PHYSICS

Paper 9702/11
Multiple Choice

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

General Comments

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

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

Candidates found **Questions 6**, **7**, **8**, **18**, **24**, **26**, **29**, **31** and **32** particularly difficult, but found **Questions 2, 14**, **20** and **38** relatively straightforward.

Comments on specific questions

Question 6

The incorrect answer **C** was the most popular with weaker candidates. The horizontal component of the velocity of the particle is $V\cos\theta$ and does not change as air resistance is negligible. The horizontal distance travelled in time T (the range R) is therefore $VT\cos\theta$ (answer **A**).

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Question 7

Candidates found this question challenging, with many thinking that the force exerted by the man on the floor is equal to the weight of the man. The force exerted by the man on the floor is equal to the force exerted by the floor on the man, R.
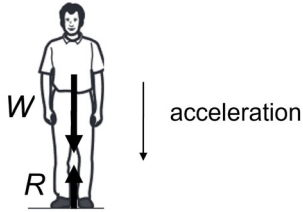
The two forces acting on the man are his weight W acting downwards and the force R acting upwards from the floor. Applying $F = ma$ to the man vertically downwards:

$W - R = ma$ where m is the mass of the man and a the (positive) downward acceleration.

Therefore $W > R$ as the man and lift are accelerating downwards. The correct answer is **D**.

Question 8

When calculating the change in momentum, candidates should be able to recall that momentum is a vector quantity. Therefore the velocity changes by $30\,\text{m s}^{-1}$ during the collision, not $10\,\text{m s}^{-1}$.

$\Delta(mv) = 0.200[20 - (-10)] = 6.0\,\text{kg m s}^{-1}$

Average force $F = \dfrac{\Delta(mv)}{\Delta t} = \dfrac{6.0}{0.10} = 60\,\text{N}$ (Answer **B**)

Question 18

Care is needed in interpreting all the information provided in the question, ensuring units are consistent when carrying out the calculation. The initial length of the cord is 16.0 cm and the stretched length is 24.0 cm, making the extension of the cord 8.0 cm. If the tension in the cord is T, then resolving the forces supporting the load of mass 0.40 kg vertically:

$2T \cos 30 = 0.40g$ so $T = 2.3\,\text{N}$

The Young modulus E is given by:

$E = \dfrac{\sigma}{\varepsilon} = \dfrac{\dfrac{2.3}{2.0 \times 10^{-6}}}{\dfrac{8.0 \times 10^{-2}}{16.0 \times 10^{-2}}} = 2.3 \times 10^6$ (Answer **C**)

Question 24

For weaker candidates, the incorrect answers **B** and **C** were the most popular. Candidates should be able to recall both Malus' law and the relationship between the amplitude and the intensity of a wave (intensity $\propto$ amplitude^2). If the original intensity of the microwaves is I_0, the intensity I_1 of the transmitted wave is:

$I_1 = I_0 \cos^2 20° = 0.88\,I_0$

If the corresponding amplitudes observed on the oscilloscope are A_0 and A_1 then:

$\dfrac{A_1}{A_0} = \sqrt{\dfrac{I_1}{I_0}} \Rightarrow A_1 = A_0 \sqrt{\dfrac{0.88 I_0}{I_0}} = 2.6 \times \sqrt{0.88} = 2.4\,\text{cm}$ (Answer **D**)

Question 26

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The lowest frequency of sound that can be produced by a musical organ pipe corresponds to its longest wavelength. For a pipe closed at one end, the closed end must be a displacement node and the open end a displacement antinode.
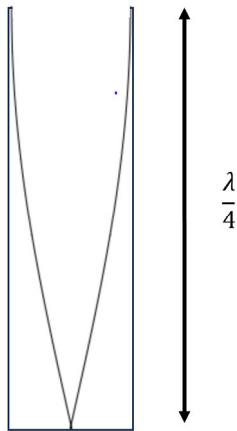
$$\frac{\lambda}{4}=10 \qquad \lambda=40 \text{ m} \quad \text{so} \quad f=\frac{v}{\lambda}=\frac{320}{40}=8 \text{ Hz (Answer B)}.$$

Many candidates thought the length of the organ pipe corresponded to a complete wavelength λ, giving a frequency of 32 Hz (Answer **D**).

Question 29

Candidates found this question challenging, with **B** and **C** popular incorrect answers.

Using the diffraction grating equation $n\lambda = s \sin \theta$, for the red light:

$$\sin \theta = \frac{n\lambda}{s} = \frac{2 \times 720 \times 10^{-9}}{s}$$

For the electromagnetic radiation of wavelength λ_X:

$$\sin \theta = \frac{n\lambda}{s} = \frac{3 \times \lambda_X}{s}$$

Equating these two equations:

$$\frac{3 \times \lambda_X}{s} = \frac{2 \times 720 \times 10^{-9}}{s} \qquad \lambda_X = 480\,nm$$

Question 31

Candidates found this question challenging, with **C** the most popular incorrect answer.

The total resistance in the circuit R_T is given by:

$$\frac{1}{R_T} = \frac{1}{R} + \frac{1}{2R} \qquad R_T = \frac{2R}{3}$$

Using $P = \frac{V^2}{R}$:

$$24 = \frac{6.0^2}{\frac{2R}{3}} \qquad R = 2.25\,\Omega \; (2.3\,\Omega) \text{ (Answer D)}$$

Question 32

As the potential difference (p.d.) across a filament lamp is increased, the current in the lamp increases, heating the filament and raising its resistance. Graph **C** shows a constant resistance and graph **D** shows the resistance of the filament decreasing, so both these graphs are incorrect. Graph **B** is also incorrect, as it shows the resistance of the filament as zero when the p.d. across the filament is zero.

The correct graph is **A**.

PHYSICS

| Paper 9702/12 |
| Multiple Choice |

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

General Comments

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

When answering numerical questions, it is a good idea to try to calculate the answer before looking at the answer options. Candidates need to ensure that the units used in a calculation are consistent, particularly if the information includes prefixes 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 10**, **13**, **14**, **15**, **21**, **29** and **37** particularly difficult, but found **Questions 5**, **16**, **17**, **19**, **25**, **27**, **35** and **40** relatively straightforward.

Comments on specific questions

Question 1

This question was answered correctly by most candidates (answer **B**). Some candidates thought that $9000\ cm\ s^{-1}$ was not a reasonable estimate of the maximum speed of a racing car.

$9000\ cm\ s^{-1} = 90\ m\ s^{-1} = 0.09\ km\ s^{-1} = 0.09 \times 60 \times 60\ km\ h^{-1} = 324\ km\ h^{-1}$ (~200 mph) (incorrect answer **C**)

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Question 2

The majority of candidates answered this question correctly. Weaker candidates confused quantities with units. In this example, time is an SI base quantity (answer **D**) and its units are seconds (incorrect answer **C**).

Question 3

Most candidates calculated the value of the acceleration correctly, though some calculated the absolute uncertainty in the value incorrectly. One approach is to calculate the difference between the maximum and minimum values and halve it to find the absolute uncertainty. In this question:

$$a_{max} - a_{min} = \frac{2 \times 16.6}{14.0^2} - \frac{2 \times 16.4}{16.0^2} = 0.04 \text{ so the absolute uncertainty is } \pm 0.02 \text{ m s}^{-2} \text{ (answer } \mathbf{D})$$

Question 4

The majority of candidates answered this question correctly (answer **A**), though some confused $\sin\theta$ and $\cos\theta$ when resolving forces parallel to, and perpendicular to, the direction of the aeroplane.

Question 6

As there is no air resistance, the horizontal component of the velocity v_x is unchanged after 9.00 s. Using $v = u + at$ to find v_y, the vertical component of velocity after 9.00 s is:

$$v_y = u + at = 8.00 - 1.62 \times 9.00 = -6.58 \text{ m s}^{-1} \quad \text{(incorrect answer } \mathbf{A})$$
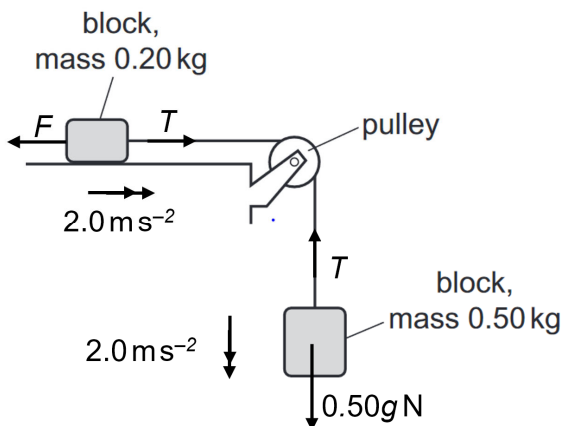
The speed v of the ball after 9.00 s is:

$$v = \sqrt{v_x^2 + v_y^2} = \sqrt{4.00^2 + (-6.58)^2} = 7.70 \text{ m s}^{-1} \quad \text{(Answer } \mathbf{B})$$

Some candidates just added the magnitudes of the two components (10.6 m – incorrect answer **C**). Others calculated the change in the vertical component of the velocity after 9.00 s :

$$(9.00 \times 1.62 = 14.6 \text{ m s}^{-1} - \text{incorrect answer } \mathbf{D})$$

Question 7

For weaker candidates, incorrect answers **B** and **C** were popular.

The tension T in the string acts on both masses as shown. If the friction force acting between the lighter block and the rough surface is F, then applying $F = ma$ to both blocks:

$$T - F = 0.20 - 2.0 \text{ and } 0.50g - T = 0.50 \times 2.0$$

Adding these two equations: $0.50g - F = 0.70 \times 2.0 \Rightarrow F = 3.5 \text{ N (Answer } \mathbf{A})$

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Question 9

Most candidates answered this question correctly. An object falling from rest from a helicopter will initially fall with an acceleration of 9.81 m s^{-2} as only the weight of the object is acting on the object. As the object's speed increases, the air resistance acting on the object increases and the net force acting on the object (weight – air resistance) decreases, so the acceleration decreases. Eventually the air resistance matches the weight and the object continues to fall at a constant (terminal) velocity. Only statement **B** is correct.

Question 10

Candidates found this challenging, with **B** the most popular incorrect answer. The total momentum of the two balls before they collide is zero, so the total momentum of the two balls after the collision is also zero. As the ball of mass m rebounds to the left with velocity v, the ball of mass $2m$ must rebound with velocity $\dfrac{v}{2}$ to the right. The loss of kinetic energy in the collision is therefore:

$$\frac{1}{2}m(2v)^2 + \frac{1}{2}2mv^2 - \frac{1}{2}mv^2 - \frac{1}{2}2m\left(\frac{v}{2}\right)^2 = \frac{9}{4}mv^2 \quad \text{(answer C)}.$$

Question 13

Candidates found this challenging, with **A** the most popular incorrect answer.
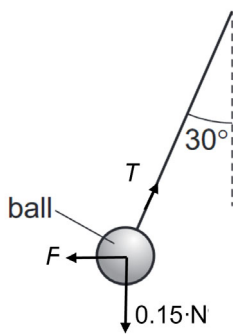
If the tension in the string is T and the force on the ball due to the air flow is F, then:

resolving horizontally: $F = T \sin 30$

resolving vertically: $T \cos 30 = 0.15$

Combining these two equations: $F = \dfrac{0.15}{\cos 30} \times \sin 30 = 0.087 \text{ N}$ (answer **B**)

Candidates selecting incorrect answer **A** calculated $0.15 \sin 30$.

Question 14

Candidates found this challenging, with **A** and **B** popular incorrect answers.

In **A**, the force due to the liquid acting on the top surface of X must be *less than* that acting on the top surface of Y as the pressure acting on the top surface of Y is greater than that on the top surface of X (greater depth) and the surface area of the top of Y is greater than the top surface of X.

In **B**, the pressure difference due to the liquid between the top and bottom surfaces of X must be *greater than* the pressure difference between the top and bottom surfaces of Y as the height of cylinder Y is greater ($\Delta p = \rho g \Delta h$).

In **C**, recalling Archimedes' principle, the upthrust is equal to the weight of the liquid displaced. As X and Y have the same volume, the upthrust on each must be the same.

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Question 15

Candidates found this challenging, with **B** and **C** popular incorrect answers.

The resistive force is $F = kv^2$, where v is the velocity of the car and k is a constant.

For the journey at 70 km h^{-1}, the work done against the resistive force F is:

$$kv^2 \times \left(80 \times 10^3\right) = k\left(\frac{70{,}000}{60 \times 60}\right)^2 \times \left(80 \times 10^3\right) = E \quad \text{equation 1}$$

For the journey at 60 kmh^{-1}:

$$kv^2 \times \left(80 \times 10^3\right) = k\left(\frac{60{,}000}{60 \times 60}\right)^2 \times \left(80 \times 10^3\right) = E' \quad \text{equation 2}$$

Combining equations 1 and 2:

$$\frac{E'}{E} = \left(\frac{60{,}000}{70{,}000}\right)^2 = 0.73 \quad E' = 0.73E \quad \text{(answer A)}$$

Question 18

Most candidates answered this question correctly, with incorrect answer **D** popular for weaker candidates. If the spring constant of one of the springs is k, the spring constant of combination **B** is $3k$ (the largest combined spring constant). The spring constant for **D** is $k/3$. The overall spring constants in **A** and **C** are, respectively, $3k/2$ and $2k/3$.

Question 20

Most candidates answered this question correctly (answer **D**) with **B** the most popular incorrect answer. The two points X and Y are three-quarters of a wavelength apart. The phase difference is therefore:

$$\frac{\frac{3}{4}\lambda}{\lambda} \times 360° = 270° \text{ (answer D)}$$

Incorrect answer **B** is half the correct answer.

Question 21

Candidates found this question challenging, with **A** or **B** popular incorrect answers. At time $t = 0$ the displacement of particle X is zero which eliminates **B** and **D** as possible answers. A short time after $t = 0$ the graph of displacement versus distance will have moved a little to the right which means the particle X will initially move *down*. The correct graph is therefore graph **C**, and not graph **A**.

Question 23

Most candidates answered this question correctly (answer **C**). Candidates should be able to recall the approximate range of wavelengths in free space of the principal regions of the electromagnetic spectrum from radio waves to γ-rays. If needed, the corresponding frequencies can be calculated using $c = f\lambda$.

Question 24

Candidates found this question challenging. The initial intensity of the light passing through the first filter is zero, indicating that the source of polarised light is horizontally polarised. From Malus' law, the light transmitted through the second filter is

$$I_1 = I_0 \cos^2 45° = \frac{I_0}{2}$$

The angle between the transmission axes of the first and second filters is 45° so the light now transmitted through the first filter is:

$$I_2 = I_1 \cos^2 45° = \frac{I_0}{2} \cos^2 45 = \frac{I_0}{4} \quad \text{(Answer } \mathbf{C}\text{)}$$

Question 28

For a double slit experiment

$$\lambda = \frac{ax}{D}$$

where λ is the wavelength of the light, a is the distance between the two slits, x is the distance between interference fringes and D is the distance between the slits and the screen. Rearranging this equation:

$$x = \frac{\lambda D}{a}$$

As the slit separation a increases, x decreases, with D and λ constant, thus eliminating graphs **C** and **D**. Since $x \propto \frac{1}{a}$ the correct graph is graph **A**.

Question 29

Candidates found this question challenging, with **A** or **B** popular incorrect answers. Weaker candidates ignored the fact that maxima ('bright spots') would be observed on **both** sides of the central zero-order maximum. Applying the diffraction grating equation:

$$\sin \theta = \frac{n\lambda}{s} < 1$$

$$n < \frac{s}{\lambda} = \frac{\dfrac{1 \times 10^{-3}}{300}}{690 \times 10^{-9}} = 4.8$$

i.e. there are 4 possible maxima either side of the central zero order maximum making a total number of 9 maxima that can be observed on the screen (Answer **D**).

Question 30

The question states that oil droplets leaving the nozzle *can* become electrically charged. Therefore, any multiple of the electronic charge e is possible, including zero. The answer to the question is **B** as this is the only value which is not a multiple of e, 1.6×10^{-19} C.

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Question 31

Candidates found this question challenging, with **C** the most popular incorrect answer.
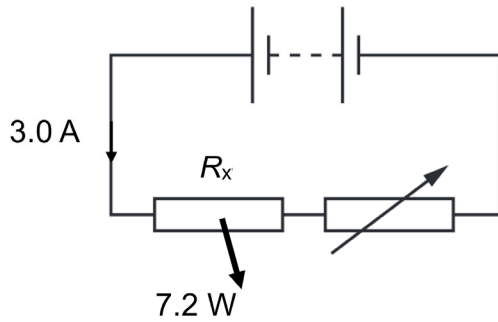
If the resistance of the fixed resistor is R_x, then using $P = I^2R$:

$$R_x = \frac{P}{I^2} = \frac{7.2}{3.0^2} = 0.8\,\Omega$$

If the power dissipated in X increases by 50%, the new current is:

$$I = \sqrt{\frac{P}{R_x}} = \sqrt{\frac{7.2 \times 1.5}{0.8}} = 3.7 \text{ A (answer } \mathbf{B})$$

Question 32

Candidates found this question challenging. For a wire of length l, cross-sectional area A and resistivity ρ, the resistance R of the wire is:

$$R = \frac{\rho l}{A}$$

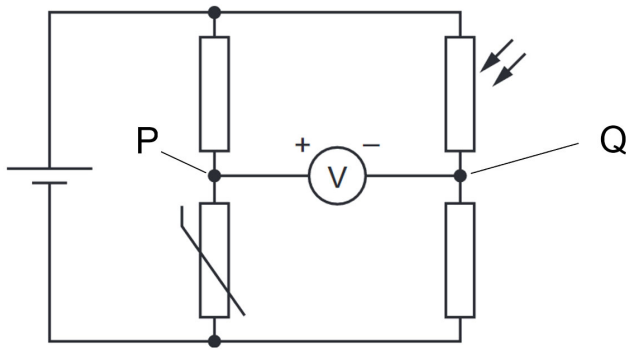The potential difference across the wire is kept constant, so:

$$I = \frac{V}{R}$$

where V is constant. Combining these two equations, and recalling the cross-sectional area of the wire $A = \frac{\pi d^2}{4}$, where d is the diameter of the wire:

$$I = \frac{VA}{\rho l} = \frac{\pi V d^2}{4\rho l}$$

The current is inversely proportional to l and directly proportional to d^2 (Answer **D**).

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Question 33

One way to approach this question is to consider the p.d. across P and Q indicated on the circuit diagram. As the temperature increases, the resistance of the thermistor decreases and the p.d. across the thermistor falls – the voltmeter reading will decrease. As the light intensity increases, the resistance of the light dependent resistor (LDR) decreases and the p.d. across the LDR falls – the voltmeter reading will again decrease. Answer **A**.

Question 37

The circuit is an example of a 'null method'. If the cell being tested has an e.m.f. of 1.5 V the galvanometer only has to read zero to confirm this; it doesn't need to be calibrated in amperes (answer **D**).

Question 39

Candidates found this question challenging. The table below shows the masses and charges of the three particles.

	charge	mass / kg	r = charge / mass
β^+	+e	9.1×10^{-31}	$1.1 \times 10^{30}e$
p	+e	1.7×10^{-27}	$5.9 \times 10^{26}e$
α	+2e	6.6×10^{-27}	$3.0 \times 10^{26}e$

In order of *increasing* magnitude of r : $\alpha \rightarrow p \rightarrow \beta^+$ (answer **B**)

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PHYSICS

Paper 9702/13
Multiple Choice

Question Number	Key	Question Number	Key	Question Number	Key	Question Number	Key
1	B	11	C	21	D	31	A
2	A	12	B	22	A	32	D
3	C	13	B	23	B	33	A
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6	C	16	B	26	B	36	D
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Comments on specific questions

Question 6

Candidates found this question challenging, with **A** the most popular incorrect answer.

The time T_M taken for an object to fall a height h from rest on Mars can be found using $s = ut + \frac{1}{2}g_M t^2$, where g_M is the acceleration of free fall on Mars. Rearranging the equation:

$$\left(T_M\right)^2 = \frac{2h}{g_M}$$

Similarly, the time T_E for an object to fall the same height from rest on Earth is:

$$\left(T_E\right)^2 = \frac{2h}{g_E}$$

Combining these two equations:

$$\left(\frac{T_M}{T_E}\right)^2 = \frac{g_E}{g_M} = \frac{9.81}{3.71} = 2.64 \quad \text{(incorrect answer } \mathbf{D})$$

and

$$\frac{T_M}{T_E} = \sqrt{2.64} = 1.63 \quad \text{(Answer } \mathbf{C})$$

Question 8

The change in momentum of the snooker ball during the collision is:

$\Delta(mv) = 0.200 \times [14.0 - (-7.0)] = 4.2 \text{ kg m s}^{-1}$

Using force = rate of change of momentum, the average force F acting on the ball is:

$$F = \frac{4.2}{0.60} = 7.0 \text{ N (answer } \mathbf{D})$$

Some candidates ignored the change in direction of the snooker ball, calculating the difference in the two momenta as $0.200 \times [14.0 - 7.0] = 1.4 \text{ kg m s}^{-1}$, leading to a value for the average force of 2.3 N (incorrect answer **B**).

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Question 12

Candidates found this question challenging, with **D** the most popular incorrect answer.
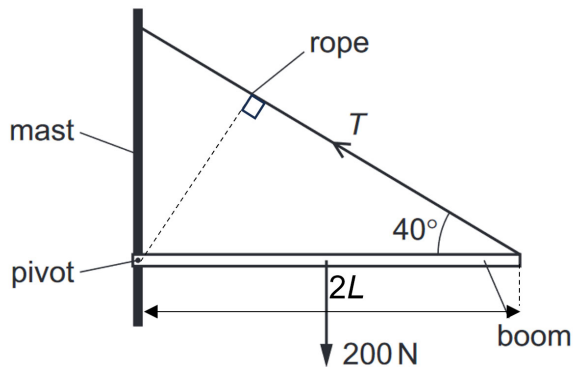
Let the length of the boom be 2*L*. Taking moments about the pivot:

$T \times 2L \sin 40° = 200 \times L$
$T = 160\,\text{N}$ (Answer **B**)

Some candidates calculated *T* assuming all the weight of the boom acted at the far end of the boom rather than its centre (incorrect answer **D**).

Question 15

- The wooden cylinder is partially submerged in a **bath** of water, so as the cylinder is pushed down into the water, some of the water must rise, gaining gravitational potential energy. (**A**)
- As the cylinder is lowered it must lose gravitational potential energy. (**B**)
- Work is done by force *F* since it moves in the direction of the force. (**C**)

Statements **A**, **B** and **C** are all correct, leaving statement **D** as the incorrect statement.

Question 17

Candidates found this question very challenging, with **C** the most popular incorrect answer.

In *t* seconds, the parachutist will fall a distance *vt*. The change in the gravitational potential energy of the parachutist in this time is *mgvt* where *m* is the mass of the parachutist. The rate *R* at which she is losing gravitational potential energy is:

$$R = \frac{mgvt}{t} = mgv \Rightarrow m = \frac{R}{gv} \quad \text{(Answer \textbf{B})}$$
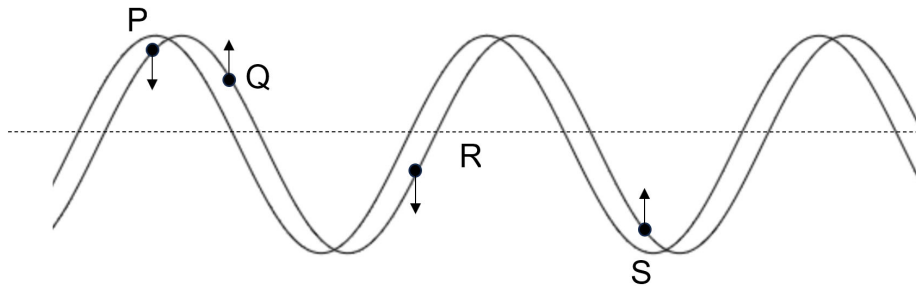
Question 20

Candidates found this question challenging.

When the gradient of the displacement–time graph is zero, the velocity of the air particle, and its kinetic energy, is also zero. This means graphs **A** and **C** are incorrect. The velocity, and kinetic energy, are zero at time zero, time *T*/2, time *T*, time 3*T*/2 and time 2*T*, so **D** is the correct graph.

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Question 21

Almost all candidates realised that the particle at S is about to move upwards though fewer candidates identified that Q would also be moving upwards, with **C** a popular incorrect answer. One approach to this type of question is to draw the wave shortly after the instant shown.

Points Q and S must move up (answer **D**) and points P and R must move down.

Question 24

From Malus' law, the intensity of electromagnetic radiation transmitted through the first polarising filter is:
$I_1 = I_0 \cos^2 30 = 0.75 I_0$

The transmission axes of the first and second filters are at an angle of $60°$ to each other, so the intensity of radiation transmitted through the second filter is:

$I_1 \cos^2 60 = 0.75 \, I_0 \cos^2 60 = 0.19 \, I_0$ (Answer **C**)

Question 25

Most the candidates answered this question correctly, with **B** the most popular incorrect answer.

A simple stationary wave on a string has all the particles oscillating in phase between two adjacent nodes. Statement **A** is correct.

The amplitude of a stationary wave is equal to the **sum** of the amplitudes of the waves causing it. The wavelength of the stationary wave is equal to **twice** the separation of two adjacent nodes. There is no displacement of a particle at a **node** at any time.

Question 26

Most candidates answered this question correctly. The stationary wave with the lowest frequency has the longest wavelength. The lowest frequency stationary wave in a pipe closed at one end and open at the other has a quarter of a wavelength in the pipe:
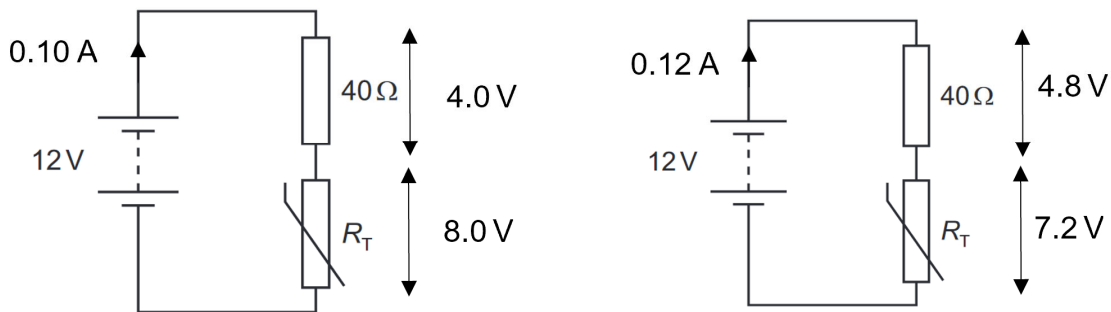
$$\frac{\lambda}{4} = 2L \qquad \lambda = 8L$$

A pipe open at both ends has half a wavelength in the pipe:

$$\frac{\lambda}{2} = 2L \qquad \lambda = 4L$$

The pipe with the lowest frequency is **B**.

Question 33

Initially, the current in the circuit is 0.10 A, so the p.d. across the fixed resistor is 4 V and the p.d. across the thermistor is 8 V.

When the temperature changes, the p.d. across the fixed resistor is 4.8 V, so the p.d. across the thermistor is 7.2 V. The resistance of the thermistor is $\frac{4.8}{0.12} = 60\,\Omega$.

The initial resistance of the thermistor was $\frac{8.0}{0.10} = 80\,\Omega$ i.e. the resistance of the thermistor has *decreased*, indicating that the temperature has *increased*. (Answer **A**)

Question 35

Most candidates answered this question correctly, with **B** and **D** popular incorrect answers.

As the three resistors are all in parallel with the cell, applying Kirchhoff's second law:

$V_0 = V_1 = V_2 = V_3$ (Answer **C**)

It is also true that $I_o = I_1 + I_2 + I_3$ (incorrect answer **B**) but this is obtained by applying Kirchhoff's first law.

Question 37

The majority of candidates answered this question correctly, though some thought that the internal resistance of the new cell must be zero (incorrect answer **C**). When the sliding contact is in the correct 'null' position, the galvanometer reads zero i.e. there is no current in the cell so no potential difference across the e.m.f. of the cell. The correct requirement is that the resistance per unit length of the wire QR is constant (answer **D**), so that the p.d. between Q and P is proportional to the length QP.

PHYSICS

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Paper 9702/21
AS Level Structured Questions 21
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Key messages

- Candidates need to be able to recall all the standard formulae given in the syllabus.

- In numerical calculations, candidates should remember to first write down the appropriate symbol equation before substituting in the relevant values. If the equation is rearranged, the new subject of the equation should always be stated.

- Candidates should read each question carefully before answering. It is important to avoid merely scanning the question as important instructions may be overlooked.

- Candidates should consider checking whether their numerical answers have a plausible magnitude, as this check can often detect power-of-ten errors or other arithmetic errors that have been made during a calculation.

General comments

There were certain question parts that most candidates found particularly challenging. Many candidates would have benefited from having a greater understanding of phase difference, double-slit interference, the Doppler effect and the α-particle scattering experiment. They found **Questions 4(c)(i)**, **4(d)**, **5(a)** and **7(a)** challenging.

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

Comments on specific questions

Question 1

(a) The majority of the candidates were able to successfully compare scalar and vector quantities.

(b)(i) Many of the calculations used an incorrect formula for the volume of a sphere. Candidates are expected to be able to use the mathematical skills and knowledge referred to in the syllabus.

(ii) Many of the stronger candidates could correctly calculate the percentage uncertainty in the volume of the sphere. Fewer candidates realised that they then needed to divide by 3 to determine the percentage uncertainty in the radius. A common mistake was to multiply by 3 instead of dividing by 3.

Question 2

(a)(i) The directions of the weight and the upthrust were usually shown correctly. Weaker candidates sometimes did not appreciate that there was a downward force on the balloon due to the tension in the rope.

(ii) Most candidates realised that they needed to use the formula for upthrust that is given on page 2 of the question paper. A common error was to assume that the upthrust acting on the balloon was equal to the balloon's weight (which ignores the force on the balloon due to the tension in the rope).

(iii) It was generally understood that the initial acceleration of the balloon would be equal to the initial resultant force on the balloon divided by its mass. A common error was to assume that the initial resultant force was equal to the upthrust (which ignores the weight of the balloon).

(b) A large majority of the candidates realised that the ball would hit the ground at a lower speed because there was air resistance acting on the ball. Stronger candidates also correctly commented that the acceleration of the ball would decrease. Very few candidates fully explained how the air resistance would affect the resultant force acting on the ball.

(c) (i) Generally, this question was well answered. In questions that have the command word 'show', it is essential that the candidates clearly and explicitly show the full calculation as well as stating the final answer.

(ii) Many candidates found it difficult to recall the appropriate formula for calculating elastic potential energy. Those that could recall the correct formula usually went on to calculate the correct answer.

(iii) The most common mistake was to assume that the lower Young modulus of the new rope would cause it to have a shorter extension and therefore a lower elastic potential energy. Only the stronger candidates correctly deduced that the new rope would have a longer extension and therefore a higher elastic potential energy.

Question 3

(a) It was expected that candidates would recall that the area under a velocity–time graph represents displacement. Many candidates also correctly stated that the area under the velocity–time graph in Fig. 3.2 represents the distance travelled by trolley B. Some of the weakest candidates thought that the area under a velocity–time graph represented acceleration.

(b) (i) This question was reasonably well answered. The weakest candidates sometimes thought that acceleration was equal to velocity divided by time and substituted values from a single point on the graph line. Such candidates did not appreciate that acceleration is equal to change in velocity divided by change in time and that this corresponds to the gradient of the velocity–time graph.

(ii) Different methods of calculation were possible. The most common method was to apply the principle of conservation of momentum to the collision of the trolleys. A small minority of the candidates attempted to apply conservation of kinetic energy to the collision. Those candidates who were able to determine the correct magnitude of the final velocity were usually also able to determine the correct direction of that velocity.

(c) Most candidates could correctly sketch the first part of the graph corresponding to the constant velocity of trolley A over the first 0.15 s. Stronger candidates also correctly deduced that between 0.15 s and 0.35 s the graph line would be a downward-sloping straight line. A common mistake was to sketch the constant velocity after 0.35 s with a positive sign instead of the required negative sign.

Weaker candidates sometimes attempted to do a sketch in the blank space at the bottom of page 7 instead of following the instruction to do the sketch on Fig. 3.2. Such 'off-grid' sketches can rarely be awarded full credit because the examiner cannot determine whether the graph line has been drawn with the required accuracy.

Question 4

(a) Some candidates were able to partially state the principle of superposition by referring to two or more waves meeting at a point. Many candidates did not state that the resultant displacement is equal to the sum of the individual displacements of the waves at that point. Some candidates confused displacement with amplitude. It is important for candidates to be able to precisely recall all the relevant laws, definitions, and terms from the syllabus as sometimes the incorrect recall of a word can mean that full credit cannot be awarded.

(b) Some of the weaker candidates were unable to recall the relevant formula. Those that could recall the appropriate formula usually went on the calculate the correct wavelength of the light. Some candidates did not remember to convert from millimetres to metres when substituting the values of the slit separation and the fringe width.

(c) (i) The majority of the candidates found this question to be challenging. There were different ways of explaining why the phase difference between the waves is 90°. The most common correct explanation was that one wave has maximum displacement when the other wave has zero displacement.

(ii) Most candidates correctly stated that the amplitude of the resultant wave would not be zero, but many found it difficult to explain why it was not zero. The most common correct explanation was that the amplitude of the resultant wave could not be zero because the two waves did not have a phase difference of 180°.

(d) Many candidates seemed to confuse the width of each slit with the separation between the slits and therefore incorrectly stated that there would be an increase in distance between adjacent fringes. Only the strongest candidates could explain that the decrease in width of each slit would lead to more diffraction and therefore more fringes would be produced without any change in the fringe spacing. Very few candidates commented that the bright fringes would become less bright.

Question 5

(a) In general, candidates found it challenging to use their knowledge of the Doppler effect to sketch the correct graph line. Many candidates did not understand that the observed frequency would be greater than the source frequency until time t_1 and then less than the source frequency after that time.

(b) Many candidates were unable to recall that power is equal to the product of intensity and area. Some candidates did not remember to convert the value of the radius from centimetres to metres when calculating the area of the circular detector.

Question 6

(a) (i) Generally, this question was well answered.

(ii) Different methods of calculation were possible. The most common method was to first determine the total resistance of the LDR and 720 Ω resistor connected in parallel. The formula for two resistors in parallel (given in the list of formulae on page 2 of the question paper) could then be used to calculate the resistance of the LDR. Candidates who used this method sometimes used the incorrect formula of $R = 1 / R_1 + 1 / R_2$ instead of the correct formula $1 / R = 1 / R_1 + 1 / R_2$.

Another common method was to first calculate the current in the 720 Ω resistor. Kirchhoff's first law could then be applied to calculate the current in the LDR and then finally that current could be used to calculate the resistance of the LDR.

(iii) Some of the weaker candidates were able to gain partial credit by recalling an appropriate formula for power. Some of the stronger candidates made the mistake of assuming that the current in the LDR was equal to the current in the 240 Ω resistor.

(b) It was important for candidates to avoid making a vague reference to resistance without being explicitly clear which resistance they were describing. A comment about a resistance changing could be referring to the resistance of the LDR, the combined resistance of the resistors in parallel or the total resistance of the circuit. Similarly, candidates needed to avoid making vague references to current or potential difference without precisely specifying which current or which potential difference they were commenting on. A common misconception was that the increase in intensity of the light incident on the LDR would cause its resistance to increase.

Question 7

(a) Many candidates vaguely stated that some of the α-particles went straight through or were deflected by small angles and that some of the particles were deflected back through large angles. It was important to state that a very *large proportion* of the particles went straight through or were deflected by small angles and that only a very *small proportion* were deflected back through large angles. Candidates should be encouraged to refer to the proportion of the α-particles that are affected when describing a result of the α-particle scattering experiment.

(b)   Candidates needed to explicitly refer to an electromagnetic wave or to electromagnetic energy. It was also acceptable to state that γ-radiation is made of photons. It was insufficient to state only that γ-radiation is composed of a wave or of energy.

Some candidates only stated that γ-radiation has no charge or no mass. This describes the radiation, but does not give its composition. A significant number of the weaker candidates left the answer line blank.

(c)   Stronger candidates usually knew that neutrinos and positrons are both leptons, although a significant number incorrectly thought that a positron was a hadron. Many candidates indicated that a neutron was only a hadron instead of indicating that it was both a baryon and a hadron.

(d) (i)   The question asked for the answer to be given to three significant figures. Therefore, it was essential that the answer was presented to exactly three significant figures. A small number of candidates appeared to overlook this instruction and gave their answers to only two significant figures.

(ii)   Most candidates correctly deduced that the hadron would consist of three quarks with each quark having a charge of +(2/3)*e*. The hadron could be composed of quarks with different possible combinations of flavours. The most common correct composition given by the candidates was three up quarks.

PHYSICS

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Paper 9702/22
AS Level Structured Questions

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Key messages

- Candidates need to be able to recall all the standard formulae given in the syllabus.

- In numerical calculations, candidates should remember to first write down the appropriate symbol equation before substituting in the relevant values. If the equation is rearranged, the new subject of the equation should always be stated.

- Candidates should read each question carefully before answering. It is important to avoid merely scanning the question as important instructions may be overlooked.

- Candidates should consider checking whether their numerical answers have a plausible magnitude, as this check can often detect power-of-ten errors or other arithmetic errors that have been made during a calculation.

General comments

There were many parts of questions that were straightforward to answer so that weaker candidates had many opportunities to be awarded credit. Other question parts were more challenging and suitable for the stronger candidates.

In **Question 1(c)(iii)**, many candidates did not know how to calculate displacement from a velocity–time graph. In **Question 3(c)(ii)**, many candidates would have benefited from having a greater understanding of how energy transfer may be used to determine an average frictional force. In **Question 4(b)**, many candidates did not realise that, in an elastic collision between two objects, the relative speed of approach is equal to the relative speed of separation. In **Question 5(c)(ii)**, many candidates would have benefited from having a deeper understanding of how to determine a wavelength of visible light by using a diffraction grating.

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

Comments on specific questions

Question 1

(a) This question was well answered. The most common mistake was to identify charge, rather than current, as an SI base quantity.

(b) Many of the stronger candidates correctly understood that the object must have a constant non-zero magnitude of acceleration. Sometimes candidates contradicted themselves by stating that the object was accelerating, but with a constant velocity. Only the strongest candidates correctly stated that the initial speed of the object must be zero. Some candidates stated that the object was moving in a straight line, but that was not awarded credit because it was already stated in the question stem.

(c) (i) In general, candidates found this part of the question to be challenging. Many candidates did not realise that the acceleration was equal to the gradient of the velocity–time graph and that they could compare the magnitudes of the accelerations by comparing the magnitudes of the gradients at the two stated times. Some candidates incorrectly interpreted the graph as being an

acceleration–time graph and so described the acceleration increasing up to a time of 12 s and then decreasing. Weaker candidates often did not appear to understand that the direction of the acceleration of the car is not necessarily in the same direction as its velocity.

(ii) Generally, this question was well answered. A small minority of candidates incorrectly thought that acceleration was equal to velocity divided by time instead of change in velocity divided by time taken.

(iii) Some candidates recalled that the displacement could be determined from the area under the velocity–time graph. Most candidates found it difficult to apply this knowledge to the given graph. Often, they did not understand that the section of the graph below the time axis corresponded to a negative (rather than positive) displacement. Candidates who used equations of uniformly accelerated motion needed to be careful that each value was substituted with the correct sign.

Question 2

(a) Generally, this question was well answered. A small minority of the weaker candidates confused weight with mass.

(b) (i) This question was usually answered correctly. The most common incorrect answer was zero.

(ii) Most responses mentioned the presence of air resistance, although some candidates did not explain that the air resistance would increase. Only a small minority of the candidates correctly explained that this would then cause the resultant force on the sphere to decrease. Many candidates correctly stated that the acceleration of the sphere would decrease, although some of the weaker candidates thought that the acceleration would initially increase before it started to decrease. A common misconception was that the air resistance would cause deceleration rather than decreasing acceleration.

(c) Many candidates were able to calculate the resultant force acting on the sphere. The strongest candidates went on to use the resultant force and the weight to determine the total resistive force.

Question 3

(a) Most candidates could recall the relevant formula for the elastic potential energy of a spring. A common mistake was to then forget to convert the compression of the spring from centimetres to metres. Other candidates did not square the value of the compression when substituting it into the formula.

(b) The formula for the kinetic energy was usually given correctly. The most common mistake was not converting the mass of the spring from grams to kilograms.

(c) (i) The formula for the change in the gravitational potential energy was usually stated correctly. A common mistake was to substitute into the formula an incorrect value for the increase in gravitational potential energy.

(ii) Most candidates found this part of the question to be very challenging and a significant number left the calculation and answer space blank. Some stronger candidates understood that they could determine the average frictional force on the spring by first calculating the work done against the frictional force. Many of those candidates began by calculating an incorrect value of the work done.

(d) Most candidates appeared to guess a line shape for their sketch graph. The most common incorrect shapes were a straight line from the origin and a curved line of decreasing gradient from the origin.

Question 4

(a) (i) This question was reasonably well answered. Some candidates omitted the mass of the ball from their calculation and therefore determined the resolved component of velocity rather than momentum. Another common mistake was to use cos 27° instead of sin 27°, which gave the wrong component of momentum.

(ii)   Most candidates realised that the algebraic sum of the two momenta perpendicular to line PQ would be zero. Many candidates made an arithmetic error when calculating the mass of the ball.

(iii)   It was expected that the candidates would use Newton's third law of motion to deduce that the two forces would be equal and opposite. A common misconception was that the magnitude of F_Y was greater than the magnitude of F_Z. It was insufficient to describe the directions as just 'different' rather than 'opposite'. Candidates should be encouraged to use precise language in descriptive questions of this type.

(b)   Many candidates tried to use equations corresponding to the conservation of momentum and the conservation of kinetic energy. Those candidates were usually unable to complete their calculations because the masses of the blocks were unknown. Typically only the stronger candidates recalled that the relative speed of approach would be equal to the relative speed of separation. Those candidates were able to obtain the correct answer using a short and simple calculation.

Question 5

(a) (i)   Although many candidates correctly deduced the angles at which the intensity of the light would be maximum and zero, only a small minority were able to sketch the shape of the overall curve correctly. A common misconception was that the graph would consist of a series of straight lines forming a 'zig-zag' shape.

(ii)   Most candidates were able to recall the correct symbol equation. The most common mistake was to then forget that the cosine function was squared when rearranging the recalled equation. Another common mistake was to substitute the intensities of the incident light and the transmitted light the wrong way round.

(b)   It was usually stated correctly that diffraction takes place when a wave passes through an aperture or by an edge. Candidates also needed to state that this causes the wave to spread (into the geometrical shadow). Candidates should be encouraged to avoid using the term 'bend' instead of 'spread' as that could be describing refraction or reflection.

(c) (i)   Generally, this question was well answered. Weaker candidates were sometimes unable to recall the correct symbol equation or made inappropriate attempts to apply the symbol equation for the double-slit interference of light.

(ii)   This question was challenging and a significant number of the weaker candidates left the calculation and answer spaces blank. A common mistake was to calculate the same wavelength of 430 nm instead of a different wavelength. Other candidates sometimes calculated a different wavelength, but not one of visible light.

Question 6

(a)   Most candidates were able to recall the relevant symbol equation and then apply it correctly.

(b) (i)   In general, this was very well answered. In questions that have the command word 'show', it is essential that the candidates clearly and explicitly show the full calculation as well as stating the final answer.

(ii)   Many candidates were able to calculate the total charge passing through the LDR, although only a small minority understood how to determine the number of free electrons from that total charge.

(iii)   Different methods of calculation were possible. The most common mistake was to treat the two fixed resistors as if they were in parallel instead of in series.

(iv)   Most candidates were able to correctly recall an appropriate formula for the power dissipated in a resistor. The most common mistake was to assume that the potential differences across the resistors were the same which then gave a final answer that was the reciprocal of the correct ratio.

(c) (i)   Most candidates successfully recalled that the resistance of an LDR decreases when the light intensity increases.

(ii) This question was usually answered correctly. A common misconception was that there would be no change to the current in the battery.

(iii) This question was usually answered correctly. The most common incorrect answer was that there would be no change to the reading of the voltmeter.

Question 7

(a) The phrase '**not** fundamental' seemed to confuse some candidates. A small proportion of the candidates appeared to misread the question and underlined only particles that were fundamental.

(b) Most candidates were able to apply the conservation of nucleon number to determine that 6 α-particles would be emitted during the sequence of decays. Fewer candidates were able to apply conservation of charge to determine the number of β⁻ particles that would also be emitted.

(c) Although this was very straightforward for stronger candidates, some of the weaker candidates had not learnt the basic knowledge needed to answer the question. Some confused a meson with a baryon. Weaker candidates could have improved by a more thorough learning of the charges of the different flavours of quarks and antiquarks.

PHYSICS

Paper 9702/23
AS Level Structured Questions 23

Key messages

- Candidates need to be able to recall all the standard formulae given in the syllabus.

- In numerical calculations, candidates should remember to first write down the appropriate symbol equation before substituting in the relevant values. If the equation is rearranged, the new subject of the equation should always be stated.

- Candidates should read each question carefully before answering. It is important to avoid merely scanning the question as important instructions may be overlooked.

- Candidates should consider checking whether their numerical answers have a plausible magnitude, as this check can often detect power-of-ten errors or other arithmetic errors that have been made during a calculation.

General comments

There were many opportunities for the weaker candidates to show their understanding in straightforward question parts. Other question parts were more demanding and required the careful application of knowledge to challenging situations.

In **Question 2(a)**, many candidates were unable to link the vertical component of the velocity to the given horizontal component. A significant number were also unable to apply the equations of constant acceleration to the whole path of the ball to the wall.

In **Questions 6(a)** and **7(c)(i)**, many candidates used the relevant formula given on the formulae sheet of the question paper, but a significant number substituted inappropriate values from the data provided. Those candidates could improve by further practice in applying the given formulae.

In **Question 7**, many candidates would have benefited from having a deeper understanding of potentiometer circuits. Candidates can improve their understanding by practising answering circuit questions when they prepare for the exam.

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

Comments on specific questions

Question 1

(a)   Most candidates were able to identify at least one of the scalar quantities in the given list. A common misconception was that upthrust (a force) is a scalar quantity.

(b)(i) The majority of the candidates correctly calculated the required percentage uncertainties. A small number of candidates inappropriately doubled the percentage uncertainty in the diameter.

   (ii)   A significant number of the candidates made an error when attempting to change the units of grams into kilograms and millimetres into metres. Some candidates did not follow the instruction to give their answer to three significant figures.

(iii) This question was usually answered correctly. A small minority of the candidates did not double the percentage uncertainty in the diameter.

Question 2

(a) (i) Most candidates were able to show the correct calculation.

(ii) Many candidates were able to link the vertical and horizontal components of the velocity with the angle given. Weaker candidates sometimes used an incorrect relationship between the vertical and horizontal components of velocity. Some candidates used the given horizontal component of velocity of $9.5\,\mathrm{m\,s^{-1}}$ as the actual velocity of the ball.

(iii) Many of the candidates were able to correctly apply the equations of uniform acceleration to the vertical motion of the ball. Different methods of calculation were possible. Some candidates wrongly assumed that the acceleration and the vertical component of the velocity were always in the same direction. A small minority of the weaker candidates attempted to calculate the height using a right-angled triangle which wrongly assumes that the ball follows a straight-line path to the wall.

(b) The majority of the candidates gave a correct answer. A significant number gave an incomplete answer by stating that the energy had decreased instead of stating that the *kinetic* energy had decreased.

Question 3

(a) The majority of the candidates gave one of the conditions for equilibrium in terms of the resultant force being zero. The condition in terms of the resultant moment being zero was not always given. Some of the weaker candidates confused moment with momentum.

(b) (i) The volume was usually calculated correctly.

(ii) Some candidates ignored the upthrust and used only the force provided by the fans to balance the weight of the airship. Other candidates inappropriately subtracted the magnitude of the force due to the fans from the magnitude of the upthrust.

(c) (i) Some candidates stated an incorrect equation for the change in momentum. Other candidates used the weight of the air, instead of the thrust force caused by the air, as the force producing the change in momentum.

(ii) The speed of the air was usually calculated correctly.

(iii) Most candidates calculated the correct kinetic energy of the air.

Question 4

(a) (i) Most candidates knew that the gradient represented the spring constant. It was insufficient to state only the symbol k as the answer without words to explain what this is.

(ii) Most candidates found this question to be challenging. Many answers merely described the area in terms of $\frac{1}{2}Fx$. Only the strongest candidates related the work done on the wire to the area under the graph. A small minority of candidates did relate the work done to the gain in the elastic potential energy of the wire.

(b) (i) In general, this question was very well answered. Weaker candidates sometimes stated the extensions the wrong way round for the two wires. A small number of candidates gave the maximum extensions for each wire rather than the extensions for a force of 2.0 N.

(ii) The majority of the candidates used the correct expression for the gain in elastic potential energy for the composite wire. A significant number did not convert the extension from millimetres to metres.

(iii) The correct ratio was obtained by the very strongest candidates. Many candidates started with the correct equation for the Young modulus, but then made errors when rearranging this equation.

Question 5

(a) (i) The majority of the candidates were able to draw a cross at an interference maximum. A significant number did not follow the instruction to label this cross Y. Some candidates gave only the letter Y without a cross and so the exact position of the maximum was difficult to estimate. Other candidates gave crosses but no labelling at all for both **(i)** and **(ii)**.

(ii) Candidates found it more difficult to show the position of an interference minimum. Many candidates put a cross on another interference maximum. A small number put crosses on Fig. 5.1 in a region where the wavefronts were not shown to be overlapping.

(b) (i) This question was very well answered by most of the candidates. A small number did not correctly convert the spacing of the interference maxima from centimetres to metres or made arithmetic errors when rearranging the relevant equation.

(ii) The majority of the candidates stated the correct principal region for the wavelength given in the question. Common incorrect answers included microwave and radio wave. There were some answers that were completely unrelated to regions of the electromagnetic spectrum such as 'transverse waves'.

Question 6

(a) Most candidates used the appropriate formula given on the formulae sheet to obtain the speed of the train. Some candidates did not substitute the given values into the formula correctly. The speed of sound was sometimes confused with the speed of the train. The observed and source frequencies were sometimes substituted the wrong way round.

(b) (i) The relationship was usually stated correctly.

(ii) Only the strongest candidates sketched a straight line through the correct points. The majority sketched their line from the correct starting point, but drew a curve instead of a straight line.

Question 7

(a) Many candidates were unable to state Ohm's law. Some candidates gave an equation for resistance without introducing the idea of constant resistance. Only a small number included the condition of constant temperature.

(b) (i) Most of the candidates obtained the correct answer. A small minority of the candidates were unable to give the correct expression for the resistivity.

(ii) Candidates found this question difficult and only a minority of the candidates gave the correct reading. The majority of the candidates did not appear to understand the operation of the potentiometer circuit.

(iii) Only the strongest candidates could determine the effect of connecting a resistor in parallel with the left-hand side of the resistance wire. Many candidates appeared to guess an answer.

(iv) Many candidates were unable to show the correct position of the slider, suggesting that they did not understand the principle of the potentiometer. A significant number of candidates gave no response at all.

(c) (i) Most responses used the correct symbol formula from the formulae sheet. Sometimes incorrect values from the data were substituted. Some candidates used a value of voltage for the velocity. Other candidates omitted the value of the cross-sectional area or tried to calculate an incorrect value for the number density of the charge carriers.

(ii) Many candidates did not realise that the value obtained for the charge was less than the value of the elementary charge and therefore not valid.

Question 8

(a) (i) Most candidates were able to state at least one correct answer. There were some responses that were considered too vague such as stating just 'mass' instead of 'nucleon number' or stating just 'protons' instead of 'proton number'.

(ii) This question was usually answered correctly.

(iii) This question was usually answered correctly.

(b) A small proportion of the candidates understood that the graph showed a single discrete kinetic energy for all the particles but that for beta-decay the graph would show a continuous range of kinetic energies.

PHYSICS

Paper 9702/31
Advanced Practical Skills 31

Key messages

- If a raw value is out of trend to that expected, candidates should be encouraged to check the readings again with the equipment provided in the early stages of data collection.

- In the table work, the number of significant figures in the calculated quantity should relate to the number of significant figures in the raw data with the least number of significant figures. Each calculated quantity should be checked row by row. It is unnecessary, and often incorrect, to force the number of significant figures to be constant down a column of calculated values.

- In the graphical work, candidates should be able to read off any points to the nearest half a small square. In particular, candidates should check carefully the read-offs of points used in the gradient calculation and when determining the y-intercept.

- When justifying a number of significant figures in a calculated quantity, candidates should relate the number of significant figures in the quantity to the raw readings used in the calculation. Candidates should not use the phrase 'raw readings' without explaining what those readings are, or attempt to use intermediate calculated quantities to justify the number of significant figures.

- To be successful answering **Question 2**, candidates should be reminded that their identified limitations and suggestions for improvement must be focused on the particular experiment being carried out. General points such as 'measurements were difficult' or 'use more precise measuring instruments' will not usually gain credit without further detail.

General comments

There was no evidence that Centres had any difficulties in providing the equipment required for use by the candidates. Any deviation between the requested equipment and that provided to the candidates should be written down in the supervisor's report, and this report must be sent with the scripts to Cambridge so that the examiners can take this into consideration when marking. No additional equipment should be available to the candidates. In some cases, this may disadvantage candidates.

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

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

Comments on specific questions

Question 1

(a)   Most candidates correctly stated L in the accepted range and with a unit. Stronger candidates also included the unit mA. Some candidates omitted the 'milli' part of the unit which gave unrealistic current values of over 1 A. Many candidates correctly stated I_1 to be larger than I_2.

(b)   Most candidates were able to collect six sets of values of L, I_1 and I_2 without assistance from the supervisor and with the correct trend. Candidates are encouraged to check their results if one value is out of trend with the rest.

Many candidates chose too small a range over which to conduct the experiment. Some candidates went up every 10.0 cm starting from L = 10.0 cm or downwards every 10.0 cm from L = 70.0 cm. Candidates are encouraged to use the whole range available to them.

Many candidates gave both the quantity and correct unit for each heading separated by a solidus or with brackets around the unit. Candidates needed to realise that a unit was not needed for the $I_2 / (I_1 - I_2)$ column heading. Where units are needed, candidates are encouraged to remember the separating mark between the quantity and unit (a bracket around the unit or a solidus).

Many candidates stated their L readings to the nearest mm. Candidates are encouraged to think about the resolution of the instrument provided and to apply this knowledge to their stated readings, i.e. all should be recorded to the nearest mm.

Many candidates calculated values for $I_2 / (I_1 - I_2)$ correctly. Candidates are encouraged to round their answers correctly and not truncate the number without consideration.

Some candidates correctly gave their values of $I_2 / (I_1 - I_2)$ to the same number of significant figures as (or one more than) the least number of significant figures in (usually) I_2. Some candidates used too many significant figures or too few, choosing to preserve the number of decimal places rather than significant figures.

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

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

(ii)   Stronger candidates were able to draw a carefully considered line of best fit with a balanced distribution of points either side of the line along the entire length. Common reasons for not awarding this mark included lines needing a rotation or a shift to get a better fit, lines that were kinked (two or more smaller lines joined up), lines that were drawn between the top and bottom point regardless of the distribution of the data and lines that were skewed so that the intercept could be read off the graph at x = 0.

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

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

Some candidates were able to correctly read off the y-intercept at x = 0 directly from the graph, but others incorrectly read off the y-intercept when there was a false origin (i.e. not x = 0). There were many instances of incorrect read-offs substituted into $y = mx + c$.

(d)   Nearly all candidates recognised that P and Q were equal to the gradient and intercept respectively. Some weaker candidates incorrectly gave their value of P or Q to only one significant figure.

Many candidates provided correct units, taking into consideration the units used in the experiment. Some candidates omitted units.

Question 2

(a) (i) Many candidates measured values of θ to the nearest degree and in the appropriate range. Some candidates incorrectly stated θ to the nearest 0.1° when the protractor can only be read to the nearest 1°.

(ii) Most candidates calculated $\cos\theta$ correctly. Candidates are encouraged to round their answers correctly and not truncate the answer.

(b) (i) Some candidates stated V to the nearest cm^3 and showed evidence of having repeated their readings. Weaker candidates did not show their repeats and/or stated V to the nearest 0.1 cm^3, which was not possible with the measuring apparatus provided.

(ii) Many candidates made too small an estimate of the absolute uncertainty in the value of V, typically 1.0 cm^3 when it is difficult to obtain an accurate value for the volume. Some candidates, having repeated their readings, correctly showed the working to give the uncertainty as half the range of the values.

(c) Most candidates recorded second values of θ and V. Many candidates correctly recorded their second V value to be larger than their first.

(d) (i) Many candidates were able to calculate k for the two sets of data, showing their working clearly. A minority of candidates rearranged the equation incorrectly or stated their values to only one significant figure.

(ii) Many candidates correctly justified the number of significant figures they had given for the values of k with reference to the number of significant figures used in V and θ. Some candidates gave reference to 'raw readings', 'previous measurements' or 'values used in calculation' without detailing the individual raw quantities concerned. Some incorrectly referred to V and $\cos\theta$ instead of the raw readings of V and θ.

(e) Stronger candidates calculated the percentage difference between their values of k, testing it against the stated 15% criterion and provided a valid statement as a conclusion. Some candidates omitted a percentage difference calculation, gave a different criterion (e.g. 10%, 20% or the uncertainty in V from **(b)(ii)**) or gave an invalid statement that was inconsistent with their findings.

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

Problems commonly awarded were 'two sets of data were not enough to draw a valid conclusion', 'difficult to measure V as some water stays behind in the container' and 'difficult to ensure trolley is held at the same position each time'. Weaker candidates often mentioned a problem but did not give enough detail for it to be awarded credit.

(ii) Improvements that were commonly seen were 'take more readings and plot a graph' and 'use a marker on the ramp'. A solution, like the problem, needs to be given with detail to gain credit. Candidates are encouraged to explain *how* a problem will be solved, detailing what additional equipment is necessary, e.g. 'use a pipette to fill up the small container'.

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

PHYSICS

Paper 9702/33
Advanced Practical Skills 33

Key messages

- If a raw value is out of trend to that expected, candidates should be encouraged to check the readings again with the equipment provided in the early stages of data collection.

- In the table work, the number of significant figures in the calculated quantity should relate to the number of significant figures in the raw data with the least number of significant figures. Each calculated quantity should be checked row by row. It is unnecessary, and often incorrect, to force the number of significant figures to be constant down a column of calculated values.

- In the graphical work, candidates should be able to read off any points to the nearest half a small square. In particular, candidates should check carefully the read-offs of points used in the gradient calculation and when determining the *y*-intercept.

- When justifying a number of significant figures in a calculated quantity, candidates should relate the number of significant figures in the quantity to the raw readings used in the calculation. Candidates should not use the phrase 'raw readings' without explaining what those readings are, or attempt to use intermediate calculated quantities to justify the number of significant figures.

- To be successful answering **Question 2**, candidates should be reminded that their identified limitations and suggestions for improvement must be focused on the particular experiment being carried out. General points such as 'measurements were difficult' or 'use more precise measuring instruments' will not usually gain credit without further detail.

General comments

Some centres gave evidence that they were not able to provide a newton meter reading to the nearest 0.01 N or 0.02 N. Where this evidence was provided, it was taken into account in the marking process. Any deviation between the requested equipment and that provided to the candidates should be written down in the supervisor's report, and this report must be sent with the scripts to Cambridge so that the examiners can take this into consideration when marking. No additional equipment should be available to the candidates. In some cases, this may disadvantage candidates.

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

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

Comments on specific questions

Question 1

(a) Most candidates stated *L* in the appropriate range.

(b) Many candidates stated their final *T* in the accepted range. Stronger candidates repeated their timing of 5 or more oscillations. Candidates are encouraged to time a number of oscillations (5 or more) and show evidence of having repeated this result. A few candidates left *T* as 10*T* and forgot to divide by 10. A small minority of candidates calculated frequencies (1 / *T*) instead of *T*.

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

Many candidates chose too small a range over which to conduct the experiment. Some candidates went up every 5.0 cm starting from *L* = 5.0 cm or downwards every 5.0 cm from *L* = 45.0 cm. Candidates are encouraged to use the whole range available to them.

Many candidates gave both the quantity and correct unit for each heading separated by a solidus or with brackets around the unit. Candidates are encouraged to remember the separating mark between the quantity and unit (a bracket around the unit or a solidus). Some candidates gave the unit of $\sqrt{L-S}$ as m instead of the correct unit ($m^{1/2}$ or $\sqrt{m}$).

Many candidates stated their *S* readings to the nearest mm. Candidates are encouraged to think about the resolution of the instrument provided and to apply this knowledge to their stated readings. In this case all values of *S* needed to be recorded to the nearest mm.

Many candidates calculated values for $\sqrt{L-S}$ correctly. Candidates are encouraged to round their answers correctly and not truncate the number without consideration.

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

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

(ii) Stronger candidates were able to draw a carefully considered line of best fit with a balanced distribution of points either side of the line along the entire length. Common reasons for not awarding this mark included lines needing a rotation or a shift to get a better fit, lines that were kinked (two or more smaller lines joined up), lines that were drawn between the top and bottom point regardless of the distribution of the data and lines that were skewed so that the intercept could be read off the graph at *x* = 0.

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

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

Some candidates were able to correctly read off the *y*-intercept at *x* = 0 directly from the graph, but others incorrectly read off the *y*-intercept when there was a false origin (i.e. not *x* = 0). There were many instances of incorrect read-offs substituted into *y* = *mx* + *c*.

(e) (i) Most candidates recognised that *A* and *B* were equal to the gradient and intercept respectively. A small number of candidates incorrectly gave their final value of *A* or *B* to only one significant figure. Candidates who inverted their axes generally did not follow through and rearrange the equation to be consistent with their choice of axes.

Many candidates provided correct units, taking into consideration the units used in the experiment. Some candidates omitted units.

(ii) Many candidates rearranged the equation, calculated *g* and gave a correct unit consistent with their working. Some candidates stated their final answer to have a unit of $m\,s^{-2}$ after working in cm throughout and not making an appropriate conversion.

Question 2

(a) (i) Many candidates measured values of *x*, *y* and *z* to the nearest mm and gave values in the accepted range. Some candidates stated *x*, *y* and *z* to the nearest 1 cm when the ruler can be read to the nearest 1 mm.

Most candidates calculated *V* correctly.

(ii) Many candidates correctly justified the number of significant figures they had given for the value of *V* with reference to the number of significant figures used in *x*, *y* and *z*. Some weaker candidates gave reference to 'raw readings', 'previous measurements' or 'values used in calculation' without detailing the individual raw quantities concerned. Some candidates incorrectly related to the number of decimal places.

(b) (i) Many candidates stated *d* in the accepted range.

(ii) Many candidates measured *F* to the nearest 0.01 N, in range, and showed evidence of repeats. Some candidates gave their force to the nearest 0.1 N or did not show that they had repeated measurements.

(iii) Many candidates made too small an estimate of the absolute uncertainty in the value of *F*, typically 0.01 N (or half the smallest division, i.e. 0.005 N). The force reading is an awkward reading to take and is likely to have a much higher uncertainty.

(iv) Most candidates recorded second values of *d* and *F*. Many candidates correctly recorded their second *F* values to be larger than their first.

(c) Many candidates were able to calculate *k* for the two sets of data, showing their working clearly. Some candidates rearranged the equation incorrectly (e.g. *Fx* / *Wd*). A minority of candidates incorrectly stated their values to only one significant figure.

(d) Stronger candidates calculated the percentage difference between their values of *k*, tested it against the stated 15% criterion and provided a valid statement of conclusion. Some candidates omitted a percentage difference calculation, gave a different criterion (e.g. 10%, 20% or the uncertainty from **(b)(iii)**) or gave an invalid statement that was inconsistent with their findings.

(e) Some candidates correctly calculated ρ and stated the value with a correct unit. Many candidates omitted the unit or gave an incorrect unit.

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

Problems commonly awarded were 'two sets of data were not enough to draw a valid conclusion', 'newton meter not vertical', 'difficult to measure *d* as centre of mass uncertain', 'measuring *F* difficult as difficult to determine when strip leaves the rod', 'mass of putty not taken into account' and '*y* small so large percentage uncertainty'. Weaker candidates often mentioned a problem but did not give enough detail to warrant credit.

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

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

PHYSICS

Key messages

- If a raw value is out of trend to that expected, candidates should be encouraged to check the readings again with the equipment provided in the early stages of data collection.

- In the table work, the number of significant figures in the calculated quantity should relate to the number of significant figures in the raw data with the least number of significant figures. Each calculated quantity should be checked row by row. It is unnecessary, and often incorrect, to force the number of significant figures to be constant down a column of calculated values.

- In the graphical work, candidates should be able to read off any points to the nearest half a small square. In particular, candidates should check carefully the read-offs of points used in the gradient calculation and when determining the *y*-intercept.

- When justifying a number of significant figures in a calculated quantity, candidates should relate the number of significant figures in the quantity to the raw readings used in the calculation. Candidates should not use the phrase 'raw readings' without explaining what those readings are, or attempt to use intermediate calculated quantities to justify the number of significant figures.

- To be successful answering **Question 2**, candidates should be reminded that their identified limitations and suggestions for improvement must be focused on the particular experiment being carried out. General points such as 'measurements were difficult' or 'use more precise measuring instruments' will not usually gain credit without further detail.

General comments

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

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

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

Some candidates would benefit from more regular opportunities to connect a variety of different circuits and components.

Comments on specific questions

Question 1

(a) Candidates had to record a value of resistance and the lengths *a* and *b*. Candidates should be encouraged to remember to provide a unit for measured values.

(b) In general, the table of results was completed well by candidates. Most candidates were able to collect and record six sets of *a* and *b* which corresponded to a large range in the independent variable *R*.

To obtain maximum credit, candidates must ensure that they provide all the columns that are stated in the question. In this question the instructions requested values of *R*, *a*, *b*, 1 / *R* and *b* / *a*. A small minority of candidates did not provide the values of *b* or *a* and so were unable to gain full credit.

Candidates should be encouraged to use the maximum range of independent variables using the equipment provided.

The units for the column headings must be provided using accepted scientific convention, i.e. with each unit, where there is one, either separated from the quantity by a solidus or in brackets. A common mistake was to provide a unit with the quantity *b* / *a* which does not have a unit.

Candidates need to remember to state all their recorded measurements to the precision of the measuring instrument, e.g. in this case length can be read to the nearest 0.1 cm. Some candidates added on a trailing zero to the end of their values of *a* and *b*. This is not awarded credit as the raw readings must reflect the precision of the ruler used.

Candidates must also consider the number of significant figures they provide for any calculated values in their table. The number of significant figures must be the same as, or one more than, the least number of significant figures of the values used in the calculation.

(c) (i) Many candidates plotted points carefully using a sharp pencil. A minority of candidates chose to plot points as 'blobs' (points with diameter greater than 1 mm) or used awkward scales (axis labels with difficult increments e.g. 3, 6, 9, 12 etc.).

A small number of candidates used non-linear scales. Graphs with non-linear scales cannot be given credit either for the axes or for the quality of data if the points are plotted in the part of the scale that is non-linear. Candidates should be encouraged to check their scales for linearity. Non-linear scales are often used unintentionally so it is good practice to check the scales before plotting the points.

Some candidates omitted labels or marked their scales with large gaps between the labels (more than a large square). Compressed scales (where the plotted points occupy less than half of the grid in one or both directions) were sometimes seen and also did not gain credit. This may have arisen because of the candidate's perceived need to start the graph at the origin.

Any data recorded in the table must be plotted on the graph. Candidates must be careful to ensure that their axes are chosen such that all their table points can fit onto the graph grid they have chosen.

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. Most candidates obtained results of the correct trend for this experiment and results remained close to the expected linear trend. Where there was an incorrect trend, it was most commonly due to the candidate calculating *a* / *b* instead of *b* / *a*.

If a point appears to be anomalous on the graph, candidates are encouraged to check their plotting first, then check their reading with the equipment available. If the candidate still has one anomalous point, they can identify this point as such by ringing it or stating the point as 'anomalous'. There is no credit specifically for identifying an anomalous point, so candidates should be reminded that they do not need to identify an anomalous point if they do not think they have one.

(ii) Stronger candidates were able to draw a carefully considered line of best fit with a balanced distribution of points either side of the line along the entire length. Common reasons for not awarding this mark included lines needing a rotation or a shift to get a better fit, lines that were kinked (two or more smaller lines joined up), lines that were drawn between the top and bottom point regardless of the distribution of the data and lines that were skewed so that the intercept could be read off the graph at $x = 0$.

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

Some candidates were able to correctly read off the y-intercept at $x = 0$ directly from the graph, but others incorrectly read off the y-intercept when there was a false origin (i.e. not $x = 0$). There were many instances of incorrect read-offs substituted into $y = mx + c$.

(d) Candidates were expected to rearrange the equation given $\left(\dfrac{b}{a}\right) = \dfrac{M}{R} + N$ following the format of $y = mx + c$ to determine that the constant N corresponded to their intercept value and the constant M corresponded to their gradient value.

Candidates must also provide units that correspond to the data they have provided i.e. $0.60\,\text{k}\Omega$ rather than $0.60\,\Omega$.

Some candidates presented their answer to only one significant figure and were not awarded credit. This was most commonly done by candidates who took a direct read-off from the graph to find the intercept value.

Question 2

(a) Most candidates were able to take readings of A, B and C. It is important that candidates follow the instructions carefully. It can be helpful for candidates to underline the key instructions in the question.

The majority of the candidates were able to gain credit for the measurement of these values. The candidates were also able to use the equation provided correctly. Candidates must correctly round their calculated values.

(b)(i) Candidates were expected to make repeated readings of the value of the height. This is a measurement that is subject to random error and is the dependent variable of this experiment. Candidates also need to record their measurements to a precision which corresponds to the measuring equipment, and to provide a unit where appropriate.

(ii) Many candidates are familiar with the equation for calculating percentage uncertainty and gave an uncertainty in h that was in the range deemed reasonable for this experiment given the inherent difficulties in taking the measurements involved.

Some candidates made too small an estimate of the absolute uncertainty in the value of h, typically 1 mm, or too large an estimate, typically 1 cm. Many candidates just used the uncertainty of 1 mm from the precision of the measuring instrument rather than considering a realistic estimate for this particular experiment.

Some candidates repeated their readings and correctly gave the absolute uncertainty in h as half the range, although other candidates did not halve the range when using this method.

(c) Most candidates were able to take readings of A, B and C after raising the bottle to a greater height than the previous measurements, leading to a decreased value in the height of the water level above the hole.

(d) (i) Most candidates were able to calculate k for the two sets of data, showing their working clearly. A minority of candidates incorrectly rearranged the equation, gave their answer to only one significant figure or inadvertently substituted the wrong values.

(ii) Candidates found it difficult to justify the number of significant figures they had given for the value of k with reference to the number of significant figures used in h, x and s. Many candidates stated that the number of significant figures depends on 'raw readings' without making reference to what the relevant raw quantity actually was.

(e) Many candidates calculated the percentage difference between their two values of k, and then compared it to the specified numerical percentage uncertainty of 20% in order to give a statement about whether their results support the relationship or not. Some candidates omitted the comparison with 20%, or gave a general statement such as 'this is valid because the values are close to each other' or 'strongly supported' without any working, which could not be accepted.

Referring to only 'within the limits of experimental accuracy' is on its own is not enough and is not credited unless explicitly linked to the percentage uncertainty of 20%. Some candidates gave their own numerical percentage uncertainty which was not 20%, and this also could not be accepted.

Occasionally candidates gave a contradictory statement such as 'my results do not support this relationship as my percentage difference is less than 20%'.

A small number of candidates made no attempt to use a calculation and just gave a conclusion. This could not be accepted.

(f) (i) Many candidates were able to identify limitations to the experiment but were not always clear enough in their description to gain credit. For example, it is not enough to state that there was 'difficulty in measuring the length'. The candidate must state which length and why there was a difficulty. So changing their statement from 'it was difficult to measure length' to 'it was difficult to measure the length A due to difficulty in holding the ruler vertical' would enable a candidate to be given credit.

It is useful for candidates to think about the different measurements being taken and identify a limitation with each of these. It can also be helpful for candidates to think about the limitations in the order in which the measurements are taken. There is no credit specifically for this, but it can help candidates to be methodical in their approach to this question.

Some candidates recognised that it was difficult to record the water level when the water jet touched the rod, but they were often not able to give a valid reason e.g. because they would need to look at two places at the same time.

Candidates should be advised that comments regarding the suitability of apparatus other than measuring apparatus, are unlikely to be given credit. Problems such as non-level benches, wobbly stands and twisty clamps are not creditworthy. Limitations that were irrelevant or that could have been removed if the candidate had taken greater care were also not given credit.

(ii) A solution, like the problem, needs to be given with detail to gain credit. Candidates are encouraged to explain *how* a problem will be solved, detailing what additional equipment is necessary, e.g. 'use a video with the metre rule in view' or 'clamp the metre rule so that it is vertical'.

Vague or generic answers such as 'too few readings' (without stating a consequence) or 'use a clamp' (without stating what these would be used for) also cannot be given credit.

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. Clarity of thought and expression separated the stronger candidates from those less prepared to deal with practical situations and the limitations.

PHYSICS

Paper 9702/35
Advanced Practical Skills 35

Key messages

- If a raw value is out of trend to that expected, candidates should be encouraged to check the readings again with the equipment provided in the early stages of data collection.

- In the table work, the number of significant figures in the calculated quantity should relate to the number of significant figures in the raw data with the least number of significant figures. Each calculated quantity should be checked row by row. It is unnecessary, and often incorrect, to force the number of significant figures to be constant down a column of calculated values.

- In the graphical work, candidates should be able to read off any points to the nearest half a small square. In particular, candidates should check carefully the read-offs of points used in the gradient calculation and when determining the *y*-intercept.

- When justifying a number of significant figures in a calculated quantity, candidates should relate the number of significant figures in the quantity to the raw readings used in the calculation. Candidates should not use the phrase 'raw readings' without explaining what those readings are, or attempt to use intermediate calculated quantities to justify the number of significant figures.

- To be successful answering **Question 2**, candidates should be reminded that their identified limitations and suggestions for improvement must be focused on the particular experiment being carried out. General points such as 'measurements were difficult' or 'use more precise measuring instruments' will not usually gain credit without further detail.

General comments

Some centres were not able to provide the resistance wire required for **Question 1**. Where evidence was provided that a different wire was used, it was taken into account in the marking process. Any deviation between the requested equipment and that provided to the candidates should be written down in the supervisor's report, and this report must be sent with the scripts to Cambridge so that the examiners can take this into consideration when marking. No additional equipment should be available to the candidates. In some cases, this may disadvantage candidates.

When electrical meters are part of the apparatus list, centres are requested to tape over any terminals which will not be used.

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

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

Comments on specific questions

Question 1

(a)   Many candidates gave a value of E in the required range. Some candidates misread the voltmeter and gave an answer that was out of range.

(b)   Many candidates were able to collect six sets of values of I and $(R_1 + R_2)$ without assistance from the supervisor, and showed a correct trend in their values. A minority of candidates took a set of results with the wrong trend or were unable to collect readings. Some candidates looked at the trend in values as they recorded their values. This 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 the general trend and repeat these readings as they experiment to double-check.

Many candidates chose too small a range of $(R_1 + R_2)$ over which to conduct the experiment and so the values ended up too close together. It is expected that candidates consider the whole range of possible values of $(R_1 + R_2)$ which can be achieved with the apparatus 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 $1 / I$ column was the most challenging. Some candidates gave no unit. Candidates should state the unit of the whole quantity, i.e. $1 / I / \text{mA}^{-1}$ or $1 / I \, (\text{mA}^{-1})$ and not $1 / I / \text{mA}$ or $1 / I(\text{mA})$.

Many candidates were awarded credit for consistency by giving all values of current to the nearest $0.1\,\text{mA}$ or all to the nearest $0.01\,\text{mA}$.

Many candidates were awarded credit for using significant figures correctly. The number of significant figures given for the quantity $1 / I$ on each line needed to be the same as, or one more than, the number of significant figures in the corresponding value of I.

Most candidates calculated and recorded their values of $1 / I$ correctly. A small number of candidates rounded their final answers incorrectly.

(c) (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 some incidences of awkward scales (e.g. based on 3, 6 or having 10 small squares equivalent to 15). Credit cannot be awarded for this type of scale, and these candidates often lost further credit for incorrect read-offs when calculating the gradient or the y-intercept of the line. A few candidates created non-linear scales by missing a number out. A small number of weaker candidates chose scales which meant that one or more points were off the graph grid. Candidates should ensure that all their points will lie on 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 for an error in recording the values. If the candidate decides that such a point should be ignored when 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 all their points lie close to a straight line.

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

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

point regardless of the distribution of the data and lines that were skewed so that the intercept could be read off the graph at $x = 0$.

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

Some candidates were able to correctly read off the y-intercept at $x = 0$ directly from the graph, but others incorrectly read off the y-intercept when there was a false origin (i.e. not $x = 0$). There were many instances of incorrect read-offs substituted into $y = mx + c$.

(d) Many candidates recognised that F was equal to the value of the gradient and G was equal to the value of the intercept. Stronger candidates recorded a value with consistent units for both F (e.g. $mA^{-1}\Omega^{-1}$) and G (e.g. mA^{-1}). Weaker candidates often stated incorrect units such as $m^{-1}A^{-1}$ or omitted units altogether.

(e) (i) Stronger candidates correctly measured the diameter d of the wire at several points along the wire, noted each reading, calculated the average value and recorded this with a correct consistent unit. Weaker candidates generally did not repeat their readings or gave a value outside the accepted range that may have been a result of misreading the micrometer scale.

(ii) Stronger candidates recognised that the unit of ρ was given as $\Omega\,m$ and correctly changed their value for d to be consistent with metres. These candidates were able to correctly calculate ρ using values from earlier parts of the question and recognised that the d value needed to be squared in the calculation.

Question 2

(a) Stronger candidates were alert and noticed the word 'determine'. These candidates placed several paper clips onto the balance and determined the mass of one paper clip by dividing the total mass by the number of paper clips. In **(f)**, many candidates who had only measured the mass of a single paper clip here suggested measuring the mass of several clips together as an improvement, but did not actually use the idea during their experiment.

(b) (i) Many candidates correctly stated a value of h to the nearest mm that was in the accepted range. Some candidates gave readings to the nearest cm. The precision of the metre rule is 1 mm therefore the candidates should record their readings using the rule to the nearest mm.

(ii) The majority of the candidates recorded a value for N.

(iii) Many candidates correctly stated a value of t in the required range and with a unit. Some weaker candidates omitted the unit.

Many candidates repeated their experiment and recorded several values of t. Some candidates only took the measurement once and only recorded one value of t.

(iv) Most candidates are familiar with the equation for calculating percentage uncertainty. Some candidates estimated Δt in the required range. Weaker candidates generally made too small an estimate of the absolute uncertainty in the value of t by giving the precision of the stop-watch. Some candidates repeated their readings and correctly gave the uncertainty in t as half the range in their values of t, while other candidates did not halve the range.

(v) Many candidates were able to correctly calculate a showing their working clearly. A minority of candidates incorrectly rearranged the equation algebraically.

(vi) Candidates generally found it difficult to correctly justify the number of significant figures they had given for the value of a with reference to the number of significant figures used in h and t. Many

candidates gave reference to only *h* or just 'raw readings', 'measured values' or 'values in the calculation' without stating specifically the quantities *h* and *t*.

(c)   Most candidates correctly recorded second values of *N* and *t*.

Many candidates correctly recorded values of *t* which showed a decrease in the second value of *t* compared to the first value of *t*. For some candidates the second *t* showed the wrong trend with an increase.

(d)   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 or stated their *k* values to only one significant figure.

(e)   Some candidates read the question carefully and correctly used the stated percentage uncertainty value given in the question, i.e. 25%. The stronger candidates clearly showed the calculation of the percentage difference between their two values of *k*, and then compared their percentage difference value to 25% before stating a correct conclusion of whether the results supported or did not support the relationship.

Some candidates referred back to the percentage uncertainty calculated for *t* rather than using the 25% value, or used their own value (e.g. 10%), and these methods were not given credit. Some candidates did not calculate the percentage difference between their two *k* values, and 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) (i)   This experiment provided many limitations for discussion. Candidates who think about the difficulties they experience in noting a measurement as they are doing the experiment are best placed to discuss limitations.

Many candidates recognised that two sets of data were insufficient to draw a valid conclusion and stated an improvement of taking more readings and plotting a graph. Some candidates stated 'take more readings' which on its own did not gain credit.

To gain credit for limitations concerning measurements, the quantity that was difficult to measure should be referred to along with the difficulty. For example, 'it was difficult to measure *h'* on its own is insufficient. Pointing out that 'it was difficult to measure *h* as the ruler is not vertical' or 'it was difficult to measure *h* as the mass was disturbed by the ruler' could gain credit.

Many candidates correctly stated difficulties involved in measuring *t*, the time of fall. A bald statement 'it was difficult to measure *t* with a stop-watch' or reference to 'human error' or 'reaction time' did not gain credit. Suggesting that '*t* was short' on its own also did not gain credit, but suggesting the '*t* is small therefore the uncertainty is large' did gain credit. Another way of phrasing this which gained credit was 'there is a large percentage uncertainty in *t*'.

Stronger candidates correctly recognised that adding adhesive putty increased the mass but that the increase is not taken into account in the equation. Stronger candidates also often recognised that as each paper clip was added the exact mass that would produce a smooth movement could be missed.

(ii)   For measuring *h*, many candidates mentioned 'eye level' or 'looking perpendicular' but on their own these could not gain credit as these are standard practice. 'Make the rule vertical' could not gain credit but stronger candidates gave detail and suggested clamping the rule, and this could be given credit.

Stronger candidates suggested that they might measure the mass of the putty and take that into account in the equation, or suggested using smaller or lighter paper clips to reduce the discrete nature of adding single clips. Weaker candidates tended to give vague ideas that lacked detail e.g. 'take account of the mass of the adhesive putty'.

Some weaker candidates stated vague errors such as random error, zero error, human error, damaged rulers, wobbling stands etc. as sources of limitation without linking these to specific difficulties, and these did not gain credit.

Many candidates mentioned 'friction' on its own which did not gain credit. Candidates need to describe the consequence of the problem to show why it is a problem. Stronger candidates described that 'the mass stops and starts as it falls'.

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. Clarity of thought and expression separated the stronger candidates from those less prepared to deal with practical situations and the limitations.

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Advanced Practical Skills 36

Key messages

- If a raw value is out of trend to that expected, candidates should be encouraged to check the readings again with the equipment provided in the early stages of data collection.

- In the table work, the number of significant figures in the calculated quantity should relate to the number of significant figures in the raw data with the least number of significant figures. Each calculated quantity should be checked row by row. It is unnecessary, and often incorrect, to force the number of significant figures to be constant down a column of calculated values.

- In the graphical work, candidates should be able to read off any points to the nearest half a small square. In particular, candidates should check carefully the read-offs of points used in the gradient calculation and when determining the y-intercept.

- When justifying a number of significant figures in a calculated quantity, candidates should relate the number of significant figures in the quantity to the raw readings used in the calculation. Candidates should not use the phrase 'raw readings' without explaining what those readings are, or attempt to use intermediate calculated quantities to justify the number of significant figures.

- To be successful answering **Question 2**, candidates should be reminded that their identified limitations and suggestions for improvement must be focused on the particular experiment being carried out. General points such as 'measurements were difficult' or 'use more precise measuring instruments' will not usually gain credit without further detail.

General comments

Most centres had no difficulty in providing the specified apparatus. Where a centre had a problem with providing the apparatus required, they noted this in their supervisor's report and this enabled examiners to make allowances in marking the candidates' work.

Many candidates showed good preparation for the practical paper and this was demonstrated in measuring, recording and processing their results. Nearly all the candidates completed the two questions.

Comments on specific questions

Question 1

(a) Nearly every candidate recorded a value for R from the resistors provided, together with the voltmeter reading V. Most values were in the expected range although in a few cases credit could not be awarded because the unit was omitted.

(b) Tables of results were usually clearly presented and nearly all candidates included six sets of readings.

Most column headings included a unit, though this was sometimes missing or incorrect in the $1/R$ column.

Units should only appear in the column headings but a small number of candidates headed their R column 'Ω' and included the 'k' prefix next to each value below the heading. This is not an

acceptable practice and any 'k' prefix that was not in the heading was ignored. Candidates should be encouraged to give the quantity and the entire unit (including any prefix) in the heading, with an appropriate separating mark to distinguish the quantity from the unit.

Stronger candidates determined V for a range of R that included the largest and smallest values that were possible with the resistors provided.

In most cases the V values were all recorded to the nearest 0.01 V.

Calculated values of $1/R$ were usually correct.

The number of significant figures given for $1/R$ was often incorrect, and this was sometimes caused by candidates trying to preserve the number of decimal places in the column. In other cases candidates had difficulty trying to deal with a change of unit.

(c) (i) The stronger candidates used simple scales that made good use of the grid and used neat crosses for their plotted points.

Most candidates were credited with good quality results, based on the small scatter about a linear trend.

(ii) Many candidates' lines of best fit were good, but some could be improved by rotation or sideways movement.

If a point appears to be anomalous on the graph, candidates are encouraged to check their plotting first, then check their reading with the equipment available. If the candidate still has one anomalous point, they can identify this point as such by ringing it or stating the point as 'anomalous'. There were a small number of cases where two points were labelled as anomalous by the candidate. All points are considered when judging the fit of the line in these cases.

(iii) Most candidates demonstrated correct methods of determining the gradient and intercept of their line. Some candidates made errors in using too small a triangle and there were some cases of reading the intercept value from the V axis when the horizontal axis did not start from zero.

(d) Most candidates compared the graph that they had drawn with the suggested equation and correctly used their gradient and intercept values for the constants a and b. Stronger candidates went on to include correct units for a and b.

Question 2

(a) Most candidates recorded a value in the required range for the unstretched length l_0.

(b) Most candidates gained credit for precision and a value in range for their measurement of d. A small number of candidates gave a value to the nearest 0.1 mm (which could not be measured with the equipment provided), or a value a very different from the 2 cm specified in the question.

(c) (i) Candidates generally recorded their drop height h successfully.

(ii) Generally candidates knew how to calculate the percentage uncertainty in h, but the choice of absolute uncertainty was often too small (e.g. 1 mm) considering this was a difficult measurement.

(iii) Most candidates gained credit for a l_{max} value greater than their l_0 value and consistent with the precision of the metre rule.

(d) Most candidates gained credit for a second set of values using the shorter string, and most were credited for a h value smaller than that for the longer string.

(e) (i) The calculations for the two C values were carried out well and most candidates recorded their values to at least two significant figures.

(ii) The number of significant figures for the C values depended on the significant figures of $(l_{max} - l_0)$, $(d_0 - d)$ and h. Very few candidates offered this as a response. A statement that listed by name <u>all</u>

the individual quantities used in the calculation was accepted as a justification. Candidates should be reminded that they need to refer to all relevant measured quantities in making this type of justification, and should not use phrases like 'raw readings', 'previous measurements' or 'values used'.

(f)   A large proportion of candidates recorded the three steps that are required to answer this question. Some weaker candidates did not compare the percentage difference between the C values with the 15% uncertainty given in the question, and instead a different uncertainty (e.g. 10%) was used.

(g) (i)   Most candidates described four sources of uncertainty, although some found it hard to describe them clearly or did not include the name of the measurement affected by the difficulty. Stronger candidates generally described problems with procedures and measurements in the sequence that they encountered them in the experiment.

Measuring the unstretched length l_0 of the elastic string was often listed as a difficulty because it wasn't straight and if straightened it might be stretched.

All of the measurements involved the metre rule and many candidates mentioned parallax as a problem with h or d, these being the measurements where the rule could not be positioned right next to the measuring points.

Many candidates identified the difficulty in determining if the 50 g mass had <u>just</u> touched the paper pad after it was dropped.

(ii)   A solution, like the problem, needs to be given with detail to gain credit. Candidates are encouraged to explain *how* a problem will be solved, detailing what additional equipment is necessary, e.g. 'tape one end of the rubber band to the bench to leave a hand free for the rule when measuring l_0'.

Some candidates suggested improved methods to determine when the mass just touches the paper, such as a method of leaving a mark on the paper or using a pressure pad or microphone to detect contact. Others said that a video with frame-by-frame replay would help.

After finding the required drop height, the 50 g mass had to be pulled down to the paper pad and held there while the length l_{max} was measured. Some candidates described the difficulty of holding the metre rule steady with only one hand.

A small number of candidates listed problems and improvements that they had seen in mark schemes for experiments from previous papers, but these were often not relevant to the experiment in this paper. Credit is also not given for suggested improvements that could have been carried out in the original experiment, e.g., 'repeat readings' or 'view the ruler at right angles'.

Some candidates seemed to have had little experience of dealing with this section of the question, often only considering a single feature of the experiment. A possible strategy for centres who do not have the resources to practise many practical papers would be to demonstrate and discuss an experiment from a past paper and then ask learners to complete the follow-up questions themselves. Their responses could be compared with the mark scheme for that paper.

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Paper 9702/41
A Level Structured Questions 41

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

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Paper 9702/42
A Level Structured Questions

Key messages

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

- In defining quantities, candidates need to take care to ensure that the definition they give is dimensionally correct. This often requires use of the phrase 'per unit' where the quantity being defined is the ratio between two other quantities, or 'product' where the quantity being defined is two other quantities being multiplied together. Examiners will only consider symbol equations to be part of a definition if the symbols used are identified.

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

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

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

General comments

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

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

Comments on specific questions

Question 1

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

(b)   Most candidates knew the equation for calculation of angular speed from the period, and many were then able to use it to calculate the angular speed correctly. Some of the weaker candidates thought that the minute hand of a clock takes 1 minute, rather than 1 hour, to undergo one complete revolution.

(c) (i)   Most candidates used their angular speed from **(b)** to calculate correctly a value for the angle moved through in the 1400 s time interval.

(ii)   This question proved to be a little more challenging for some of the candidates, but stronger candidates were generally able to calculate the value of L correctly. There were two possible methods, using either the answer to **(b)** or the answer to **(c)(i)**. Full credit was available by the 'error carried forward' principle from incorrect previous answers, but this did occasionally result in values for L that were implausible. Candidates should be advised that a quick mental check on the plausibility of their answers can often help them to identify where they have made mistakes.

(iii)   Most candidates knew the equation for calculating centripetal acceleration from angular speed and radius, but a significant minority of weaker candidates did not appreciate that the value of L is the radius of the circle. Many of them took the arc length 0.44 m as the radius.

(d)   This was a challenging question. Some good responses were seen from the strongest candidates. The key advice to candidates is that quantities are very rarely 'negligible' in absolute terms; they are only negligible in relation to another quantity. Many candidates made the statement that the centripetal acceleration is negligible, but without any reference to a comparison. Examiners were looking for a comparison with the acceleration of free fall; this comparison then leads directly to the fact that the resultant force on the modelling clay is negligible in comparison with its weight, and hence the force exerted by the minute hand is approximately equal to the weight with negligible variation. Many of the weaker candidates attempted to explain why the force exerted by the minute hand is negligible, rather than explaining why its variation with time is negligible.

Question 2

(a) (i)   Most candidates were awarded at least partial credit, but full credit was often not possible because of a dimensionally incorrect definition that gave an energy rather than an energy per unit mass.

(ii)   Most candidates were able to be awarded credit for the substitution of the given numbers into the equation for gravitational potential. Some candidates did not realise that gravitational potential must be negative or did not know the unit.

(b) (i)   Most candidates realised that the magnitude of potential energy is obtained by multiplying the potential by the mass, but a significant minority thought that there is a negative relationship between gravitational potential and gravitational potential energy. Some weaker candidates attempted to give expressions in terms of quantities other than the two asked for in the question.

(ii)   This was generally well answered by candidates who realised that the loss in kinetic energy of the particle must equal the gain in gravitational potential energy, though some were a little confused over signs in the starting equation. Many weaker candidates tried to answer this question by equating gravitational and centripetal forces.

(c)   This question was generally well answered, with most candidates able to use their answer to **(a)(ii)** with the given equation to calculate a speed.

(d)   Many of the more able candidates calculated the correct answer with relative ease, although a significant minority forgot to take the square root of their value of mean-square speed at the end. Some of the weaker candidates realised that the starting point required the mean kinetic energy to

be equated with $(3/2)kT$, but then found the subsequent arithmetic difficult. Many others were a little confused and attempted to equate $(3/2)kT$ with $(1/3)Nm<c^2>$.

(e) This was another challenging question. Even many of the stronger candidates missed the point that, even though the r.m.s. speed of the molecules is a little less than the escape speed, there is a *distribution* of molecular speeds in which the r.m.s. value is only an average. As a result, many of the molecules do have the speed required to escape, and over time all will do so. Many responses did not discuss molecular speeds at all, and only referred to the speed of the gas or of the Moon.

Question 3

(a) There was much confusion between the definition of internal energy and the first law of thermodynamics (which deals with ways in which internal energy can be changed).

(b) In both parts of this question, there was a widespread misunderstanding of the terms involved in the first law of thermodynamics. Many candidates seemed to think that all three of internal energy, thermal energy and work are quantities that are possessed by the system. Awareness was rare that it is internal energy that is possessed by the system, and that the transfer of thermal energy and the doing of work are simply ways in which internal energy may be changed. It was common for candidates to write about work and thermal energy increasing or decreasing, or remaining constant, and it was clear that these candidates had a poor understanding of the law.

It is also important to stress to candidates that explanation questions like this require accurate use of technical terminology, and that credit is not awarded for use of undefined symbols. Responses should be rooted in the context of the question, in this case a spring and a puddle of water, rather than some undefined 'gas' or 'system'.

In **(b)(i)**, it was common for weaker candidates to think of the spring as a gas, and to conclude that if it expands it must be doing work against the atmosphere. Candidates that realised that work has to be done on a spring to stretch it were usually then able to conclude that the internal energy increases.

In **(b)(ii)**, the candidates that understood the physics of evaporation were usually able to state that the water does work against the atmosphere (or that the work done on the water is negative) as it evaporates and that thermal energy is supplied to the water by the Sun. For the award of credit, the directions of energy transfer needed to be clear. Full credit required reasoning how these two transfers interact to result in an increase in internal energy, and proved to be challenging but nevertheless accessible to the strongest candidates.

Question 4

(a) (i) This question was generally well answered. Among candidates that did not give the correct answer, the most common mistakes were misreading the scale, omission of the 10^{-15} factor, or forgetting to halve the peak–trough height.

(ii) There was some confusion among weaker candidates between frequency and angular frequency, but otherwise this question was well answered.

(iii) Most candidates knew or were able to deduce the correct relationship between maximum speed and amplitude for simple harmonic motion.

(b) (i) Most candidates realised that a substitution into $I = nAvq$ was required. The common mistake among the more able candidates was a power-of-ten error in the unit conversion for the area. Some of the weaker candidates attempted to square the area, and a small number did not know that the value of q required was the elementary charge.

(ii) Most candidates realised that a sinusoidal curve was required with an amplitude I_0 and a period of $0.20\,\mu s$. Many candidates found it difficult to draw the curve with the correct curvature in the different parts of the graph. The stronger candidates were generally able to deduce that the current has the largest magnitude when the electrons are moving with the fastest speed and therefore draw a curve with the correct phase.

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(iii) Many candidates found this question difficult. Partial credit was awarded to candidates who substituted their values from **(a)(ii)** and **(b)(i)** into $I = I_0 \sin \omega t$ but, as with **(b)(ii)**, it was generally only the stronger candidates that realised it was a cosine rather than sine equation that was required here.

(iv) This question was generally well answered.

Question 5

(a) This question was well answered, with most candidates able to give a correct statement of Coulomb's law.

(b) Many candidates made a correct substitution into the equation, but some candidates then had difficulty with the subsequent arithmetic (often forgetting to take the square root of Q^2). A common mistake among weaker candidates was either to confuse the equation for force with the equation for field strength, thereby starting with Q rather than Q^2, or to think that the two charges should be added (giving $2Q$) rather than multiplied.

(c) (i) Most candidates realised that, for the droplet to be held in equilibrium, the electric force must be upwards leading correctly to a conclusion that the droplet must be negatively charged. A small number of candidates did not seem to understand the situation and concluded that, despite having calculated a charge in **(b)**, the droplet is uncharged (and so the sign is neutral).

(ii) This question was generally well answered. In most instances where full credit was not awarded, this was due to carelessness with drawing the diagram rather than the candidate not knowing what the pattern should be.

(iii) Most candidates realised that the electric field strength between the plates can be calculated from the potential gradient. The more able candidates realised that the electric force needed to be equated with the weight of the oil droplet, and many then went on to calculate the correct mass.

Question 6

(a) (i) This question was generally well answered, with most candidates realising that the energy stored in the capacitor is given by the area under the graph. Candidates needed to be careful with the unit conversions in this 'show that' question, with the μC to C and J to mJ conversions both needing to be clear.

(ii) This question was also generally well answered.

(b) (i) This was a challenging question that the weaker candidates found difficult. Many candidates did get to the equation $V = V_0 \exp(-t / \tau)$, but then attempted to substitute numbers from the graph rather than realising that they just needed to put $t = \tau$ and then take natural logarithms.

(ii) Many candidates were able to correctly read off the time of 3.2 s at the point where $-\ln(V / 8\,V)$ is equal to 1.0. A common incorrect answer was 6.4 s.

(iii) This question was generally well answered by candidates that offered a response.

Question 7

(a) (i) This question was generally well answered. A significant number of weaker candidates thought that the t in the equation for the Hall voltage is a time rather than the thickness of the slice. It is important to note that candidates were asked to show that the Hall voltage is 5.0 V, which required a calculation using the data supplied. Some candidates assumed a Hall voltage of 5.0 V and reverse-calculated a value for magnetic flux density, which is not what was asked.

(ii) Many candidates were able to achieve at least partial credit for this question. A common misunderstanding was that the Hall voltage decreased to zero at $t = 0.050$ s, rather than to 2.5 V. Some candidates did calculate the 2.5 V figure, but found it difficult to locate that value correctly on the V_H-axis.

(b)(i) This question was well answered, with many candidates achieving full credit.

(ii) A significant minority of candidates thought that the variation with time of the induced e.m.f. was proportional to the magnetic flux rather than to its rate of change. Candidates that did understand the laws of electromagnetic induction were usually able to achieve at least some of the credit available, and the mark scheme was structured in such a way as to enable a variety of ways of obtaining partial credit. Many of the stronger candidates obtained full credit.

Question 8

(a) The identity of a photon as a quantum of energy of electromagnetic radiation was generally well understood.

(b)(i) Many candidates correctly identified the phenomenon described as the photoelectric effect.

(ii) Candidates that read the question and took time to try to answer it had a variety of ways in which credit could be awarded. Many candidates attempted to answer a different question, and either attempted to list the other features of the photoelectric effect that provide evidence for the photon model or repeated the description of what is meant by the threshold frequency that was already contained in the question. These responses could not be awarded credit, so candidates should always be encouraged to check that they are answering the question that has been asked.

(c) A variety of different answers were seen for both parts of this question. Part **(c)(i)** was generally more often correctly answered than **(c)(ii)**. Many candidates did realise that the answer to **(c)(ii)** was an energy, but common incorrect answers were the photon energy and the kinetic energy of the emitted electron.

Question 9

(a)(i) Many candidates gave part of the answer but not a full answer as to what is meant by a tracer. A significant minority of weaker candidates attempted to describe how a tracer is used rather than answering the question that was asked.

(ii) This question was a straightforward exercise in balancing a nuclear equation. Some candidates did not know the symbol for a positron, and many others did not know the effect on proton number and nucleon number of beta-plus decay.

(b)(i) Most candidates were able to state that positrons encounter electrons and undergo annihilation. The idea that this involves all of the mass of the particles becoming the energy of the gamma photons was less well articulated by many candidates.

(ii) There was much confusion with other types of medical imaging in responses seen to this question, with image formation in ultrasound scanning and CT scanning being commonly discussed.

(c)(i) Many candidates were able to access either or both of the marks available for use of the correct starting equations. Full credit for a fully correct final expression was only awarded to a small number of candidates who realised that there are two photons produced from each decay.

(ii) Many candidates correctly drew a smooth exponential decay curve or a line passing through the correct points at $t = T$ and $t = 2T$. The number of candidates who demonstrated both of these features was comparatively small.

Question 10

(a) Most candidates knew that Wien's displacement law involves a wavelength being inversely proportional to a temperature, but only the strongest candidates were able to correctly identify what, in the context of Wien's law, is meant by wavelength and temperature. Common mistakes were to describe the wavelength as a 'maximum wavelength' and/or to omit that the temperature is the thermodynamic temperature of a surface.

(b)(i) This question was generally well answered, although a significant minority of candidates attempted to describe what standard candles are used for rather than stating what one is.

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(ii) Many candidates described the consequence of redshift on the observed wavelength, rather than explaining the reason why the light is redshifted.

(iii) This question required candidates to think carefully about the calculations and the effect of redshift. All five possible mark outcomes were common.

PHYSICS

Key messages

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

- In defining quantities, candidates need to take care to ensure that the definition they give is dimensionally correct. This often requires use of the phrase 'per unit' where the quantity being defined is the ratio between two other quantities, or 'product' where the quantity being defined is two other quantities being multiplied together. Examiners will only consider symbol equations to be part of a definition if the symbols used are identified.

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- 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.

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General comments

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

Most candidates showed their working. Some candidates would benefit from presenting their calculations more clearly.

Comments on specific questions

Question 1

Please note that due to a series-specific issue with question 1, full marks have been awarded to all candidates for this question to make sure that no candidates were disadvantaged.

Question 2

(a) Many candidates did not give the expected definition for specific heat capacity. Some candidates were awarded credit for stating the idea of energy per unit mass. Many did not say 'per unit change in temperature'. The 'per' (or other words to that effect) was necessary to indicate division. Some very weak candidates missed the idea that energy causes a change in temperature.

(b)(i) Most candidates were able to show their method for this calculation. A small number stated the volume change as $0.025 \, \text{m}^3$ but they did not show where this value came from.

(ii) There were many responses here that gained full credit. Weaker candidates were less sure of the direction of the work done and stated that the work done on the gas was positive rather than negative.

(iii) Many candidates gained full credit for this calculation.

(iv) Most candidates knew which formula to use here. A common error was to use an incorrect value for the thermal energy, for example using the increase in internal energy instead. Another common error was adding 273 to 56 in an attempt to convert the change in temperature into kelvin, rather than realising that a change in temperature is the same in both degrees Celsius and in kelvin.

(c) There were many responses that gained partial credit because candidates generally recognised there was no work done by the gas because there was no change in volume. A significant number also linked the need for less thermal energy to be supplied to a lower specific heat capacity. Generally only the strongest candidates recognised that there was the same gain in internal energy and so the same temperature rise.

Question 3

(a)(i) Many candidates knew the meaning of the symbols. Candidates needed to make it clear that m is the mass of a single molecule.

The wording used to describe the meaning of $<c^2>$ was sometimes unclear or incorrect. For example, 'the mean square speed of the gas' is not correct (as it relates to the molecules of the gas).

(ii) Many candidates worked through this derivation very well with clear indication of all the formulae that needed to be used.

(b) Many candidates calculated the correct temperature. Some candidates lost credit through not quoting their final answer to the required three significant figures. A small number of candidates did not square the r.m.s. speed they were given.

(c)(i) Many candidates knew the correct formula here and calculated the correct answer. A small number of candidates forgot to square the distance and some candidates incorrectly attempted to use the Stefan–Boltzmann law.

(ii) Many candidates knew the correct starting formula. A small number only squared the temperature.

(d) Candidates found this unusual application of the assumptions of an ideal gas to be challenging. Many candidates did not mention that the gas molecules would be much closer together.

Question 4

(a) The majority of candidates gave very good statements of the meaning of simple harmonic motion.

(b)(i) Most candidates were able to correctly calculate the angular frequency of the oscillations.

(ii) There were many correct answers for the total energy of the oscillations. Some weaker candidates did not know the correct equation to use and tried to include an additional term for the gravitational potential energy.

(c)   Candidates were not confident with drawing a graph to show critically damped oscillations. Some lines showed oscillations that were not damped at all, had very little damping or were overdamped instead.

Question 5

(a)   Most candidates were able to gain at least partial credit here. The idea of the work done per unit charge was commonly stated, but some candidates omitted the idea of division. Some omitted that the electric potential is defined for the movement of a positive charge.

(b)   Many candidates answered this question very well. The most common error was to write about the potentials of the two spheres because the graphs showed this. The question asked for conclusions relating to the spheres themselves, so these responses did not answer the question.

(c)   This was the most challenging part of the question and one of the most difficult questions on the question paper. Some candidates mentioned the positively charged particle moving towards X, but did not say why and did not give the detail that the particle would accelerate.

Question 6

(a)   Candidates need to use the word 'per' here or explicitly state that division is part of the definition. The phrase 'carrying unit current' does not convey division by current, while 'per unit current' does. Some candidates did not make it clear that the length (of the wire) or the current (in the wire) needs to be perpendicular to the field (lines). Some stated that the force was perpendicular to the current, which is not part of the definition of magnetic flux density.

(b)(i)   There were many correct statements here about the direction. Weaker candidates found it difficult to determine the correct direction.

(ii)   There were many correct calculations to show the magnitude of the force on the electron.

(iii)   Many arrows were drawn with the correct direction at X on the diagram.

(iv)   A large number of candidates knew the equations to use here. The most common errors were firstly to quote an answer to only one significant figure (0.04 m) where two significant figures were needed, and secondly to determine the radius but then not double it to give the diameter d of the circular path.

(c)   Most candidates had their path showing an upward deflection due to the opposite direction of force caused by the opposite charge of the positron. The detail of the path drawn was often not correct. The new radius (and hence diameter) was double that of the electron's path, so the point of exit from the field is twice as far from point X as the point of exit of the original path.

Question 7

(a)   Many candidates stated the correct expressions.

(b)   Candidates found some aspects of this sketch difficult. There were many correct shapes, but a large number of responses did not have an appropriate scale on the y-axis.

(c)(i)   Stronger candidates were able to achieve full credit. Weaker candidates often produced expressions that were not dimensionally consistent with power.

(ii)   Many candidates did not recognise the difference between the r.m.s. of a sinusoidally varying current and one (as in this question) that varied as a square wave. The relationship $I_0 / 2$ was often used here in error because candidates did not realise that it applies only to a sinusoidal current. Again, weaker candidates often gave answers that were not dimensionally consistent with a current.

Question 8

(a) (i) Stronger candidates used the correct method to derive the required expression. A common incorrect starting point was $E = mc^2$.

(ii) The wavelength was correctly calculated by most candidates. Many candidates did not explicitly make a connection between the wavelength and the fact that the light is red.

(b) (i) Only the stronger candidates were able to show this calculation adequately. Many candidates gained partial credit for the equation power = intensity $\times$ area.

(ii) Again, the only stronger candidates generally could work through this calculation. Many candidates omitted the effect of reflection by the mirror on the change in momentum of the light.

(c) Very few candidates realised that the photons would have greater momentum but there would also be fewer photons per unit time and hence the pressure would be unchanged. Some candidates omitted the word photon and made statements such as 'the blue light has greater momentum' which could not be awarded credit.

Question 9

(a) There were many good statements of the meaning of nuclear fusion. Some candidates were not awarded credit because they used the word 'nuclei' in place of the word 'nucleus'.

(b) Some candidates drew the variation of the binding energy per nucleon with nucleon number very well. In many cases the line had too steep a negative gradient to the right of the peak. Some very weak candidates drew a line with no peak at all.

(c) Most candidates labelled X and Y in appropriate places. In some cases, the X and Y were reversed. The lines of some candidates were such that it was not possible for credit to be awarded for **(c)**.

(d) This was a challenging question. Many candidates obtained the correct nucleon number of 233 for Z. A significant number of candidates did not take the 1.00 mol of Z into account and did not divide the energy by the Avogadro constant, thereby producing a final answer that was implausibly high. Some candidates did not set up the energy equation correctly and added the binding energies of Sr and Xe to that of Z rather than carrying out a subtraction.

Question 10

Please note that due to a series-specific issue with question 10, full marks have been awarded to all candidates for this question to make sure that no candidates were disadvantaged.

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PHYSICS

Paper 9702/51
Planning, Analysis and Evaluation 51

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

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Key messages

- In **Question 1**, candidates' responses should include detailed explanations of experimental procedures such as how to control variables, how to take measurements and how to analyse the data.

- The numerical answers towards the end of **Question 2** require candidates to show all their working and for the values to be correctly evaluated with appropriate units. A full understanding of significant figures and the treatment of uncertainties is required.

- Candidates need to understand how to use logarithms (both logarithms to base ten and natural logarithms) correctly.

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

General comments

In **Question 1**, it is advisable that candidates should think carefully about how they would perform the experiment in the laboratory using the points given on the question paper to aid their answer. Planning a few key points before answering **Question 1** is useful. Weaker candidates often did not rearrange the proposed relationship into a suitable equation of a straight line ($y = mx + c$). It is essential for candidates to have experienced practical work in preparation for answering this question.

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

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

Comments on specific questions

Question 1

Most candidates correctly identified the independent and dependent variables. Candidates should then consider the control of variables and explicitly state the quantities that need to be kept constant to make the experiment a fair test. In this experiment, it was expected that candidates would state that *h* would be kept constant. Credit was also available for stating that *M* would be kept constant. Credit is not given for simply stating 'control' *h* since this is just repeating the stem of the question and does not indicate what is meant by 'control'. Stronger candidates tend to use the given symbols rather than attempting to describe the quantities to be kept constant.

Candidates were awarded credit for a clearly labelled diagram. Diagrams should be drawn of the workable experiment. In this experiment, most candidates drew the pulley with the beakers and added appropriate labels. A common error was not to support the pulley using a clamp and stand placed on the bench.

Many stronger candidates drew a metre rule vertically on their diagram with the distance h clearly marked by dashed lines.

The most common method to measure the independent variable V was to use a measuring cylinder. Using a beaker was not considered appropriate since the precision was not as good as using a measuring cylinder.

To determine the speed of the beaker as it reached the surface, many candidates suggested a stop-watch or timer. Candidates did not gain credit for stating 'use a stop-watch to measure time' unless it was clear that the time being measured was for the beaker to fall to the surface. There was credit for explaining how z was determined from the time for the beaker to fall to the surface. Many candidates inappropriately stated how to determine the average speed for the beaker to fall (= h / time to fall) rather than the speed z (= $2h$ / time to fall). Some candidates described methods to use a light gate or a pair of light gates. It was expected that the light gate(s) would be connected to a timer. Credit was available for describing how the light gates would be used to determine z, but many candidates attempting to use this method actually described how to find the average speed rather than z.

Many candidates suggested correct axes for a graph. A significant number of candidates incorrectly suggested plotting z^2 against V. Candidates must explicitly state the quantities to be plotted on each axis either in the text or on drawn axes – credit is not given for just writing $y = mx + c$ under an equation.

Candidates also needed to explain how the graph would confirm the suggested relationship. Candidates need to use the words 'relationship is valid if' and the word 'straight' to describe the line. Some candidates did not gain credit because they incorrectly stated that the line would pass through the origin. Stronger candidates often stated the y-intercept that the straight line would pass through if the relationship was valid.

Candidates needed to explain how they would determine values for the constants a and b from the experimental results using the gradient and y-intercept. Candidates needed a and b to be the subjects of the relevant equations. Credit was not awarded to candidates who did not correctly identify appropriate axes for a graph to plot. Some candidates did not understand that a graph of $1 / z^2$ against $1 / V$ means that $1 / z^2$ is plotted on the y-axis and $1 / V$ is plotted on the x-axis.

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

When describing safety precautions, candidates should be encouraged to explain how the precaution proposed is relevant to the experiment. In this experiment, precautions that were relevant to the spillage of oil were needed. It is important that candidates think of genuine precautions, such as using a lid on the beaker to prevent oil spilling, rather than weaker solutions such as 'using towels to mop up spillages'.

Other additional detail that gained credit included a method to keep h constant for each experiment. A clear description was needed for this mark. Some candidates suggested the use of large values of h. To gain credit, candidates needed to explain the effect on the measured quantities, i.e. the time for the beaker to fall; simply stating that it would reduce the (percentage) uncertainty did not gain credit without further explanation. There was also credit available for repeating the measurements of the time for the beakers to fall for the same value of V and determining the average time of fall or average value of z. Simply 'repeating the experiment' is not sufficient without further explanation of what is being repeated.

Question 2

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

(b)   There were some errors in values of ln (V / V) caused by incorrect rounding. Many candidates did not allow correctly for the number of significant figures in ln (V / V). Since V was recorded to three significant figures, values of ln (V / V) should have been recorded to three (or four) decimal places – the number before the decimal point in a logarithmic quantity is not included. A common error was to incorrectly record values of ln (V / V) to two decimal places.

Some candidates calculated the values of 1 / C with incorrect rounding – common errors were 0.90 instead of 0.91 and 0.60 instead of 0.61.

Most candidates correctly determined the uncertainties in ln (V / V).

(c) (i) The points and error bars were straightforward to plot. A common error was plotting vertically 1.131 at 1.115 (three small squares difference). When plotting points, the diameter of each point should be less than half a small square. Candidates need to take greater care over the accuracy of the error bars and ensure that the error bars are symmetrical.

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

(iii) Most candidates clearly demonstrated the points that they used to calculate the gradient. Some candidates misread coordinates or did not use 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 on the line of best fit which are easy to read, i.e. points that are on grid lines. Stronger candidates often included the 10^4 power in their calculations, which assisted in the interpretation of the gradient and y-intercept in **(d)**. A significant minority of candidates incorrectly calculated the gradient as Δx / Δy.

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

(iv) The majority of the candidates who were awarded full credit set out their working clearly. Stronger candidates often substituted data from the gradient calculation **(c)(iii)** into $y = mx + c$. Some weaker candidates incorrectly read-off the y-intercept when 1 / C = 0.3. Other errors seen included candidates incorrectly dividing the y value by mx or inconsistent use of powers of ten between the gradient and the x-axis value used.

(d) (i) Candidates should show the substitution of the gradient and y-intercept into correct expressions to determine the values of R and I_0. Credit was not given for substituting data values from the table. Candidates are also expected to give the values of R and I_0 to an appropriate number of significant figures and with appropriate units which should have the correct power of ten. Common errors included omitting the 10^4 from the x-axis of the graph resulting in a power-of-ten error and incorrect units (e.g. s V F^{-1}) since candidates did not understand that the quantity ln (V / V) is dimensionless. Candidates should be encouraged to go back to the beginning of **Question 2** to remind themselves of the meaning of the quantities that are being calculated. It is clear from the question that R is resistance and I_0 is current.

(ii) Most candidates added the percentage uncertainty in the time to the percentage uncertainty in the gradient, clearly showing the numbers that are substituted into the equations. A common error was subtracting the percentage uncertainties. Some candidates determined the percentage uncertainty by maximum and minimum methods. It was essential that either the maximum time and minimum gradient (or the minimum time and maximum gradient) were shown to be used to determine the maximum (or minimum) value of R.

(e) There were different methods that candidates could use to determine C. Some candidates used the gradient and y-intercept, while others substituted values for R and I_0 from **(d)(i)**. Candidates needed to show clear and logical working for this question as well as considering the powers of ten. It was expected that the final answer would be given to at least two significant figures.

PHYSICS

> **Paper 9702/53**
> **Planning, Analysis and Evaluation 53**

Key messages

- In **Question 1**, candidates' responses should include detailed explanations of experimental procedures such as how to control variables, how to take measurements and how to analyse the data.

- The numerical answers towards the end of **Question 2** require candidates to show all their working and for the values to be correctly evaluated with appropriate units. A full understanding of significant figures and the treatment of uncertainties is required.

- Candidates need to understand how to use logarithms (both logarithms to base ten and natural logarithms) correctly.

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

General comments

In **Question 1**, it is advisable that candidates should think carefully about how they would perform the experiment in the laboratory using the points given on the question paper to aid their answer. Planning a few key points before answering **Question 1** is useful. Drawing circuit diagrams proved to be challenging for many candidates. Some candidates drew circuit diagrams that did not show a workable experiment, often with the incorrect positioning of voltmeters, oscilloscopes and ohmmeters. Other problems with the circuit diagram included a misunderstanding of the experiment, leading to the coils being connected or arranged incorrectly. Many candidates were successful in the analysis section with clear identification of how the constants could be determined. Weaker candidates often did not rearrange the proposed relationship into a suitable equation of a straight line ($y = mx + c$). It is essential for candidates to have experienced practical work in preparation for answering this question.

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

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

Comments on specific questions

Question 1

Most candidates correctly identified the independent and dependent variables. Candidates should then consider the control of variables and explicitly state the quantities that need to be kept constant to make the experiment a fair test. In this experiment, it was expected that candidates would state that V and R would be kept constant. Many candidates appeared to be confused regarding the meaning of V. Some candidates incorrectly stated that the potential difference across R should be kept constant. Credit is not given for simply stating 'control' V since this is just repeating the stem of the question and does not indicate what is meant by 'control'. Other candidates also gained credit for keeping the number of turns on each coil constant and the

distance between each coil constant. Candidates could only be awarded these marks if the statement was clear. For example, candidates needed to clearly state that the number of *turns* on both coils should stay constant, and a statement referring to just one coil was not credited. Since the experiment has two coils, statements referring to the number of coils, rather than the number of turns on the coils, could not be given credit.

Candidates were awarded credit for a clearly labelled diagram. Diagrams should be drawn of the workable experiment. In this experiment, most candidates drew two separate circuits. A circuit was needed to measure E; most candidates drew a voltmeter in parallel with coil D with only a small number of candidates using an oscilloscope. A common error was to place the voltmeter in parallel with a connecting lead in parallel with coil D (causing a short circuit of the coil) or to connect a power supply to coil D. There was also credit for the drawing of the circuit diagram for coil C. Many candidates drew a d.c. battery symbol rather than using an a.c. power supply. Other candidates did not place a voltmeter or oscilloscope to measure the potential difference across R and coil C.

Other common errors in drawing circuit diagrams included adding in an ohmmeter into one of the coil circuits, placing the oscilloscope in series or placing a signal generator in series with a power supply. Stronger candidates often correctly drew a signal generator or a.c. power supply with an oscilloscope connected in parallel. For candidates who used an oscilloscope, there was also credit for describing how the value of V was determined from the oscilloscope using the y-gain and the height of the trace.

Credit was also given if a workable circuit to determine R was shown. Stronger candidates drew a separate circuit for this containing the resistor connected to a power supply, with an ammeter and voltmeter correctly connected. Many candidates did not explain clearly how R was determined. Just quoting $R = V / I$ was not sufficient; candidates needed to make it clear that R is equal to the potential difference across R divided by the current in R.

Many candidates suggested the use of an oscilloscope to determine the frequency f of the changing magnetic flux. Stronger candidates included how the period T would be determined using the horizontal distance of one wave multiplied by the time-base, and stated that $f = 1 / T$. Some weaker candidates misunderstood the term 'changing magnetic flux' and incorrectly suggested the use of a Hall probe and a stop-watch.

Many candidates suggested correct axes for a graph, either lg E against lg f or ln E against ln f. Some candidates incorrectly suggested plotting E against f. Other candidates suggested plotting lg f against lg E, which did gain credit, but subsequent manipulation of the equation is harder with the axes reversed and this often led to errors in determining p and q. Candidates must explicitly state the quantities to be plotted on each axis either in the text or on drawn axes – credit is not given for just writing $y = mx + c$ under an equation.

Candidates also needed to explain how the graph would confirm the suggested relationship. Candidates need to use the words 'relationship is valid if' and the word 'straight' to describe the line. Some candidates did not gain credit because they incorrectly stated that the line would pass through the origin. Candidates should be encouraged to state if the line would have a y-intercept and what that intercept would be. For example, 'the relationship is valid if the graph shows a straight line with a y-intercept equal to lg (pV / R)'.

Candidates needed to explain how they would determine values for the constants p and q from the experimental results using the gradient and y-intercept. Candidates needed p and q to be the subjects of the relevant equations. Credit was not awarded to candidates who did not correctly identify appropriate axes for a graph to plot. Some candidates did not understand that a graph of lg E against lg f means that lg E is plotted on the y-axis and lg f is plotted on the x-axis.

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

When describing safety precautions, candidates should be encouraged to explain how the precaution proposed is relevant to the experiment. In this experiment, the precautions needed to be relevant to hot coils or resistors.

Other additional detail which gained credit included a method to keep the coils fixed in position (not just measuring the distance between the coils) and a method to increase the value of E such as the use of an iron core or increasing V. There was no credit simply for stating 'to reduce the (percentage) uncertainty' – it was the method to reduce the (percentage) uncertainty that was needed.

Question 2

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

(b)   Many candidates correctly calculated $\sqrt{\dfrac{1}{h}}$ with an appropriate absolute uncertainty. There were some errors due to incorrect rounding (often 0.261 instead of 0.262 in row 4) and some due to use of an incorrect number of significant figures. Since h was recorded to three significant figures, values of $\sqrt{\dfrac{1}{h}}$ should have been recorded to three (or four) significant figures.

Most candidates correctly calculated the absolute uncertainties in $\sqrt{\dfrac{1}{h}}$.

(c) (i)   The error bars were straightforward to plot, but some candidates incorrectly plotted one or more data points. When the data point is between grid lines, candidates should take extra care to ensure it is drawn accurately. For example, data point (637, 0.237) should not be drawn on the 640 grid line since it would be more than half a small square (1 mm) from the correct position. When plotting points, the diameter of each point should be less than half a small square. Candidates also need to take greater care over the accuracy of the error bars and ensure that the error bars are symmetrical.

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

   (iii)   Most candidates clearly demonstrated the points that they used to calculate the gradient. Some candidates misread coordinates or did not use a sensibly sized triangle. A small number of candidates incorrectly chose data points that did not lie on the lines, often using data from the table that is close to the line instead. Candidates should be encouraged to select two points on the line of best fit which are easy to read, i.e. points that are on grid lines. A significant minority of candidates calculated the gradient as $\Delta x / \Delta y$.

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

   (iv)   The majority of the candidates who were awarded full credit set out their working clearly. Stronger candidates often substituted data from the gradient calculation **(c)(iii)** into $y = mx + c$. A significant number of candidates incorrectly read-off the y-intercept when $M = 550$ g. Other errors seen included candidates incorrectly dividing the y value by mx or inconsistent use of powers of ten.

   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. There must also be evidence of subtraction between the y-intercept of the line of best fit and the y-intercept of the worst acceptable line. Some candidates incorrectly attempted to determine the uncertainty in the y-intercept by either assuming that the fractional uncertainty in the gradient was the same as the fractional uncertainty in the y-intercept or by adding fractional uncertainties.

(d) (i)   Candidates should show the substitution of the y-intercept to determine the value of u and the substitution of the gradient to determine the value of Z. Credit was not given for substituting data values from the table. Candidates are also expected to give the final values of u and Z to an

appropriate number of significant figures and with appropriate units which should have the correct power of ten. Many candidates gave incorrect units for one or both calculated values. Candidates should be encouraged to go back to the beginning of **Question 2** to remind themselves of the meaning of the quantities that are being calculated. It is clear from the question that u is speed and Z is mass.

(ii) Most candidates added the percentage uncertainty in the y-intercept to the percentage uncertainty in the gradient, clearly showing the numbers that are substituted into the equations. Some candidates determined the percentage uncertainty by maximum and minimum methods. It was essential that either the maximum u and maximum gradient (or the minimum u and minimum gradient) were shown to be used to determine the maximum (or minimum) value of Z.

(e) There were different methods that candidates could use to determine M. Some candidates used the gradient and y-intercept, while others substituted values for u and Z from **(d)(i)**. Candidates needed to show clear and logical working for this question including full substitution of the numbers used. It was expected that the final answer would be given to at least two significant figures.