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

General comments

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

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

Candidates found **Questions 1**, **3**, **8**, **21**, **24** and **38** difficult. They found **Questions 11**, **16**, **19**, **26**, **27** and **32** relatively straightforward.

Comments on specific questions

Question 1

Candidates found estimating the volume of an adult person difficult. One approach is to estimate the volume of a cuboid with the approximate dimensions of an adult, typically $1.6\,m \times 0.4\,m \times 0.2\,m$, giving a volume of $0.13\,m^3$.

Alternatively, as the human body is mostly water of density $10^3\,kg\,m^{-3}$ and the mass of an adult is approximately 80 kg, an estimate of the volume could be calculated using volume = mass / density = 80 kg / 10^3 kg m^{-3} = 0.08 m^3.

Either of these methods would show that **A** is correct and the other answers are too large.

Question 3

Candidates found this question difficult. Some may have tried to calculate the horizontal and vertical components and selected **A** which gives the correct horizontal component (10 cos 30° – 5) but an incorrect vertical component (10 cos 30° rather than 10 sin 30°). Others may have confused the sin and cos functions, selecting (10 sin 30° – 5) for the horizontal component and 10 cos 30° for the vertical component.

The correct answer can be found by calculating the components in the direction of the 10 N force and perpendicular to it. The component in the direction of the 10 N force is (10 – 5 cos 30°); the component perpendicular to it is 5 sin 30° (answer **C**).

Question 5

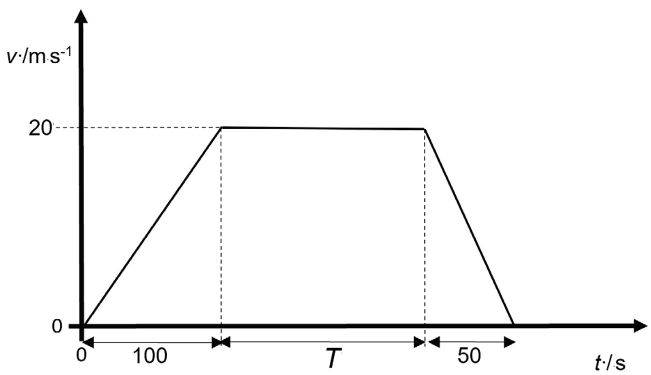
Most candidates realised that the absolute uncertainty in the diameter of the wire would be ± 0.04 mm rather than ± 0.02 mm, but some did not take into account the negative sign in the zero error of the micrometer. In moving the jaws of the micrometer from the closed position to the diameter of the wire, the jaws would move a total distance of 1.03 – (–0.05) = 1.08 mm.

Question 6

A simple approach to this question is to consider the energy changes taking place. As the projectile rises it is gaining gravitational potential energy and therefore losing kinetic energy and hence speed, eliminating **A** as the answer. The projectile will never come to rest as it always has a constant horizontal velocity (air resistance is negligible) eliminating **B** and **D** as possible answers, leaving **C** as the correct answer.

Question 7

Rather than trying to apply the equations of motion directly, it is sometimes easier to answer this type of question by first sketching a velocity–time graph. The train, moving with a uniform acceleration of 0.20 m s^{-2}, takes 100 s to accelerate from rest to a speed of 20 m s^{-1}. It takes half this time to decelerate from 20 m s^{-1} to rest when moving with a uniform deceleration of 0.40 m s^{-2}. If the train travels at constant speed for time T, the graph would be:



The total distance travelled by the train is 3000 m, represented by the total area under the graph.

$(\frac{1}{2} \times 100 \times 20) + (20 \times T) + (\frac{1}{2} \times 50 \times 20) = 3000$

This gives T = 75 s, and the total time to travel between the stations is then given by **C**.

Question 8

Candidates found this question difficult, suggesting a fundamental misunderstanding of Newton's third law. The 'action and reaction' pair of forces in this instance are the gravitational pull of the Earth on the rocket (the weight of the rocket) and the gravitational pull of the rocket on the Earth. Two key points candidates should remember when applying Newton's third law:

- the two forces are of the same type (in this example, gravitational forces)
- the two forces act on different objects and in opposite directions.

Question 17

The trolley is at rest at points P and Q, so the change in gravitational potential energy of the trolley must equal the work done against the resistive force:

$600 \times 9.81 \times (80 - h) = 300 \times 1.5 \times 10^3$

Solving this gives h = 3.5 m.

Some candidates selected **B** which is the change in the height of the trolley, not the height h of the trolley above ground level at point Q.

Question 20

Most candidates recognised that the work done during plastic deformation is the shaded area beyond the elastic limit, but some did not notice that the extension e of the rod has been plotted on the y-axis and the applied force F on the x-axis, rather than the other way round. The work done during plastic deformation is the shaded area in graph **C**, not graph **D**.

Question 21

Candidates found this question difficult, and **B** was a common incorrect answer.

The distance QR – PR is equivalent to (100 – 80) / 6.0 = 3.33λ. As the two waves are in phase at point R, they must be out of phase at points P and Q by $\frac{\lambda}{3}$, equivalent to a phase difference of $\frac{360°}{3} = 120°$.

Question 24

Candidates found this question very difficult, with many selecting **C** rather than **A**.

As the ambulance approaches the observer, the frequency of sound heard by the observer is $f_o = f_s v / (v - v_s)$ where f_o is the frequency of sound heard by the observer, f_s is the frequency of sound emitted by the source, v_s is the velocity of the source and v the velocity of sound. As the ambulance approaches the observer it decelerates, i.e. v_s decreases, so the quantity $v - v_s$ increases. This means the observed frequency f_o **decreases**.

As the ambulance moves away from the observer, the frequency of sound heard by the observer is $f_o = f_s v / (v + v_s)$. As the ambulance moves away from the observer it accelerates, i.e. v_s increases, so the quantity $v + v_s$ increases. This means the observed frequency f_o again **decreases**.

Question 25

Most candidates recognised that microwaves and X-rays must travel at the same speed in a vacuum, eliminating **C** and **D** as possible answers. The wavelengths of X-rays are typically 10^{-10} m, while the wavelengths of microwaves are typically 10^{-2} m (1 cm). The ratio of the two wavelengths is $\frac{10^{-10}}{10^{-2}} = 10^{-8}$.

Question 31

Most candidates determined that the oil drop would have an upward acceleration, though many candidates ignored the weight of the oil drop in their calculations, which reduces the upward acceleration of the oil drop significantly.

Question 38

Candidates found this question difficult, with many selecting incorrect answer **A** rather than the correct answer **B**.

The reading on the galvanometer is zero when the potentiometer circuit is 'balanced' – there is then no current in cell X and no 'lost volts' across the internal resistance of the cell, so the value of the internal resistance is not needed.

If cell X has e.m.f. E_x then $E_x / E = V_{QS} / V_{QR}$. As the distance QS must be less than distance QR, E_x must be less than E for the value of E_x to be found.

PHYSICS

Paper 9702/12
Multiple Choice

Question Number	Key
1	D
2	B
3	D
4	D
5	D
6	D
7	B
8	C
9	B
10	D

Question Number	Key
11	A
12	C
13	B
14	C
15	A
16	A
17	D
18	D
19	A
20	D

Question Number	Key
21	B
22	A
23	B
24	A
25	B
26	C
27	B
28	B
29	C
30	A

Question Number	Key
31	D
32	A
33	A
34	B
35	A
36	C
37	A
38	C
39	C
40	A

General comments

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

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

Candidates found **Questions 7**, **8**, **13**, **22** and **36** difficult. They found **Questions 11**, **12**, **18**, **21**, **23**, **27**, **35**, **37** and **39** relatively straightforward.

Comments on specific questions

Question 1

Most of the candidates answered this question correctly, though some thought that the estimate of the momentum of a lorry moving along a road was unreasonable. Estimating the mass of a lorry as 20 000 kg, travelling at a speed of 90 km h^{-1} (25 m s^{-1}), the momentum of the lorry would be:

$$\text{momentum} = 20\,000 \times 25 = 5 \times 10^5 \text{ N s}.$$

Estimating the mass of an adult as 80 kg, the weight of an adult is then 8×10^2 N. The mass of a fully grown racehorse is much larger than the weight of an adult, so an estimate of 6×10^2 N for the weight of a racehorse is **not** reasonable, giving **D** as the correct answer.

Question 7

Candidates found this question difficult, with less than half of the candidates answering the question correctly. One approach is to apply the equation $s = ut + ½at^2$ from P to Q in the horizontal and vertical directions, noting that the vertical displacement from P to Q is zero.

If the time taken for the projectile to travel from P to Q is T, then:

vertically: $0 = V\sin\theta \times T - ½gT^2$

horizontally: $R = V\cos\theta \times T$

Eliminating T from these equations gives $R = V\cos\theta \times \frac{2V\sin\theta}{g} = \frac{2V^2\sin\theta\cos\theta}{g}$.

Question 8

Many candidates misinterpret the 'action equals reaction' pair of forces described in Newton's third law as the forces acting on an object to maintain its equilibrium. It is true in this example that the weight of the book is equal to the force upwards acting on the book from the table, but this is not the pair of forces in Newton's third law. The weight of the book is the gravitational pull of the Earth on the book; the 'reaction' force is the gravitational pull of the book on the Earth. Two key points for candidates to remember about Newton's third law:

- the two forces are of the same type (in this case, gravitational)
- the two forces act on different objects and in opposite directions.

Question 13

In this question, it is important to realise that the centre of gravity of the sign is at its geometric centre. When the sign is hanging at an angle θ to the vertical, the centre of gravity has a moment of $(40 \times 0.40 \times \sin\theta)$ N m about the hinge and this must equal the 6.0 N m torque provided by the hinge. Solving for θ gives answer **B**.

Question 14

Most of the candidates answered this question correctly, though some omitted g from their calculations (which leads to incorrect answer **A**) or forgot to take account of the elephant's four feet (which leads to incorrect answer **D**).

Question 15

Just over half of the candidates answered this question correctly, with **B** a common incorrect answer. As the stone is falling at a constant velocity, the kinetic energy of the stone remains constant. The gravitational potential energy lost by the stone as it falls changes to thermal energy, i.e. the stone and the air become warmer.

Question 20

The majority of the candidates answered this question correctly, though a significant minority thought that the ratio of the strain energy in string X to the strain energy in string Y was ½ rather than ¼. As the strings obey Hooke's law, the energy in the stretched strings is $½Fx$. The force stretching string Y is twice the force stretching string X, and the extension of string Y is twice the extension of string X, so the strain energy in string Y must be four times the strain energy in string X.

Question 22

This proved to be a difficult question, with many candidates deducing that the wave must be a transverse wave rather than a longitudinal wave. If the two graphs did represent a transverse wave, the two particles would be in 'antiphase' – an odd number of half-wavelengths apart. The distance between a peak and the next trough could be 10 cm, 10/3 cm, 10/5 cm... but not 20 cm. The distance between adjacent peaks (the wavelength) could be 20 cm, 20/3 cm 20/5 cm... but not 10 cm.

Question 29

Just over half of the candidates answered this question correctly. The *n*th order maximum of the light with the larger wavelength must overlap with the $(n + 1)$th order maximum of the light with the shorter wavelength.

Using the diffraction grating equation:

$(n + 1) \times 420 \times 10^{-9} = n \times 630 \times 10^{-9}$.

Solving this gives $n = 2$. Now that n is known, the diffraction grating equation can be used again to determine the line spacing d:

$2 \times 630 \times 10^{-9} = d \sin 31°$.

Solving this gives answer **C**.

Question 32

Most of the candidates answered this question correctly, though almost a third selected an answer where the drift speed of the electrons increases as they travel from X to Y.

The cross-sectional area of the metal conductor increases from X to Y but the current must remain constant. Applying the equation $I = nAqv$, it follows that the drift speed v of the electrons must decrease as they move from X to Y, eliminating graphs **B** and **D**. Graph **C** can also be rejected, as this graph implies that the electrons stop at Y.

Question 33

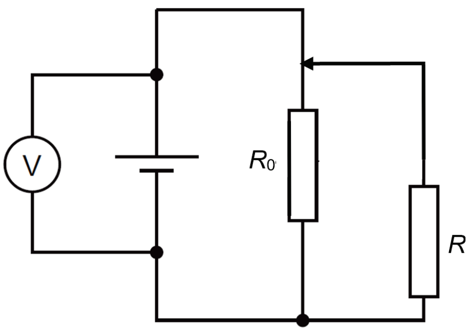
Just over half of the candidates answered this question correctly. The current from the power supply is given by $I = P / V = 2.4 \times 10^3 / 240 = 10$ A.

The potential difference across the kettle is $240 - 2 \times 0.5 \times 10 = 230$ V.

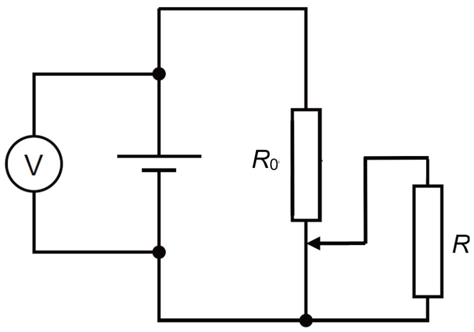
The power supplied to the kettle is $230 \times 10 = 2300$ W (2.3 kW).

Question 36

Many candidates found this question difficult, with only a third answering the question correctly. One approach is to consider what happens in the circuit when the sliding contact of the potentiometer is at the two extreme positions. Let the resistance of the fixed resistor be R and the total resistance of the potentiometer be R_0.



position 1



position 2

For position 1 of the potentiometer, the two resistors are in parallel with each other and so the combined resistance must be less than R_0.

For position 2 of the potentiometer, the fixed resistor is 'short circuited' and has no effect, so the resistance of the combination of resistors is equal to R_0.

As the sliding contact is moved downwards, the effective resistance steadily increases from a value less than R_0 towards R_0, so the current in the circuit steadily decreases.

The reading V on the voltmeter is given by $V = E - Ir$ where E is the e.m.f. of the cell, r is the internal resistance of the cell and I is the current. As the current decreases, the 'lost volts' term Ir decreases and the reading on the voltmeter increases, i.e. answer **C**.

PHYSICS

Paper 9702/13
Multiple Choice

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

General comments

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

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

Candidates found **Questions 7**, **34**, **35**, **36** and **38** difficult. They found **Questions 3**, **6**, **10**, **19**, **20**, **27**, **32** and **39** relatively straightforward.

Comments on specific questions

Question 1

The majority of the candidates answered this question correctly, though some estimated the kinetic energy to be 400 J rather than 4000 J. For an athlete of mass 80 kg running with a speed of 10 m s^{-1}, the kinetic energy would be 4000 J.

Question 5

Almost all the candidates calculated the area of the circular disc correctly (answers **A** or **B**) but many estimated the absolute uncertainty incorrectly. One approach is to calculate the largest and smallest possible values for the area, and the absolute uncertainty is then ± half the difference between these two values. Another method is to use the fact that the percentage uncertainty in the area must be twice the percentage uncertainty in the diameter. Either of these methods will lead to answer **B**.

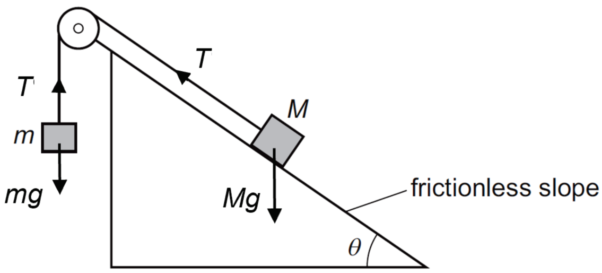
Question 7

Many candidates found this question difficult. Applying the equation $s = ut + ½at^2$ gives $h = 0 \times t + ½at^2$.

A graph of h versus t^2 will have a gradient of $½a$. If this gradient is G, then $a = 2G$.

Question 8

Just over half of the candidates answered this question correctly. The forces acting on the masses M and m are as shown on the diagram below (T is the tension in the string):



As the mass M accelerates <u>down</u> the slope, $Mg \sin\theta > T$ and $T > mg$. Combining these two inequalities:

$Mg \sin \theta > mg$

and therefore

$\sin\theta > \frac{m}{M}$.

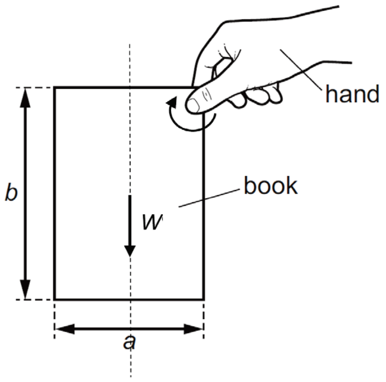
Question 11

Fewer than half of the candidates answered this question correctly. As the steel ball is falling, the upthrust and the viscous drag forces must both be acting upwards, while the weight acts downwards. The ball is falling at constant speed, so the resultant force acting on the ball is zero, which implies that the sum of the viscous drag force and the upthrust is equal to the weight of the ball. The weight must therefore always be the largest force.

A stationary steel ball in air must have a weight much greater than the upthrust on it, and then as it falls the viscous drag will gradually increase until it equals the difference between the weight and the upthrust. At this point the viscous drag will be much greater than the upthrust (and slightly less than the weight), so **A** is the correct answer.

Question 14

The book has a rectangular shape and is of uniform thickness, implying that the centre of gravity of the book is at its geometric centre.



The moment of the weight of the book about the corner is ½*Wa* anticlockwise. The torque exerted by the hand in order to maintain the equilibrium of the book is therefore ½*Wa* clockwise.

Question 17

Almost all candidates calculated the change in volume of the gas in the cylinder correctly ($0.80 \times 10^{-4}\,m^3$), using the equation work done = $p\Delta V$. The question asks for the volume of the gas after doing this work. Since the gas is *doing* work rather than work being done on the gas, the gas must be expanding – the volume of the gas after doing work must be greater than the original volume. Answer **A** is the change in the volume of the gas, and **B** implies the gas is being compressed. The correct answer is **C**:

initial volume + increase in volume = $2.40 \times 10^{-4} + 0.80 \times 10^{-4} = 3.20 \times 10^{-4}\,m^3$.

Question 26

The majority of the candidates answered this question correctly, though a significant number chose incorrect answer **A** which lists the four regions of the electromagnetic spectrum in order of **decreasing** wavelength.

Question 33

Approximately a third of the candidates answered this question correctly, and more candidates selected the incorrect answer **B** than the correct answer **C**. The density *n* of free electrons in the wire is given by:

$$n = \frac{\text{no. of charge carriers in wire}}{\text{volume of wire}} = \frac{5.1 \times 10^{22}}{12 \times 10^{-2} \times A}$$

where *A* is the (unknown) cross-sectional area of the wire. The current in the wire is then given by $I = nAqv$ and the unknown value of *A* then cancels out:

$I = (5.1 \times 10^{22} / 12 \times 10^{-2} A) \times A \times 1.60 \times 10^{-19} \times 4.0 \times 10^{-6}$

giving $I = 0.27\,A$.

Candidates who selected the incorrect answer **B** must have multiplied their expression for I by 12×10^{-2} rather than dividing it.

Question 34

Many candidates seemed confused by the meaning of a 'battery marked 9.0 V'. The value of 9.0 V is the e.m.f. of the battery – the electrical energy supplied to the whole circuit per unit charge. It is not the energy per unit charge supplied to an external circuit as some energy is dissipated in the internal resistance of the battery, and this depends on the current (so could not be marked as a constant value on a battery).

The potential difference across any component connected to the battery, and the potential difference across the battery terminals, will also be less than 9.0 V because of the 'lost volts' across the internal resistance of the battery.

Question 35

This was a difficult question. The key to answering the question is to notice that the two batteries are connected in opposite directions, so the overall e.m.f. in the circuit is 4.0 V. Applying Kirchhoff's second law:

$12.0 - 8.0 = I \times 1.0 + I \times 0.5$.

Solving this for I gives $I = 2.7$ A.

Question 36

Answering this question required the correct application of the circuit laws, including the addition of resistors in parallel and an understanding of the effect of the internal resistance of the cell on the rest of the circuit.

Although candidates could work out what happens algebraically by assigning variables to different quantities in the circuit, this is not needed as only a qualitative answer is required. Adding a second resistor in parallel with the original resistor must decrease the total circuit resistance, and so the current (ammeter reading) will increase. This will increase the 'lost volts' across the internal resistance in the cell and so the reading on the voltmeter across R must decrease, giving answer **C**.

Question 37

Many candidates selected incorrect answer **C** rather than the correct answer **B**. Since the two resistors (in series) of resistances R_1 and R_2 are in parallel with the two resistors (in series) of resistances R_3 and R_4, the potential difference across each pair of resistors is the same:

$E = I_1(R_1+R_2) = I_2(R_3+R_4)$

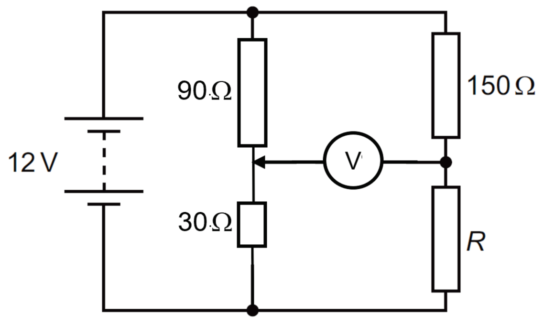
and therefore

$0 = I_1(R_1+R_2) - I_2(R_3+R_4)$.

Answer **C** is not a correct application of Kirchhoff's second law because a closed loop cannot be constructed that involves the cell, I_1 and I_2.

Question 38

Many candidates selected the incorrect answer **A**. When the slider is $\frac{1}{4}$ of the way from its lower end, the potentiometer is effectively two resistors in series, of resistance 30 Ω and 90 Ω.



When the voltmeter reads zero, the pairs of resistors must have resistances in the same ratio:

$R / 150 = 30 / 90$

giving $R = 50\,\Omega$.

PHYSICS

Paper 9702/21
AS Level Structured Questions

Key messages

- Candidates should pay close attention to the command words used in each question. For example, 'state and explain' indicates that an explanation is required as part of the answer. The syllabus contains a glossary of command words.
- When combining parallel vectors, candidates must always consider whether the vectors are in the same or opposite directions.
- Candidates should present all equations with a subject. This presentation helps to prevent errors when equations are rearranged or manipulated in any way.
- In 'show that' questions, all the steps in the solution must be shown. Full credit cannot be awarded if key steps, such as the rearrangement of an equation, are not shown.
- Candidates should be encouraged to write their responses only in the answer spaces provided. If part of a response is unavoidably written elsewhere in the answer booklet, it should be clearly labelled so that the Examiner knows which question it belongs to.

General comments

The more challenging questions were generally those that required the application of knowledge and understanding. Examples were the determination of the pressure of the pyramid on the surface of a bench in **Question 1(c)**, the time taken for a trolley to come to rest and the trolley's speed after travelling down a slope in **Questions 2(a)(ii)** and **2(b)(i)**, the determination of the moment of the weight of the sphere in **Question 3(e)** and the calculation of resistance *R* in **Question 5(b)(iii)**.

Many weaker candidates successfully gained partial credit in questions where there was a requirement to give a standard definition or to perform a simple substitution of values into a basic equation.

Comments on specific questions

Question 1

(a) The majority of the candidates gave the correct definition of density.

(b) (i) The majority of the candidates were able to determine the absolute uncertainty in the length.

(ii) Many candidates found it difficult to use the percentage uncertainties in the question to directly calculate the percentage uncertainty in the density. A significant number did not double the percentage uncertainty of the quantity *x*. Others did not add all the percentage uncertainties but instead used an invalid combination of addition and subtraction.

Some candidates attempted to use the fractional uncertainties for each of the quantities and a value for the density in order to calculate the percentage uncertainty in the density. This method often resulted in arithmetic errors or an incomplete solution.

(c) Stronger candidates were able to determine the pressure. A number of candidates started with the correct symbol expression for pressure but were then unable to calculate the base area of the pyramid. A significant number made power-of-ten errors when calculating either the weight or the base area of the pyramid. Other candidates used an invalid expression for the pressure on a surface, such as the expression for pressure at a depth below the surface of a liquid.

Question 2

(a) (i) Most candidates gave the correct symbol equation. A significant number used the wrong value of force, often subtracting the resistive force from the weight. Some candidates attempted to calculate the power using the work done divided by the time taken but were unable to calculate the work done or the time taken.

(ii) Many candidates used the correct equation to calculate the acceleration of the trolley and then went on to determine the time taken for it to come to rest. Some candidates used the acceleration of free fall, even though the trolley was travelling along a horizontal surface. Other candidates attempted an inappropriate calculation of the time taken that used the value of the power calculated in **(a)(i)**.

(b) (i) A significant number of candidates calculated the acceleration using the correct resultant force acting on the trolley. These candidates generally used an appropriate equation for constant acceleration to determine the speed. Some weaker candidates incorrectly assumed that the acceleration was equal to the acceleration of free fall.

(ii) Many candidates did not use the correct value for the force F even though this was given in the question. A common mistake was to calculate the work done by using the resultant force instead of using force F.

(iii) Stronger candidates realised that, as the trolley moved with constant acceleration, the distance moved (and hence the work done) would be proportional to the square of the time. Many candidates drew a straight line from the origin that corresponded to a constant speed.

(c) The majority of the candidates referred to the frictional forces at the wheels of the trolley varying even though the question stated that these frictional forces were constant. Only the strongest candidates could explain that the air resistance would change owing to the increasing speed of the trolley.

Question 3

(a) The majority of responses were correct. Candidates needed to draw a precise line that started at the centre of the sphere at position X and finished at the centre of the sphere at position Y.

(b) The majority of the candidates were able to state the correct symbol equations for kinetic energy and momentum. A significant number were able to use these two equations to show the correct value for the mass of the sphere.

A small minority of candidates used the value given for the mass to determine the velocity of the sphere at X using the equations for momentum or kinetic energy. This value of velocity was then substituted into the equation for kinetic energy or momentum to determine the mass given in the question. This circular calculation was not an acceptable method.

(c) Most candidates correctly rearranged the expression for the change in gravitational potential energy to calculate the height. A reverse calculation from **(d)** using the given angle of 47° was not accepted. Some candidates expressed their answer as 0.30 m which has a rounding error or as 0.3 m which has too few significant figures.

(d) Only the strongest candidates were able to show that angle θ is equal to 47°.

(e) Most candidates found it difficult to determine the perpendicular distance of the line of action of the weight from the pivot. The majority confused this perpendicular distance with either the length of the string or the length (0.93 – 0.29) m.

(f) A common mistake was to state that the sphere must be in equilibrium because it is stationary. A significant number of candidates recognised that the sphere is not in equilibrium, but did not refer to the resultant force or resultant moment in their explanations.

Question 4

(a) Many candidates gave incomplete statements such as the distance between two wavefronts or the distance between two crests. Candidates should instead refer to the <u>minimum</u> distance between wavefronts or crests. Alternatively, they should refer to the distance between <u>adjacent</u> wavefronts or crests.

(b) A small minority of the candidates made power-of-ten errors when calculating the time period.

(c) The majority of the candidates gave only part of the required explanation. Some simply stated that the waves spread at the grating. A smaller number added that this occurred as the waves passed through the slits on the grating. Some responses gave the results of the interference of the waves after they had passed through the grating, which was not asked for in the question. A small number of candidates confused diffraction with refraction and described the bending of the waves.

(d) (i) The general symbol equation for diffraction at a grating was usually stated correctly. Stronger candidates were able to link this formula to the gradient of the graph. A significant number did not substitute the value of the order, clearly stated in the question as the fourth order, into the final expression for *d*.

(ii) Only a minority of candidates realised that the line for the second order would have half the gradient of the original line and would, when extrapolated, go through the origin. A significant number of the weakest candidates did not give a response to **(d)(i)** or **(d)(ii)**.

Question 5

(a) The majority of the candidates were able to give only a partial statement of Kirchhoff's second law. Some candidates did not mention that the law applies to a closed loop or closed circuit. Others did not refer to 'the sum of' when relating the e.m.f.s to the potential differences. A small minority confused Kirchhoff's first and second laws.

(b) (i) The majority of the candidates calculated the correct current.

(ii) A significant number of candidates were able to calculate the charge passing through the battery. Only the stronger candidates went on to determine the number of charge carriers. Some candidates seemed to confuse the number of charge carriers with the number density of the charge carriers.

(iii) Stronger candidates were able to apply Kirchhoff's second law to the circuit in order to determine resistance *R*. A significant number calculated the total resistance outside the battery or calculated the combined resistance of *R* and internal resistance. These candidates omitted one of the potential differences when determining the total potential difference around the closed loop.

(c) (i) A significant number of candidates confused the e.m.f. of the battery with the potential difference across XY.

(ii) In general, the candidates found this question difficult. The stated change to the position P on the wire was often based on incorrect physics. A significant number of the weakest candidates did not give a response to **(c)(i)** or **(c)(ii)**.

Question 6

(a) (i) A significant number of candidates gave the correct response. Many weaker candidates needed to improve their knowledge of how a proton decays to form a neutron.

(ii) A significant number of candidates gave the correct response. A similar number gave answers that suggested a lack of knowledge of the interaction in the nucleus which causes the decay.

(iii) Many of the answers suggested that the information on the data page of the question paper had not been considered. Candidates should be reminded that this information is available to them and that they do not need to memorise the values given.

(iv) Generally, this question was well answered. Most candidates clearly stated the charge of the up and down quarks. Others did not give the quark composition of the proton or did not clearly show the summation of the charges for the three quarks to give a resultant charge of $+e$.

(v) This question was usually answered correctly. A small proportion of weaker candidates did not explicitly describe the change in the quark composition and merely stated the quark composition of the neutron.

(b) (i) A significant number of candidates gave the correct answer.

(ii) Only a minority of candidates realised that the answer to **(b)(i)** could be combined with the ratio of the mass numbers to give the ratio of the accelerations. Many weaker candidates did not attempt a response.

(iii) Most candidates did not realise that in a uniform electric field the force acting on a charged particle produces a constant acceleration. Many candidates drew straight lines passing through the origin suggesting confusion between velocity and acceleration.

PHYSICS

Paper 9702/22
AS Level Structured Questions

Key messages

- Candidates should pay close attention to the command words used in each question. For example, 'state and explain' indicates that an explanation is required as part of the answer. The syllabus contains a glossary of command words.
- When combining parallel vectors, candidates must always consider whether the vectors are in the same or opposite directions.
- Candidates should present all equations with a subject. This presentation helps to prevent errors when equations are rearranged or manipulated in any way.
- In 'show that' questions, all the steps in the solution must be shown. Full credit cannot be awarded if key steps, such as the rearrangement of an equation, are not shown.
- Candidates should be encouraged to write their responses only in the answer spaces provided. If part of a response is unavoidably written elsewhere in the answer booklet, it should be clearly labelled so that the Examiner knows which question it belongs to.

General comments

Each of the six questions contained straightforward parts that were accessible to weaker candidates. There were also much more challenging parts for stronger candidates which assessed their ability to apply their knowledge and understanding. In parts of **Questions 1** and **2**, some candidates tried to combine vectors without considering whether they were in the same or opposite directions. In **Question 5(c)**, some candidates did not know how to use the standard linear form $y = mx + c$ to determine what is represented by the gradient and intercept of a straight-line graph. In **Question 6(a)**, many candidates did not know what could be inferred about the structure of the atom from the given result of the alpha-particle scattering experiment.

There was no evidence of candidates being short of time to complete the paper.

Comments on specific questions

Question 1

(a) This was a straightforward question and the majority of responses were correct.

(b) The majority of the candidates could state the correct conditions for an object to be equilibrium. Weaker candidates sometimes referred to 'zero moment about any point' and 'zero force in any direction', without realising that they needed to explicitly refer to the resultant moment and the resultant force. Another common mistake was to use the word 'momentum' instead of 'moment'

(c) (i) The weakest candidates sometimes calculated a pressure difference instead of the upthrust. Another common mistake was to ignore the instruction in the question to calculate the upthrust to three significant figures and to instead express the answer to only two significant figures. Candidates should be encouraged to read questions carefully rather than merely scan them.

(ii) The majority of the candidates were able to show the correct calculation.

(iii) The majority of the responses gave the correct symbol equation for calculating stress. The most common mistake was a power-of-ten error in the value of the area due to an incorrect conversion from mm^2 to m^2. Some of the weaker candidates used the weight or the upthrust instead of the tension in their calculation of the stress.

(iv) Most candidates correctly stated that the strain energy would increase. Some candidates did not explain that this was due to the increasing stress in the wire caused by the increasing upthrust. Such candidates may have overlooked the instruction in the question to give an explanation. Some of the weakest candidates seemed to confuse the terms ‘strain energy’ and ‘strain’.

Question 2

(a) This question was very well answered. A small minority of candidates substituted the value of the acceleration of free fall with the wrong (inconsistent) sign into the appropriate equation.

(b) Most responses were correct. A significant proportion of the candidates did not make it clear that there were two separate forces, one acting on the ball and the other acting on the ground, that were equal and opposite. Some of the weaker candidates gave only a general statement of Newton’s third law without applying it to the collision between the ball and ground.

(c) (i) A significant minority of the candidates did not consider that momentum is a vector quantity rather than a scalar quantity. They therefore made the mistake of subtracting the magnitudes of the momenta instead of adding them.

(ii) The average resultant force acting on the ball during the collision was usually calculated correctly. The most common mistake was to assume that the average resultant force was simply equal to the weight of the ball.

(iii) Most candidates found this part of the question challenging. Many recognised that the force exerted by the ground was a combination of the average resultant force and the weight of the ball, but did not take into account that the resultant force and weight act in opposite directions. Consequently, the magnitudes of the resultant force and weight were often subtracted instead of being added. Some of the weaker candidates thought that the force exerted by the ground was equal to the resultant force.

(d) The majority of the candidates realised that they needed to sketch a line of constant positive gradient. A common mistake was to draw the straight line from the origin of the graph. Candidates should be encouraged to always use a ruler when drawing straight line graphs.

(e) Most candidates realised that the gradient would decrease with time and some mentioned that this would be due to an increasing air resistance. Only the strongest candidates gave a full explanation of how the increasing air resistance would lead to a decreasing resultant force on the ball and thus a decreasing acceleration.

Question 3

(a) Almost all of the candidates could state the general symbol expression for the change in gravitational potential energy. A very small minority of the weaker candidates confused the mass of the child with its weight.

(b) Most candidates realised that the distance moved could be obtained by dividing the work done against the frictional force by the magnitude of the frictional force. The value of the work done was often calculated incorrectly.

(c) (i) The general symbol expression for kinetic energy was well known and so the speed of the child was usually calculated correctly. Some of the weakest candidates confused the mass of the child with its weight.

(ii) Some candidates used an incorrect trigonometric function (usually sin 41° instead of cos 41°) in their calculation. Others incorrectly stated that the speed at point Z would be zero, possibly due to confusion between the horizontal and vertical components of the velocity at that point.

Question 4

(a) Candidates needed to give a precise statement of what is meant by the period of a wave. Vague statements such as 'the time for a wave to form' or 'the time for a wave to pass' could not be given credit. The weakest candidates sometimes confused the period of a wave with its frequency.

(b) The principle of superposition was usually stated correctly. Some candidates incorrectly referred to amplitude instead of displacement in their statements.

(c) (i) Many candidates were unable to use the wavelength of the waves to identify the correct region of the electromagnetic spectrum. Common incorrect answers included infrared and radio wave. A small proportion of the candidates appeared to misunderstand the question and gave a response that was unrelated to any region of the electromagnetic spectrum.

(ii) Generally, this question was well answered. The most common mistake a power-of-ten error when converting the unit of the period from seconds to picoseconds.

(iii) Successful candidates recognised the command word 'show' and carefully presented all the steps in their calculation. A significant proportion of the weakest candidates did not attempt a response.

(iv) The most common incorrect answers were 90° and 630°.

(v) The majority of the candidates did not realise that the waves would superpose to give zero resultant amplitude and therefore zero intensity at point Z. Many candidates simply stated the general relationship between intensity and amplitude, but did not attempt to apply this relationship.

(vi) Only the strongest candidates understood that the distance between adjacent intensity maxima would increase. Some candidates referred to bright and dark fringes, perhaps confusing microwaves with visible light.

Question 5

(a) Some candidates did not appreciate that a unit should be defined in terms of other units. The definition of resistance was often given instead of the definition of the ohm.

(b) The general symbol equation $R = \rho L / A$ was usually recalled correctly, but weaker candidates sometimes made errors when combining it with the equation $A = V / L$.

(c) (i) The majority of responses were correct.

(ii) Generally, this question was well answered. Most candidates recalled a correct formula for electric power. The weakest candidates sometimes calculated the total power produced by the battery instead of the power dissipated by the variable resistor.

(iii) Although most candidates realised that the gradient of the graph represented a resistance, only a minority of the candidates correctly identified it as representing the internal resistance of the battery. Some candidates incorrectly stated that it represented the resistance of the variable resistor. A significant proportion of the weakest candidates did not attempt a response to this question.

Question 6

(a) Many candidates correctly stated that the nucleus of the atom must be charged. A common mistake was to say that all of the charge of the atom is in the nucleus. Only a small minority of candidates correctly stated that most of the mass of the atom must be in the nucleus. Many candidates gave an incomplete statement such as 'the nucleus has mass'.

Many weaker candidates wrote about the structure of the atom from their own general knowledge rather than from what could be inferred from the experimental result in the question. Others described an alpha-particle instead of the structure of the atom. The weakest candidates sometimes confused the terms 'nucleus', 'nuclear' and 'nucleon'.

(b) A common misconception was that a proton is a fundamental particle. Some of the candidates who stated that it was not fundamental did not provide a supporting explanation in their answer.

(c) Most candidates were able to calculate the total charge passing a fixed point in the beam in a time of 1.0 minute. However, the conversion of this total charge into the number of alpha-particles proved to be challenging. The most common mistake was to assume that an alpha-particle has a charge of 1.6×10^{-19} C instead of 3.2×10^{-19} C.

(d) This question was difficult for many candidates. A common mistake was to state that the acceleration would increase rather than stay constant, possibly because candidates were confusing acceleration with velocity. Those candidates who did realise that the acceleration would stay constant often omitted a valid supporting explanation.

(e) Most responses were correct. Some candidates incorrectly thought that the electric force on the nucleus X in the uniform electric field would be greater because it had greater mass. Such candidates seemed to assume, incorrectly, that the two nuclei had the same acceleration.

PHYSICS

Paper 9702/23
AS Level Structured Questions

Key messages

- Candidates should pay close attention to the command words used in each question. For example, 'state and explain' indicates that an explanation is required as part of the answer. The syllabus contains a glossary of command words.
- When combining parallel vectors, candidates must always consider whether the vectors are in the same or opposite directions.
- Candidates should present all equations with a subject. This presentation helps to prevent errors when equations are rearranged or manipulated in any way.
- In 'show that' questions, all the steps in the solution must be shown. Full credit cannot be awarded if key steps, such as the rearrangement of an equation, are not shown.
- Candidates should be encouraged to write their responses only in the answer spaces provided. If part of a response is unavoidably written elsewhere in the answer booklet, it should be clearly labelled so that the Examiner knows which question it belongs to.

General comments

The more challenging questions were generally those that required the application of knowledge and understanding. Examples were the determination of the resultant velocity in **Questions 1(b)(iii)** and **(iv)**, the explanation of the shape of the velocity–time curve in **Question 2(b)(i)** and the determination of the increase in length of the spring in **Question 3(b)(i)**. In **Question 5,** candidates needed to have a detailed knowledge and understanding of the effect of an internal resistance of a battery on the potential difference in a circuit.

Many weaker candidates successfully gained partial credit in questions where there was a requirement to give a standard definition or to perform a simple substitution of values into a basic equation.

Comments on specific questions

Question 1

(a) (i) A significant number of candidates gave correct answers for both the scalar and vector quantities. Some candidates incorrectly thought that work and power were vector quantities.

(ii) The majority of candidates could name one property possessed by physical quantities. This was usually the magnitude. A smaller number of responses referred to a unit.

(b) (i) This question was usually answered correctly by stronger candidates. A small number of candidates gave the components of the velocity the wrong way around.

(ii) Generally, this question was well answered by the candidates that gave correct answers to **(b)(i)**.

(iii) This question was usually answered correctly by candidates who had shown a good understanding of the vector calculations in **(b)(i)** and **(b)(ii)**.

(iv) Only a minority of candidates were able to use the correct trigonometric function to determine the angle between the resultant velocity and north.

Question 2

(a) The correct definition was given by the majority of the candidates.

(b) (i) The question asked for the shape of the curve to be explained in terms of the forces acting on the stone. Many answers did not refer to the forces at all and just described the changes to the acceleration or stated that the stone reached terminal velocity. Most candidates could have improved their answers by explaining how the air resistance increased with speed until the air resistance and the weight of the stone were equal.

(ii) The majority of the candidates gave the correct value for the terminal speed of the stone.

(iii) A minority of the candidates realised that the height could be determined from the area under the velocity–time graph. Many of these candidates who attempted to determine the area did not do so with sufficient accuracy. A significant number of candidates inappropriately used an equation of uniform acceleration in their calculation.

(iv) A significant number of candidates realised that the acceleration started at $9.8\,\mathrm{m\,s^{-2}}$. Stronger candidates went on to sketch the correct curve of negative gradient that reached zero acceleration at a time of approximately 20 s. Some candidates incorrectly sketched a straight line from the acceleration axis to the time axis. Many candidates did not realise that the gradient of the velocity–time graph was equal to the acceleration.

Question 3

(a) Most candidates could state at least the basic expression of force × distance for the definition of the moment of a force about a point. Only the stronger candidates also stated that the distance is the perpendicular distance of the line of action of the force from the point.

(b) (i) Only a minority of the candidates were able to show a correct calculation. Many candidates could improve by giving a neater and more logical presentation of their calculations.

(ii) In general, this question was well answered by the stronger candidates.

(iii) Only the stronger candidates realised that they needed to apply the principle of moments.

(iv) The majority of the candidates gave the correct symbol expression for the spring constant, but only a minority went on to determine the correct value of the spring constant.

Question 4

(a) The majority of candidates stated that waves should overlap. Only a minority went on to describe the resultant displacement as being the sum of the individual displacements of the overlapping waves.

(b) The stronger candidates obtained the correct resultant intensity by first determining the amplitudes of the two waves and adding these to determine the resultant amplitude. A large number of weaker candidates incorrectly thought that the resultant intensity could be obtained by simply adding the two individual intensities.

(c) (i) This question was well answered by the majority of the candidates. There were a number of candidates that made power-of-ten errors with the values of the wavelength or the slit separation.

(ii) The majority of the candidates could explain that the wavelength of the red light is longer than the wavelength of the light that was initially used. A minority of the candidates were then able to correctly deduce that there would be an increase in the fringe separation. A small number of candidates stated the correct change in the fringe separation but did not include the required explanation.

Question 5

(a) Some candidates referred just to the energy transferred rather than to the energy transferred per unit charge.

(b) Most candidates needed to give a more detailed explanation. It was necessary to explain that there would be a change in the potential difference across the internal resistance as the external resistance was changed. Most candidates did not realise that the potential difference across the external resistance (the terminal potential difference) only changed because the battery had an internal resistance.

(c) (i) The most common incorrect response was the value of the potential difference at the upper end of the straight line in the graph (instead of at the *y*-intercept of the extrapolated line).

(ii) The most common incorrect response was a maximum value of current that is equal to the current at the lower end of the straight line in the graph (instead of at the *x*-axis intercept of the extrapolated line).

(iii) The stronger candidates were able to calculate the internal resistance. Different methods of calculation could be used. The most common method was to use $E = V + Ir$ along with values taken from the graph. Very few candidates realised that the value of the internal resistance was equal to the magnitude of the gradient of the graph line.

(d) The line was sketched correctly by the strongest candidates. Often candidates did not appreciate that the value of potential difference for zero current is equal to the e.m.f. and that the magnitude of the gradient of the graph line is equal to the internal resistance.

Question 6

(a) (i) This question was generally well answered

(ii) The correct answer was usually given.

(iii) Weaker candidates often did not know the correct numbers of protons and neutrons in an alpha-particle and therefore could not determine required numbers of down and up quarks.

(b) (i) Only a minority of the candidates stated that most of the atom is empty space.

(ii) Some candidates were able to infer that the nucleus must be charged. A small minority were able to state that most of the mass of an atom must be in the nucleus.

(c) The strongest candidates were able to determine the correct ratio. Most candidates did not know how the acceleration of a particle depends on its mass and charge in a uniform electric field.

PHYSICS

Paper 9702/31
Advanced Practical Skills 1

Key messages

- Candidates need to practise plotting and reading off graphs accurately. They should take particular care to ensure that they do not plot, for example, 34.0 instead of 30.4. It is also important to check read-offs for the gradient and *y*-intercept carefully.

- When collecting data, candidates should be encouraged to use the whole range of the variable available and plan carefully what values should be used early on so that the table can take the form of a sequential set of readings. Once they have obtained a set of data, they should ask themselves whether the trend in their data looks right and whether it is what they expect. This is easier to do if the table shows a systematic sequence. When each data set is collected, the candidate can then see whether the data fits the general trend or whether they should repeat a potentially erroneous measurement.

- Candidates find identifying the uncertainty in a value difficult. Consideration is needed as to how difficult that reading is to take, especially if there is an element of judgement involved. The uncertainty is rarely the smallest reading possible.

- The evaluation of the experiment at the end of **Question 2** is always challenging. A focus on particular measurements from the experiment and an explanation as to why they are difficult to take will be awarded more credit than a more general approach that does not focus on the experiment. One way of tackling this question is chronologically: as the candidate does the experiment, they should note down the problems encountered.

General comments

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

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

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 most candidates. They demonstrated good skills in the generation and handling of data but could improve by giving more thought to the analysis and evaluation of experiments.

Comments on specific questions

Question 1

(a) Many candidates stated the value of *L* with units and set up the apparatus correctly so that the 100 g mass was placed with its centre as close as possible to the 80 cm mark. Some candidates omitted units, or gave readings to the nearest cm. With a distance for *L* such as 30 cm the strongest candidates remembered to record this as 30.0 cm.

(b) Many candidates stated raw values of *x* and *b* to the nearest 0.1 cm with units and set up the apparatus correctly, adjusting the string loop until the rule was horizontal. The values should be recorded to the nearest 0.1 cm as a rule with a precision of 0.1 cm had been provided. Some candidates omitted units, or gave readings to the nearest cm.

In an attempt to give all values to 3 significant figures, some candidates recorded values such as L = 30.0 cm, x = 9.00 cm and b = 25.5 cm. Here the *x* value is now given to 0.01 cm and so cannot be awarded credit.

(c) (i) Many candidates were able to collect six sets of values of *x* and *b* without assistance from the Supervisor, and showed a correct trend in their values. A minority of candidates took 7–8 sets of results and then did not plot all their observations on the graph grid. Few candidates took the time to repeat their readings. This may have helped to identify anomalous results and improve data quality. If time is limited, candidates should be encouraged to look out for possible outliers which do not fit a general trend and repeat these readings to double-check.

Many candidates chose too small a range of mass over which to conduct the experiment and so the values ended up close together. It is expected that candidates consider the whole range of possible values of mass and aim to use as wide a range as possible.

Many candidates were awarded credit for the column headings, giving both the quantity and correct unit for each heading with both separated by a solidus or with the unit in brackets. Some candidates omitted either the unit or the separating mark for one of the columns. The $1/b$ column was the most common column to have its unit omitted.

Most candidates calculated and recorded their values of $1/b$ correctly, i.e. to the same number of significant figures as (or one more than) the number of significant figures of the raw values of *b*. Some candidates rounded their final answers incorrectly.

(d) (i) Most candidates gained credit for drawing appropriate axes, with labels and sensible scales. Compressed scales (in either the *x* or *y* direction) were often seen and could not be awarded credit. There were many incidences of awkward scales (e.g. based on 3, 6 or having 20 squares equivalent to 3.0 cm). Some candidates chose the highest and lowest values in their tables as the lowest and highest points on their graph scales and then calculated intermediate values. Although this appears to make good use of the graph grid, it invariably makes it very difficult to plot all the points correctly. Credit cannot be awarded for the scale, and these candidates often lost further credit later for incorrect read-offs when calculating the gradient or the *y*-intercept of the line. Some candidates chose non-linear scales, or scales which meant that one or more points were off the graph grid.

Many candidates gained credit for plotting their tabulated readings correctly to within half a small square. If a point seems anomalous, candidates should repeat the measurement to check that an error in recording the values has not been made. If such a point is ignored in drawing the line of best fit, the anomalous point should be labelled clearly, e.g. by circling the point. There is no credit specifically for identifying anomalous points, so candidates should be reminded that they do not need to identify an anomalous point if they do not think they have one.

Many candidates plotted points carefully with dots less than or equal to half a small square in diameter. Some points were drawn as dots with a diameter greater than half a small square, and these points could be improved by using a finer pencil.

The majority of the candidates were able to collect a set of data that was awarded credit for quality.

(ii) Some candidates were able to draw carefully considered lines of best fit, but others joined the first and last points on the graph regardless of the distribution of the other points or forced the line through the origin. There should always be a balanced distribution of points either side of the line along the entire length. Many lines needed rotation to get a better fit, or an anomalous point needed to be identified to justify the line drawn. Some candidates were not awarded credit because their lines were kinked in the middle (candidates used too small a ruler), a double line (broken pencil tip) or drawn freehand without the aid of a ruler.

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

(iii) Some candidates used a suitably large triangle to calculate the gradient, gaining credit for correct read-offs, and substituted into a correct expression for the gradient. Other candidates needed to check that the read-offs used were within half a small square of the line of best fit and show the substitution clearly.

Candidates need to check that the triangle for calculating the gradient is large enough (the hypotenuse should be greater than half the length of the line drawn). There were many instances of incorrect read-offs, and many candidates would benefit from double-checking their read-offs.

Some candidates were able to correctly read off the *y*-intercept at $x = 0$ directly from the graph, but a large number of candidates incorrectly read off the *y*-intercept when there was a false origin. Stronger candidates correctly substituted a read-off into $y = mx + c$ to determine the *y*-intercept. Others needed to check that the point chosen (if it was from the table) was on the line drawn.

(e) Most candidates recognised that *P* was equal to the gradient and *Q* was equal to the intercept. Stronger candidates recorded a value with consistent units for *P* and *Q*. Weaker candidates stated incorrect units or omitted units altogether.

(f) Some candidates were able to draw line W with a greater gradient. Weaker candidates often either drew a line with the same gradient or did not attempt to draw the line.

Question 2

(a) Many candidates stated value *d* to the nearest 0.1 cm with a unit. Some candidates omitted units or gave readings to the nearest cm.

(b) Many candidates were able correctly to record the starting temperature θ_0 as 75 °C and noted a temperature θ two minutes later which was lower than θ_0. Some candidates were too eager and noted θ_0 straight away without waiting for the temperature to reach 75 °C, and this led to values of $\Delta\theta$ which were negative.

(c) (i) Many candidates stated value *h* with a unit. Some candidates omitted units.

Many candidates stated value *D* where *D* correctly had a value greater than the value of *d* from **(a)**. Some candidates gave a value which was less than *d*.

(ii) Most candidates are familiar with the equation for calculating percentage uncertainty. Some candidates made too small an estimate of the absolute uncertainty in the value of *h*, given that it was difficult to measure *h* owing to the opaque nature of the cup. These candidates often gave the precision of the rule (0.1 cm) as Δh. Some candidates repeated their readings and correctly gave the uncertainty in *h* as half the range, while other candidates using this method did not halve the range.

(iii) Many candidates were correctly able to calculate *C* using their values of *D* and *d*.

(iv) Many candidates correctly justified the number of significant figures they had given for the value of *C* with reference to the number of significant figures used in *D* and *d*. Weaker candidates often gave reference to just ‘raw readings’ or ‘measured values’ or ‘values in calculation’ without stating what these values were.

(d) Nearly all of the candidates correctly recorded second values of θ_0 and θ.

Nearly all of the candidates correctly recorded second values of *h* and *D*.

Many candidates correctly recorded values of $\Delta\theta$ which showed a decrease in temperature and with the second value of $\Delta\theta$ less than the first value of $\Delta\theta$. Some candidates' values of $\Delta\theta$ were negative or showed the wrong trend.

(e) (i) Many candidates were able to calculate *k* for the two sets of data, showing their working clearly. A minority of candidates incorrectly rearranged the equation algebraically to calculate 1 / *k* or inadvertently substituted the wrong values e.g. using their *D* value instead of their *C* value.

(ii) Some candidates calculated the percentage difference between their two values of *k*, and then tested it against a specified numerical percentage uncertainty as a criterion, commonly using 20%. These candidates understand the need for a stated criterion which they can use to test the relationship. Some candidates referred back to the percentage uncertainty calculated for *h* and this was also credited. Some candidates omitted a criterion. Other candidates made a statement such as 'this is valid because the values are close to each other' which was not credited as there was no justification for the conclusion.

(f) This experiment provided many limitations for discussion. The investigation involved using $\Delta\theta$ to assess the cooling of two different quantities of water. Many candidates retreated into familiar ideas about heat loss. This led to suggestions for improvements involving insulation to prevent heat loss which shifted the focus away from this experiment and did not gain credit.

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

To gain credit for limitations concerning measurements, the quantity that was difficult to measure must be referred to along with the difficulty. For example, 'it was difficult to measure *D*' on its own is insufficient. Better answers would point out that 'it was difficult to measure *D* as the ruler is far from the surface of the liquid' or use the technical term 'parallax error', although a bald statement such as 'parallax error' on its own does not gain credit. Many candidates correctly stated difficulties involved in measuring *h* and *D* while others mentioned judging one-third of a cup (which did not gain credit) or discussed the measurement of *d*. As *d* could be measured by directly placing the ruler on the base of the cup with no parallax error involved, this measurement was not a significant source of uncertainty. The cup provided had a slanted side. Many candidates considered how to improve the measurement of both *h* and *D* for this cup. Suggestions involving a container with vertical sides or a container with a marked scale did not gain credit as this would have been a different experiment.

Many candidates recognised that reducing the uncertainty in $\Delta\theta$ required a more precise thermometer. Credit was not given for suggestions of digital or electronic thermometers unless it was mentioned that these would have improved precision.

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

PHYSICS

Paper 9702/32
Advanced Practical Skills 2

Key messages

- Candidates need to practise plotting and reading off graphs accurately. They should take particular care to ensure that they do not plot, for example, 34.0 instead of 30.4. It is also important to check read-offs for the gradient and *y*-intercept carefully.

- When collecting data, candidates should be encouraged to use the whole range of the variable available and plan carefully what values should be used early on so that the table can take the form of a sequential set of readings. Once they have obtained a set of data, they should ask themselves whether the trend in their data looks right and whether it is what they expect. This is easier to do if the table shows a systematic sequence. When each data set is collected, the candidate can then see whether the data fits the general trend or whether they should repeat a potentially erroneous measurement.

- Candidates find identifying the uncertainty in a value difficult. Consideration is needed as to how difficult that reading is to take, especially if there is an element of judgement involved. The uncertainty is rarely the smallest reading possible.

- The evaluation of the experiment at the end of **Question 2** is always challenging. A focus on particular measurements from the experiment and an explanation as to why they are difficult to take will be awarded more credit than a more general approach that does not focus on the experiment. One way of tackling this question is chronologically: as the candidate does the experiment, they should note down the problems encountered.

General comments

There was little evidence that centres had serious difficulties in providing the equipment required for use by the candidates. A small number of centres had difficulties with the photocopying required for **Question 1** and so some candidates were given a grid that was not of the expected size. Details of these changes were helpfully recorded on the Supervisor's Report. Providing such information is encouraged as it allows a candidate who has recorded readings that are outside of the expected range to still be given credit where appropriate. If Supervisors are unsure of any instruction, they should contact Cambridge using the details provided on the Confidential Instructions.

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. Supervisors are also reminded to submit both a sample set of results and the Supervisor's Report.

The general standard of work carried out by the candidates was good with some producing excellent scripts. Working was usually clear and legible. Candidates should be encouraged to draw tables carefully using ruled lines and, where possible, to record data systematically. For graph work, candidates should be encouraged to use a 30cm 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) It appeared that most candidates had not encountered a problem like this and so were not aware of how to approach it. Rather than measuring across *n* spaces then dividing by *n* to obtain a value of s_A, most candidates seem to have attempted a direct measurement of a single space, sometimes several times, and so arrived at an answer that was outside of the acceptable range. Of those candidates who did use multiple spaces, the reciprocal of s_A was sometimes given.

The units (mm) were provided on the answer line. Some candidates made the error of converting their measurement and provided an answer was incorrect by a factor of 10.

(b) Almost all candidates were able to select and record a suitably small angle for *G* that was within the accepted range.

(c) The majority of candidates were able to collect six sets of *G* and *F* without assistance from the Supervisor. In a small number of cases, the expected trend was not observed. This was possibly due to using the wrong scale on the protractor or the candidate being unable to carry out the procedure for measuring the observed fringes. Most tables were neatly presented and legible.

Stronger candidates tested a full range of *G* values, including $G \leqslant 3°$ and $G \geqslant 17°$. Weaker candidates often did not include values of $G \leqslant 3°$.

Table headings were often correct and presented using the usual scientific convention. One common error was the omission of a suitable separating mark between the quantity and unit, e.g. *G* ° instead of *G* / ° or *G* (°). Another common error was to provide a unit for the quantities sin *F* and sin (*F* – *G*).

Most candidates correctly recorded all raw values of *G* and *F* to the nearest degree. A small number of candidates chose to record all values to the same number of significant figures and so incorrectly added a decimal place to account for the change from 3-digit to 2-digit values, e.g. recording 4° as 4.0°. Since this is measured data, it was then not consistent with the precision of the protractor and so credit could not awarded for consistency.

Most candidates recognised that values of sin *F* should be recorded to the same number of significant figures (or one more than) the number of significant figures in the corresponding value of *F*. It is worth noting that the number may vary down the column. For example, if *F* in one row is 9°, sin *F* in that row should have 1 or 2 significant figures whereas another row may have a value for *F* of 12° and so sin *F* could be recorded to 2 or 3 significant figures.

Most calculations were correct. A small number of candidates made rounding errors or calculated a different quantity e.g. cos *F.*

(d) (i) There were some very good graphs. These had scales chosen to give simple intervals (using ratios of 1, 2 or 5) as well as making good use of the available grid area. A significant number of candidates were unable to select suitable scales, instead choosing awkward intervals or scales that resulted in the plotted points occupying less than half the grid in the *x* and/or *y* directions. A significant number of candidates also attempted to plot (0,0) at a false origin.

All data recorded in the table must be plotted on the graph. Candidates who used small crosses or small circled dots produced the clearest plotted points. The use of large dots with diameters greater than 1 mm cannot be awarded credit because their accuracy cannot be judged. Some candidates identified their own plotting errors as anomalies. Candidates should be encouraged to double-check such points.

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

(ii) Many candidates produced suitable lines of best fit which had a balanced distribution of points either side along the entire length. Treatment of anomalous data was sometimes incorrect; either because a true anomaly was ignored without clear indication (i.e. circling or labelling the point as an anomaly) or because a seemingly good point was ignored when drawing the line. Some candidates identified two or more anomalies and ignored these when drawing the line. It is worth noting that only one should be ignored in this way. Poorly joined, kinked or double lines were relatively common, and lines often needed rotation or translation.

(iii) When calculating the gradient of their line, many candidates selected suitable points on the line (greater than half of the length of the line apart) and substituted correct read-off values into a correct expression for the gradient. Points chosen were clearly identified on the graph, usually as a drawn triangle. Of those candidates who were not awarded credit, most had incorrectly determined the read-off values or used points from the table that were not on the line. Others used triangles that were too small. It is worth noting that selecting awkward scales often resulted in incorrect read-off values being taken and loss of credit here as well as in **(d)(i)**.

When selecting scales for the graph, the nature of the data meant that many candidates started their *x*-axis with a non-zero value. Most candidates recognised that it was therefore not possible to take a direct read-off to determine the *y*-intercept. Most candidates substituted correct values from their line into $y = mx + c$ to arrive at their answer. Some candidates incorrectly quoted the *y*-axis value at the point where the line crossed, even though this was not at $x = 0$.

(e) The majority of the candidates recognised that the value of *a* was equal to their gradient value and that *b* was equal to their *y*-intercept value. Some candidates attempted calculations and did not simply transfer values across from **(d)(iii)**. Some candidates gave their answer to 1 significant figure and so were not awarded credit.

Many candidates recognised that both *a* and *b* had no units.

(f) Most candidates were able to multiply the value of s_A from **(a)** by *p* and state their answer. Some incorrectly used *q* rather than *p* while others did not recognise the units on the answer line and so incorrectly converted their s_A value. A small number were unable to rearrange the equation correctly.

Question 2

(a) (i) Some candidates were able to record a minimum of 2 readings of *nT*, where $n \geqslant 5$, to determine a period T_V that was within the acceptable range and had a suitable unit. A significant number recorded only one time reading e.g. one value of 10*T* or took multiple readings using $n = 1$. Others simply stated the final value without showing any raw readings. Many answers were out of range, suggesting candidates may not have kept up with counting the rapid oscillations, or because candidates had recorded e.g. $0.5T_V$ or $10T_V$ as T_V. A small number of candidates calculated frequency instead of period.

(ii) Most candidates recorded a period T_S that was greater than T_V.

(b) Most candidates recorded second values of T_V and T_S with the second value of T_S being greater than the first.

(c) (i) Most candidates were able to correctly calculate two values of $T_S^2 - T_V^2$ and record their answers using 2 or more significant figures. Common reasons for not being awarded credit included errors in calculation (e.g. forgetting to square the values) and recording one or both values to 1 significant figure.

(ii) The majority of candidates were able to link the significant figures in $T_S^2 - T_V^2$ with those in T_S and T_V. Although a small number of candidates referred to 'raw readings' rather than identifying the specific readings that should be considered, this was less common than in previous series and suggests an improvement in candidates' understanding.

(iii) Many candidates gave very good responses, calculating a percentage difference between their two calculated values of $T_S^2 - T_V^2$ and testing this against a stated criterion. Some candidates showed a sound understanding of the process but chose to test their percentage difference against an unqualified criterion (e.g. 'it is less than the uncertainty') and so were not awarded credit. Others concluded incorrectly e.g. 'the percentage difference is 4% which is less than 10% so it does not support the suggestion'.

(d) (i) The majority of candidates recorded a value for x_1 that was within the expected range or, if outside of range, suitably close to the Supervisor's value when compared.

(ii) Most candidates showed their working, and were aware of how to calculate percentage uncertainty. Since there are difficulties in measuring the length of the spring using a ruler, it was not appropriate to use an absolute uncertainty of 1 mm. Acceptable responses used an absolute uncertainty in the range 2–3 mm or half the range of readings where repeated readings had been taken.

(iii) The majority of candidates provided a value of x_2 to the nearest 0.1 cm. Where raw readings were shown, it was necessary for all measured values to be recorded to the nearest 0.1 cm. Some candidates measured the overall length of the mass hanger then subtracted the length of the base. In this case, candidates sometimes recorded raw data inconsistently e.g. 12.3 cm – 1 cm (rather than 1.0 cm) and so were not awarded credit.

(iv) Most candidates were able to correctly calculate a value of g. Where a unit is not provided on the answer line, it is expected that the candidate provides one if appropriate. Many candidates gave no unit or an incorrect one. Others gave a dimensionally correct unit that was inconsistent with their values e.g. using m s^{-2} when lengths were in cm.

(e) The majority of candidates recognised that calculating only two values of $T_S^2 - T_V^2$ is insufficient to draw a conclusion. Some incorrectly linked the lack of $T_S^2 - T_V^2$ values to accuracy whereas others gave insufficient statements such as 'two $T_S^2 - T_V^2$ values are not enough'. When suggesting an improvement for the limited readings, most were able to suggest collecting more data and plotting a graph.

Candidates are advised, where appropriate, to state both the quantity being measured and the reason for any uncertainty. Many candidates gave partial statements in one or more of their responses and so were unable to gain credit for these parts. For example, instead of 'parallax error when measuring length' a better response would be 'parallax error when measuring x_1'.

Many candidates correctly suggested that multiple modes of oscillation were a source of error. Improvements were sometimes suggested (e.g. use of a guide) but this was less common than identifying the limitation.

A number of candidates recognised that the spring slid along the rod during oscillations, but this was often expressed incompletely, e.g. 'spring slips'. The suggested improvements linked to this limitation were often better addressed, e.g. cutting a notch in the rod or providing a method of fixing the spring to the rod (tape, adhesive putty etc.).

Many candidates recognised the difficulty in judging the end/start or completion of an oscillation. The most common solution for this was the use of video or a marker. It is worth noting that the use of video was only accepted if there was clear reference to a timer (in view) or reviewing it frame-by-frame. Suggesting the use of a fiducial marker is good provided it is placed at the equilibrium position.

T_V is a very small value and so it was acceptable to state this as a limitation provided there was a link to (percentage) uncertainty. Many candidates found it difficult to describe this limitation sufficiently.

Many candidates identified the limitations when measuring the lengths of the spring (x_1) and mass hanger (x_2). Some responses were too vague to be awarded credit, e.g. 'difficult to measure spring with a ruler'.

PHYSICS

Paper 9702/33
Advanced Practical Skills 1

Key messages

- Candidates need to practise plotting and reading off graphs accurately. They should take particular care to ensure that they do not plot, for example, 34.0 instead of 30.4. It is also important to check read-offs for the gradient and *y*-intercept carefully.

- When collecting data, candidates should be encouraged to use the whole range of the variable available and plan carefully what values should be used early on so that the table can take the form of a sequential set of readings. Once they have obtained a set of data, they should ask themselves whether the trend in their data looks right and whether it is what they expect. This is easier to do if the table shows a systematic sequence. When each data set is collected, the candidate can then see whether the data fits the general trend or whether they should repeat a potentially erroneous measurement.

- Candidates find identifying the uncertainty in a value difficult. Consideration is needed as to how difficult that reading is to take, especially if there is an element of judgement involved. The uncertainty is rarely the smallest reading possible.

- The evaluation of the experiment at the end of **Question 2** is always challenging. A focus on particular measurements from the experiment and an explanation as to why they are difficult to take will be awarded more credit than a more general approach that does not focus on the experiment. One way of tackling this question is chronologically: as the candidate does the experiment, they should note down the problems encountered.

General comments

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

Any help given to a candidate should be noted on the Supervisor’s Report. Supervisors are reminded that help should **not** be given with the recording of results, graphical work or analysis. Supervisors are also reminded to submit both a sample set of results and the Supervisor’s Report.

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 most candidates. They demonstrated good skills in the generation and handling of data but could improve by giving more thought to the analysis and evaluation of experiments.

Comments on specific questions

Question 1

(a) Many candidates recorded *L* with a consistent unit and within the appropriate range. A minority of candidates stated values of *L* greater than 70 cm or omitted units.

(b) Stronger candidates stated raw values of I to the nearest 0.1 mA and with a consistent unit. Many candidates did not recognise the current was in mA (e.g. stating 54.2 A instead of 54.2 mA or 0.0542 A).

(c) Many candidates were able to collect six sets of values of *x* and I without assistance from the Supervisor. Some candidates needed help setting up the circuit. Some candidates collected the data and did not think about the expected trend and whether each data set looks appropriate given the previous reading. Candidates need to ask themselves whether the results are as expected; it is easier to see and judge this when the results are set out sequentially. Careful planning is needed early on to use the full range of the variables available.

Many candidates chose too small a range over which to conduct the experiment. It was expected that they would use a value less than 10 cm and a value more than 60 cm in order to make use of all of the length provided.

Many candidates gave both the quantity and correct unit for each heading separated by a solidus or brackets around the unit. Some omitted the unit or separating mark, or gave the unit of current for the $1/I$ column heading.

Many candidates correctly recorded their raw values of *x* to the nearest 0.1 cm but some stated *x* to the nearest cm e.g. 45 cm instead of 45.0 cm. The rule provided could be read to the nearest 0.1 cm.

Many candidates correctly recorded their calculated values for $1/I$ to the same number of significant figures as the raw current readings. A common error was to state $1/I$ to too few significant figures. This increased the scatter in the results on the graph grid.

Most candidates calculated values for $1/I$ correctly but some incorrectly rounded their answers.

(d) (i) Many candidates plotted the correct graph with suitable labels and chose axes so that the plotted points occupied over half of the graph grid available. Common mistakes in the graph presentation were compressed scales (in either the *x* or *y* direction), awkward scales (e.g. multiples of 3 or 1.2) on the *y*-axis and irregular (i.e. non-linear) scales such as increments of 0.2, 0.4, 0.2, 0.2 along the *y*-axis.

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

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

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

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

(e) Nearly all candidates recognised that P and Q were equal to the gradient and intercept respectively. Stronger candidates recorded a value with consistent units for P and Q. Weaker candidates often stated incorrect units or omitted the units.

(f) Most candidates went on to correctly calculate the ratio. A minority of candidates did not rearrange the equation correctly or substituted an incorrect value of L that was not the L measured in **(a)**.

Question 2

(a) The majority of candidates measured values of d in the appropriate range and gave a unit. Some candidates omitted units or stated a value above the range, suggesting that they had read the ruler the wrong way round.

(b) Most candidates are familiar with the equation for calculating percentage uncertainty. Some candidates made too small an estimate of the absolute uncertainty in the value of d, typically 1 mm, when it was difficult to identify the middle of the 100 g mass. Some candidates chose to repeat their readings and correctly gave the uncertainty in d as half the range.

(c) (i) Many candidates stated b to the nearest mm, in the appropriate range and with a unit. Weaker candidates stated b to the nearest cm when the ruler can be read to the nearest mm. Some candidates set up or measured b to be a value other than 10 cm.

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

(iii) Stronger candidates correctly justified the number of significant figures they had given for the value of α with reference to the number of significant figures used in d and b. Many candidates referred to 'raw readings' and this cannot be given credit unless it is described what these readings are.

(d) Stronger candidates repeated 5 or 10 sets of oscillations at least twice and calculated a value of T that was in the required range. Weaker candidates were more likely to just take one set of 5 oscillations, or sometimes a set of single oscillations. Some determined a value of T that was too small, perhaps inadvertently timing half an oscillation or having set up the value of b incorrectly.

(e) Nearly all candidates recorded second values of b and T. Most candidates correctly recorded a second T value that was smaller than their first value.

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

(ii) Stronger candidates calculated the percentage difference between their two values of C, tested it against a criterion, e.g. 10% or 20% and gave a valid concluding statement. Some candidates omitted a criterion, or gave invalid or general statements such as 'this is valid because the values are close to each other', which could not be accepted.

(g) Stronger candidates were able to calculate a value for k with consistent units. Many candidates omitted the units.

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

Other problems that were often identified were being able to judge whether the strip was horizontal or judging whether the string and spring were vertical.

Candidates were less likely to mention the reasons for difficulty in measuring b or d, such as having to hold the ruler in mid-air for b, or finding the centre of the 100 g mass for d. To gain credit, the quantity that was difficult to measure must be specified along with the difficulty.

Credit is not given for suggested improvements that could be carried out in the original experiment, such as measuring each end of the strip to the bench to see if it is the same.

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

PHYSICS

Paper 9702/34
Advanced Practical Skills 2

Key messages

- Candidates need to practise plotting and reading off graphs accurately. They should take particular care to ensure that they do not plot, for example, 34.0 instead of 30.4. It is also important to check read-offs for the gradient and *y*-intercept carefully.

- When collecting data, candidates should be encouraged to use the whole range of the variable available and plan carefully what values should be used early on so that the table can take the form of a sequential set of readings. Once they have obtained a set of data, they should ask themselves whether the trend in their data looks right and whether it is what they expect. This is easier to do if the table shows a systematic sequence. When each data set is collected, the candidate can then see whether the data fits the general trend or whether they should repeat a potentially erroneous measurement.

- Candidates find identifying the uncertainty in a value difficult. Consideration is needed as to how difficult that reading is to take, especially if there is an element of judgement involved. The uncertainty is rarely the smallest reading possible.

- The evaluation of the experiment at the end of **Question 2** is always challenging. A focus on particular measurements from the experiment and an explanation as to why they are difficult to take will be awarded more credit than a more general approach that does not focus on the experiment. One way of tackling this question is chronologically: as the candidate does the experiment, they should note down the problems encountered.

General comments

Experiments are designed with the view that only the equipment specified in the Confidential Instructions will be provided to candidates. Centres should contact Cambridge in advance of the examination before making any changes or additions to the equipment provided to 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. Supervisors are also reminded to submit both a sample set of results and the Supervisor's Report.

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

Comments on specific questions

Question 1

(a) (i) Most candidates recorded a value for *C* to the nearest mm.

(ii) The majority of the candidates obtained a value for *T* in the appropriate range and gave it with a unit. Fewer candidates were awarded credit for repeating measurements of the time for multiple oscillations. Measuring the time for one oscillation several times is not sufficient – the time for at least 5 complete oscillations should be repeated two or three times, and a mean value calculated. All working should be shown, including the value of *n*, where *n* is the number of oscillations.

(b) Almost all candidates recorded six values of *C* and time correctly, showing the correct trend. A small number of candidates recorded only the calculated quantities and omitted the raw values of *T* and *C* from their table. Candidates should be reminded that it is essential to record the measurements, not just calculated quantities derived from them.

Some candidates chose values of *C* to give the widest possible range of values; others needed to select values both below and above the value for *C* in **(a)(i)**.

Most candidates were awarded credit for using the correct column headings in their tables, giving both the quantity recorded and suitable units for each quantity, with the two separated by a solidus, or with the units in brackets. Some candidates were confused by the units for $\frac{1}{\sqrt{C}}$, recording the units as cm^{-1} or $cm^{1/2}$.

Most candidates recorded all their raw values of time to the nearest 0.1 s or all to the nearest 0.01 s. Consistency is assessed on a candidate's raw readings, and candidates who only record processed data (e.g. the mean values of *T* or 10*T* recorded to 0.001 s) cannot be given credit for consistency of their raw readings. Some candidates were not awarded credit because they added an extra zero to all their raw time values.

Most candidates calculated their values for $\frac{1}{\sqrt{C}}$ to the same number of significant figures as (or one more than) the significant figures of *C*.

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

(c) (i) Most candidates gained credit for drawing appropriate axes, with labels and sensible scales. Some candidates chose extremely awkward scales making the correct plotting of points much more difficult. A good choice of scale for this experiment would have been 1 large square representing $0.25\,m^{-1/2}$ on the *x*-axis and 1 large square representing $0.1\,s^{-1}$ on the *y*-axis. Candidates who choose awkward scales often lose further credit for incorrect read-offs when calculating the gradient or the *y*-intercept of the line. A few candidates chose non-linear scales, or scales which meant that one or more points were outside the graph grid.

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

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

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

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

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

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

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

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

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

The majority of the candidates recorded correct units for *a* and *b*. Others omitted the units for *a* or *b*. The units for *a* and *b* can be derived directly from the quantities plotted on the graph or deduced from the equation given in **(d)**.

Question 2

(a) (i) Candidates were asked to use the metre rule to measure D_1 and D_2, so it was expected that these readings would be recorded to the nearest mm. Many candidates did this, though others recorded raw values to the nearest 0.1 mm or 0.01 mm.

Some candidates recorded what would have been correct values of D_1 and D_2 in cm, but did not give the unit or change the unit given on the answer line.

Credit was available for repeating measurements for both D_1 and D_2. Some candidates did this, while others only recorded repeat values of D_2 or did not include any repeat measurements.

(ii) Most candidates were familiar with the equation for calculating percentage uncertainty, but many underestimated the absolute uncertainty in their value(s) of D_2 and gave estimates of 1.0 mm or less. The foam rings are not perfectly circular and a better estimate of the overall uncertainty in the measurement would be in the range 2–5 mm.

(b) Candidates were asked to measure h_1 and h_2 using the calipers provided and were awarded credit if all their raw values of h_1 and h_2 were to the nearest 0.1 mm or all to the nearest 0.01 mm. The majority of the candidates achieved this, though some only recorded raw values to the nearest mm.

Almost all the candidates calculated the value of *y* correctly.

(c) (i) Almost all the candidates recorded values of *A* and *B* correctly, with *B* greater than *A*.

(ii) Most candidates calculated the value of *F* correctly, though a few confused the substitution of the values of *A* and *B* in the equation, or rounded their final value for *F* incorrectly.

(iii) This mark was for justifying the number of significant figures given for the value of *F*. Some candidates made a direct and explicit link between the significant figures of *F* and the significant figures of *A* and *B*, and were awarded credit. Others could not be awarded credit because they only referred to the 'raw data', or they included reference to the significant figures of *y* or *h*, which are not relevant to the significant figures of *F*.

(d) Most candidates were able to record a second set of results for the smaller of the two foam rings. Credit for the quality of data depended on accurate measurement of the heights h_1 and h_2 for both the large ring and the small ring using the calipers, and many candidates found it difficult to read the calipers and obtain accurate values.

(e) (i) Most candidates were able to calculate two values for *k* correctly. Some candidates misread the equation and divided $(D_2^2 - D_1^2)$ by D_2^2 rather than D_2^3, and others inappropriately rounded their final values for *k* to 1 significant figure.

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

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

(f) (i) Many candidates recognised that two sets of data were insufficient to draw a valid conclusion, though some confused conclusions with results. Some suggested that it was difficult to make the rod horizontal without explaining why.

Some candidates simply described measurements that were difficult, without explanation e.g. 'it was difficult to measure *A* or *B*'. More detailed answers such as '*A* was difficult to measure because of parallax error' or '*B* was difficult to measure because the exact centre of the slotted mass was not known' would have gained credit.

(ii) Valid improvements included taking more readings for different values of D_2 and then plotting a suitable graph to test the suggested relationship. Some candidates suggested calculating further values for *k* and then calculating an average value, implying that *k* is constant. They should instead state that the values of *k* should be compared with each other to see if *k* is constant.

Some candidates suggested using vernier calipers or micrometers to measure the diameters of the foam rings, but there is no value in measuring the diameter to the nearest 0.1 mm if the uncertainty in the diameter is 2 mm or more.

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

PHYSICS

Paper 9702/35
Advanced Practical Skills 1

Key messages

- Candidates need to practise plotting and reading off graphs accurately. They should take particular care to ensure that they do not plot, for example, 34.0 instead of 30.4. It is also important to check read-offs for the gradient and *y*-intercept carefully.

- When collecting data, candidates should be encouraged to use the whole range of the variable available and plan carefully what values should be used early on so that the table can take the form of a sequential set of readings. Once they have obtained a set of data, they should ask themselves whether the trend in their data looks right and whether it is what they expect. This is easier to do if the table shows a systematic sequence. When each data set is collected, the candidate can then see whether the data fits the general trend or whether they should repeat a potentially erroneous measurement.

- Candidates find identifying the uncertainty in a value difficult. Consideration is needed as to how difficult that reading is to take, especially if there is an element of judgement involved. The uncertainty is rarely the smallest reading possible.

- The evaluation of the experiment at the end of **Question 2** is always challenging. A focus on particular measurements from the experiment and an explanation as to why they are difficult to take will be awarded more credit than a more general approach that does not focus on the experiment. One way of tackling this question is chronologically: as the candidate does the experiment, they should note down the problems encountered.

General comments

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

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

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 most candidates. They demonstrated good skills in the generation and handling of data but could improve by giving more thought to the analysis and evaluation of experiments.

Comments on specific questions

Question 1

(a) Many candidates recorded *L* with a consistent unit and within the correct range. A minority of candidates stated values of *L* greater than 10.5 cm or omitted the unit.

(b) Stronger candidates stated values of *T* that were in the correct range. Weaker candidates timed half-oscillations or a single oscillation (instead of carrying out repeats of several) and this increased the likelihood of *T* being outside the accepted range.

(c) Most candidates were able to collect six sets of values of *d* and *T* without assistance from the Supervisor. Some candidates collected the data and did not think about the expected trend and whether each data set looks appropriate given the previous reading. Candidates need to ask themselves whether the results are as expected; it is easier to see and judge this when the results are set out sequentially. Careful planning is needed early on to use the full range of the variables available.

Many candidates chose too small a range over which to conduct the experiment. It was expected that they would choose a value less than 25 cm and more than 40 cm in order to make full use of the apparatus.

Stronger candidates gave the quantity and correct unit for each column heading, noticing that the $\sqrt{\frac{(d-L)}{d}}$ column has no unit. A common mistake was to include a unit for $\sqrt{\frac{(d-L)}{d}}$.

Many candidates recorded correctly their raw values of *d* to the nearest 0.1 cm. Some stated *x* to the nearest cm e.g. 25 cm instead of 25.0 cm when the ruler could be read to the nearest mm.

Many candidates correctly recorded their calculated values for $\sqrt{\frac{(d-L)}{d}}$ to the same number of significant figures as the *d* or *L* readings (whichever was least). Some candidates used too few significant figures, and this increased the scatter in the results on the graph grid.

Most candidates carried out the calculations correctly, but some incorrectly rounded their answers or did a different calculation.

(d) (i) Many candidates plotted the correct graph with suitable labels and chose axes so that the plotted points occupied over half of the graph grid available. Common mistakes in the graph presentation were compressed scales (in either the *x* or *y* direction), awkward scales (e.g. multiples of 3 or 1.2) on the *y*-axis and irregular (i.e. non-linear) scales such as increments of 0.2, 0.4, 0.2, 0.2 along the *y*-axis.

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

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

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

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

(e) Nearly all candidates recognised that *P* and *Q* were equal to the gradient and *y*-intercept respectively. The determination of the units was more difficult. Stronger candidates recorded values with consistent units for *P* and *Q*. Others stated incorrect units or omitted the units.

Question 2

(a) The majority of candidates measured values of *H* in the correct range. A few candidates stated a value above the range suggesting that they read the ruler the wrong way round.

(b) (i) Many candidates stated *x* to the nearest mm and θ to the nearest degree, but it was relatively common for candidates to read the ruler to the nearest cm and/or the angle θ to the nearest 0.1°.

(ii) Most candidates are familiar with the equation for calculating percentage uncertainty. Some candidates made too small an estimate of the absolute uncertainty in the value of θ, typically 1°. It was difficult to hold the protractor in mid-air to get a reading so this uncertainty was unrealistically small. Some candidates repeated their readings and correctly gave the uncertainty in θ as half the range.

(iii) The majority of the candidates were able to calculate $x \tan\theta$.

(iv) Stronger candidates correctly justified the number of significant figures they had given for the value of $x \tan\theta$ with reference to the number of significant figures used in *x* and θ. Some candidates gave reference to 'raw readings' without detailing what these values were, or referred to just one of the relevant quantities.

(c) Nearly all candidates recorded second values of *x* and θ. Most candidates correctly recorded a second θ value that was smaller 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 incorrectly rearranged the equation algebraically to calculate $1/k$ rather than *k*.

(ii) Stronger candidates calculated the percentage difference between their two values of *k*, tested it against a criterion, e.g. 10% or 20% and gave a valid concluding statement. Some candidates omitted a criterion, or gave invalid or general statements such as 'this is valid because the values are close to each other', which could not be accepted.

(e) Stronger candidates were able to calculate a value for *M* with a consistent unit. Many candidates omitted the unit.

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

Other problems that were often identified were being able to judge whether the string was horizontal or setting up the apparatus so that the string is horizontal. Stronger candidates were able to identify the reasons for difficulty in measuring *H* or θ, such as having to hold the protractor in mid-air for θ, finding the centre of the modelling clay for *H*, or using too short a ruler to measure *H*. To gain credit, the quantity that was difficult to measure must be specified along with the difficulty.

Credit is not given for suggested improvements that could be carried out in the original experiment.

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

PHYSICS

Paper 9702/41
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.

- 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 wording of definitions and descriptions needs to be precise. Some candidates were not awarded credit in **1(a)**, **3(a)**, **5(a)**, **7(a)**, **9(a)**, **9(c)(i)** and **10(a)** because their wording was not sufficiently detailed. The wording in the mark scheme shows the detail that is expected.

There were three 'show that' questions on this paper, **1(c)(i)**, **2(a)** and **7(b)(i)**. In such questions, every step must be clear, and care should be taken with the presentation of calculations.

When required to sketch lines on graph axes such as in **Question 6**, candidates should draw their lines carefully. For example, curves showing inverse proportionality should not begin with a vertical section and end with a horizontal section. Examiners will check that the line goes through certain key coordinates.

There was no evidence of candidates not having enough time to complete the paper. Many candidates are better at recalling information learnt by heart than they are at applying principles to new situations.

Comments on specific questions

Question 1

(a) Candidates answered this question well. Only the very weakest candidates gave incorrect definitions. The most common incorrect alternative was to give the definition for gravitational potential.

(b) This calculation was well completed. The combination of equations and working leading to $T^2 / r^3 = 4\pi^2 / GM$ was successfully carried out by many candidates. Only a minority did not convert minutes into seconds or did not square values correctly in the equation.

(c) (i) Most responses showed that candidates went back to the equation in **(b)**, rather than using one of the relationships $r^3\omega^2$ = constant or r^3 / T^2 = constant. In a 'show that' question, candidates need to make each step clear. Here there was sometimes unclear presentation leading to confusion between r^3 and r.

(ii) Most candidates realised that the separation between the satellite and the Earth had increased but were not able to say that there was also an increase in the gravitational potential energy. Many responses indicated that separation and energy are inversely proportional, forgetting that gravitational potential energy is negative. Candidates often know the equation for gravitational potential energy, but they do not always realise that, because it is negative, the energy will increase as the denominator (r) increases.

(iii) There were many correct calculations here. The most common mistake was to calculate the change in potential, rather than the change in potential energy. Another error was to use $\Delta E = GMm / (r_2 - r_1)$.

Question 2

(a) This calculation was completed very well by candidates who used $pV = NkT$. Those who used $pV = nRT$ and $nN_A = N$ were often less successful. In this 'show that' question, it was important to make clear the progression from n to N and not treat them in the presentation as the same quantity.

(b) This explanation proved to be challenging. Many candidates used the first law of thermodynamics in their response rather than kinetic theory, as requested by the question. A common misconception was that collisions produce thermal energy which increases the temperature.

(c) (i) Candidates found this calculation difficult. Some candidates found the work done during the expansion of the gas and some found the increase in kinetic energy of just one molecule, rather than the increase in internal energy of the gas.

(ii) This was one of the most challenging questions on the paper. The answer required a comparison between the change in internal energy of the gas and the work done by the gas in order to work out whether thermal energy was transferred to or from the gas. This could be done numerically or in words.

Question 3

(a) The majority of the candidates were able to state what is meant by simple harmonic motion.

(b) A large number of responses showed that candidates were able to relate the expression given in the question to the general expression for simple harmonic motion and use this to calculate the frequency of the oscillations. The most common error was to equate $2k / m$ with ω rather than ω^2.

(c) (i) This question was well answered.

(ii) Candidates found this explanation difficult. The key idea is that energy is being supplied by the oscillator but the energy of the oscillations of the trolley is constant, so energy must be dissipated by resistive forces. Many candidates did not make this connection and most answers did not refer to energy. A significant number of candidates showed a misconception that the amplitude was constant at all frequencies.

Question 4

Many candidates were well prepared for this question. Common mistakes included not identifying the piezo-electric crystal as both the generator and detector of the ultrasound pulse, referring vaguely to reflection rather than reflection at the *boundary* between tissues, and being insufficiently detailed about what information can be gained from the intensity of the reflected wave (i.e. the nature of the tissue).

Question 5

(a) Candidates found it difficult to state what is meant by amplitude modulation. Many candidates did not appreciate that it is the carrier wave being modified or did not distinguish between the carrier wave and the signal.

(b) (i) Many candidates were able to determine the wavelength of the carrier wave. The most common error was a power of ten mistake in not converting from kHz to Hz.

(ii) This was answered very well.

(iii) A large number of candidates stated 308 kHz (i.e. the maximum frequency of the modulated wave) instead of 8 kHz.

(c) Around half of the candidates gained full credit here. Common mistakes were having the ratio of powers upside-down or not using the logarithmic formula for attenuation.

Question 6

(a) There were some accurate lines drawn for the electric field strength. Some candidates did not realise that the electric field strength is zero inside the sphere. Weaker candidates drew the curved section of the line inaccurately so that it did not have the correct shape.

(b) Weaker candidates often drew a straight line joining two correct points (p_0, λ_0) and ($\frac{1}{2}p_0$, $2\lambda_0$). A minority of candidates drew the correct curve.

(c) Answers to this question highlighted the importance of reading the question carefully rather than simply assuming that it is the same as a familiar question. A large number of candidates drew the more familiar curve for the decaying isotope rather than the stable product.

Question 7

(a) Most candidates realised that capacitance is the ratio of charge to potential difference. Many candidates did not give the detail that the charge is on one plate and the potential difference is between the plates.

(b) (i) Many candidates were able to go through the necessary steps leading to the expression given here. Three other formulae were needed and it must be clear how each formula is being used to reach the answer.

(ii) There were many correct answers determined using the expression here. A large number of power-of-ten errors were made as candidates found it difficult to convert their value into pF.

(c) This was another challenging explanation. Many candidates were able to state the new reading on the ammeter. A large number of candidates correctly stated or calculated that the total capacitance was now half of the previous value. Candidates then needed to make a connection between this and the current, rather than simply saying that the current is halved. The current needed to be related to the charge or the capacitance, frequency and p.d.

Question 8

(a) The potential at the non-inverting input to the amplifier is the p.d. across the 3.0 kΩ resistor. A common mistake was to use the p.d. across the 2.0 kΩ resistor. Many candidates did not realise this and consequently were not able to be awarded credit.

(b) This question was difficult. Some of the stronger candidates forgot to mention the reason that the LED was not emitting light, that being that the output voltage was negative. Weaker candidates often had the incorrect comparison of the input potentials and were not able to gain credit.

(c) In this type of question, candidates need to show their reasoning. Simply stating that V^- would be greater than V^+ for all values above 0 °C is not a complete explanation and could not be awarded full credit.

(d) Most candidates gained credit for identifying the resistance of the thermistor at 20 °C. This was a simple potential divider but, as in **(a)**, candidates often found the potential difference across the incorrect resistor in the potential divider.

Question 9

(a) Most candidates gained full credit here. However, it is important to realise that the magnetic force is exerted on a *moving* charge, not just any charge.

(b) (i) The majority of the candidates shaded the correct face.

(ii) Those candidates who accessed this question realised that the accumulation of electrons created an electric field. There was some confusion between the fields and the forces that they exerted, and candidates frequently forgot to say that the two forces acting on the electrons acted in opposite directions.

(c) (i) Many candidates could not explain the meaning of *n* in this context and so could improve by learning this definition more carefully. The weakest candidates did not mention electrons or charge carriers at all. Of those who did, vague responses such as 'number of electrons' were common. The importance of the phrase 'number density' was often not known and many candidates did not describe the electrons as being free or delocalised electrons.

(ii) There were many correct answers here.

(d) A comparative statement was needed for full credit, rather than just '*n* is small'. Candidates also needed to make the link between *n* and the Hall voltage.

Question 10

(a) Candidates' statements of Lenz's law were often not precise enough for full credit to be awarded. Many candidates do not realise that Lenz's law is about the direction of the e.m.f., rather that the magnitude of the e.m.f. Some candidates confused e.m.f. with current or stated that the e.m.f. was flowing.

(b) Candidates found this question difficult. In this type of question, candidates need to start with how the e.m.f. is induced and then go on to talk about the current that results from this. From there, it is possible to explain why the existence of this current will result in a decrease in the number of oscillations. Many candidates did not realise the importance of the current and found it difficult to set out the logical steps needed to explain what is happening.

(c) Candidates generally were able to gain more credit here than in **(b)**. The most frequent incorrect answer was to assume that the cut in the ring meant that there would be no current at all, rather than reducing the magnitude of the current. Another common mistake was to refer to the energy loss rather than the rate of energy loss. The same amount of energy is lost in both situations, but over different lengths of time.

Question 11

(a) Candidates generally knew that intensity and hardness are controlled by changing current and potential difference. However, some candidates answered these in reverse and many did not describe exactly which current (filament current) and which p.d. (accelerating p.d.) are changed.

(b) (i) This calculation was completed well by many candidates. Conversion of units from cm to m was not needed, and some candidates made mistakes in the unnecessary conversion.

(ii) This calculation was more challenging, and many candidates did not know how to combine the attenuation due to the two materials. Some candidates used an incorrect length for the soft tissue (e.g. 9.0 cm) or they used their answer from **(b)(i)** instead of using a thickness of soft tissue of 6.0 cm.

(c) Candidates were expected to draw a conclusion based upon their numerical values in **(b)**. Some candidates did not refer to these values or intensities. The answer needed to include both a comparison and a conclusion.

Question 12

(a) This was a challenging explanation. Explanation of the photoelectric effect hinges upon treating electromagnetic waves as discrete photons. Many responses did not include the word 'photon'. Many answers described what was observed but did not provide an explanation for it.

(b) (i) This calculation was well answered.

(ii) This calculation was well answered.

PHYSICS

Paper 9702/42
A Level Structured Questions

Key messages

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

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

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

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

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

General comments

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 who were properly prepared for the examination had insufficient time in which to complete the paper. However, it was not uncommon for candidates to omit the occasional part-question. Candidates should be advised that it is always worth offering a response to each part-question; no credit can be obtained where a question has been omitted, but if a response is attempted then it may be possible to award partial credit.

Comments on specific questions

Question 1

(a) Most candidates knew the definition of gravitational field and were able to express it correctly as the gravitational force per unit mass. Some weaker candidates did not make the force / mass ratio clear and gave a definition of a force rather than a field. A small number of candidates confused the question (asking for the definition of the quantity) with a different question asking for the meaning of the concept of gravitational field.

(b) (i) Most candidates knew the correct starting equation and were able to calculate the field strength to the required three significant figures. Some candidates forgot to square the radius or gave the answer to a different number of significant figures.

(ii) Most candidates knew the correct starting equation, but many candidates ignored the instruction to calculate their answer to three significant figures. Answers of 0.017 $m\,s^{-2}$ were common; some candidates invented an incorrect third significant figure, having only calculated the answer to two (usually by adding a zero as the third significant figure). A significant minority of candidates worked through the whole question calculating a force rather than an acceleration.

(iii) This was a challenging final part to the question. The strongest candidates realised that the answer to this question was the difference between their answers to **(b)(i)** and **(b)(ii)** and correctly calculated the answer to the specified three significant figures.

Question 2

(a) Candidates should be reminded that, in a 'show that' question, marks are not awarded for calculating an answer. They are awarded for showing how the given answer is reached from the data in the question. This always requires full substitution of all the relevant data (including physical constants) into whichever starting equation is appropriate. In this case, the strongest candidates started from the most appropriate equation ($pV = NkT$) and were able to show how the substitution of all the values into this equation led to the answer of 6.6×10^{23} molecules.

A more common approach was to start from $pV = nRT$ and demonstrate that the amount of gas is 1.09 mol. Candidates who went down this route created extra work for themselves, because they then had to show the additional step (in full), demonstrating the multiplication of n by 6.02×10^{23} to get to N. A small number of candidates wrote lists of numbers and linked them with arrows or ratio symbols. Candidates should be reminded that such lists of numbers are meaningless and that they must show full substitution into the equation to be awarded credit.

(b) (i) Candidates who were able to answer **(a)** generally had little difficulty with **(b)(i)**. The same comments regarding the need for full substitution apply here.

(ii) Many candidates found this question difficult, and often only got as far as calculating the change in kinetic energy of a single molecule. The idea that the internal energy of the gas is the total kinetic energy of all the molecules did not appear to be well understood. Of the candidates that did correctly calculate the value of 1400 J, only a minority appreciated that the internal energy of the gas was decreasing and that therefore the increase in internal energy is negative.

(c) There was much confusion between the definition of internal energy (in terms of the kinetic and potential energy of molecules) and the first law of thermodynamics (which deals with the ways in which the internal energy can be *changed*). Consequently, there were many statements of the first law in terms of (absolute) internal energy rather than the change in internal energy. Those who gave a correct statement of the first law were usually able to go on to observe that the thermal energy transferred is zero and that the increase in internal energy therefore equals the work done on the gas.

Question 3

(a) Many candidates did not read the question properly and answered a question just asking for the defining properties of simple harmonic motion. The question asked for an explanation of how the given equation *shows* that the motion is simple harmonic. Candidates who correctly related the features of the equation to the corresponding properties of simple harmonic motion were awarded credit.

(b) Most candidates were able to at least make a start with this question, and the award of full credit for the correct answer was common. Of the candidates who correctly identified $\omega^2 = g / L$ as the starting point, the most common reasons for not reaching the correct answer were forgetting to square T (when applying $\omega = 2\pi / T$) and forgetting to apply the required unit conversion to L.

(c) Candidates found this question difficult. Many knew that energy is proportional to amplitude^2 or that the amplitude must decrease by 0.94^3, but most were not able to put these together to get to the answer of 0.69. This emphasises the importance of setting out working and reasoning clearly, so that part credit can be awarded when a step in the reasoning is clearly set out.

A common misunderstanding was that the amplitude will decrease by 18%; this led to an incorrect answer (of 0.67) that is quite close to the correct answer. This underlines the importance of candidates giving their answers to the appropriate precision. Both of these answers round to 0.7 when expressed to one significant figure. In the absence of any working, there is no way of knowing whether it came from the correct method or the incorrect method.

Question 4

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

(ii) 1. This question was answered correctly by most candidates. In some cases, it was unclear whether candidates were describing the amplitude or the variation in amplitude. For example, responses to the effect of 'it is constant' were common. Candidates should be encouraged to ensure that the wording they use answers the question they are asked, not a related question that is not the one that was asked.

2. This part proved to be more challenging for many candidates who did not appreciate the meaning of the command word 'determine'. The question required a quantitative determination of the magnitude and period of the frequency variation.

(b) (i) Most candidates appreciated the need to use $c = f\lambda$ and that the frequency of the carrier wave is 240 kHz. The main difficulty experienced by these candidates was in one or other (or occasionally both) of the unit conversions required. A small number of candidates used the incorrect frequency (either the audio frequency or one of the sideband frequencies). Others were confused between **(a)** and **(b)** and used the carrier frequency from **(a)**. A small number of candidates used a value for speed that resembled the speed of sound.

(ii) This question was generally well answered. A significant minority of weaker candidates gave the audio frequency rather than the bandwidth.

(iii) This question was less well answered than **(b)(ii)**, with the carrier wave frequency being a common incorrect answer.

Question 5

In answering graphical questions, candidates should draw single, well-defined lines of the correct shape, passing through the key points with a high degree of accuracy (usually to within half a small square). Lines should be thick enough that lines drawn along a grid-line can be distinguished, but not so thick that there is ambiguity over where the line is intended to cross the key points. Multiple lines where there should be one will usually be treated as contradictory unless all lines drawn separately satisfy the requirements of the mark scheme.

(a) Many candidates did not show the potential at $1.0V_0$ between $x = 0$ and $x = r$. Between $x = r$ and $x = 3r$, there should be a curve of decreasing negative gradient starting at (r, V_0). Common incorrect curves were straight for too much of their length or either started vertical or ended up horizontal for too much of their length.

Many curves passed through $0.5V_0$ at $x = 2r$, but then went too low at $x = 3r$. Many other curves clearly confused potential with electric field and indicated a $1/r^2$ relationship rather than $1/r$.

(b) This was the most challenging of the three question parts for candidates. A significant minority of candidates did not appreciate the inverse relationship between electron energy and wavelength, and drew lines with a positive gradient. The significance of the threshold wavelength as the wavelength at which the maximum kinetic energy of the electrons is zero was only appreciated by the stronger candidates. Only the strongest candidates were able to deduce that the maximum kinetic energy at $\lambda_0/3$ is $2E_{MAX}$.

(c) Most candidates correctly labelled the time axis. Many candidates also realised that the two graphs would cross at $N = N_0/2$. Candidates found determining the number of nuclei at $t = T$ (to be $N_0 - N$) to be rather more challenging.

Question 6

(a) There were many good descriptions of charge separation and energy storage. In many responses, candidates did not mention that a potential difference needs to be applied across the plates.

(b) (i) Marks were generally awarded where it was clear which relationships between quantities were being used, and how. Many candidates were awarded credit. Nevertheless, candidates should be encouraged to set their reasoning out clearly in questions asking for proof of an equation. They should state the equations that are being used to substitute quantities, and make clear in the working how the quantity is being substituted.

(ii) This question was essentially about unit conversions. Two conversions were required, the first being the conversion from μA to A, and the second being the conversion from F to pF. It was common for candidates to find the second of these more difficult than the first. A small number of candidates made errors with the arithmetic and gave answers of 270 pF rather than 280 pF.

(c) There was some confusion between series and parallel capacitor combinations, but most candidates realised that the parallel combination has the effect of increasing the capacitance. Explanations of why this leads to an increase in the current were variable, but many candidates were able to achieve full credit, either by discussing the increase in charge released by the capacitors during each cycle or by discussing the proportionality of current and capacitance in the equation in **(b)(i)**.

Question 7

(a) (i) Many candidates were unable to give the meaning of infinite input impedance. Some confused it with infinite slew rate, and some essentially restated the question. Others conflated current with potential difference, or were unclear over which part of the op-amp carries no current. Answers to the effect of 'there is no current in the op-amp' were common.

(ii) More candidates gave a correct answer here than to **(a)(i)**. Some candidates were not clear enough about what is the same for all frequencies, or omitted that the constant gain condition applies to <u>all</u> frequencies.

(b) (i) This question was generally well answered. Some candidates were not awarded credit due to carelessness in the use of symbols, for example '+' signs written as '×' or '=' symbols. In a 'show that' question, where credit is awarded for showing how the answer is reached, these things must be correct.

(ii) Many candidates found this a challenging question. Some weaker candidates were awarded part credit for either identifying or calculating the gain of the circuit as the starting point. The most common error was then to use 1.5 V as the input voltage to the amplifier, rather than the 0.40 V they had just demonstrated as the input voltage in **(b)(i)**. The stronger candidates were generally able to calculate the correct final answer for full credit.

(iii) Candidates were expected to state that the increase in temperature results in the resistance of the thermistor decreasing, thereby decreasing the magnitude of the gain and therefore the magnitude of the output voltage. Common reasons for not being awarded credit were omission of the effect on gain and not making it clear which resistance in the circuit decreases.

(iv) Candidates needed to make clear that the gain of 12.5 results in an output voltage of 5.0 V and that, therefore, this is the point at which the output becomes saturated. Many responses contained one or other half of this explanation, but not the other.

Question 8

(a) In defining magnetic flux density as force per unit current per unit length, many candidates were able to make one of the ratios clear but not the other. Some candidates gave an answer in terms of units, effectively attempting to define the tesla rather than the quantity. Other candidates either gave a definition of magnetic flux or stated Faraday's law.

For full credit, candidates were required to give the condition that the wire (or current) had to be at right angles to the magnetic field; some, in attempting to do that, did not make it sufficiently clear what it is that must be at right angles to the field. This was often due to casual use of the word 'it', which led to answers that implied that the force must be perpendicular to the field. To improve, candidates should be discouraged from using vague words like 'it', and should be more specific over what they are referring to.

(b) This question was generally well answered. As a matter of general principle, in questions like this where upper and lower case versions of the same letter are used to represent different quantities (in this case, *V* and *v*), candidates should be advised of the importance of making sure that the letters they write are distinguishable.

(c) (i) Many candidates were able to correctly explain the reasoning behind this derivation, by equating magnetic and centripetal force as the starting point, but it was common for candidates to then stumble at some stage in the subsequent algebra.

(ii) This question was well answered by many candidates, and full credit for the correct answer was common. Some candidates misread the question and multiplied the specific charge by the mass of an electron to calculate a charge. Mistakes involving the unit conversions in *B* and *r* were rare, but forgetting to square one or other of these quantities in the substitution was more common.

(iii) Many candidates found this question difficult, and either contradicted the information in the question by stating that *B* and *V* would have to change, or suggested that the α-particle would not undergo circular motion owing to its positive charge. Some candidates did successfully observe that the α-particle has a smaller specific charge than the electron, but only the strongest candidates went on from there to discuss the effect of this on the radius of the path, which would be impracticably large.

Question 9

(a) Many candidates were able to achieve full credit for giving both of the conditions under which there will be no force. Common errors were confusion with current-carrying conductors and discussion of resultant force rather than magnetic force.

(b) Candidates' responses showed a wide range of misconceptions of the physics involved in this question. A large number of candidates thought it was something to do with electromagnetic induction. Relatively few realised that the situation was one involving forces between parallel wires. Candidates often realised that the force between adjacent coils is attractive, and that therefore the coil contracts, but discussion of why these forces arise was rare. Only the strongest candidates were able to gain full credit.

(c) The question asks candidates to *use* the laws of electromagnetic induction to explain a phenomenon. Many candidates filled the answer space just *quoting* the laws (for which there was no credit). In questions like this, candidates should be advised that they must make it clear how the principles of the laws apply to the specific situation; simply quoting the laws, or reproducing the mark scheme for a previous question in which the laws of electromagnetic induction were applied to a different situation, is not likely to meet the requirements of the mark scheme.

The first point that candidates needed to make was that the changing separation of the coils of the spring leads to a change in magnetic flux linkage. Many candidates could not be awarded credit because they described either the mass or the flexible lead cutting the flux lines. The second point they needed to make was that the change in flux linkage causes an induced e.m.f. in the coil. Many candidates did refer to an induced e.m.f., but the role of the change in flux linkage in *causing* this was often not clear. It was also often unclear where the e.m.f. was being induced. Some candidates displayed a fundamental misunderstanding of the situation by discussing an induced current. The final point that candidates needed to make was that the current in the spring fluctuates because the induced e.m.f. in the coil is varying. Only a small number of candidates made this point.

Question 10

(a) The meaning of r.m.s. current, as the steady current that produces the same heating effect as the alternating current, was not well understood by many candidates. Answers that suggested that the r.m.s. current varies were common, as were answers defining it as an average current or a peak current.

(b) (i) This question was generally well answered, with most candidates able to read the peak value from the graph and then calculate the r.m.s. value.

(ii) This question was less well answered, with many candidates thinking that the division by $\sqrt{2}$ also applies to a square wave. Candidates that demonstrated the correct understanding of the meaning of r.m.s. current in **(a)** were usually able to answer this question correctly.

(c) (i) Most candidates realised that k in the equation corresponds to $2\pi f$ and were therefore able to calculate the 314 rad s^{-1} figure. However, a significant number ignored the instruction to give the answer to two significant figures and could therefore not be awarded full credit.

(ii) The stronger candidates had little difficulty in reaching the correct $9.0\,\Omega$ answer. Among the weaker candidates, there was much confusion between peak, mean and r.m.s. values, with the peak p.d. often being used in conjunction with the mean power to get an answer of $18\,\Omega$.

Question 11

(a) The purpose of a CT scan, to create a 3-dimensional image of an internal structure, was well understood by many candidates. Some answers confused 'image' with 'structure', and suggested that the purpose of the CT scan was to create a structure or a model.

(b) Many candidates answered this question well, and the principles behind CT scanning are clearly generally well understood. Some candidates are not precise in their use of terminology. In particular, there was often confusion between 'image' and 'section'. This confusion appears to be particularly prevalent when candidates use the word 'slice' to mean 'section'.

Question 12

(a) This question was generally well answered. Most candidates knew that a photon is a packet of energy, and many also knew that the energy in question is electromagnetic. A small number of candidates demonstrated the misconception that photons are either carried by or emitted by electromagnetic radiation.

(b) (i) Most candidates knew the correct starting equation, and many successfully went on to calculate the correct wavelength. Some candidates had difficulty converting the energy from MeV to J.

(ii) This is another question that was well answered by many candidates. Only a small number gave the final answer to an insufficient precision. The weaker candidates did not generally know the relationship between momentum and wavelength and attempted to answer the question using momentum = mass × velocity. This was could not be awarded credit for a photon.

(c) (i) Full credit by error-carried-forward was possible from the candidate's answer to **(b)(ii)**. However, at this point candidates really should have been aware of the plausibility of their answers. Answers that were many times the order of magnitude of the speed of light were common, and usually appeared to be accepted without question. A moment's thought about the impossibility of this should have alerted candidates to the fact that they must have made a mistake somewhere along the way. Following that back may have resulted in their being able to identify an error in **(b)(i)** or **(b)(ii)**.

The common reason for not being awarded full credit in this question concerned the identification of the mass of the samarium nucleus. Often, the conversion from 157 to the mass in kg was omitted. Some candidates who used the Avogadro constant rather than the unified atomic mass constant calculated a mass in g rather than kg and omitted the 10^3 conversion.

(ii) Many candidates ignored the word 'quantitatively' in the question and just gave a qualitative description of the comparison of the speeds. Reference to the numbers involved was needed to gain credit.

PHYSICS

Paper 9702/43
A Level Structured Questions

Key messages

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

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

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

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

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

General comments

The wording of definitions and descriptions needs to be precise. Some candidates were not awarded credit in **1(a)**, **3(a)**, **5(a)**, **7(a)**, **9(a)**, **9(c)(i)** and **10(a)** because their wording was not sufficiently detailed. The wording in the mark scheme shows the detail that is expected.

There were three 'show that' questions on this paper, **1(c)(i)**, **2(a)** and **7(b)(i)**. In such questions, every step must be clear, and care should be taken with the presentation of calculations.

When required to sketch lines on graph axes such as in **Question 6**, candidates should draw their lines carefully. For example, curves showing inverse proportionality should not begin with a vertical section and end with a horizontal section. Examiners will check that the line goes through certain key coordinates.

There was no evidence of candidates not having enough time to complete the paper. Many candidates are better at recalling information learnt by heart than they are at applying principles to new situations.

Comments on specific questions

Question 1

(a) Candidates answered this question well. Only the very weakest candidates gave incorrect definitions. The most common incorrect alternative was to give the definition for gravitational potential.

(b) This calculation was well completed. The combination of equations and working leading to $T^2 / r^3 = 4\pi^2 / GM$ was successfully carried out by many candidates. Only a minority did not convert minutes into seconds or did not square values correctly in the equation.

(c) (i) Most responses showed that candidates went back to the equation in **(b)**, rather than using one of the relationships $r^3\omega^2$ = constant or r^3 / T^2 = constant. In a 'show that' question, candidates need to make each step clear. Here there was sometimes unclear presentation leading to confusion between r^3 and r.

(ii) Most candidates realised that the separation between the satellite and the Earth had increased but were not able to say that there was also an increase in the gravitational potential energy. Many responses indicated that separation and energy are inversely proportional, forgetting that gravitational potential energy is negative. Candidates often know the equation for gravitational potential energy, but they do not always realise that, because it is negative, the energy will increase as the denominator (r) increases.

(iii) There were many correct calculations here. The most common mistake was to calculate the change in potential, rather than the change in potential energy. Another error was to use $\Delta E = GMm / (r_2 - r_1)$.

Question 2

(a) This calculation was completed very well by candidates who used $pV = NkT$. Those who used $pV = nRT$ and $nN_A = N$ were often less successful. In this 'show that' question, it was important to make clear the progression from n to N and not treat them in the presentation as the same quantity.

(b) This explanation proved to be challenging. Many candidates used the first law of thermodynamics in their response rather than kinetic theory, as requested by the question. A common misconception was that collisions produce thermal energy which increases the temperature.

(c) (i) Candidates found this calculation difficult. Some candidates found the work done during the expansion of the gas and some found the increase in kinetic energy of just one molecule, rather than the increase in internal energy of the gas.

(ii) This was one of the most challenging questions on the paper. The answer required a comparison between the change in internal energy of the gas and the work done by the gas in order to work out whether thermal energy was transferred to or from the gas. This could be done numerically or in words.

Question 3

(a) The majority of the candidates were able to state what is meant by simple harmonic motion.

(b) A large number of responses showed that candidates were able to relate the expression given in the question to the general expression for simple harmonic motion and use this to calculate the frequency of the oscillations. The most common error was to equate $2k/m$ with ω rather than ω^2.

(c) (i) This question was well answered.

(ii) Candidates found this explanation difficult. The key idea is that energy is being supplied by the oscillator but the energy of the oscillations of the trolley is constant, so energy must be dissipated by resistive forces. Many candidates did not make this connection and most answers did not refer to energy. A significant number of candidates showed a misconception that the amplitude was constant at all frequencies.

Question 4

Many candidates were well prepared for this question. Common mistakes included not identifying the piezo-electric crystal as both the generator and detector of the ultrasound pulse, referring vaguely to reflection rather than reflection at the *boundary* between tissues, and being insufficiently detailed about what information can be gained from the intensity of the reflected wave (i.e. the nature of the tissue).

Question 5

(a) Candidates found it difficult to state what is meant by amplitude modulation. Many candidates did not appreciate that it is the carrier wave being modified or did not distinguish between the carrier wave and the signal.

(b) (i) Many candidates were able to determine the wavelength of the carrier wave. The most common error was a power of ten mistake in not converting from kHz to Hz.

(ii) This was answered very well.

(iii) A large number of candidates stated 308 kHz (i.e. the maximum frequency of the modulated wave) instead of 8 kHz.

(c) Around half of the candidates gained full credit here. Common mistakes were having the ratio of powers upside-down or not using the logarithmic formula for attenuation.

Question 6

(a) There were some accurate lines drawn for the electric field strength. Some candidates did not realise that the electric field strength is zero inside the sphere. Weaker candidates drew the curved section of the line inaccurately so that it did not have the correct shape.

(b) Weaker candidates often drew a straight line joining two correct points (p_0, λ_0) and ($\frac{1}{2}p_0$, $2\lambda_0$). A minority of candidates drew the correct curve.

(c) Answers to this question highlighted the importance of reading the question carefully rather than simply assuming that it is the same as a familiar question. A large number of candidates drew the more familiar curve for the decaying isotope rather than the stable product.

Question 7

(a) Most candidates realised that capacitance is the ratio of charge to potential difference. Many candidates did not give the detail that the charge is on one plate and the potential difference is between the plates.

(b) (i) Many candidates were able to go through the necessary steps leading to the expression given here. Three other formulae were needed and it must be clear how each formula is being used to reach the answer.

(ii) There were many correct answers determined using the expression here. A large number of power-of-ten errors were made as candidates found it difficult to convert their value into pF.

(c) This was another challenging explanation. Many candidates were able to state the new reading on the ammeter. A large number of candidates correctly stated or calculated that the total capacitance was now half of the previous value. Candidates then needed to make a connection between this and the current, rather than simply saying that the current is halved. The current needed to be related to the charge or the capacitance, frequency and p.d.

Question 8

(a) The potential at the non-inverting input to the amplifier is the p.d. across the 3.0 kΩ resistor. A common mistake was to use the p.d. across the 2.0 kΩ resistor. Many candidates did not realise this and consequently were not able to be awarded credit.

(b) This question was difficult. Some of the stronger candidates forgot to mention the reason that the LED was not emitting light, that being that the output voltage was negative. Weaker candidates often had the incorrect comparison of the input potentials and were not able to gain credit.

(c) In this type of question, candidates need to show their reasoning. Simply stating that V^- would be greater than V^+ for all values above 0 °C is not a complete explanation and could not be awarded full credit.

(d) Most candidates gained credit for identifying the resistance of the thermistor at 20 °C. This was a simple potential divider but, as in **(a)**, candidates often found the potential difference across the incorrect resistor in the potential divider.

Question 9

(a) Most candidates gained full credit here. However, it is important to realise that the magnetic force is exerted on a *moving* charge, not just any charge.

(b) (i) The majority of the candidates shaded the correct face.

(ii) Those candidates who accessed this question realised that the accumulation of electrons created an electric field. There was some confusion between the fields and the forces that they exerted, and candidates frequently forgot to say that the two forces acting on the electrons acted in opposite directions.

(c) (i) Many candidates could not explain the meaning of *n* in this context and so could improve by learning this definition more carefully. The weakest candidates did not mention electrons or charge carriers at all. Of those who did, vague responses such as 'number of electrons' were common. The importance of the phrase 'number density' was often not known and many candidates did not describe the electrons as being free or delocalised electrons.

(ii) There were many correct answers here.

(d) A comparative statement was needed for full credit, rather than just '*n* is small'. Candidates also needed to make the link between *n* and the Hall voltage.

Question 10

(a) Candidates' statements of Lenz's law were often not precise enough for full credit to be awarded. Many candidates do not realise that Lenz's law is about the direction of the e.m.f., rather that the magnitude of the e.m.f. Some candidates confused e.m.f. with current or stated that the e.m.f. was flowing.

(b) Candidates found this question difficult. In this type of question, candidates need to start with how the e.m.f. is induced and then go on to talk about the current that results from this. From there, it is possible to explain why the existence of this current will result in a decrease in the number of oscillations. Many candidates did not realise the importance of the current and found it difficult to set out the logical steps needed to explain what is happening.

(c) Candidates generally were able to gain more credit here than in **(b)**. The most frequent incorrect answer was to assume that the cut in the ring meant that there would be no current at all, rather than reducing the magnitude of the current. Another common mistake was to refer to the energy loss rather than the rate of energy loss. The same amount of energy is lost in both situations, but over different lengths of time.

Question 11

(a) Candidates generally knew that intensity and hardness are controlled by changing current and potential difference. However, some candidates answered these in reverse and many did not describe exactly which current (filament current) and which p.d. (accelerating p.d.) are changed.

(b) (i) This calculation was completed well by many candidates. Conversion of units from cm to m was not needed, and some candidates made mistakes in the unnecessary conversion.

(ii) This calculation was more challenging, and many candidates did not know how to combine the attenuation due to the two materials. Some candidates used an incorrect length for the soft tissue (e.g. 9.0 cm) or they used their answer from **(b)(i)** instead of using a thickness of soft tissue of 6.0 cm.

(c) Candidates were expected to draw a conclusion based upon their numerical values in **(b)**. Some candidates did not refer to these values or intensities. The answer needed to include both a comparison and a conclusion.

Question 12

(a) This was a challenging explanation. Explanation of the photoelectric effect hinges upon treating electromagnetic waves as discrete photons. Many responses did not include the word ‘photon’. Many answers described what was observed but did not provide an explanation for it.

(b) (i) This calculation was well answered.

(ii) This calculation was well answered.

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.
- The practical skills required for this paper should be developed and practised with a 'hands-on' approach throughout the course.

General comments

In **Question 1**, it is advisable that candidates should think carefully about the experiment following the points given on the question paper and to imagine how they would perform the experiment in the laboratory. Planning a few key points before answering this question is useful. This question required candidates to plan an experiment which required the measurement of time of the order of milliseconds linked to an electric circuit. It was expected that candidates would understand appropriate data logging techniques since operating a stop-watch would not be able to measure times of the order of milliseconds. Some candidates drew diagrams that did not show a workable experiment. Some candidates were confused about the correct use of ammeters, voltmeters and ohmmeters. Many candidates were successful in the analysis section with clear identification of how the constant could be determined. It is essential for candidates to have experienced practical work in preparation for answering this paper.

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

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

Comments on specific questions

Question 1

Most candidates correctly identified the independent and dependent variables. Candidates should be encouraged then to consider the control of variables and to explicitly state the quantities that need to be kept constant to make the experiment a fair test – in this case the number *N* of turns of the coil as well as the cross-sectional area *A* and length *L* of the coil needed to be kept constant. Some candidates use the incorrect term 'control' rather than stating that *N*, *A* and *L* needed to be kept constant. Candidates should identify the variables to be controlled from the given relationship.

Candidates were awarded credit for a clearly labelled circuit diagram. To gain credit, the drawn circuit diagram needed to be workable and include a power supply, coil, resistor, switch and a method to determine the current. Standard circuit symbols were expected to be drawn. Common errors included drawing an ammeter in parallel with the resistor, including a voltmeter/CRO in series with the resistor and coil, connecting an ohmmeter in the circuit and omitting the switch.

Candidates also needed to draw a circuit diagram to determine *R*. Some candidates gained credit by drawing a voltmeter in parallel across the resistor shown in the main circuit. Other candidates gained credit by drawing a separate circuit with a resistor and a correctly positioned ammeter and voltmeter or an ohmmeter. If an ohmmeter was used, it must be drawn in a separate circuit as placing it in the main circuit would make that circuit unworkable.

To measure the time *t* for the current in the resistor to reach a maximum value, it was expected that a current sensor connected to a data logger would be used or a (storage) oscilloscope connected across the resistor. Some explanation was expected.

Most candidates gained credit for suggesting using calipers or a micrometer screw gauge to measure the diameter of the coil and then gave a relevant equation to determine the area *A* of the coil. Stronger candidates suggested repeating the measurements of the diameter in different directions or along the coil and then finding the mean. Several candidates suggested calipers or a micrometer screw gauge to measure *r* or *A* directly, but this is not possible and did not gain credit. Some candidates suggested using a ruler – this suggestion only gained credit if additional detail was given, e.g., using blocks to make sure the maximum distance was measured.

Many candidates suggested correct axes for a graph (often *t* against $1/R$). A significant number of candidates incorrectly suggested plotting *t* against *R*. Candidates must explicitly state the quantities to be plotted on each axis either in the text or on drawn axes – credit is not given for just writing $y = mx + c$ under an expression. Having suggested an appropriate graph, candidates needed to explain how the graph would confirm the suggested relationship. Candidates need to use the words ‘relationship is valid if’ and the word ‘straight’ to describe the line. For a *t* against $1/R$ graph, candidates needed to state that the relationship is valid if a straight line through the origin is produced. Candidates who proposed plotting lg *t* against lg *R* needed to state that the straight line would have a gradient of –1.

Candidates needed to explain how they would determine a value of *K* from the experimental results. Some candidates correctly identified a relationship between *K* and the gradient but did not make *K* the subject of the equation. Some candidates suggested other graphs to plot such as $1/t$ against *R*; these could be given credit if the reasoning was correct and the equation for *K* was correct. Similarly, candidates who suggested plotting lg *t* against lg *R* could also gain credit if *K* was the subject of the expression in terms of the *y*-intercept.

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

Question 2

(a) Candidates who were mathematically confident were able to work through the algebra and achieve credit. It is expected that expressions should be simplified, for example, for the *y*-intercept $\frac{A}{uA}$ should have been written as $\frac{1}{u}$. Candidates should be encouraged to use the white space on the question paper to rearrange the equation into an equation of a straight line.

(b) Most candidates were able to calculate values for $\frac{1}{v}$. Some candidates did not use an appropriate number of significant figures. Since values of *v* were recorded to three significant figures, values of $\frac{1}{v}$ should have been recorded to three (or four) significant figures. Some candidates incorrectly added trailing zeros to the $(M + m)$ values, e.g. 930.0.

Most candidates calculated the absolute uncertainties in (*M* + *m*) correctly. Some candidates incorrectly added the percentage uncertainties (10%) before determining the absolute uncertainties in (*M* + *m*). Candidates need to understand the rules for combining uncertainties, including the conversion from an absolute uncertainty to a percentage uncertainty and the conversion from a percentage uncertainty to an absolute uncertainty.

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

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

(iii) Most candidates clearly demonstrated the points that they used to calculate the gradient. Some candidates misread coordinates or did not use a sensibly sized triangle. A 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 which are easy to read from the graph.

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

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

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) It is expected that candidates will clearly show the substitution of the gradient and *y*-intercept to determine values of *A* and *u*. Credit is not given for substituting data vales from the table into the expression. Candidates are also expected to give the final values of *A* and *u* to an appropriate number of significant figures, with appropriate units and the correct power of ten. Some candidates incorrectly wrote m s^{-1} instead of cm s^{-1}. Similarly, several candidates incorrectly included units of speed for *A*.

(ii) The percentage uncertainty in *A* required the addition of the percentage uncertainty in the gradient and either the percentage uncertainty in the *y*-intercept or *u*. Candidates who used the percentage uncertainty in *u* needed to show how this was obtained. Some candidates used maximum/minimum methods – credit could only be awarded for these methods when clear working was shown.

(e) There were many ways that candidates could determine *m*. Candidates needed to show clear and logical working for this question. Some candidates used the gradient and *y*-intercept, and others substituted values for *A* and *u* from **(d)(i)**.

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.
- The practical skills required for this paper should be developed and practised with a 'hands-on' approach throughout the course.

General comments

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

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

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

Comments on specific questions

Question 1

Most candidates correctly identified the independent and dependent variables. Candidates should be encouraged then to consider the control of variables and to explicitly state the quantities that need to be kept constant to make the experiment a fair test – in this case the increase in temperature of the water $\Delta\theta$ as well as the power P of the heater and height h of the cylinder needed to be kept constant. Some candidates use the incorrect term 'control' rather than stating that $\Delta\theta$, P and h needed to be kept constant. Vague references to keeping temperature constant did not gain credit. Candidates should identify the variables to be controlled from the given relationship. There was also additional detail credit for stating that the initial temperature of the water and the volume (or mass) of water used should be kept constant. In the latter case, 'amount' of water was not credited. Level of water was also not credited here since the level was likely to change with the different cross-sectional areas of the cylinder.

Candidates were awarded credit for a clearly labelled diagram. Diagrams should be drawn of the workable experiment. In this experiment, candidates needed to clearly show a beaker on a bench or supported in a clamp. Candidates were also expected to show the cylinder and heater submerged in the water with a thermometer to measure the temperature. Stronger candidates labelled the beaker, cylinder, heater, thermometer and water.

Candidates needed to draw a circuit diagram to show how *P* would be determined. It was expected that candidates would draw a voltmeter in parallel with the heater and an ammeter in series with the heater. A common error was to include a variable resistor (to keep *P* constant) but connecting the voltmeter in parallel across both the heater and variable resistor.

Many candidates suggested the use of a stop-watch to measure the time *t* for the temperature of the water to increase by $\Delta\theta$. Vague statements such as 'use a stop-watch to measure time' cannot be given credit, so candidates should be encouraged to be specific in describing what they are measuring.

Most candidates gained credit for suggesting using calipers or a micrometer screw gauge to measure the diameter of the cylinder and then gave a relevant equation to determine the area *A* of the cylinder. Stronger candidates suggested repeating the measurements of the diameter in different directions or along the cylinder and then finding the mean. Some candidates suggested calipers or a micrometer screw gauge to measure *r* or *A* directly, but this is not possible and did not gain credit. Some candidates suggested using a ruler – this suggestion only gained credit if additional detail was given, e.g. using blocks to make sure the maximum distance was measured.

Many candidates suggested correct axes for a graph, often *t* against *A*. Candidates must explicitly state the quantities to be plotted on each axis either in the text or on drawn axes – credit is not given for just writing $y = mx + c$ under an expression. Having suggested an appropriate graph, candidates needed to explain how the graph would confirm the suggested relationship. Candidates need to use the words 'relationship is valid if' and the word 'straight' to describe the line. For a *t* against *A* graph, candidates needed to state that the equation is valid if a straight line is produced. Many candidates were not awarded credit because they stated that the straight line would pass through the origin.

Candidates needed to explain how they would determine values of *W* and *Z* from the experimental results. Some candidates correctly identified a relationship between *W* and the gradient but did not make *W* the subject of the equation. Similarly, some candidates correctly identified a relationship between *Z* and the *y*-intercept but did not make *Z* the subject of the equation. Other candidates suggested other graphs to plot such as *Pt* against *hA*; these could be given credit if the reasoning was correct and the equations for *W* and *Z* were correct. For this experiment, logarithmic graphs were not appropriate and were not given credit.

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

Question 2

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

(b) Completing the table appeared to be straightforward for most candidates. Most candidates were able to calculate values for $\frac{1}{I}$; sometimes candidates did not use an appropriate number of significant figures, for example giving all the $\frac{1}{I}$ values to two significant figures. Since values of I were recorded to three significant figures, values of $\frac{1}{I}$ should have been recorded to three (or four) significant figures. A common rounding error was in the fourth row when the value for $\frac{1}{I}$ was written as 80.7 rather than 80.6. Some candidates also incorrectly added trailing zeros to the ($R_1 + R_2$) values, e.g. 103.0.

Most candidates determined the absolute uncertainty in ($R_1 + R_2$) correctly. Some candidates incorrectly added the percentage uncertainties (10%) before determining the absolute uncertainties in ($M + m$). Candidates need to understand the rules for combining uncertainties, including the conversion from an absolute uncertainty to a percentage uncertainty and the conversion from a percentage uncertainty to an absolute uncertainty.

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

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

(iii) Most candidates clearly demonstrated the points that they used to calculate the gradient. Some candidates misread coordinates or did not use a sensibly sized triangle. A 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 which are easy to read from the graph.

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

(iv) The majority of the candidates who were awarded full credit set out their working clearly. Stronger candidates often substituted data from the gradient calculation in **(c)(iii)** into $y = mx + c$. A significant number of candidates read the value of $\frac{1}{I}$ from the y-axis when ($R_1 + R_2$) = 50 Ω, which is a false origin.

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. Credit was not gained by candidates who just read a value from the y-axis where ($R_1 + R_2$) = 50 Ω.

(d) (i) It is expected that candidates will clearly show the substitution of the gradient and y-intercept to determine values of E and r. Credit is not given for substituting data vales from the table into the expression. Candidates are also expected to give the final values of E and r to an appropriate number of significant figures.

(ii) Stronger candidates clearly demonstrated the method to determine the absolute uncertainty in E, with most working out the fractional uncertainty in the gradient and multiplying by the E value determined in **(d)(i)**. Some candidates used maximum/minimum methods – credit could only be awarded for these methods when clear working was shown. A common error was to incorrectly copy the uncertainty in the gradient value. Other candidates incorrectly added the percentage uncertainty in the gradient to the percentage uncertainty in the y-intercept.

(e) There were many ways that candidates could determine R_2. Candidates needed to show clear and logical working for this question. Some candidates used the gradient and y-intercept, while others substituted values for E and r from **(d)(i)**.

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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.
- The practical skills required for this paper should be developed and practised with a 'hands-on' approach throughout the course.

General comments

In **Question 1**, it is advisable that candidates should think carefully about the experiment following the points given on the question paper and to imagine how they would perform the experiment in the laboratory. Planning a few key points before answering this question is useful. This question required candidates to plan an experiment which required the measurement of time of the order of milliseconds linked to an electric circuit. It was expected that candidates would understand appropriate data logging techniques since operating a stop-watch would not be able to measure times of the order of milliseconds. Some candidates drew diagrams that did not show a workable experiment. Some candidates were confused about the correct use of ammeters, voltmeters and ohmmeters. Many candidates were successful in the analysis section with clear identification of how the constant could be determined. It is essential for candidates to have experienced practical work in preparation for answering this paper.

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

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

Comments on specific questions

Question 1

Most candidates correctly identified the independent and dependent variables. Candidates should be encouraged then to consider the control of variables and to explicitly state the quantities that need to be kept constant to make the experiment a fair test – in this case the number *N* of turns of the coil as well as the cross-sectional area *A* and length *L* of the coil needed to be kept constant. Some candidates use the incorrect term 'control' rather than stating that *N*, *A* and *L* needed to be kept constant. Candidates should identify the variables to be controlled from the given relationship.

Candidates were awarded credit for a clearly labelled circuit diagram. To gain credit, the drawn circuit diagram needed to be workable and include a power supply, coil, resistor, switch and a method to determine the current. Standard circuit symbols were expected to be drawn. Common errors included drawing an ammeter in parallel with the resistor, including a voltmeter/CRO in series with the resistor and coil, connecting an ohmmeter in the circuit and omitting the switch.

Candidates also needed to draw a circuit diagram to determine *R*. Some candidates gained credit by drawing a voltmeter in parallel across the resistor shown in the main circuit. Other candidates gained credit by drawing a separate circuit with a resistor and a correctly positioned ammeter and voltmeter or an ohmmeter. If an ohmmeter was used, it must be drawn in a separate circuit as placing it in the main circuit would make that circuit unworkable.

To measure the time *t* for the current in the resistor to reach a maximum value, it was expected that a current sensor connected to a data logger would be used or a (storage) oscilloscope connected across the resistor. Some explanation was expected.

Most candidates gained credit for suggesting using calipers or a micrometer screw gauge to measure the diameter of the coil and then gave a relevant equation to determine the area *A* of the coil. Stronger candidates suggested repeating the measurements of the diameter in different directions or along the coil and then finding the mean. Several candidates suggested calipers or a micrometer screw gauge to measure *r* or *A* directly, but this is not possible and did not gain credit. Some candidates suggested using a ruler – this suggestion only gained credit if additional detail was given, e.g., using blocks to make sure the maximum distance was measured.

Many candidates suggested correct axes for a graph (often *t* against $1/R$). A significant number of candidates incorrectly suggested plotting *t* against *R*. Candidates must explicitly state the quantities to be plotted on each axis either in the text or on drawn axes – credit is not given for just writing $y = mx + c$ under an expression. Having suggested an appropriate graph, candidates needed to explain how the graph would confirm the suggested relationship. Candidates need to use the words 'relationship is valid if' and the word 'straight' to describe the line. For a *t* against $1/R$ graph, candidates needed to state that the relationship is valid if a straight line through the origin is produced. Candidates who proposed plotting lg *t* against lg *R* needed to state that the straight line would have a gradient of –1.

Candidates needed to explain how they would determine a value of *K* from the experimental results. Some candidates correctly identified a relationship between *K* and the gradient but did not make *K* the subject of the equation. Some candidates suggested other graphs to plot such as $1/t$ against *R*; these could be given credit if the reasoning was correct and the equation for *K* was correct. Similarly, candidates who suggested plotting lg *t* against lg *R* could also gain credit if *K* was the subject of the expression in terms of the *y*-intercept.

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

Question 2

(a) Candidates who were mathematically confident were able to work through the algebra and achieve credit. It is expected that expressions should be simplified, for example, for the *y*-intercept $\frac{A}{uA}$ should have been written as $\frac{1}{u}$. Candidates should be encouraged to use the white space on the question paper to rearrange the equation into an equation of a straight line.

(b) Most candidates were able to calculate values for $\frac{1}{v}$. Some candidates did not use an appropriate number of significant figures. Since values of *v* were recorded to three significant figures, values of $\frac{1}{v}$ should have been recorded to three (or four) significant figures. Some candidates incorrectly added trailing zeros to the $(M + m)$ values, e.g. 930.0.

Most candidates calculated the absolute uncertainties in ($M + m$) correctly. Some candidates incorrectly added the percentage uncertainties (10%) before determining the absolute uncertainties in ($M + m$). Candidates need to understand the rules for combining uncertainties, including the conversion from an absolute uncertainty to a percentage uncertainty and the conversion from a percentage uncertainty to an absolute uncertainty.

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

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

(iii) Most candidates clearly demonstrated the points that they used to calculate the gradient. Some candidates misread coordinates or did not use a sensibly sized triangle. A 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 which are easy to read from the graph.

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

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

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) It is expected that candidates will clearly show the substitution of the gradient and *y*-intercept to determine values of *A* and *u*. Credit is not given for substituting data vales from the table into the expression. Candidates are also expected to give the final values of *A* and *u* to an appropriate number of significant figures, with appropriate units and the correct power of ten. Some candidates incorrectly wrote m s^{-1} instead of cm s^{-1}. Similarly, several candidates incorrectly included units of speed for *A*.

(ii) The percentage uncertainty in *A* required the addition of the percentage uncertainty in the gradient and either the percentage uncertainty in the *y*-intercept or *u*. Candidates who used the percentage uncertainty in *u* needed to show how this was obtained. Some candidates used maximum/minimum methods – credit could only be awarded for these methods when clear working was shown.

(e) There were many ways that candidates could determine *m*. Candidates needed to show clear and logical working for this question. Some candidates used the gradient and *y*-intercept, and others substituted values for *A* and *u* from **(d)(i)**.