PHYSICS

Paper 9702/11
Multiple Choice

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

General comments

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

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

Candidates found **Questions 1**, **6**, **9**, **13**, **30** and **34** difficult. They found **Questions 11, 20**, **21** and **26** relatively straightforward.

Comments on specific questions

Question 1

Candidates should understand that all physical quantities consist of a numerical magnitude and a unit. Very few candidates selected **B** or **C**, but many candidates selected **A** suggesting confusion distinguishing between units and quantities. The correct answer was **D** as spring constant has a magnitude and a unit.

Question 6

Candidates seemed to find this question difficult, and answers were evenly distributed over all four choices.

With negligible air resistance, the horizontal component of velocity v_H will remain constant at $10.0\,m\,s^{-1}$ but the vertical component of velocity v_V will increase as the ball experiences free fall acceleration. Substituting the data into $v_V = u + at$ gives $v_V = 29\,m\,s^{-1}$. Pythagoras' theorem can then be used to determine the speed of the ball at the instant before it hits the ground, i.e. $31\,m\,s^{-1}$, which is **C**. Candidates who added the vertical and horizontal components of velocity together without considering their perpendicular directions obtained incorrect answer **D**.

Question 9

As with **Question 6**, for questions involving projectile motion, the challenges for candidates are in handling several pieces of information and there being more than one step to calculate the final answer.

Many candidates appreciated that the projectile experiences weight acting vertically downwards, but many candidates held the common misconception that objects require a force in the direction of motion. Almost half of all candidates incorrectly chose **A**.

The projectile is travelling through air, and air resistance is **not** described as negligible. At position X the instantaneous motion of the projectile is horizontally to the right, so air resistance must act to the left. This means that **B** is correct.

Question 13

This question required an understanding of the conditions for a system to be in equilibrium.

The rod at P and the person at R both exert downward forces on the board, and the rod at Q exerts an upward force. The board is trying to pivot about point Q. As the person moves from R to Q, the downward force exerted by the person does not change.

As the perpendicular distance between the person and point Q decreases, the clockwise moment about Q decreases. Consequently, the anticlockwise moment and the force at P must also decrease. Since the total downward force has decreased, so the upward force at Q must also decrease, and **A** is correct.

Question 19

The lengths of the wires are related by $L_Q = ½L_P$ and, because the diameter is doubled, the cross-sectional areas are $A_Q = 4A_P$. Both wires experience the same force F, and being made of the same material they have the same Young modulus E.

E = stress / strain = $(F / A) / (x / L)$ and so extension $x = FL / AE$.

The ratio of the extensions is then given by:

$x_P / x_Q = (L_P / A_P) / (L_Q / A_Q)$

$= (L_P / A_P) / (½L_P / 4A_P)$

= 8 (answer **A**).

A common incorrect answer was **B**. Candidates who did not square the factor of 2 in the diameter would have concluded that $A_Q = 2A_P$, and arrived at **B**.

Question 22

This question proved challenging. Many candidates chose the incorrect answer **C**.

Constant frequency means that the time period is unchanged, so **A** and **B** can be ruled out.

Using *intensity* $\propto$ (*amplitude*)^2, candidates needed to take the square root of the ratio of intensities to find the ratio of amplitudes: $\sqrt{\frac{1}{2}} = 0.71$ (to 2 significant figures), so **D** is correct. Answer **C** arises from erroneously thinking that halving the intensity simply halves the amplitude.

Question 28

More candidates chose the incorrect answer **B** than the correct answer **A**. Candidates should be able to show an understanding of experiments that demonstrate diffraction including the qualitative effect of the gap width relative to the wavelength of the wave. For a gap that is much wider than the wavelength of the wave, the spreading of the wave – and hence the diffraction angle – is less than for a smaller gap. The wavelength is unaffected.

Question 30

For light that has passed through the diffraction grating, the maximum diffraction angle for dots appearing on the semicircular screen is 90°, measured from the straight through (zero-order) position:

$n\lambda = d \sin \theta$

$n = (2.0 \times 10^{-6} \times \sin 90°) / 5.4 \times 10^{-7}$

$= 3.7.$

The order number must be an integer, so the maximum order number for viewable bright dots on the screen is 3 – this would suggest **A** for candidates who took their deductions no further. Candidates who recognised that there is also a zero-order dot may have thought that the answer is: 3 + 1 = 4, whereas those who recognised that the pattern is symmetrical on the screen but forgot about the zero order will have doubled 3 to incorrectly arrive at **C**.

The correct answer is **D**: 3 + 1 + 3 = 7 bright dots.

Question 33

More candidates selected **A** than the correct answer **D**.

Candidates should appreciate that resistance is calculated by dividing a specific value of potential difference by the corresponding value of current. It is **not** determined from the gradient of the current–voltage characteristic. Considering $R = V / I$ it is apparent that **D** is correct.

Above the threshold voltage for the diode, the current–voltage characteristic becomes very steep and approximately linear. Candidates who mistakenly believed that a linear relationship is the same as direct proportionality may have thought that the diode behaves as an ohmic conductor for values of p.d. above the threshold voltage.

Question 34

This question was found to be very difficult, with many candidates selecting the incorrect answer **C**.

The wires are made from the same material, so they have the same resistivity and the same density. The wires must also have the same volume since they have the same mass.

For wire 1: $R_1 = \rho L / A$

For wire 2: $R_2 = \rho 3L / \frac{1}{3} A = 9 \rho L / A = 9R_1$

For **C** to be most popular answer, the majority of the candidates correctly identified the factor of three in relation to the length but did not realise the effect on the cross-sectional area and consequently on the resistance.

PHYSICS

Paper 9702/12
Multiple Choice

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

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

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

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

General comments

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

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

Candidates found **Questions 5**, **8**, **22**, **23**, **26** and **37** difficult. They found **Questions 2**, **16**, **21**, **24**, **27** and **32** relatively straightforward.

Comments on specific questions

Question 4

Over half of the candidates chose the incorrect answer **A**. Answer **A** represents the simple vector sum (resultant) of the two velocities, but the question asks about the *change* in the velocity.

The change in the velocity is the final velocity *minus* the initial velocity, and is found by reversing the direction of the initial velocity before adding this to the final velocity. The correct answer is **B**.

Question 5

This question was found to be difficult, with many candidates selecting the incorrect answer **D**.

The magnitude of an object's instantaneous velocity is its speed, and so the average magnitude of velocity (i.e. average speed) for this car as it travels from P to Q would be:

average speed = total distance / time taken

$= (2\pi \times 12 \times 3/4) / 4$

$= 14\ \text{m s}^{-1}$ (option **D**).

However, the question asks for the magnitude of the average velocity. The first step for candidates should be to determine the average velocity, which is given by total displacement / time taken. Since only the magnitude is required, candidates do not need to concern themselves with the direction:

average velocity = $\left(12^2 + 12^2\right)^{\frac{1}{2}} / 4.0 = 4.2\,\text{m s}^{-1}$

The correct answer is **A**.

Question 8

Candidates found this question to be difficult.

The child and the sledge should be treated as two separate objects with the same acceleration a (hence the child is stationary relative to the sledge). The relationship $F = ma$ may then be applied to each object.

Considering the forces acting on the child, there is a 12 N force to the right (due to the rope) and the frictional force of the sledge on the child acts to the left: $12 - F_{\text{friction}} = 20 \times a$.

For the sledge, the rope exerts a force of 12 N to the right, and the frictional force between the child's feet and the sledge also acts to the right: $12 + F_{\text{friction}} = 40 \times a$.

These two equations are then solved to give $F_{\text{friction}} = 4.0$ N.

Question 20

Candidates need to understand and use the terms *elastic limit* and *limit of proportionality*. Many candidates use the terms interchangeably, but they have distinct meanings: the elastic limit is the maximum force (or stress) before the onset of plastic behaviour, whereas the limit of proportionality is the end of the linear region of a force–extension (or stress–strain) graph.

In many cases, the limit of proportionality and the elastic limit lie very close together (and may even coincide), but a wire can exhibit elastic behaviour even though the limit of proportionality has been exceeded. So, while **D** may be true in a particular instance, only **A** is correct in all circumstances.

Question 22

The wave frequency of 0.20 Hz enables the time period to be determined as 5.0 s. The stated time of 20 s corresponds to 20 / 5.0 = 4.0 complete wave cycles.

For a transverse water wave, the displacements of the particles of the wave are at right angles to the direction of energy transfer of the wave, so in each cycle the ball will move through a vertical distance of $4 \times 0.70 = 2.8$ m, as it goes down to a trough and then back up to a peak again. For 4.0 wave cycles, the total distance travelled is therefore 11.2 m – answer **C**.

Almost half of all candidates chose **D**, which is consistent with the misconception that the ball moves in the direction of wave travel or energy transfer, horizontally to the right.

Question 23

This question proved to be difficult. Candidates needed to recognise that sound waves are longitudinal and that the air pressure is lowest where the air molecules are most widely spaced apart.

A simple method for visualising this is to draw five evenly spaced spots under the graph, lining up with the origin O and points A, B, C and D, which represent five air molecules at their equilibrium positions. The graph can then be used to redraw those spots in their new positions as the sound wave passes: the spot at O remains in its original position; the spot at A is shifted to the right; the spot at B remains in its original position; the spot at C is shifted to the left; the spot at D remains in its original position. It is then apparent that **D** represents an air molecule which is furthest from its neighbours.

Question 26

This question required care, and for some candidates sketching a diagram may have been a helpful strategy.

The intensity of the light transmitted from the second polarising filter is determined by applying Malus's law twice:

$I_1 = 8.0 \times \cos^2 50°$

then $I_2 = I_1 \cos^2\theta_2$ where $I_1 = 8.0 \times \cos^2 50°$ and $\theta_2 = 30°$ to give **B**.

The most popular answer, **C**, is obtained if θ_2 is taken as 20°. This suggests that many candidates did not fully appreciate the underlying physics and understand that the light emerging from the first filter has had its plane of polarisation rotated through 50°.

Question 28

The speed of a wave depends upon the physical characteristics of the medium through which it propagates, so the speed of the water waves in the ripple tank can be regarded as constant. By using the wave equation $v = f\lambda$, the effect of changing the frequency on the wavelength can be deduced.

The smallest diffraction angle is for the smallest wavelength (highest frequency) and largest gap width, so **D** is correct.

Question 37

This question proved to be very challenging, and incorrect answer **A** was the most popular choice. Just under a quarter of candidates selected the correct answer **D**.

At a glance, **A** has the closest visual resemblance to the way potentiometer circuits are often presented in textbooks, but the polarity of the cells is incorrect.

To determine the unknown e.m.f. E_X, the driver cell of known (larger) e.m.f. E_0 must be connected across the entire length PQ, thus circuit **B** can be eliminated. The galvanometer must be connected adjacent to E_X, as its role is to identify the position where the current is zero (i.e. the 'balance' position, when the p.d. between J and one end of wire PQ is equal to E_X), so circuit **C** can be dismissed.

For the circuit to work as intended, the cells must be arranged such that they are driving the current in the same direction in PQ – circuit **D** fulfils this requirement, whereas in circuit **A**, terminals of opposite polarity are connected to P.

This question highlights the importance of careful scrutiny of all options and the need for candidates to properly understand the underlying physics of a system.

PHYSICS

Paper 9702/13
Multiple Choice

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

General comments

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

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

Candidates found **Questions 1**, **9**, **18**, **31** and **35** difficult. They found **Questions 2**, **3**, **5**, **7**, **14**, **17**, **21**, **26** and **33** relatively straightforward.

Comments on specific questions

Question 1

Candidates should understand that all physical quantities consist of a numerical magnitude and a unit. **A** and **C** were the most popular choices, which suggests confusion distinguishing between units and quantities, as each of the first three options contained a unit. The correct answer was **D**.

Question 4

The percentage uncertainty in the diameter is $(0.01 / 5.00) \times 100 = 0.2\%$, and the percentage uncertainty in the radius will be the same. Since calculating the volume involves cubing the radius, the percentage uncertainty in the volume will be: $3 \times 0.2 = 0.6\%$ – so the correct answer is **C**, which was chosen by almost half of the candidates. The second most popular choice was **A**; these candidates had not considered the effect on the uncertainty of cubing the diameter or radius.

Question 9

This question involved an understanding of Newton's laws, and it proved to be very difficult. Only the strongest candidates selected the correct answer **D**.

More than half of candidates chose **A**, which suggests a misconception that the momentarily stationary ball is in equilibrium, with the total downwards force $P + W$ being equal to the only upwards force N.

However, candidates needed to realise that the ball is not in equilibrium – it bounces upwards, therefore it accelerates and must have a resultant upward force acting on it (Newton **I** and **II**). Candidates also needed to consider the forces acting <u>on the ball</u> – i.e. W and N, but not P which acts on the ground (Newton **III**).

Question 18

This is a simple question to interpret and solve, but it proved to be difficult for many candidates.

The instantaneous power output <u>from the engine</u> can be found using $P = Fv$, where F is the force provided <u>by the engine</u> (12 000 N) and v is the instantaneous velocity (24 m s^{-1}) giving **C**. The most popular choice was the incorrect answer **B**, which uses the resultant force (12 000 – 3000 = 9000 N) and is the effective or useful power.

Question 23

The amplitude of a sound wave is the maximum displacement from the equilibrium position, so its unit is m. The y-gain scale of the CRO is in units of V div^{-1}. Using the amplitude of the CRO trace to determine the amplitude of the sound wave involves a calculation converting V to m, and this would require knowledge of the behaviour of the microphone.

The time-base scale of the CRO is in units of s (or some multiple), so a direct reading of a single wave cycle on the horizontal axis of the CRO display would give the period of the wave.

Question 27

Candidates should be able to explain and use the principle of superposition. A statement of the principle of superposition involves only one of the four words in the answer options: displacement, hence **B** is the correct answer. Despite this being a straightforward piece of knowledge, many candidates thought that **A** was the correct answer.

Question 31

Candidates needed to know how to determine the maximum order number for a diffraction grating experiment. For light that has passed through the grating, the maximum diffraction angle for dots appearing on the semicircular screen is 90°, measured from the straight through (zero-order) position:

$$n\lambda = d \sin \theta$$

$$n = ([1 \times 10^{-3} / 300] \times \sin 90°) / 400 \times 10^{-9}$$

$$= 8.3.$$

The order number must be an integer, so the largest valid value for n is 8 – this would suggest **A** for candidates who took their deductions no further. Candidates who recognised that there is also a zero-order dot may have thought that the answer is: 8 + 1 = 9 (answer **B**), whereas those who recognised that the pattern is symmetrical on the screen but forgot about the zero order will have doubled 8 to incorrectly arrive at answer **C**. The correct answer is **D**: 8 + 1 + 8 = 17 bright dots.

Question 32

The wires are connected in series, so the current is the same for both. Using $I = nAvq$:

$nA_Xv_Xq = nA_Yv_Yq$

$A_Xv_X = A_Yv_Y$

$v_X / v_Y = A_Y / A_X$

The diameter of Y is twice the diameter of X, so $A_Y = 4A_X$, leading to the answer **D** for the ratio. A similar number of candidates got the ratio the wrong way round and chose **A**.

Question 35

About a quarter of the candidates chose the correct answer **D**, but more candidates chose **B**.

The same volume of conducting putty is re-formed into cylinders of increasing length. The resistance is related to the dimensions by $R = \rho L / A$. It is helpful to use $V = AL$ to re-write the equation as $R = \rho L^2 / V$, after which it is much more obvious that **D** is the correct answer.

For **B** to be most popular answer, it seems that the majority of candidates identified the effect of increasing length on the resistance, but they did not consider the decreasing cross-sectional area or its effect on the resistance.

A useful strategy with questions like this is to try dummy numbers: for example, a cylinder whose original dimensions are $L = L_0$ and $A = A_0$ has a resistance $R = R_0$; if $L = 2L_0$, then $A = ½A_0$, so $R = 4R_0$. If $L = 3L_0$, then $A = ⅓A_0$ and $R = 9R_0$, etc., and it becomes apparent that the relationship is non-linear with R increasing rapidly with length.

PHYSICS

Paper 9702/21
AS Level Structured Questions

Key messages

- Candidates should pay close attention to the command words used in each question. For example, 'state and explain' indicates that an explanation is required as part of the answer. Candidates who do not pay close attention to the command words for a question may either waste time giving an explanation when it is not required or omit an essential explanation when they have been asked to provide one. The syllabus contains a glossary of command words.

- For questions using the command word 'show', candidates need to carefully show all the steps in the solution. It is important to present these steps in a logical order in the calculation space. When an equation is rearranged, the new subject of the equation should always be shown.

- Candidates should avoid prematurely rounding interim answers within a calculation as this can lead to an incorrect final answer.

- The number of significant figures in the question data can be used as a guide to the number of significant figures required in the final answer. In the majority of cases, a minimum of two significant figures is appropriate for the final answer.

General comments

All of the questions contained straightforward parts that gave weaker candidates a chance to be awarded credit. Other questions were more challenging, such as **Questions 1(c)**, **2(c)(ii)**, **3(b)(iii)**, **3(b)(iv)**, **5(b)**, **5(d)** and **6(b)(i)**.

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

Comments on specific questions

Question 1

(a) This definition was well answered by the majority of candidates. The most common correct answer was 'rate of change of displacement'. Some candidates wrongly defined velocity as 'the rate of change of displacement per unit time'. Other candidates incorrectly referred to distance instead of displacement in their answer.

(b) (i) The majority of the candidates used the area under the graph or the equations of uniform acceleration to determine the height. A common error was to assume an acceleration of $9.81\,\mathrm{m\,s^{-2}}$ or to add (instead of subtract) the areas of the two triangles. Some stronger candidates used $s = ½(u + v)t$ to calculate the height directly.

A significant minority misread the value of the final velocity from the graph as either $2.2\,\mathrm{m\,s^{-1}}$ or $2.0\,\mathrm{m\,s^{-1}}$. Those candidates who used very small triangles to determine the gradient of the graph line often had difficult coordinates to read which resulted in an incorrect value of acceleration. Candidates should use as long a part of the line as possible and choose easy-to-read coordinate points.

(ii) Stronger candidates realised that there was a change in direction of the rock after 2.5 s and obtained the change in velocity and hence the change in momentum by adding the initial and final speeds. A common error was to subtract these two speeds. A small minority of candidates calculated the rate of change of momentum instead of the change in momentum.

(iii) Candidates could use either $W = mg$ or $W = \Delta p / t$. A common error when using the first equation was to use $g = 9.81\,\mathrm{m\,s^{-2}}$ which incorrectly assumes that the planet is Earth.

(c) Many candidates found this question very difficult. A significant number described the effect on the resultant force for a rock falling instead of moving vertically upwards. This resulted in inappropriate comments about the rock reaching terminal velocity. Only a small minority of candidates correctly described the viscous force as decreasing due to the velocity of the rock decreasing as it moves upwards. Weaker candidates sometimes thought that there must be another force acting upwards on the rock to enable it to move upwards.

Question 2

(a) A significant number of candidates did not give a precise definition. Many candidates referred to mass or gravity instead of weight. Others stated that the centre of gravity is the point where all the weight of an object acts, rather than 'is taken to act'. Many thought that the whole weight of the object is concentrated at this point, which is not correct. Some candidates tried to give an answer in terms of a balance point.

(b) (i) Generally, this question was well answered. A significant number of candidates correctly calculated at least two of the moments. The moment of the 3.0 N force was sometimes incorrectly calculated by using the distance to the centre of gravity of the rod instead of to the pivot.

(ii) Most candidates realised that the upward force at the pivot was equal to the sum of the three downward forces acting on the rod. A significant number of weaker candidates gave the weight of the rod as the answer without considering the condition for the rod to be in equilibrium.

(c) (i) Some candidates substituted the value of the weight of the sphere instead of the value of the upthrust into the relevant symbol formula. Many candidates were also unable to recall the correct symbol formula for the volume of the sphere. Errors were often made when calculating the value of r from the value of r^3, such as taking the square root instead of the cube root. Some candidates expressed their answers to one significant figure when a minimum of two significant figures was appropriate.

(ii) Many candidates attempted a full moments analysis, but often used an incorrect value for either the force due to the sphere or the perpendicular distance of that force from the pivot. Very few candidates realised that the resultant moment was due to the upthrust. The stated direction of the resultant moment was often vague such as 'to the left' or 'downwards' instead of anticlockwise. A significant number of candidates did not attempt a response.

Question 3

(a) (i) Most candidates correctly defined power as work done per unit time. If the definition is given in terms of energy, it is important to refer to energy transferred per unit time (and not just energy per unit time). A significant number stated 'power = force × velocity'. Although this is a correct mathematical relationship, it is not the definition of power.

(ii) Generally, this question was well answered. Candidates were expected to use the given symbol x for displacement and not a different unexplained symbol such as d.

(b) (i) A significant number of candidates realised that for the block to move at constant velocity the tension in the wire must be equal to the component of the weight acting down the slope. Some candidates used an incorrect trigonometric function to calculate the component of the weight. Others wrongly thought that the tension was equal to the actual weight.

(ii) Most candidates were able to determine the speed of the block using their value of the tension from **(b)(i)**. A significant number used a different force value with the weight being the most common.

(iii) Only a small proportion of the candidates gave the correct reason, which was that the kinetic energy of the block remained constant.

(iv) The most common errors were to calculate 80% of the output power as the input power or to use 56 W as the input power.

Question 4

(a) The majority of the candidates gave the correct symbol equation for determining the spring constant. Common errors included using the length of the spring instead of the extension and not converting the extension from cm to m.

(b) A significant number of candidates obtained the correct answer. There were a variety of incorrect symbol equations stated for the elastic potential energy. The error in **(a)** of using the length of the spring instead of the extension was often repeated here.

Question 5

(a) Candidates found it difficult to explain the formation of the stationary wave on the string in the question. Many candidates described only the formation of any stationary wave in general. Many candidates mentioned reflection without stating where the reflection occurred. For full credit the answer had to make clear that the waves are travelling in opposite directions **and** then superpose. Candidates often tended to state just one or the other part of this explanation.

(b) The phrase in the question about point P moving downwards is there so that the candidates are able to deduce that, one quarter of a cycle later, P will be below its initial position. A significant number of the candidates drew point P above its initial position. Many candidates drew two contradicting positions of the string, one above and one below the straight-line position. Candidates needed to ensure their drawn line passed through all the nodal points. A significant number of candidates did not draw any line.

(c) Most candidates could calculate the wavelength of the stationary wave. Stronger candidates then realised that the length of the string was equivalent to two and a half wavelengths. Weaker candidates thought that the string length was equal to the wave speed multiplied by the period.

(d) Only a small proportion of the candidates were able to calculate that the string moved through 1.5 cycles in the time of 0.060 s. Only the very strongest candidates realised that the string moved through six amplitudes in 1.5 cycles.

Question 6

(a) There were many correct answers. Some candidates stated that the currents into a junction are equal to the currents out of the junction without explicit reference to the sum of the currents. Weaker candidates described currents around a loop or in a circuit rather than at a junction. Other candidates confused Kirchhoff's first and second laws.

(b)(i) Only a small percentage of the candidates explained that the potential difference would be the same across both resistors. A significant number that thought that there would be a higher potential difference across resistor X than across resistor Y. Some candidates used $P = I^2R$ and so incorrectly deduced that $P \propto R$ without considering that there are different currents in the two resistors.

(ii) Most answers were correct. A significant number of candidates did not include the required supporting explanation in their answer.

(c)(i) The current was usually calculated correctly. A small minority of candidates used the e.m.f. of the battery for the potential difference across the resistor instead of using the reading on the voltmeter.

(ii) There was a large number of correct answers. Some candidates used the potential difference across the 1800 Ω fixed resistor instead of that across the LDR.

(iii) Some candidates did not realise that the resistance of the LDR would decrease as the intensity of the light increased. Many thought that the current would not be affected. Others did not comment on the current at all, even though the question explicitly asked for a reference to the current.

Question 7

(a) (i) The majority of the candidates realised that there would be no change in *A*. Some candidates thought that Z would change by –1 rather than +1.

The question required the candidates to give the **change** in the values of *A* and *Z*, so final answers of *A* and *Z* + 1 were not correct.

(ii) Most answers were correct. Common incorrect answers included 'neutrino', 'electron' and 'positron'.

(b) (i) This question was well answered by the majority of the candidates. Weaker candidates sometimes made the mistake of assuming that the down antiquark had a charge of $-\frac{1}{3}e$.

(ii) Most candidates could give at least one correct class of particle.

PHYSICS

Paper 9702/22
AS Structured Questions

Key messages

- Candidates should pay close attention to the command words used in each question. For example, 'state and explain' indicates that an explanation is required as part of the answer. Candidates who do not pay close attention to the command words for a question may either waste time giving an explanation when it is not required or omit an essential explanation when they have been asked to provide one. The syllabus contains a glossary of command words.

- For questions using the command word 'show', candidates need to carefully show all the steps in the solution. It is important to present these steps in a logical order in the calculation space. When an equation is rearranged, the new subject of the equation should always be shown.

- Candidates should avoid prematurely rounding interim answers within a calculation as this can lead to an incorrect final answer.

- The number of significant figures in the question data can be used as a guide to the number of significant figures required in the final answer. In the majority of cases, a minimum of two significant figures is appropriate for the final answer.

General comments

All of the questions contained straightforward parts that gave weaker candidates a chance to be awarded credit. Other parts of questions were more challenging. In **Question 2(d)(ii)**, most candidates found it difficult to apply the relationship between the extension of a wire and its elastic potential energy when Hooke's law is obeyed. In **Question 7(b)(ii)**, candidates found it difficult to explain which particle was a meson and which particle was a baryon.

A small minority of candidates left a significant number of their answer spaces blank. Candidates should be encouraged to attempt every question as sometimes marks can be awarded for a partial calculation or answer.

Comments on specific questions

Question 1

(a) The two SI base units in the list were usually identified correctly. Some of the weaker candidates thought that degree Celsius was an SI base unit.

(b) (i) The majority of the answers were correct. Some candidates forgot to double the percentage uncertainty of *T*. Other candidates confused percentage uncertainty with absolute uncertainty. A common error was to substitute the percentage uncertainty values directly into the given Young modulus equation.

(ii) Most candidates knew how to calculate the absolute uncertainty of the Young modulus. Only the strongest candidates realised that the answer inside the brackets on the answer line should show the value of *E* expressed to the same number of decimal places as the absolute uncertainty.

Question 2

(a) Many candidates found it difficult to set up the required equation for the forces acting on the sphere in the vertical direction. In many instances, the term representing the vertical component of the force from the wire contained the wrong trigonometric function.

(b) (i) Most candidates realised that they needed to use the symbol formula for upthrust given on the Formulae sheet at the front of the question paper. A common mistake was to substitute the value of the weight of the sphere instead of the value of the upthrust acting on the sphere.

(ii) This question was well answered. Some candidates confused the mass of the sphere with its weight.

(c) Almost all of the candidates could recall the relevant symbol formula for the change in the gravitational potential energy of the sphere. A significant number of candidates made the mistake of adding the change in height of the sphere to the original height when they should have been subtracting it. Weaker candidates sometimes gave the change in height instead of the final height of the sphere as their final answer.

(d) (i) The candidates were asked to state an equation in terms of the symbols T and x and to identify any other symbols used. Some candidates used different unexplained symbols instead of T and x. Other candidates correctly stated $T = kx$, but did not identify the symbol k.

(ii) A common misconception was that doubling the extension of the wire would double, instead of quadruple, its elastic potential energy. This misconception stems from the incorrect assumption that $E_P \propto x$ because $E_P = ½Fx$. This incorrectly assumes that the tension of the wire remains constant as the extension doubles, when in fact the tension also doubles.

Question 3

(a) In general, this question was well answered. The command word 'show' was used in the question and so candidates needed to explicitly present each interim step of the calculation. The subject of any equation needed to be explicitly stated and the substitution of all values clearly shown. Candidates needed to choose either the upwards or downwards direction as positive and then ensure that each value had the appropriate sign when substituted into the relevant symbol equation.

(b) Although there were many successful responses, a common error was to assume that the ball had a velocity of $5.6\,\text{m}\,\text{s}^{-1}$ at its maximum height. Weaker candidates sometimes gave the value of t^2 as their final answer, forgetting that they needed to take the square root of the value. Candidates needed to use $9.81\,\text{m}\,\text{s}^{-2}$ and not $10\,\text{m}\,\text{s}^{-2}$ for the value of g because substituting its value with only one significant figure led to an inaccurate final answer.

(c) Most candidates realised that the velocity would change sign from positive to negative. A common mistake was to draw the graph line so that the final speed was equal to the initial speed. Weaker candidates sometimes drew a curved line and did not appreciate that the constant acceleration of the ball meant that the line must have a constant gradient. The candidates needed to ensure that the graph line was drawn over the full range of time so that it continued all the way to time $t = T$.

(d) The majority of responses were correct. The most common incorrect response was 'displacement'.

(e) (i) A common misconception was that when air resistance is negligible the acceleration of the ball is dependent upon its mass. A significant proportion of weaker candidates believed that the second ball would have less acceleration because it had a larger mass.

(ii) The most common misconception was that the second ball would hit the ground with a greater speed than the first ball because it had a larger mass.

Question 4

(a) Candidates needed to make it clear in their statement that the total momentum would remain constant. A significant number of candidates forgot to refer to a closed system. Some of the weakest candidates confused 'momentum' with 'moment'.

(b) (i) A common mistake was to use the wrong trigonometric function when calculating the initial momenta along the line AB. Some of the weakest candidates believed that the total velocity in the direction of the line AB would be conserved (instead of the total momentum).

(ii) The total kinetic energy after the collision was usually calculated correctly. A common mistake was to calculate the initial kinetic energy of a ball by using only the component of the initial velocity in the direction along line AB (instead of using the 'full' velocity).

Question 5

(a) Most responses were correct. It was insufficient to state that coherence means only that the waves have a constant frequency. Some candidates inappropriately stated that the waves must have the 'same phase difference' (instead of 'constant phase difference'). This wrongly implies that the phase difference is a property of each of the waves rather than something that is derived from a comparison of the two waves.

(b) (i) Most candidates did not realise that the path difference would be equivalent to 1.5λ. A common incorrect answer was 330 nm. Some of the weaker candidates thought that they were being asked to calculate the separation of the fringes on the screen.

(ii) Most answers were correct.

(c) The equation $\lambda = ax / D$ was usually recalled correctly. Candidates needed to ensure that each numerical value had the correct power of ten when it was substituted into this equation. A common mistake was to think that the symbol x in the equation represented the distance between a bright fringe and an adjacent dark fringe. This mistake then led to a final answer that was twice as large as the correct final answer.

(d) The candidates were asked only to compare the appearance of the fringes before and after the increase in intensity of the light incident on the double slit. Some candidates gave the reasons for the differences and similarities, even though the question did not ask for an explanation. Most candidates realised that the bright fringes would get brighter, although a common misconception was that the dark fringes would become darker. Some candidates did not appreciate that a full comparison of the appearances of the fringes includes a description of things that have stayed the same as well as things that have changed. Only the stronger candidates remembered to state that there would be no change to the fringe separation.

(e) The majority of the candidates knew that the blue light had a smaller wavelength. Some candidates were then unable to deduce that there should be a decrease in slit separation. Weaker candidates sometimes confused the slit separation with the fringe separation.

Question 6

(a) This question used the command word 'show' and so it was essential to explicitly show all the interim steps of the derivation. Successful candidates carefully presented each of the steps in a logical order and remembered to give the subject of each equation. The most common mistake was to omit the first step of equating the sum of the individual potential differences to the total potential difference across the combination of resistors.

(b) (i) The majority of the candidates found the calculation to be straightforward.

(ii) It was necessary to convert the units of the resistances from kΩ to Ω to avoid making a power-of-ten error in the calculation. Many candidates realised that for the first step of the calculation they needed to use the formula for finding the combined resistance of two resistors in parallel. However, some candidates thought that they had calculated the value of the combined resistance when they had instead calculated only the reciprocal of that value.

(c) Most candidates knew that the resistance of the thermistor would increase. Candidates needed to be clear about which resistances they were referring to in their explanations. A vague reference to 'resistance' could mean the resistance of the thermistor, the resistance of a fixed resistor, the combined resistance of the resistors in parallel or the total resistance of the entire circuit. Some candidates did not comment on the current in the battery even though the question specifically instructed the candidates to refer to that current in their explanations.

Question 7

(a) (i) The majority of the candidates knew that the nucleon number would be conserved for the decay process and so the numbers for P and Q were usually given correctly. Some of the weaker candidates were unable to recall the number for R and were therefore unable to determine the number for S.

(ii) Generally, this question was well answered and the spelling of 'leptons' was usually correct.

(b) (i) The question used the command word 'show' and so it was essential that the candidates clearly presented all their working in a logical order.

(ii) Some candidates identified which particle was a meson and which was a baryon, but did not provide the required supporting explanations. Other candidates gave general descriptions of a meson and a baryon, but did not remember to state which group contained particle Y or particle Z. A common misconception was that a baryon can only contain three quarks that are the same type.

PHYSICS

Paper 9702/23
AS Level Structured Questions

Key messages

- Candidates should pay close attention to the command words used in each question. For example, 'state and explain' indicates that an explanation is required as part of the answer. Candidates who do not pay close attention to the command words for a question may either waste time giving an explanation when it is not required or omit an essential explanation when they have been asked to provide one. The syllabus contains a glossary of command words.

- For questions using the command word 'show', candidates need to carefully show all the steps in the solution. It is important to present these steps in a logical order in the calculation space. When an equation is rearranged, the new subject of the equation should always be shown.

- Candidates should avoid prematurely rounding interim answers within a calculation as this can lead to an incorrect final answer.

- The number of significant figures in the question data can be used as a guide to the number of significant figures required in the final answer. In the majority of cases, a minimum of two significant figures is appropriate for the final answer.

General comments

All of the questions contained straightforward parts that gave weaker candidates a chance to be awarded credit. Other parts of questions were more challenging, such as **Questions 2(c)**, **3(c)(i)**, **3(c)(ii)**, **5(b)(iii)**, **5(b)(iv)**, **6(a)(ii)** and **7(b)(i)**.

The relationship *intensity* = *power* / *area* for progressive waves is an addition to the syllabus in 2022 and many candidates did not appear to be familiar with it. In general, candidates had difficulty with **Question 5** and would benefit from further study of waves.

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

Comments on specific questions

Question 1

(a) The majority of the candidates gave the appropriate symbol equation for density. Stronger candidates were also able to recall the formula for the volume of a sphere. Common errors included using an incorrect formula for the volume of a sphere and confusing the diameter of the sphere with its radius.

(b) Stronger candidates found this calculation to be straightforward. Some candidates did not multiply the percentage error in the diameter by a factor of three.

Question 2

(a) This was well answered by the majority of the candidates. There were some calculations that incorrectly used the 'full' velocity of the arrow instead of the component of the velocity in the horizontal direction.

(b) Most candidates found this question to be challenging. The candidates usually realised that they needed to use the equations of uniformly accelerated motion, but often substituted incorrect values into those equations. Common mistakes included substituting the value of the acceleration with an incorrect sign or using the 'full' initial velocity instead of the component of the initial velocity in the vertical direction. Many candidates just calculated the maximum height of the arrow.

(c) Many candidates did not appreciate that the arrow ended at a height lower than the starting height. Some candidates who had calculated the final velocity were able to state that the final kinetic energy was greater than at the start. Very few candidates were able to relate the increase in kinetic energy of the arrow to the decrease in its gravitational potential energy. A small minority of the candidates did not read the question carefully and described only the energy changes as the arrow was brought to rest when hitting the target.

Question 3

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

(b) (i) Most answers were correct.

(ii) This question was very well answered by most candidates. Only a small number of candidates did not relate the value of the acceleration calculated in **(b)(i)** to the gradient of the graph line. It is important that candidates always use a ruler when drawing straight-line graphs.

(c)(i) This question was generally well answered. The majority of the candidates drew a curve with a decreasing gradient up to a time of 12 s. A common mistake was to sketch a graph line that was above the straight line drawn in **(b)(ii)** for the first part of the car's motion. Some candidates drew a freehand horizontal line after 12 s instead of drawing that part of the graph line using a ruler.

(ii) The majority of the candidates correctly described an increase in the velocity. Only a small minority mentioned that the car would eventually reach a new terminal velocity that was higher than the original terminal velocity.

Question 4

(a) The majority of the candidates were able to give a correct expression for the work done. Only the more able candidates went on to explicitly show that the work done was equal to the gain in gravitational potential energy.

(b) Many candidates found this question to be challenging. The most common incorrect answer was that gravitational potential energy is converted to kinetic energy. This implies that there is an increase in kinetic energy which is not possible when the mass is falling at a steady speed.

(c) (i) This question was well answered by the majority of the candidates. A small number of candidates calculated the work done instead of the rate of work done. It is important that candidates carefully read the details of each question.

(ii) Most answers were correct. Some calculations used an incorrect symbol formula for electrical power or did not convert the current given in milliamperes into amperes. A significant number of candidates did not attempt a response.

(iii) The stronger candidates used the two answers obtained in **(c)(i)** and **(c)(ii)** to calculate the efficiency. Weaker candidates were unable to apply an appropriate expression for efficiency or did not attempt a response.

Question 5

(a) (i) Only the stronger candidates were able to apply the correct expression for the power of the light. Common errors included not converting the units for the radius from centimetres into metres or not recalling the correct formula for the area of a circle. A significant number of candidates did not attempt a response.

(ii) The stronger candidates were able to use answer from **(a)(i)** to determine the new intensity of the light. A significant number did not use the correct units for the radius or did not use the correct expression for the intensity of the light. A significant number of candidates did not attempt a response.

(b) (i) Most candidates could recall the equation relating the wavelength to the velocity and frequency of the wave. The question used the command word 'show' and so it was important for the candidates to show the full substitution of the values of the velocity and frequency as well as stating the final answer.

(ii) Stronger candidates could state the correct region of the electromagnetic spectrum. Many weaker candidates appeared to state a random incorrect region of the electromagnetic spectrum.

(iii) Only a small minority of candidates obtained the correct final answer. Some of the stronger candidates obtained the correct number of maxima for one side of the semicircular path of the detector, but did not consider that there would be an equal number of maxima on the other side. Some candidates were able to recall the correct symbol equation $n\lambda = d \sin\theta$ but were unable to calculate the distance d between two adjacent slits. A significant number of weaker candidates did not attempt a response.

(iv) Candidates needed to explain that the wavelength of the light from the second laser was greater than the wavelength of the light from the original laser. A significant number of candidates incorrectly predicted that the number of maxima would increase despite correctly explaining that the wavelength had increased. Some of the weakest candidates did not attempt a response.

Question 6

(a) (i) A small number of candidates were able to sketch the fully correct I–V characteristic. Some candidates sketched a line in only the first quadrant of the graph. Other candidates sketched a line in the first and third quadrants, but sketched their line so that its gradient increased where it should have decreased.

(ii) A small proportion of the candidates could explain that the increased current caused the temperature and therefore the resistance of the filament to increase. Fewer candidates were able to further explain that as current increases the graph curves because the ratio V / I increases.

(b) Most candidates were able to recall the relevant symbol equation and then calculate the correct resistance.

(c) Although most candidates were awarded at least partial credit, there were very few correct answers to the last two rows of the table. Most candidates found it difficult to interpret the given circuit diagram showing two resistors of different resistance values connected in parallel across a cell. A key point of understanding is that the potential difference across two components in parallel is the same, and in this circuit many candidates did not realise that the potential difference across both of the resistors was the same. This meant that they were then unable to relate the currents in the resistors to the values of resistance.

Question 7

(a) (i) A common mistake was to omit the neutrino from the nuclear equation. Some candidates gave the β^+ particle without showing its nucleon number and proton number.

(ii) Generally, this question was well answered.

(b)(i) Only a small proportion of the answers explained that the maximum negative charge of a quark is $-\frac{2}{3}e$. The candidates then found it difficult to explain how the number of quarks required to reach a total charge of $-2e$ must be three.

(ii) The strongest candidates were able to name a correct possible quark composition, but there were a significant number of weaker candidates who did not attempt this question.

PHYSICS

Paper 9702/31
Advanced Practical Skills 1

Key messages

- If a raw value is out of trend to that expected, candidates should be encouraged to check the readings again with the equipment provided in the early stages of data collection.
- In the table work, the number of significant figures in the calculated quantity should relate to the number of significant figures in the raw data with the least number of significant figures. Each calculated quantity should be checked row by row.
- In the graphical work, candidates should be able to read off any points to the nearest half a small square. Incorrect read-offs of plotted points into the gradient calculation or when determining the *y*-intercept was a common feature.
- 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

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

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

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

Comments on specific questions

Question 1

(a) Many candidates gave a value of T in the required range with a unit and set up the apparatus correctly so that the lower mass m had a value of 250 g. Some candidates omitted units, gave a value of nT having forgotten to divide by n, or gave a value well out of range owing to misreading the stop-watch.

Many candidates recorded repeat values of nT where n was clearly shown as 5, 10 or 20. Some candidates recorded the time for single oscillations, only recorded one value of nT, or did not show the number n of oscillations they had used.

(b) Many candidates gave the total value of mass i.e. upper mass + m as 450 g. Some candidates omitted units or gave values outside this range.

(c) Many candidates were able to collect six sets of values of m and T 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. Some candidates took the time to repeat their readings, recording both nT and T. 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 a general trend and repeat these readings as they experiment to double-check.

Many candidates chose too small a range of mass 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 mass which are provided 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 $\sqrt{T}$ column was the most common for which the unit was omitted. Sometimes the column heading was recorded as $\sqrt{T}$ / s rather than $\sqrt{T}$ / $s^{½}$. Some candidates wrote the units in the body of the table rather than in the column heading.

Many candidates were awarded credit for consistency, giving all raw time values to the same precision of either 0.1 s or 0.01 s. Some candidates only recorded times to 0.001 s having calculated T before recording any times. Candidates should be encouraged always to record their raw data, not just calculated quantities that are derived from the raw data.

Most candidates calculated and recorded their values of $\sqrt{T}$ correctly, i.e. to the same number of significant figures as (or one more than) the number of significant figures of the raw values of T. Some candidates rounded their final answers incorrectly.

(d) (i) Most candidates gained credit for drawing appropriate axes, with labels and sensible scales. Compressed scales (where the data points occupy less than half of the grid) were often seen and could not be awarded credit. There were some incidences of awkward scales (e.g. based on 3, 6 or having 15 squares equivalent to 100 g). Credit cannot be awarded for this type of scale, and these candidates often lost further credit later for incorrect read-offs when calculating the gradient or the y-intercept of the line.

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

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 they do not think they have one.

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

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

(ii) Some candidates were able to draw carefully considered lines of best fit, but others did not balance the distribution of points along the length of the line. Some candidates joined the first and last points on the graph regardless of the distribution of the other points or forced the line through the origin. There should always be a balanced distribution of points either side of the line along the entire length. Many lines needed rotation to get a better fit, or an anomalous point needed to be identified to justify the line drawn.

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

Some candidates were able to correctly read off the *y*-intercept at $x = 0$ directly from the graph, but 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) Many candidates recognised that *P* was equal to the gradient and *Q* was equal to the intercept. Stronger candidates recorded a value with consistent units for *P* ($s^{½}\,g^{-1}$) and *Q* ($s^{½}$). Weaker candidates stated incorrect units using s or omitted units altogether.

Question 2

(a) (i) Many candidates correctly stated a value of *d* to the nearest mm in the required range, noticing the unit given was m. Some candidates gave readings to the nearest cm, or did not notice the unit and consequently gave a value outside the range, or measured the radius rather than the diameter.

(ii) Many candidates were correctly able to calculate *A* using their value of *d*.

(b) (i) Many candidates correctly stated a value of *h* in the required range, noticing the unit given was m. Some candidates did not adjust the apparatus to bring *h* into the required range or did not notice the unit and consequently gave a value outside the range. Some candidates made an incorrect conversion from their reading in cm to the required m. Most candidates correctly stated a value of *y*.

(ii) Most candidates are familiar with the equation for calculating percentage uncertainty. Some candidates made too small an estimate of the absolute uncertainty, often giving the precision of the rule 0.1 cm as Δh without recognising that the reading is subject to uncertainty. Some candidates repeated their readings and correctly gave the uncertainty in *h* as half the range, while other candidates did not halve the range.

(iii) Stronger candidates were able to calculate *C* correctly using their values.

(iv) Some candidates correctly justified the number of significant figures they had given for the value of *C* with reference to the number of significant figures used in *L*, *d*, *h*, ρ and *M*. Many candidates gave reference to *A* rather than *d*, or just 'raw readings' or 'measured values' or 'values in calculation' without stating what these values were.

(c) Nearly all candidates correctly recorded second values of *x* and *y*.

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

(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.

(e) Some candidates read the question carefully and correctly used the stated percentage uncertainty value given in the question i.e. 10%. These candidates clearly showed the calculation of the percentage difference between their two values of *k* and compared their percentage difference value to the 10% value, stating a correct conclusion for whether the results supported or did not support the relationship.

Several candidates referred back to the percentage uncertainty calculated for *h* and this was not awarded credit; the given uncertainty of 10% must be used. Some weaker candidates made a statement such as 'this is valid because the values are close to each other' which was not given credit as there was no justification for the conclusion.

(f) (i) This experiment provided many limitations for discussion. The investigation found how the balance point of a metre rule, indicated by length *y*, varied as the depth of sand in a tube changed the depth *h* of the tube in water. Many candidates retreated into familiar ideas about balancing with general statements such 'the rule was difficult to balance' which did not gain credit.

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

Many candidates correctly stated difficulties involved in measuring *d* due to the curved shape, but a bald statement of 'it was difficult to measure the diameter with a ruler' did not gain credit.

To gain credit for limitations concerning measurements, the quantity that was difficult to measure must be referred to along with the difficulty. For example, 'it was difficult to measure *x*' on its own is insufficient. More specific answers such as 'it was difficult to measure *h* as the ruler is far from the tube', using the technical term 'parallax error', or giving the reason that 'the tube was distorted due to refraction effects' could gain credit. However, a bald statement such as 'parallax error' or 'the tube is in water' on its own could not gain credit.

(ii) Many candidates realised that the experiment could be improved by taking more readings and plotting a graph, and another common improvement that was given credit was the use of calipers to measure *d* accurately.

Some candidates provided solutions such as 'look at eye level' or 'look perpendicular'. These improvements could have been carried out in the original experiment and so they are not given credit. Some candidates suggested 'use a mirror' but there was not enough detail given to understand how this would have improved the experiment.

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

PHYSICS

Paper 9702/32
Advanced Practical Skills 2

Key messages

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

General comments

The Confidential Instructions ask centres to submit a Supervisor’s Report and a set of sample results along with the scripts for each practical session. As a minimum, the sample results should include a value for every measurement candidates are asked to make in both questions on the paper. These values are used by Examiners to make suitable allowance in awarding marks when a candidate’s value occurs outside an expected range shown in the mark scheme. Where no values are provided, it is not possible to make this allowance.

There are a number of questions in the paper where the candidates needed to give measurements to the precision of the measuring instrument (e.g. 30 cm ruler and ohmmeter) in order to gain credit. Likewise, where an answer line does not include a unit, candidates are expected to provide a correct unit with the numerical answer. Across the paper, several marks are dependent on candidates using the correct precision and/or unit of a measurement, so it is worthwhile for centres to give this aspect attention when preparing candidates for the paper.

The majority of candidates were able to complete both questions in the time available, and without seeking assistance.

Comments on specific questions

Question 1

(a) Both parts of this question were generally well answered. A small number of candidates were not awarded credit because the precision was incorrect in **(i)** or the unit was omitted in **(ii)**.

(b) The table of values was completed successfully by a significant majority of candidates. Nearly all candidates included five sets of readings, with some candidates recording six sets. Only rarely was an incorrect trend shown in the recorded values.

Many candidates were not awarded credit for their range of values of n, and these candidates could have improved their experiments by using a wider range. In some cases, the values of R were much smaller than expected, probably owing to some aspect of the candidate's experimental arrangement.

Calculated values of $(n - 1/n)$ were correctly rounded by most candidates, with incorrect rounding being the main reason for candidates not gaining credit for the calculation. All R values should have been recorded to the nearest $0.1\,\Omega$, and most candidates did this correctly.

Some candidates did not recognise that the experiment produces values of n that are all odd, and should have increased in intervals of two, instead giving values of n that changed in intervals of one.

(c) (i) Many candidates had been well prepared for the expectation that they should place regularly spaced numerical labels at least every 2 cm (1 large square) on the axes of their graph. Many candidates used sensible scale intervals, but a minority used very awkward scales. This appeared to be with the intention of stretching out the plotting of points across the whole of the grid, and involved placing the highest and lowest values on the edge line of the grid and dividing by 8 or 12 to determine the scale interval. It is only necessary for the points to occupy at least half of the large squares in each direction, and candidates should be discouraged from choosing awkward scales in an attempt to make better use of the grid. Scale intervals of 1.5, 3 or 6 are considered to be awkward scales and are not awarded credit.

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

(ii) Fewer than half of the candidates were awarded credit for the line of best fit. Often, candidates' points allowed a good straight line through four points, with one outlier point that was disregarded by the candidate in drawing the line of best fit. Where this outlier point was not indicated by the candidate as being anomalous, the line of best fit mark could not be awarded. Centres should encourage candidates to indicate any one such outlier point as anomalous (e.g. by circling it or labelling it), so that their line of best fit can be marked on the remaining points only.

In many other cases, candidates' lines would have been improved by a rotation or sideways movement of their line. Candidates could usefully recognise that a good line of best fit will have, as best as possible, an even distribution of points either side of both the upper section and the lower section of the line, seen separately. Where the points are, for example, above the line at the top while below the line at the bottom, the line can be rotated.

(iii) Most candidates were able to correctly calculate their gradient and intercept values, using read-offs that were correct. Candidates should be encouraged to use read-offs that are at least half the length of their drawn line apart. Where points from the table are used, credit is only given if the points lie on the candidate's drawn line of best fit. Occasionally, a candidate showed no working for the gradient and/or intercept values, and it was not possible to see an intercept read-off from the graph. In these cases, it was not possible to award credit for the gradient and/or intercept.

(d) The majority of the candidates correctly transferred their values from **(c)(iii)**, including the negative sign with the gradient, and gave a correct unit for both a and b. Weaker candidates often omitted the units, especially for b.

(e) Most candidates successfully calculated a value of *r*, though a significant number then gave an incorrect or inconsistent unit. A minority did not identify the value of *x* with their answer in **(a)(i)**, and instead used a randomly chosen value such as 1.5 m.

Question 2

(a) (i) The majority of the candidates were able to record a value for *L* with a correct unit and to the nearest mm. Some candidates were not awarded credit because they omitted the unit or used an incorrect precision.

(ii) Candidates should take care to read the instructions carefully and not make assumptions about what the question is asking. Values for t_s were often around 1.0 s, suggesting that the period of the twisting motion had been recorded and not the time between swings. Many candidates were able to gain credit for a repeated measurement despite having a value for t_s that was out of range.

(iii) The strongest candidates used an appropriate absolute uncertainty of 0.2–0.5 s to correctly calculate the percentage uncertainty. Many candidates used unrealistically small values for the absolute uncertainty, often appearing to use the precision of the stop-watch as their value. A small proportion of candidates who attempted to use a half-range calculation from repeated values determined the full range instead and were not given credit.

(b) (i) Most candidates recorded measurements from their stop-watch to the expected precision of the stop-watch. Often these were measurements of multiple oscillations which were then divided typically by 5 or 10 to give a value for T_1 on the answer line.

(ii) The majority of the candidates recorded a value of T_2 that was smaller than T_1, and gained credit. Where a larger T_2 value was recorded, the candidates appear to have measured the period for the shorter pendulum in **(i)** instead of in **(ii)**. Some instances were seen where a candidate determined $1 / T_1$ and $1 / T_2$ (that is, the frequencies of the two oscillations) and so credit was not awarded.

(iii) Values of *B* were generally calculated correctly. In most cases, a correct unit of seconds was given. Credit was sometimes not awarded because candidates omitted the unit entirely or gave an incorrect unit of s^2.

(c) Most candidates were able to gain a second set of values, and to calculate a second value for *B*. A minority of candidates recorded a second value of *L* that was equal to or larger than that in **(a)(i)**.

(d) A significant majority of candidates correctly calculated two values of *k*. A common error among candidates who were not successful was to calculate $1 / k$, usually because of an error in rearranging after a correct initial substitution of values into the given formula. Centres should encourage candidates to provide values of the constant to at least two significant figures so that an effective comparison of the two values for the constant can be made in the next part of the question.

(e) Most candidates were familiar with the expected calculation of a percentage difference between the two values of *k*, and the use of a criterion against which to judge their calculated percentage difference. The weakest candidates did not calculate a percentage difference and offered vague judgements that were not worthy of credit. Others adopted a criterion of their own devising (typically 10% or 20%) rather than the criterion of 15% in the question, and such answers did not gain credit.

Candidates who offered a judgement as to whether or not the results for their values of *k* supported the given relationship, without explicitly comparing their calculated percentage difference to the given percentage uncertainty, also did not gain credit. Candidates should be clear that they will only gain credit if the result of their percentage difference calculation is compared to the percentage uncertainty criterion set in the question.

(f) (i) This section called for descriptions of sources of uncertainty and limitations in carrying out the procedures. In the case of uncertainties in measurement, candidates were directed in the stem of the question to state the quantity being referred to and a reason for the uncertainty. In many cases, an otherwise valid limitation did not gain credit because it was not clearly linked to the relevant quantity.

Many candidates correctly identified that two sets of data were not sufficient to give a valid conclusion. Some did not gain credit because they referred to, for example, 'accurate results' instead of a conclusion about the proposed relationship.

Very few candidates directly considered the size of the uncertainty in the value of *B*. Difficulties in measuring T_1 and T_2 in isolation were not generally credited, as candidates were expected to have been able to largely resolve these in carrying out the experiment as it stood.

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

Many responses repeated answers seen in previous mark schemes, often without appearing to consider their relevance for this particular experiment. Generic answers about the use of a video camera with a timer, for example, did not gain credit unless they specifically referred to videoing the rod (in order to improve the measurement of t_s).

Credit is not given for suggested improvements that could have been carried out in the original experiment e.g. 'repeat readings' or 'time multiple periods'.

PHYSICS

Paper 9702/33
Advanced Practical Skills 1

Key messages

- If a raw value is out of trend to that expected, candidates should be encouraged to check the readings again with the equipment provided in the early stages of data collection.
- In the table work, the number of significant figures in the calculated quantity should relate to the number of significant figures in the raw data with the least number of significant figures. Each calculated quantity should be checked row by row.
- 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

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

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

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

Comments on specific questions

Question 1

(a) Most candidates stated L in the correct range to the nearest mm and with a correct unit. Some candidates stated their length only to the nearest cm or omitted the unit.

(b) Many candidates recorded V values with a consistent unit and to the nearest mV. The majority of the candidates stated V_2 larger than V_1. Some candidates stated their value of voltage to the nearest 10mV or 0.1mV whilst others stated inconsistent units e.g. 300 V instead of 300 mV.

(c) Most candidates were able to collect six sets of values of d, V_1 and V_2 with the correct trend without assistance from the Supervisor. Some candidates had V values with either the same value or out of trend for the increasing d values. Candidates should be encouraged to double-check their experimental setups. A small number of candidates needed help setting up the circuit.

Some candidates chose too small a range over which to conduct the experiment. Many candidates went up every 10.0 cm to 60.0 cm but a larger range could have been used. Candidates are encouraged to use the whole length of wire.

Stronger candidates gave both the quantity and correct unit for each heading, separated by a solidus or with brackets around the unit. Some candidates omitted the unit or separating mark or gave a comma as the separating mark, or gave an incorrect unit e.g. V m instead of m for the $(V_2 / V_1)d$ column.

Some candidates correctly recorded their calculated values for $(V_2 / V_1)d$ to the correct number of significant figures, but many candidates did not appreciate that each row needed to be looked at on an individual basis. In each row, the raw reading with the least number of significant figures needed to be identified and then the calculated quantity can be written with the same number of significant figures or one more. Candidates need to be especially careful when there is a change of significant figures within the column of the raw data.

Many candidates calculated values for $(V_2 / V_1)d$ correctly. Some candidates incorrectly rounded by truncating their answers, while others calculated a different quantity e.g. (V_2 / V_1) and either labelled the column as such or stated it to be $(V_2 / V_1)d$. Some candidates calculated $(V_1 / V_2)d$ or $(V_2 / V_1)d^2$.

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

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

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

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

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

(ii) Many candidates were able to draw carefully considered lines of best fit. There should always be a balanced distribution of points either side of the line along the entire length. Some lines needed a rotation or a shift to get a better fit, while other lines were not straight or too thick.

(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) Most candidates recognised that P and Q were equal to the gradient and intercept respectively. Some candidates recorded a value with consistent units for P (m^{-1}) and Q (m), but weaker candidates often stated incorrect units or omitted them. Some candidates wrote their final answer to one significant figure.

(f) Only the strongest candidates were able to draw a line W with a smaller intercept and steeper gradient. Many omitted drawing the line, or drew a line that crossed the original either with the same or a reversed gradient.

Question 2

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

(ii) Most candidates are familiar with the equation for calculating percentage uncertainty. Some candidates made too small an estimate of the absolute uncertainty in the value of A, typically only 1–2 mm, when this was a difficult reading to take. Some candidates repeated their readings and correctly gave the uncertainty in A as half the range, having showed clear working for this method.

(b) (i) Many candidates stated θ to the nearest degree and in the appropriate range. Some candidates stated θ to the nearest 0.1° when the protractor can measure to the nearest degree, or stated an angle that was out of range. Many candidates recorded H and included a unit.

(ii) Many candidates were able to calculate $\cos^2 \theta$. Some candidates calculated $\cos \theta$ instead or had their calculator set in radians mode.

(c) Nearly all candidates recorded second values of d. Many candidates correctly recorded a larger second H value.

(d) (i) Many candidates were able to calculate k for the two sets of data, showing their working clearly. Some candidates incorrectly rearranged the equation algebraically.

(ii) Only the strongest candidates correctly justified the number of significant figures they had given for the value of k with reference to the number of significant figures used in the raw data: H, A and θ. Many candidates gave reference to 'raw readings', 'previous measurements', 'values used in calculation' or related to H/A and $\cos^2 \theta$ (or sometimes θ^2) without detailing the individual raw quantities concerned.

(e) Stronger candidates calculated the percentage difference between their two values of k, testing it against the stated 20% criterion. Some candidates incorrectly stated a different criterion, or gave invalid statements.

(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 by chronologically going through the experiment systematically and stating clearly each difficulty. Candidates should then try to think of solutions that address each problem identified.

Problems that were commonly given credit included 'two sets of data were insufficient to draw a valid conclusion' and 'difficult to measure the angle as holding the protractor by hand so it was hard to keep still'. Also common were 'difficult to judge that the string is horizontal', 'the ruler was not vertical', 'the masses collided on release' or 'the string slipped off the rod'. Candidates often mentioned the problems without sufficient detail or did not relate the difficulty to the quantity affected. For example, an answer such as 'hard to keep protractor still by holding it' should have reference to the angle (the quantity that it is difficult to measure) and a statement such as 'hard to measure length' should include a reason why it is difficult.

(ii) Improvements that were commonly seen were 'take more readings and plot a graph', 'clamp the protractor', 'use a thinner string', 'use a spirit level', 'use a plumb-line' or 'use a longer rod so the string does not slip off'. A solution, like a problem, needs to be given with enough detail to gain credit. Vague statements such as 'use a set square' without detailing how this will be used cannot be given credit. Candidates are encouraged to turn vague statements that have relevance into detailed responses in order to gain credit. Careful consideration is needed.

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

PHYSICS

Paper 9702/34
Advanced Practical Skills 2

Key messages

- If a raw value is out of trend to that expected, candidates should be encouraged to check the readings again with the equipment provided in the early stages of data collection.
- In the table work, the number of significant figures in the calculated quantity should relate to the number of significant figures in the raw data with the least number of significant figures. Each calculated quantity should be checked row by row.
- 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

Centres did not generally have any difficulties in providing the equipment required for use by the candidates. Some candidates found that the newton meter in **Question 2** did not register a reading when measuring the weight of the block. The Examiners took this into account and there was no need for different meters to be provided. If different apparatus is provided to the candidates from that specified in the Confidential Instructions, this may make it more difficult for candidates to identify limitations and improvements.

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 work carried out by the candidates was good, with some producing excellent scripts. Where candidates were weaker, this was often due to improper presentation of data and weak processing skills. Working was usually clear and legible, but some candidates should be reminded to draw tables carefully using ruled lines and, where possible, record data systematically. For graph work, candidates should be encouraged to use a 30 cm ruler to draw lines of best fit and to provide legible scale markings on axes.

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

Comments on specific questions

Question 1

(a) The majority of the candidates provided a value that was in the accepted range and recorded to the precision of the voltmeter. Some candidates had values that were outside the expected range, but they could be awarded credit if the value was within range of the Supervisor's value.

(b) Most candidates recorded a value of time with a unit and within the expected range. A small number appeared to have problems reading the value on the stop-watch, which resulted in much smaller than expected values being stated. Candidates should be encouraged to take repeated readings where appropriate. A significant number of candidates did not repeat their measurements.

(c) The majority of candidates successfully followed the instructions and recorded six sets of values of R and t. The most successful candidates presented their data sequentially and ensured that the full range of resistance values available was included in their data (22 kΩ and 470 kΩ).

Column headings in the table were usually correct and included a suitable separator between the quantity and unit. Candidates who were not awarded credit often did not provide a suitable unit for the $1/R$ and $1/t$ values.

When recording t values, candidates were expected to present their data using consistent precision. Many candidates did this by recording all values to the nearest 0.1 s or all values to the nearest 0.01 s. A significant number of candidates could not be awarded credit because they focused on presenting their data to a constant number of significant figures instead. Candidates should be aware that raw data should be recorded consistently to the precision of the instrument used.

Most candidates recognised the need to present $1/t$ values to the same number of significant figures as (or one more than) the corresponding significant figures in their raw t values. Candidates should be aware that each row of the table is checked independently. It is not necessary for each $1/t$ value in the column to have the same number of significant figures. Each value of $1/t$ is judged in isolation against the raw data from which it was derived.

The calculation of $1/t$ was correct in most cases. A small number of candidates gave a value that was incorrectly rounded.

(d) (i) Candidates producing successful graphs did so by choosing sensible scales that allowed plotted points to occupy at least 4 large squares horizontally and 6 large squares vertically. Scale markings were clear, and values were usually written one large square apart. A significant number of candidates selected unsuitable scales, some labelling axes using fractions which also led to non-linear scales. While the plotting of points was generally accurate, some candidates drew points using large circles ('blobs') which could not be awarded credit. The quality of data collected by the majority of the candidates was good.

(ii) When drawing the straight line of best fit, many candidates produced thin lines that had an even distribution of points either side of the line along the full length. The most common reasons for lines not being given credit were broken or kinked lines (often the result of using short rulers forcing the line to be drawn in two parts) and lines requiring rotation to better fit the points. Candidates should be made aware that, if they identify a point as anomalous and decide to ignore it when drawing the line, they need to indicate this by either circling the point or labelling it. They should only do this for a maximum of one point.

(iii) Most candidates were able to correctly read off two points from their line that were at least half the length of the line apart and then substitute the points into the equation $\frac{\Delta y}{\Delta x}$ or equivalent.

For the y-intercept, most candidates correctly substituted values into $y = mx + c$ (or equivalent) or took a correct read-off directly from the graph. Candidates should be aware that this second method is not valid if their x-axis has a false origin i.e. does not actually start at $x = 0$.

(e) Most candidates recognised that *a* was equal to their gradient value and *b* was equal to their *y*-intercept value. Units were usually provided but these were not always dimensionally correct.

Question 2

(a) The majority of the candidates provided a value that was measured to at least the nearest 0.1 N. Some candidates were worried that the weight of the block provided by their centre was insufficient to register a reading on the newton meter. Candidates should be reassured that zero may be a valid reading and in this case zero was awarded credit.

(b) (i) Successful candidates took repeated readings and recorded these to the precision of the newton meter provided.

(ii) When asked to estimate the percentage uncertainty in the measured value of *F*, stronger candidates chose an absolute uncertainty that factored the difficulty in determining *F* due to, for example, the short time available to take the reading. They then divided the absolute uncertainty by their *F* value before multiplying the result by 100. Most of the candidates who did not gain credit stated the resolution of the newton meter (0.1 N) as their absolute uncertainty.

(iii) Almost all candidates were able to correctly calculate *E*.

(c) Most candidates were able to provide a value for *T* that was in the accepted range. A significant number did not record repeated readings.

(d) Almost all candidates provided second values of *F* and *T*. In a small number of cases, credit for quality was not awarded because the candidate's second value of *F* (for the oil) was not larger than the equivalent for water.

(e) (i) Most candidates were able to correctly calculate the *k* values. Of the minority of candidates not awarded credit, most had incorrectly rearranged the equation $kE^2 = T$.

(ii) Many candidates successfully linked the significant figures in *k* with those in *E* (or *F* and *W*) and *T*. A significant number of candidates referred to 'raw data' rather than stating the relevant quantities.

Some candidates chose to add numerical detail but provided an accompanying argument that was incorrect and so were not awarded credit. For example, '*E* had 1 significant figure whereas *T* had 3 significant figures and so *k* has 3 significant figures'.

(f) Candidates were provided with a numerical criterion to test against (40%) and needed to provide a correct percentage difference calculation and a comparison with 40% along with a correct conclusion linking both. Some candidates were able to correctly carry out a suitable percentage difference calculation, but many candidates found this difficult. Another common error was to test against their own criterion, often 10% or 20%, rather than the criterion provided.

(g) (i) This question provided a challenge for many candidates. Most candidates recognised that there were too few data points to draw a conclusion, but other limitations were less well addressed. Candidates should be encouraged to follow the instructions and always state the quantity being measured along with the reason for the uncertainty. Many candidates recognised limitations but often did not link these to the correct quantity. For example, stating that the block detached suddenly from the liquid was correct but needed to be linked to *F*, which is the quantity that cannot be measured accurately as a result. One possible way for candidates to improve their responses would be to begin each one with the quantity affected. For example, 'it was difficult to measure *T* because…'.

(ii) Most candidates recognised the need for more data so that a graph could be plotted. Other common correct suggestions were using a more precise newton meter or using a heavier block. Many candidates suggested recording the experiment using video, and this was a suitable idea for improving the measurements of *F* and *T*. However, they often did not specify what was being recorded (the newton meter or syringe) or what was being measured (*F* or *T*).

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 9702/35
Advanced Practical Skills 1

Key messages

- If a raw value is out of trend to that expected, candidates should be encouraged to check the readings again with the equipment provided in the early stages of data collection.
- In the table work, the number of significant figures in the calculated quantity should relate to the number of significant figures in the raw data with the least number of significant figures. Each calculated quantity should be checked row by row.
- 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

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

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

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

Comments on specific questions

Question 1

(a) Many candidates calculated T in the appropriate range and gave a correct unit, having measured the time for at least five oscillations and repeated this measurement. Some candidates forgot to divide by the number of oscillations, measured the time of only one oscillation or did not repeat their measurements of several oscillations (or did not provide evidence of this, and so it was not possible to award credit). Some values of T given were too low, suggesting that the candidate had measured half a cycle for T.

(b) Most candidates were able to collect six sets of values of *m* and *T* with the correct trend and without assistance from the Supervisor. Some candidates had *T* values with either the same value or odd values out of trend for the different increasing *m* values.

Some candidates chose too small a range over which to conduct the experiment, often going up in 50 g increments from 100 g or going down in 50 g increments from 450 g. Candidates are encouraged to use the whole range of masses provided.

Stronger candidates gave both the quantity and correct unit for each heading, separated by a solidus or with brackets around the unit. Some candidates omitted the unit in either all the headings or in the *T* / *m* and 1 / *m* headings, omitted the separating mark in all the column headings or gave a comma as the separating mark, or gave an incorrect unit e.g. g instead of g^{-1} for the 1 / *m* column.

Most candidates gave their raw readings of *nT* in the table to the nearest hundredth of a second, gaining credit for consistency. Some candidates omitted the *nT* column and presented the calculated *T* value as their raw data in the table e.g. T = 1.473 s. This did not gain credit for consistency as the time is stated to one thousandth of a second.

Some candidates correctly recorded their calculated values for *T* / *m* to the correct number of significant figures. Some candidates did not appreciate that each row needed to be looked at on an individual basis. In each row, the raw reading with the least number of significant figures needed to be identified and then the calculated quantity can be written with the same number of significant figures or one more. Candidates need to be especially careful when there is a change of significant figures stated within the column of the raw data. A small number of candidates rounded automatically to one significant figure.

Many candidates calculated values for *T* / *m* correctly.

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

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

Some candidates used irregular (i.e. non-linear) scales, including in some cases fractions such as 1/100, 1/150, 1/200. Irregular scales could not be given credit, and often the data could not be awarded credit for quality either, because the error occurred in the region of the plotted points. Candidates should be encouraged to set up their graphs to make them easy to work with in later parts of the question.

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

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

(ii) Stronger candidates were able to draw carefully considered lines of best fit. There should always be a balanced distribution of points either side of the line along the entire length. Some lines needed a rotation or a shift to get a better fit, while other lines were not straight or too thick.

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

Some candidates were able to correctly read off the *y*-intercept at $x = 0$ directly from the graph, but 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 candidates recorded a value with consistent units for *P* (s) and *Q* (s kg^{-1}). Weaker candidates often stated incorrect units or omitted them, or wrote their final answer to only one significant figure.

Question 2

(a) (i) Many candidates measured values of *d* in the correct range, with a consistent unit and to a precision of either 0.01 mm or 0.001 mm consistent with measuring *d* with a micrometer screw gauge. Some candidates stated readings that were 0.50 mm too large or had the wrong power of ten e.g. 49.0 cm. In the latter case it is possible that the candidate was in fact measuring the length instead of the diameter.

(ii) Most candidates measured values of *L* in the correct range, with a consistent unit and to millimetre precision consistent with measuring *L* with a ruler.

(iii) Most candidates are familiar with the equation for calculating percentage uncertainty. Some candidates made too small an estimate of the absolute uncertainty in the value of *L*, typically 1 mm, when this was a difficult reading to take. A more realistic uncertainty would have been in the range 2–6 mm. Some candidates repeated their readings and correctly gave the uncertainty in *L* as half the range, showing clear working.

(iv) Many candidates were able to calculate *C*. Some candidates calculated *C* with mixed units of *d* in mm and *L* in cm, and this led to a power-of-ten error in the calculation.

(v) Some candidates correctly justified the number of significant figures they had given for the value of *C* with reference to the number of significant figures used in the raw data: *d* and *L*. Many candidates gave reference to ‘raw readings’, ‘previous measurements’ or ‘values used in calculation’ without detailing the individual raw quantities concerned.

(b) Many candidates stated θ to the nearest 1 °C or 0.5 °C and in the appropriate range. Some candidates stated θ to the nearest 0.1 °C e.g. 74.3 °C when the thermometer could not be read to this precision. The majority of the candidates calculated the temperature difference correctly.

(c) (i) Nearly all candidates recorded second values of *d* and *L*. Many candidates correctly recorded a smaller second *d* value.

(ii) Nearly all candidates recorded second values of I with a unit. Some candidates omitted a unit or gave the wrong unit e.g. coulomb.

(d) Many candidates were able to calculate *k* for the two sets of data, showing their working clearly. A small number of candidates made arithmetical errors or stated *k* to only one significant figure.

(e) Stronger candidates calculated the percentage difference between their two values of *k*, testing it against the stated 30% criterion. Some candidates incorrectly stated a different criterion, did not show the percentage difference calculation or gave invalid statements.

(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 by chronologically going through the experiment systematically and stating clearly each difficulty. Candidates should then try to think of solutions that address each problem identified.

Problems that were commonly awarded credit included ‘two sets of data were insufficient to draw a valid conclusion’ and ‘difficult to measure *L* as the wire had kinks or was not straight’. Also common was ‘difficult to measure I as the readings fluctuated’. Candidates often mentioned the problems without necessary detail or did not relate the difficulty to the quantity affected. For example, ‘difficult to measure *L* accurately’ without reference to the actual difficulty of the measurement is not sufficient, and ‘readings fluctuated’ cannot be accepted without providing a quantity affected.

(ii) Improvements that were commonly seen were ‘take more readings and plot a graph’, ‘tape the wire onto the ruler’ or ‘use a digital thermometer’. A solution, like a problem, needs to be given with enough detail to gain credit. Vague statements such as ‘use a video’ without detailing how this will be used, cannot gain credit. Candidates are encouraged to turn vague statements that have relevance into detailed responses in order to gain credit. Careful consideration is needed.

Credit is not given for suggested improvements that could have been carried out in the original experiment e.g. ‘repeat readings’ or ‘get the eye level with the scale of the thermometer’.

PHYSICS

Paper 9702/41
A Level Structured Questions

Key messages

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

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

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

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

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

General comments

There was generally no evidence of candidates finding it difficult to complete the questions in the time allowed.

Most candidates appeared to be well prepared for the material that is new to the syllabus this year.

Comments on specific questions

Question 1

(a) (i) This definition well known and most candidates answered very well and were awarded full credit. A small number of candidates omitted the fact that the separation is squared.

(ii) Most candidates were able to use the required starting point of Newton's law of gravitation to reach the expression for gravitational field strength with distance.

(b) (i) The majority of the candidates substituted the correct values in order to determine the gravitational field strength at the surface of the Moon. A small number used the wrong data or did not square the radius.

(ii) This explanation proved challenging for many candidates, particularly those who referred to forces rather than fields. Some candidates who did mention fields could not gain full credit because they did not say that the directions were opposite.

(iii) This type of calculation can be challenging unless the candidates take the square root of the entire expression in the early stages of the algebra. It is then not necessary to wade through a cumbersome quadratic equation. Many candidates gained credit for setting up the expression ($3.84 \times 10^8 - x$) to find the required distance. Weaker candidates often used an incorrect formula such as potential instead of field strength.

Question 2

Candidates found this question challenging as it involved gravitational fields, electric fields and magnetic fields. In addition, there were two diagrams viewing the same situation from two different directions.

(a) (i) Candidates found it difficult to determine the correct direction for the magnetic field. Some candidates wrote 'into the page' but needed to say that this was for Fig. 2.2 as it was incorrect for Fig. 2.1. The expected answer of 'downwards' was relative to the ground and therefore correct for both diagrams.

(ii) Many responses gained at least partial credit here as candidates realised that the magnetic force provided the centripetal force. A significant proportion of those also included the fact that the magnetic force is perpendicular to the velocity. The weakest candidates referred to the electric force here which was not contributing to circular motion.

(b) Many candidates used the formula for the electric field strength due to a point charge. Others calculated the centripetal force. Only a small number of candidates correctly used the vertical equilibrium due to the weight and the electric force.

(c) Candidates need to ensure that all stages are clear in a 'show that' question. The combination of the three fields was challenging and not all candidates equated the centripetal force with the magnetic force.

Question 3

(a) (i) An ideal gas obeys the expression $pV \propto T$. Stating that it follows $pV = nRT$ is only equivalent when it is made clear that n and R are constants. Candidates need to define all symbols used in this type of question.

(ii) Most candidates correctly calculated the amount of gas here. Only a very small proportion did not convert the temperature from degrees Celsius to kelvin.

(b) (i) Again, all steps in 'show that' questions should be clearly stated. It was necessary to show the subtraction of the two volumes here, and a small number of candidates did not do this.

(ii) The majority of candidates gained partial credit for completing this table. Many candidates thought that 0 kJ of thermal energy was supplied to the gas in change CA and that the increase in the internal energy of the gas for this change was 31.6 kJ. It was stated in the question that from C to A the ideal gas expanded at constant temperature, so the increase of internal energy during this change was in fact 0 kJ.

Question 4

(a) Some candidates clearly linked the graph with the requirements for simple harmonic motion. Other candidates listed the graph features and then the simple harmonic motion characteristics without clearly linking the correct feature with the correct characteristic. Many candidates omitted reference to the origin which is vital when proving a proportional relationship.

(b) (i) This calculation was correctly completed by most candidates. A small number of candidates left their answer as a surd. Decimal answers are always expected.

(ii) Most candidates correctly completed this calculation. Some candidates were unable to deduce the correct unit for *k*.

(c) This explanation proved challenging. Only the strongest candidates managed to gain full credit because they realised that ω would decrease leading to a consequent increase in amplitude. Others simply said the amplitude would remain the same because energy remained the same. The weakest candidates mentioned phenomena such as damping or the lack of it, or other factors which had little bearing on the question asked.

Question 5

(a) (i) Most candidates could state what is meant by rectification.

(ii) The majority of the candidates correctly named the type of rectification, but some of the weakest omitted the word 'wave' which was necessary here.

(b) (i) The majority of candidates labelled the polarity of the output voltage correctly.

(ii) One label is not enough to define a scale – a number of candidates drew only a single label when labelling the *y*-axis. Some candidates worked out the correct period for the *x*-axis but then labelled it incorrectly, thinking that one peak was one period.

(c) (i) Most candidates added the capacitor in parallel. Some candidates added the capacitor in series on the 'input' side of the circuit. Candidates should take care to ensure they use correct symbols as defined in the syllabus.

(ii) While there were many good lines drawn here, candidates needed to take care with the details of their lines. A line that curved upwards was incorrect and even a straight downwards line was not strictly correct. In addition, the 10% drop in voltage was often not correctly shown.

(iii) This calculation proved challenging. Some candidates used the time at the end of the capacitor discharge section rather than the time difference between the start and the end of the discharge section.

Question 6

(a) This definition was not well known. Many candidates omitted that the area is perpendicular to the field lines.

(b) (i) This calculation was completed well by many candidates. A small number of candidates used the area of a circle instead of a square. Candidates need to read and look at questions and diagrams carefully.

(ii) Many candidates knew that the e.m.f. was constant because the line was straight. Some candidates did not refer to the graph shape but rather described what that shape meant, that the increase in *B* was proportional to *t*.

(iii) A significant number of candidates only calculated the gradient of the graph, and omitted the area and the number of turns.

(c) Many responses were awarded partial credit but relatively few could be given full credit. Candidates often do not realise the correct order of cause and effect. The change of flux linkage induces an e.m.f. in the coil which, when the terminals were connected, means there is a current in the coil. Many candidates suggested that a current induced an e.m.f. Others thought that the connecting of the terminals would increase a current that was already in the coil.

Question 7

(a) Many responses gained full credit here. Some candidates did not mention energy and this word was necessary in order to gain full credit.

(b) (i) The majority of the candidates were able to name the phenomenon.

(ii) Stronger candidates answered this question well and gave three conclusions from the graph. Others just quoted facts about the photoelectric effect they had learnt by heart which did not answer the question. A common error here was to say that E_{MAX} was proportional to the frequency. This is clearly incorrect because the line does not go through the origin.

(c) (i) Candidates were generally awarded partial credit for realising that a different metal gives a different threshold frequency. However, for full credit they needed to say that the gradient was the same <u>and</u> that the *x*-intercept was different.

(ii) Most candidates realised that the shape of the graph would stay the same but found it difficult to give a reason. They did not realise that the most fundamental aspect was that the photon energy had not changed.

Question 8

(a) (i) There were many correct answers here gaining full credit. Candidates should be careful not to write 'energy to split the nucleons' as this statement is too vague (for example it could refer to splitting a nucleon into quarks).

(ii) Candidates found it difficult to recall and draw the correct line. A significant number of those that had the correct idea were only close to the correct shape. Many weaker candidates drew lines with a negative gradient starting from a positive *y*-intercept or straight lines through the origin.

(b) (i) Most candidates correctly stated the name of the nuclear process.

(ii) Candidates found this explanation challenging. Many candidates showed evidence of the misconception that binding energy would decrease as a result of the reaction.

(c) This was a very challenging calculation. The majority of candidates who gained credit found the energy for only one reaction, not for the energy released from the reaction of 1.00 mol of deuterium. The weakest candidates only gained partial credit for the recall of $E = \Delta mc^2$. Some weaker candidates also had difficulty finding the loss in mass for the reaction.

Question 9

(a) (i) Many candidates showed that they knew how X-rays are produced and were able to gain at least partial credit. Some candidates thought the question was asking for how an X-ray image is produced, perhaps having previously learnt an answer to this question.

(ii) Many responses did not provide sufficient detail. The requirement for combining images of sections was often omitted.

(b) (i) This was very often successfully answered. The candidates who knew the relevant formula generally did not have difficulty in applying it. Some candidates left the constant e in their answer rather than evaluating the numerical value.

(ii) Combining transmitted intensities through more than one medium proved to be challenging. Some candidates used incorrect dimensions by not subtracting to find the length of soft tissue and some added exponentials instead of multiplying them.

(c) Candidates found this question difficult. Some candidates did not refer to their own values, others thought that the attenuation coefficients being different was the reason, and others provided a conclusion that was not consistent with the values.

Question 10

(a) A common reason for not being awarded credit was omitting the idea of 'maximum' or 'peak' intensity.

(b) (i) There were many correct answers here, but a common error was to misread the scale on the *x*-axis.

(ii) Some candidates were confused here and thought star B had a smaller wavelength because its maximum intensity peak was lower. Others referred to the brightness of the star, but this had been eliminated as an answer by the wording of the question.

(c) (i) Candidates often did not give enough detail in their answers. They needed to make it clear that it is the observed/apparent wavelength that is greater, rather than just a greater wavelength caused by the recession of the source.

(ii) Only the strongest candidates gained credit. Many candidates did not know that the observed spectrum from the star was compared with a known spectrum.

PHYSICS

Paper 9702/42
A Level Structured Questions

Key messages

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

General comments

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

There was no evidence that candidates had insufficient time in which to complete the paper. This was the first June series to examine the new syllabus, including the topics of cosmology, PET scanning and C–R discharge circuits. In general, candidates seemed well prepared for these topics and had clearly studied them effectively.

Comments on specific questions

Question 1

(a) (i) Many candidates knew the definition of gravitational potential and were able to achieve full credit. Of those who were only awarded partial credit, the most common error was to give an answer that suggested that potential is an energy rather than the ratio energy per unit mass.

(ii) This question was generally well answered by candidates who knew the relationship between potential and potential energy.

(b) (i) Many candidates answered this question correctly and were awarded full credit.

(ii) Most candidates realised that the potential energy decreases but more found it difficult to give a convincing explanation as to why. A common incorrect answer was to attribute the decrease in potential energy to the fact that it is negative, overlooking the irrelevance of where the arbitrary zero of potential energy is taken to be. Others gave cyclic arguments that attributed the decrease to a loss of energy.

(iii) This question discriminated between the candidates who understood the physics and those who just tried to apply learnt equations. Candidates who ignored the initial kinetic energy completely were unable to be awarded credit. Of those who did start with the correct physics, there were various details that were needed in order to arrive at the correct answer: one was dealing with the unit conversion from $km\,s^{-1}$ to $m\,s^{-1}$, another was ensuring the relative signs of the three energy terms were correct, and another was remembering to convert back to $km\,s^{-1}$ again at the end. Finally, candidates needed to appreciate that the three significant figure nature of the data in the question demands three significant figure precision in the final answer. Despite all these challenges, a significant proportion of the more able candidates were able to be awarded full credit.

(c) The strongest candidates realised that the mass of the comet cancels out in the energy equations and so the fact that its mass is changing is immaterial to the path of the comet.

Question 2

(a) Many candidates discussed force between masses rather than force between point charges. Others found it difficult to use the terms ‘proportional’ and ‘inversely proportional’ appropriately, using terms such as ‘perpendicular’ instead of ‘proportional’ and ‘indirectly’ rather than ‘inversely’. Some candidates referred to ‘distance’ or ‘radius’ without making it clear they were referring to the separation between the charges. Some candidates neglected the inverse-square nature of the variation of force with separation.

(b) (i) Many candidates addressed the issue of why there is a force between the two particles, rather than answering the question about why this force causes circular motion of the particles.

(ii) Most candidates knew the general equation for the electrostatic force between two charges, and many appreciated that in this case the magnitudes of the two charges are both the elementary charge. It was often not demonstrated that the distance between the charges is double the orbital radius. Candidates need to remember that, in ‘show that’ questions, the expectation is that full substitution into the equation must be seen, including any relevant physical constants. In this case, some candidates were not awarded full credit because they did not show the substitution of the permittivity of free space.

(iii) Most candidates were awarded credit for a correct starting equation. Many found it difficult to substitute the data, with incorrect masses and/or an incorrect radius being common. Of those who did use the correct data, some candidates gave an answer to two significant figures when the data provided justified three significant figures.

(c) (i) There were many excellent descriptions of how gamma photons are produced from the annihilation of the electron and the positron. A common misconception was that electrons and positrons are both antiparticles (as opposed to one being a particle and the other an antiparticle). Candidates needed to make clear that the entire mass of the electron and the positron gets converted into energy in the form of gamma photons; it was common for candidates to just write vaguely about 'mass being converted into energy'. This happens in all nuclear reactions so it is not a complete description of annihilation. The unique feature of annihilation, that <u>all</u> of the mass becomes energy, was frequently missing.

(ii) This question was generally well answered, and was a generally well understood topic for a new addition to the syllabus.

Question 3

(a) It was very common for candidates to be awarded at least partial credit, but only a minority of candidates were able to state the definition of specific latent heat of vaporisation in full. Common mistakes were not making it clear that specific latent heat is an energy per unit mass, not identifying the state change, or not making it clear that the state change is happening at constant temperature.

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

(ii) This question was well answered by many candidates, and most candidates were able to achieve partial credit. A common reason for not achieving full credit was not showing the working for how the amount of substance is calculated from the mass of water and the mass of 1.0 mol.

(iii) The equation $W = p\Delta V$ was well known and the question was generally well answered.

(iv) Most candidates were able to calculate the increase in internal energy correctly, and to show the subtraction of the work done from the thermal energy supplied. Many candidates did not convincingly explain why the work done is subtracted rather than added. Incorrect statements such as 'the work done by the water against the atmosphere is negative' were common. The stronger candidates understood the difference between work done by the water and work done on the water, which one was positive and which one was negative, and were able to articulate it.

(c) Candidates were able to adopt a variety of different approaches to answering this question. They needed to give a coherent discussion of the effect of the higher pressure on the work done by the water, and a convincing application of the first law that included discussion of all three of the terms involved in it. Confusion between thermal energy transferred and change in internal energy was common, with many candidates thinking that specific latent heat related to the latter rather than the former.

Question 4

(a) The definition of resonance was well articulated by many candidates. There was some confusion between resonance and damping.

(b) (i) This question was generally well answered by those candidates who appreciated that the 5.0π term in the sinusoidal equation represented the angular frequency of the oscillations.

(ii) This proved to be a challenging question for many candidates. It required candidates to combine their knowledge of the physics of simple harmonic motion with the skill of labelling graph axes. Common errors were to think that the period calculated in **(b)(i)** was the time for half a cycle rather than for a complete cycle and/or to label only the positive half of the displacement axis.

(iii) This question was generally well answered by many candidates, though a significant minority appeared to think that phase difference is a time interval rather than an angle.

Question 5

(a) The definition of capacitance, as the charge/potential ratio, was generally well known. Fewer candidates were able to correctly relate this to the specific case of a parallel-plate capacitor by correctly identifying what 'charge' and 'potential' mean in that situation. Some weaker candidates saw the word 'parallel' in the question and quoted the equation for the combined capacitance of capacitors in parallel.

(b) This derivation was set out well by many candidates. Some candidates did not achieve full credit because they did not clearly show the links between steps or changed letter conventions without explanation.

(c) (i) This question was generally well answered. The most common reason for not awarding credit was for omitting to show the final inversion, leading to a statement such as $1 / C_T = 15\,\mu F$.

(ii) Many candidates made more work for themselves than was necessary in answering this question. A simple approach was to take $E = ½CV^2$ and substitute the combined capacitance and the supply p.d. into it.

(iii) This was a challenging question that was only successfully answered by the strongest candidates. Most candidates realised they needed to use the exponential discharge equation that is available to them on the formulae page, but then related 6 V to 12 V in it, using a time constant of (2.7 × 22) s. Candidates who realised either that they needed to relate 6 V to 8.2 V (or 8.8 V to 12 V), or that they needed to use a time constant of (2.7 × 15) s, were able to achieve partial credit. Candidates who realised both of these things were usually able to then go on to arrive at the correct answer.

Question 6

(a) Most of the stronger candidates realised that the two requirements for there to be a force are that there is a current in the wire and that the wire is not parallel to the field. Weaker candidates found it difficult to articulate some of this, with some suggesting that the wire had to be able to carry current (i.e. be a conductor) or giving information that was already provided in the question stem. The weakest candidates confused the situation with electromagnetic induction and thought the wire had to be moving, or confused carrying a current with the wire being charged.

(b) The two parts of this question proved to be very discriminating in testing whether candidates understood the significance of the field pattern around a solenoid. Many were able to correctly deduce the directions at X and Z, though the direction at Y was problematic for many candidates. The comparisons of the magnitudes were more variable, with many candidates getting one or other of the comparisons correct but only a small number answering both correctly.

(c) The explanation of why two parallel current-carrying wires exert forces on each other was poorly answered by many candidates, despite being knowledge directly required by the syllabus. Many candidates made no attempt to answer the question that was actually asked, and instead answered a question asking either about the directions of the forces or about why the forces are equal and opposite. Candidates were given a space in which they could draw a diagram if they wished, and many took up the invitation to do so. However, many diagrams were not drawn carefully enough to be able to demonstrate the answer effectively.

Question 7

(a) Faraday's law was generally well known and many candidates gave complete statements of it.

(b) Many good graphs were seen from candidates, with many achieving full credit. The most difficult aspect was to realise that the magnitude of the induced e.m.f. in the middle section must be three times the magnitude before $t = 0.15$ s and after $t = 0.25$ s. Some candidates had already drawn a line from $t = 0$ to $t = 0.15$ s that was more than a third of the maximum value available on the grid, and this made it impossible to draw a middle section three times greater without starting again. Examiners allowed some leeway on the factor of three, but candidates could improve their graphs by considering what the whole graph is going to look like before starting to draw their lines.

(c) (i) There were many attempts at an answer to this question that vaguely discussed the right concepts (such as flux cutting, induced e.m.f.s, currents etc.) but which did not contain sufficient detail to be awarded credit. Many appeared to be learnt standard answers to electromagnetic induction questions with little attempt to apply the principles to the situation presented. Weaker candidates often gave an attempt at a description of Lenz's law. Lenz's law can be used to predict a direction, but it cannot explain why a particular phenomenon happens – for that, a deeper understanding of the electromagnetic processes taking place, and where they are taking place, is required.

(ii) Most candidates thought that the force on the ring would now be downwards. Of those who did realise it would still be upwards, very few candidates were able to give a convincing explanation.

Question 8

(a) Both parts of this question were generally well answered by most candidates.

(b) (i) Candidates generally knew the equation for the de Broglie wavelength correctly, and many candidates were able to calculate the correct answer. The most common reason for not achieving full credit was not knowing the mass of an alpha-particle.

(ii) Most candidates realised the inverse nature of the relationship between wavelength and speed, but there were various reasons for candidates not being awarded full credit. Some candidates drew straight lines or curves that became horizontal or vertical. For full credit, candidates needed to draw an inverse proportion curve that was asymptotic to both axes.

(c) This was a challenging question intended to discriminate between the more able candidates. To achieve credit, candidates needed to make a comparison between the de Broglie wavelength of the person and the width of the doorway.

Question 9

(a) (i) The proportionality between speed and distance was well known and widely articulated. Many candidates achieved full credit. Some candidates were less successful at defining what, in the context of Hubble's law, speed and distance meant.

(ii) Candidates needed to give a statement of what the relevant observations are (namely that spectral lines appear at increased wavelengths from their known values) and to relate these to the conclusion that can be drawn from them (that the stars emitting this light are moving away from the observer). Many candidates described decreased wavelengths or even wavelengths that are continuously increasing. Many confused the Universe with the stars being observed and tried to suggest that the Universe is moving away from the Earth, or suggested that the observation gives evidence that stars are moving away from each other.

(b) Some candidates attempted to describe events that happened long in the past by using the present (or even future) tense. The Examiners are not testing language, but it is important that candidates make the physics clear in their answers. A common misconception was that stars speed up with time as they move apart from each other, but Hubble's law compares <u>different</u> stars that are at different distances from the Earth.

Question 10

(a) The definition of radioactive decay, as the spontaneous emission of ionising radiation from unstable nuclei, was only given in full by a minority of the stronger candidates. Many weaker candidates gave responses that relied on the word 'decay', without appreciating that this is one of the two words in the technical term they have been asked to explain (and that they therefore cannot rely on in their answer).

(b) (i) This question was well answered by the majority of candidates, and full credit was common. Some candidates did not draw the curve sufficiently carefully, not paying sufficient attention to the key points it need to pass through and not ensuring that the gradient does not become horizontal.

(ii) Very many candidates were able to achieve full credit here. Common reasons for not achieving full credit were carelessness in the start and finish points for the line or not drawing a straight line.

(c) Most candidates knew that the gradient of Fig. 10.2 is the decay constant. Fewer candidates were able to identify the gradient of Fig. 10.1 as the activity of the sample, but nevertheless full credit was common.

(d) Most candidates who correctly set up the equation were also able to go on to solve it to calculate the correct answer. Candidates who did not perform a calculation (as instructed), but instead attempted to read a value off the graph of Fig. 10.1, were unable to do so to the precision required to obtain the correct answer.

PHYSICS

Paper 9702/43
A Level Structured Questions

Key messages

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

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

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

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

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

General comments

There was generally no evidence of candidates finding it difficult to complete the questions in the time allowed.

Most candidates appeared to be well prepared for the material that is new to the syllabus this year.

Comments on specific questions

Question 1

(a) (i) This definition well known and most candidates answered very well and were awarded full credit. A small number of candidates omitted the fact that the separation is squared.

(ii) Most candidates were able to use the required starting point of Newton's law of gravitation to reach the expression for gravitational field strength with distance.

(b) (i) The majority of the candidates substituted the correct values in order to determine the gravitational field strength at the surface of the Moon. A small number used the wrong data or did not square the radius.

(ii) This explanation proved challenging for many candidates, particularly those who referred to forces rather than fields. Some candidates who did mention fields could not gain full credit because they did not say that the directions were opposite.

(iii) This type of calculation can be challenging unless the candidates take the square root of the entire expression in the early stages of the algebra. It is then not necessary to wade through a cumbersome quadratic equation. Many candidates gained credit for setting up the expression ($3.84 \times 10^8 - x$) to find the required distance. Weaker candidates often used an incorrect formula such as potential instead of field strength.

Question 2

Candidates found this question challenging as it involved gravitational fields, electric fields and magnetic fields. In addition, there were two diagrams viewing the same situation from two different directions.

(a) (i) Candidates found it difficult to determine the correct direction for the magnetic field. Some candidates wrote 'into the page' but needed to say that this was for Fig. 2.2 as it was incorrect for Fig. 2.1. The expected answer of 'downwards' was relative to the ground and therefore correct for both diagrams.

(ii) Many responses gained at least partial credit here as candidates realised that the magnetic force provided the centripetal force. A significant proportion of those also included the fact that the magnetic force is perpendicular to the velocity. The weakest candidates referred to the electric force here which was not contributing to circular motion.

(b) Many candidates used the formula for the electric field strength due to a point charge. Others calculated the centripetal force. Only a small number of candidates correctly used the vertical equilibrium due to the weight and the electric force.

(c) Candidates need to ensure that all stages are clear in a 'show that' question. The combination of the three fields was challenging and not all candidates equated the centripetal force with the magnetic force.

Question 3

(a) (i) An ideal gas obeys the expression $pV \propto T$. Stating that it follows $pV = nRT$ is only equivalent when it is made clear that n and R are constants. Candidates need to define all symbols used in this type of question.

(ii) Most candidates correctly calculated the amount of gas here. Only a very small proportion did not convert the temperature from degrees Celsius to kelvin.

(b) (i) Again, all steps in 'show that' questions should be clearly stated. It was necessary to show the subtraction of the two volumes here, and a small number of candidates did not do this.

(ii) The majority of candidates gained partial credit for completing this table. Many candidates thought that 0 kJ of thermal energy was supplied to the gas in change CA and that the increase in the internal energy of the gas for this change was 31.6 kJ. It was stated in the question that from C to A the ideal gas expanded at constant temperature, so the increase of internal energy during this change was in fact 0 kJ.

Question 4

(a) Some candidates clearly linked the graph with the requirements for simple harmonic motion. Other candidates listed the graph features and then the simple harmonic motion characteristics without clearly linking the correct feature with the correct characteristic. Many candidates omitted reference to the origin which is vital when proving a proportional relationship.

(b) (i) This calculation was correctly completed by most candidates. A small number of candidates left their answer as a surd. Decimal answers are always expected.

(ii) Most candidates correctly completed this calculation. Some candidates were unable to deduce the correct unit for *k*.

(c) This explanation proved challenging. Only the strongest candidates managed to gain full credit because they realised that ω would decrease leading to a consequent increase in amplitude. Others simply said the amplitude would remain the same because energy remained the same. The weakest candidates mentioned phenomena such as damping or the lack of it, or other factors which had little bearing on the question asked.

Question 5

(a) (i) Most candidates could state what is meant by rectification.

(ii) The majority of the candidates correctly named the type of rectification, but some of the weakest omitted the word 'wave' which was necessary here.

(b) (i) The majority of candidates labelled the polarity of the output voltage correctly.

(ii) One label is not enough to define a scale – a number of candidates drew only a single label when labelling the *y*-axis. Some candidates worked out the correct period for the *x*-axis but then labelled it incorrectly, thinking that one peak was one period.

(c) (i) Most candidates added the capacitor in parallel. Some candidates added the capacitor in series on the 'input' side of the circuit. Candidates should take care to ensure they use correct symbols as defined in the syllabus.

(ii) While there were many good lines drawn here, candidates needed to take care with the details of their lines. A line that curved upwards was incorrect and even a straight downwards line was not strictly correct. In addition, the 10% drop in voltage was often not correctly shown.

(iii) This calculation proved challenging. Some candidates used the time at the end of the capacitor discharge section rather than the time difference between the start and the end of the discharge section.

Question 6

(a) This definition was not well known. Many candidates omitted that the area is perpendicular to the field lines.

(b) (i) This calculation was completed well by many candidates. A small number of candidates used the area of a circle instead of a square. Candidates need to read and look at questions and diagrams carefully.

(ii) Many candidates knew that the e.m.f. was constant because the line was straight. Some candidates did not refer to the graph shape but rather described what that shape meant, that the increase in *B* was proportional to *t*.

(iii) A significant number of candidates only calculated the gradient of the graph, and omitted the area and the number of turns.

(c) Many responses were awarded partial credit but relatively few could be given full credit. Candidates often do not realise the correct order of cause and effect. The change of flux linkage induces an e.m.f. in the coil which, when the terminals were connected, means there is a current in the coil. Many candidates suggested that a current induced an e.m.f. Others thought that the connecting of the terminals would increase a current that was already in the coil.

Question 7

(a) Many responses gained full credit here. Some candidates did not mention energy and this word was necessary in order to gain full credit.

(b) (i) The majority of the candidates were able to name the phenomenon.

(ii) Stronger candidates answered this question well and gave three conclusions from the graph. Others just quoted facts about the photoelectric effect they had learnt by heart which did not answer the question. A common error here was to say that E_{MAX} was proportional to the frequency. This is clearly incorrect because the line does not go through the origin.

(c) (i) Candidates were generally awarded partial credit for realising that a different metal gives a different threshold frequency. However, for full credit they needed to say that the gradient was the same and that the *x*-intercept was different.

(ii) Most candidates realised that the shape of the graph would stay the same but found it difficult to give a reason. They did not realise that the most fundamental aspect was that the photon energy had not changed.

Question 8

(a) (i) There were many correct answers here gaining full credit. Candidates should be careful not to write 'energy to split the nucleons' as this statement is too vague (for example it could refer to splitting a nucleon into quarks).

(ii) Candidates found it difficult to recall and draw the correct line. A significant number of those that had the correct idea were only close to the correct shape. Many weaker candidates drew lines with a negative gradient starting from a positive *y*-intercept or straight lines through the origin.

(b) (i) Most candidates correctly stated the name of the nuclear process.

(ii) Candidates found this explanation challenging. Many candidates showed evidence of the misconception that binding energy would decrease as a result of the reaction.

(c) This was a very challenging calculation. The majority of candidates who gained credit found the energy for only one reaction, not for the energy released from the reaction of 1.00 mol of deuterium. The weakest candidates only gained partial credit for the recall of $E = \Delta mc^2$. Some weaker candidates also had difficulty finding the loss in mass for the reaction.

Question 9

(a) (i) Many candidates showed that they knew how X-rays are produced and were able to gain at least partial credit. Some candidates thought the question was asking for how an X-ray image is produced, perhaps having previously learnt an answer to this question.

(ii) Many responses did not provide sufficient detail. The requirement for combining images of sections was often omitted.

(b) (i) This was very often successfully answered. The candidates who knew the relevant formula generally did not have difficulty in applying it. Some candidates left the constant e in their answer rather than evaluating the numerical value.

(ii) Combining transmitted intensities through more than one medium proved to be challenging. Some candidates used incorrect dimensions by not subtracting to find the length of soft tissue and some added exponentials instead of multiplying them.

(c) Candidates found this question difficult. Some candidates did not refer to their own values, others thought that the attenuation coefficients being different was the reason, and others provided a conclusion that was not consistent with the values.

Question 10

(a) A common reason for not being awarded credit was omitting the idea of 'maximum' or 'peak' intensity.

(b) (i) There were many correct answers here, but a common error was to misread the scale on the *x*-axis.

(ii) Some candidates were confused here and thought star B had a smaller wavelength because its maximum intensity peak was lower. Others referred to the brightness of the star, but this had been eliminated as an answer by the wording of the question.

(c) (i) Candidates often did not give enough detail in their answers. They needed to make it clear that it is the observed/apparent wavelength that is greater, rather than just a greater wavelength caused by the recession of the source.

(ii) Only the strongest candidates gained credit. Many candidates did not know that the observed spectrum from the star was compared with a known spectrum.

PHYSICS

Paper 9702/51
Planning, Analysis and Evaluation

Key messages

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

General comments

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

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

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

Comments on specific questions

Question 1

Most candidates correctly identified the independent and dependent variables. Candidates should be encouraged then to consider the control of variables and to explicitly state the quantities that need to be kept constant to make the experiment a fair test. In this experiment it was expected that candidates would state that *A* would be kept constant. There was additional credit for also stating that the initial potential difference of the power supply would be kept constant.

Candidates were awarded credit for a clearly labelled diagram. Diagrams should be drawn of the workable experiment. In this experiment, a workable circuit diagram is important and allows the candidate to more easily describe an experiment that would allow the relevant data to be collected. The best diagrams included the plates connected in parallel with both a d.c. supply and a capacitor, with a switch included on each branch to allow the plates to be charged by the d.c. supply (without any charge delivered to the capacitor at the same time) and then discharged to the capacitor (without a connection to the d.c. supply), and a voltmeter was also connected in parallel with the capacitor. Correct circuit symbols should be used for all components. A circuit diagram such as this allows the candidate to describe the experimental procedure by referring to the diagram.

Stronger candidates gained further credit for describing how the capacitor could be discharged by operation of a switch in parallel with the capacitor and for the operation of switches for the experiment to work. Many candidates did connect the capacitor correctly across the plates with a voltmeter, but often incorrectly connected a power supply in series or connected the power supply without any switches to isolate it.

In this experiment the area A, the capacitance C and the separation d needed to be measured. The separation d of the plates is small and it was expected that candidates would describe the use of calipers to measure this small separation, with additional credit available for a description of repeating measurements of d at different positions and taking an average. Many candidates suggested using a ruler, which is not appropriate for measuring this small gap between two plates. Many candidates correctly suggested determining A by measuring the length and width and then stating the calculation that area A = length $\times$ width. Stronger candidates described a suitable method to determine a value of C by describing an experiment to measure the variation of current (or potential difference) when discharging the capacitor through a resistor. Candidates who quoted $C = It / V$ did not gain credit.

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

Candidates needed to explain how they would determine values of W and K from the experimental results. Some candidates correctly identified a relationship between K and the gradient but did not make K the subject of the equation. Similarly, some candidates correctly identified a relationship between W and the y-intercept but did not make W the subject of the equation. For this experiment, logarithmic graphs were not appropriate and were not given credit. Credit was not awarded to candidates who did not correctly identify appropriate quantities to plot on the axes of a graph.

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

The use of gloves or avoiding touching the metal plates to prevent electric shocks were accepted as safety precautions.

Many candidates gained credit for stating that measurements of V would be repeated for each value of d and an average determined. The strongest candidates also gained credit for suggesting isolating the bottom plate by using a specific insulating material and using a high potential difference to increase the charge on the plates.

Question 2

(a) Candidates who were mathematically confident were able to work through the algebra and achieve credit. Some candidates also gained credit for stating that the y-intercept was equal to lg S + lg Z. Candidates should use the white space on the question paper to rearrange the equation into an equation of a straight line.

(b) Many candidates incorrectly calculated the values of lg (M / 10^{30} kg) and lg (L / 10^{28} W). Some of these errors were due to incorrect rounding. Candidates often did not use an appropriate number of significant figures for lg (M / 10^{30} kg). A common error was to match the significant figures of the lg value to the significant figures of the value of M used. Since M was recorded to two significant figures, values of lg (M / 10^{30} kg) should have been recorded to two (or three) decimal places – the number before the decimal point in a logarithmic quantity is not included. A common mistake was to incorrectly record the last four rows in lg (M / 10^{30} kg) as 1.1, 1.4, 1.6 and 2.0. Some weaker candidates also incorrectly recorded the lg (L / 10^{28} W) in the fourth row as 1.5 (one decimal place).

Many candidates did not determine the absolute uncertainty in lg (M / 10^{30} kg) correctly. Some of these candidates incorrectly calculated the uncertainty using a percentage method.

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

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

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

(iv) The majority of the candidates who were awarded full credit set out their working clearly. Stronger candidates often substituted data from the gradient calculation **(c)(iii)** into $y = mx + c$. Errors sometimes seen included candidates incorrectly dividing the y value by mx or determining the adding the y value to mx giving a positive y-intercept.

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

(d) The value of n was equal to candidate's gradient value. Candidates needed to show the substitution of the y-intercept to determine the value of Z. Some candidates incorrectly used e instead of 10, confusing natural logarithms and logarithms to base 10. Credit is not given for substituting data values from the table and using simultaneous equations to determine n and Z.

Candidates are also expected to give the final values of n and Z to an appropriate number of significant figures – in this case, since the raw values of M and L in Table 2.1 were given to two significant figures, the values of n and Z should have been recorded to two (or three) significant figures.

Many candidates did not understand that logarithmic quantities are dimensionless and ignored the factor of 10^{30} and 10^{28}. Candidates should be encouraged to think about the physical quantity represented by these calculated values.

The absolute uncertainty in Z required candidates to determine the maximum or minimum value of Z. Candidates should clearly show the substitution of the y-intercept from the worst acceptable line. Many candidates incorrectly calculated the fractional uncertainty of the y-intercept and multiplied by Z.

(e) There were many ways that candidates could determine *L*. Some candidates used the gradient and *y*-intercept, while others substituted values for *n* and *Z* from **(d)**. Candidates needed to show clear and logical working for this question as well as considering the powers of ten in the logarithmic quantities plotted. Some candidates were confused by the powers of ten in the units and used 10^{26} from the luminosity of the Sun. It was expected that the final answer would be given to at least two significant figures.

PHYSICS

Paper 9702/52
Planning, Analysis and Evaluation

Key messages

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

General comments

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

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

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

Comments on specific questions

Question 1

Most candidates correctly identified the independent and dependent variables. Candidates should be encouraged then to consider the control of variables and to explicitly state the quantities that need to be kept constant to make the experiment a fair test. In this experiment it was expected that candidates would state that E would be kept constant. There was additional credit for also stating that A, x and y would be kept constant.

Candidates were awarded credit for a clearly labelled diagram. Diagrams should be drawn of the workable experiment. In this experiment, candidates needed to connect a power supply to the two cylindrical conductors with an ammeter to measure the current in the conductors. A common mistake was incorrectly connecting an ammeter across the ends of the two conductors opposite the power supply. Candidates also needed to indicate how to measure the e.m.f. of the power supply. Stronger candidates connected a voltmeter across the power supply and also positioned a switch so that the rest of the circuit was isolated for the measurement of E.

Candidates often suggested using a rule to measure both L and x, and calipers were also allowed. To measure y it was expected that candidates would use either calipers or a micrometer. To determine A, candidates needed to state explicitly that the diameter d of the conductors would be measured with either calipers or a micrometer and then give an appropriate equation to find the area. To use πr^2, candidates needed to state halving the diameter to obtain r. Some weaker candidates were vague in their responses and suggested using calipers to measure y^2 (as opposed to y) or a micrometer to measure A. Some stronger candidates gained additional credit for the measurement of L to the side of the bar and adding $y / 2$, or measuring the distance between the two conductors and adding the diameter of the conductor to find x.

Many candidates suggested correct axes for a graph. A significant number of candidates incorrectly suggested plotting I against L. Candidates must explicitly state the quantities to be plotted on each axis either in the text or on drawn axes – credit is not given for just writing $y = mx + c$ under an expression. Candidates also needed to explain how the graph would confirm the suggested relationship. Candidates need to use the words 'relationship is valid if' and the word 'straight' to describe the line. Some candidates did not gain credit because they incorrectly stated that the line would pass through the origin. Another common mistake was to suggest plotting I against $1 / L$.

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

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

When describing safety precautions, candidates should be encouraged to explain how the precaution proposed is relevant to the experiment. In this experiment, precautions that were relevant to hot conductors were given credit. In this case switching off the circuit between readings was also allowed as a relevant precaution.

Question 2

(a) Candidates who were mathematically confident were able to work through the algebra and achieve credit. Some candidates also gained credit for stating that the y-intercept was equal to lg S + lg K. Candidates should use the white space on the question paper to rearrange the equation into an equation of a straight line.

(b) Many candidates incorrectly calculated the values of lg (T / days) and lg (L / 10^{30} W). Some of these errors were due to incorrect rounding. A particular difficulty was using an appropriate number of significant figures for lg (L / 10^{30} W), and a common error was to match the significant figures of the lg value to the significant figures of the value of T or L used. Since L was recorded to two significant figures, values of lg (L / 10^{30} W) should have been recorded to two (or three) decimal places – the number before the decimal point in a logarithmic quantity is not included. The common error was to incorrectly record the last two rows in the lg (L / 10^{30} W) as 1.2 and 1.3. Some weaker candidates also incorrectly recorded the lg (T / days) to one decimal place.

Many candidates did not determine the absolute uncertainty in lg (L / 10^{30} W) correctly. Some of these candidates incorrectly calculated the uncertainty using a percentage method.

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

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

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

(iv) The majority of the candidates who were awarded full credit set out their working clearly. Stronger candidates often substituted data from the gradient calculation **(c)(iii)** into $y = mx + c$. Some weaker candidates incorrectly read-off the y-intercept when lg (T / days) = 1.3. Other errors seen included candidates incorrectly dividing the y value by mx or adding the y value to mx giving a positive y-intercept.

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

(d) The value of a was equal to the candidate's gradient value. Candidates needed to show the substitution of the y-intercept to determine the value of K. Some candidates incorrectly used e instead of 10, confusing natural logarithms and logarithms to base 10. Credit is not given for substituting data values from the table and using simultaneous equations to determine a and K.

Candidates are also expected to give the final values of a and K to an appropriate number of significant figures – in this case, since the raw values of T and L in Table 2.1 were given to two significant figures, the values of a and K should have been recorded to two (or three) significant figures.

Many candidates did not understand that logarithmic quantities are dimensionless and ignored the factor of 10^{30}. Candidates should be encouraged to think about the physical quantity represented by these calculated values.

The absolute uncertainty in K required candidates to determine the maximum or minimum value of K. Candidates should clearly show the substitution of the y-intercept from the worst acceptable line. Many candidates incorrectly calculated the fractional uncertainty of the y-intercept and multiplied by K.

(e) There were many ways that candidates could determine L. Some candidates used the gradient and y-intercept, while others substituted values for a and K from **(d)**. Candidates needed to show clear and logical working for this question as well as considering the powers of ten in the logarithmic quantities plotted. Some candidates gave an answer of about 0.4 W indicating that the power of 10^{30} had been ignored. Other candidates were confused by the powers of ten in the units and used 10^{26} from the luminosity of the Sun. It was expected that the final answer would be given to at least two significant figures.

PHYSICS

Paper 9702/53
Planning, Analysis and Evaluation

Key messages

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

General comments

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

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

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

Comments on specific questions

Question 1

Most candidates correctly identified the independent and dependent variables. Candidates should be encouraged then to consider the control of variables and to explicitly state the quantities that need to be kept constant to make the experiment a fair test. In this experiment it was expected that candidates would state that *A* would be kept constant. There was additional credit for also stating that the initial potential difference of the power supply would be kept constant.

Candidates were awarded credit for a clearly labelled diagram. Diagrams should be drawn of the workable experiment. In this experiment, a workable circuit diagram is important and allows the candidate to more easily describe an experiment that would allow the relevant data to be collected. The best diagrams included the plates connected in parallel with both a d.c. supply and a capacitor, with a switch included on each branch to allow the plates to be charged by the d.c. supply (without any charge delivered to the capacitor at the same time) and then discharged to the capacitor (without a connection to the d.c. supply), and a voltmeter was also connected in parallel with the capacitor. Correct circuit symbols should be used for all components. A circuit diagram such as this allows the candidate to describe the experimental procedure by referring to the diagram.

Stronger candidates gained further credit for describing how the capacitor could be discharged by operation of a switch in parallel with the capacitor and for the operation of switches for the experiment to work. Many candidates did connect the capacitor correctly across the plates with a voltmeter, but often incorrectly connected a power supply in series or connected the power supply without any switches to isolate it.

In this experiment the area A, the capacitance C and the separation d needed to be measured. The separation d of the plates is small and it was expected that candidates would describe the use of calipers to measure this small separation, with additional credit available for a description of repeating measurements of d at different positions and taking an average. Many candidates suggested using a ruler, which is not appropriate for measuring this small gap between two plates. Many candidates correctly suggested determining A by measuring the length and width and then stating the calculation that area A = length $\times$ width. Stronger candidates described a suitable method to determine a value of C by describing an experiment to measure the variation of current (or potential difference) when discharging the capacitor through a resistor. Candidates who quoted $C = It / V$ did not gain credit.

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

Candidates needed to explain how they would determine values of W and K from the experimental results. Some candidates correctly identified a relationship between K and the gradient but did not make K the subject of the equation. Similarly, some candidates correctly identified a relationship between W and the y-intercept but did not make W the subject of the equation. For this experiment, logarithmic graphs were not appropriate and were not given credit. Credit was not awarded to candidates who did not correctly identify appropriate quantities to plot on the axes of a graph.

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

The use of gloves or avoiding touching the metal plates to prevent electric shocks were accepted as safety precautions.

Many candidates gained credit for stating that measurements of V would be repeated for each value of d and an average determined. The strongest candidates also gained credit for suggesting isolating the bottom plate by using a specific insulating material and using a high potential difference to increase the charge on the plates.

Question 2

(a) Candidates who were mathematically confident were able to work through the algebra and achieve credit. Some candidates also gained credit for stating that the y-intercept was equal to lg S + lg Z. Candidates should use the white space on the question paper to rearrange the equation into an equation of a straight line.

(b) Many candidates incorrectly calculated the values of lg (M / 10^{30} kg) and lg (L / 10^{28} W). Some of these errors were due to incorrect rounding. Candidates often did not use an appropriate number of significant figures for lg (M / 10^{30} kg). A common error was to match the significant figures of the lg value to the significant figures of the value of M used. Since M was recorded to two significant figures, values of lg (M / 10^{30} kg) should have been recorded to two (or three) decimal places – the number before the decimal point in a logarithmic quantity is not included. A common mistake was to incorrectly record the last four rows in lg (M / 10^{30} kg) as 1.1, 1.4, 1.6 and 2.0. Some weaker candidates also incorrectly recorded the lg (L / 10^{28} W) in the fourth row as 1.5 (one decimal place).

Many candidates did not determine the absolute uncertainty in lg (M / 10^{30} kg) correctly. Some of these candidates incorrectly calculated the uncertainty using a percentage method.

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

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

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

(iv) The majority of the candidates who were awarded full credit set out their working clearly. Stronger candidates often substituted data from the gradient calculation **(c)(iii)** into $y = mx + c$. Errors sometimes seen included candidates incorrectly dividing the y value by mx or determining the adding the y value to mx giving a positive y-intercept.

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

(d) The value of n was equal to candidate's gradient value. Candidates needed to show the substitution of the y-intercept to determine the value of Z. Some candidates incorrectly used e instead of 10, confusing natural logarithms and logarithms to base 10. Credit is not given for substituting data values from the table and using simultaneous equations to determine n and Z.

Candidates are also expected to give the final values of n and Z to an appropriate number of significant figures – in this case, since the raw values of M and L in Table 2.1 were given to two significant figures, the values of n and Z should have been recorded to two (or three) significant figures.

Many candidates did not understand that logarithmic quantities are dimensionless and ignored the factor of 10^{30} and 10^{28}. Candidates should be encouraged to think about the physical quantity represented by these calculated values.

The absolute uncertainty in Z required candidates to determine the maximum or minimum value of Z. Candidates should clearly show the substitution of the y-intercept from the worst acceptable line. Many candidates incorrectly calculated the fractional uncertainty of the y-intercept and multiplied by Z.

(e) There were many ways that candidates could determine *L*. Some candidates used the gradient and *y*-intercept, while others substituted values for *n* and *Z* from **(d)**. Candidates needed to show clear and logical working for this question as well as considering the powers of ten in the logarithmic quantities plotted. Some candidates were confused by the powers of ten in the units and used 10^{26} from the luminosity of the Sun. It was expected that the final answer would be given to at least two significant figures.