PHYSICS

Paper 9702/11
Multiple Choice

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

PHYSICS

Paper 9702/12
Multiple Choice

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

General comments

Candidates should always read each question through in its entirety before looking at the answers, taking particular care when, for instance, a question asks 'which statement is **not** correct?'. All four answer options should be considered carefully, trying to justify eliminating three of the options as a check to make sure the answer selected is the correct one.

When answering numerical questions, it is a good idea to try to calculate the answer before looking at the answer options. Candidates need to ensure that the units used in a calculation are consistent, particularly if the information includes prefixes such as k, μ or M, or data which includes areas in mm^2 or cm^2 or volumes in mm^3 or cm^3.

Candidates found **Questions 6**, **15**, **22** and **28** difficult. They found **Questions 1**, **4**, **7**, **31**, **33** and **35** relatively straightforward.

Comments on specific questions

Question 3

The majority of the candidates answered this question correctly, though **B** was a common incorrect answer. Candidates choosing **B** had perhaps confused $v_y \cos\theta$ with $v \cos\theta$.

Question 5

Most candidates answered this question correctly. A common incorrect method was to add the percentage uncertainty in T to the percentage uncertainty in l but then ignore the square root.

Question 6

Candidates found this question difficult. Many candidates selected the incorrect answer **A**, suggesting that they knew that the acceleration at time $t = 3.0\,\text{s}$ is the gradient of the graph at $t = 3.0\,\text{s}$, but interpreted the scale on the y-axis incorrectly, i.e. 4 squares / 6 squares (= 0.67) rather than $8\,\text{m}\,\text{s}^{-1} / 6.0\,\text{s} = 1.3\,\text{m}\,\text{s}^{-2}$.

Question 8

The majority of the candidates understood the meaning of the mass of an object, though some weaker candidates thought the mass of an object was the number of atoms in the object.

Question 9

Just over half the candidates answered this question correctly, though many thought that the acceleration of parachutist Y would be half the acceleration of parachutist X. The question is designed to test the correct application of $F = ma$. The mass and drag force on Y are both double the values for X, and so:

for X: $mg - R = ma_X$
for Y: $2mg - 2R = 2ma_Y$.

The acceleration of Y is therefore the same as the acceleration of X.

Question 11

Many candidates chose **C** rather than the correct answer **B**. The difference in pressure between the top and the bottom of the cylindrical block is $(p_b - p_t)$, so the upthrust on the block is simply $(p_b - p_t)A$. The value given in **C** is the resultant force on the block.

Question 14

Candidates found this question difficult, and many candidates selected the incorrect answer **A**. A key skill in this type of question is recognising the directions of the different forces acting on point Q. There are three forces on point Q: the horizontal tension from the wire, the vertical force of 4.0 kN, and the unknown force F applied by the beam at an angle of 30° to the horizontal.

The simplest solution is to consider the vertical components: $F \sin 30° = 4.0\,\text{kN}$ and therefore $F = 8.0\,\text{kN}$.

Question 15

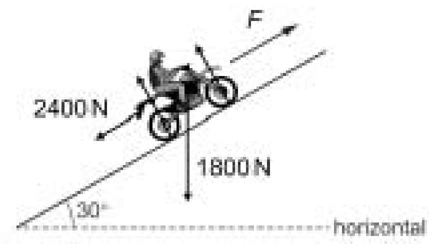
Many candidates found this question difficult. The incorrect answers **A**, **B** and **D** were each chosen by approximately equal numbers of candidates. When the cylinder is fully immersed in the water, the upthrust on the cylinder is constant, so the reading R on the newton meter is constant. As the cylinder leaves the water, the upthrust from the water decreases (linearly) with distance d, so the value of R must increase (linearly). When the cylinder is lifted above the water, the upthrust is again constant so the value of R is again constant, though larger than before.

Question 16

As many candidates selected **D** as the correct answer **B**. The first line of the question makes it clear that the ball is being thrown vertically upwards in air, and therefore there is air resistance to be considered. At the top of its path the ball's total energy will be less than its initial total energy as it will have lost some energy (as heat) because of air resistance, so **D** is a true statement and is therefore not the correct answer.

Question 20

Less than half of the candidates answered this question correctly, with many selecting **C** rather than the correct answer **B**. The diagram shows the different forces acting on the motorbike and rider (*F* is the driving force from the engine).



As the motorbike is travelling at constant speed up the slope:

$F = 2400 + 1800 \sin 30° = 3300\,\text{N}$.

The useful output power of the motorbike is 36 000 W. Using $P = Fv$:

$v = P / F = 36\,000 / 3300 = 11\,\text{m}\,\text{s}^{-1}$.

Candidates selecting **C** ignored the component of the weight force acting down the slope in their calculations.

Question 22

This proved to be a difficult question. The area under the stress–strain graph is:

$\tfrac{1}{2}\sigma\varepsilon = \tfrac{1}{2} \times (F / A) \times (x / L)$

$= (\tfrac{1}{2}Fx) / (AL)$

= (strain energy in the wire) / (original volume of the wire).

Question 23

The majority of the candidates answered this question correctly, though **C** was a popular incorrect answer. Sound waves are longitudinal waves, so the oscillations of the medium carrying sound waves are parallel to the direction of energy transfer.

Question 25

The majority of the candidates answered this question correctly, applying the expression for the Doppler effect to find the observed frequency as the train approaches the observer, then the frequency as it moves away from the observer, and then calculating the difference between the two frequencies. Some candidates only calculated the difference between the observed frequency as the train approaches the observer and the source frequency, which gave incorrect answer **B**.

Question 26

Less than half of the candidates answered this question correctly. Some candidates may have interpreted the 'T' prefix incorrectly and determined an incorrect wavelength, and others may have been unable to recall the principal regions of the electromagnetic spectrum. The wavelength is 10^{-5} m and this is in the infrared region.

Question 28

Candidates found this question difficult and **C** was the most popular incorrect answer. A beam of light passing through a vertical slit will produce diffraction in the horizontal plane and a horizontal diffraction pattern will be observed.

Question 30

Two key points to note in the question are that the second-order maximum is shown and the angle between the second-order maximum and the original path of the light (θ in the diffraction grating equation) is 40° (not 80°). Applying the diffraction grating equation $d = n\lambda / \sin\theta$ gives $d = 1.7 \times 10^{-6}$ m and therefore the line spacing is $5.8 \times 10^{5}\,\text{m}^{-1}$.

Question 34

Just over half the candidates answered this question correctly. In the circuit given, the 5.0 Ω load resistor is replaced by a 50 Ω load resistor. This decreases the current in the circuit so the power dissipated in the internal resistance (= I^2r) must also decrease. The total power dissipated in the circuit [= $V^2 / (R + r)$] also decreases.

The potential difference across the load resistor increases, so **B** is the correct answer.

Question 38

The maximum p.d. measured by the voltmeter occurs when the sliding contact is at the right-hand edge of the 3.0 Ω resistor. The reading V on the voltmeter is then:

$V = 9.0 \times [3.0 / (3.0 + 5.0 + 1.0)] = 3.0\,\text{V}$.

Question 39

Just under half the candidates answered this question correctly, with many candidates confusing β^- with β^+ decay.

In β^+ decay, a proton changes into a neutron, and a positron and a neutrino are emitted. The nucleon number is unchanged. Mass–energy is conserved in all nuclear processes (including both β^- and β^+ decay), so answer **C** is correct.

PHYSICS

Paper 9702/13
Multiple Choice

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

General comments

Candidates should always read each question through in its entirety before looking at the answers, taking particular care when, for instance, a question asks 'which statement is **not** correct?'. All four answer options should be considered carefully, trying to justify eliminating three of the options as a check to make sure the answer selected is the correct one.

When answering numerical questions, it is a good idea to try to calculate the answer before looking at the answer options. Candidates need to ensure that the units used in a calculation are consistent, particularly if the information includes prefixes such as k, μ or M, or data which includes areas in mm^2 or cm^2 or volumes in mm^3 or cm^3.

Candidates found **Questions 5**, **13**, **19**, **20**, **26**, **30** and **34** difficult. They found **Questions 1**, **3**, **4**, **11**, **17**, **18**, **28** and **31** relatively straightforward.

Comments on specific questions

Question 5

Almost all the candidates realised that the error described is an example of a systematic error but, of these, the majority thought that measured value for the width of the shelf would be greater than the true value. The opposite is true: if the graduations are too far apart, the measured value is less than the true value.

Question 6

The majority of the candidates answered this question correctly, though some thought that the area under the graph represented the average velocity rather than the change in velocity. The graph shows that the acceleration of the car is constant, so the equations of uniformly accelerated motion can be applied. The area under the graph is *at* and, from $v - u = at$, it follows that the area under the graph represents the change in velocity ($v - u$).

Question 8

The majority of candidates answered this correctly (answer **A**) though a significant number of candidates selected **C**, omitting to convert the mass flow rate from kg per minute to $kg\,s^{-1}$ in order to have consistent units in their calculation of the force needed to hold the hose-pipe.

Question 9

Most candidates answered this question correctly, though some selected **B** rather than the correct answer **A**, perhaps confusing **B** with the velocity–time graph of an object falling a long distance through air. The key point is to recognise that after the skydiver has fallen vertically through a long distance, the constant (terminal) velocity will have been reached and the acceleration of the skydiver is then zero. Graphs **B**, **C** and **D** can all be rejected as they show non-zero values for the acceleration at large values of *s*.

Question 10

The majority of the candidates answered this question correctly. The key knowledge and understanding required is to recall that, for elastic collisions, velocity of separation = velocity of approach. The question can also be answered by calculating the total kinetic energy of both spheres before and after the collision, though this takes longer and there is more chance of making an arithmetical slip in the calculations.

Question 13

Candidates found this question difficult, with less than half of the candidates answering the question correctly. Many may have assumed that the weight of the sign acts at the bottom of the sign rather than its midpoint, while others may have used cos 25° in their calculations rather than sin 25°.

Question 19

Candidates found this question difficult. Most candidates calculated correctly the change in the gravitational potential energy of the water as it is lifted 30 m (using $\Delta GPE = mg\Delta h$) but many did not take into account the efficiency of the pump in calculating the useful output power of the engine operating the pump.

If the output power of the engine is P, then $0.70P = 0.50 \times 1000 \times 9.81 \times 30 / 60$ and solving this gives $P = 3500\,W$.

Question 20

This question was also found to be difficult, with many candidates selecting **B** rather than the correct answer **C**. The overall spring constant *k* for each of the spring combinations is given by:

k = (force applied to spring combination) / (extension of spring combination).

Only **C** has the required spring constant of $8.0\,N\,m^{-1}$.

Question 26

Candidates need to be able to recall the approximate range of wavelengths of the principal regions of the electromagnetic spectrum from radio waves to γ-rays. The approximate range of wavelengths of visible light is 400–700 nm, so the bumps must all be less than 400 nm in size. Answer **C** (720 nm) is red light and **D** (5.0 μm) is in the infrared region. The approximate maximum size of the bumps is 350 nm, just inside the ultraviolet region, which is answer **B**.

Question 30

This proved to be a difficult question. Changing the distance between the diffraction grating and the screen has no effect on the angles at which the bright spots (maxima) occur, only on their distance apart on the screen, so **A** and **C** can be disregarded.

Rearranging the diffraction grating equation, maxima occur at angles θ given by $\theta = \sin^{-1}(n\lambda / s)$, where n is the order of the maximum, λ is the wavelength of the light and s is the distance between adjacent lines on the grating. Red light has a longer wavelength than green light, so s would have to be larger if the angles at which maxima occur are to stay the same, which means *decreasing* the number of lines per unit length in the grating.

Blue light has a shorter wavelength than green light, so s would have to be smaller if the angles at which maxima occur are to stay the same, which means *increasing* the number of lines per unit length in the grating. This gives **B** as the correct answer.

Question 34

Less than half of the candidates selected the correct answer **D**. Incorrect answer **C** was commonly chosen.

A quick way to answer the question is to realise that the circuit with the new cell has half the total resistance of the original circuit, and so will have twice the current. The power in the external resistor is I^2R and R has not changed, so the new power must be $4P$.

Candidates may prefer to work through the question using potential differences. In the circuit shown in the question paper, the e.m.f. of 6 V is shared equally across the internal resistance and the external resistor, so there is 3 V across each and $P = V^2 / R = 3^2 / R = 9 / R$. In the new circuit, all the e.m.f. is across the external resistor so $V^2 / R = 6^2 / R = 36 / R$. Again this gives a new power of $4P$, which is answer **D**.

Question 37

The majority of the candidates answered this question correctly, though some were confused by the polarities of the three cells when using Kirchhoff's second law. The overall e.m.f. of the three cells is $3.0 + 2.0 - 4.0 = 1.0$ V. The current in the circuit is therefore $I = V / R = 1.0 / 5.0 = 0.20$ A, which is answer **A**.

PHYSICS

Paper 9702/21
AS Level Structured Questions

Key messages

- Candidates should read each question carefully and pay particular attention to the command words that are used. The syllabus contains a glossary of command words. Candidates who quickly scan questions may overlook key information or instructions.
- Candidates should attempt every single question part as sometimes credit can be awarded for a partial calculation or answer, even when they are not able to arrive at a correct final answer.
- Candidates should avoid prematurely rounding interim answers within a calculation as this can lead to the final answer given on the answer line being incorrect.
- In numerical calculations it is important that candidates always explicitly state the subject of any equations. If an equation is rearranged, the new subject should also be stated.

General comments

The examination paper contained a balanced set of questions ranging from easy to very difficult. The performance of the candidates taking the paper varied considerably. Some of the weakest candidates did not attempt to give a response to a significant number of the questions. Candidates should always make every effort to give a response as marks can sometimes be obtained for just a partial calculation.

Comments on specific questions

Question 1

(a) The definition of density was usually stated correctly. Some candidates incorrectly defined density as the mass in a unit volume.

(b) (i) The most common correct response was calipers. The most common incorrect response was a ruler.

(ii) The percentage uncertainty was usually calculated correctly.

(c) (i) This question instructed the candidates to ‘show’ their working. Successful candidates explicitly showed the key steps of the calculation as well as stating the final answer. Weaker candidates sometimes omitted steps when presenting their calculation.

(ii) Only a minority of the candidates understood how to combine the percentage uncertainties of the values in the table to find the overall percentage uncertainty in the value of the density. Some candidates confused absolute uncertainties with percentage uncertainties. A significant number of candidates did not attempt a response.

(iii) Many candidates were able to calculate the value of the density. However, most candidates found the calculation of the absolute uncertainty to be challenging and only a small proportion appreciated that it was appropriate to express the final value of the absolute uncertainty to one significant figure.

Question 2

(a) The definition of momentum was usually given correctly. Some of the weakest candidates held the misconception that momentum was a type of force.

(b) (i) The majority of the candidates were able to recall the symbol formula for kinetic energy. Most candidates were then able to apply this formula to the question, although a small number calculated the kinetic energy of ball Y instead of ball X. It is important that candidates avoid this type of mistake by carefully reading the question rather than merely scanning it.

(ii) The stem of the question stated that the change in momentum of ball Y is represented by the area between the graph lines and the time axis. Stronger candidates were able to use this information to determine the correct answer. Sometimes a power-of-ten error was caused by not converting the units of time from ms to s. Weaker candidates did not realise that the question stem contained a strong hint about how to determine the answer.

(iii) The most common method of calculating the answer was to first calculate the final momentum of ball Y and then use that to find its final velocity. Some candidates first calculated the change in velocity of ball Y and then used that to determine its final velocity. Weaker candidates found this part of the question to be challenging and sometimes did not attempt a response.

(c) There were many fully correct graphs. The most common mistake was to draw the lines with F_x always positive instead of always negative. Another common mistake was to draw the graph with an incorrect magnitude of the maximum force.

Question 3

(a) (i) Candidates who had learnt the basic formula for stress found it straightforward to apply that formula to the question.

(ii) Candidates found it slightly more difficult to determine an algebraic expression for the strain of the bar. Some candidates appeared to confuse strain with stress.

(iii) Stronger candidates were usually able to recall the basic formula for the Young modulus, although sometimes the simplification of the final algebraic expression proved to be difficult.

(b) (i) Most answers were correct. The most common incorrect answer was 12 mm which was the overall maximum extension of the wire and not the maximum extension for which it obeys Hooke's law.

(ii) Most candidates could recall a general formula for strain energy. Sometimes a power-of-ten error was made when the unit of the value of the extension was not converted from mm to m. The weakest candidates sometimes confused strain energy with strain.

(iii) Many candidates correctly explained that the wire deformation would be plastic. However, only a small proportion went on to relate how this meant that some energy would be dissipated as thermal energy.

Question 4

(a) Candidates needed to state that in a longitudinal wave the oscillations of the particles are parallel to the direction of transfer of energy. Weaker candidates sometimes gave an incorrect or vague statement such as 'the direction of transfer of energy is parallel to the wave direction'.

(b) (i) It was generally understood that the change in frequency was due to the movement of the vehicle relative to the observer. For full credit, the candidates needed to explain that the observed frequency is higher than 1.2 kHz when the vehicle is moving towards the observer and lower than 1.2 kHz when the vehicle is moving away from the observer.

(ii) The name of the phenomenon was usually stated correctly.

(iii) The most common incorrect position given by weaker candidates was the right-hand edge (3 o'clock) position on the track. A significant number of candidates did not attempt a response.

(iv) The most common incorrect position given by weaker candidates was the bottom (6 o'clock) position on the track. A significant number of candidates did not attempt a response.

(c) Stronger candidates found it straightforward to apply the Doppler effect formula that is listed on the Formulae page. However, many candidates did not realise which formula to use and so wrote down numerical calculations that were not underpinned by correct physics.

Question 5

(a) Although there were many correct statements, a common mistake was to phrase the law in terms of a single current at a junction rather than in terms of the sum of the currents at a junction.

(b) (i) The candidates needed to explicitly show all the steps in the calculation as well as stating the final answer. It was essential not to omit a step, even if that step appeared to be a minor one in the context of the overall calculation. The most common method of calculation was to first find the potential difference across R_3 and then use the current in that resistor to determine the answer. A less common method was to first find the current in R_4 and then use the potential difference across that resistor to determine the answer.

(ii) This was a straightforward calculation for the stronger candidates. Weaker candidates sometimes did not attempt a response or made mistakes when trying to apply Kirchhoff's second law.

(c) Many candidates correctly realised that the total power produced by the battery would decrease, but could not explain why this would occur. Successful responses referred to the increase in the total resistance of the circuit and to the decrease in the current in the battery.

(d) Weaker candidates were often unable to recall the relevant formula. Candidates should be encouraged to use the standard symbols given in the syllabus. For example, the syllabus uses the symbol ρ (and not r) to represent resistivity.

Question 6

(a) Stronger candidates were able to recall all the masses and charges of the three particles. However, a common misconception was that a β-particle has no mass or has a mass of 1 u.

(b) (i) A significant number of candidates simply described the nature of the emitted β^- particle instead of explaining its origin.

(ii) A large proportion of the weaker candidates needed to have a better knowledge of the quark changes that occur during beta decay in order to successfully answer this part of the question.

(iii) Weaker candidates sometimes referred to the emission of a neutrino, rather than an antineutrino. Stronger candidates usually knew that an antineutrino would be emitted, but often did not appreciate that the energy released in the decay would be shared between the β^- particle and the antineutrino.

PHYSICS

Paper 9702/22
AS Level Structured Questions

Key messages

- Candidates should read each question carefully and pay particular attention to the command words that are used. The syllabus contains a glossary of command words. Candidates who quickly scan questions may overlook key information or instructions.
- Candidates should attempt every single question part as sometimes credit can be awarded for a partial calculation or answer, even when they are not able to arrive at a correct final answer.
- Candidates should avoid prematurely rounding interim answers within a calculation as this can lead to the final answer given on the answer line being incorrect.
- In numerical calculations it is important that candidates always explicitly state the subject of any equations. If an equation is rearranged, the new subject should also be stated.

General comments

All of the questions contained straightforward parts that gave opportunities for weaker candidates to be awarded credit. Other question parts provided more of a challenge and enabled stronger candidates to demonstrate a deeper understanding of the syllabus topics.

In **Question 2(b)**, some candidates did not understand how the electric force on a charged particle would combine with its weight to cause its motion. In **Question 3(d)**, many candidates did not understand the overall energy transfers that were occurring as the car moved along the slope. In **Question 5**, a significant number of candidates needed to have a better understanding of stationary waves in air columns.

Comments on specific questions

Question 1

(a) Most candidates found this part of the question to be straightforward. Weaker candidates sometimes misspelt the prefix 'pico'.

(b) The majority of the candidates were able to correctly identify the two SI base units. The most common mistake was to identify the coulomb as a base unit.

(c) (i) This question was generally well answered. Some candidates calculated the absolute uncertainty instead of the percentage uncertainty of the resistivity. The two most common errors were not doubling the percentage uncertainty of the diameter and subtracting, instead of adding, some of the individual percentage errors.

(ii) Most answers were correct. A small proportion of the candidates did not divide by 100 when converting the percentage uncertainty of the resistivity to its absolute uncertainty.

Question 2

(a) (i) The appropriate symbol formula for electric field strength was usually applied correctly. Some of the weaker candidates incorrectly believed that the electric field strength would be equal to the electric force on the oil drop divided by the charge of one electron.

(ii) Most responses contained the relevant symbol formula for the electric force. Weaker candidates often did not appreciate that, when the oil drop is stationary, the electric force acting on it must be equal to its weight. Some of the weakest candidates thought that the sign of the charge on the drop would be positive, rather than negative.

(b) (i) The candidates were asked to compare the new pattern of electric field lines to the previous pattern. The command word 'compare' requires the candidates to provide both similarities and differences. Many candidates realised that the direction of the field lines would be opposite. Weaker candidates sometimes stated only that the new field lines would point in the upward direction, without stating the original direction as a comparison. Only a small proportion of the responses referred to the unchanged spacing of the field lines.

(ii) Many candidates did not realise that the resultant force on the oil drop would be equal to the sum of its weight and the electric force acting on it. A common mistake was to think that the resultant force would be equal to only the weight or only the electric force.

(iii) The appropriate symbol equation was usually given. A common error was to directly substitute the value of the mass without showing how that value had been calculated. Candidates should be encouraged to show all the steps in their calculations, especially when the question uses the command word 'show'. A minority of candidates did not attempt a response to this part of the question.

(iv) The majority of the candidates realised that this part of the question could be solved by using an equation representing uniform acceleration. The most common error was to substitute a value of displacement that was equal to the distance between the plates instead of half that distance. Another common error was to express the final answer to two decimal places (0.03 s) instead of to two significant figures (0.026 s). The weakest candidates often substituted an incorrect acceleration of $9.81\,\mathrm{m\,s^{-2}}$ or did not attempt a response.

(c) Only a minority of the graphs were fully correct. Some candidates drew a straight-line graph which was inappropriate as this represents constant velocity and not acceleration. Other candidates appeared to confuse the distance travelled by the oil drop from its start position with the distance of the oil drop to the bottom plate.

Question 3

(a) The majority of candidates correctly defined power as the work done per unit time. A significant number of candidates stated a correct definition that was then contradicted by an incorrect one. The most common incorrect definitions were 'energy per unit time', 'work done in unit time' and 'rate of doing work per unit time'.

(b) (i) Some candidates attempted complex calculations, without realising that when the velocity is constant then the change in kinetic energy must be zero. Many candidates seemed to overlook the reference to constant velocity given in the question stem.

(ii) Generally, this question was well answered. A small minority of candidates incorrectly calculated the work done by multiplying the displacement of the vehicle and its weight.

(c) (i) The majority of responses were correct. A small proportion of the final answers contained a rounding error.

(ii) This question was usually answered correctly. The most common mistake was to confuse the sine of the angle with the cosine of the angle so that the final answer represented the angle of the slope to the vertical rather than to the horizontal.

(d) Many candidates knew that they could apply the equation 'power = work done / time taken' to the question. However, only a small proportion realised that the work done by the engine of the car would be equal to the gain in gravitational potential energy of the car added to the work done against the resistive forces. Most candidates thought that the work done by the car engine would be equal to only the gain in gravitational potential energy or only the work done against the resistive forces.

Question 4

(a) (i) Most candidates realised that the frequency of the sound heard by the child would decrease.

(ii) Only a minority of responses correctly described the frequency heard by the child as increasing. A common misconception was that the frequency would decrease.

(b) Most candidates correctly stated the Doppler effect equation in symbol form, but mistakes were often made when substituting in the numerical values. Sometimes the final answer was not expressed to three significant figures as instructed by the question. Candidates should always read questions carefully, rather than just quickly scan them, to ensure that any instructions are not overlooked.

(c) The first step of the calculation was to determine the distance travelled by the car. Sometimes this distance was incorrect because the wrong area under the graph had been used. Candidates who did determine the correct distance often made the mistake of then dividing it by the speed of the car rather than by the speed of the sound. The weakest candidates sometimes gave the period of the emitted sound as their final answer.

Question 5

(a) Only a small proportion of the candidates knew that a much louder sound would be heard when a stationary wave is formed in the air column as the tube is being raised. Weaker candidates sometimes thought that ripples would be seen on the water. In general, many candidates needed to have a better understanding of experiments that demonstrate stationary waves using air columns.

(b) The wavelength of the wave was usually calculated correctly. Stronger candidates realised that the height of the top end of the tube above the water surface was equivalent to one quarter of a wavelength. Weaker candidates often thought that the height would be equivalent to one half of a wavelength.

(c) Successful candidates realised that the distance moved by the tube corresponded to one half of a wavelength. However, many candidates did not understand how to determine the distance moved and so guessed a value or did not attempt a response.

Question 6

(a) The majority of responses were fully correct. Some candidates did not convert the given time from minutes to seconds.

(b) The majority of the candidates could recall at least one symbol formula for power. Most candidates were able to calculate either the total power supplied by the battery or the power dissipated by wire X, but only a minority calculated both of these powers correctly. Some candidates prematurely rounded up the values of the two individual powers which then caused the final value of the efficiency to be incorrect. Candidates should always avoid prematurely rounding any interim answers within a calculation as this can sometimes lead to an incorrect final answer.

(c) (i) Many candidates could not determine the number density of the free electrons because they did not appreciate that this was the number of free electrons per unit volume.

(ii) The relevant symbol formula from the Formulae page was usually stated. However, the substitution of the numerical values into this formula was often problematic. The most common mistakes were to substitute the charge calculated in **(a)** instead of the charge on an electron and to substitute the total number of free electrons in the wire instead of the number density of the free electrons.

(d) Successful responses contained a comprehensive supporting explanation as well as the final statement. A common misconception was that changing the length of the wire would change the resistivity or would change the number density of the free electrons.

Question 7

(a) Candidates generally found this question to be challenging. The majority stated the principle of conservation of momentum but did not apply it to explain why the velocities of nucleus Q and the α-particle must be in opposite directions.

(b) Most candidates calculated the correct answer by equating the momentum of nucleus Q to that of the α-particle. The most common mistake was to calculate the momentum of nucleus Q by using a mass of 243 u instead of 239 u.

(c) The symbol expression for kinetic energy was usually recalled correctly. Some candidates did not know how to convert the units of mass from u into kg. Others did not know how to convert the units of kinetic energy from J to MeV. A significant number of candidates stated the correct symbol expression for kinetic energy, but then did not square the substituted value of the speed.

(d) (i) Nucleus R was usually plotted correctly on the graph. However, nucleus S was frequently plotted incorrectly. This showed that many of the candidates did not understand how the emission of a β^- particle affects the number of protons and the number of neutrons in a nucleus.

(ii) The majority of responses were correct. Many weaker candidates seemed to guess a particle, such as ‘gamma’ or ‘electron’.

PHYSICS

Paper 9702/23
AS Level Structured Questions

Key messages

- Candidates should read each question carefully and pay particular attention to the command words that are used. The syllabus contains a glossary of command words. Candidates who quickly scan questions may overlook key information or instructions.
- Candidates should attempt every single question part as sometimes credit can be awarded for a partial calculation or answer, even when they are not able to arrive at a correct final answer.
- Candidates should avoid prematurely rounding interim answers within a calculation as this can lead to the final answer given on the answer line being incorrect.
- In numerical calculations it is important that candidates always explicitly state the subject of any equations. If an equation is rearranged, the new subject should also be stated.

General comments

There were many opportunities for the weaker candidates to show their understanding in straightforward questions. There were also more challenging questions for the stronger candidates. For example, determining the change in the elastic potential energy from the area under a force against length graph in **Question 1(c)**, motion in electric fields in **Question 4** and the potentiometer in **Questions 6(c)** and **6(d)**.

A single word or phrase can make a difference to a definition or an explanation. For example, in **Question 3(a)**, defining velocity as 'the rate of change of displacement' is correct, whilst 'rate of change of distance' or 'speed in a particular direction' is not. In **Question 5(a)** stating that amplitude is 'maximum displacement' or 'maximum distance from the equilibrium position' is acceptable, whilst 'maximum height of a wave' or 'distance to a peak or trough' is not.

Comments on specific questions

Question 1

(a) The majority of the candidates were able to show all the steps necessary for determining the cross-sectional area of the cylinder. The working was difficult to follow for some candidates where they had no subjects for various equations which were linked only by the values given in the question. Some candidates did not show how the mass was determined from the weight. All steps are required for questions that use the command word 'show'.

(b) (i) The majority of the candidates were able to show the correct value for the upthrust using the given values of the weight and the tension in the spring.

(ii) Stronger candidates were able to use the upthrust to calculate the pressure on the base of the cylinder. Many candidates did not equate this pressure with the pressure at a depth in a liquid. Instead of equating pressure with $\rho g \Delta h$, a significant number of candidates equated the upthrust force with $\rho g \Delta h$. Some considered the whole cylinder to be immersed in the liquid instead of only part of the cylinder.

Many of the weaker candidates tried to use 'density = mass / volume' and substituted the mass and volume of the cylinder into the expression. This gave the density of the cylinder and not the density of the liquid.

(c) (i) The majority of the candidates gave the correct symbol expression for the elastic potential energy or linked it to the area under the graph. Only a minority of the candidates were able to calculate the correct answer. The majority of candidates confused the length of the spring with its extension. Some made a power-of-ten error by not converting the extensions from cm into m.

(ii) Stronger candidates realised that the spring was not extended when the upthrust was equal to the weight of the cylinder. These candidates were able to read the non-extended length of the spring from the graph. A significant number gave the extension of the spring (zero) rather than the length of the spring as their answer.

Question 2

(a) A significant number of candidates did not include the condition that the displacement must be in the same direction as the force. Those who wrote distance instead of displacement needed to state that it is the distance moved in the direction of the force.

(b) This question was well answered by the majority of the candidates. A small minority did not use their answer from **(a)** but another expression for energy and hence did not give an acceptable answer.

(c) There were many well-presented solutions. Weaker candidates sometimes inappropriately eliminated the units for temperature by subtracting the units for ($T_1 - T_2$). These candidates thought that this gave 'K – K' and therefore that there was no unit for the change in temperature. Many candidates made arithmetic errors when simplifying the powers for s and K. A small number of candidates did not use the base units for energy but left the unit J in the final answer.

Question 3

(a) The majority of the candidates gave an acceptable definition for velocity. Some candidates defined velocity as 'distance / time' which was not acceptable.

(b) Stronger candidates were able to determine the magnitude of the resultant velocity. Many candidates made mistakes when trying to apply the cosine rule. Other candidates resolved the wind velocity into a component in the southerly direction and then subtracted this value from the aircraft velocity, but completely ignored the easterly component of the velocity of the wind.

Very few candidates calculated the resultant velocity using a scale diagram. Those that did generally obtained the correct answer.

(c) (i) This question was well answered by the majority of the candidates. A small number correctly calculated the change in height of the aircraft but then used an incorrect trigonometric function to find the angle. Some candidates seemed not to realise that the *mg* in the expression for the change in gravitational potential energy represents the weight of the object so that the change in gravitational potential energy can be calculated by multiplying the weight by the change in height.

(ii) Only the stronger candidates realised that the constant velocity of the aircraft meant that the air resistance would be equal to the component of the weight parallel to the path of the aircraft. Weaker candidates sometimes realised that the component of the weight in the direction along the path was required, but then used an incorrect trigonometric function in their calculation.

(d) The speed of the aircraft was calculated correctly by the majority of the candidates. However, the speed of the aircraft was sometimes added to, instead of subtracted from, the speed of sound when substituted into the Doppler effect equation. Stronger candidates were usually able to make the correct substitutions of the values into the equation that is given on the Formulae page.

Weaker candidates often misunderstood the meaning of the symbols in the equation. Many confused the source frequency and the observed frequency. Others confused the speed of the sound with the speed of the aircraft.

Question 4

(a) The majority of the candidates gave a correct answer.

(b) Generally, this question was well answered. The weaker candidates often stated a correct symbol equation representing uniform acceleration, but then made mistakes when substituting in the numerical values. Sometimes the value of the acceleration was substituted with the wrong sign. A significant number of candidates correctly stated that $v^2 = u^2 + 2as$, but then did not square the substituted value of the speed. A significant number of candidates inappropriately rounded the final answer to two decimal places (0.03 m) instead of to two significant figures (0.031 m).

(c) Only the stronger candidates were able to select and substitute the relevant values into the correct symbol equation. Many candidates used an incorrect symbol equation. A significant number substituted either an incorrect value of mass or an incorrect value of charge for the α-particle.

(d) Generally, this was well answered by the stronger candidates. The graph needed to represent the motion of the α-particle which had been brought to rest in a uniform electric field and therefore by a constant force. Weaker candidates sometimes drew a straight line from the origin or drew a curve.

(e) Most candidates realised that the gradient of the graph represented the force acting on the α-particle.

(f) (i) This question was generally well answered. Incorrect answers were given by candidates who used the mass of an α-particle instead of the mass of a β^- particle. Some candidates stated the correct symbol equation for kinetic energy, but then neglected to square the substituted value of the speed.

(ii) Most responses referred to the electric field rather than the electric force. Many candidates correctly identified the charge on each particle, but did not go on to state that the forces were in opposite directions. A common misconception was that the force would be greater on the β^- particle because it has less mass and would be easily deviated. Another misconception was that the force on the α-particle would be greater because it has a larger mass.

(iii) The majority of candidates gave the correct name of the lepton.

Question 5

(a) This question was well answered by the majority of the candidates.

(b) Most answers were correct. The most common mistake was to incorrectly convert the wavelength from nm to m. Some candidates made errors when rearranging their equations.

(c) (i) The majority of the candidates could recall the relevant symbol formula for double-slit interference using light. However, weaker candidates were often unable to relate that formula to the gradient of the graph.

(ii) Most candidates drew the correct line on the graph. A significant number drew an incorrect line that had twice the gradient of the original line.

Question 6

(a) This question was well answered by the majority of the candidates

(b) (i) The majority of the candidates calculated the correct value for the current in the circuit. A small proportion of the candidates incorrectly used the electromotive force of the cell instead of the potential difference across the wire.

(ii) This question was well answered by the stronger candidates. Various different methods were used to calculate the internal resistance of the cell.

(c) Only the stronger candidates could obtain the correct electromotive force (e.m.f.) of the cell that was now connected into the circuit. A common mistake was to assume that the potential difference across the wire was equal to the e.m.f. of the original cell at the top of the circuit. Many candidates appeared to be unfamiliar with the principle of equating the ratio of two lengths to the ratio of two potential differences.

(d) Most candidates realised that the second wire would have a greater resistance than the original wire. Some then immediately stated that the length XP for the second wire would be shorter than the length XP for the original wire. Only the strongest candidates could fully explain why the greater resistance of the wire would lead to a shorter length XP.

PHYSICS

Paper 9702/31
Advanced Practical Skills 1

Key messages

- Candidates should be encouraged to ask for assistance from the Supervisor if the experiment does not seem to be working or they are having difficulty assembling apparatus correctly (e.g. an electrical circuit).
- Candidates should be encouraged to repeat their readings, especially for measurements that are difficult to take such as timings (which inevitably have a large variation) or any situation where a single reading may not be representative of the true value, e.g. the diameter of a circle.
- Candidates need to make good use of the graph grid in **Question 1**, but this should not be achieved by the choice of awkward scales. Candidates are not awarded credit for awkward scales and also often make further errors in plotting and read-offs because the scale is so difficult to use.
- It is important that candidates always show clearly how a numerical value has been obtained. For example, in **Question 1**, where the gradient of a straight line is calculated, it is a good idea to mark both read-offs on the graph and draw lines to construct a right-angled triangle. All the steps in calculating the value of the gradient, including the read-offs themselves, should be shown.
- The evaluation of the experiment at the end of **Question 2** is always challenging. One way of tackling this question is chronologically: as the candidate does the experiment, they should note down the problems encountered and then think of practical ways to improve the experiment.

General comments

Centres did not generally have any difficulties in providing the equipment required for use by the candidates. Any deviation between the requested equipment and that provided to the candidates should be written down in the Supervisor's Report, and this report must be sent with the scripts to Cambridge so that the Examiners can take this into consideration when marking. No additional equipment should be available to the candidates. In some cases this may disadvantage candidates.

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

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

Comments on specific questions

Question 1

(a) Most candidates recorded x with a consistent unit and within the appropriate range. A few candidates omitted units or set up the apparatus out of range.

(b) Most candidates recorded p with a consistent unit and in the appropriate range. Some candidates omitted units or, again, set up the apparatus out of range.

(c) Many candidates did not repeat their measurement of n.

(d) Stronger candidates were able to collect six sets of values of p without assistance from the Supervisor. Many candidates chose too small a range over which to conduct the experiment. Careful planning is needed early on to take into account the full range of p available.

Strong candidates gave both the quantity and correct unit for each heading, separated by a solidus or with brackets around the unit. Some candidates omitted the unit or separating mark or gave an incorrect unit for either $1/p$ (often cm instead of cm^{-1}) or p. A minority of candidates gave no units for the headings.

A small number of candidates stated their p values to the nearest cm without realising they can read the ruler to the nearest mm.

Some candidates correctly recorded their calculated values for $1/p$ to the same number of significant figures as their raw p readings (or one more). A common mistake was to state the $1/p$ values to two more significant figures than were in the raw readings of p.

Most candidates calculated values for $1/p$ correctly. Some incorrectly rounded by truncating their answers.

The table work was generally done well by candidates. The most common skills for which credit was not given were the choice of range of p values, the column headings and the consistency in precision of p values.

(e) (i) Many candidates plotted the correct graph with suitable labels and chose axes so that the plotted points occupied over half of the graph grid available. Common mistakes in the graph presentation were compressed scales in the y direction, awkward scales (e.g. multiples of 3 or 7) and irregular (non-linear) scales such as those containing gaps. Some candidates labelled their axes correctly when actually the numerical scales were inverted.

Many points were drawn as neat crosses such that the centre was no more than half a square thick and were plotted correctly within half a small square in the x and y directions. Some candidates drew filled circles ('blobs') with a diameter greater than half a small square and some candidates did not plot their points within half a small square of the correct position. If a point seems anomalous, candidates should be encouraged to first check their plotting. If time permits and candidates do identify an anomalous point (having checked the plotting first), they should check their calculation. If the fault is still not identified, they should repeat the reading.

(ii) Stronger candidates were able to draw carefully considered lines of best fit. There should always be a balanced distribution of points either side of the line along the entire length. Some lines needed a rotation or a shift to get a better fit, while other lines were not straight, either because a short ruler had been used or the line was drawn by connecting one point to another.

(iii) Some candidates used a large triangle to calculate the gradient, used correct read-offs and substituted into a correct expression. Other candidates used too small a triangle (the hypotenuse should be greater than half the length of the line drawn) and there were many instances of incorrect read-offs. Some candidates did not draw a triangle and instead attempted to use points from the table to determine the gradient.

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

(f) Nearly all candidates recognised that A and B were equal to the gradient and intercept respectively. Stronger candidates correctly recorded a value with consistent units for A (m or cm) and no units for B. Weaker candidates often omitted units for A or gave a unit for B.

Question 2

(a) (i) Most candidates recorded values of l with a unit and in the appropriate range.

(ii) Most candidates measured values of D that were in the appropriate range and had a unit. Stronger candidates stated all their raw values to the nearest 0.1 mm or better.

(iii) Most candidates were able to calculate *V*. Weaker candidates did not round their answers correctly either by truncating their answer or otherwise.

(iv) Stronger candidates correctly justified the number of significant figures they had given for the value of *V* with reference to the number of significant figures used in *D* and *l*. Many candidates gave reference to 'raw readings', 'previous measurements' or 'values used in calculation' without detailing the quantity concerned. These vague statements were not given credit. It is important that candidates specify exactly which values/measurements are used.

(b) (i) Stronger candidates repeated the time taken for the first part of the oil to reach the circle at least twice, calculated a value of average time that was in the appropriate range and included the correct unit. Weaker candidates often measured just one time, omitted the units or recorded a time that was too large.

(ii) Most candidates are familiar with the equation for calculating percentage uncertainty. Some candidates made too small an estimate of the absolute uncertainty in the value of *t*, typically 0.1 s. Some candidates repeated their readings and correctly gave the uncertainty in *t* as half the range showing clear working.

(c) Nearly all candidates recorded second values of *l* and *t*, and nearly all candidates correctly recorded a smaller second *t* value than their first *t* value.

(d) (i) The majority of candidates were able to calculate *k* for the two sets of data, showing their working clearly. A few candidates incorrectly rearranged the equation algebraically to calculate $1/k$.

(ii) Stronger candidates calculated the percentage difference between their two values of *k*, testing it against a chosen criterion e.g. 10% or the percentage uncertainty in *t* from **(b)(ii)**, and provided a valid statement of conclusion. Some weaker candidates omitted a criterion, or gave invalid or general statements such as 'this is valid because the values are close to each other', which was not accepted.

(e) (i) Many candidates recognised that two sets of data were insufficient to draw a valid conclusion and stated an improvement of taking more readings and plotting a graph.

Other problems that were awarded credit included difficulty in measuring the time i.e. lifting the straw and starting the stopwatch simultaneously, difficulty in seeing the colourless oil and difficulty in positioning the straw in the centre. Candidates often mentioned these problems but did not give enough detail to be awarded credit.

(ii) Improvements that were commonly seen were using a video with a timer in shot, adding dye to the oil or drawing a cross on the paper. Vague statements like 'video and play back in slow motion' without detailing either the use of a timer in the shot or the use of frame-by-frame playback are not awarded credit.

Some candidates suggested using a robotic arm or a clamp to lift the straw, but this was not considered to be a genuine improvement to this experiment. Credit also cannot be given for suggested improvements that are standard experimental technique that could be carried out in the original experiment, such as taking repeats of *D* at different points of the straw and averaging.

Candidates can improve their answers by identifying genuine problems associated with setting up this experiment and in obtaining readings. They can do this by writing about the different measurements taken or go through the experiment systematically and state the difficulties they encounter and the reasons for them. Candidates should then try to think of solutions that address each problem.

PHYSICS

Paper 9702/33
Advanced Practical Skills 1

Key messages

- Candidates should be encouraged to ask for assistance from the Supervisor if the experiment does not seem to be working or they are having difficulty assembling apparatus correctly (e.g. an electrical circuit).
- Candidates should be encouraged to repeat their readings, especially for measurements that are difficult to take such as timings (which inevitably have a large variation) or any situation where a single reading may not be representative of the true value, e.g. the diameter of a circle.
- Candidates need to make good use of the graph grid in **Question 1**, but this should not be achieved by the choice of awkward scales. Candidates are not awarded credit for awkward scales and also often make further errors in plotting and read-offs because the scale is so difficult to use.
- It is important that candidates always show clearly how a numerical value has been obtained. For example, in **Question 1**, where the gradient of a straight line is calculated, it is a good idea to mark both read-offs on the graph and draw lines to construct a right-angled triangle. All the steps in calculating the value of the gradient, including the read-offs themselves, should be shown.
- The evaluation of the experiment at the end of **Question 2** is always challenging. One way of tackling this question is chronologically: as the candidate does the experiment, they should note down the problems encountered and then think of practical ways to improve the experiment.

General comments

Centres did not generally have any difficulties in providing the equipment required for use by the candidates. Any deviation between the requested equipment and that provided to the candidates should be written down in the Supervisor's Report, and this report must be sent with the scripts to Cambridge so that the Examiners can take this into consideration when marking. No additional equipment should be available to the candidates. In some cases this may disadvantage candidates.

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

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

Comments on specific questions

Question 1

(a) Stronger candidates recorded I with a consistent unit and within the appropriate range. Many candidates did not recognise that the current I was in mA and stated a value such as 70.1 A instead of 70.1 mA.

(b) Most candidates were able to collect six sets of values of I with different resistance pairings without assistance from the Supervisor. Many candidates chose too small a range over which to conduct the experiment. Careful planning is needed to take into account the full range of resistor combinations available. Candidates were expected to choose the two smallest resistors and the two largest resistors to make full use of the range of resistor combinations available. Some candidates used a duplicate pair of resistors so, instead of 6 results, they actually had 5.

Stronger candidates gave both the quantity and correct unit for each heading, separated by a solidus or with brackets around the unit. Some omitted the unit or separating mark or gave an incorrect unit for either $1/I$ (commonly A instead of A^{-1}) or $R_1R_2/(R_1 + R_2)$ (often a complex unit such as $\Omega^2/(\Omega + \Omega)$ instead of simply Ω). A minority of candidates gave no units for the headings.

Some candidates incorrectly tried to keep the number of significant figures the same throughout the I column instead of concentrating on the precision of the ammeter used to measure the current.

Some candidates correctly recorded their calculated values for $R_1R_2/(R_1 + R_2)$ to the same number of significant figures as, or one more than, the number of significant figures in the raw resistance readings. Other candidates stated too many significant figures, often after also adding additional zeros to the resistance values.

Most candidates calculated values for $1/I$ and $R_1R_2/(R_1 + R_2)$ correctly. Some candidates incorrectly truncated their answers. Candidates should be reminded to record their raw data and not just derived values. For candidates who did not record the raw values of I and R, it was impossible to award credit for the calculation of the derived values.

(c) (i) Stronger candidates plotted the correct graph with suitable labels, and with the plotted points occupying over half of the graph grid available.

A minority of candidates set the minimum value and maximum value of the scale on the graph grid to be the minimum and maximum readings in the table, leading to very time-consuming work plotting and using the scale. This type of scale cannot be awarded credit and it was very common for candidates using such awkward scales to lose further credit later for read-offs that were incorrect.

Some candidates used irregular (i.e. non-linear) scales. Irregular scales could not be given credit, and often the data could not be awarded credit for quality either, because the error occurred in the region of the plotted points. Candidates should be encouraged to set up their graphs to make them easy to work with in later parts of the question.

Some candidates drew filled circles ('blobs') with a diameter greater than half a small square and some candidates did not plot their points within half a small square of the correct position. If a point seems anomalous, candidates should be encouraged to first check their plotting. If time permits and candidates do identify an anomalous point (having checked the plotting first), they should check their calculation. If the fault is still not identified, they should repeat the reading.

There is no credit specifically for identifying anomalous points, so candidates should be reminded that they do not need to identify an anomalous point if they do not think they have one.

(ii) Many candidates were able to draw carefully considered lines of best fit. There should always be a balanced distribution of points either side of the line along the entire length. Some lines needed a rotation or a shift to get a better fit, while other lines were not straight, either because a short ruler had been used or the line was drawn by connecting one point to another.

(iii) Candidates need to use a large triangle to calculate the gradient, use correct read-offs and substitute into a correct expression. Weaker candidates used too small a triangle (the hypotenuse should be greater than half the length of the line drawn) and there were many instances of incorrect read-offs. Some candidates did not draw a triangle and instead attempted to use points from the table to determine the gradient.

Some candidates were able to correctly read off the y-intercept at $x = 0$ directly from the graph, but many candidates incorrectly read off the y-intercept when there was a false origin (i.e. not $x = 0$).

(d) (i) Nearly all candidates recognised that *P* and *Q* were equal to the gradient and intercept of the graph. Stronger candidates recorded values with consistent units, but weaker candidates often stated incorrect units or omitted the units.

(ii) Some candidates went on to correctly calculate *E* and *Z* and present the answers with correct units. Some candidates stated answers such as 3000 V (where 3000 mV would have been correct) and these candidates may have benefited from a quick check of whether the answer given is of a realistic magnitude.

Question 2

(a) (i) Most candidates measured values of *d* in the appropriate range. Stronger candidates repeated their values of *d* and stated all their raw values to the nearest mm.

(ii) Most candidates were able to calculate *A*. Weaker candidates often did not round their answers correctly.

(iii) Stronger candidates correctly justified the number of significant figures they had given for the value of *A* with reference to the number of significant figures used in *d*. Many candidates gave reference to 'raw readings', 'previous measurements' or 'values used in calculation' without detailing the quantity concerned and these vague statements could not be awarded credit.

(b) (i) Stronger candidates repeated the time taken to drop at least twice and calculated a value of average time. Weaker candidates often measured just one time, or their time of drop was unrealistically large. A minority of candidates misread their stop-watch and stated times in the region of 0.05 s.

(ii) Most candidates are familiar with the equation for calculating percentage uncertainty. Some candidates made too small an estimate of the absolute uncertainty in the value of *t*, typically 0.1 s, when it was a difficult reading to take. Some candidates repeated their readings and correctly gave the uncertainty in *t* as half the range after showing clear working.

(iii) Many candidates stated a value of *m* to the nearest 0.1 g that was in the accepted range and with a unit. Weaker candidates stated *m* to the nearest g when the balance can measure to the nearest 0.1 g, or sometimes omitted the unit.

(c) (i) Nearly all candidates recorded second values of *d*.

(ii) Nearly all candidates correctly recorded a larger second *t* value for larger filter papers than their first value.

(d) (i) The majority of candidates were able to calculate *k* for the two sets of data, showing their working clearly. A very small number of candidates incorrectly rearranged the equation algebraically to calculate $1/k$.

(ii) Stronger candidates calculated the percentage difference between their two values of *k*, testing it against a chosen criterion (e.g. 10% or the percentage uncertainty in *t* from **(b)(ii)**) and provided a valid concluding statement. Some candidates omitted a criterion, or gave invalid or general statements such as 'this is valid because the values are close to each other', which was not accepted.

(e) (i) Many candidates recognised that two sets of data were insufficient to draw a valid conclusion and stated an improvement of taking more readings and plotting a graph. Other problems that candidates often described included identifying the starting position (or keeping the starting point the same) with a reason e.g. difficult to keep the ruler vertical or hold the papers with hands which are constantly moving. Candidates also often mentioned the difficulty in starting the stop-watch and releasing the filter papers simultaneously, and difficulty in stopping the stop-watch at the right time. Weaker candidates often mentioned these problems but without sufficient detail to be awarded credit.

Many candidates stated that the filter papers were 'affected' by draughts without stating when, where or how the papers were affected.

(ii) Improvements that were commonly seen were using a video with a timer in shot, gluing the filter papers together, using a wind shield and using a greater distance to drop the papers through. A solution, like the problem, needs to be given with detail to be awarded credit. Vague statements like 'video and playback in slow motion' cannot be accepted without some detail about how time will be determined, either with a timer in the shot or by using the frame-by-frame playback. Similarly, answers such as 'use a set square' cannot gain credit without detail of how it will be used, and 'stick papers together' needed some idea of how this might be done. Some candidates suggested using paper clips or adhesive putty which would have been too heavy for this particular experiment.

Candidates are encouraged to turn vague statements that have relevance into detailed responses in order to gain credit. For example, candidates often stated 'use light gates': with a little more thinking, the candidate may realise that light gates are impractical here and perhaps a motion sensor would be more practical. The next question to ask would be where is the best place to put this piece of equipment? Placing the motion sensor above the filter papers or even a pressure sensor positioned at the base where the papers fall could be a possibility.

Credit is not given for suggested improvements that could have been carried out in the original experiment, such as taking repeats of *d* at different points of the circle.

Candidates can improve their answers by identifying genuine problems associated with setting up this experiment and in obtaining readings. They can do this by writing about the different measurements taken or systematically go through the experiment and state the difficulties they encounter and the reasons for them. Candidates should then try to think of solutions that address each problem.

PHYSICS

Paper 9702/34
Advanced Practical Skills 2

Key messages

- Candidates should be encouraged to ask for assistance from the Supervisor if the experiment does not seem to be working or they are having difficulty assembling apparatus correctly (e.g. an electrical circuit).
- Candidates should be encouraged to repeat their readings, especially for measurements that are difficult to take such as timings (which inevitably have a large variation) or any situation where a single reading may not be representative of the true value, e.g. the diameter of a circle.
- Candidates need to make good use of the graph grid in **Question 1**, but this should not be achieved by the choice of awkward scales. Candidates are not awarded credit for awkward scales and also often make further errors in plotting and read-offs because the scale is so difficult to use.
- It is important that candidates always show clearly how a numerical value has been obtained. For example, in **Question 1**, where the gradient of a straight line is calculated, it is a good idea to mark both read-offs on the graph and draw lines to construct a right-angled triangle. All the steps in calculating the value of the gradient, including the read-offs themselves, should be shown.
- The evaluation of the experiment at the end of **Question 2** is always challenging. One way of tackling this question is chronologically: as the candidate does the experiment, they should note down the problems encountered and then think of practical ways to improve the experiment.

General comments

Experiments are designed with the view that <u>only</u> the equipment specified in the Confidential Instructions will be provided to candidates. Centres should not change or add to the equipment specified.

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

Comments on specific questions

Question 1

(a) (i) Most candidates recorded a value for p in the range 35.0–45.0 cm, approximately half-way along wire 1.

(ii) The majority of the candidates recorded a value for q in the range 50.0–70.0 cm. Those who did not are likely to have assembled the circuit incorrectly, perhaps connecting the two fixed resistors the wrong way round, or they may have measured the distance between C and D rather than C and E.

(b) Most candidates recorded six values of p and q showing the correct trend (q should decrease as p increases). A significant number of candidates obtained results showing an incorrect trend, suggesting the circuit used was incorrect, or the distance q was measured incorrectly.

Most candidates were awarded credit for the range of values used, choosing values of p to give the widest possible range of results.

Most candidates recorded the correct column headings in their table of results, listing each quantity and its unit at the top of each column, with the quantity and the unit separated by a solidus (/) or with the unit in brackets. A few candidates omitted the units for $1/q$ or recorded units for p/q.

Most candidates recorded all their raw values of p and q to the nearest mm. Some candidates were not awarded credit because they recorded their values for q to the nearest mm but then recorded their values of p to the nearest cm. A small number of candidates recorded all their values of q with a '0' in the mm place.

Most candidates recorded their values for $\frac{1}{q}$ with the same number of significant figures as (or one more than) their raw values of q.

Almost all candidates were able to calculate the values of $\frac{1}{q}$ correctly, though a few candidates rounded their answers incorrectly.

(c) (i) Most candidates gained credit for drawing appropriate axes, with labels and sensible scales. Some candidates chose extremely awkward scales, making the correct plotting of points much more difficult. Candidates who choose awkward scales often lose further credit for incorrect read-offs when calculating the gradient or the y-intercept of the line. A few candidates chose non-linear scales, or scales which meant that one or more points were outside the graph grid.

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

Most candidates plotted their points on the graph paper carefully; others needed to draw the plotted points so that the diameters of the points were equal to, or less than, half a small square. Some candidates plotted points as dots or crosses that were too faint to see clearly or were hidden by the line of best fit (a small but clear pencil cross, or a point with a circle, is recommended). Some candidates can improve by plotting the points more accurately i.e. to within half a small square.

The majority of the candidates were awarded credit for the quality of their data.

(ii) Some candidates were able to draw a straight line that was a good fit to the points plotted, with a reasonable distribution of points above and below the line. Common mistakes were to join the first and last points on the graph, regardless of the distribution of the other points, or to draw a line which could clearly be improved by rotation. A small number of candidates drew a double line or a kinked line.

(iii) Many candidates used a suitably large triangle to calculate the gradient, gaining credit for correct read-offs and substitution into a correct expression. Others needed to check that the read-offs used were within half a small square of the line drawn, show the substitution clearly, or check that the triangle for calculating the gradient was large enough (the hypotenuse should be greater than half the length of the line drawn).

It is important that candidates show their working, making it clear which points they have chosen for the read-offs e.g. by drawing a triangle on the graph. A value for the gradient without any clear working to show how the value was obtained cannot be awarded credit.

Several candidates correctly substituted a read-off into the equation $y = mx + c$ in order to determine the y-intercept. Others needed to check the point chosen was actually on the line. A point from the table can be only be used if the point lies on the line.

Some candidates tried to read the value of the intercept directly from the graph. This is only a valid method if the scale in the $\frac{1}{q}$ direction really starts at zero, i.e. is not a 'false origin'.

(d) Most candidates recognised that *a* was equal to the value of the gradient of the line and *b* was equal to the value of the intercept calculated in **(c)(iii)**.

The majority of the candidates recorded correct units for *a* and *b* (cm^{-1} or m^{-1}); others omitted the units for *a* or *b*. The units for *a* and *b* can be derived directly from the quantities plotted on the graph or deduced from the equation given in **(d)**.

Question 2

(a) (i) Most candidates measured the distance *y* between the two holes in the wooden rod accurately and to the correct precision. Some candidates only recorded *y* to the nearest cm or measured the distance between the two ends of the rod.

(ii) The majority of the candidates measured the angle θ correctly, recording raw values in the range 40–60°. Some recorded raw values to too great a precision (0.1°), and a few candidates read the wrong scale on the protractor, recording values greater than 90°.

(iii) Many candidates made poor estimates of the absolute uncertainty in their value of θ. Any such estimate needs to take into account not only the precision of the protractor as an instrument but also the potential errors in making the measurement, such as parallax error and the difficulty of holding the protractor steady. A realistic estimate for the uncertainty in the value of θ is 2–5°.

(iv) Almost all candidates calculated the value of *D* correctly, though a few candidates rounded their final answer incorrectly.

(v) Many answers given by candidates to justify the number of significant figures recorded for the value of *D* were vague. Answers should not simply refer to 'raw readings'. A more detailed answer is needed such as 'the significant figures of *D* are determined by the significant figures of *y* and θ – whichever is the smallest'.

(b) (i) Most candidates measured the time taken for several swings and repeated their measurements to find an average value for *S*. A general rule would be to try to measure the time for at least 5 oscillations, repeating this measurement two or three times and finding an average value.

The majority of the candidates calculated a value for *S* that was in the correct range and had a unit, though a few either forgot to divide their raw times by the number of oscillations or omitted the unit.

(ii) Almost all candidates correctly recorded all their raw times to the same precision.

(c) Almost all candidates were able to record a second set of values for θ, *S* and *B*, and most correctly found that *B* decreases as θ decreases.

(d) (i) Most candidates were able to calculate two values for *k* correctly. Some candidates recorded their final values for *k* to only one significant figure.

(ii) Most candidates calculated the percentage difference between their two values of *k*, and then tested it against a specified numerical percentage uncertainty, either taken from **(a)(iii)** or estimated themselves. Where candidates state a percentage uncertainty value, it is a good idea to try to justify this value in some way, particularly if a very large percentage uncertainty is suggested.

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

(e) (i) Many candidates recognised that two sets of data were insufficient to draw a valid conclusion, though some confused conclusions with results.

Some candidates simply stated measurements that were difficult without explanation e.g. ‘it was difficult to measure θ’ without explaining why. In these cases, more detailed answers such as ‘θ was difficult to measure because of parallax error’ or ‘the angle was difficult to measure because it was difficult to hold the protractor steady’ would have gained credit.

Some candidates gave a valid reason why it was difficult to measure *B* (or *S*) e.g. ‘it was difficult to determine the exact moment an oscillation is completed’. Several candidates noted that the rod tended to oscillate in more than one plane.

(ii) Valid improvements included taking more readings for different values of θ and then plotting a suitable graph to test the suggested relationship. Some candidates suggested repeating the experiment with different values of θ, calculating the value of *k* in each experiment and then comparing them to see if *k* can be considered constant. Other good answers included:

- videoing the experiment with a clock/timer in view, then replaying the video slowly, or frame-by-frame, to establish the exact time an oscillation started or was completed
- clamping the protractor in order to measure θ
- using a (fiducial) marker at the centre of the oscillation when measuring *B*.

Some candidates suggested improvements which could have been carried out in the original experiment such as measuring the height of each end of the rod above the bench to find out if the rod is horizontal. No credit is given for these suggestions.

PHYSICS

Paper 9702/35
Advanced Practical Skills 1

Key messages

- Candidates should be encouraged to ask for assistance from the Supervisor if the experiment does not seem to be working or they are having difficulty assembling apparatus correctly (e.g. an electrical circuit).

- Candidates should be encouraged to repeat their readings, especially for measurements that are difficult to take such as timings (which inevitably have a large variation) or any situation where a single reading may not be representative of the true value, e.g. the diameter of a circle.

- Candidates need to make good use of the graph grid in **Question 1**, but this should not be achieved by the choice of awkward scales. Candidates are not awarded credit for awkward scales and also often make further errors in plotting and read-offs because the scale is so difficult to use.

- It is important that candidates always show clearly how a numerical value has been obtained. For example, in **Question 1**, where the gradient of a straight line is calculated, it is a good idea to mark both read-offs on the graph and draw lines to construct a right-angled triangle. All the steps in calculating the value of the gradient, including the read-offs themselves, should be shown.

- The evaluation of the experiment at the end of **Question 2** is always challenging. One way of tackling this question is chronologically: as the candidate does the experiment, they should note down the problems encountered and then think of practical ways to improve the experiment.

General comments

Centres did not generally have any difficulties in providing the equipment required for use by the candidates. Any deviation between the requested equipment and that provided to the candidates should be written down in the Supervisor's Report, and this report must be sent with the scripts to Cambridge so that the Examiners can take this into consideration when marking. No additional equipment should be available to the candidates. In some cases this may disadvantage candidates.

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

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

Comments on specific questions

Question 1

(a) Many candidates stated a value of H with a correct unit and set up the apparatus correctly so that H was in the accepted range. Some candidates omitted units.

(b) Many candidates stated a value of T and set up the apparatus correctly so that T was in the accepted range. Many candidates recorded repeat readings of at least five oscillations. Some candidates only recorded one value of time or repeated the timing of only 1–3 oscillations.

(c) Many candidates were able to collect six sets of values of *w* and time without assistance from the Supervisor, and showed a correct trend in their values. Many candidates took the time to repeat their readings. Repeating readings may have helped to identify anomalous results and improve data quality. If time is limited, candidates should be encouraged to look out for possible outliers which do not fit a general trend and repeat these readings to double-check.

Candidates were guided to take readings for *w* in the range 5.0–20.0 cm. Many candidates recorded values in this range. It is expected that candidates use the whole range of values that can be achieved with the apparatus provided. Some candidates did not include small enough or large enough *w* values.

Many candidates were awarded credit for the column headings, giving both the quantity and a correct unit for each heading, with the quantity and unit separated by a solidus or with the unit in brackets. Some candidates omitted either the unit or the separating mark for one of the columns.

Many candidates correctly recorded their raw values for *w* to the nearest 0.1 cm. Some candidates stated their measurement to the nearest cm e.g. 15 cm without considering that they can read the ruler to the nearest 0.1 cm. A few candidates stated measurements with too many trailing zeros, e.g. 15.00 cm.

Many candidates recorded their calculated values for 1 / *w* to the correct number of significant figures i.e. to the same number of significant figures as (or one more than) the number of significant figures in the raw values of *w*. Each row of figures must be correct in itself, which means the number of significant figures down the 1 / *w* column may vary.

Most candidates calculated values for 1 / *w* correctly. A few candidates rounded their values incorrectly.

Overall the table work was done well by candidates.

(d) (i) Many candidates plotted points carefully using a sharp pencil, and the points were close to a straight line.

A minority of candidates set the minimum value and maximum value of the scale on the graph grid to be the minimum and maximum readings in the table, leading to very time-consuming work plotting and using the scale. This type of scale cannot be awarded credit and it was very common for candidates using such awkward scales to lose further credit later for read-offs that were incorrect.

Some candidates used irregular (i.e. non-linear) scales. Irregular scales could not be given credit, and often the data could not be awarded credit for quality either, because the error occurred in the region of the plotted points. Candidates should be encouraged to set up their graphs to make them easy to work with in later parts of the question.

Some candidates drew filled circles ('blobs') with a diameter greater than half a small square and some candidates did not plot their points within half a small square of the correct position. If a point seems anomalous, candidates should be encouraged to first check their plotting. If time permits and candidates do identify an anomalous point (having checked the plotting first), they should check their calculation. If the fault is still not identified, they should repeat the reading.

There is no credit specifically for identifying anomalous points, so candidates should be reminded that they do not need to identify an anomalous point if they do not think they have one.

(ii) Stronger candidates were able to draw carefully considered lines of best fit. There should always be a balanced distribution of points either side of the line along the entire length. Some lines needed a rotation or a shift to get a better fit, while other lines were not straight, either because a short ruler had been used or the line was drawn by connecting one point to another.

Candidates should be encouraged to draw the line according to the positions of the plotted points, and not to force the line through the origin.

(iii) Some candidates used a large triangle to calculate the gradient, used correct read-offs and substituted into a correct expression. Other candidates used too small a triangle (the hypotenuse should be greater than half the length of the line drawn). Some candidates did not draw a triangle and instead attempted to use points from the table to determine the gradient.

There were many instances of incorrect read-offs, and many candidates would benefit from double-checking their read-offs.

(e) (i) Many candidates recognised that the gradient value was equal to the value of *B* and gave a correct unit.

(ii) Many candidates successfully calculated *g*, having recognised that, as the unit of $m\,s^{-2}$ was given on the answer line, values that were used in the calculation needed to be in metres.

Question 2

(a) (i) Many candidates stated a value of L_0 and set up the apparatus correctly so that L_0 was in the appropriate range.

(ii) Most candidates are familiar with the equation for calculating percentage uncertainty. Some candidates made too small an estimate of the absolute uncertainty in the value of L_0 by choosing to use the smallest division on the ruler, i.e. 1 mm. Some candidates repeated their readings and correctly gave the uncertainty in L_0 as half the range, while other candidates did not halve the range.

(b) (i) Many candidates stated a value of L_1 and added mass to the apparatus correctly so that L_1 was greater than L_0.

(ii) Most candidates correctly used their L_0 and L_1 values to calculate $(L_1 – L_0)$.

(iii) Most candidates were able to calculate *k* for the two sets of data, showing their working clearly.

(iv) Many candidates were able to justify the number of significant figures given in *k* by linking to the values of *F* and $(L_1 – L_0)$.

(c) (i) The rulers provided to make the measurements had a precision of 1 mm. Many candidates were able to accurately measure and record the distance *d* and length *L* to the nearest mm. To improve, some candidates need to record values to the nearest mm rather than to the nearest cm e.g. 92.0 cm rather than 92 cm, and other candidates need to resist the temptation to add extra zeros to their readings e.g. recording 8.2 cm as 8.20 cm.

(ii) Most candidates recorded second *d* and *L* values which correctly gave a greater value of $(L_1 – L_0)$ than their first value.

(d) (i) Many candidates were able to calculate *C* for the two sets of data, showing their working clearly. A minority of candidates incorrectly rearranged the equation algebraically to calculate $1 / C$ or chose to round their final answer to only one significant figure.

(ii) Many candidates calculated the percentage difference between their two values of *C*, and then tested it against a specified numerical percentage uncertainty as a criterion, commonly using 10% or 20%. Some candidates referred back to the percentage uncertainty calculated for L_0 and this was also credited. Weaker candidates often omitted a criterion, or gave a general statement such as ‘this is valid because the values are close to each other’.

(e) Many candidates were able to calculate *W,* showing their working clearly. Candidates needed to read the question with care to ensure a value of 100 cm or 1 m was correctly used for d_0.

(f) (i) This experiment provided many limitations to comment on, ranging from the difficulty arranging the rule to stay on the mass hanger to the practical difficulties of measuring the length of a coiled spring. Many candidates recognised how difficult it was to measure *d* as the rule slipped from the hanger, the difficulty in adjusting the spring until vertical and the small value of $(L_1 – L_0)$ giving a large percentage uncertainty. Having recognised these difficulties, candidates gave detailed descriptions of the difficulties with detailed suggestions of how to improve the measurements.

Many candidates recognised that two sets of data were insufficient to draw a valid conclusion and stated an improvement of taking more readings and plotting a graph. Some candidates stated ‘two readings is not enough to draw a graph’ which did not have enough detail either as a limitation or as an improvement.

Some candidates gave problems that were irrelevant or that could have been removed if the candidate had taken greater care; these were not given credit. Vague or generic answers such as ‘too few readings’ (without stating a consequence), ‘faulty apparatus’ or ‘unstable stand’ do not gain credit.

(ii) To gain credit for improvements, candidates need to provide detail about how the improvement would be made in practice, such as ‘use vernier calipers to measure the length of the spring’ or ‘measure the mass of the putty with a balance’. Vague improvements such as ‘keep eye level’ or ‘fix the rule’ cannot be given credit.

Candidates can improve their answers by identifying genuine problems associated with setting up this experiment and in obtaining readings. They can do this by writing about the different measurements taken or go through the experiment systematically and state the difficulties they encounter and the reasons for them. Candidates should then try to think of solutions that address each problem.

PHYSICS

Paper 9702/36
Advanced Practical Skills 2

Key messages

- Candidates should be encouraged to ask for assistance from the Supervisor if the experiment does not seem to be working or they are having difficulty assembling apparatus correctly (e.g. an electrical circuit).
- Candidates should be encouraged to repeat their readings, especially for measurements that are difficult to take such as timings (which inevitably have a large variation) or any situation where a single reading may not be representative of the true value, e.g. the diameter of a circle.
- Candidates need to make good use of the graph grid in **Question 1**, but this should not be achieved by the choice of awkward scales. Candidates are not awarded credit for awkward scales and also often make further errors in plotting and read-offs because the scale is so difficult to use.
- It is important that candidates always show clearly how a numerical value has been obtained. For example, in **Question 1**, where the gradient of a straight line is calculated, it is a good idea to mark both read-offs on the graph and draw lines to construct a right-angled triangle. All the steps in calculating the value of the gradient, including the read-offs themselves, should be shown.
- The evaluation of the experiment at the end of **Question 2** is always challenging. One way of tackling this question is chronologically: as the candidate does the experiment, they should note down the problems encountered and then think of practical ways to improve the experiment.

General comments

Very few centres reported difficulty in providing the equipment needed. It is important to return the Supervisor's Report and sample results as these make it possible for the Examiners to allow for any small changes to equipment when assessing the candidates' work.

Nearly all candidates completed the two questions. Many candidates demonstrated good skills in measuring, recording and processing their results.

Many candidates are familiar with the technique of measuring the total time for a number of oscillations before dividing to find the period. Candidates should be reminded that a similar procedure may be used to improve the precision of a thickness measurement when they have access to several identical items.

The addition of a line to a set of plotted points is a skill that can benefit from opportunities to practise, using provided data points. When practising this skill, candidates can check their efforts against a least-squares fit on their calculator or in a spreadsheet such as Excel.

Comments on specific questions

Question 1

(a) (i) Most values recorded for *L* were in the expected range but in a few cases were well outside it, suggesting that the apparatus had not been adjusted exactly as instructed.

(ii) The majority of candidates obtained a value of *T* in the expected range.

Examiners expected to see measurement of nT followed by division by n to obtain T. Many candidates carried this out. There were also some common errors such as recording the nT value as T, or repeating and averaging T for only a single oscillation.

(b) There were many neat, clear tables of results and nearly all candidates included six sets of readings. Most column headings included a unit, though this was sometimes missing in the L^2 and T^2 columns.

All L values should have been recorded to the nearest millimetre but in a few cases an extra zero was added.

In many cases the range of L values used by the candidate was too small to gain credit. This can lead to an additional problem in that two close L values could give the same T value and then the correct trend cannot be seen. Candidates should be encouraged to make maximum use of the range of values that is available to them when carrying out an experiment.

Calculated values of L^2 were generally correctly rounded. The use of the correct number significant figures for calculated values was usually good, although some candidates kept the same number of decimal places down the column, and this could lead to an incorrect number of significant figures for one or more of the values.

(c) (i) There were many cases of poor choice of scales for the graph axes, with awkward interval values on the grid (e.g. 100 for three large squares on the L^2 axis). This appeared to be caused by an attempt to use the entire graph grid. It is only necessary for the points to occupy at least half of the large squares in each direction, and candidates should be discouraged from choosing awkward scales in an attempt to make better use of the grid.

Candidates should check that they have not changed the scale part-way along an axis (e.g. 0.97, 0.98, 0.99, 1.0, 1.1, 1.2) as this makes the scale non-linear.

Plotting of points was generally accurate. In some cases a blunt pencil had produced a heavy cross and it was not possible for the accuracy of the plotting to be checked.

For most candidates the scatter of the points about a linear trend was small enough to gain credit for the quality of the results.

(ii) Many candidates' lines of best fit could be improved by rotation or sideways movement, and in many cases a kinked line was drawn (probably by joining two lines drawn using a short ruler).

(iii) Most candidates knew how to calculate the gradient and intercept of their line. In most cases coordinates were read accurately, although awkward scales often made this difficult and sometimes led to errors. Use of values from the table of results was only accepted if they lay on the candidate's line.

(d) The majority of candidates correctly transferred their values from **(c)(iii)**, with only a few cases of candidates giving their final values to just one significant figure.

The units for a and b were sometimes omitted by weaker candidates.

Question 2

(a) (i) Stronger candidates measured the height of a stack of rings to determine their mean thickness. Others measured several rings individually (to low precision) and then averaged them, but this method was not awarded credit.

(ii) Most candidates gained credit for this straightforward task, the only common error being to give their ruler measurements to an unreasonable precision (e.g. 1.10 cm).

(iii) This calculation was correct in most cases.

(iv) Most candidates were correctly able to list all of d_1, d_2 and t as the quantities whose significant figures had been considered when deciding the significant figures for the volume of the ring.

(b) (i) Most candidates were awarded credit. A common error was to record a value to too high a precision (e.g. 50.0 cm^3).

(ii) Most candidates carried out these measurements successfully.

(iii) Stronger candidates used an appropriate uncertainty of 2 or 3 cm^3 when calculating the percentage uncertainty in V_A. Weaker candidates used a very small uncertainty (e.g. 0.1 cm^3) and some tried to add individual uncertainties for x_1 and x_2.

(c) Many candidates recorded their second set of syringe measurements, with the values showing the expected trend.

(d) (i) Most candidates calculated the two *k* values correctly, with just a few cases of arithmetical error or incorrect rearrangement of the expression.

(ii) Many candidates correctly evaluated the percentage difference between the two *k* values and most stated the numerical standard that they used to decide whether the *k* values were close enough.

(e) (i) This section called for descriptions of difficulties found in carrying out the procedures, and limitations in the accuracy of readings. Although there were some good answers, weaker candidates often had difficulty in describing the limitations and linking them to a particular procedure or measurement.

Many candidates identified the problem of verifying a relationship with only two sets of test data.

Many candidates were concerned about the low precision of the measuring instrument (the ruler) but often linked it to 'accuracy' rather than 'high percentage uncertainty' in ring diameter. It is important for candidates to use appropriate physics terminology.

Another concern was the measurement of the quantity of air needed to lift the cup and its load of rings. Associated problems were stopping the syringe plunger when the cup started to rise, and the false air volume caused by part of it actually being water that had got into the tube.

There were several answers that mentioned that the theory only considered the rings but ignored the mass of the cup, paper clip and string.

No credit was given for descriptions of features that did not affect the procedure or measurements (e.g. not being able to see the water level clearly).

(ii) Candidates generally found it easier to describe improvements than to identify the problems in **(e)(i)**.

Many candidates said that taking more readings and plotting a graph could be used to test the suggested relationship.

A named higher-precision instrument for measuring the rings was often suggested and this was given credit. The idea of recording a video of the experiment (including the syringe) to find the reading when the cup started to rise was also credited.

The suggestion of adding the mass of the cup, paper clip etc. to the mass of the rings was accepted provided the measuring instrument was named (e.g. a top-pan balance).

A small number of candidates listed problems and improvements that they had seen in mark schemes for experiments from previous papers, but these were often not relevant to the experiment in this paper and so could not gain credit.

PHYSICS

Paper 9702/41
A Level Structured Questions

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

PHYSICS

Paper 9702/42
A Level Structured Questions

Key messages

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

- In defining quantities, candidates need to take care to ensure that the definition they give is dimensionally correct. This often requires use of the phrase 'per unit' where the quantity being defined is the ratio between two other quantities, or 'product' where the quantity being defined is two other quantities being multiplied together.

- Candidates need to take care to ensure that they read the question properly, understand what is being asked and give responses that answer the question that is asked. It is not uncommon to find candidates giving answers to questions that were not asked, but that have been asked in recent past papers. Candidates should be advised not to rely heavily on memorising previous mark schemes.

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

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

General comments

Some candidates had a weak basic knowledge of the syllabus, and many candidates found it difficult to access questions asking for routine recall of syllabus knowledge. There seemed to be a greater number of questions left un-attempted than is usual. Candidates who knew the 'bookwork', read the questions carefully and answered the questions asked, and who were able to apply their knowledge of physics to unfamiliar situations, were able to perform well.

The paper contained several questions (including **3(a)(ii)** and **7(b)**) where candidates were asked to give a specified number of points in their responses. It is important for candidates to understand that, if they give more than the specified number of points, the Examiners will only assess what they have written up to the point where the required number of points have been made. Any points made beyond the specified number are disregarded, and so it is important that candidates think carefully about the points they are going to make and avoid filling up the page with everything that comes into their heads. Many candidates made points in response to **Questions 3(a)(ii)** and **7(b)** that were worth credit but which could not be awarded credit because so many incorrect points had been made first.

Comments on specific questions

Question 1

(a) Correct responses were seen either in terms of acceleration perpendicular to velocity or in terms of the acceleration that causes circular motion. Many candidates gave responses that were too vague to gain credit. Common vague responses were those that just stated an equation that can be used for calculating centripetal acceleration or that relied on the word 'centripetal' as part of the explanation.

(b) (i) Many candidates did not appreciate that the car moves more slowly at Y than at X, and that the centripetal acceleration at Y is therefore smaller than at X.

(ii) Candidates found this question difficult and many demonstrated a weak understanding of the forces involved in circular motion. There was a widespread misunderstanding that centripetal force is some sort of additional force that has to 'balance' the weight; very few candidates appeared to understand that the centripetal force is the resultant of the weight and the normal contact force from the track. The more able candidates were generally able to gain partial credit, but only the strongest candidates could be awarded full credit.

(c) This was a challenging question that first required candidates to apply the principle of conservation of energy to determine the speed of the car at Y. Having found that, candidates then needed to determine the centripetal acceleration at Y and correctly compare it with $9.8\,\mathrm{m\,s^{-2}}$ (the test given to them in **(b)(ii)**). Many candidates obtained credit for knowing the equation for centripetal acceleration in terms of speed and radius, but only the stronger candidates made any attempt at applying conservation of energy.

(d) Some candidates were able to give a reasoned explanation of why the speed (or acceleration) of the car at Y is independent of the mass of the car (usually by showing that mass cancels in the equations) and that therefore the conclusion will be unchanged. However, many candidates thought that the greater the mass of the car the greater will be the centripetal acceleration.

Question 2

(a) This question tested straightforward recall of syllabus knowledge. Many candidates, instead of giving the relationship between field strength and potential, gave separate definitions of the two quantities.

(b) (i) Many candidates were given credit for identifying that the gravitational force is attractive and that potential is defined to be zero at infinity. Only the stronger candidates were able to successfully explain why the potential energy of two masses decreases as they approach each other.

(ii) There was a variety of ways in which candidates could access marks, but what Examiners were looking for was an understanding of the significance of aspects of the graph to the planet–moon system and not simply descriptions of the shape of the curve. Credit could be gained by description of the relative magnitudes of the potential at the surfaces of the planet and the moon, comparisons of the field strengths (using the gradient of the graph) at the surfaces, descriptions of the trend of the variation of potential with distance near to the surfaces, or identification of the point at which the resultant field strength is zero. Many responses started to address some of these points but were unable to gain credit either because of confusion between magnitudes and absolute values or by not qualifying the point made as only applying near to the surface. Some responses involved repeating or re-phrasing information that had already been provided (i.e. relating to the potential always being negative).

(iii) Some good responses were seen to this question, and a significant number of candidates demonstrated a good understanding of how the field strength relates to the potential graph. Most candidates were awarded at least one of the three marks available. The marking point most commonly achieved was the one dealing with the general shape of the curve; realisation that the gravitational field changes direction at the point where it becomes zero was less common, and some candidates were not given full credit because they took insufficient care over the value of *x* at which the curve crosses the axis.

Question 3

(a) (i) Many candidates did not state that an elastic collision is one in which kinetic energy is conserved. Responses in which conservation of momentum and/or conservation of energy generally were discussed were common. A significant minority of candidates discussed elastic deformation of the particles.

(ii) Most candidates were able to identify at least one of the assumptions of the kinetic theory. A common error was to not recognise that the kinetic theory deals with the particles that make up the gas rather than the gas itself.

(b) The four different parts to this question provided a structured test of the understanding of candidates of some of the steps involved in the derivation of $pV = \frac{1}{3}Nm\langle c^2\rangle$ that is required by the syllabus. Many candidates were awarded full credit and many others obtained various degrees of part credit. Common errors were to omit the factors of 2 in **(i)** and/or **(ii)**, and to invent letters not defined in the question in the answers to **(iii)** and/or **(iv)**.

(c) This syllabus derivation was well recalled and set out by many candidates. Those that started from $pV = NkT$ generally found it more straightforward to get to the required expression than those that started from $pV = nRT$. Both starting points were possible, but candidates choosing the latter needed to make the relationships between n and N, and between R and k, clear at some point in their answer.

(d) Many candidates were able to get as far as calculating a value for $\langle c^2\rangle$, but the relationship between $\langle c^2\rangle$ and r.m.s. speed was less well understood. Some weaker candidates left the temperature in °C and were thus unable to obtain credit.

Question 4

(a) Many candidates did not answer the question that was asked. Many excellent descriptions of the characteristic properties of simple harmonic motion were seen from candidates that missed the fact the question asked for *features of the line*. Most candidates that did answer the question asked were able to be awarded at least partial credit.

(b) This question was answered well by many candidates, with full credit being common. The most common reason for a mark not being awarded was not dealing with the power-of-ten conversion in the value of x. Inversion of the gradient was a more serious error that usually limited credit to one mark, and candidates that used incorrect starting equations (most commonly $a = -\omega x$) could not be awarded credit.

(c) (i) This question was generally well answered, with most candidates appreciating that the end of the line corresponds to zero velocity and therefore zero kinetic energy.

(ii) This was a more challenging question, and only the strongest candidates realised that the squared nature of the variation of potential energy with displacement (or kinetic energy with velocity) means that the displacement where these quantities have half their maximum value is more than half of the amplitude.

Question 5

(a) (i) Many candidates gave descriptions of what modulation is, rather than answering the question about why modulation is used. Of those that did answer the question, common misconceptions were that modulation reduces attenuation, reduces noise, or enables the signal to travel further.

(ii) The advantages and disadvantages of frequency modulation over amplitude modulation were slightly better understood than the purposes of using modulation. It was more common for candidates to be awarded credit for the disadvantage than for the advantage, with the lower signal range for FM being well understood. Many responses were seen in which ‘higher quality’ was discussed but in which it was not clear enough what has a higher quality.

(b) Candidates who understood the effects of the different types of modulation on the carrier wave were able to gain access to full credit with relative ease. Many other candidates were able to access varying degrees of partial credit. The less able candidates had very little appreciation of the difference between AM and FM.

(c) This question was generally well answered by candidates who were familiar with the topic.

Question 6

(a) The definition of electric potential appeared to be well known by many candidates but only described fully by some. Many candidates established the correct sign convention, but it was common for candidates to define an energy rather than an energy per unit charge.

(b) This question was generally well answered, with candidates that knew the definition of capacitance usually able to combine that with the expression for the potential at the surface of a sphere to deduce the required expression.

(c) Most candidates found this to be a challenging question. They were generally able to calculate correctly the initial charge on the dome but then often assumed (despite the clue in the question) that the potential remains 4.5 kV on both spheres.

Only the strongest candidates appreciated that conservation of charge means that the total charge remains the same when distributed across the two spheres. Two different valid methods were seen in the responses of these candidates from that point onwards; some obtained expressions for the potentials across the two spheres in terms of the total charge and the charge transferred, and then equated these expressions. Others calculated the combined capacitance of the two spheres and then used the total charge to determine the final potential before then applying this potential to the smaller sphere. Both of these methods led to the correct answer, and the candidates that understood the physics of the question were usually successful in obtaining this answer.

Question 7

(a) The general definition of gain, as the ratio of the output potential to the input potential, was well known. Only the strongest candidates answered the question fully by explaining what is meant by the 'input potential' in the specific case of an operational amplifier.

(b) The effects of negative feedback on the gain of an op-amp were generally well known, with many candidates earning at least partial credit. Two common misconceptions were that negative feedback eliminates saturation and that it always results in a negative output.

(c) (i) Candidates that understood the circuit were usually able to identify it as an inverting amplifier.

(ii) Many candidates that did not understand the role of the virtual earth in the inverting amplifier circuit generally labelled a point that was on the actual earth rail. Some labelled the output. Candidates that understood the circuit were usually able to label the correct point.

(iii) Most candidates knew the equation for the gain of the inverting amplifier, but many that calculated the correct numerical value ended up inexplicably dropping the essential minus sign in the presentation of their final answers. A small number of candidates added a unit (usually 'V') to the answer. Some weaker candidates used an incorrect starting equation, often for the gain of the non-inverting amplifier.

(iv) Candidates that gave an answer to **(c)(iii)** were usually able to use their value to calculate a correct answer to this question.

(v) Many candidates calculated correctly the product of gain and V_{IN}, but then neglected to appreciate that the output will be saturated.

Question 8

(a) (i) The large number of random directions shown for the magnetic field at Q due to the current in P revealed that candidates would benefit from better familiarity with the basic principles of electromagnetism. Candidates should know that the magnetic field around wire P (which carries a current into the page) is clockwise, and therefore be able to deduce that the direction of this field at wire Q is down the page.

(ii) More candidates realised that the force on Q is towards P than answered **(a)(i)** correctly, indicating that these candidates knew the attractive nature of the force as a fact rather than being able to correctly deduce it from the directions of the field and current at Q. Some candidates knew the attractive nature of the force but did not take enough care over the line of action of the drawn arrow for credit to be awarded.

(b) (i) Stronger candidates appreciated that the forces have equal magnitude and were able to reason this either by reference to Newton's 3rd law or by consideration of the factors affecting the force on each wire. Many of the weaker candidates thought that the force on wire Q must be double the force on wire P, due to it having double the current, but omitted to consider that this current is in a magnetic field that has half the flux density of that at wire P.

(ii) This question was generally well answered, with most candidates (particularly those that referenced Newton's 3rd law in **(b)(i)**) appreciating that the forces must be in opposite directions.

Question 9

(a) (i) Many candidates were able to describe the photoelectric effect as the emission of electrons from a surface when electromagnetic radiation is incident on it and therefore achieved full credit. Common reasons for not achieving full credit were attributing the cause of emission to only one specific named part of the electromagnetic spectrum or confusing photons with electrons as the particle emitted. Some candidates confused photoelectric emission with electrons transitioning between energy levels in an atom.

(ii) Common reasons for not achieving credit were omission of the word 'minimum' or not making it clear that the minimum energy relates to emission from the surface of the metal. Some candidates thought that the work function is the energy needed to move the electron to the surface.

(b) (i) Candidates that understood the photoelectric effect generally knew the term 'threshold frequency'.

(ii) Many candidates made no reference to the photon model of electromagnetic radiation. Many such answers were written entirely in terms of frequency (rather than energy considerations), and therefore essentially did little more than to re-state the question. Other candidates made no attempt to answer the question but instead listed other observations of the photoelectric effect that provide evidence for the photon model. There were various ways in which candidates could obtain credit by describing features of the photon model, but for full credit the key statement was that photoemission only takes place when the energy of a photon is at least as large as the work function.

(iii) Most candidates were able to get as far as calculating the work function energy in J, but some had difficulty converting this to eV.

Question 10

(a) (i) There was much misunderstanding of the function of the iron core in a transformer, with responses in terms of conducting current or converting voltages being common. Many candidates that did appreciate that the function is something to do with magnetism were unable to articulate their responses clearly enough for credit to be awarded. Many candidates did not use the correct terminology relating to magnetic flux linkage.

(ii) Many candidates did appreciate the problem of energy losses due to induced currents in the core but thought that the purpose of lamination is to eliminate these. Full credit was only obtainable by candidates that realised that induced currents and their subsequent energy losses were reduced by lamination (but cannot be eliminated altogether). A significant minority of weaker candidates thought that the purpose of lamination was to prevent corrosion of the iron.

(b) (i) This question was generally well answered, with most candidates that offered a response calculating the value of V_{OUT} correctly.

(ii) There were two steps involved in this calculation: firstly calculation of the peak current from the maximum value of V_{OUT}, and secondly the division by $\sqrt{2}$ to convert from the peak value to the r.m.s. value. Candidates who did not reach the correct answer generally missed out one or other of these steps.

(iii) The strongest candidates were able to achieve full credit here, but partial credit was much more common. In particular, the shape of the power–time graph (which is essential for understanding the relationship between peak power and mean power), as a $\sin^2\theta$ graph, was poorly understood. Many candidates were unable to obtain credit for the shape because they drew $|\sin\theta|$ graphs rather than $\sin^2\theta$ graphs.

(c) Candidates were not generally aware that the symmetry of the power–time graph about $P_0/2$ is the reason why the mean power is half the peak power for sinusoidal a.c. Some good explanations, in terms of the area of the curve above $P_0/2$ being the same as the area below it, were seen from the strongest candidates.

Question 11

(a) Many candidates were able to make a start with this question, either by discussing the function of the quartz crystal in producing ultrasound or by describing the piezoelectric effect. Fewer candidates made reference to the role of the crystal in detecting reflected ultrasound, and full credit was only achieved by the strongest candidates.

(b) (i) Many candidates knew that specific acoustic impedance is defined as the product of density and speed, but fewer were able to describe correctly that the speed refers to the speed of the ultrasound in the medium. Many weaker candidates described it as the speed of light.

(ii) Many candidates appreciated that it is the comparison between the two specific acoustic impedances (how similar or different they are) that determines the value of the intensity reflection coefficient. The stronger candidates correctly related the two. It was common for weaker candidates to make no reference at all to the value of the coefficient in their responses, instead using vague references to ‘amounts’ reflected or transmitted.

Question 12

(a) (i) Most candidates appreciated that randomness of decay is something to do with unpredictability, but many responses were too vague about what it is that is unpredictable. It is clear that some candidates think that everything about radioactive decay is unpredictable and are unaware that on a macroscopic level it is very predictable. Only responses that discussed the unpredictability of decay of individual nuclei were awarded credit.

(ii) Generally, candidates were more successful in answering this question than **(a)(i)**, and the idea that radioactive decay is unaffected by external environmental conditions was well known. A small number of candidates confused ‘random’ and ‘spontaneous’ and gave their responses to these two questions the wrong way around.

(b) (i) Candidates found this to be a challenging question. There were various methods that could be used to arrive at the final answer, and many candidates were able to make a start. Candidates that chose to calculate the activities often struggled with the fact that the data was presented as logarithms of activity, and those that used the gradient route (to find decay constant and hence half-life) often had difficulty because the *y*-axis did not start at the origin.

(ii) This proved to be another challenging question for many candidates. The mark scheme ensured that partial credit was relatively easy to access, and many candidates obtained credit for either knowing $A = \lambda N$ or for correctly relating nucleon number to N, m and either the unified atomic mass constant or the Avogadro constant.

There was a lot to consider in putting everything together for the final calculation (including a unit conversion from minutes to seconds in determining decay constant and a power-of-ten conversion in the mass if the Avogadro method was used). Only the strongest candidates achieved full credit.

PHYSICS

Paper 9702/43
A Level Structured Questions

Key messages

- It is important that candidates use technical language accurately. Examples of words that are often confused by candidates are atom and molecule, nuclide and nucleus, and force and field. Candidates are not able to obtain full credit if they use an inappropriate word that makes the response technically incorrect.
- In defining quantities, candidates need to take care to ensure that the definition they give is dimensionally correct. This often requires use of the phrase 'per unit' where the quantity being defined is the ratio between two other quantities, or 'product' where the quantity being defined is two other quantities being multiplied together.
- Candidates need to take care to ensure that they read the question properly, understand what is being asked and give responses that answer the question that is asked. It is not uncommon to find candidates giving answers to questions that were not asked, but that have been asked in recent past papers. Candidates should be advised not to rely heavily on memorising previous mark schemes.
- When answering questions involving calculations, it is important for candidates to show their reasoning clearly. This includes taking care to use the correct conventional symbols for physical quantities. If working is clear and based on use of correct physics, it is often possible for examiners to award partial credit even when the final answer is incorrect. Incorrect answers that are not supported by working cannot be awarded credit.
- Answers to numerical questions should be given to an appropriate number of significant figures; the precision of the data provided in the question is generally indicative of the appropriate number of significant figures for an answer. When performing intermediate calculations within a question, candidates should take care to avoid premature rounding; as a general rule, any intermediate calculated values should always carry at least one more significant figure than will be used in the final answer. Candidates should be made aware that giving answers to an inappropriate number of significant figures, or that are inaccurate as a result of rounding intermediate values prematurely, can both lead to full credit not being awarded.

General comments

Some candidates had a weak basic knowledge of the syllabus, and many candidates found it difficult to access questions asking for routine recall of syllabus knowledge. There seemed to be a greater number of questions left un-attempted than is usual. Candidates who knew the 'bookwork', read the questions carefully and answered the questions asked, and who were able to apply their knowledge of physics to unfamiliar situations, were able to perform well.

Candidates should ensure that the working for calculations is logically presented. If an answer is not correct, it is more likely that partial credit may be awarded for working when this working is clearly shown.

Comments on specific questions

Question 1

(a) Many candidates referred to velocity and acceleration, but incorrect statements were often made, for example, 'the velocity is constant and its direction is changing'. Other candidates just quoted equations for velocity and acceleration. These equations did not answer the question as candidates were required to describe circular motion.

(b) (i) This was a straightforward calculation that was answered well by most candidates.

(ii) The time taken for the one lap of the track was the most difficult part of this question.

Question 2

(a) Many candidates gave the correct definition of gravitational potential. Some candidates did not make the ratio 'work done per unit mass' clear. The idea of 'work done in moving a mass' does not convey the idea that gravitational potential is the work done divided by the mass.

(b) (i) A large number of candidates approached this question by discussing forces. This could not be awarded credit because the question asked about gravitational field strength. The idea that the gravitational field strengths from the Earth and the Moon were both equal in magnitude and opposite in direction was only mentioned by the strongest candidates. Referring to the two gravitational fields 'cancelling each other out' was not considered sufficient.

(ii) A significant number of candidates were able to show how to reach the value of x. In this type of question, the answer can be obtained by taking square roots on both sides of the equation equating field strengths, and this is a much easier method than expanding and needing to solve a quadratic equation.

(iii) Many candidates found the gravitational potential due to the Earth alone. Of those who did calculate the gravitational potential due to both the Earth and the Moon, many did not combine them correctly and subtracted the negative values rather than adding them. These candidates had forgotten that gravitational potential is a scalar rather than a vector quantity.

Question 3

(a) The definition of specific heat capacity requires the division of the quantities to be clearly stated. Some candidates included the phrase 'energy per unit mass' but it was less common to see the phrase 'per unit change in temperature'.

(b) (i) A large number of candidates knew the required formula here, $pV = NkT$, but a significant number did not quote the formula with thermodynamic temperature T as the subject.

(ii) This proof was answered well by many candidates. A few candidates confused the symbols and treated n and N as the same quantity.

(iii) Many candidates stated that there are no intermolecular forces in an ideal gas. It was less common to see candidates mention that the potential energy of the *molecules* is zero, i.e. they often did not include the link between molecules and their potential energy.

(c) (i) Very few candidates stated the first law of thermodynamics in words although the symbol equation was often given. Some candidates referred to just 'internal energy' rather than 'increase in internal energy'. Many candidates knew that no work was done (by or on the gas) but few candidates gave the reason clearly.

(ii) Many candidates did not answer the question that was asked here. They showed how to reach an expression for the specific heat capacity of a single gas atom or molecule, rather than the specific heat capacity of the gas. To answer the question, candidates needed to include N to represent the number of molecules in both the kinetic energy formula and the mass in the specific heat capacity formula.

(d) A significant number of candidates thought that the specific heat capacity of the gas would not change as it is a material constant. This is not true for gases where the volume can change. In this situation, the gas does work and so more thermal energy is required for the same temperature rise and hence the specific heat capacity increases.

Question 4

(a) (i) Most candidates determined the initial amplitude correctly.

(ii) Most candidates determined the angular frequency correctly.

(iii) Most candidates calculated the maximum speed correctly, but a small number of candidates tried to use the formula for velocity with time which was largely unsuccessful.

(b) Candidates usually gained credit for recognising that damping began after a time of around 12 s and also that the damping was light. There was significant misconception based around the idea that the motion was simple harmonic before the damping began and then not simple harmonic after the damping began. The motion continued as damped simple harmonic motion. A small number of responses stated that the motion was damped from $t = 0$.

(c) This sketch graph proved to be challenging. Only the strongest candidates drew a closed loop based about (20, 0). There were many sinusoidal waves with a maximum v and a minimum v of $\pm$ 7.9 cm s^{-1}. Candidates often did not realise that the motion was restricted between the two values of L = 15 cm and L = 25 cm.

Question 5

(a) Most candidates were able to state two advantages of converting an analogue signal into digital form for transmission.

(b) (i) The majority of candidates were able to determine the potential difference at the times required and convert these potential differences into digital signals.

(ii) There were many correct graphs to represent the received signal. A significant number of candidates did not realise that the sampling frequency of 250 Hz meant that the length of each step was 4 ms.

(c) Most candidates used 2 ms step lengths for this graph. Some candidates did not treat the sampled voltages at 1.0 V, 5.0 V and 7.0 V consistently.

Question 6

(a) Most candidates were able to state the required expression for the charge on one plate of the capacitor. The expression for the energy stored was more challenging. A significant number forgot to include the factor of ½ or stated ½QV, when the question had asked for expressions in terms of C and V.

(b) These expressions proved to be challenging for candidates. Weaker candidates were not able to correctly use the information given about the inversely proportional relationship between C and x to determine the new capacitance. It was not often realised that the charge on each plate of the capacitor was trapped and so could not change. Candidates should have realised that the potential difference between the plates would change. In all three expressions, candidates often did not limit their expressions to the quantities allowed (C, V, L and D).

(c) This was a challenging explanation, especially for candidates who were not able to arrive at correct expressions in **(b)**. Many candidates considered that the energy stored would increase. Of those who had correctly stated a decrease in energy stored, few were able to give an adequate explanation. The most successful responses tended to use a formula for energy stored, e.g. E = ½QV, and explained what had happed to both Q and V rather than using the simpler explanation involving the attraction between the oppositely charged plates.

Question 7

(a) The majority of the candidates were able to state two correct properties of an ideal operational amplifier.

(b) Most candidates could correctly name the thermistor. Many candidates were not able to correctly name the relay. The most common incorrect response was light-dependent resistor.

(c) (i) Candidates often did not realise what the output of the op-amp was, and many thought that the diode was the reason for the two output states, i.e. the two states were the diode letting current pass and not letting current pass. Others who had the correct idea did not refer to saturation or outputs of +5 V and –5 V.

(ii) This question was well answered.

(iii) A large number of candidates did not refer to an environmental condition here. Of those that did, most only referred to temperature and how this affects the input p.d., rather than there being a critical temperature that would operate the relay and hence turn the lamp on.

(iv) This question was generally answered more successfully than **(c)(iii)** as more candidates realised that the variable resistor would adjust the temperature at which the lamp was switched on.

Question 8

(a) In this definition the use of the word ‘per’ was vital. Many responses referred to quantities instead of units, referring to force and current and length rather than newtons, amperes and metres. The idea of the current or wire being perpendicular to the magnetic field was often omitted.

(b) (i) There were occasional errors in this calculation due to using the incorrect length, not converting into mT correctly, using cosine instead of sine or sometimes ignoring the angle completely.

(ii) A large number of candidates were able to correctly apply Fleming’s left-hand rule to this situation. The statement and reason given were often correct.

(iii) Many candidates realised that the frame would rotate or be deformed. A significant number thought there would be no effect as the forces would cancel out. These candidates did not realise that the lines of action of the two forces were separated by a distance, so a turning effect would be produced.

Question 9

(a) There were some good answers here that correctly explained root-mean-square (r.m.s.) voltage by referring to power dissipated in a resistor. Some candidates just quoted the formula used to determine r.m.s. voltage from peak voltage or the r.m.s. power from peak current and peak voltage.

(b) (i) Many candidates quoted Faraday’s law of electromagnetic induction without referring to this particular situation. The key phrase here was the ‘rate of change’ which was often missing. Candidates often did not note the significance of doubling the speed of rotation on the magnitude of the r.m.s. value of the induced e.m.f.

(ii) The line on the graph needed to show the new time period (half of the original value) and the peak worked out from the r.m.s. voltage and doubled due to the doubling of the speed. Often one or more of these aspects was missing.

(c) Many candidates realised that the coil would slow down but few realised that it would eventually stop. The key concept here was that connecting the resistor would complete the circuit and hence current would flow. It was the effect of this current that would slow down and stop the rotation of the coil.

Question 10

(a) (i) Most candidates were able to state a correct experimental phenomenon demonstrating the particulate nature of electromagnetic radiation.

(ii) Fewer candidates were able to state evidence for the wave nature of matter.

(b) The majority of the candidates were able to state the correct formula here and also name the Planck constant and the de Broglie wavelength.

(c) (i) A significant number of candidates were able to equate the kinetic energy of the electrons with the work done on the electrons to determine their final speed.

(ii) Again, most candidates successfully calculated the effective (de Broglie) wavelength here. A small number of candidates tried incorrectly to use the photon energy equation $E = hc / \lambda$.

Question 11

(a) (i) Many candidates were able to correctly state what is meant by the sharpness of an X-ray image.

(ii) Fewer candidates were successful here as contrast is more challenging to describe.

(b) On the whole, this calculation was completed successfully. A small number of candidates subtracted from 100% and used 88% as the amount transmitted. Some weaker candidates were unable to include the correct unit for the linear attenuation (absorption) coefficient.

Some candidates converted unnecessarily from cm to m here. The key point to emphasise is that the power of the exponential function must have no units, so the distance can be in cm and then the linear attenuation coefficient will be in cm^{-1}.

(c) Most candidates could correctly suggest an advantage and a disadvantage of CT scanning compared with X-ray imaging.

Question 12

(a) A significant majority of candidates knew that the decay constant is the probability of decay, but some missed out the second half of the definition ‘per unit time’. Weaker candidates often confused the decay constant with the half-life.

(b) This calculation proved to be challenging. Candidates were generally awarded credit for $A = \lambda N$, but then did not know how to gain the number of nuclei N from the information given in the question. Those that used the atomic mass often ended up being incorrect by a factor of 1000 because they used a value in g rather than kg.

(c) Stronger candidates were able to give correct suggestions here, but many responses included the fact that the decay is random, the decay produces an unstable daughter product or noted the presence of background radiation. All of these ideas were incorrect here.

PHYSICS

Paper 9702/51
Planning, Analysis and Evaluation

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

PHYSICS

Paper 9702/52
Planning, Analysis and Evaluation

Key messages

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

General comments

In **Question 1**, it is advisable that candidates should think carefully about the experiment following the points given on the question paper and to imagine how they would perform the experiment in the laboratory. Planning a few key points before answering **Question 1** is useful. Some candidates drew diagrams that did not show a workable experiment. Many candidates were successful in the analysis section with clear identification of how the constant could be determined. It is essential for candidates to have experienced practical work in preparation for answering this paper.

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

In question parts requiring mathematical manipulation, stronger candidates clearly stated the equation used with correct substitution of numbers, and then calculated the answer and unit. Candidates should be encouraged to set out their working in a logical and readable manner. Care should be taken when numbers are crossed out.

Comments on specific questions

Question 1

Most candidates correctly identified the independent and dependent variables. Candidates should be encouraged then to consider the control of variables and to explicitly state the quantities that need to be kept constant to make the experiment a fair test. In this experiment it was expected that candidates would state that β would be kept constant. There was additional credit for also stating that d (and L) would be kept constant. Some stronger candidates gained further credit by explaining a method to keep β constant.

Candidates were awarded credit for a clearly labelled diagram. Diagrams should be drawn of the workable experiment. In this experiment, candidates needed to support the spring using a clamp and stand on a bench and needed to be clear that the strip was able to rotate. Further credit was given to candidates who explained how the wire was attached to the strip and how the strip was allowed to rotate but not move in the horizontal direction. A significant number of candidates incorrectly suggested a change to the experiment by adding masses to the end of the strip.

Most candidates suggested using a rule to measure both L and d and a protractor to measure θ (and β). Stronger candidates drew protractors on the diagram, clearly indicating the correct position. Some candidates explained how the angles may be determined using trigonometry.

Candidates did not gain credit for the vague statement 'use a ruler to measure extension' – candidates needed to explicitly state that, to determine the extension x of the spring, the original length of the spring and the new length of the spring needed to be measured either with a rule(r) or calipers. Credit was also available for the additional detail that the original length would be subtracted from the new length.

To ultimately determine W, candidates also needed to determine a value of k. Stronger candidates described a preliminary (separate) experiment of weighing masses and then hanging the masses from the spring and measuring extension. Some candidates then stated that k could be determined by mg / x while others discussed finding k from the gradient of an appropriate graph. Credit was not awarded to candidates who simply wrote down the equation for spring constant without explaining an experimental method.

Many candidates suggested correct axes for a graph (often x against $\cos\theta$). A significant number of candidates incorrectly suggested plotting x against θ. Candidates must explicitly state the quantities to be plotted on each axis either in the text or on drawn axes – credit is not given for just writing $y = mx + c$ under an expression. Candidates also needed to explain how the graph would confirm the suggested relationship. Candidates need to use the words 'relationship is valid if' and the word 'straight' to describe the line passing through the origin.

Candidates needed to explain how they would determine a value of W from the experimental results using the gradient, and the constant W needed to be the subject of the equation. Credit was not awarded to candidates who did not correctly identify appropriate quantities to plot on the axes of their graph.

The additional detail section had a maximum of six marks that could be awarded. Candidates should be encouraged to write their plans including appropriate detail; some candidates' answers suggested that they did not have sufficient practical experience. Vague responses were not credited. It is essential that candidates' answers are relevant to the experiment in question rather than general 'textbook' rules for working in the laboratory.

When describing safety precautions, candidates should be encouraged to explain how the precaution proposed is relevant to the experiment. In this experiment, relevant precautions were to prevent injury from the spring or wire entering the eyes.

Question 2

(a) Candidates who were mathematically confident were able to work through the algebra and achieve credit. Candidates should use the white space on the question paper to rearrange the equation into an equation of a straight line.

(b) Most candidates were able to calculate values for average t and $\ln(R / \text{s}^{-1})$ correctly. Many candidates did not use an appropriate number of significant figures for $\ln(R / \text{s}^{-1})$. Since R was recorded to three significant figures, values of $\ln(R / \text{s}^{-1})$ should have been recorded to three (or four) decimal places – the number before the decimal point in a logarithmic quantity is not relevant.

Many candidates did not determine the absolute uncertainty in average t correctly. From repeated values, the absolute uncertainty should be determined by finding half the range.

(c) (i) The points and error bars were straightforward to plot. When plotting points, the diameter of each point should be less than half a small square. Candidates need to take greater care over the accuracy of the error bars and ensure that the error bars are symmetrical.

(ii) Most candidates appear to be using a sharp pencil and a transparent 30 cm ruler. For correctly plotted data, the line of best fit did not pass through both the highest and lowest point. The worst acceptable line was drawn well in general, and many stronger candidates drew a line that passed through all error bars. Candidates should clearly label the lines drawn. Where a dashed line is used to represent the worst acceptable line, the dashed parts of the line should cross the error bars.

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

When determining the uncertainty in the gradient, candidates need to show their working, including the coordinates that they have used from the worst acceptable line and an appropriate subtraction.

(iv) The majority of the candidates who were awarded full credit set out their working clearly. Stronger candidates often substituted data from the gradient calculation **(c)(iii)** into $y = mx + c$. Some candidates were confused by the negative gradient and omitted the minus sign in their calculation. Other candidates incorrectly read off the *y*-intercept when $t = 0.1$ mm. Some candidates incorrectly divided the *y* value by *mx*.

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

(d) The value of μ was the negative of the candidate's gradient value; some candidates were confused by the sign. Candidates should show the substitution of the *y*-intercept to determine the value of R_0. Credit is not given for substituting data vales from the table and using simultaneous equations to determine μ and R_0.

Candidates were also expected to give the final values of μ and R_0 with appropriate units. Some candidates did not understand that logarithmic quantities are dimensionless and incorrectly gave $\mathrm{s\,mm^{-1}}$ or $\mathrm{s^{-1}\,mm^{-1}}$ as the unit for μ. Candidates should be encouraged to think about the physical quantity represented by these final calculated values and give the matching unit, e.g. $\mathrm{mm^{-1}}$ for μ.

The absolute uncertainty in R_0 required candidates to determine the maximum or minimum value of R_0. Candidates should clearly show the numbers that are substituted into the equations.

(e) There were many ways that candidates could determine *t*. Some candidates used the gradient and *y*-intercept, while others substituted values for μ and R_0 from **(d)**. Candidates needed to show clear and logical working for this question. It was expected that the final answer would be given to an appropriate number of significant figures.

PHYSICS

Paper 9702/53
Planning, Analysis and Evaluation

Key messages

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

General comments

In **Question 1**, it is advisable that candidates should think carefully about the experiment following the points given on the question paper and to imagine how they would perform the experiment in the laboratory. Planning a few key points before answering **Question 1** is useful. Some candidates drew diagrams that did not show a workable experiment and often important measurements and detail on how to obtain them were omitted from the method. Many candidates were successful in the analysis section with clear identification of how the constants could be determined. It is essential for candidates to have experienced practical work in preparation for answering this paper.

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

In question parts requiring mathematical manipulation, stronger candidates clearly stated the equation used with correct substitution of numbers, and then calculated the answer including the correct power of ten and unit. Candidates should be encouraged to set out their working in a logical and readable manner. Care should be taken when numbers are crossed out.

Comments on specific questions

Question 1

Most candidates correctly identified the independent and dependent variables and stated that the length L of the tube needed to be kept constant. Candidates should be encouraged to consider the control of variables and to explicitly state the quantities that need to be kept constant to make the experiment a fair test.

Candidates were awarded credit for a clearly labelled diagram. Diagrams should be drawn of the workable experiment. In this experiment, candidates needed to clearly show a tube supported by a clamp and stand or by a bench. Additional credit for the diagram was awarded where there was a labelled speaker positioned at one end of the tube connected to a signal generator, and a labelled microphone connected to a labelled cathode-ray oscilloscope at the other end. Some candidates did not label the equipment. It is expected that any circuits drawn should be correct.

Many candidates did not explain how to determine the frequency f at which the stationary wave was formed. To gain credit, candidates needed to describe how the frequency was changed until a loudest sound or maximum amplitude was detected. Additional credit was available to candidates who described how they would increase the frequency of the sound wave until the first harmonic was formed in the tube and for including a method to create the first harmonic, such as increasing the frequency from zero using a signal generator until the oscilloscope (connected to a microphone) shows the first largest amplitude. Further credit was given for describing how to determine the time period from the oscilloscope using the time-base and then using $f = 1/T$. Just quoting the relationship $f = 1/T$ was not awarded credit unless it was linked to a time period measurement taken from the oscilloscope.

Most candidates gained credit for suggesting using calipers or a micrometer screw gauge to measure the diameter of the tube and then describing how to correctly repeat the measurement at different points along the tube to obtain a mean value for d. Some candidates suggested using a ruler to measure d – this suggestion only gained credit if additional detail was given, e.g. using blocks to make sure the maximum distance was measured. Many candidates suggested using a rule to measure L. For this measurement, candidates who suggested calipers or a micrometer screw gauge did not gain credit.

Many candidates suggested correct axes for a graph (often $1/f$ against d). A significant number of candidates incorrectly suggested plotting f against d or f against $1/d$. Candidates must explicitly state the quantities to be plotted on each axis either in the text or on drawn axes – credit is not given for just writing $y = mx + c$ under an expression. For this experiment, logarithmic graphs were not appropriate. Candidates also needed to explain how the graph would confirm the suggested relationship. Candidates need to use the words 'relationship is valid if' and the word 'straight' to describe the line. Some candidates were not awarded credit because they stated incorrectly that the straight line would pass through the origin.

Candidates needed to explain how they would determine values of v and k from the experimental results using the gradient and/or the y-intercept. Candidates needed the constants k and v to be the subject of the equations. Credit was not given to candidates who did not correctly identify appropriate quantities to plot on the axes of their graph.

The additional detail section had a maximum of six marks that could be awarded. Candidates should be encouraged to write their plans including appropriate detail; some candidates' answers suggested that they did not have sufficient practical experience. Vague responses were not credited. It is essential that candidates' answers are relevant to the experiment in question rather than general 'textbook' rules for working in the laboratory.

When describing safety precautions, candidates should be encouraged to explain how the precaution proposed is relevant to the experiment. In this experiment, precautions that prevented damage to hearing gained credit.

Question 2

(a) Candidates who were mathematically confident were able to work through the algebra and achieve credit. Candidates should be encouraged to use the white space on the question paper to rearrange the equation into an equation of a straight line.

(b) Most candidates were able to calculate values for $\dfrac{1}{R_1 + R_2}$. Some candidates did not use an appropriate number of significant figures. Since values of R_1 and R_2 were recorded to two significant figures, values of $\dfrac{1}{R_1 + R_2}$ should have been recorded to two (or three) significant figures. Where values of ($R_1 + R_2$) were recorded to three significant figures, values of $\dfrac{1}{R_1 + R_2}$ were also credited if they were recorded to four significant figures.

Most candidates determined the absolute uncertainty in ($R_1 + R_2$) and $\dfrac{1}{R_1 + R_2}$ correctly. Some candidates incorrectly added the percentage uncertainties (5%) before determining the absolute uncertainties in ($R_1 + R_2$). Candidates need to understand the rules for combining uncertainties, including the conversion from an absolute uncertainty to a percentage uncertainty and the conversion from a percentage uncertainty to an absolute uncertainty.

(c) (i) The points and error bars were straightforward to plot. When plotting points, the diameter of each point should be less than half a small square. Candidates need to take greater care over the accuracy of the error bars and ensure that the error bars are symmetrical.

(ii) Most candidates appear to be using a sharp pencil and a transparent 30 cm ruler. For correctly plotted data, the line of best fit did not pass through both the highest and lowest point. The worst acceptable line was drawn well in general, and many stronger candidates drew a line that passed through all error bars. Candidates should clearly label the lines drawn. Where a dashed line is used to represent the worst acceptable line, the dashed parts of the line should cross the error bars.

(iii) Most candidates clearly demonstrated the points that they used to calculate the gradient. Some candidates misread coordinates or did not use a sensibly sized triangle. A few candidates did not state that the gradient was negative. A small number of candidates chose data points that did not lie on the lines, often using data from the table that is close to the line instead. Candidates should be encouraged to select two points on the line of best fit that are easy to read, i.e. the points are on grid lines. A number of candidates omitted the 10^{-6} factor from the *x*-axis which then caused difficulties in the calculations in **(d)(i)** and **(e)**.

When determining the uncertainty in the gradient, candidates need to show their working, including the coordinates that they have used from the worst acceptable line and an appropriate subtraction.

(iv) The majority of the candidates who were awarded full credit set out their working clearly. Stronger candidates often substituted data from the gradient calculation **(c)(iii)** into $y = mx + c$. Some candidates incorrectly mixed the powers of ten in the *x*-values and the gradient. Other candidates were confused by the negative gradient and omitted the minus sign in their calculation.

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

(d) (i) It is expected that candidates clearly show the substitution of the gradient and *y*-intercept to determine values of *C* and *E*. Credit is not given for substituting data vales from the table into the expression.

Candidates are also expected to give the final values of *C* and *E* to an appropriate number of significant figures, with appropriate units. Some candidates did not understand that logarithmic quantities are dimensionless and incorrectly gave $\mathrm{V\,s\,\Omega^{-1}}$ or $\mathrm{V^{-1}\,s\,\Omega^{-1}}$ as the unit for *C*. Candidates should be encouraged to think about the physical quantity represented by these final calculated values and give the matching unit. In this case *C* represents capacitance and so the correct unit is F or $\mathrm{s\,\Omega^{-1}}$.

(ii) The percentage uncertainty in *C* required the addition of the percentage uncertainty in the gradient and the percentage uncertainty in *t*. Candidates should clearly show their method for calculating the percentage uncertainty. Some candidates incorrectly subtracted the percentage uncertainties because of the negative gradient.

Some candidates used maximum/minimum methods, and credit could be awarded for these methods when clear working was shown. A common error when using the maximum/minimum method was to use a value of 60 s for *t* instead of the appropriate maximum or minimum value of *t*.

(e) There were many ways that candidates could determine $(R_1 + R_2)$. Some candidates used the gradient and *y*-intercept, while others substituted values for *C* and *E* from **(d)(i)**. Candidates needed to show clear and logical working for this question. Many candidates worked through the mathematics correctly, but the final answer had a power-of-ten error of the order 10^6 due to omitting the power of ten in $\dfrac{1}{R_1 + R_2}$ plotted on the *x*-axis.