PHYSICS

Paper 9702/11
Multiple Choice

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

General comments

It is important to carefully read the text of the question before considering the four options presented. Candidates should be familiar with the definitions of physical quantities in the syllabus, for instance understanding the difference between definitions for units and quantities.

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

In general, candidates found **Questions 3**, **6**, **28** and relatively difficult. Candidates found **Questions 1**, **8**, **10**, **18**, **22**, **23**, **40** relatively easy.

Comments on specific questions

Question 2

The majority correctly selected option **A**. Weaker candidates were split between options **B**, **C** and **D**. This suggests candidates are not confident rearranging equations, or are not confident of the SI base units for energy and momentum.

Question 3

Candidates found this very challenging with more than half selecting the incorrect option **B**. Candidates may have assumed that the question was asking for the resultant velocity of adding *u* and *v*. Candidates are encouraged to carefully read the question, as it asks for the **change** in velocity.

Question 4

Most candidates correctly selected option **B**. Some weaker candidates selected option **C**, suggesting that they were recognising the at^2 term from a different equation of motion. Candidates should be familiar with all the equations of motion for uniformly accelerated objects.

Question 6

Many of the stronger candidates correctly selected option **D**. Some candidates selected option **B**. Option **B** suggests candidates recognised that to calculate the percentage uncertainty, the denominator had to be the difference in temperature, but failed to realise that the absolute uncertainty of a single reading from the thermometer needs to be doubled.

Question 7

Many candidates selected the correct answer **C**. Some candidates choose **D**, suggesting they were confusing the behaviour of the vertical component of the velocity (decreasing and then increasing) with the vertical component of the acceleration.

Question 13

Most candidates selected the correct answer **D**. Candidates who used the change in speed of the ball ($20 - 15 = 5\,\mathrm{m\,s^{-1}}$) as opposed to the change in **velocity** of the ball ($20 - -15 = 35\,\mathrm{m\,s^{-1}}$) selected option **B** which accounted for most of the incorrect responses.

Question 14

Most candidates found this question straightforward, correctly selecting option **A**. Some candidates instead chose option **B**, which displays a couple, and so means the object cannot be in equilibrium.

Question 16

Candidates found this question challenging with incorrect options **A**, **C** and **D** all proving popular. This calculation can be solved using trigonometric functions, which are often the source of arithmetic errors, especially among weaker candidates. It can also be solved by recognising that each half of the cord forms a 3-4-5 triangle, and so the force can be deduced from similar triangles.

Question 19

This was challenging for all candidates. Candidates needed to use the equations power = intensity × area, and intensity is proportional to amplitude^2. Stronger candidates were able to combine these equations to arrive at the correct answer **B**. Incorrect options **A** and **C** were both popular, suggesting one or both of the relevant equations were not known.

Question 24

This was challenging for all candidates, requiring candidates to combine Malus's law $I = I_0\cos^2\theta$ with $I \propto A^2$ to get the correct option **A**. Option **B** was the most popular incorrect answer, suggesting that candidates recalled Malus's law but did not know how to deal with the amplitude.

Question 25

Most candidates answered this correctly. The most popular incorrect option was **D**, which suggests that candidates understand the relationship between wavelength and period, but are not confident with SI prefixes.

Question 26

A significant proportion of candidates selected incorrect options **B** and **C**, which were the angle of the 2nd and 3rd order maxima from the central maxima. This suggests candidates know how to use the diffraction grating equation. Candidates need to carefully read the question, which asked for the angle **between** the second and third order maxima.

Question 28

Candidates found this question very challenging, with many candidates selecting incorrect option **C**. Graphical representations of progressive waves should be practiced by all candidates.

Question 31

Many candidates found this straightforward. Some candidates selected incorrect option **C**, confusing resistance with resistivity.

Question 34

Some candidates were able to correctly determine the resistance of R by finding the parallel combination of resistance between X and Y, using $120 = (R \times 3R) / (R + 3R)$ to get $R = 160$ W. Many candidates chose incorrect option **A**, treating the resistor network as a series combination of 4 resistors and so getting 120 / 4 = 30 W.

Question 35

Many candidates chose the correct option **C**. Some candidates selected the incorrect option **D**, suggesting a confusion about the effect of internal resistance on terminal potential.

PHYSICS

Paper 9702/12
Multiple Choice

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

General comments

It is important to carefully read the text of the question before considering the four options presented. Candidates should be familiar with the definitions of physical quantities in the syllabus, for instance understanding the difference between definitions for units and quantities.

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

In general, candidates found **Questions 3**, **19** and **23** and relatively difficult. Candidates found questions **1**, **4**, **11**, **24**, **29**, **32** relatively easy.

Comments on specific questions

Question 2

Most candidates correctly selected option **D**. Some candidates selected incorrect option **A**, the result of simply multiplying the two percentage uncertainties.

Question 3

Candidates found this challenging, with many candidates selecting the incorrect option **C**. This would be correct for an object falling from rest in the presence of air resistance, but not for a ball moving upwards in air. As well as understanding the motion of objects falling from rest, candidates should be aware of other motions in the presence of air resistance.

Question 5

Many correctly selected option **B**. Some candidates assumed that the feather was falling at a constant velocity, and therefore it would fall half the distance in half the time, and so selected incorrect option **D**.

Question 9

Most candidates correctly calculated the change in the velocity 8 – – 3 = 11 $m\,s^{-1}$, and so chose option **C**. Options **A**, **B** and **D** were all selected about equally, demonstrating a misunderstanding in either the difference of direction (taking 8 – 3 = 5 $m\,s^{-1}$), the direction of the change in velocity, or both.

Question 10

Many candidates were able to correctly apply conservation of energy to the pellet and clay and selected the correct option **A**.

Question 12

Many candidates were able to solve the equilibrium of moments and calculate F = 3cos30 / 2sin30 = 2.6 N (**C**). Option **B** could be attained by recognising the distance from the pivot to F was twice the distance to the centre of mass then ignoring the angles of the forces. Option **D** could be attained by calculating the components of the forces correctly then not realising that the distance from the pivot to F was twice the distance to the centre of mass. **B** and **D** were equally popular incorrect options, suggesting candidates should practice more complex moments problems.

Question 14

Most candidates were able to determine that the constant of proportionality relating force and velocity^2 was 2, and so correctly calculated the force as 3200 N and the power as 128 kW (option **C**). Candidates that recalled $P = Fv$ but could not calculate the correct force often arrived at options **A** or **B**, with many candidates selecting one of these two options.

Question 16

Many candidates were able to correctly use $E_K = \frac{1}{2}mv^2$ to determine that the velocity must have increased by a factor of 2 (option **A**). Some candidates instead chose a factor 16, perhaps confusing the information given in the question and assuming that the velocity had increased by a factor of 4 and calculating the consequent change to kinetic energy. Candidates are reminded to carefully read the question.

Question 18

Some candidates correctly selected ‘elastic and not plastic’ (**C**) for the behaviour of the material between X and Y. Many candidates chose options **A** and **D**, suggesting that the definitions of elastic and plastic behaviour are not well understood.

Question 21

Some candidates selected the incorrect option **A.** Candidates need to understand the doppler effect and the meaning of the term ‘frequency’, as well as distinguishing between the volume of the sound and the frequency.

Question 23

This was challenging for candidates, with incorrect option **D** the most popular answer. This suggests that candidates were treating the distance between X and Y as the wavelength of the wave, rather than half the wavelength. Candidates may not have appreciated that a stationary sound wave had been formed between the loudspeaker and the wall.

Question 26

Stronger candidates were able to relate the graph shown to the diffraction grating equation and determine that $\sin\theta / \lambda = nN$. Weaker candidates tended to favour option **C**, suggesting some struggled to re-arrange the equation, or confused the number of lines per m, N, with the slit separation d.

Question 30

This proved challenging for many candidates. Some candidates were able to determine that the current in the lower branch would be half the current in the upper branch, and so the current in X must be the sum of the two currents. Some candidates selected incorrect options **A** and **B**, suggesting that they did not realise the total current must increase when the switch was closed.

Question 33

This was very straight-forward for the stronger candidates, who correctly selected option **B**. Incorrect options **A**, **C** and **D** were popular with weaker candidates, suggesting that they were not confident in converting charge in coulombs into charge in terms of e, or were not confident of the quantisation of charge.

Question 37

The majority of candidates correctly selected option **B**, with the most popular incorrect option being option **A**. This suggests that some candidates are not confident with the difference between beta-plus and beta-minus decay.

PHYSICS

Paper 9702/13
Multiple Choice

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

General comments

It is important to carefully read the text of the question before considering the four options presented. Candidates should be familiar with the definitions of physical quantities in the syllabus, for instance understanding the difference between definitions for units and quantities.

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

In general, candidates found **Questions 6**, **7** and relatively difficult. Candidates found **Questions 1**, **2** relatively easy.

Comments on specific questions

Question 2

The vast majority correctly selected option **D**, suggesting that the difference between random and systematic errors is well understood by all candidates.

Question 3

Candidates found this question challenging. Stronger candidates were able to work out the contribution of each measurement to the percentage uncertainty in *E* and determine that the diameter (**B**) was the most significant.

Question 4

Most candidates correctly selected option **A**. Candidates clearly recognised force as the product of mass and acceleration. Some candidates struggled to recognise **C** as being equivalent to force, and some candidates incorrectly identified acceleration (**D**) as a scalar.

Question 6

Most candidates were able to correctly determine the rate of change of momentum from the graph by finding the gradient (1.5 – 2.7) / 0.40 = –3.0 N. Many struggled to then apply this resultant force to the situation in the diagram by recognising that $F - 5 = -3$ and so $F = 2.0$ N.

Question 7

Candidates found this question challenging, suggesting that Newton's third law is not well understood.

Question 13

Most candidates answered this question correctly. Some candidates chose the incorrect option **A**, which is the volume occupied by a single atom.

Question 18

Candidates found this question challenging. The strongest candidates were able to either determine a resultant force down the slope and use equations of motion or use conservation of energy to calculate the final speed.

Question 19

This was generally well answered, with a majority of candidates correctly selecting option **B**. The most popular incorrect answer was option **A**. Candidates are encouraged to read the questions carefully and realise that as both wires obey Hooke's law during the experiment, the lines must be straight.

Question 21

This question was very challenging for candidates. Candidates who were able to derive $E = \frac{1}{2} F^2 / k$ recognised that F_2 was twice F_1 and correctly selected option **C**. Option **D** was the most popular incorrect answer, suggesting that candidates had identified the elastic potential energy of the second wire was 4 times greater than the original wire, but then assumed a linear relationship between elastic potential energy and force, or didn't realise that x will also be different for the new wire.

Question 23

Only a small number of candidates correctly answered with option **C**. Many candidates misunderstood the question and calculated the distance travelled by a wavefront in 2 s (48 × 2 = 96 cm) (option **D**) rather than the distance travelled by a point on the wave. Options **A** and **B** were popular incorrect answers, suggesting that candidates had correctly determined the period of the wave (12 / 48 = 0.25 s) but did not correctly account for the distance travelled by a point on the wave in a single period (4 × 1.5 = 6 cm).

Question 26

The majority of candidates chose the correct option **A**. Option **C** was the most popular incorrect answer, with candidates using $I = I_0 \cos\theta$. **B** and **D** were also popular, using $I = I_0 \sin\theta$ or $I = I_0 \sin^2\theta$. Candidates need to be confident in recalling and applying Malus's law.

Question 28

Most candidates answered this correctly (option **A**) correctly identifying that the highest order of maximum formed was 4, and then applying the diffraction grating equation. Candidates should be able to interpret how the 9 bright dots relate to the diffraction grating equation.

Question 35

This proved challenging for candidates. Many candidates were able to determine that closing the switch would lower the total resistance and so increase the total current I_1, whilst the lower terminal pd would cause I_2 to fall. The most popular incorrect answer was **A**, suggesting candidates incorrectly thought that adding a parallel resistance would increase the total resistance.

Some candidates selected the incorrect option **B**, correctly reasoning that I_1 must increase, thinking this would not affect I_2, failing to recognise that the terminal pd would be lower than before.

Question 37

This was challenging for all candidates. Questions involving null methods using a galvanometer should be practiced by all candidates.

Question 40

Most candidates found this straight-forward. Some candidates chose the incorrect option C, suggesting the term ‘lepton’ was not well understood.

PHYSICS

Paper 9702/21
AS Level Structured Questions

Key messages

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

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

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

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

General comments

Most candidates show a good amount of working to support their answers to numerical questions, allowing marks to be awarded for correct methods even where errors then occur. Many candidates write algebraic or numerical expressions without subjects and could improve by ensuring that the subject of an equation is always given.

There were three questions that required candidates to draw lines on diagrams provided. Two of these questions involved drawing straight lines. A significant number of candidates could have improved their answers by using a ruler to help them draw the line. The third question involved drawing a reflection of a sine curve provided, but many drawings were not sufficiently accurate to receive credit. Candidates should be reminded that accuracy in drawing diagrams is as important as accuracy in calculations or in written answers.

Candidates found **Questions 4(b)(i)**, **5(e)** and **6(d)(i)** to be straightforward. They found **1(d)**, **2(b)(iii)**, **3(b)**, **3(c)** and **7(b)(i)** to be difficult.

There was no evidence that candidates were short of time.

Comments on specific questions

Question 1

(a) Most candidates gave the correct SI units for the quantities given in the equation for the drag force. A small minority were unable to give the base units for density or did not square the units for velocity. A significant number of candidates rearranged the equation with *C* as the subject and then solved for the units and obtained an answer for C of 1 or 2. The expression for C was required in terms of base units only. There was some incorrect cancelling of units to ensure the final expression had no units.

(b) Many candidates did not draw their arrows vertically and many did not use a ruler. Some candidates labelled the upward force as 'upthrust' whereas the question states that upthrust is negligible. A significant number labelled the downward force as 'gravity' and this was not considered acceptable as a term for the force in place of weight or gravitational force.

(c) The majority of the candidates equated the drag force with the weight. A significant number of candidates did not convert the mass given in grams into kilograms. A small minority read the mass as $49g$ and gave the weight as $49g^2$.

(d) The strongest candidates were able to complete this calculation correctly. There were several common errors. Many candidates used the surface area of a sphere ($4\pi r^2$ or πd^2) despite A being defined as the cross-sectional area of the sphere at the beginning of the question. Some weaker candidates simply used the diameter or radius instead of area and some used the formula for the volume of a sphere.

A number of candidates rounded the value of area to two significant figures before using it in their calculation, which gives an incorrect final answer of 0.46 rather than 0.45.

A small minority did not square the value of velocity in their calculation.

Question 2

(a) The majority of candidates gave an acceptable definition of velocity. Only a small minority used distance instead of displacement.

(b) (i) The stronger candidates calculated the horizontal component of velocity and used the formula time = displacement / velocity to determine the time. A significant number of candidates did not understand that the motion could be resolved into horizontal and vertical components that are independent of each other.

A large number of candidates tried to use an equation of uniform accelerated motion, with $a = 9.81\,\mathrm{m\,s^{-2}}$. These candidates did not understand that the horizontal component of velocity is constant, and so there is no acceleration in the horizontal direction. A small number of candidates did not resolve the initial value of the velocity into a horizontal component.

(ii) The majority of candidates gave the correct component of velocity.

(iii) Many candidates found this question to be difficult. The initial direction of the vertical component of velocity is opposite to the direction of vertical acceleration. A significant number of candidates used $s = ut + ½at^2$, having obtained the time to reach the wall in **(b)(i)**, but substituted a value of $a = 9.81\,\mathrm{m\,s^{-2}}$ rather than $a = -9.81\,\mathrm{m\,s^{-2}}$. Many of those who successfully calculated the height reached above the launch position then did not add the value of 1.2 m to account for the ball being released 1.2 m above ground level. Some candidates gave their answer to only one significant figure where two significant figures were required.

Question 3

(a) The majority of the candidates gained at least partial credit. The key point about the principle of conservation of momentum is that the <u>total</u> momentum remains constant, not the momentum of an individual object. A significant number of candidates either left out the word 'total' or the phrase 'sum of' in their answer. A minority of candidates confused the conservation of momentum with conservation of energy and a small number referred to 'moment' rather than 'momentum'.

(b) Many candidates considered only the horizontal components of the momentum and tried to determine two unknowns from one equation. A significant number who considered the vertical components of momentum gave $2mv\cos 60° + 3mw\cos 60° = 0$ instead of $2mv\cos 60° = 3mw\cos 60°$.

Only the strongest candidates obtained the correct solutions.

(c) A significant number of candidates obtained the correct answer.

An error made by a considerable number of candidates was to assume the distance was covered at a constant speed instead of at a constant acceleration by the constant force. As a result, their value for the time elapsed was incorrect. This led to an incorrect acceleration or an incorrect rate of change of momentum.

Those who made an error in their calculation were able to obtain credit for a correct equation for the force. Many chose $F = ma$ and gained credit but those who chose to use the rate of change of momentum route often stated the initial formula incorrectly as $F = p / t$ or $F = mv / t$. These are not correct as they do not signify a change in momentum. The equations $F = \Delta p / \Delta t$ or $F = m(v - u) / \Delta t$ should be used instead.

Question 4

(a) There were a significant number of correct answers. A common error was to omit 'original' from the denominator 'original length'. Some candidates gave strain in terms of the Young modulus and stress.

(b)(i) The majority of candidates gained full credit. A small minority did not convert the extension given in millimetres to metres. A few candidates used incorrect expressions for strain, such as original length / extension or new length (extension plus original length) / original length.

(ii) The majority of candidates drew a straight line through the origin. A significant number ignored the instruction to finish the line at the limit of proportionality and their line was drawn to the full extent of the graph. Not all lines were drawn with a ruler. In many of these cases it was difficult to judge whether the line was intended to be straight and credit could not be awarded.

(c) Most candidates stated that the stress was less in the second wire. The answers for the strain were varied. Many candidates did not seem to realise that the strain needed to have the same change as the stress when the material is the same (because the ratio stress / strain (Young modulus) is the same).

Question 5

(a) The stronger candidates were able to describe how stationary waves are formed with the apparatus shown in the question. Many answers gave a general description of how stationary waves are produced and could not be awarded credit. When attempting questions requiring a descriptive answer, it is important that candidates frame their answer in the context of the question.

A significant number of candidates who described the motion of the waves on the string did not refer to waves reflecting at point Q, but used words such as 'bounce', 'rebound' and 'deflect' which are not appropriate technical terms in this situation. For the formation of the stationary wave, some candidates just mentioned 'waves' without making clear that these are the incident and reflected waves. Others neglected to mention that these waves must superpose.

A number of candidates referred to coherent waves or waves with a constant phase difference which is not correct in this context.

(b) This question was well answered by the majority of the candidates. A small minority gave the full length of the string.

(c) There were a number of well drawn stationary waves by the strongest candidates.

A significant number of candidates drew waves approximating to the correct shape but with variable amplitudes that were either too large or too small. Many candidates' curves did not cross the zero displacement line at the nodes. Some drew waves that were completely wrong such as a horizontal line at zero displacement or a wave in phase with the original wave.

(d) A correct answer was given by the strongest candidates. Weaker candidates often gave an answer of 135° which suggests candidates were misinterpreting the diagram as a progressive wave rather than a stationary wave.

(e) There were a considerable number of correct answers. A common error was to use a mixture of distances and times and the equation speed = distance / time rather than speed = frequency × wavelength or speed = wavelength / time period.

Question 6

(a) The majority of the candidates gave Kirchhoff's first law. A significant number omitted 'sum of' the currents or described the currents flowing into or out of a circuit or closed loop.

(b) The stronger candidates related the potential difference across each resistor to the total potential difference across both resistors. A significant number of candidates left the answer blank.

(c) The most common error was to use the e.m.f. as the potential difference across the two external resistors instead of the terminal potential difference when calculating the current in the circuit.

(d) (i) Stronger candidates gave a correct explanation of the resistance of the circuit decreasing when an additional resistor is placed in parallel across the original two resistors. There were a significant number of weaker candidates who thought that the circuit resistance would increase due to the additional parallel resistor and some who then stated that the current increases.

(ii) Only the strongest candidates were able to give an appropriate answer to this question. A significant number confused the potential difference across the internal resistance with the terminal potential difference.

Candidates should be reminded to give both a statement and an explanation in 'state and explain' questions. No credit was available for the statement without an explanation.

Question 7

(a) The majority of the candidates gave the correct nuclide notation. A significant number gave the number of neutrons for the nucleon number and some gave the atomic number and the nucleon number in the wrong places. A small minority gave an attempt at the nuclear decay equation when the question asked for the nuclide notation for the copper isotope.

(b) (i) Many candidates found this question difficult. Very few candidates mentioned that the energy of the decay is constant. Many candidates simply tried to describe the shape of the graph without reference to the varying energies of the beta particles. Some candidates who correctly referred to the variation of the energy of the beta particles were unable to explain why this suggests that there must be emission of other particles. A significant number of candidates did not attempt the question.

(ii) This question was generally well answered by the stronger candidates. A minority of candidates gave an 'anti-electron neutrino'. The electron antineutrino is correct but writing 'anti-electron neutrino' is ambiguous as an anti-electron is a positron.

(iii) There were a large number of correct answers. Some candidates omitted the proton and nucleon numbers for the antineutrino. A significant number omitted the antineutrino or gave an unidentifiable symbol for the particle. A number of weaker candidates gave combinations of symbols that did not resemble a beta decay equation, or gave no response at all.

PHYSICS

Paper 9702/22
AS Level Structured Questions

Key messages

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

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

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

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

General comments

Most candidates show a good amount of working to support their answers to numerical questions, allowing marks to be awarded for correct methods even where errors then occur. Many candidates write algebraic or numerical expressions without subjects and could improve by ensuring that the subject of an equation is always given.

Candidates found **Questions 2(a)(i)**, **3(a)** and **6(b)(i)** to be straightforward. They found **Questions 1(b)(iv)**, **2(c)(i)**, **4(b)(ii)** and **5(b)(iii)** to be difficult.

There was no evidence that candidates were short of time.

Comments on specific questions

Question 1

(a) Most candidates found this introductory question straightforward. The most common mistake was to select current rather than charge.

(b) (i) Most candidates were able to correctly calculate the intensity of the incident light. Some very weak candidates started with a physically incorrect equation such as power = intensity / area, and some candidates did not convert the side length of the panel from mm to m.

(ii) This question proved to be more difficult, with only stronger candidates obtaining a correct answer through the addition of percentage uncertainties. Candidates frequently forgot to double the uncertainty in the side length when calculating the overall percentage uncertainty, and many weaker candidates did not know how to find the percentage uncertainty of the side length. Some of the weaker candidates did not understand the difference between absolute uncertainty and percentage uncertainty and so calculated 3 + 2 × 5 = 13%. Very few candidates attempted to calculate the uncertainty by finding the difference between the maximum and minimum possible intensities, and those who did this often got lost in the arithmetic.

(iii) This was straightforward for most candidates. A small number of weaker candidates calculated the fractional uncertainty instead of the percentage uncertainty.

(iv) This question allowed candidates to demonstrate their understanding of the concept of efficiency. Nearly all candidates recognised that the shorter sides led to a smaller surface area for the new panel, though occasionally this was not stated explicitly. Stronger candidates recognised that this would lead to a reduction in the input power to the panel. A common misconception was that the reduction in area would cause a greater intensity of the light incident on the panel.

Many candidates offered vague descriptions, often noting just that ‘power’ decreased, without being specific as to whether the input power, total power, useful output power or total output power was being described. Candidates are reminded to be specific in their descriptions. Many candidates attempted to reason using the equation intensity = power / area, but weaker candidates often got confused and described power increasing in order to ‘maintain’ a constant intensity, or thought that the intensity must change to maintain a constant power.

Candidates were usually able to correctly reason the change to the efficiency of the panel based on their change in input power. Candidates who stated that input power had increased could not be awarded full credit. Some candidates incorrectly stated that efficiency of the new panel would be larger because the output power of the new panel was larger. As this directly contradicted the stem of the question, this was not able to be given credit.

Candidates are reminded to carefully read the questions in order to ensure they fully understand the constraints given.

Question 2

(a) (i) Most candidates correctly read the terminal velocity from the graph.

(ii) This question proved challenging for many candidates. A significant proportion of candidates stated that acceleration is the gradient of the graph or gave the symbol formula $a = \Delta v / t$, but then went on to calculate the average acceleration over the first 9.0 s, rather than the instantaneous acceleration at time t = 9.0 s.

Those candidates that realised they needed to find the instantaneous acceleration generally drew reasonable tangents. The most common error in the tangent was to draw it at the wrong point on the time axis, which gave an acceleration that was outside the accepted range.

(b) Most candidates realised that they needed to use Newton’s second law to find the acceleration. Stronger candidates recognised that the resultant force was the difference between the weight and the stated drag force. Weaker candidates often assumed simply that the drag force was equal to the resultant force and neglected the weight of the skydiver.

Many candidates correctly stated ‘vertically upwards’ for the direction of the acceleration, but weaker candidates often gave responses such as ‘south’ or ‘forwards’. Candidates are reminded to think about the context of the question, as there are often directions given in the stem that can be used for reference.

(c) (i) This question was answered well only by the strongest candidates. Whilst many were able to identify that acceleration decreases between t_2 and t_3, few candidates explained that this was because the resultant force decreased over the period. A smaller number of candidates noted that this was because the drag force decreased over the period. There was often irrelevant discussion of changes to the acceleration and the drag force between t_1 and t_2. Candidates are reminded to carefully read the question, especially the constraints put on the required answer.

A significant number of candidates described the drag force increasing as the skydiver's velocity increased and approached terminal velocity. Candidates are discouraged from memorising answers to similar problems from previous exam series to avoid this type of error.

(ii) This question was straightforward for many candidates. Common errors included finding only the momentum at t_3 or only the momentum at t_1 rather than the change in momentum. Some candidates attempted to find the change in momentum using $F = \Delta p / \Delta t$ but inappropriately calculated the product of the resultant force at t_1 and the time taken to reach terminal velocity.

Some weaker candidates seemed to confuse force and change of momentum and attempted to use $\Delta p = (mv - mu) / t$.

Question 3

(a) This question was straightforward for nearly all candidates. Very weak candidates tended to omit this question, or to start with the physically incorrect equation $Q = I / t$.

(b) Most candidates correctly recalled $P = IV$, but converting from W to GW proved more challenging for the weaker candidates. A significant number of candidates confused tera and giga and so divided by 10^{12} instead of by 10^9.

Some weaker candidates confused power and work, and thought that the power was the product of the potential difference and the charge transferred.

(c) (i) This question was generally answered well. The symbol equation $R = \rho L / A$ was generally well known, although it was sometimes incorrectly recalled as $R = \rho A / L$. The most common error was to use the wrong expression for the cross-sectional area of the cylindrical cable, with some using the surface area for a cylinder instead.

(ii) Many candidates did not realise that the question stem provided them with enough information to give a quantitative answer and so they gave only a qualitative one by simply saying that the 'resistance decreases' rather than 'resistance decreases by a factor of four'.

When candidates stated a numerical difference, the language was often imprecise. Many candidates stated that the resistance would 'decrease by ¼' which implies the resistance is ¾ of the original resistance. Candidates are encouraged to be careful with their use of language when making proportional comparisons.

(d) This question was also generally well answered by candidates of all abilities. The most common error was to start with a correct expression for Young modulus, but to then make an error in the rearrangement or substitution. Often weaker candidates confused the given value of stress with a force and so could not get the correct answer. Occasionally, candidates correctly calculated the strain, but then multiplied this by 95 instead of by 0.12 (confusing the length of the test section with the length of the whole lightning rod).

Candidates are reminded to be careful in their handwriting as 'E' for Young modulus and 'ε' for strain are often written in such a way as to be indistinguishable.

Question 4

(a) Weaker candidates sometimes began with an incorrect expression for elastic potential energy such as $E = ½kx$. In other cases, the expression was correct initially but the power of 2 on the compression was lost when substituting the values into the equation.

(b) (i) Nearly all candidates correctly recalled $\Delta E = mg\Delta h$, though on this question more than any other candidates tended to omit the subject and write just 'mgh'. Candidates should always write a full equation, rather than just one half of an equation, to make it clear what they are calculating.

Some candidates were able to calculate the increase in height of the ball, but a common mistake was to prematurely round this interim value to less than three significant figures, which then caused the final answer to be incorrect to two significant figures.

Weaker candidates sometimes assumed that the increase in height was equal to the full compression of the spring instead of to the vertical component of the compression. Others used an incorrect trigonometrical function to calculate the change in height. Stronger candidates generally found this a straightforward problem.

(ii) Only stronger candidates determined the correct velocity of 1.9 $m\,s^{-1}$. Most candidates were correctly able to recall $E = \frac{1}{2}mv^2$, but many candidates then incorrectly set the kinetic energy equal to the elastic potential energy only, rather than to the difference between the elastic potential energy and the gravitational potential energy.

Some of the weaker candidates tried to use an equation of uniform acceleration, not realising that the acceleration of the ball changes as it moves up the ramp.

(c) (i) This question was generally well answered, with most candidates able to set up a correct equation for the moments in equilibrium. It was very common for candidates to neglect to convert the distances from cm to m. A small minority chose to inappropriately round their final answer to one significant figure.

(ii) This question was straightforward for many candidates. A significant minority attempted to describe the direction with imprecise terms such as 'upwards' or 'downwards' or 'towards the ball'. Candidates are reminded that the directions of moments can be described simply as either clockwise or anticlockwise.

Question 5

(a) Only the stronger candidates were able to precisely recall Kirchhoff's second law with the expected amount of detail. In many cases an important detail was missing, such as reference to a closed loop or closed circuit. Others referred to a 'closed system'. A significant number mentioned only 'electromotive force' instead of the 'sum of the electromotive forces', perhaps not realising that the law covers multiple sources of electromotive force.

Very weak candidates sometimes muddled Kirchhoff's first and second laws and talked about the total e.m.f. and voltage entering or leaving a junction.

Candidates are encouraged to learn concise and precise definitions for terms from the syllabus.

(b) (i) This question was generally well answered. The most common mistake was to use the potential difference across Y instead of the potential difference across X.

(ii) The majority of candidates correctly read the resistance of the thermistor from the graph. This was usually shown clearly through labelling such as 'R_Y = 25' but sometimes candidates simply wrote '25' somewhere in the working space. Candidates are reminded that their working should be shown clearly.

There were several methods to get the correct potential difference across Y and all were used by candidates successfully. The most popular method was to find the current in the circuit first, and then to use Ohm's law to find the potential difference across Y.

The most common error was not realising that the current had changed from **(b)(i)** and to neglect the resistance of X. A large number of candidates made this error.

Candidates frequently made the mistake of prematurely rounding the value of the new current to less than three significant figures, which then caused the final answer to be incorrect to two significant figures.

(iii) Many candidates were given credit for correctly identifying that the potential difference across Y would decrease. Strong candidates gave concise answers with sound physical reasoning. A significant number of candidates correctly applied a potential divider argument to reason that the potential difference would decrease, but some did not follow the instruction in the prompt and did not mention the change to the current in the circuit.

Weaker candidates often repeated from the stem that the resistance of X increased but did not state that the total resistance increased.

The weakest candidates could not connect the increase in the total resistance to a logical change to current and potential difference. Many seemed to be confused by the difference between e.m.f. and p.d.

It was also common for candidates to state that 'the current in a series circuit remains the same'. It was often clear that candidates had confused the concept that current is the same at all points in a series circuit at any given instant with the incorrect idea that the current in a series circuit cannot ever vary.

Question 6

(a) Most candidates correctly recalled the diffraction grating equation. A few candidates incorrectly attempted to use $\lambda = ax / D$. A small number of candidates confused the line spacing for number of lines per unit length, but this was rare.

Most candidates were able to correctly determine the highest order of fringe formed. Converting this to a total number of fringes was less successful, with many candidates simply stating the highest order (7) as their final answer. Most candidates recognised that the final answer needed to be an integer, but did not always deal with the central bright fringe and the other half of the diffraction pattern correctly. 7, 8, 14 and 16 were all common incorrect answers.

A few weaker candidates wrongly used sin 180° instead of sin 90°, possibly becoming confused by the full screen extending over an angle of 180°.

(b) (i) This question was straightforward for many candidates. Some candidates seemed to confuse frequency and wavelength and incorrectly stated that the frequency of the red light would be greater than that of the original light.

(ii) Many candidates correctly identified that the wavelength of red light was longer than that of the original light, and so the number of bright fringes visible would decrease. Many answers referred to a proportional relationship between the number of bright fringes and the wavelength, which is not correct. Candidates should remember that the highest order of the bright fringe formed is not the same as the total number of bright fringes.

Candidates who had used the double-slit equation in **(b)(i)** were unable to reach the correct answer.

Question 7

(a) Most candidates correctly identified Q and R as mesons. Candidates are reminded to learn the correct spellings of terms from the syllabus so that they can give unambiguous answers. The most common incorrect answers were 'baryon' and 'lepton'.

(b) Every possible quark was seen in the answers to this question. Stronger candidates found this straightforward, but weaker candidates often appeared to be guessing. Many weaker candidates correctly stated 'up' for the second quark in R, but often gave 'anti-strange' for the second quark in Q. This suggests that candidates are generally confident that mesons consist of a quark and an antiquark, but may incorrectly assume that the quarks must be of the same flavour.

PHYSICS

Paper 9702/23
AS Level Structured Questions

Key messages

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

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

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

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

General comments

Most candidates show a good amount of working to support their answers to numerical questions, allowing marks to be awarded for correct methods even where errors then occur. Many candidates write algebraic or numerical expressions without subjects and could improve by ensuring that the subject of an equation is always given.

Candidates found **Questions 1(a), 1(b)**, **2(b)(i)** to **2(b)(iv)**, **3(c)(i)** and **4(c)** to be straightforward. They found **Questions 1(d)(ii)**, **2(b)(v)**, **3(e)**, **4(d)** and **6(b)(i)** to be difficult.

There was no evidence that candidates were short of time.

Comments on specific questions

Question 1

(a) The majority of candidates found this question straightforward.

(b) The majority of candidates were able to rearrange the given equation to determine the viscosity. A minority of candidates made a power of ten error in the conversion of the radius from centimetres to metres. Some weaker candidates made no conversion.

(c) The majority of the arrows were drawn in approximately the correct directions. Many candidates did not draw their arrows vertically and many did not use a ruler. A significant number of candidates labelled the downward force as ‘gravity’ which is not acceptable as a term for the force in place of weight or gravitational force.

(d) (i) This question was well answered by the majority of the candidates. Some candidates attempted to use an incorrect equation for the volume of a sphere. A significant number rounded their value for the volume of the sphere to two significant figures prematurely and obtained an incorrect answer for the upthrust.

(ii) Stronger candidates were able to obtain the mass of the sphere. These candidates realised that the weight of the sphere was equal to the drag force plus the upthrust as the sphere travelled at terminal velocity. A small number equated the weight of the sphere to only the upthrust or the drag force. Weaker candidates tended to try to use $\rho = mV$ using the density of the water and hence determined the mass of the displaced water, rather than the mass of the sphere.

Question 2

(a) There were many answers that described a distance between two points with no mention of a direction.

(b) (i) This question was generally well answered by most candidates. A minority of candidates attempted to use an equation of uniform acceleration even though the question asked for the horizontal distance.

(ii) This question was generally well answered. There were a minority of candidates who used the horizontal velocity as the initial vertical velocity.

(iii) This question was generally well answered. A minority of candidates used an incorrect relationship for tan θ or cos θ.

(iv) This question was generally well answered. Most candidates gained full credit, often as a result of error carried forward from the previous questions.

(v) Only the stronger candidates determined a correct answer to this question. A significant number of candidates omitted the initial kinetic energy of the object in determining the final speed. A number of candidates ignored the instruction to consider energy and instead determined a final vertical component of speed using equations of uniform acceleration. Some gave this as the answer, but others were able to determine a correct resultant velocity.

Question 3

(a) This definition was generally well answered. Candidates should be reminded to define any symbols used in a definition.

(b) (i) A significant number of stronger candidates marked the limit of proportionality close to the correct point, though in many cases the point was well into the curved region of the graph and so outside the allowed tolerance. Weaker candidates often confused the limit of proportionality with the elastic limit or the breaking point.

(ii) Candidates found this question difficult. Many candidates placed the elastic limit at an extension of around 140 mm or at point X, the breaking point. Candidates are reminded to read the question carefully, as the information required to answer the question was readily available just below the diagram.

(c) (i) This question was generally answered well. The most common errors were in misreading a point on the graph and in converting from mm to m.

(ii) The majority of the candidates gave the correct expression for Young modulus in terms of stress and strain. The stronger candidates rearranged and substituted correctly the quantities given that enabled the stress and strain to be calculated. Weaker candidates often made errors in the rearrangement of the quantities involved with stress and strain or made errors in the powers of ten when converting the extension from mm to m or the area from mm^2 to m^2.

(d) Some candidates explained their working in terms of equating the area under the line to the work done. The majority merely gave the equation for work done as force $\times$ distance. A significant number calculated the area under the straight-line section only, and gave this as their answer. Stronger candidates were able to approximate the area under the whole curve using geometry or counting squares.

(e) Only the stronger candidates were able to relate the spring constant with the cross-sectional area. The majority of candidates were unable to link the spring constant with the Young modulus and hence the cross-sectional area. Many of the candidates who identified that the spring constant would be larger often did not give a clear explanation. Weaker candidates often incorrectly stated that there was no relationship between spring constant and area, or omitted the question altogether.

Question 4

(a) The majority of candidates gave the correct phase difference.

(b) There were many arrows that pointed upwards or there was no response. The direction of movement of the particles in a progressive wave seemed to be poorly understood by candidates of all abilities. A significant number did not use a ruler to help them draw the arrow, making it difficult to judge if the line was straight or vertical.

(c) The majority of candidates were able to use an appropriate equation to determine the frequency. A small number used the distance RT as the wavelength. Some candidates did not convert the distance given in cm to m.

(d) A significant number of candidates were able to identify that the waves from S_1 and S_2 superpose or overlap at P. Many candidates were able to reason that the resultant amplitude will be zero, though several explanations confused displacement and amplitude. Candidates should be encouraged to use precise language in describing physical phenomena. Only the stronger candidates connected the concept of superposition and the resultant amplitude with a correct statement about phase difference or path difference.

Question 5

(a) (i) Candidates found it difficult to give a clear statement of the second law. A small number confused Kirchhoff's first and second laws. A significant number omitted the 'sum of' the e.m.f.s or the 'sum of' the potential differences. A similar number omitted the condition that it is for a closed circuit or closed loop of a circuit. Candidates should be encouraged to learn concise and precise definitions or laws included in the syllabus.

(ii) The majority of candidates gave the correct conservation law. Weaker candidates sometimes gave conservation of momentum or mass.

(b) (i) A minority of candidates stated that the potential difference was the same across both resistors. The stronger candidates related the current through each resistor to the total circuit current. Weaker candidates often omitted this question or wrote the required 'show that' answer alongside the definition of resistance $R = V / I$. A small minority confused series and parallel resistance.

(ii) This question was answered well by a wide range of candidates. A majority were able to calculate a correct total external resistance. The most common method candidates used was to determine the current in the cell. A significant number of candidates incorrectly used the total external resistance and the e.m.f. to determine the current, rather than the terminal potential difference. A number incorrectly used the e.m.f. of the cell (rather than the 'lost volts') and the current through the cell to determine the internal resistance of the cell.

(c) (i) The majority of candidates gave a correct explanation with the resistance of the circuit decreasing when an additional resistor is placed in parallel across the original two resistors. A significant minority thought that the circuit resistance would increase when the additional parallel resistor is included.

(ii) Only the stronger candidates were able to give an appropriate answer to this part. Very few candidates correctly recognised that the 'lost volts' had increased. A significant number confused the e.m.f. of the cell with the terminal potential difference and stated that there was no change to the external p.d. Many who had correctly answered **(c)(i)** incorrectly reasoned that, as the current had increased and resistance had decreased, these effects would cancel out.

Candidates should give both a statement and an explanation in ‘state and explain’ questions. No credit was given in this question if only the statement was provided without the explanation.

Question 6

(a) The majority of candidates gave the correct nuclide notation. A significant number gave the number of neutrons for the nucleon number and some gave the atomic number and the nucleon number in the wrong places.

(b) (i) This question was answered well by only the strongest candidates. The majority of these candidates described the energy of the emitted particles as discrete, and some went on to describe beta emission as having a range of energies. Weaker candidates tended to omit this question, or to try to justify that beta particles could not be emitted as they have no mass and so no kinetic energy.

(ii) This was straightforward for all but the weakest candidates. A significant number of candidates did not attempt a response.

(c) (i) This was straightforward for all but the weakest candidates.

(ii) This was straightforward for all but the weakest candidates.

PHYSICS

Paper 9702/31
Advanced Practical Skills 1

Key messages

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

General comments

Most centres did not have difficulties in providing the equipment requested, although some candidates were not provided with the requested ammeters reading to 0.1 mA. Any deviation between the requested equipment and that provided to the candidates should be written down in the supervisor’s report, and this report must be sent with the scripts to Cambridge so that the examiners can take this into consideration when marking. No additional equipment should be available to the candidates. In some cases, this may disadvantage candidates.

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

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

Comments on specific questions

Question 1

(a) Most candidates stated *y* in the accepted range, to the nearest mm and with a unit. Some candidates omitted the unit, added an extra zero (e.g. 49.50 cm) or did not include a number to reflect the mm place (e.g. 50 cm). Candidates are encouraged to think about the precision of the instrument provided (1 mm for a ruler) and apply this knowledge to their stated readings.

Many candidates stated I to the nearest 0.1 mA and with a correct unit. Weaker candidates often stated their value of current with an inconsistent power of ten e.g. 57.3 A instead of 57.3 mA.

(b) Most candidates stated y to be larger than their first y value in **(a)**.

(c) Most candidates were able to collect six sets of values of n and y without assistance from the supervisor and with the correct trend. Candidates are encouraged to check their results if one value is out of trend with the rest. Some weaker candidates found it difficult to adjust the value of n, to keep the current value constant or to take a usable set of readings.

Many candidates chose too small a range over which to conduct the experiment. Many candidates went from $n = 1$ to $n = 3.5$, thereby not extending their data over the available range of $n = 0.5$ to $n = 4$. Candidates are encouraged to use the whole range available to them.

Many candidates gave both the quantity and correct unit for each heading, separated by a solidus or with brackets around the unit. Candidates are encouraged to remember the separating mark between the quantity and unit (a bracket around the unit or a '/ ' dividing sign). Some candidates gave the unit of n as Ω instead of leaving the n and $n / (n + 1)$ column headings without a unit.

Many candidates stated their calculated values to a mixture of significant figures when the question specifically asks to state $n / (n + 1)$ to two significant figures. A few candidates considered that 0.5 and 0.6 had two significant figures.

Many candidates calculated values for $n / (n + 1)$ correctly. Candidates are encouraged to round their answers correctly and not to truncate the numbers without consideration.

(d) (i) Many candidates plotted the correct graph with labels of the quantities asked for, and used easy-to-read, sensible and regular scales. Candidates are encouraged to choose scales such that all their points can fit on the grid available and occupy over half the graph grid in both the x and y directions.

Some candidates divided up the grid to make the points at the extremities lie on the edges of the grid. This method should be strongly discouraged. The resulting scale is difficult to use (requiring a calculator), so no credit is given for the scale and candidates with such scales often make further mistakes later in reading off values.

Many points were drawn as neat crosses such that the centre was no more than half a square thick and were plotted correctly so that the position was within half a small square in both the x and y directions. Common mistakes were to use 'blobs' (points of diameter greater than half a small square) or mis-plotting a point more than half a square from the correct position.

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

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

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

Weaker candidates often 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 occasionally others incorrectly read off the y-intercept when there was a false origin (i.e. not $x = 0$).

(e) (i) Some candidates recognised that *P* was equal to the negative of the gradient value and *Q* was equal to the *y*-intercept value. Many candidates transcribed their values of gradient and intercept for *P* and *Q* without any consideration of the change of sign of the gradient for *P*. A few candidates incorrectly gave their value of *P* or *Q* to only one significant figure. Candidates who inverted their axes on their graph generally did not rearrange the equation to be consistent.

Many candidates provided correct units, taking into consideration the units used in the experiment. Some candidates omitted units or used different units to those used in the experiment without any evidence of converting correctly.

(ii) Many candidates rearranged the equation and correctly calculated *C*. Occasionally a candidate substituted into a wrongly arranged expression e.g. P / QX or Q / XP.

Question 2

(a) (i) Many candidates measured values of *L* to the nearest mm and stated a correct unit. Some candidates stated *L* to the nearest cm when the ruler can be read to the nearest mm.

(ii) Many candidates measured values of *M* to the nearest 0.1 g (or better), stating a correct unit. Some candidates stated *M* to the nearest g when the balance can be read to the nearest 0.1 g (or better).

(iii) Many candidates correctly justified the number of significant figures they had given for the value of *S* with reference to the number of significant figures used in *L* and *M*. A few candidates referred to L^2 or the number 12. Candidates need to refer to the specific raw quantities involved in the calculation. Many candidates incorrectly gave reference to 'raw readings', 'previous measurements' or 'values used in calculation' without detailing the individual raw quantities involved in this particular equation.

(b) (i) Many candidates measured *a* in the accepted range, to the nearest mm and with a unit. Some candidates omitted a unit or stated the measurement to the nearest cm.

(ii) Candidates often made too small an estimate of the absolute uncertainty in the value of *a*, typically 1 mm or 0.5 mm. This distance is difficult to measure and a larger estimate of the uncertainty would have been appropriate. Some candidates, having repeated their readings, correctly showed the working to give the uncertainty as half the range. Some candidates who repeated their results did not halve their range to give the uncertainty.

(c) Many candidates stated *T* in the accepted range and with the correct unit, and showed two or more sets of multiple oscillations. Some candidates did not show repeated readings, missed out a unit or stated a value that was out of range (perhaps by timing half an oscillation or not dividing the total time by the number of oscillations to give the period).

(d) The majority of the candidates measured new values of *m* and *a* for the lower 10 g masses. Most candidates measured and calculated their new value of *T* to be larger than their first value.

(e) Candidates were generally able to calculate *k* for the two sets of data, showing their working clearly. Some candidates rearranged the equation to get *k* incorrectly (multiplying T^2 by $(S + a^2m)$ instead of dividing).

(f) Some candidates calculated the percentage difference between their values of *k*, tested it against the stated 10% criterion and provided a valid statement. Some candidates omitted a percentage difference calculation, gave a different criterion (e.g. 15%, 20% or the percentage uncertainty from **(b)(ii)**) or gave an invalid statement inconsistent with their findings. Candidates giving vague statements referring to 'beyond experimental accuracy' do not gain credit here.

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

Problems commonly awarded were 'two sets of data were not enough to draw a valid conclusion', 'difficult to measure *a* because of parallax error', 'difficult to measure *T* as difficult to judge the end of a complete oscillation', 'the mass of the putty was not taken into account' and 'the oscillation took place in more than one plane'. Candidates are advised not to spend time suggesting that the labelled 10 g and 50 g masses may not be accurate when there are much more significant sources of uncertainty in the experimental method.

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

When addressing the issue of accurate timing, reference to a video camera with a 'slow motion feature' is not sufficient. Candidates should be advised to refer to a 'video camera with a timer' or to view a recording frame by frame. When thinking about how to improve the measurement of a, candidates needed to recognise that there was a parallax issue between the ruler and the wire at the centre of the rod. The use of calipers would solve this problem.

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

PHYSICS

Paper 9702/32
Advanced Practical Skills 2

Key messages

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

General comments

The supervisor's reports from many centres contained useful details of any difficulties encountered by candidates as well as any help given by the supervisor. Supervisors are asked to provide a sample set of results with their supervisor's report. This is necessary so that full benefit can be given to the candidate where needed. For example, supervisor's values allow the examiner to gauge data ranges, time periods and angles for the specific setup used by that centre. Where a candidate's value falls outside of an expected range, the supervisor's value can be used to determine whether the candidate deserves credit.

Candidates for future examinations might be encouraged to recognise that, where the question paper does not provide a unit on the answer line, they are expected to give a correct unit with their numerical value. They should also take care, where a unit is provided on an answer line, to write their value in that unit by, for example, converting a value measured in cm to m. The indication of a second mark for a response that is a measured value can often be a reminder that something in addition to a numerical value is expected, such as evidence of a repeat measurement.

Candidates were able to successfully complete both questions in the time available, and only a small number of scripts suggested that the candidate had experienced time pressure.

Comments on specific questions

Question 1

(a) The mark scheme indicated a range of expected values for the final value of *T*. Examiners referred to the supervisor's value if the candidate's value was outside this expected range. Candidates from centres where no supervisor's values were provided were sometimes unable to gain credit in this situation when the provision of a supervisor's value might have enabled them to do so.

Candidates were expected to repeat their measurement of *T*. Candidates who were not awarded full credit here generally omitted to provide a unit and/or did not provide a repeated measurement.

(b) Almost all candidates were able to provide a set of six measurements of V_S and *T* with a correct trend, and to present their measurements in a well constructed table. The syllabus expects that measurements and calculated values are recorded in a single table. In a small number of cases, some data was recorded outside the main table and, though candidates were not disadvantaged when they did this, centres should encourage candidates to use a single table. If candidates wish to change a value written in a cell of their table, they should be encouraged to cross out the first value and write a new value clearly rather than overwriting their original value.

Many candidates were not awarded credit for their range of values of V_S. This frequently occurred when either the highest value of V_S was greater than 10.00 V but the lowest value was not below 4.00 V, or the other way round. Candidates should be encouraged to identify the full possible range that the experimental arrangement allows in the independent variable before they start their measurements, and then to make the fullest possible use of this range as they record their measurements. Candidates who choose instead to have a regular interval in their values (e.g. 1.0 V) as they make their measurements are likely to miss at least one of the upper or lower range limits as they reach their sixth value.

Many candidates were able to gain credit for the column headings, with the most common reasons for not gaining credit being the omission of a separator between the 1 / *T* value and its unit or the omission of units altogether.

The majority of the candidates gained credit for providing values of *T* to the nearest 0.01 s (two decimal places), with fewer candidates gaining it by providing values to the nearest 0.1 s. Many candidates had a range of *T* values that included values both above and below 10.00, with a mix of four significant figures and three significant figures to correctly achieve the same precision/consistency. This led to difficulty in choosing the correct number of significant figures for 1 / *T*. Candidates should be reminded to treat each row of their table independently and give each calculated value to the same number of significant figures as, or one more than, the number in the raw data.

Many candidates gained credit for the calculation of 1 / *T*. Candidates who did not gain credit had generally made an incorrect rounding of the last figure in a value of 1 / *T*.

(c) (i) Most candidates placed regularly spaced numerical labels at least every 2 cm (1 large square) on the axes of their graph. Many candidates used sensible scale intervals, but a minority used very awkward scales. 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 what they see as a better use of the grid. Scale intervals of 1.5, 3, 6 or 7, and multiples thereof, are considered to be awkward scales and are not awarded credit. Very occasionally, a reversed axis was seen (where the highest value was shown nearest to the origin and the lowest value furthest from the origin) and did not gain credit.

The plotting of points was generally accurate. A small minority of candidates used round dots to mark their points which were larger than 1 mm in diameter ('blobs') and therefore were not awarded credit. Candidates should be encouraged to use sharpened pencils when plotting points.

(ii) Sometimes candidates' points allowed a good straight line through five points, with a further outlier point that was disregarded by the candidate in drawing the line of best fit. Where this outlier point was ignored but not identified by the candidate as being anomalous, credit for the line of best fit could not be awarded. Centres should encourage candidates to indicate any outlier point as anomalous (e.g. by circling it or labelling it), so that their line of best fit can be marked on the remaining points only. If more than one point is indicated as anomalous, the examiners will not allow either point to be ignored in assessing the line of best fit.

In other cases, candidates' lines would have been improved by a rotation or sideways translation of their line. Candidates could usefully recognise that a good line of best fit will have, as best as possible, an even distribution of points either side of both the upper section and the lower section of the line. Where the points are, for example, generally above the line at the top while being below the line at the bottom, an anticlockwise rotation is indicated. The need for a rotation of this type is a common reason for the mark not being awarded. Candidates need to be careful about trying to draw a line that goes through as many points as possible without considering the overall distribution of all the points about the line.

Candidates should be encouraged to use a sharp pencil when drawing their lines of best fit.

(iii) Most candidates were able to correctly calculate their gradient and intercept values, using read-offs that were correct. Candidates should be encouraged to use read-offs that are greater than half the length of their drawn line apart. Where points from the values in the table are used, credit is only given if the points lie on the candidate's drawn line of best fit, and this often does not turn out to be the case.

While most candidates used a substitution into $y = mx + c$ to determine the value of the y-intercept, a number of candidates used a read-off from the $1 / T$ axis. This was not able to gain credit in those situations where the V_S axis showed a false origin (i.e. the V_S axis scale did not begin at zero). A small but noticeable number of candidates attempted to extend the $1 / T$ axis beyond the printed grid in order to find the y-intercept. This was also unable to gain credit.

(d) Most candidates were able to transfer their values from **(c)(iii)** to the answer lines.

Candidates were sometimes unable to gain credit as they gave one or both of their values to only one significant figure.

Some candidates omitted units or gave incorrect units with their values. Candidates could be advised to look at the units on the axes of their graphs in choosing units at this point.

Question 2

(a) (i) Most candidates measured a value of L_0 that lay within the range expected. This was a marking point that required candidates to record their value to the precision of the measuring instrument, that is, to the nearest mm. Candidates who did not gain credit here either gave an answer to just the nearest 0.01 m or wrote a value on the answer line in cm without converting it into m.

(ii) Many candidates were able to gain full credit. Candidates were expected to record the time taken for at least 5 oscillations, and to do that at least twice, before using their measurements to determine an average to be their final value. Candidates who did not gain credit typically measured the time for one oscillation three or four times before averaging, or measured a single value of, for example, $10T$ only. A number of candidates correctly measured, for example, three values of $10T$, but then only divided their total value by 3, neglecting to further divide by 10. This was not able to gain credit. A similar number of candidates also calculated n / nT rather than nT / n, which was also unable to gain credit.

(iii) Nearly all the candidates who gained credit did so by quoting a number of significant figures for T, typically three, and then identifying that the value of k should also have three significant figures. Candidates should be aware that they need to name the specific quantities used in the calculation, and relate the number of significant figures in these quantities to the number given in the outcome of the calculation. In this case, this meant referring only to the significant figures in T. A small number of candidates also included a reference to the significant figures in L_0, which was not part of the calculation of k, and this was considered to contradict the correct answer. Generalised references to choosing a number of significant figures 'for accuracy' or undefined references to 'the quantities used in the calculation' do not gain credit.

(b) (i) Most candidates were able to gain full credit. Some candidates quoted their measured values of θ to a precision greater than the nearest degree. Only the occasional candidate recorded a value of θ outside the expected range or a value of L that was smaller than L_0.

(ii) The strongest candidates used an appropriate absolute uncertainty of 2°–5° to correctly calculate the percentage uncertainty. Many candidates used unrealistically small values for the absolute uncertainty, often appearing to use the smallest scale division (or half the smallest scale division) on the protractor as their value for the absolute uncertainty.

A small proportion of candidates who attempted to use a half-range calculation from repeated values determined the full range instead and were usually unable to gain credit. Candidates who gained credit here appeared to be candidates with experience of similar questions and therefore a good sense of a realistic value for the absolute uncertainty.

(iii) A majority of candidates were able to gain full credit. Occasionally the second value of was *L* smaller than the first value of *L*.

(c) Most candidates were able to correctly calculate values for *D*. Candidates appear to have found the correct rearrangement of the given expression difficult, with the value of cos θ frequently just multiplying the $B = 2.0\,\text{N}$ rather than the entire expression on the left-hand side as given. Another error seen was that the value of the left-hand side of the given expression was divided by the value of cos θ rather than being multiplied by it. Sometimes a correctly rearranged expression, with a correct substitution, still resulted in incorrect answers for *D*, suggesting an incorrect use of the calculator. In some cases this may have been a result of the calculator being set in radians mode rather than degrees mode.

(d) Many candidates were able to calculate a percentage difference between the two values of *D* and compare it to the 10% criterion given in the question, with a correct conclusion being drawn. Only a small number of candidates used a different criterion, either of their own or based on the percentage uncertainty from **(b)(ii)**, and these candidates were not able to gain credit. Candidates were able to gain credit here by calculating a 10% range from one or both of their *D* values, and showing that these ranges overlapped. A number of such attempts were then unclear in the wording of their conclusion. Centres who encourage candidates to use this method might also try to make sure that candidates can express the relevant conclusion successfully.

In stating their conclusions, a number of candidates referred to their values of *D* being within or outside the 'limit of experimental accuracy', a term which appears to come from their experience in examinations before AS Level. On its own, this was not able to gain credit for the stating of a conclusion, but it could be credited provided the candidate made clear that they were actually comparing with the 10% criterion.

(e) (i) There was a wide range of candidate performance in this question. The candidates who achieved higher marks appear to have had significant practical experience, and to be giving attention to the wording of the second paragraph of the question stem which encourages them to both state a quantity being considered and give a reason for uncertainty in that quantity. In many cases, an otherwise valid limitation did not gain credit because it was not clearly linked to the relevant quantity. An example of this occurred when candidates referred to uncertainty in measuring 'length', which was not sufficient to identify *L* or L_0.

Some candidates made only very general suggestions of limitations, and these were not able to gain credit. Candidates should be aware that they need to describe uncertainties and limitations that arise from the specific experiment being carried out. Difficulties such as wind from open windows or cooling fans (which are generally not significant) and vague references to inaccurate equipment are unlikely to gain credit.

(ii) There was a wide range of candidate performance, with candidates who appeared to have good practical experience performing best. Weaker candidates made very general statements or offered improvements that were only partly described, and so could not gain credit. 'Take more readings', for example, needs to be supported by the idea of plotting a graph or comparing values of *D* in order to gain credit. General references to 'use more accurate equipment' or to switching off air conditioning fans do not gain credit.

Candidates should be encouraged to think about apparatus that they might suggest using to improve their measurements or method but that has not been provided for them in the examination. An example of this is the use of calipers to measure a length, when only a metre rule or 30 cm ruler were provided.

Improvements to the measurement of the time for an oscillation have occurred in previous examinations, and mark schemes for this paper and for previous papers indicate accepted candidate responses. Candidates should note the care that is needed in describing these improvements, and should include sufficient detail in their answers. ‘Using a fiducial marker’, for example, is not enough to gain credit unless the position of that marker at the centre point of the oscillation is also described, and ‘use a sensor’ is not sufficient unless the type of sensor, its position and the use of a data logger are included in the response.

PHYSICS

Paper 9702/33
Advanced Practical Skills 1

Key messages

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

General comments

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

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

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

Comments on specific questions

Question 1

(a) Most candidates stated *a* in the accepted range and with a unit.

(b) Most candidates stated *y* to the nearest mm and with a unit. Some candidates omitted the unit, added an extra zero (e.g. 9.50 cm) or did not include a number in the mm place (e.g. 10 cm).

Candidates are encouraged to think about the resolution of the instrument provided, i.e. 1 mm for a ruler, and apply this knowledge to their stated readings.

(c) Most candidates were able to collect six sets of values of *n* and *y* without assistance from the supervisor and with the correct trend. Candidates are encouraged to check their results again if one value is out of trend with the rest. Some candidates used $n = 0$ which did not constitute a useful data point given that they needed to calculate $1 / n$ and y / n.

Many candidates chose too small a range over which to conduct the experiment. Many candidates went from $n = 1$ to $n = 6$ or from $n = 2$ to $n = 7$, thereby not extending their data over the available range of $n = 1$ to $n = 7$. Candidates are encouraged to use the whole range available to them.

Many candidates gave both the quantity and correct unit for each heading, separated by a solidus or with brackets around the unit. Candidates are encouraged to remember the separating mark between the quantity and unit (a bracket around the unit or a '/' dividing sign). Some candidates gave the units of *n* and $1 / n$ as g and g^{-1} respectively instead of leaving these column headings without a unit.

Some candidates stated their calculated values to a mixture of significant figures when the question specifically asks to state y / n to three significant figures.

Many candidates calculated values for y / n correctly. Candidates are encouraged to round their answers correctly and not to truncate the numbers without consideration.

(d) (i) Many candidates plotted the correct graph with labels of the quantities asked for, and used easy-to-read, sensible and regular scales. Candidates are encouraged to choose scales such that all their points can fit on the grid available and occupy over half the graph grid in both the *x* and *y* directions.

Some candidates divided up the grid to make the points at the extremities lie on the edges of the grid. This method should be strongly discouraged. The resulting scale is difficult to use (requiring a calculator), so no credit is given for the scale and candidates with such scales often make further mistakes later in reading off values.

Many points were drawn as neat crosses such that the centre was no more than half a square thick and were plotted correctly so that the position was within half a small square in both the *x* and *y* directions. Common mistakes were to use 'blobs' (points of diameter greater than half a small square) or mis-plotting a point more than half a square from the correct position.

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

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

(iii) Candidates need to use a large triangle to calculate the gradient, use correct read-offs and substitute into a correct expression. Weaker candidates often 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 occasionally others incorrectly read off the *y*-intercept when there was a false origin (i.e. not $x = 0$).

(e) (i) Some candidates recognised that *P* and *Q* were equal to the gradient and the negative *y*-intercept respectively. Many candidates transcribed their values of gradient and intercept for *P* and *Q* without any consideration of the change of sign of the *y*-intercept for *Q*. A small number of candidates incorrectly gave their value of *P* or *Q* to only one significant figure. Candidates who inverted their axes on their graph generally did not follow through and rearrange the equation to be consistent.

Many candidates provided correct units, taking into consideration the units used in the experiment. Some candidates omitted units or used different units from those used in the experiment without any evidence of converting correctly.

(ii) Many candidates rearranged the equation and correctly calculated *R*. Some candidates did not substitute *a* in the equation from page 2 but instead inappropriately used $a = 9.81$. Some weaker candidates did not use the same units for *a* and *P* so that their answer had a power-of-ten error.

Question 2

(a) (i) Many candidates measured values of L_0 to the nearest mm and gave a correct unit. Some candidates stated L_0 to the nearest cm when the ruler can be read to the nearest mm.

(ii) Many candidates incorrectly made too small an estimate of the absolute uncertainty in the value of L_0 (typically 0.1 cm or 0.05 cm). This length reading is difficult to take accurately and a larger estimate of the uncertainty was needed. Some candidates, having repeated their readings, correctly showed the working to give the uncertainty as half the range.

(b) Stronger candidates correctly stated w_0 and *t* to the precision of the micrometer screw gauge. Many candidates measured the thickness with the micrometer and not the width, or used a ruler for both measurements. A few candidates incorrectly stated a value for the thickness as larger than that for the width.

(c) (i) Most candidates stated *L* as being greater than L_0.

(ii) Most candidates were able to correctly calculate ΔL and Δw.

(iii) Many candidates correctly justified the number of significant figures that they had given for the value of ΔL with reference to the number of significant figures used in L_0 and *L*. The quantities are subtracted so the final number of significant figures depends on what remains after the subtraction (e.g. 3.6 – 3.4 = 0.2) and is not necessarily the same number of significant figures as in the original quantities.

Many candidates gave reference to 'raw readings', 'previous measurements' or 'values used in calculation' without detailing the individual raw quantities concerned, and some candidates gave reference to *t* and/or *w* which did not feature in the calculation.

(d) Most candidates recorded second values of *L* and *w*. Many candidates correctly recorded their second *w* values to be smaller than their first values.

(e) Most candidates were able to calculate *k* for the two sets of data, showing their working clearly. Many candidates used different powers of ten in their units (e.g. mixing mm and cm without converting). Whilst the answer was dimensionless, many candidates stated their answer with units. A few candidates inappropriately stated their values to one significant figure.

(f) Some candidates calculated the percentage difference between their values of *k*, tested it against the stated 25% criterion and provided a valid statement. Some candidates omitted a percentage difference calculation, gave a different criterion (e.g. 10%, 20% or the uncertainty from **(a)(ii)**) or gave an invalid statement inconsistent with their findings.

(g) Some candidates correctly calculated *F* and stated it with a correct unit. Many candidates omitted one or more of the measurements or calculated using different powers of ten (e.g. some measurements were in cm whilst others were in mm). The value of *E* was given in N m^{-2} so the most straightforward approach was to convert all measurements to m. A few candidates incorrectly converted *E* to N cm^{-2} by dividing by 100 instead of 100^2.

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

Problems commonly awarded were 'two sets of data were not enough to draw a valid conclusion', 'difficult to measure L_0 as measuring to a curved edge (or parallax error)' and '*w* or *t* difficult to measure as the micrometer screw gauge squashed the rubber band'. Candidates often mentioned problems that were not deemed important for this particular experiment (e.g. holding the ruler vertical to measure L_0).

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

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

PHYSICS

Paper 9702/34
Advanced Practical Skills 2

Key messages

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

General comments

The supervisor's reports from many centres contained useful details of any difficulties encountered by candidates as well as any help given by the supervisor. Supervisors are asked to provide a sample set of results with their supervisor's report. This is necessary so that full benefit can be given to the candidate where needed. For example, supervisor's values allow the examiner to gauge data ranges, time periods and angles for the specific setup used by that centre. Where a candidate's value falls outside of an expected range, the supervisor's value can be used to determine whether the candidate deserves credit.

The general standard of work carried out by the candidates was good, with some candidates producing excellent scripts. Where candidates scored less well, this could often have been improved by better presentation of data and processing skills. Working was usually clear and legible, but some candidates should be reminded to draw tables carefully using ruled lines and, where possible, to record data systematically. For graph work, candidates should be encouraged to use a 30 cm ruler to draw lines of best fit and to provide legible scale markings on axes.

There did not seem to be a shortage of time and all sections of the two questions were answered by almost all the candidates.

Comments on specific questions

Question 1

(a) The angle recorded by most candidates was within the expected range. Some had values just outside the expected range but, where supervisor's results were provided, were still able to gain credit for being suitably close to the supervisor's value. Candidates who were not awarded credit had possibly not placed the protractor correctly. For example, some candidates had angles greater than 90° so must not have had the zero in the correct position.

(b) The majority of the candidates successfully followed the instructions and recorded six sets of values of *x* and θ. The most successful candidates presented their data sequentially and ensured that the maximum and minimum mass values available were included in their data. A significant number of candidates used a reduced range of masses (e.g. 10 g to 60 g) and so were not awarded credit for the range of their values.

Column headings in the table were usually correct and included a suitable separator between the quantity and unit. Those who were not awarded credit often omitted the separator between the angle and its unit (e.g. θ° rather than θ / °) or added a unit where it was inappropriate to do so (e.g. for 1 / cos θ).

When recording raw θ values, candidates are expected to present their data using an appropriate precision. Whilst many did this by recording all measured values to the nearest degree, some recorded angles to the nearest 0.1° which was not realistic.

Most candidates recognised the need to present 1 / cos θ values to the same number of significant figures as (or one more than) the raw θ values. Candidates should be aware that the examiners check each row of the table independently, with each value of 1 / cos θ judged in isolation against the raw data from which it was derived.

The calculation of 1 / cos θ was correct in most cases. A small number of candidates gave a value that was incorrectly rounded, while others appeared to have used their calculators in radian mode.

(c) (i) Candidates producing successful graphs did so by choosing sensible scales that allowed plotted points to occupy at least 4 large squares horizontally and 6 large squares vertically. Axes were generally labelled with the correct quantities and scale markings had values that were usually written 1 large square apart. A significant number of candidates selected unsuitable scales. It was not uncommon to see 30:10 scales being chosen and these cannot be awarded credit. Even more awkward scales were chosen by some candidates, e.g. labelling the extreme points on the grid with their minimum and maximum table values and then dividing the range by the number of squares available on the grid provided. These scales require a calculator to determine where points should be. Such graphs are not awarded credit for the scale and create an increased likelihood of a misplaced point or incorrect read-off value in the gradient and *y*-intercept calculations.

Although most plotted points were accurate, a significant number of points were too large to be judged to the nearest mm. Candidates are advised to use a sharp pencil.

The quality of the data is judged by whether it is possible to draw a straight line that lies within a given tolerance of all plotted points (including any points identified as anomalies). Candidates who chose to use small ranges of mass or who were unable to successfully measure the angle using the protractor collected data with too much scatter and did not gain credit for the quality.

(ii) When drawing the straight line of best fit, many candidates produced thin lines that had an even distribution of points either side of the line along the full length. The most common reasons for lines not being credited were broken or kinked lines, often the result of using short rulers forcing the line to be drawn in two parts, or lines requiring a rotation.

Candidates should be made aware that, if they identify a point as anomalous and decide to ignore it when drawing the line, they need to indicate this by either circling the point or labelling it. Only one anomaly can be ignored.

(iii) Most candidates correctly selected two points from their line that were at least half the length of the line apart and then substituted the values into the equation Δy / Δx or equivalent. Some candidates incorrectly used Δx / Δy or used points in their equation that were not on the line of best fit. A significant number made errors when reading values from the graph, and this was often exacerbated by poorly chosen scales.

For the y-intercept, most candidates correctly substituted values into $y = mx + c$ (or equivalent) or took a correct read-off directly from the graph. Candidates should be aware that this second method is not valid if the x-axis has a false origin.

(d) Most candidates recognised that a was equal to their gradient value and b was equal to their y-intercept value. Some candidates recalculated values in **(d)** and so had not followed the instruction to use their values from **(c)(iii)**. Some candidates quoted value(s) of a and/or b to only one significant figure and this was not credited.

Units were often omitted but the majority of those providing a unit did so correctly.

(e) This calculation was successfully attempted by a large majority of candidates. A small number of candidates incorrectly or too severely rounded their M value, resulting in an incorrect value for the mass of Q.

Question 2

(a) (i) The majority of the candidates provided a value for T_0 with a unit that was within the expected range. Some candidates seemed to find it difficult to read the stop-watch and so recorded a value that appeared too small (e.g. 0.0146 s instead of 1.46 s).

Repeated readings were seen in most cases.

(ii) When asked to estimate the percentage uncertainty in T_0, successful candidates chose an absolute uncertainty in the range 0.2–0.5 s. They then divided the absolute uncertainty by their T_0 value from **(a)(i)** before multiplying the result by 100. Almost all candidates were familiar with the method of calculation, but many chose an unsuitable absolute uncertainty, often 0.01 s or 0.1 s. Many candidates who had taken repeated readings of T_0 used half the range for their absolute uncertainty. For candidates to gain credit, they must show their working.

(b) (i) The candidates' values of L and W were usually correct. A small number recorded the length and width of the card to the nearest 0.1 mm which was unrealistic.

(ii) Almost all candidates were able to record a value of T with appropriate precision. The value of T was nearly always correctly measured to be greater than T_0.

(c) Nearly all candidates provided second values of L, W and T. In a very small number of cases, the second value of T (larger card) was not greater than the first value of T (smaller card), indicating that the experiment had not been carried out correctly.

(d) (i) Most candidates were able to correctly calculate two k values. Some candidates used their first set of data (for the smaller card) to calculate the second k value but this was accepted.

(ii) Whilst some candidates successfully linked the significant figures in k with those in ($T – T_0$), W and L, a significant number referred only to 'raw data' or made a partial reference to the correct quantities, most commonly not including T_0.

(e) Candidates were provided with a numerical criterion to test against (15%). As such, the examiners were looking for a correct percentage difference calculation, a comparison with 15% and a correct conclusion linking both. Whilst the majority of candidates were able to correctly carry out a suitable percentage difference calculation, some were not. Some candidates had a correct calculation, but then tested this against their own criterion (e.g. 10% or the value of percentage uncertainty from **(a)(ii)**) and so were not credited.

A small but significant number of candidates stated a contradictory conclusion, e.g. 'my percentage difference is lower than 15% so my results do not support the suggestion'.

(f) (i) Most candidates recognised that there were too few data points to draw a conclusion, but other marking points were less well addressed. One of the limitations was that the time T_0 was very short so the percentage uncertainty in T_0 was large. Subsequent measurements of time (with the cards inserted) were larger and so candidates needed to be specific; linking a large percentage uncertainty to 'time' or T rather than specifically to T_0 was not credited.

Answers deemed not worthy of credit often referred to friction, wobbling or air conditioning. Although air conditioning might be a factor in some experiments, its effect on this one would be negligible, especially if conditions in the room remained constant. Candidates should be discouraged from suggesting air conditioning as a default limitation.

(ii) Most candidates recognised the need for more data so that a graph could be plotted.

Candidates are encouraged to explain *how* a problem will be solved, detailing what additional equipment is necessary.

Since friction and air conditioning were often stated as limitations, the use of lubricants and switching off air conditioning/carrying out the experiment in a vacuum were often suggested as improvements. These issues were not accepted as a limitations and so the associated improvements were not credited either. Credit is also not given for suggested improvements that could have been carried out in the original experiment, e.g. 'repeat readings' or 'view the ruler at right angles'.

Candidates should be aware that the examiners do not look for links between responses in **(i)** and **(ii)**. As such, candidates should restate any apparatus/quantity in **(ii)** even if it has been mentioned in **(i)**, and avoid using phrases such as 'measure it' assuming the examiner knows what 'it' is because of working from **(i)**.

PHYSICS

Paper 9702/35
Advanced Practical Skills 1

Key messages

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

General comments

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

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

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

Comments on specific questions

Question 1

(a) Many candidates stated T_0 in the accepted range and with the correct unit, and showed evidence of two or more sets of multiple oscillations. Some candidates did not show repeated readings, missed out a unit or stated a value that was out of range (perhaps by timing half an oscillation or not dividing the total time for multiple oscillations by the number of oscillations to give the period).

(b) Many candidates stated a value for T to be greater than T_0.

(c) Most candidates were able to collect six sets of values of x and time (nT or T) without assistance from the supervisor and with the correct trend. Candidates are encouraged to check their results again if one value is out of trend with the rest.

Many candidates chose too small a range over which to conduct the experiment. Many candidates went from x = 10.0 cm to x = 35.0 cm or from x = 15.0 cm to x = 40.0 cm, thereby not extending their data over the available range as stated in the question. Candidates are encouraged to use the whole range available to them.

Many candidates gave both the quantity and correct unit for each heading, separated by a solidus or with brackets around the unit. Candidates are encouraged to remember the separating mark between the quantity and unit (a bracket around the unit or a '/' dividing sign). Some candidates gave the unit of $(T – T_0)^2$ as s instead of s^2.

Candidates usually stated x to the nearest mm. Some candidates either added an extra zero (e.g. 10.00 cm) or stated x to the nearest cm (e.g. 10 cm). Candidates are encouraged to think about the resolution of the instrument provided (1 mm for a ruler) and apply this knowledge to their stated readings.

Many candidates calculated values for $(T – T_0)^2$ correctly. Some candidates forgot to square. Candidates are encouraged to round their answers correctly and not truncate the numbers without consideration.

(d) (i) Many candidates plotted the correct graph with labels of the quantities asked for, and used easy-to-read, sensible and regular scales. Candidates are encouraged to choose scales such that all their points can fit on the grid available and occupy over half the graph grid in both the x and y directions.

Many points were drawn as neat crosses such that the centre was no more than half a square thick and were plotted correctly so that the position was within half a small square in both the x and y directions. Common mistakes were to use 'blobs' (points of diameter greater than half a small square) or mis-plotting a point more than half a square from the correct position.

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

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

(iii) Candidates need to use a large triangle to calculate the gradient, use correct read-offs and substitute into a correct expression. Weaker candidates often 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 occasionally others incorrectly read off the y-intercept when there was a false origin (i.e. not x = 0).

(e) Many candidates recognised that P and Q were equal to the negative of the gradient and the y-intercept respectively. Some candidates transcribed their values of gradient and y-intercept for P and Q without any consideration of the change of sign of the gradient for P. A few candidates incorrectly gave their value of P or Q to only one significant figure. Candidates who inverted their axes on their graph often did not rearrange the equation to be consistent.

Many candidates provided correct units, taking into consideration the units used in the experiment. Some candidates omitted units or used different units from those used in the experiment without any evidence of converting correctly.

Question 2

(a) Many candidates measured values of D to the nearest mm and with a correct unit. Some candidates stated D to the nearest cm or added an extra zero when the ruler can only be read to the nearest mm. Some candidates feel obliged to give a three significant figure answer such as 6.40 cm when the ruler can only measure 6.4 cm.

(b) (i) Many candidates stated y to the nearest mm and with a unit. Some candidates stated repeated values of y. Repeated readings were needed as the value of y was a difficult measurement to determine. A few candidates omitted the unit or added an extra zero (e.g. 9.50 cm) or did not include a number to reflect the mm place (e.g. 10 cm). Candidates are encouraged to think about the resolution of the instrument provided (1 mm for a ruler) and apply this knowledge to their stated readings.

(ii) Many candidates made too small an estimate of the absolute uncertainty in the value of y, typically 0.1 cm or 0.05 cm, when this length reading is difficult to take. Some candidates, having repeated their readings, correctly showed the working to give the uncertainty as half the range. Some candidates just calculated the range of their repeated readings and did not halve it.

(iii) Most candidates calculated $(r + y)$ correctly. Occasionally candidates used mixed units without converting to the same unit (e.g. tried to add cm and mm) or rounded their answer incorrectly.

(c) Most candidates stated a second value of D and y for the larger jar B with their second value of y larger than their first value.

(d) (i) Most candidates were able to calculate k for the two sets of data, showing their working clearly. Some candidates used different powers of ten in their units, i.e. mixing mm and cm without converting. A few candidates incorrectly stated their values to only one significant figure.

(ii) Only the strongest candidates were able to correctly justify the number of significant figures they had given for the value of k with reference to the number of significant figures used in the raw quantities D and y or D and $(r + y)$. Many candidates gave reference to r when D was the measured quantity, or used other terms such as ‘raw readings’, ‘previous measurements’ or ‘values used in calculation’ without detailing the individual raw quantities concerned.

(e) Some candidates calculated the percentage difference between their values of k, tested it against the stated 20% criterion and provided a valid statement. Some candidates worked out 20% for one or both k values. Whilst this is an acceptable approach, the argument does need development to show clearly whether one k lies within 20% of the other or the two 20% ranges overlap. Some candidates omitted a percentage difference calculation, gave a different criterion (e.g. 10%, 25% or the uncertainty from **(b)(ii)**) or gave an invalid statement inconsistent with their findings.

(f) Most candidates recorded a value of y and calculated r for the lens with an appropriate unit.

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

Problems commonly awarded were ‘two sets of data were not enough to draw a valid conclusion’, ‘difficult to measure D (or y) due to parallax error’, ‘difficult to judge when nail disappears’ and ‘difficult to measure the y for lens as you have to hold the lens by hand’.

(ii) Improvements that were commonly seen were ‘take more readings and plot a graph’, ‘use calipers to measure D’ and ‘clamp lens’. A solution, like the problem, needs detail to gain credit. Candidates are encouraged to explain *how* a problem will be solved, detailing what additional equipment is necessary.

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

PHYSICS

Paper 9702/41
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. Examiners will only consider symbol equations to be part of a definition if the symbols used are identified.

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

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

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

General comments

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

Most candidates showed their working. Some candidates would benefit from presenting their calculations more clearly. Some candidates answered questions asking for an explanation in a way that just described the information that was given in the question, diagram or graph, thereby gaining little or no credit. Candidates should be encouraged to ensure that their answers to such questions contain explanations and not just descriptions.

The number of marks gained on the later questions of the paper indicated that the time available was well managed by most candidates.

Comments on specific questions

Question 1

(a) Most candidates understood that the definition involved work done moving a mass from infinity, but fewer candidates appreciated that gravitational potential equated to the work done per unit mass (or the equivalent ratio).

(b) (i) The reference point of zero potential at infinity was well understood. Candidates often did not refer to what was doing the work to bring the masses closer together. Any reference made to work being done usually referred to only the satellite rather than both masses.

(ii) A significant number of candidates were unable to gain credit because they did not give answers in terms of Φ. Those candidates who also appreciated that the expression for Φ should be negative could receive full credit.

(iii) Stronger candidates were able to achieve full credit in this question, and many weaker candidates were also awarded credit by the principle of error carried forward.

Question 2

(a) (i) There were a number of different misunderstandings shown of absolute zero on the thermodynamic scale. These included values of ± 273 K, temperatures in Celsius and the wrong inclusion of the degree symbol (°K rather than K). This indicates that candidates would benefit from further study of the thermodynamic scale of temperature.

(ii) Stronger candidates appreciated that a temperature measurement using a liquid-in-glass thermometer depends on a physical property of the liquid, whereas the thermodynamic scale is based on the properties of an ideal gas.

(b) (i) Where candidates referred to the quantities of resistivity and temperature in their explanation, they were more likely to be awarded credit. Simply describing the graph as a straight line did not provide an explanation.

(ii) In many cases it was not possible to identify whether a candidate thought there was (wrongly) a delay in the change of the resistance or (correctly) a delay in the thermometer reaching thermal equilibrium with the outside temperature. There were some good answers that referred to the delaying effect of the glass tube and the air inside it on the heat transfer to the platinum. Weaker answers wrongly focused on possible detrimental effects of extreme temperatures rather than rapid changes in temperature.

(iii) The limitations in using a liquid-in-glass thermometer for measuring rapid temperature changes were not understood by many candidates.

(c) Many candidates understood the difference in temperature variation between the two types of thermometers listed in this question.

Question 3

(a) (i) The majority of candidates were able to achieve full credit. Where this was not possible, the ideal gas relationship between *p, V* and *T* was usually given correctly in one form or another, but the symbol *T* was not identified as the thermodynamic temperature. Occasionally an inappropriate physical constraint such as standard conditions was included.

(ii) The majority of the candidates identified both the assumption of no intermolecular forces and the implication of zero potential energy. The inclusion of a second basic assumption of the kinetic theory sometimes negated a correct answer regarding the intermolecular forces.

(b) (i) Many candidates gained full credit for this calculation.

(ii) When it was appreciated that only one molecule was being considered, many candidates achieved full credit. Some candidates gave an answer to only one significant figure. Weaker candidates often did not identify the correct starting equation $E = (3/2)kT$.

(iii) Whilst many candidates were able to combine their answers to the previous two questions (allowing for errors carried forward) to give an accepted numerical answer, the explanation of their reasoning was often incomplete. In particular, although many candidates understood that the potential energy of the molecules was zero, they rarely explained that the internal energy was the sum of the individual molecular kinetic energies. The symbols E_K and KE were often used without indicating whether they referred to one or all molecules.

(c) The majority of the candidates identified the proportionality between the volume of the gas and its internal energy, and drew a straight line with a positive gradient. Stronger candidates showed the line clearly going through the origin. Weaker candidates sometimes described a negative or inverse relationship between the two variables.

Question 4

(a) The majority of the candidates gave very good explanations of the matching of driving and natural frequencies in resonance. Fewer were able to explain that the oscillations reach maximum amplitude. Some weaker candidates did not mention oscillations at all.

(b) (i) Although most candidates identified the phenomenon as damping, a significant number of those did not give a complete answer including the type of damping.

(ii) Most candidates appreciated the role of resistive forces in damping, but few described the oscillations having their energy reduced as the cause of the amplitude reduction.

(iii) The majority of candidates correctly read the period from the graph and calculated the frequency from that value.

(c) Only the stronger candidates were able to sketch the resonance curve. Where that was done, it generally peaked at the correct frequency. Candidates would benefit from further study of this aspect of resonance.

Question 5

(a) Definitions were often incomplete because of the omission of the ratio of force to (positive) charge, indicated by words such as ‘per unit charge’.

(b) (i) Carefully drawn sketches of the electric field lines using a ruler made it more likely that they were evenly spaced and started and finished on the plates, as was required. In most cases the field direction was given correctly.

(ii) Where the correct starting equation was stated, most candidates were able to go on to calculate the electric field strength. A common incorrect starting point was to use the equation for the field around a point charge.

(iii) Most candidates correctly sketched a path deviating in the correct direction. Common errors seen included an electron path that remained undeviated for too long within the plates, a curved path once the electron was beyond the plates, and the electron hitting a plate. The last error could have been avoided with a more careful reading of the question.

(c) (i) Stronger candidates were able to identify both the correct plane and correct direction of the magnetic field for an electron. Although not required or assessed, Fleming’s left-hand rule was sometimes quoted indicating its use to answer the question. Weaker candidates had the magnetic field direction opposite to that of the electric field. This error was then generally repeated in **(ii)**.

(ii) Most candidates were able to explain the equality and opposite direction of the two forces. Weaker candidates equated opposite fields rather than forces.

(iii) Where the starting equation was correctly shown, candidates were usually able to progress to a correct final answer for full credit. Many candidates tried to apply the equation for the force on a current in a wire. Whilst it is then possible to derive the correct equation from that starting point, it was rarely done successfully.

Question 6

(a) This was a challenging question. Most candidates simply gave a description of the graph and of the current reduction, rather than explaining how the exponential fall took place by showing the relationships between charge, potential difference and current. It was often unclear whether the capacitor or the resistor was being referred to, with generic symbols V, I and Q being used.

(b) (i) Incorrect reading of the current value from the graph was a common reason for full credit not to be awarded. This error was seen across the range of abilities, and included a wrong power of ten and a misjudgement of the scale beyond the 0.1 mA point.

(ii) Stronger candidates were able to identify an appropriate point on the line, insert those values into the equation for exponential decay and calculate a time constant. The use of a small time period often increased the error in reading the current, resulting in an incorrect final answer. Weaker candidates unsuccessfully attempted to use the $\tau = RC$ equation.

(c) Most candidates were able to state the $\tau = RC$ equation. The majority of those were then able to use their previous two answers to successfully proceed to a value for the time constant.

Question 7

(a) The majority of candidates recognised that rectification was taking place, but ‘full-wave’ was not always included in their response. A small number of candidates tried to describe a different circuit that included a capacitor, and therefore wrongly talked about smoothing.

(b) (i) Most candidates recognised that this ‘show that’ question required full working to be shown.

(ii) The majority of the candidates found it difficult to appreciate the impact of squaring the voltage to produce the sinusoidal shape of the power–time graph, and they repeated a full-wave rectification graph instead. Phase and period were generally incorporated correctly into the sketch graph. Weaker answers showed a lack of precision in the sketching of the curves, resulting in errors in the position of one or more of the maxima. Stronger candidates drew accurate sine waves in general, but often the beginning and end of their sketch graph was that of a ‘rectified’ rather than sinusoidal shape.

(iii) The correct answer was shown by most candidates. The most common error was to include $\sqrt{2}$ in the calculation.

(c) Stronger candidates were able to describe the independence of power from the current direction across all values of voltage or current, or to indicate the manifestation of that in identical power–time graphs.

Question 8

(a) This was a straightforward question that was possible to answer by recall. However, where candidates deviated from a learned response, their answer often displayed a fundamental misunderstanding that a photon was a part of, or a component of, electromagnetic radiation. A significant minority did not mention energy at all.

(b) (i) This question was generally well answered, although giving more than one name indicated uncertainty by some candidates.

(ii) Despite correctly identifying electrons as the particles emitted in **(b)(i)**, many candidates then did not appreciate that the anode (and therefore terminal Y) needed to be positive.

(c) (i) Many candidates tried to carry out an unnecessary conversion by applying the charge on an electron to the accelerating voltage. This would seem to indicate a weakness in understanding the use of the electronvolt as an appropriate unit of energy, and further study of this topic might be helpful.

(ii) Stronger candidates were able to utilise the equation $E = pc$ and convert the energy into joules to obtain the maximum photon momentum. The conversion factor was often omitted by many candidates but credit was still gained for the starting equation.

(iii) Either of the two previous answers could have been used by candidates with the appropriate starting equation linking energy or momentum with wavelength. This was sometimes not appreciated, and it was not uncommon to see both methods attempted or combined.

(d) This question produced a broad range of responses. A move from the given phrase 'body structures' to identifying actual contrasting mediums in those structures (e.g. bone and soft tissue) achieved credit. However, descriptions were often simplistic, describing 'stopping' X-rays, and therefore did not compare two different mediums in the same way (i.e. the greater/lesser absorption properties of each). The strongest answers identified that it was the transmitted intensities that produced the difference in contrast on the film or detector. Weaker answers talked about different 'blackening' without an explanation of the cause of any difference.

Question 9

(a) Many answers used imprecise statements, expressing the half-life in terms of mass or total nuclei rather than activity. Terms such as atom, nucleon and nucleus were often used wrongly in this context.

(b) (i) An understanding that the gradient of the curve was the number of nuclei decaying per unit time meant that the majority of the candidates correctly identified the name of the quantity as 'activity'.

(ii) A full range of marks was seen on this question. Responses that directly described the graph without drawing a conclusion did not gain credit. Some element of processing or derivation was required. Stronger candidates were able to derive a numerical value for the half-life, or for the activity at some fixed time, and could include an appropriate number of significant figures and the correct unit.

(c) This was a question in which the ability to set working out clearly was of benefit to the candidate, as credit was available for stages in the process of getting to the final answer. Despite the complexity caused by the variety of possible approaches, it was generally well answered. Many candidates understood that the final answer for nucleon number needed to be an integer.

Question 10

(a) (i) This was a recall question that was generally answered successfully.

(ii) Many candidates were familiar with the method, starting with a clear explanation of a standard candle and finishing with the correct equation to link luminosity, radiant flux intensity and distance. There was often some confusion shown as to how the radiant flux intensity was arrived at. Weaker answers attempted to combine Doppler shift and Hubble's law with luminosity.

(b) (i) Many candidates correctly applied the Stefan's law equation and calculated a correct final answer including a correct unit. However, some of those did not appreciate that the data were given to three significant figures and the answer could also be given to three significant figures.

(ii) The relationship between the wavelength of peak radiation and temperature was known by many candidates, although it was common for the ratio between the two wavelengths to then be written the wrong way around, yielding an incorrect answer. Some candidates ignored the data provided for the Sun and instead used a remembered value for Wien's constant that did not match the precision of the other data. This resulted in an inaccurate final answer.

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. Examiners will only consider symbol equations to be part of a definition if the symbols used are identified.

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

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

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

General comments

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

There was no evidence that candidates had insufficient time in which to complete the paper. There were, however, significant numbers of candidates who did not offer a response to one or more questions. If there is no response, it is never possible for credit to be awarded, so candidates should be encouraged to offer a response to every question on the paper. Even if the candidate is not confident about the answer, it is always possible that the examiner may be able to award partial credit where there is some response.

Comments on specific questions

Question 1

(a) The definition of the radian was well known by many candidates. It was important to note that this question asked for the definition of the unit, not the definition of the quantity 'angle' in radians.

(b) (i) Most candidates knew the general direction for the linear velocity of the modelling clay at the position shown, and examiners allowed a reasonable range for the precise direction in which the arrow was drawn. Some candidates did not take sufficient care to ensure that the direction was tangential to the circle at that point, and others drew curved arrows (implying that the velocity at that point has multiple directions).

(ii) Most candidates realised that the acceleration is centripetal and drew the arrow accordingly.

(c) (i) Most candidates used the correct starting equation, but only a minority correctly worked out the radius of the circle described by the modelling clay.

(ii) Many candidates were able to achieve full credit on this question, either by arriving at the correct answer or by the principle of error carried forward.

(d) The stronger candidates generally answered this question correctly, whereas weaker candidates largely appeared to guess.

Question 2

(a) There was a widespread misunderstanding that thermal equilibrium results in no transfer of thermal energy at all between the two objects. Candidates who realised that the rate of transfer of energy between them is constant, and so there is no net transfer between them, were awarded credit.

(b) (i) Very many candidates achieved full credit in this question. As always with a 'show that' question, marks are not awarded for getting to the answer, but for showing the working that leads to the answer. The common reasons for credit not being awarded were not showing the full substitution into $pV = nRT$ or not showing the final subtraction of 273 to convert the temperature from kelvin to degrees Celsius.

(ii) Most candidates were awarded credit for the correct starting equation, but some did not realise that the precision of the data provided in the question demanded a three significant figure answer. Others neglected the 'explain your reasoning' aspect of the question, and did not explain that the temperatures of the two gases are equal as a consequence of their being in thermal equilibrium.

(iii) Many candidates achieved at least partial credit, and many of the strongest candidates were awarded full credit. Among weaker candidates there was considerable confusion between r.m.s. speed and mean-square speed.

Question 3

(a) The definition of internal energy was generally well known, although many of the weaker candidates confused the definition of internal energy with the first law of thermodynamics as a means of describing how the internal energy of an object may be changed.

(b) In both parts of this question, candidates were expected to explain how the change in temperature affected molecular kinetic energy and how the change in molecular separation affected molecular potential energy. Having deduced the changes (or lack of changes) in those two energies, they were then expected to relate the overall change in internal energy to them.

These extended writing questions proved to be a good test of understanding of physics and the ability to articulate physics. Many of the stronger candidates were awarded full or almost full credit. For all candidates, a significant problem was not reading the question carefully enough, and therefore not answering it. Many candidates ignored the instruction to discuss the molecular kinetic and potential energies, and instead gave arguments based on the first law of thermodynamics.

Many weaker candidates confused the notion of no change in energy with the energy being zero. Candidates that stated that the kinetic or potential energy of the molecules was zero were very restricted in the credit that could be received.

Question 4

(a) Many candidates answered a different question from the one that was asked. The question did not ask candidates to define simple harmonic motion; it asked candidates to explain how the graph shows that the motion of the block is simple harmonic, and so answers relating to features of the graph were expected.

(b) Common mistakes in **(i)** were either to forget to take the square root of the expression for ω^2 or to include a minus sign inside the square root. Many weaker candidates took the amplitude and maximum acceleration as *Y* and *A*, respectively, rather than 3*Y* and 2*A* as given in the question.

In **(ii)** and **(iii)**, many candidates knew the equations for maximum speed and total energy, but made mistakes in the algebra in arriving at a concise answer in terms of *A* and *Y*. Some candidates left the answers in terms of other letters such as ω, and therefore did not answer the question.

(c) This was well answered by many candidates.

Question 5

(a) The definition of electric potential was generally well known, although it was common for omission of important detail to result in full credit not being awarded. For example, many candidates gave a definition of an energy, rather than an energy per unit charge.

(b) Many candidates were awarded full credit. In answering this type of question, it is important for candidates to be aware that they need to draw conclusions from the graph, not just describe the graph. This question asked for properties of the spheres that could be deduced from the graph, and the mark scheme provided various ways of achieving credit for discussing the radius of the spheres and the sign and magnitude of the charges on them.

(c) Candidates were expected to deduce that the proton will remain at rest at the point of release, and the mark scheme allowed various ways of achieving credit for explaining why this is the case, either in terms of the resultant force being zero, or in terms of the resultant field strength being zero, or in terms of the fact that the proton is already at the position where its potential energy is a minimum. Many candidates found this a difficult question, with many of them thinking that the proton accelerates towards one or other of the spheres.

Question 6

(a) No credit was available just for unexplained algebra. First, candidates needed to make clear the two principles of physics upon which the derivation is based (that the charges on the capacitors are equal and equal to the total charge, and that the p.d.s across the capacitors and the total p.d. are related by Kirchhoff's second law. Once the physics was made clear, candidates were then able to complete the algebra to show how the equation is derived. Many of the weaker candidates made no attempt to produce the derivation, and instead simply quoted the relevant capacitor combination equation from the formula sheet.

(b)(i) This was generally well answered by most candidates.

(ii) Generally, many candidates arrived at the correct answer and were awarded full credit. Some weaker candidates used the series combination equation rather than the one for capacitors connected in parallel, and were therefore unable to make a start. Some other candidates just calculated the energy of the 400 μF capacitor, rather than the total energy.

(iii) Candidates who obtained the correct answer in **(b)(ii)** were generally able to go on to gain full credit for the graph. Full credit was also possible where **(b)(ii)** was not answered correctly, but generally such candidates found it difficult to meet the requirements of the mark scheme.

Question 7

(a) Faraday's law was generally well known, and well stated by many candidates.

(b)(i) Whilst most candidates knew that they need to use the equation for magnetic flux in terms of flux density, many did not appreciate that the flux density they needed was the one corresponding to the maximum value on the graph. Other, generally weaker, candidates confused the flux in one turn with the flux linkage through the whole coil.

(ii) Most candidates found this question difficult. A common mistake was to find the average change of flux linkage over a part of a cycle, rather than to find the instantaneous rate of change of flux at the steepest part of the graph.

(iii) Most candidates appreciated that a consequence of Faraday's law is that the maximum e.m.f. induced across the coil is numerically equal to the maximum rate of change of flux linkage.

(iv) Candidates generally appreciated that the variation of V with t is a sinusoidal curve of period 2.0 ms and amplitude V_0. More challenging, though, was turning that appreciation into an accurate sketch. It was common for credit not awarded because a line was insufficiently sinusoidal in its shape. The more difficult aspect of the question was determining the correct phase for the variation, and appreciating that the times at which V has its maximum magnitude are when the flux density is changing at the greatest rate.

(v) Many candidates realised that A represents the maximum e.m.f., and gave A as the numerical answer from **(b)(iii)** with the unit V. Common mistakes with the calculation of the angular frequency B were to miss the power of ten conversion, to leave the answer in terms of π rather than calculating it to the appropriate precision, or to give an incorrect unit. Most of the stronger candidates were able to achieve full credit.

Question 8

(a)(i) This question required candidates to explain that the observed frequency is lower than the emitted frequency because of the redshift caused by the recession of the galaxy. Many candidates struggled to articulate this using the correct technical language, but the more able candidates were usually able to achieve at least partial credit.

(ii) Examiners were expecting to see all three lines shifted to the left by a consistent distance. All three possible mark outcomes were common.

(b)(i) Most candidates knew the correct starting equation, and in many cases the substitution was also correct. Some candidates did not appreciate that the precision of the data requires a three significant figure answer.

(ii) This was a demanding question, and many candidates were able to achieve partial credit for converting the photon energy into eV. Only the strongest candidates appreciated how the photon energy needs to be combined with the –3.40 eV energy level to get to the answer of –0.85 eV.

(iii) Many candidates continued to attempt to use the photon energy equation, apparently unaware that this question is about Doppler shift. Of those that did realise that they needed to use the Doppler shift equation, most successfully calculated the 10 nm value of $\Delta\lambda$, and the majority also went on to correctly add that to the 488 nm figure to get to the answer of 498 nm.

(c) This question involving Hubble's law was well answered by the majority of candidates.

Question 9

(a) The definition of binding energy was not well known by the weaker candidates, and candidates of average ability sometimes found it difficult to get the technical wording right. Nucleus, nuclei, nucleons and neutrons were often confused, and the direction of the energy transfer was sometimes the wrong way around. Some candidates gave contradictory definitions and therefore could not be awarded credit.

(b) (i) Many candidates got as far as calculating the mass defect in u, but then stopped short of converting that mass into kg. Some of those that did go further introduced an error into the third significant figure of their answer, either by premature rounding within the question, or because of the use of the proton mass rather than the unified atomic mass unit.

(ii) The calculation of binding energy from the mass defect, using the mass–energy equation, was generally well done. A common mistake was to forget to square the speed of light when carrying out the calculation.

(iii) The division of the binding energy by the nucleon number to calculate the binding energy per nucleon was also generally well done. The common mistakes here were to use either the proton number or the neutron number rather than the nucleon number.

(c) (i) Most candidates knew the general shape of the curve, but it was common for the peak to be too far to the right or for the line to the right of the peak to descend too steeply.

(ii) Many candidates were able to gain credit. To be awarded credit, candidates needed to judge how far along the axis 212 is compared with 250, and then to mark their X on the line at the appropriate point. It was common for the X to be either too far to the left, or to not be on the line.

(iii) A very large number of candidates did not discuss alpha-decay, but instead talked about the polonium nucleus undergoing a fission reaction. This confusion did not necessarily prevent the candidate from achieving the marking points, but generally this did not happen. Many candidates did not heed the instruction in the question to refer to Fig. 9.1, with reference to the graph often not being made at all. Candidates were expected to explain that the nucleus formed as a result of the alpha-decay has a lower nucleon number than polonium-212, and as a result it has a greater binding energy per nucleon. Only a small minority of candidates made either of these points.

Question 10

(a) Many responses focussed on how ultrasound pulses are generated or detected, rather than addressing the question about how the pulses are used to obtain diagnostic information.

(b) (i) The definition of specific acoustic impedance was generally well known, although some candidates struggled to convey that it is the <u>product</u> of a density and a speed. Many responses were ambiguous as to whether it was a product or a ratio that was being described.

(ii) This was a multi-step calculation which nevertheless was answered well by many candidates. The majority of the candidates realised that the first step was to calculate the specific acoustic impedances of the materials from the density and speed data, then to put these values into the intensity reflection coefficient equation. Some candidates forgot to square at the end, or made an arithmetic error in the final calculation, but the correct final answer was common and many candidates were able to achieve 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. Examiners will only consider symbol equations to be part of a definition if the symbols used are identified.

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

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

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

General comments

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

Most candidates showed their working. Some candidates would benefit from presenting their calculations more clearly. Some candidates answered questions asking for an explanation in a way that just described the information that was given in the question, diagram or graph, thereby gaining little or no credit. Candidates should be encouraged to ensure that their answers to such questions contain explanations and not just descriptions.

The number of marks gained on the later questions of the paper indicated that the time available was well managed by most candidates.

Comments on specific questions

Question 1

(a) Most candidates understood that the definition involved work done moving a mass from infinity, but fewer candidates appreciated that gravitational potential equated to the work done per unit mass (or the equivalent ratio).

(b) (i) The reference point of zero potential at infinity was well understood. Candidates often did not refer to what was doing the work to bring the masses closer together. Any reference made to work being done usually referred to only the satellite rather than both masses.

(ii) A significant number of candidates were unable to gain credit because they did not give answers in terms of Φ. Those candidates who also appreciated that the expression for Φ should be negative could receive full credit.

(iii) Stronger candidates were able to achieve full credit in this question, and many weaker candidates were also awarded credit by the principle of error carried forward.

Question 2

(a) (i) There were a number of different misunderstandings shown of absolute zero on the thermodynamic scale. These included values of ± 273 K, temperatures in Celsius and the wrong inclusion of the degree symbol (°K rather than K). This indicates that candidates would benefit from further study of the thermodynamic scale of temperature.

(ii) Stronger candidates appreciated that a temperature measurement using a liquid-in-glass thermometer depends on a physical property of the liquid, whereas the thermodynamic scale is based on the properties of an ideal gas.

(b) (i) Where candidates referred to the quantities of resistivity and temperature in their explanation, they were more likely to be awarded credit. Simply describing the graph as a straight line did not provide an explanation.

(ii) In many cases it was not possible to identify whether a candidate thought there was (wrongly) a delay in the change of the resistance or (correctly) a delay in the thermometer reaching thermal equilibrium with the outside temperature. There were some good answers that referred to the delaying effect of the glass tube and the air inside it on the heat transfer to the platinum. Weaker answers wrongly focused on possible detrimental effects of extreme temperatures rather than rapid changes in temperature.

(iii) The limitations in using a liquid-in-glass thermometer for measuring rapid temperature changes were not understood by many candidates.

(c) Many candidates understood the difference in temperature variation between the two types of thermometers listed in this question.

Question 3

(a) (i) The majority of candidates were able to achieve full credit. Where this was not possible, the ideal gas relationship between *p, V* and *T* was usually given correctly in one form or another, but the symbol *T* was not identified as the thermodynamic temperature. Occasionally an inappropriate physical constraint such as standard conditions was included.

(ii) The majority of the candidates identified both the assumption of no intermolecular forces and the implication of zero potential energy. The inclusion of a second basic assumption of the kinetic theory sometimes negated a correct answer regarding the intermolecular forces.

(b) (i) Many candidates gained full credit for this calculation.

(ii) When it was appreciated that only one molecule was being considered, many candidates achieved full credit. Some candidates gave an answer to only one significant figure. Weaker candidates often did not identify the correct starting equation $E = (3/2)kT$.

(iii) Whilst many candidates were able to combine their answers to the previous two questions (allowing for errors carried forward) to give an accepted numerical answer, the explanation of their reasoning was often incomplete. In particular, although many candidates understood that the potential energy of the molecules was zero, they rarely explained that the internal energy was the sum of the individual molecular kinetic energies. The symbols E_K and KE were often used without indicating whether they referred to one or all molecules.

(c) The majority of the candidates identified the proportionality between the volume of the gas and its internal energy, and drew a straight line with a positive gradient. Stronger candidates showed the line clearly going through the origin. Weaker candidates sometimes described a negative or inverse relationship between the two variables.

Question 4

(a) The majority of the candidates gave very good explanations of the matching of driving and natural frequencies in resonance. Fewer were able to explain that the oscillations reach maximum amplitude. Some weaker candidates did not mention oscillations at all.

(b) (i) Although most candidates identified the phenomenon as damping, a significant number of those did not give a complete answer including the type of damping.

(ii) Most candidates appreciated the role of resistive forces in damping, but few described the oscillations having their energy reduced as the cause of the amplitude reduction.

(iii) The majority of candidates correctly read the period from the graph and calculated the frequency from that value.

(c) Only the stronger candidates were able to sketch the resonance curve. Where that was done, it generally peaked at the correct frequency. Candidates would benefit from further study of this aspect of resonance.

Question 5

(a) Definitions were often incomplete because of the omission of the ratio of force to (positive) charge, indicated by words such as ‘per unit charge’.

(b) (i) Carefully drawn sketches of the electric field lines using a ruler made it more likely that they were evenly spaced and started and finished on the plates, as was required. In most cases the field direction was given correctly.

(ii) Where the correct starting equation was stated, most candidates were able to go on to calculate the electric field strength. A common incorrect starting point was to use the equation for the field around a point charge.

(iii) Most candidates correctly sketched a path deviating in the correct direction. Common errors seen included an electron path that remained undeviated for too long within the plates, a curved path once the electron was beyond the plates, and the electron hitting a plate. The last error could have been avoided with a more careful reading of the question.

(c) (i) Stronger candidates were able to identify both the correct plane and correct direction of the magnetic field for an electron. Although not required or assessed, Fleming’s left-hand rule was sometimes quoted indicating its use to answer the question. Weaker candidates had the magnetic field direction opposite to that of the electric field. This error was then generally repeated in **(ii)**.

(ii) Most candidates were able to explain the equality and opposite direction of the two forces. Weaker candidates equated opposite fields rather than forces.

(iii) Where the starting equation was correctly shown, candidates were usually able to progress to a correct final answer for full credit. Many candidates tried to apply the equation for the force on a current in a wire. Whilst it is then possible to derive the correct equation from that starting point, it was rarely done successfully.

Question 6

(a) This was a challenging question. Most candidates simply gave a description of the graph and of the current reduction, rather than explaining how the exponential fall took place by showing the relationships between charge, potential difference and current. It was often unclear whether the capacitor or the resistor was being referred to, with generic symbols V, I and Q being used.

(b)(i) Incorrect reading of the current value from the graph was a common reason for full credit not to be awarded. This error was seen across the range of abilities, and included a wrong power of ten and a misjudgement of the scale beyond the 0.1 mA point.

(ii) Stronger candidates were able to identify an appropriate point on the line, insert those values into the equation for exponential decay and calculate a time constant. The use of a small time period often increased the error in reading the current, resulting in an incorrect final answer. Weaker candidates unsuccessfully attempted to use the $\tau = RC$ equation.

(c) Most candidates were able to state the $\tau = RC$ equation. The majority of those were then able to use their previous two answers to successfully proceed to a value for the time constant.

Question 7

(a) The majority of candidates recognised that rectification was taking place, but ‘full-wave’ was not always included in their response. A small number of candidates tried to describe a different circuit that included a capacitor, and therefore wrongly talked about smoothing.

(b)(i) Most candidates recognised that this ‘show that’ question required full working to be shown.

(ii) The majority of the candidates found it difficult to appreciate the impact of squaring the voltage to produce the sinusoidal shape of the power–time graph, and they repeated a full-wave rectification graph instead. Phase and period were generally incorporated correctly into the sketch graph. Weaker answers showed a lack of precision in the sketching of the curves, resulting in errors in the position of one or more of the maxima. Stronger candidates drew accurate sine waves in general, but often the beginning and end of their sketch graph was that of a ‘rectified’ rather than sinusoidal shape.

(iii) The correct answer was shown by most candidates. The most common error was to include $\sqrt{2}$ in the calculation.

(c) Stronger candidates were able to describe the independence of power from the current direction across all values of voltage or current, or to indicate the manifestation of that in identical power–time graphs.

Question 8

(a) This was a straightforward question that was possible to answer by recall. However, where candidates deviated from a learned response, their answer often displayed a fundamental misunderstanding that a photon was a part of, or a component of, electromagnetic radiation. A significant minority did not mention energy at all.

(b)(i) This question was generally well answered, although giving more than one name indicated uncertainty by some candidates.

(ii) Despite correctly identifying electrons as the particles emitted in **(b)(i)**, many candidates then did not appreciate that the anode (and therefore terminal Y) needed to be positive.

(c)(i) Many candidates tried to carry out an unnecessary conversion by applying the charge on an electron to the accelerating voltage. This would seem to indicate a weakness in understanding the use of the electronvolt as an appropriate unit of energy, and further study of this topic might be helpful.

(ii) Stronger candidates were able to utilise the equation $E = pc$ and convert the energy into joules to obtain the maximum photon momentum. The conversion factor was often omitted by many candidates but credit was still gained for the starting equation.

(iii) Either of the two previous answers could have been used by candidates with the appropriate starting equation linking energy or momentum with wavelength. This was sometimes not appreciated, and it was not uncommon to see both methods attempted or combined.

(d) This question produced a broad range of responses. A move from the given phrase 'body structures' to identifying actual contrasting mediums in those structures (e.g. bone and soft tissue) achieved credit. However, descriptions were often simplistic, describing 'stopping' X-rays, and therefore did not compare two different mediums in the same way (i.e. the greater/lesser absorption properties of each). The strongest answers identified that it was the transmitted intensities that produced the difference in contrast on the film or detector. Weaker answers talked about different 'blackening' without an explanation of the cause of any difference.

Question 9

(a) Many answers used imprecise statements, expressing the half-life in terms of mass or total nuclei rather than activity. Terms such as atom, nucleon and nucleus were often used wrongly in this context.

(b) (i) An understanding that the gradient of the curve was the number of nuclei decaying per unit time meant that the majority of the candidates correctly identified the name of the quantity as 'activity'.

(ii) A full range of marks was seen on this question. Responses that directly described the graph without drawing a conclusion did not gain credit. Some element of processing or derivation was required. Stronger candidates were able to derive a numerical value for the half-life, or for the activity at some fixed time, and could include an appropriate number of significant figures and the correct unit.

(c) This was a question in which the ability to set working out clearly was of benefit to the candidate, as credit was available for stages in the process of getting to the final answer. Despite the complexity caused by the variety of possible approaches, it was generally well answered. Many candidates understood that the final answer for nucleon number needed to be an integer.

Question 10

(a) (i) This was a recall question that was generally answered successfully.

(ii) Many candidates were familiar with the method, starting with a clear explanation of a standard candle and finishing with the correct equation to link luminosity, radiant flux intensity and distance. There was often some confusion shown as to how the radiant flux intensity was arrived at. Weaker answers attempted to combine Doppler shift and Hubble's law with luminosity.

(b) (i) Many candidates correctly applied the Stefan's law equation and calculated a correct final answer including a correct unit. However, some of those did not appreciate that the data were given to three significant figures and the answer could also be given to three significant figures.

(ii) The relationship between the wavelength of peak radiation and temperature was known by many candidates, although it was common for the ratio between the two wavelengths to then be written the wrong way around, yielding an incorrect answer. Some candidates ignored the data provided for the Sun and instead used a remembered value for Wien's constant that did not match the precision of the other data. This resulted in an inaccurate final answer.

PHYSICS

Paper 9702/51
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 logarithms (both logarithms to base ten and natural logarithms) correctly, including calculating their uncertainties.
- The practical skills required for this paper should be developed and practised with a 'hands-on' approach throughout the course.

General comments

In **Question 1**, it is advisable that candidates should think carefully about how they would perform the experiment in the laboratory using the bullet points given on the question paper to aid their answer. Planning a few key points before answering **Question 1** is useful. Only the strongest candidates drew a diagram of a workable experiment to measure the surface temperature of the cylinder as it cooled. The drawn diagram should show how the experiment should be set up. Some candidates were successful in the analysis section with clear identification of how the constants could be determined. Weaker candidates often did not rearrange the proposed relationship into a suitable equation of a straight line ($y = mx + c$). Candidates should take care to describe exactly how each measurement will be obtained, including both the equipment used and the method to take the measurement. It is essential for candidates to have experienced practical work in preparation for answering this question.

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

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

Comments on specific questions

Question 1

Most candidates correctly identified the independent and dependent variables. Candidates should then consider the control of variables and to explicitly state the quantities that need to be kept constant to make the experiment a fair test. In this experiment it was expected that candidates would state that T_R would be kept constant. Credit is not given for simple stating 'control' T_R since this is just repeating the stem of the question and does not indicate what is meant by 'control'. Candidates should be encouraged to use the quantity names given in the question paper when referring to them to (for example t rather than just 'time'), as this improves the clarity of description and therefore makes it more likely for the description to be awarded credit.

Candidates were awarded credit for a clearly labelled diagram. Diagrams should be drawn of the workable experiment. In this experiment, the surface temperature of the cylinder needs to be measured while the cylinder is insulated and cooling. Therefore, the cylinder should be drawn with its outer surface fully covered with insulation. The temperature sensor needs to be positioned between the insulation and the cylinder for it to measure the surface temperature of the cylinder. This often was not drawn clearly enough in candidates' diagrams and temperature sensors were often positioned where it was impossible to measure the surface temperature of the cylinder. For example, an infra-red thermometer is not appropriate as the cylinder is covered with insulation.

Most candidates described the use of a stop-clock to measure the time t. Some candidates incorrectly referred to the time as the time for heating. Weaker candidates often referred to using a stop-watch to measure 'time' but with no reference to the time to be measured.

Many candidates also described how to measure both L and d using relevant equipment. Some candidates described the use of a ruler to measure d, which is not an appropriate piece of equipment for measuring the diameter of a cylinder accurately. Additional detail credit was also available for measuring the diameter of the cylinder along the length of the cylinder and determining a mean value for the diameter, and for including a correct mathematical equation to calculate the surface area A.

Before the cylinder could be cooled, it required heating to a uniform temperature. Stronger candidates drew a diagram of the cylinder fully submerged in a water bath or beaker of hot water and described how the cylinder was left in the water until its temperature was uniform throughout the cylinder.

Some candidates suggested correct axes for a graph. A significant number of candidates incorrectly suggested plotting ln T_C against t. This is an incorrect rearrangement of the equation. 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 equation.

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 did not gain credit since they incorrectly stated the line would pass through the origin.

Candidates needed to explain how they would determine values for the constants U and Z from the experimental results using the gradient and y-intercept. Candidates needed U and Z to be the subjects of the relevant equations. Credit was not awarded to candidates who did not correctly identify appropriate axes for a graph to plot.

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

When describing safety precautions, candidates should be encouraged to explain how the precaution proposed is relevant to the experiment. In this experiment, a precaution needed to be clearly linked to the risk of receiving a burn from the hot cylinder, oven or hot water.

Another additional detail mark was available for suggesting using a top-pan balance to measure the mass m of the cylinder, together with a method to determine c accurately. To determine c, an experiment needed to be described to heat the cylinder using an electrical heater so that the energy supplied could be determined and thus c could be calculated using the equation for specific heat capacity.

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) Many candidates correctly calculated *v* and $\frac{1}{f}$ with an appropriate absolute uncertainty for *v.* The most common error was to round the values of $\frac{1}{f}$ incorrectly or to give them to only three significant figures. Since *f* was recorded to four significant figures, values of $\frac{1}{f}$ should have been recorded to four (or five) significant figures.

(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 points. The worst acceptable line was drawn well in general, and many stronger candidates drew a line that passed through all error bars.

Candidates should clearly label the lines drawn. Where a dashed line represents 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 triangle that covered half of the drawn line. A small number of candidates chose data points that did not lie on the lines, often using data from the table that is close to the line instead. Candidates should be encouraged to select two coordinates on the line of best fit which are easy to read, i.e. coordinates on grid lines (candidates do not need to select plotted points that are on the line).

Stronger candidates often included the 10^{-3} power from the *y*-axis in their calculations, which assisted in the interpretation of the gradient in **(d)(i)**. A significant minority of candidates incorrectly calculated the gradient as Δx / Δy.

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

(iv) The majority of the candidates who were awarded full credit set out their working clearly. Stronger candidates often substituted data from the gradient calculation **(c)(iii)** into $y = mx + c$.

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. A small number of candidates incorrectly attempted to determine the uncertainty in the *y*-intercept by adding fractional uncertainties.

(d) (i) Candidates should show the substitution of the *y*-intercept to determine the value of f_s. Credit was not given for substituting data values from the table. Candidates were also expected to give the final values of f_s and *k* to an appropriate number of significant figures and a unit which should have the correct power of ten. Some candidates gave *k* to too many significant figures. Many candidates omitted the 10^{-3} from the *y*-axis of the graph and therefore calculated at least one of the values to an incorrect power of ten.

(ii) Most candidates added the percentage uncertainty in the gradient to the percentage uncertainty in the *y*-intercept, clearly showing the numbers that were substituted into the equations. Some candidates determined the percentage uncertainty by maximum and minimum methods. It was essential that the maximum *y*-intercept and minimum gradient were shown to be used to determine the maximum value of *k* (or vice versa for the minimum value) followed by further working to calculate the percentage uncertainty in *k*. The most common error here was to only give the percentage uncertainty in the gradient and to omit the percentage uncertainty in the *y*-intercept.

(e) There were two likely ways that candidates could determine *v.* The stronger candidates often recognised that they could use the gradient and *y*-intercept, while others substituted values for *k* and f_s into the given equation. Candidates needed to show clear and logical working for this question including full substitution of numbers. It was expected that the final answer would be given to at least two significant figures.

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 logarithms (both logarithms to base ten and natural logarithms) correctly, including calculating their uncertainties.
- The practical skills required for this paper should be developed and practised with a 'hands-on' approach throughout the course.

General comments

In **Question 1**, it is advisable that candidates should think carefully about how they would perform the experiment in the laboratory using the bullet points given on the question paper to aid their answer. Planning a few key points before answering **Question 1** is useful. Many candidates were successful in the analysis section with clear identification of how the constant could be determined. Weaker candidates tended to suggest a suitable graph but were not explicit in how the relationship could be proved or how they would determine *Z*. Candidates should take care to describe exactly how each measurement will be obtained, including both the equipment used and the method to take the measurement. It is essential for candidates to have experienced practical work in preparation for answering this question.

In **Question 2**, candidates should be familiar with completing a results table for quantities and their uncertainties, and with finding the gradient and *y*-intercept of a graph. Many candidates did not record values of lg (*L* / cm) to an appropriate number of decimal places in **(b)**. For some candidates, credit was not awarded because the plotted points were not balanced about the line best fit, the worst acceptable line did not pass through the error bars correctly or coordinates were wrongly read off when determining the gradient and/or *y*-intercept. Another common error was in determining the absolute uncertainty in *C*.

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

Comments on specific questions

Question 1

Most candidates correctly identified the independent and dependent variables. Candidates should then consider the control of variables and to explicitly state the quantities that need to be kept constant to make the experiment a fair test. In this experiment, it was expected that candidates would state that *k* would be kept constant. There was additional credit for also stating that *A*, *L* and *B* would be kept constant. The examiners did not allow just 'same magnet' as this was not a specific quantity in the relationship. Credit is not given for simply stating 'control' *k* since this is just repeating the stem of the question and does not indicate what is meant by 'control'.

Candidates were awarded credit for a clearly labelled diagram. Diagrams should be drawn of the workable experiment. In this experiment, many candidates did not understand the difficulty in measuring the length of the spring as the magnet left the card. One method of improving the accuracy was to support a metre rule using a stand near to the spring. Candidates needed to explain how the extension *S* was determined – by subtracting the original length of the spring from the length of the spring as the magnet left the card. Some candidates did not think that the new length would be larger than the original length. Additional detail credit was awarded to candidates who suggested the use of fiducial marks on the spring (not the rule) as well as a method to determine the maximum length of the spring as the magnet left the card. Some candidates described in detail the use of a video and then replaying the video frame by frame. Other candidates suggested small increases to the force applied to the spring or doing this slowly. The word 'carefully' did not gain credit because all experiments should be attempted carefully, whereas 'slowly' was a measure specific to this experiment.

Most candidates gained credit for suggesting the use of a micrometer to measure the thickness of the card. Some candidates also gained further credit for suggesting repeating the measurement of thickness in different positions on the card and determining the mean thickness.

Candidates also needed to state suitable methods to collect values of *A*, *L* and *B*. Many candidates suggested a rule for *L.* Often a micrometer or calipers were suggested to determine the diameter of the magnet and then an appropriate equation was given to determine *A* which included the diameter. Some weaker candidates did not gain credit because they made a direct statement of 'use a micrometer to determine *A*' or 'use a micrometer to measure the radius of the magnet'. Neither of these measurements can be made directly. The physical measurement would be the diameter and then *A* (or the radius) could be determined.

Many candidates stated the use of a Hall probe but did not give the method of measuring *B*. Some suggested that the probe should be at right angles but did not state how this could be checked. There were some excellent methods described by stronger candidates, discussing the rotation of the probe so that a maximum reading was obtained and repeating the measurement by reversing the probe and measuring in it in the opposite direction.

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

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 as well as (for this experiment) stating that the straight line would pass through the origin. Weaker candidates found it challenging to describe how the relationship may be shown to be true. Some candidates correctly suggested plotting a graph of lg *s* against lg *t*. To test the relationship using this method, candidates needed to use the words 'relationship is valid if' and the word 'straight' to describe the line as well as stating the gradient of the line which corresponded to their suggested graph.

Candidates needed to explain how they would determine a value for the constant *Z* from the experimental results using the gradient. Candidates needed *Z* to be the subject of the relevant equation. Credit was not awarded to candidates who did not correctly identify appropriate axes for a graph to plot. Determining *Z* from a graph of lg *s* against lg *t* could also gain credit, but a common error was confusion between logarithms to base 10 (lg) and natural logarithms (ln).

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

When describing safety precautions, candidates should be encouraged to explain how the precaution proposed is relevant to the experiment. In this experiment, precautions that were relevant to the magnet or spring travelling at speed towards the face or eyes meant that goggles should be worn or a safety screen used.

Other additional detail that gained credit included an experimental method to determine the spring constant *k*. Weaker candidates often quoted $F = kx$ without any experimental method. Some candidates correctly described a separate experiment and an appropriate graph to determine *k* from the gradient. Some candidates also described how the length of the spring would be checked to ensure that the spring has not exceeded its elastic limit.

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) Many candidates correctly calculated lg *T* with an appropriate absolute uncertainty. Many candidates incorrectly recorded lg *L* to two decimal places in the last three rows, and some weaker candidates only gave lg *L* to one decimal place. For logarithmic quantities, the number of decimal places in the logarithm should correspond to the number of significant figures in the quantity. For example, if *L* / cm has three significant figures, then lg (*L* / cm) should have three (or four) decimal places.

(c) (i) The points and error bars were straightforward to plot, although some candidates did not interpret the *y*-axis scale correctly. 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 points. The worst acceptable line was drawn well in general, and many stronger candidates drew a line that passed through all error bars and within the extremities of the error bar at the bottom.

Candidates should clearly label the lines drawn. Where a dashed line represents the worst acceptable line, the dashed parts of the line should cross each of the error bars.

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

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

(iv) The majority of the candidates who were awarded full credit set out their working clearly. Stronger candidates often substituted data from the gradient calculation in **(c)(iii)** into $y = mx + c$. Some weaker candidates incorrectly read off the *y*-intercept where lg (*L* / cm) = 1.7. Other errors seen included candidates incorrectly dividing the *y* value by *mx*, inconsistent use of powers of ten between the gradient and the *y*-axis value used or calculating $mx - y$ to give a positive value.

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

(d) Credit was not gained for substituting data values from the table. Most candidates realised that *n* was equal to the gradient. Many lower-scoring candidates did not gain credit since they did not give their values of *n* and *C* to an appropriate number of significant figures. It was expected that both *n* and *C* would be given to two (or three) significant figures. Many candidates appeared unsure on how to incorporate the 10^{-5} from the *T* column heading. A further common error when determining *C* was to use *e* instead of 10 because of confusion between logarithms to base 10 and natural logarithms.

Whilst most candidates realised that the uncertainty in *n* was the same as the uncertainty in the gradient, many candidates incorrectly calculated the uncertainty in *C*. The majority of these incorrect answers were using a fractional method. Either the maximum value of *C* or the minimum value of *C* (or both values) needed to be calculated.

(e) There were many incorrect answers observed. It was essential that candidates showed their method of working. The strongest candidates wrote down the equation and clearly substituted in correct values with the corresponding value of *T* allowing for both the ms and the 10^{-5} s. Candidates should be given the opportunity to practise working through questions that involve logarithmic relationships.

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 logarithms (both logarithms to base ten and natural logarithms) correctly, including calculating their uncertainties.
- The practical skills required for this paper should be developed and practised with a 'hands-on' approach throughout the course.

General comments

In **Question 1**, it is advisable that candidates should think carefully about how they would perform the experiment in the laboratory using the bullet points given on the question paper to aid their answer. Planning a few key points before answering **Question 1** is useful. Only the strongest candidates drew a diagram of a workable experiment to measure the surface temperature of the cylinder as it cooled. The drawn diagram should show how the experiment should be set up. Some candidates were successful in the analysis section with clear identification of how the constants could be determined. Weaker candidates often did not rearrange the proposed relationship into a suitable equation of a straight line ($y = mx + c$). Candidates should take care to describe exactly how each measurement will be obtained, including both the equipment used and the method to take the measurement. It is essential for candidates to have experienced practical work in preparation for answering this question.

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

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

Comments on specific questions

Question 1

Most candidates correctly identified the independent and dependent variables. Candidates should then consider the control of variables and to explicitly state the quantities that need to be kept constant to make the experiment a fair test. In this experiment it was expected that candidates would state that T_R would be kept constant. Credit is not given for simple stating 'control' T_R since this is just repeating the stem of the question and does not indicate what is meant by 'control'. Candidates should be encouraged to use the quantity names given in the question paper when referring to them to (for example t rather than just 'time'), as this improves the clarity of description and therefore makes it more likely for the description to be awarded credit.

Candidates were awarded credit for a clearly labelled diagram. Diagrams should be drawn of the workable experiment. In this experiment, the surface temperature of the cylinder needs to be measured while the cylinder is insulated and cooling. Therefore, the cylinder should be drawn with its outer surface fully covered with insulation. The temperature sensor needs to be positioned between the insulation and the cylinder for it to measure the surface temperature of the cylinder. This often was not drawn clearly enough in candidates' diagrams and temperature sensors were often positioned where it was impossible to measure the surface temperature of the cylinder. For example, an infra-red thermometer is not appropriate as the cylinder is covered with insulation.

Most candidates described the use of a stop-clock to measure the time *t*. Some candidates incorrectly referred to the time as the time for heating. Weaker candidates often referred to using a stop-watch to measure 'time' but with no reference to the time to be measured.

Many candidates also described how to measure both *L* and *d* using relevant equipment. Some candidates described the use of a ruler to measure *d*, which is not an appropriate piece of equipment for measuring the diameter of a cylinder accurately. Additional detail credit was also available for measuring the diameter of the cylinder along the length of the cylinder and determining a mean value for the diameter, and for including a correct mathematical equation to calculate the surface area *A*.

Before the cylinder could be cooled, it required heating to a uniform temperature. Stronger candidates drew a diagram of the cylinder fully submerged in a water bath or a beaker of hot water and described how the cylinder was left in the water until the temperature was uniform throughout the cylinder.

Some candidates suggested correct axes for a graph. A significant number of candidates incorrectly suggested plotting ln T_C against *t*. This is an incorrect rearrangement of the equation. 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 equation.

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 did not gain credit since they incorrectly stated the line would pass through the origin.

Candidates needed to explain how they would determine values for the constants *U* and *Z* from the experimental results using the gradient and *y*-intercept. Candidates needed *U* and *Z* to be the subjects of the relevant equations. Credit was not awarded to candidates who did not correctly identify appropriate axes for a graph to plot.

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

When describing safety precautions, candidates should be encouraged to explain how the precaution proposed is relevant to the experiment. In this experiment, a precaution needed to be clearly linked to the risk of receiving a burn from the hot cylinder, oven or hot water.

Another additional detail mark was available for suggesting using a top-pan balance to measure the mass *m* of the cylinder, together with a method to determine *c* accurately. To determine *c*, an experiment needed to be described to heat the cylinder using an electrical heater so that the energy supplied could be determined and thus *c* could be calculated using the equation for specific heat capacity.

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) Many candidates correctly calculated *v* and $\frac{1}{f}$ with an appropriate absolute uncertainty for *v*. The most common error was to round the values of $\frac{1}{f}$ incorrectly or to give them to only three significant figures. Since *f* was recorded to four significant figures, values of $\frac{1}{f}$ should have been recorded to four (or five) significant figures.

(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 points. The worst acceptable line was drawn well in general, and many stronger candidates drew a line that passed through all error bars.

Candidates should clearly label the lines drawn. Where a dashed line represents 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 triangle that covered half of the drawn line. A small number of candidates chose data points that did not lie on the lines, often using data from the table that is close to the line instead. Candidates should be encouraged to select two coordinates on the line of best fit which are easy to read, i.e. on grid lines (candidates do not need to select plotted points that are on the line).

Stronger candidates often included the 10^{-3} power from the *y*-axis in their calculations, which assisted in the interpretation of the gradient in **(d)(i)**. A significant minority of candidates incorrectly calculated the gradient as Δx / Δy.

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

(iv) The majority of the candidates who were awarded full credit set out their working clearly. Stronger candidates often substituted data from the gradient calculation **(c)(iii)** into $y = mx + c$.

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. A small number of candidates incorrectly attempted to determine the uncertainty in the *y*-intercept by adding fractional uncertainties.

(d) (i) Candidates should show the substitution of the *y*-intercept to determine the value of f_s. Credit was not given for substituting data values from the table. Candidates were also expected to give the final values of f_s and *k* to an appropriate number of significant figures and a unit which should have the correct power of ten. Some candidates gave *k* to too many significant figures. Many candidates omitted the 10^{-3} from the *y*-axis of the graph and therefore calculated at least one of the values to an incorrect power of ten.

(ii) Most candidates added the percentage uncertainty in the gradient to the percentage uncertainty in the *y*-intercept, clearly showing the numbers that were substituted into the equations. Some candidates determined the percentage uncertainty by maximum and minimum methods. It was essential that the maximum *y*-intercept and minimum gradient were shown to be used to determine the maximum value of *k* (or vice versa for the minimum value) followed by further working to calculate the percentage uncertainty in *k*. The most common error here was to only give the percentage uncertainty in the gradient and to omit the percentage uncertainty in the *y*-intercept.

(e) There were two likely ways that candidates could determine *v*. The stronger candidates often recognised that they could use the gradient and *y*-intercept, while others substituted values for *k* and f_s into the given equation. Candidates needed to show clear and logical working for this question including full substitution of numbers. It was expected that the final answer would be given to at least two significant figures.