meant by the internal energy of the system.

Limited responses
- Some candidates did not make clear that the energy was the energy of molecules. Phrases such as 'energy of the system of molecules' or 'energy in the system of molecules' were commonly used.

(b) (i) Comprehensive responses
- Candidates gave a fully correct answer with the substitution of each quantity shown clearly.

Limited responses
- A few candidates used an incorrect starting equation.

(ii) Comprehensive responses
- Candidates calculated the correct value for the internal energy and some of these candidates also correctly stated that the potential energy of molecules is zero.

Limited responses
- Many candidates calculated the mean kinetic energy of molecules.
- Many candidates stated only that the potential energy is zero.

(c) Comprehensive responses
- Most candidates were able to give at least one correct conclusion about the energy changes.

Limited responses
- Some candidates gave statements relating to changes in other quantities, such as pressure, volume or temperature.

Question 4

(a) (i) Comprehensive responses
- Candidates gave clear statements about the equal magnitudes and same directions of the two fields at point P.

Limited responses
- The statement 'equal and opposite' was not sufficient.
- Some candidates answered only in terms of the forces rather than the fields.

(ii) Comprehensive responses
- Candidates gave clear statements about the equal magnitudes and opposite signs of the two potentials at point P.

Limited responses
- The statement 'equal and opposite' was not sufficient.
- Some candidates answered only in terms of the charges rather than the potentials.

(b) (i) Comprehensive responses
- Candidates gave a fully correct answer with all numerical factors combined to show a factor of 16 in the denominator.

Limited responses
- Some candidates did not combine all numerical factors in their expression.
- Some candidates did not start with a Coulomb's law expression.

(ii) Comprehensive responses
- Candidates gave the correct answer in terms of only F and x.

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Limited responses

- Many candidates did not give an answer in terms of only *F* and *x*.

Question 5

(a) Comprehensive responses

- Candidates gave a complete definition of the capacitance of a parallel plate capacitor, in terms of charge per potential difference, with the charge on one plate and the potential difference between the two plates.

Limited responses

- The statement 'charge on a unit potential difference' is not sufficient because the ratio between charge and potential difference is not clear.
- Some candidates used the phrase 'potential difference across the plates'. This phrase is ambiguous as it could be interpreted as the potential difference between one side of a single plate and the other side of the same plate.

(b) Comprehensive responses

- Candidates started with an expression to show that charge was conserved followed by correct working through to the final answer. Some candidates also stated the important assumption that $V_x = V_y$.

Limited responses

- Some candidates answered in terms of C_1 and C_2 rather than C_x and C_y.

(c) Comprehensive responses

- Candidates gave a fully correct answer in the correct units to three significant figures.

Limited responses

- Most candidates were able to recall the equation for the energy stored on the capacitor.

Question 6

(a) Comprehensive responses

- Many candidates gave a complete definition for magnetic flux density.

Limited responses

- The statement 'force on a unit length on a unit current' is not sufficient.

(b) (i) Comprehensive responses

- Candidates made clear statements on the direction of the force on the particles and the direction of the current.

Limited responses

- Most candidates identified the charge as positive.

(ii) Comprehensive responses

- Candidates made a clear statement on the direction of the force on the particles (always perpendicular to the velocity) and then explained that the force causes centripetal acceleration.

Limited responses

- Some candidates answered in terms of the field rather than the force.

(c) (i) Comprehensive responses

- Many candidates gave a fully correct answer.

Limited responses

- Some candidates did not convert diameter to radius.

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(ii) Comprehensive responses

- Many candidates gave a fully correct answer with the correct unit T.

Limited responses

- Some candidates did not give the correct unit for magnetic flux density.

(d) Comprehensive responses

- Some candidates drew a circular trajectory in the correct direction with half the radius of the printed semi-circle along the whole length of the line.

Limited responses

- Most candidates drew a trajectory in the correct direction.

Question 7

(a) (i) Comprehensive responses

- Candidates gave a complete explanation of half-wave rectification, in terms of allowing current in one direction and blocking current in the other direction.

Limited responses

- A common incorrect approach was to refer to the sign of the current or potential difference.

(ii) Comprehensive responses

- Many candidates gave a complete response, which was simply a single diode connected into the circuit.

Limited responses

- Some candidates drew circuits with four diodes (full-wave rectification)
- Some candidates drew circuits with additional components and/or wires connecting the terminals. Many of these additional components and wires would prevent the circuit from working as a half-wave rectification circuit.

(b) Comprehensive responses

- Candidates demonstrated a clear understanding of the effect of half-wave rectification on sinusoidal and square wave input voltages.

Limited responses

- Most candidates identified the correct r.m.s. value for the unrectified sinusoidal voltage.

Question 8

(a) Comprehensive responses

- Candidates gave a complete definition of a photon: ‘a quantum of energy of electromagnetic radiation’.

Limited responses

- Most candidates defined a photon as a packet or quantum of energy.
- Clear reference to the energy being the energy of electromagnetic radiation was required. Phrases such as ‘energy in electromagnetic radiation’ or ‘energy carried by electromagnetic radiation’ were also seen.

(b) (i) Comprehensive responses

- Most candidates stated the name of the particle correctly.

Limited responses

- Some candidates stated the name of the particle incorrectly.

(ii) Comprehensive responses

- Candidates used physics terminology accurately. Specific keywords required here were ‘deceleration’, ‘kinetic energy’ and ‘photon energy’.

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Limited responses
- Some candidates used abbreviations or symbols, which were not sufficient.

(iii) Comprehensive responses
- Candidates used physics terminology accurately. Specific keywords required here were 'kinetic energy', 'thermal energy' and 'photon energy'.

Limited responses
- This question was about energy changes during X-ray production. Many candidates described other processes in Physics such as the photoelectric effect or absorption spectra.
- Some candidates used abbreviations or symbols, which were not sufficient.

(iv) Comprehensive responses
- Many candidates gave a fully correct answer to three significant figures.

Limited responses
- Some candidates did not convert eV to J.

(c) Comprehensive responses
- Candidates used the correct name of the property (either attenuation or absorption co-efficient) and then linked good contrast to very different transmitted intensities.

Limited responses
- A common incorrect property was density and / or acoustic impedance.
- A common incorrect process was partial reflections at boundaries.

Question 9

(a) Comprehensive responses
- Many candidates gave a complete definition of the mass defect of a nucleus.

Limited responses
- The words nucleus, nuclei, nucleons, nucleon, neutron, neutrons, neutrino are similar. Any misspelling introduces ambiguity or contradiction into a candidate's answer.

(b) (i) Comprehensive responses
- Candidates used their knowledge from the relevant AS topic to determine the products of alpha, beta-minus and beta-plus decay of Th-228 and recognised that the total mass defect must increase for a nuclear decay to occur.

Limited responses
- Most candidates identified that alpha decay of Th-228 produces Ra-224.

(ii) Comprehensive responses
- Many candidates used the correct starting equation, values given in the Table 9.1, and values of constants given on the formula sheet, to determine the correct value of the energy in MeV.

Limited responses
- Most candidates identified the correct starting equation.
- Some candidates used values of constants different from those given on the formula sheet.

Question 10

(a) Comprehensive responses
- Candidates gave complete statements of Wien's displacement law, including the additional details required for temperature and wavelength.

Limited responses
- Most candidates stated that wavelength was inversely proportional to temperature.
- Some candidates gave equations without defining symbols.

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(b) (i) Comprehensive responses

- Many candidates gave fully correct answers to three significant figures.

Limited responses

- Some candidates used the distance between the Earth and Sun in their calculations rather than the radius of the Sun.

(ii) Comprehensive responses

- Many candidates gave fully correct answers to three significant figures with unit W m^{-2}.

Limited responses

- Some candidates used the radius of the Sun in their calculations rather than the distance between the Earth and Sun.

(iii) Comprehensive responses

- Candidates recalled the equation of Wien's displacement law, re-arranged the equation correctly and substituted the value of wavelength given. Candidates gave their answer to three significant figures.

Limited responses

- Most candidates could recall the equation for Wien's displacement law.

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PHYSICS

Paper 9702/44
A Level Structured Questions

Key messages

What candidates did well

- Candidates generally provided responses to all question-parts in the paper, with few cases where there were question-parts left blank.
- Candidates generally read the questions carefully and attempted to provide answers to the questions asked.
- Candidates generally knew the equations of the syllabus well and were often successful in the calculation questions. Candidates that did not reach the correct final answers were able to demonstrate knowledge of the correct starting equations, by setting out their working clearly.
- Key principles and concepts in the syllabus were generally well-known, with many candidates providing correct answers to the questions asking for statements of laws, definitions of quantities and the meanings of concepts.

What candidates needed to improve

- When deciding how many significant figures should be given in a numerical answer, candidates need to consider carefully the precision of the data in the question and take care to avoid presenting a final answer to a precision that is less than that justified by the data.
- When providing descriptive answers, candidates need to use the technical language of the syllabus accurately and to take care to avoid contradicting themselves. They also need to ensure that all aspects of the question have been addressed.
- When drawing sketches and graphs, candidates need to use a sharp pencil so that the widths of the lines drawn do not make the intended value unclear and so that mistakes can be erased and corrected. Also, when straight lines are required, candidates need to use a ruler or straight edge.
- When answering questions involving several stages and more than one equation, candidates need to show all the equations clearly at the point where they have been used. This is especially true in 'show that' questions.
- Candidates need to read questions carefully to avoid giving an answer which is not in the form required (for example in terms of another quantity) or omitting an explanation which is required.

Comments on specific questions

Question 1

(a) Comprehensive responses

- Most candidates addressed both aspects of the answer correctly.

Limited responses

- Some candidates did not make it clear that the force is proportional to the product of the charges or that it is inversely proportional to the square of the separation.
- A few candidates confused Coulomb's law with Newton's law of gravitation.

(b) (i) Comprehensive responses

- Most candidates provided an answer with the full substitution of quantity values as required by a 'show that' question.

Limited responses

- Some candidates did not substitute a value for ε_0.

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(ii) Comprehensive responses

- Many candidates gave the correct answer with an appropriate number of significant figures.

Limited responses

- Some candidates gave the numerical answer with too few significant figures for the information provided in the question having used the correct method.

(iii) Comprehensive responses

- Most candidates gave the correct answer with an appropriate number of significant figures including those involving an error carried forward from **1(b)(ii)** for an incorrect value for the force.

Limited responses

- Some candidates gave the numerical answer with too few significant figures for the information provided in the question having used the correct method.
- A few candidates used an incorrect value for the mass of an electron.

(iv) Comprehensive responses

- Most candidates gave the correct starting equations and the correct answer with an appropriate number of significant figures including those involving an error carried forward from **1(b)(iii)** for an incorrect value for the acceleration.

Limited responses

- Some candidates gave the numerical answer with too few significant figures for the information provided in the question having used the correct method.
- A few candidates did not identify appropriate starting equations.

(c) Comprehensive responses

- Some candidates recognised that the radius of the orbit must decrease if the potential energy decreases and then completed the remainder of the table correctly.

Limited responses

- Some candidates did not recognise that the potential energy decreasing (becoming more negative) meant the magnitude of its value increased. As a result, they incorrectly concluded that the radius of the orbit increases, and therefore the remainder of the table was also completed incorrectly.
- Other candidates gave incorrect answers for one or more of the changes which did not seem to be consistent with each other.

Question 2

(a) (i) Comprehensive responses

- Few candidates correctly answered the question by stating that the satellite remains above the same point on Earth's surface or equator.

Limited responses

- Some candidates used the word 'stationary' to define 'geostationary'.
- Many candidates stated one or more properties of a geostationary orbit without explaining the meaning (that is, responses appropriate to **2(a)(ii)**).

(ii) Comprehensive responses

- Many candidates stated two properties correctly.

Limited responses

- Some candidates did not distinguish between Earth's orbit and its rotation/spin, so their answers could be interpreted as the period of the satellite's orbit was the same as the period of Earth's orbit.
- Some candidates stated that the satellite orbits from east to west.

(b) (i) Comprehensive responses

- Most candidates gave the correct expression.

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Limited responses

- A few candidates gave incorrect expressions including $v = R / T$ and $\pi R / T$.

(ii) Comprehensive responses

- Most candidates provided a correct expression equating the gravitational force with the centripetal force.
- Many candidates clearly showed the substitution of $2\pi / T$ for ω or $2\pi R / T$ for v.

Limited responses

- Some candidates did not make use of Newton's law of gravitation.
- Many candidates did not clearly show the substitution of $2\pi / T$ for ω or $2\pi R / T$ for v, by carrying out multiple manipulations in one stage.

(c) Comprehensive responses

- Most candidates used the correct expression for the volume of a sphere and the correct value for the radius of Earth to obtain the volume of Earth.
- Many candidates used the expression from **2(b)(ii)** to correctly determine the mass of Earth.
- Almost all candidates provided the correct expression for density, either explicitly or by implication from the substitution of mass and volume quantities.

Limited responses

- Many candidates substituted the height of the orbit for its radius in the expression from **2(b)(ii)**, which was therefore wrong physics and so not allowing error carried forward for the value of the density of Earth.
- Some candidates used an incorrect expression for the volume of a sphere, which was therefore wrong physics and so not allowing error carried forward for the value of the density of Earth.
- Many candidates obtained an incorrect value for the density by using rounded values for the mass and volume.

Question 3

(a) Comprehensive responses

- Most candidates correctly answered the question.

Limited responses

- Some candidates referred to 'energy' rather than 'thermal energy'.
- Some candidates stated that there was no thermal energy transfer rather than no net/overall thermal energy transfer.
- Some candidates used the word 'transform' instead of 'transfer'.

(b) (i) Comprehensive responses

- Most candidates stated that thermal energy was transferred to the thermistor.
- Many candidates stated that the thermal energy was transferred from the water resulting in the temperature of the water decreasing.

Limited responses

- Some candidates stated that thermal energy was transferred to the surroundings.

(ii) Comprehensive responses

- Most candidates calculated the correct value of the specific heat capacity by equating the thermal energy gained by the thermistor with that lost by the water.

Limited responses

- Some candidates did not provide a correct starting equation.
- Some candidates added 273 to the temperature changes.
- Some candidates substituted incorrect temperature values for either the thermistor or the water, or both.

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(c) Comprehensive responses

- Many candidates suggested the use of a thermocouple instead of a thermistor.
- Many candidates suggested using a smaller or lower-mass thermistor.
- Many candidates suggested increasing the initial temperature of the thermistor.
- Some candidates explained that the smaller mass or the lower temperature difference would reduce the amount of thermal energy transferred from the water to the thermistor or thermocouple.

Limited responses

- Many candidates suggested using a thermistor made from a material of lower specific heat capacity without qualifying this by stating the mass should be the same or less.
- Some candidates suggested using a 'thermometer' or 'electronic thermometer' stating that this would produce a more accurate result without further valid explanation.
- Some candidates who suggested the use of a thermocouple gave incorrect explanations including the shorter response time would result in a more accurate result and that the thermocouple did not need to reach thermal equilibrium with the water.

Question 4

(a) Comprehensive responses

- Some candidates correctly answered the question.
- Some candidates provided a statement which did not specify one or more directions associated with a change in internal energy, thermal energy transfer or work done. Part of the required information was included in the response.

Limited responses

- Many candidates did not give expressions which showed clear equality and summation.
- Some candidates gave definitions of internal energy.

(b) (i) Comprehensive responses

- Most candidates gave the correct starting equation and showed a full substitution and final answer with sufficient significant figures, as required for a 'show that' question.

Limited responses

- Some candidates did not show the substitution of all the quantities, most commonly for the Boltzmann constant.
- Some candidates gave the final answer with less than three significant figures.

(ii) Comprehensive responses

- Most candidates calculated the correct value of the number of moles.

Limited responses

- Some candidates did not provide sufficient significant figures in their answers.

(iii) Comprehensive responses

- Most candidates used the correct starting equation and calculated the correct value of the kinetic energy.

Limited responses

- Some candidates did not provide a correct starting equation.
- Some candidates did not provide sufficient significant figures in their answers.

(iv) Comprehensive responses

- Most candidates correctly stated that the intermolecular forces are negligible or zero.

Limited responses

- Some candidates gave the large separation of molecules as the reason.
- Some candidates gave the low mass of a molecule as the reason.
- Some candidates just stated that the reason was that the gas is ideal.

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(v) Comprehensive responses

- Most candidates calculated a correct value for the internal energy including those involving an error carried forward from **4(b)(iii)** for an incorrect value for the average translational kinetic energy of one molecule.

Limited responses

- Some candidates gave an answer with insufficient significant figures.

(c) (i) Comprehensive responses

- Some candidates correctly stated that no work was done because there was no change in volume.
- Some candidates gave a correct expression for the thermal energy in terms of U_A.
- Few candidates provided a correct explanation and correct expression.

Limited responses

- Many candidates did not provide a clear explanation.
- Many candidates gave expressions in terms of U_A and joules or just joules.

(ii) Comprehensive responses

- Some candidates gave a clear explanation, most commonly that the internal energy at C was twice the internal energy at A.
- Some candidates gave a correct expression for the work done in terms of U_A.
- Few candidates provided a correct explanation and correct expression.

Limited responses

- Many candidates did not provide a clear explanation or correct expression.

Question 5

(a) (i) Comprehensive responses

- Most candidates drew a correct sketch graph of the variation as a loop around the origin with correct crossing points on the *v* and *x* axes.

Limited responses

- Some candidates drew straight or curved lines passing through the origin.
- Some candidates drew a loop around the origin with one or more crossing points at incorrect values.

(ii) Comprehensive responses

- Many candidates gave the correct starting equations (including those which were clarified by the substitution of values).
- Many candidates gave a full substitution of values and the answer as required for a 'show that' question.

Limited responses

- Some candidates did not clearly state both starting equations.
- Some candidates left gaps in their reasoning leading to the answer.

(b) (i) Comprehensive responses

- Most candidates gave correct statement which covered both aspects of the answer.
- Many candidates referred to 'nature frequency' of the system instead of 'natural frequency'.

Limited responses

- Some candidates referred to 'maximum displacement' instead of 'maximum amplitude'.

(ii) Comprehensive responses

- Most candidates drew a correct sketch graph of the variation of amplitude with frequency *f* from $f = 0$ to $f = 0.4$ Hz with the single peak at 0.28 Hz.

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Limited responses
- Some candidates drew sketch graphs with no peak.
- A few candidates drew sketch graphs with more than one peak.
- A few candidates drew sketch graphs which did not extend from $f = 0$ to $f = 0.4$ Hz.

Question 6

(a) (i) Comprehensive responses
- Most candidates recalled that the time constant is the product of resistance and capacitance.
- Most candidates calculated the correct value of the resistance.

Limited responses
- A few candidates obtained answers incorrect by a number of powers of ten for incorrectly recalling the meanings of either kilo, micro or both.

(ii) Comprehensive responses
- Most candidates correctly identified the discharge time for the capacitor as 2.5 s.
- Most candidates correctly substituted values into the exponential discharge equation and stated the answer as required for a 'show that' question.

Limited responses
- A few candidates substituted values incorrectly into the exponential discharge equation without checking that the required answer would be produced.
- A few candidates attempted incorrect methods and claimed the result was the required answer.

(b) Comprehensive responses
- Many candidates drew straight horizontal lines as $V_C = 1.50$ V for the times switch S was in position X.
- Many candidates drew smooth discharge curves for the times switch S was in position Y.
- Many candidates drew graphs which had minima at $V_C = 0.53$ V.
- Some candidates drew accurate sketches satisfying all the points above.

Limited responses
- Some candidates drew sinusoidal curves.
- Some candidates drew sketch graphs with $V_C = 0$ V at $t = 0$.
- Some candidates drew discharge curves which did not have continuously decreasing negative gradient either because they drew sections of a sinusoidal curve or the curve became horizontal.

(c) Comprehensive responses
- Most candidates concluded that the minimum p.d. is greater than 0.53 V.
- Many candidates explained that the discharge time was shorter.

Limited responses
- Some candidates concluded that the minimum p.d. was unchanged with the explanation that the time constant was the same.
- Some candidates stated that $e^{-t/RC}$ was smaller without explaining the reason for this.
- Some candidates stated that t was shorter without giving its meaning.

Question 7

(a) Comprehensive responses
- Most candidates stated that the direction of the current reverses.
- Some candidates explained that the direction of the current reverses regularly/periodically.

Limited responses
- Many candidates did not explain that the direction of the current reverses regularly/periodically.
- Some candidates used the term 'alternating' to define 'alternating current'.

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(b) (i) Comprehensive responses

- Some candidates drew accurate sketches correctly showing the field lines inside and outside the solenoid with arrows indicating the correct directions of the field.

Limited responses

- Many candidates attempted to draw the field lines inside the solenoid free hand, and many of these attempts did not show field lines sufficiently straight and/or parallel.
- Many candidates drew a single field line or no field lines inside the solenoid.
- Many candidates drew field lines outside the solenoid which merged or crossed each other or omitted horizontal field lines at the ends of the solenoid.

(ii) Comprehensive responses

- Most candidates correctly identified the N and S magnetic poles of the solenoid.

Limited responses

- Some candidates incorrectly identified the N and S magnetic poles of the solenoid.

(c (i) Comprehensive responses

- Most candidates gave a clear substitution of values and the answer as required for a 'show that' question.

Limited responses

- Some candidates omitted either π in their substitution or the answer.

(ii) Comprehensive responses

- Most candidates drew sinusoidal curves with the correct period and amplitude.
- Most candidates drew sinusoidal curves with the correct phase.

Limited responses

- Some candidates drew approximately sinusoidal curves with crossing points out of tolerance with regard to time, so the phase was incorrect and for some the period was also incorrect.

(d) (i) Comprehensive responses

- Most candidates calculated the correct value for the maximum flux and gave the correct unit.

Limited responses

- Some candidates substituted the radius for the area having given the correct equation.
- Some candidates omitted the number of turns from their calculation.
- Some candidates gave an incorrect unit, for example Bq or T.

(ii) Comprehensive responses

- Many candidates recognised that the maximum gradient of the curve was required.
- Very few candidates correctly explained how the maximum gradient could be obtained.
- Some candidates gave a correct expression for the maximum e.m.f. (maximum gradient × number of turns × area).
- Some candidates stated that e.m.f. is equal to rate of change of magnetic flux linkage.

Limited responses

- Many candidates stated that e.m.f. is proportional to rate of change of magnetic flux linkage.
- Some candidates incorrectly stated that e.m.f. is equal to the gradient of the graph.
- Some candidates incorrectly stated that maximum e.m.f. occurs when *B* is maximum.

Question 8

(a) (i) Comprehensive responses

- Most candidates correctly named the phenomenon as photoelectric effect/emission.

Limited responses

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- Some candidates gave the name of the phenomenon as photonelectric effect.
- Some candidates gave incorrect names including fusion, annihilation, etc.

(ii) Comprehensive responses

- Most candidates gave correct statements of the meaning of threshold frequency as the minimum frequency needed to cause emission (of electrons).

Limited responses

- Some candidates stated that the threshold frequency was the minimum frequency for the photoelectric effect to take place.
- A few candidates referred to emission of photons.
- A few candidates stated that it was the maximum frequency or the minimum wavelength.

(iii) Comprehensive responses

- A few candidates gave three valid points in their explanations.
- Some candidates stated that electrons require a minimum energy to be emitted.
- Some candidates stated that minimum photon energy means minimum frequency.
- A few candidates described a photon as a packet/quantum of energy proportional to frequency.

Limited responses

- Many candidates stated points which were true regarding the photoelectric effect that did not explain why the existence of the threshold frequency is evidence for the photon model.

(b) (i) Comprehensive responses

- Many candidates calculated the correct value for the Planck constant which would be obtained from the data provided.

Limited responses

- Many candidates attempted the question using an incorrect starting equation, either by omitting the kinetic energy or the work function term.
- Some candidates did not recall correctly the relationship between frequency and wavelength and therefore used an incorrect expression for photon energy in terms of wavelength.

(ii) Comprehensive responses

- Most candidates obtained the correct value of the work function in eV.

Limited responses

- Some candidates attempted the question using an incorrect starting equation by omitting the kinetic energy term.
- Many candidates who had obtained an incorrect value for the work function in J, correctly converted this to eV.
- Some candidates did not convert the answer from J to eV.

Question 9

(a) Comprehensive responses

- Some candidates correctly stated that an alternating potential difference applied to the piezoelectric crystal would cause it to vibrate.
- Very few candidates explained that the vibration of the crystal would cause oscillations in the external medium (that is, the production of ultrasound).

Limited responses

- Some candidates referred to an e.m.f. or current being applied.
- Many candidates only referred to the transducer and not the piezoelectric crystal within it.
- Some candidates described ultrasound distorting the crystal and generating an e.m.f.

(b) (i) Comprehensive responses

- Most candidates obtained the correct value for the specific acoustic impedance with sufficient significant figures and the correct unit.

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Limited responses

- Many candidates obtained answers with insufficient significant figures.
- Some candidates did not recall the equation for specific acoustic impedance correctly (for example, the ratio of density and speed rather than the product).

(ii) Comprehensive responses

- Some candidates drew three valid conclusions.

Limited responses

- Many candidates gave incomplete quantitative conclusions by omitting units.
- Many candidates gave values for μ which were incomplete because μ was not named as the attenuation/absorption coefficient.
- Some candidates gave conclusions which were properties of the graph rather than the structure and materials of the structure, for example gradient of the line = μ or attenuation/absorption coefficient.

Question 10

(a) (i) Comprehensive responses

- Most candidates gave a correct meaning for a standard candle as an object/star of known luminosity.

Limited responses

- Some candidates named an incorrect object, for example is a planet.
- A few candidates stated the meaning was a known luminosity.

(ii) Comprehensive responses

- Many candidates gave a correct explanation which referred to measuring the radiant flux intensity and calculating the distance using the equation $F = L / 4\pi d^2$.

Limited responses

- A significant number of candidates incorrectly named the measured quantity as radiant flux density.
- Some candidates did not make a distinction between measuring and calculating quantities.

(b) (i) Comprehensive responses

- Most candidates referred to the observed wavelength being larger than the emitted wavelength due to the star/galaxy moving away from the observer.

Limited responses

- Some candidates only referred to the wavelength instead of observed or measured wavelength being larger.
- Some candidates referred to galaxies moving apart without being clear that this meant the source of the radiation was moving away from the observer.

(ii) Comprehensive responses

- Most candidates stated the correct expression for T_{STAR}.

Limited responses

- Some candidates gave the expression as $\lambda_{STAR} T_0 / \lambda_0$.

(iii) Comprehensive responses

- Many candidates gave the correct expression and identified the symbol σ in the expression as the Stefan-Boltzmann constant.

Limited responses

- Many candidates did not identify the symbol σ in the expression as the Stefan-Boltzmann constant.
- Some candidates gave an expression which contained T instead of T_{STAR}.

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PHYSICS

Paper 9702/51
Planning, Analysis and Evaluation

Key messages

What candidates did well

- In **Question 1**, candidates identified independent, dependent variables and the quantities that needed to be kept constant.
- Identified an appropriate graph to analyse their measurements and described the expected graph as a straight line.
- In **Question 2**, candidates were able to work through the algebra to obtain expressions for the gradient, complete the table of results, plot the data points on the graph and calculate the gradient.

What candidates needed to improve

- In **Question 1**, more detailed explanations of experimental procedures such as ensuring the apparatus is correctly set up and methods of reducing uncertainty in measured data.
- Some candidates had difficulty manipulating logarithmic expressions to obtain information from logarithmic graphs.
- In **Question 2**, some candidates did not draw lines of best fit with an appropriate balance of data points about the line or use the gradient to determine β.
- Some candidates did not show sufficient working in the numerical answers towards the end of the question, making their method unclear.
- Some candidates made errors with powers of ten when evaluating quantities, particularly when converting mm² to m².

Comments on specific questions

Question 1

Comprehensive responses

- Showed an understanding that the distance a needed to be varied and period T needed to be determined for each value of a.
- Had an explicit statement that L and M needed to be kept constant.
- Included a diagram showing a bar suspended from a clearly supported rod, with supporting apparatus clearly standing on a bench or work surface.
- Described the timing of a number n of oscillations and how the period of oscillation could then be determined in terms of n.
- Described how required values of a, L and M could be measured.
- Considered ways to ensure the apparatus was suitably arranged, such as checking the bar and rod were horizontal, that the strings were at the same distance from the centre of the bar, or ways to ensure the strings did not slide during the oscillations.
- Contained clear expressions for determining such as use of a fiducial mark, using larger values of L, use of small amplitude oscillations or repeating and averaging suitable readings.
- Considered methods of reducing the risk of injury or damage caused by the rod or bar falling during the experiment.
- Correctly identified a graph of logarithmic values on both axes, such as lg **(*a*)** vs lg (L), that could be used to check the validity of the given relationship and determine values for q and P.
- Contained clear expressions for determining the values P and q from the graph, with P and q as the subjects of those expressions.

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Limited responses

- Simply repeated the stem of the question and used the word 'control' instead of stating the quantities that should be kept constant.
- Did not indicate how the rod was fixed to stands placed on a bench.
- Included vague statements like 'use a stopwatch to measure time' instead of 'use a stopwatch to measure the period of oscillation', or 'use a stopwatch to measure T' (since T is defined in the question as period of oscillation).
- Stated which quantities needed to be measured but neither stated the measuring instrument nor described how the measuring instrument would be used.
- Used vague terms for measuring apparatus such as 'measure length with a scale', 'measure mass with a scale', 'measure time with a mobile phone', 'measure time using a video recorder'.
- Some candidates did not explicitly state the quantities to be plotted on each axis. A few of these candidates simply wrote $y = mx + c$ below an expression, which was not sufficient for credit.
- Some candidates suggested an appropriate graph but were not explicit in how the graph could be used to identify whether the given relationship was true. Other candidates did not explain how the constants P and q were determined.

Question 2

(a) **Comprehensive responses**

- Rearranged the equation appropriately and determined a suitable expression for the gradient.

Limited responses

- Usually produced an inverted expression for the gradient or no expression at all. Some incorrect expressions were seen with no clear working or working that was difficult to follow.

(b) **Comprehensive responses**

- Calculated correct values of $1/d^2$ to two or three significant figures.
- Correctly determined the absolute uncertainties.

Limited responses

- Calculated lower values to just 1 significant figure. In particular the final value of 0.40(0) was commonly expressed as 0.4, even though all other values were expressed to the correct precision.
- Corrected values of $1/d^2$ incorrectly, such as 0.148 corrected as 0.150 instead of 0.15.
- Gave wrong values for the absolute uncertainties. These were often one half of the expected value, indicating the quite common error of dividing the absolute uncertainty by two or not understanding the power in d^2.

(c) (i) **Comprehensive responses**

- Showed accurately plotted data points using a small sharply-drawn cross or a dot occupying less than half a small square in any direction.
- Showed horizontal error bars accurately drawn with a clear small line at the end of each bar.

Limited responses

- Included plotted points that occupied half a small square or more in at least one direction.
- Had error bars of the wrong length or not drawn symmetrically about the plotted point. A few responses had lengths of error bars that differed from the data by a factor of ten.
- Occasionally had error bars drawn in the vertical direction rather than the horizontal.

(ii) **Comprehensive responses**

- Used a sharp pencil and a transparent 30 cm ruler so that they could draw a line where the data points were balanced about the line.
- Drew either the steepest or shallowest line that passed through all the data points.

Limited responses

- Had straight lines that did not show a reasonable balance of points around the line, often incorrectly drawn by joining the end plots.
- Had thick, sometimes not straight, lines that made interpretation of the graph more difficult.
- The worst acceptable lines shown could have been steeper or shallower while still passing through all of the error bars.

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(iii) Comprehensive responses

- Showed clearly indicated points on the line of best fit used to calculate the gradient, often easy to read points on grid lines.
- Showed clearly indicated coordinates used to determine the gradient of the worst acceptable line, and then showed working to calculate the absolute uncertainty as the difference in gradients of the line of best-fit and the worst acceptable line.

Limited responses

- Used coordinates that had been misread, or used data points from the table that were not actually on the best fit line.
- Used data points which were closer together than half of the length of the drawn line.
- Did not use the gradient of the worst fit line but showed an attempted calculation of the uncertainty in gradient using uncertainties of data points from the table of results.
- Did not show a worst allowed line so that the uncertainty could not be calculated.

(d) Comprehensive responses

- Showed a correct subtraction of 1250 from 7850, and a correct addition of the two uncertainty values.

Limited responses

- Showed a calculation of the average of the values of 7850 and 1250.
- Showed an addition of the percentage uncertainties of the two values.

(e) (i) Comprehensive responses

- Showed correct substitution into the gradient expression, with correct conversion of powers of ten where necessary, to find a correct value of β.
- Showed a value of β given to 2 or 3 significant figures and with the correct SI unit.

Limited responses

- Attempted to calculate β by substitution of data values rather than using the gradient as stated in the question.
- Used a wrong expression to calculate β.
- Calculated β correctly but with the wrong power of ten due to inconsistent powers of ten for the different values used in the expression for β.
- Gave no unit, or stated a unit that was either dimensionally incorrect or not consistent with the stated value of β.

(ii) Comprehensive responses

- Correctly calculated the percentage uncertainty by either calculating maximum and minimum values, or by adding the percentage uncertainties associated with the gradient, z and the difference in densities.

Limited responses

- Did not take into account all of the factors affecting the uncertainty or used wrong methods of evaluation.
- Responses where a maximum or minimum method was used often introduced errors. Candidates attempting a min/max method sometimes did not consistently use maximum values in the denominator and minimum values in the numerator (or the other way around).

(f) Comprehensive responses

- Correctly calculated t by substitution into original equation or by using the gradient.
- Determined the absolute uncertainty using one of a range of valid methods, with correct substitution shown.

Limited responses

- Had calculated values with the wrong power of ten consistent with the method used.
- Did not consider all factors affecting the uncertainty, often missing the factor of 2 in the uncertainty of d^2.

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Paper 9702/52
Planning, Analysis and Evaluation

Key messages

What candidates did well

- In **Question 1**, candidates identified independent, dependent variables and the quantities that needed to be kept constant.
- Candidates were often able to identify an appropriate graph to analyse their measurements and describe the expected graph as a straight line.
- In **Question 2**, candidates were able to work through the algebra to obtain expressions for the gradient, complete the table of results, plot the data points on the graph and calculate the gradient.

What candidates needed to improve

- In **Question 1**, candidates' responses should include detailed explanations of experimental procedures such as how to control variables, how to take measurements and how to analyse the data.
- Some candidates did not draw circuit diagrams using correct circuit symbols.
- Some candidates did not provide sufficient detail about how measurements would be taken or which measuring instruments would be used.
- In **Question 2**, draw lines of best fit with a balance of data points about the line and use the gradient to determine α.
- Show all their working in the numerical answers towards the end of the question and be careful to check through the working if time allows.
- Use appropriate units and powers of ten when evaluating quantities.
- Understand how to determine uncertainties for repeated measurements and how to determine an uncertainty in equations with power terms.

Comments on specific questions

Question 1

Comprehensive responses

- Most candidates correctly understood that the value of h needed to be varied and I needed to be measured for each value of h.
- Explicitly stated that f, A and E needed to be kept constant.
- Drew a circuit diagram with an ammeter and voltmeter correctly positioned using correct circuit symbols to measure.
- Added an a.c. power supply to the terminals of the reed switch.
- Connected an oscilloscope in parallel with the terminals of the reed switch and signal generator to determine the frequency.
- Explained how the oscilloscope was used to determine the frequency by first determining the period using the time-base and the length of one cycle. Some candidates also described adjusting the time-base so that there was a large trace observed or taking the mean period over several waves observed.
- Drew a diagram to show how the capacitor plates were supported often including reference to insulating material placed between the plates and the support.
- Understood that the distance between the plates was likely to be small so suggested the use of calipers to measure h.
- Described a method of measuring the diameter of the capacitor plates and then stating how this value was used to determine A.
- Most candidates explicitly stated plotting a graph with I on the y-axis against h on the x-axis. Other acceptable graphs seen were h against $1/I$ and lg I against lg h.

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- Explained how the graph would confirm the suggested relationship correctly by stating that the relationship between I and h would be valid if a straight line passing through the origin could be drawn. Candidates who stated plotting a graph of and lg I against lg h stated that the relationship between I and h would be valid if a straight line with a gradient of -1 could be drawn.
- Candidates identified how K was determined – K needed to be the subject of the equation.
- Described a hazard specific to the experiment, for example for capacitor plates held in stands, the stands would be clamped to the bench to prevent them falling or toppling or to not touch the plates when adjusting the distance h between them.
- Explained how to increase the accuracy of h by measuring h in different positions between the plates and finding the mean or clearly describing a method to ensure that the plates were parallel and aligned.
- Considered how to reduce the percentage uncertainty in their measurement of I by increasing the value of A so that I would increase.

Limited responses

- Some candidates incorrectly thought that I was the independent variable possibly since it appeared on the right-hand side of the given relationship.
- Some candidates repeated the stem of the question and used the word 'control' rather than identifying quantities that needed to be kept constant.
- Often found positioning instruments in the circuit challenging. Common errors included placing the ammeter in a parallel with the resistor and placing an oscilloscope in series with the a.c. supply or signal generator.
- Omitted how the capacitor plates would be positioned.
- Stated incorrect instruments to measure the distances for example, micrometer to measure the diameter of the plates which should have been a large distance.
- Gave vague explanations of how the frequency could be determined from an oscilloscope.
- Some candidates did not explicitly state the quantities to be plotted on each axis. A few of these candidates wrote $y = mx + c$ below an expression, which was not sufficient for credit.
- Some candidates suggested an appropriate graph but were not explicit in how the graph could be used to identify whether the given relationship was true, often omitting that the straight line would pass through the origin. Other candidates did not explain how the constant K was determined.

Question 2

(a) **Comprehensive responses**

- Rearranged the given equation into $y = mx + c$ format with y represented by T^2 and correctly identified the gradient.

Limited responses

- A few candidates did not include the correct power for π.

(b) **Comprehensive responses**

- Many candidates understood that L was recorded to three significant figures so $1/L^2$ needed to be recorded to three (or four) significant figures. Similarly, most candidates correctly calculated the values of T^2 with an appropriate number of significant figures.
- Most candidates correctly determined the absolute uncertainties in T and in T^2.

Limited responses

- Some candidates incorrectly rounded values of $1/L^2$, to one decimal place (two significant figures) in rows 3 to six of the table rather than rounding to three significant figures. Other candidates incorrectly rounded data, for example, $1.58^2 = 2.4964$ was truncated to 2.49 rather than 2.50.
- Most candidates understood that the uncertainty in each T value was ±0.02, many candidates either multiplied the uncertainty by two giving uncertainties of ±0.04 or did not understand how to the deal with the power of 2 and gave uncertainties decreasing from ±0.03 to ±0.02.

(c) (i) **Comprehensive responses**

- Most candidates plotted each data point within half a small square often using a small cross. The diameter of each point was less than half a small square.
- Error bars were accurately drawn with a clear small line at the end of each bar.

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Limited responses

- A few candidates did not plot the points to the nearest half a small square.
- Some candidates mis-read the scale on the *y*-axis.
- A common error was to plot an error bar half the length it should have been.

(ii) Comprehensive responses

- Used a sharp pencil and a transparent 30 cm ruler so that they could draw a line where the data points were balanced about the line.
- Drew either the steepest or shallowest line that passed through all the data points for the worst acceptable line.

Limited responses

- Some candidates did not draw a straight line with a balance of points, often incorrectly drawing a line from the top plot to the bottom plot.
- Some candidates did not consider that the worst acceptable line should be the steepest or shallowest line that passes through all the error bars.

(iii) Comprehensive responses

- Most candidates clearly demonstrated the points that they used to calculate the gradient often selecting two points on the line of best fit which are easy to read, i.e. the points are on grid lines.
- Most candidates indicated the coordinates that they have used from the worst acceptable line to determine the gradient of the worst acceptable line and then showed how the absolute uncertainty is determined by finding the difference in gradients of the line of best-fit and the worst acceptable line.

Limited responses

- Some candidates misread coordinates or did not use a triangle that covered more than half of the drawn line.
- A small number of candidates chose data points that did not lie on the lines, often using data from the table that is close to the line instead.

(d) Comprehensive responses

- Clearly demonstrated the calculation of the mean distance *D* as 0.825.
- Clearly showed the calculation of half the range of values to determine the absolute uncertainty in *D*.

Limited responses

- While most candidates calculated the mean value of *D*, many did not understand how to calculate the absolute uncertainty. Common errors include 0.001 and 0.008 (the range of values).

(e) (i) Comprehensive responses

- Many candidates were able to substitute the gradient value into an expression and correctly evaluate the value of α.
- Since the least significant data, *M*, was given to two significant figures, candidates generally gave the value of α to two or three significant figures..
- The SI unit of α was clearly determined with the correct power of ten as either g m^2 or kg m^2.

Limited responses

- A small minority of candidates did not gain credit since they did not use the gradient but substituted data points from the table.
- Some candidates were not able to evaluate the expression correctly.
- Common incorrect units given included g/m^2 or g m^{-2}.

(ii) Comprehensive responses

- Most correctly calculated the percentage uncertainty by showing the addition of fractional uncertainties.

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Limited responses

- A few candidates guessed an uncertainty in the value of α, for example, ± 0.001 rather than calculating a value using the uncertainty of the gradient and the uncertainties in D and M.
- Responses where a maximum or minimum method was used often introduced errors. Candidates attempting a min/max method sometimes did not consistently use maximum values in the denominator and minimum values in the numerator (or the other way around).

(f) **Comprehensive responses**

- Clearly showed the method to determine L by correctly substituting values into an appropriate expression.
- Many candidates realised that L could be easily determined by using the gradient.
- Clearly substituted values to work out the fractional uncertainty in L before calculating the absolute uncertainty in L.

Limited responses

- Some responses did not show clear substitution of relevant data either for determining the value of L or for the absolute uncertainty in L.
- Many responses indicated that dealing with square roots was not understood particularly in terms of calculating uncertainties.
- The use of maximum or minimum methods to determine the uncertainty in L proved challenging. Candidates attempting a min/max method sometimes did not consistently use maximum values in the denominator and minimum values in the numerator (or the other way around).

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Paper 9702/53
Planning, Analysis and Evaluation

Key messages

What candidates did well

- In **Question 1**, candidates identified independent, dependent variables and the quantities that needed to be kept constant.
- Identified an appropriate graph to analyse their measurements and described the expected graph as a straight line.
- In **Question 2**, candidates were able to work through the algebra to obtain expressions for the gradient, complete the table of results, plot the data points on the graph and calculate the gradient.

What candidates needed to improve

- In **Question 1**, more detailed explanations of experimental procedures such as ensuring the apparatus is correctly set up and methods of reducing uncertainty in measured data.
- Some candidates had difficulty manipulating logarithmic expressions to obtain information from logarithmic graphs.
- In **Question 2**, some candidates did not draw lines of best fit with an appropriate balance of data points about the line or use the gradient to determine β.
- Some candidates did not show sufficient working in the numerical answers towards the end of the question, making their method unclear.
- Some candidates made errors with powers of ten when evaluating quantities, particularly when converting mm² to m².

Comments on specific questions

Question 1

Comprehensive responses

- Showed an understanding that the distance a needed to be varied and period T needed to be determined for each value of a.
- Had an explicit statement that L and M needed to be kept constant.
- Included a diagram showing a bar suspended from a clearly supported rod, with supporting apparatus clearly standing on a bench or work surface.
- Described the timing of a number n of oscillations and how the period of oscillation could then be determined in terms of n.
- Described how required values of a, L and M could be measured.
- Considered ways to ensure the apparatus was suitably arranged, such as checking the bar and rod were horizontal, that the strings were at the same distance from the centre of the bar, or ways to ensure the strings did not slide during the oscillations.
- Contained clear expressions for determining such as use of a fiducial mark, using larger values of L, use of small amplitude oscillations or repeating and averaging suitable readings.
- Considered methods of reducing the risk of injury or damage caused by the rod or bar falling during the experiment.
- Correctly identified a graph of logarithmic values on both axes, such as lg **(*a*)** vs lg (L), that could be used to check the validity of the given relationship and determine values for q and P.
- Contained clear expressions for determining the values P and q from the graph, with P and q as the subjects of those expressions.

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Limited responses

- Simply repeated the stem of the question and used the word 'control' instead of stating the quantities that should be kept constant.
- Did not indicate how the rod was fixed to stands placed on a bench.
- Included vague statements like 'use a stopwatch to measure time' instead of 'use a stopwatch to measure the period of oscillation', or 'use a stopwatch to measure T' (since T is defined in the question as period of oscillation).
- Stated which quantities needed to be measured but neither stated the measuring instrument nor described how the measuring instrument would be used.
- Used vague terms for measuring apparatus such as 'measure length with a scale', 'measure mass with a scale', 'measure time with a mobile phone', 'measure time using a video recorder'.
- Some candidates did not explicitly state the quantities to be plotted on each axis. A few of these candidates simply wrote $y = mx + c$ below an expression, which was not sufficient for credit.
- Some candidates suggested an appropriate graph but were not explicit in how the graph could be used to identify whether the given relationship was true. Other candidates did not explain how the constants P and q were determined.

Question 2

(a) **Comprehensive responses**

- Rearranged the equation appropriately and determined a suitable expression for the gradient.

Limited responses

- Usually produced an inverted expression for the gradient or no expression at all. Some incorrect expressions were seen with no clear working or working that was difficult to follow.

(b) **Comprehensive responses**

- Calculated correct values of $1/d^2$ to two or three significant figures.
- Correctly determined the absolute uncertainties.

Limited responses

- Calculated lower values to just 1 significant figure. In particular the final value of 0.40(0) was commonly expressed as 0.4, even though all other values were expressed to the correct precision.
- Corrected values of $1/d^2$ incorrectly, such as 0.148 corrected as 0.150 instead of 0.15.
- Gave wrong values for the absolute uncertainties. These were often one half of the expected value, indicating the quite common error of dividing the absolute uncertainty by two or not understanding the power in d^2.

(c) (i) **Comprehensive responses**

- Showed accurately plotted data points using a small sharply-drawn cross or a dot occupying less than half a small square in any direction.
- Showed horizontal error bars accurately drawn with a clear small line at the end of each bar.

Limited responses

- Included plotted points that occupied half a small square or more in at least one direction.
- Had error bars of the wrong length or not drawn symmetrically about the plotted point. A few responses had lengths of error bars that differed from the data by a factor of ten.
- Occasionally had error bars drawn in the vertical direction rather than the horizontal.

(ii) **Comprehensive responses**

- Used a sharp pencil and a transparent 30 cm ruler so that they could draw a line where the data points were balanced about the line.
- Drew either the steepest or shallowest line that passed through all the data points.

Limited responses

- Had straight lines that did not show a reasonable balance of points around the line, often incorrectly drawn by joining the end plots.
- Had thick, sometimes not straight, lines that made interpretation of the graph more difficult.
- The worst acceptable lines shown could have been steeper or shallower while still passing through all of the error bars.

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(iii) Comprehensive responses

- Showed clearly indicated points on the line of best fit used to calculate the gradient, often easy to read points on grid lines.
- Showed clearly indicated coordinates used to determine the gradient of the worst acceptable line, and then showed working to calculate the absolute uncertainty as the difference in gradients of the line of best-fit and the worst acceptable line.

Limited responses

- Used coordinates that had been misread, or used data points from the table that were not actually on the best fit line.
- Used data points which were closer together than half of the length of the drawn line.
- Did not use the gradient of the worst fit line but showed an attempted calculation of the uncertainty in gradient using uncertainties of data points from the table of results.
- Did not show a worst allowed line so that the uncertainty could not be calculated.

(d) Comprehensive responses

- Showed a correct subtraction of 1250 from 7850, and a correct addition of the two uncertainty values.

Limited responses

- Showed a calculation of the average of the values of 7850 and 1250.
- Showed an addition of the percentage uncertainties of the two values.

(e) (i) Comprehensive responses

- Showed correct substitution into the gradient expression, with correct conversion of powers of ten where necessary, to find a correct value of β.
- Showed a value of β given to 2 or 3 significant figures and with the correct SI unit.

Limited responses

- Attempted to calculate β by substitution of data values rather than using the gradient as stated in the question.
- Used a wrong expression to calculate β.
- Calculated β correctly but with the wrong power of ten due to inconsistent powers of ten for the different values used in the expression for β.
- Gave no unit, or stated a unit that was either dimensionally incorrect or not consistent with the stated value of β.

(ii) Comprehensive responses

- Correctly calculated the percentage uncertainty by either calculating maximum and minimum values, or by adding the percentage uncertainties associated with the gradient, z and the difference in densities.

Limited responses

- Did not take into account all of the factors affecting the uncertainty or used wrong methods of evaluation.
- Responses where a maximum or minimum method was used often introduced errors. Candidates attempting a min/max method sometimes did not consistently use maximum values in the denominator and minimum values in the numerator (or the other way around).

(f) Comprehensive responses

- Correctly calculated t by substitution into original equation or by using the gradient.
- Determined the absolute uncertainty using one of a range of valid methods, with correct substitution shown.

Limited responses

- Had calculated values with the wrong power of ten consistent with the method used.
- Did not consider all factors affecting the uncertainty, often missing the factor of 2 in the uncertainty of d^2.

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Paper 9702/54
Planning, Analysis and Evaluation

Key messages

What candidates did well

- In **Question 1**, candidates identified independent, dependent variables and the quantities that needed to be kept constant.
- Candidates were often able to identify an appropriate graph to analyse their measurements and describe the expected graph as a straight line.
- In **Question 2**, candidates were able to work through the algebra to obtain expressions for the gradient and *y*-intercept and plot the data points on the graph and calculate the gradient.

What candidates needed to improve

- In **Question 1**, candidates' responses should include detailed explanations of experimental procedures such as how to control variables, how to take measurements and how to analyse the data.
- Draw workable diagrams that include clamped equipment where appropriate.
- Include detail in how measurements are taken, in particular, choosing an appropriate instrument to measure a quantity.
- In **Question 2**, use the gradient to calculate quantities towards the end of the question.
- Show all their working in the numerical answers and be careful to check through the working if time allows.
- Use appropriate units and powers of ten when evaluating quantities.
- Understand how to determine uncertainties for repeated measurements and how to determine an uncertainty in equations with power terms.

Comments on specific questions

Question 1

Comprehensive responses

- Most candidates correctly understood that the value of *r* needed to be varied and *c* needed to be determined for each value of *r*.
- Explicitly stated that *v* needed to be kept constant.
- Diagrams were usually detailed with sufficient labelling.
- Description of measurement of spring length before and after compression with a subtraction to determine *c*.
- Description of *r* measurement usually through use of calliper to measure diameter with $r = \frac{d}{2}$.
- Explained how to determine *v* by explicitly identifying a distance *h* and then giving a relevant equation.
- Most candidates explicitly stated plotting a graph with $\frac{1}{c^2}$ on the y-axis against $\frac{1}{r^3}$ on the *x*-axis.
- Many candidates explained how the graph would confirm the suggested relationship correctly by stating that the relationship would be valid if a straight line (not passing through the origin) could be drawn.
- Many candidates also identified how α and *Z* were determined using the gradient and y-intercept α and *Z* needed to be the subject of each equation to score.
- Described how the density of the steel could be determined using a balance to measure mass and the equation for the volume of a sphere with the density equation.
- Many recognised that the experiment would need to be recorded using a video camera and played back in slow motion to accurately determine the compressed length of the springs.

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Limited responses

- Some candidates repeated the stem of the question and used the word 'control' rather than identifying quantities that needed to be kept constant.
- Some candidates did not include a clamped rule in their diagram.
- Described a direct measurement of compression.
- Did not include a fixed release position for the ball in the diagram, nor did they measure the height that the ball falls through so that v could be determined.
- Some candidates did not explicitly state the quantities to be plotted on each axis. A few of these candidates wrote $y = mx + c$ below an expression which was not sufficient for credit.
- Some candidates suggested an appropriate graph but were not explicit in how the graph could be used to identify whether the given relationship was true. Other candidates did not explain how the constants α and K were determined.
- Some candidates did not provide a workable method for preventing the ball rolling off the bench.

Question 2

(a) Comprehensive responses

- Rearranged the given equation into $y = mx + c$ format and gave the correct expression for the gradient.

Limited responses

- A few candidates missed a power for one quantity or gave the wrong power.

(b) Comprehensive responses

- Some candidates understood that t was recorded to three significant figures so T and T^2 needed to be given to three or four significant figures.
- Most candidates correctly determined the absolute uncertainty in T^2.

Limited responses

- Some candidates gave the final three values of T^2 to two significant figures, perhaps giving the value to three decimal places instead.
- Some candidates made a rounding error in the absolute uncertainty values.

(c) (i) Comprehensive responses

- Most candidates plotted each data point within half a small square often using a small cross. The diameter of each point was less than half a small square.
- Error bars were accurately drawn with a clear small line at the end of each bar.

Limited responses

- A few candidates did not plot the points to the nearest half a small square.
- Some candidates mis-read the scale on one of the axes.
- A common error was to draw an error bar that was too short for the uncertainty it represented. Most commonly drawing an error bar 4 small squares long for an uncertainty of 0.0023.

(ii) Comprehensive responses

- Used a sharp pencil and a transparent 30 cm ruler so that they could draw a straight line where the data points were balanced about the line.
- Drew either the steepest or shallowest line that passed through all the error bars for the worst acceptable line.

Limited responses

- Some candidates did not draw a straight line with a balance of points.
- Some candidates did not consider that the worst acceptable line should be the steepest or shallowest line that passes through all the error bars.

(iii) Comprehensive responses

- Most candidates clearly demonstrated the points that they used to calculate the gradient often selecting two points on the line of best fit which are easy to read, that is, the points are on grid lines.
- Most candidates indicated the coordinates that they used from the worst acceptable line to determine the gradient of the worst acceptable line and then showed how the absolute

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uncertainty is determined by finding the difference in gradients of the line of best-fit and the worst acceptable line.

Limited responses
- Some candidates misread coordinates or read a coordinate from the best fit line and another from the worst acceptable line.
- Some used a triangle for the gradient with a hypotenuse that was less than half the length of the drawn line.
- A small number of candidates chose data points that did not lie on the lines, often using data from the table that is close to the line instead.

(d) Comprehensive responses
- Clearly demonstrated the calculation of mean *d*.
- Clearly showed the calculation of half the range of values to determine the absolute uncertainty in *d*.

Limited responses
- A number of candidates gave an incorrect uncertainty or no uncertainty at all. The most common incorrect uncertainty was 0.04.

(e) (i) Comprehensive responses
- Most candidates successfully rearranged the equation to determine *E* substituting the gradient value correctly.
- Candidates considered the number of significant figures and gave *E* to two or three significant figures since the least significant data for *w* in the table was two significant figures.
- Gave an appropriate unit for *E* that matched the power of ten for their answer.

Limited responses
- A few candidates attempted to calculate *E* using values from the table instead of using the gradient.
- Some candidates were not able to evaluate the expression correctly.
- A significant number of candidates either gave an incorrect unit for *E* or gave a unit that did not match the power of ten, this was usually because of incorrect unit conversion for the quantities used in the calculation.

(ii) Comprehensive responses
- Many correctly calculated the percentage uncertainty in *E* by adding the fractional uncertainties of the given quantities to the fractional uncertainty in the gradient.
- Some candidates successfully used a maximum or minimum method by calculating either the maximum or minimum *E* and doing a subtraction.

Limited responses
- Some candidates made an arithmetic error in their calculation.
- Some candidates did not multiply the fractional uncertainty in *L* and/or *d* by three as they are cubed in the equation.
- Candidates attempting a minimum or maximum method sometimes did not consistently use maximum values in the denominator and minimum values in the numerator (or the other way around).

(f) Comprehensive responses
- Most candidates successfully substituted their value of *E* into the given equation along with the other given quantities and rearranged to determine w.
- A large number instead used their gradient value, recognising that a large part of the equation could be represented by the gradient.
- Many correctly calculated the absolute uncertainty in *w* by adding the fractional uncertainties of the all the given quantities to the fractional uncertainty in their value of *E.* Alternatively those using the gradient sometimes determined the absolute uncertainty be adding the fractional uncertainty in the gradient to the fractional uncertainty in *T* multiplied by two.
- Some candidates successfully used maximum or minimum methods by calculating either the maximum or minimum *w* and doing a subtraction.

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Limited responses

- Some candidates made an arithmetic error in their calculation of w and/or the uncertainty.
- Some used an incorrect method for the uncertainty calculation, for example adding together the percentage uncertainty in *E* and *T* or halving the final absolute uncertainty.
- Some candidates did not multiply the fractional uncertainty in *T* two as *T* is squared in the equation.
- The use of maximum or minimum methods to determine the uncertainty in *L* proved challenging. Candidates attempting a min/max method sometimes did not consistently use maximum values in the denominator and minimum values in the numerator (or the other way around).

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