PHYSICS

Paper 9702/11
Multiple Choice

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

General comments

It is important to carefully read the text of the question before considering the four options presented. In numerical questions, candidates should be careful to consider SI prefixes and powers of ten and should be encouraged to apply a common-sense check to their answers to ensure they are a sensible magnitude.

Candidates should be aware of the difference between scalar and vector quantities, and of the importance of considering the direction of vectors in calculations where an object's vector changes.

Familiarity with different representations of waves is a key part of the syllabus, and candidates should be comfortable with drawing, describing and graphing the motion of both transverse and longitudinal waves.

In general, candidates found **Question 10**, **14**, **19**, **20**, **25**, **30**, **34** and **35** relatively difficult. Candidates found **Question 2**, **13**, **26**, **28** and **32** relatively easy.

Comments on specific questions

Question 3

This question required candidates to recall the volume of a sphere, and account for the uncertainty given in terms of the diameter rather than the radius. Around half of candidates correctly selected option **B**. Option **C** resulted from calculating percentage rather than absolute uncertainty and was a common incorrect answer.

Question 4

A majority of candidates correctly selected option **B**. Candidates should be familiar with both vector addition and vector subtraction.

Question 6

Approximately half of candidates correctly determined the time as 1.0 ms (option **D**). Roughly a quarter of candidates calculated the time for the pulse to travel from the device to the wall. Some candidates neglected to double this to account for the return time and so chose option **C**. Candidates should carefully consider the physics of the situation.

Question 8

This question tested candidate's understanding of graphical representations of uniformly accelerated motion. A large majority of candidates selected options **A** or **B**, suggesting that the constant horizontal component of velocity was well known. Stronger candidates correctly chose option **A**, whilst weaker candidates chose **B**, confusing the graph of displacement in the vertical direction with velocity in the vertical direction.

Question 9

Approximately half of the candidates correctly selected option **B**, with nearly all other candidates selecting option **A**. Options **C** and **D** were rarely chosen, suggesting that candidates are confident in identifying an elastic collision as one in which total kinetic energy is conserved. Candidates selecting **A** recalled that the relative **speed** of approach is equal to the relative **speed** of separation, confusing speed with velocity.

Question 10

Newton's 3rd law is always challenging for candidates, and fewer than half of candidate selected the correct option **C**. Both **B** and **D** were popular options amongst candidates, suggesting that many candidates do not appreciate that the forces that make up a third law pair must act on **different objects**.

Question 11

This question was challenging for candidates. Roughly a third of candidates correctly chose option **C**. Option **B** was the most popular incorrect option, with candidates neglecting to account for the vector nature of momentum and so finding the difference in the magnitude of block L's momentum, not the difference in momentum. Option **A** was also popular, with students confusing the change of momentum of block L with the total momentum of the system. Candidates should carefully consider the direction of momentum before and after collision.

Question 16

A large majority of candidates selected either option **C** or option **D**, suggesting that the formula for hydrostatic pressure is well known. Roughly half of the candidates correctly chose option **C**. Candidates need to carefully read the question, as incorrect option **D** is the total pressure due to the seawater at a depth of 260 m. The question specifically asks for the **difference** in pressures.

Question 19

This was a challenging question, which tested candidates' ability to manipulate momentum and energy equations. A common error is for candidates to incorrectly calculate a change in kinetic energy as $\frac{1}{2}m(\Delta v)^2$ rather than the correct $\frac{1}{2}m\Delta(v^2)$. This error led to incorrect option **B** and was a popular choice. Candidates should be aware that the difference of squares is not the same as the square of differences.

Question 20

This was a challenging question, suggesting that the concept of energy transfer at terminal velocity is not well understood.

Question 25

Roughly a third of candidates correctly selected option **C**. Options **A**, **B** and **D** were equally popular choices, suggesting that candidates are not familiar with the key principles of wave motion in transverse and longitudinal waves.

Question 26

Candidates found this question relatively easy, with approximately three quarters selecting the correct option **A**, suggesting that the concept of phase difference in a graphical representation of a wave is well understood.

Question 30

Most of the stronger candidates correctly selected option **D**, with weaker candidates selecting all four options with similar frequency. Candidates should be familiar in the use of the diffraction grating equation, including presenting a number of lines per mm instead of a line spacing, and giving angles between second and third order maxima.

Question 32

This question was answered correctly by the vast majority of candidates. The definition of resistance is clearly well known.

Question 34

This was a challenging question, with only the strongest candidates correctly selecting option **D**. To solve this problem, candidates were required to consider the total resistance of each branch, as well as the resistance of each combination between nodes, in order to determine the power dissipated in each combination.

Question 35

This question was challenging for candidates. To solve this question, candidates needed to recognise that the total p.d. across the two components must equal the e.m.f. (12 V), and that the current in both components is equal. This means that candidates can draw a horizontal line on the graph such that the total of the two p.d. values is 12 V.

Question 39

This was answered correctly by approximately half of the candidates. Amongst the weaker candidates, option **A** was the most popular choice, demonstrating a common misconception that the energy released in alpha and beta decay is identical, and so the smaller mass of the beta particle allows for higher velocities (or ranges of velocity).

PHYSICS

Paper 9702/12
Multiple Choice

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

General comments

It is important to carefully read the text of the question before considering the four options presented. Candidates should be familiar with the definitions of physical quantities in the syllabus.

In numerical questions, candidates should be careful to consider SI prefixes and powers of ten and should be encouraged to apply a common-sense check to their answers to ensure they are a sensible magnitude. Candidates should be aware of powers of two and factors of a half.

Candidates should be familiar with constructing and taking measurements from a variety of electrical circuits.

In general, candidates found **Questions 2**, **5**, **7**, **15**, **23**, **31**, **35** and **36** relatively difficult. Candidates found **Question 1**, **6**, **9**, **10**, **20**, **21**, **82** and **38** relatively easy.

Comments on specific questions

Question 2

This question proved very challenging. The majority of the stronger candidates correctly selected option **D**, but weaker candidates selected all four options roughly equally. Candidates should be familiar with quadratic and cubic unit conversions as well as linear unit conversions.

Question 5

This question was challenging. To solve this problem candidates needed to recall the speed of electromagnetic waves in a vacuum, recognise that the pulse travels twice the distance between Earth and Jupiter and then use distance = speed × time. Candidates then had to convert their answer to km. Roughly half of the strongest candidates correctly chose option **A**, although some did not convert their answer to km and instead selected option **C**. Candidates need to check the units of the options presented.

Question 6

This question was answered well by a majority of candidates, suggesting that the velocity-time diagram is well understood.

Question 7

This question tested candidates understanding of the resultant force acting on the object, and of the directions of the velocity and acceleration vectors. Stronger candidates typically chose the correct option **A**, with many weaker candidates selecting option **B**. This suggests that many candidates correctly determined the resultant force but neglected to consider the change in velocity.

Question 11

Newton's 3rd law is challenging for candidates, with a little over half selecting the correct option **B**. Option **D** was popular among weaker candidates, suggesting that these candidates do not appreciate that the forces that make up a third law pair must act on **different objects**.

Question 12

Roughly half of the candidates correctly chose option **D**. Option **A** was the most popular incorrect option, suggesting that candidates had correctly identified the falling stone would reach terminal velocity, but had confused acceleration with velocity. Candidates need to carefully read the question.

Question 14

A majority of candidates correctly chose option **D**. Some candidates selected incorrect option **B**. These candidates had correctly identified the forces of weight and upthrust acting on the block (in addition to the tension) and then had not correctly considered the directions of all three forces. Candidates are encouraged to use sketches in problems involving multiple vectors, in order to help them consider the directions of the vectors.

Question 16

This question was challenging. Candidates needed to recognise that pressure increases with depth, and so options **B** and **D** are incorrect. Additionally, pressure acts equally in all directions, and so option **A** is the correct answer. Candidates should be familiar with numerical and graphical problems involving the variation of hydrostatic pressure.

Question 18

There were several ways to solve this problem, the most efficient being to recognise that as the ball is brought to rest, the work done must be the loss of kinetic energy. Some candidates made arithmetic mistakes in using $\frac{1}{2}mv^2$. Neglecting the factor of ½ led to option **D**, and neglecting to square the velocity led to option **B**. Weaker candidates selected option **A**, the product of the weight of the ball and the horizontal distance travelled, suggesting that they were able to recall $W = Fd$, but unable to apply it to this situation.

Question 23

This question tested candidate's understanding of the difference between the elastic limit and the limit of proportionality. This distinction is not well understood with half of the weaker candidates and a quarter of the stronger candidates incorrectly selecting option **A**. Around a third of candidates correctly selected option **D**, and incorrect option **B** was also popular. Candidates should be aware that the elastic limit and limit of proportionality are often close for a given object, but they are not necessarily the same.

Question 28

This was answered correctly by the majority of candidates, suggesting that polarisation being only associated with transverse waves is generally well understood.

Question 30

Stronger candidates found this straightforward, demonstrating a good understanding of the conditions required to form a stationary wave. Candidates need to be familiar with the meaning of the wave terminology in the syllabus.

Question 31

This question required candidates to recall the formula $\lambda / a = x / D$, and that this ratio is constant before and after the change of distance. Most candidates carried out this reasoning, selecting the correct option **C** or incorrect option **B**. Those who selected **B** incorrectly used 0.90 m as the new distance **D**, rather than correctly **increasing D** by 0.90 m for a new distance of 1.50 m. Candidates need to carefully read the question and to note where the text describes increases or decreases, as opposed to new total values.

Question 35

Candidates found this question on the effect of internal resistance on terminal p.d. very challenging. Candidates could solve algebraically for new values of current and resistance directly. Alternatively, they could recognise that doubling the external resistance did not quite double the total resistance, so the new current would be slightly more than half the original current, eliminating **A** and **B** as options. They could then reason that a reduction in current would lead to an increase in terminal pd and so select the key **D**.

Weaker candidates selected incorrect options **A** and **B** equally frequently, suggesting that they had not understood or accounted for the internal resistance of the cell.

Question 36

This question was particularly challenging for candidates. Most of the stronger candidates correctly selected option **D**. Options **A** and **B** were popular with weaker candidates. Candidates should be familiar with drawing correct functional circuit diagrams. Option **A** was the most popular amongst weaker candidates, but inspection shows that it would give a current in the left-hand ammeter and not give any current in the right-hand ammeter.

PHYSICS

Paper 9702/13
Multiple Choice

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

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

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

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

General comments

It is important to carefully read the text of the question before answering the question.

Candidates should be familiar with the definitions of physical quantities in the syllabus and be able to distinguish between definitions for units and quantities.

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

In general, candidates found **Question 15**, **18**, **23**, **28**, **29** and **37** relatively difficult. Candidates found **Question 1**, **3**, **10**, **13**, **17**, **19**, **21**, **25**, **30** and **39** relatively easy.

Comments on specific questions

Question 2

Most candidates correctly selected option **C**. Option **B** was the most popular incorrect answer, and **D** was also popular for a some of the weaker candidates. Making estimates of physical quantities is a key part of the syllabus.

Question 4

Stronger candidates found this straightforward, whilst weaker candidates often selected incorrect option **C** instead of the correct option **B**. Candidates should be familiar with expressing derived quantities in SI base units and checking the homogeneity of equations. Candidates should also know the SI base units, as both incorrect options **A** and **C** can be immediately ruled out for including a unit that is not an SI base unit.

Question 7

Candidates can determine the answer to this question via a number of methods, the easiest of which is to recognise that both coins have the same initial kinetic energy and gravitational potential energy and so will have the same final kinetic energy and thus speed. Incorrect options **C** and **D** were popular with weaker candidates, demonstrating a lack of understanding of the motion of objects in free fall.

Question 9

Half of the candidates correctly selected option **B** in this simple definition question. It is essential that candidates are familiar with the definitions of key quantities within the syllabus and are able to distinguish between a definition of a quantity, and a method to calculate that quantity.

Question 12

This question can be solved by taking moments about end P, to find the unknown distance from P to the centre of mass. Approximately half of the candidates successfully did this and arrived at the correct option **D**. A significant number of candidates selected incorrect option **C**, which would be correct for a uniform bar. Candidates need to carefully read the question.

Question 13

Nearly half of the weaker candidates selected incorrect option **C**, confusing the quantity ‘volume’ with the unit ‘cubic metre’. Candidates should be confident of the difference between quantities and units, and that quantities must always be defined in terms of other quantities.

Question 14

Candidates should be aware of the difference between a diagram representing the resultant of two vectors, and a vector triangle representing an object in equilibrium. Incorrect options **A** and **B** were both popular, especially with weaker candidates. As they do not form a closed cyclic triangle, these options cannot represent an object in equilibrium.

Question 15

This was a challenging question, requiring candidates to consider how the pressure in the liquid varies with depth. The stronger candidates correctly chose option **D**. Incorrect option **B** was popular. This suggests that many candidates were able to recall the relationship between pressure and depth, and then assumed that 60 cm was a depth, rather than a height. Candidates are encouraged to sketch problems in order to help them understand the specific question they are being asked.

Question 18

This presentation of kinetic energy against height proved challenging. Roughly a third of candidates correctly selected option **D**. Candidates need to be familiar with a variety of graphical representations of falling objects.

Question 23

Candidates found this very challenging, with slightly more candidates overall selecting incorrect option **B** than the correct option **D**. Candidates need to recognise that doubling the length of the wire will cause double the extension for **the same** force, as diameter and Young Modulus are constant.

Question 24

Approximately half the candidates correctly selected option **D**, with most of the rest choosing incorrect option **A**. Candidates should be familiar with graphical representations of waves, in particular with visualising the motion of particles on waves.

Question 25

This was answered correctly by the majority of candidates, suggesting that polarisation being only associated with transverse waves is generally well understood.

Question 28

Candidates can find the path difference of 40 cm between XZ and XY and then need to relate the path difference to the wavelength. Weaker candidates selected **A** and **D** roughly equally, and some selected option **C**, halving the path difference. These candidates perhaps assumed that the sources at X and Y were in phase with one another, rather than the 180° phase difference stated. Stronger candidates correctly chose option **B**, correctly accounting for the phase difference.

Question 33

This was straight-forward for the stronger candidates, whilst a significant number of weaker candidates selected the incorrect option **D**. This suggests that some candidates incorrectly think that only electrons act as charge carriers, and so these candidates immediately ruled out the positive answer.

Question 35

This was answered correctly by approximately half of the candidates, suggesting that many were able to consider this more complex potential divider question correctly. The most common incorrect answer was option **A**. This may result from candidates assuming that a null method is being used here. Candidates need to be familiar with comparing p.d.s across separate branches of a circuit.

Question 40

This was answered correctly by a majority of candidates, although many weaker candidates selected the incorrect option **C**. This demonstrates that the connection between proton number and element is not well understood. Candidates should know the definitions of the key terms within the syllabus.

PHYSICS

Paper 9702/14
Multiple Choice

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

General comments

It is important to carefully read the text of the question before considering the four options presented.

Candidates should be familiar with the definitions of physical quantities in the syllabus and be able to distinguish between definitions for units and quantities.

Candidates typically found questions involving a calculation straight-forward but found the questions involving definitions and verbal reasoning more challenging.

In general, candidates found **Question 3** and **21** difficult. Candidates found **Question 2**, **5**, **6**, **15**, **17**, **20**, **22**, **30**, **32**, **34**, **35**, and **39** relatively easy.

Comments on specific questions

Question 1

Slightly over half of the candidates correctly selected option **B**. Options **A** and **C** were both popular incorrect answers, suggesting that candidates found it challenging to estimate the volume of an atom, or a phone or both. Estimation problems are a useful tool for helping candidates assess the magnitude of their calculated answers.

Question 3

This was a challenging question. Candidates needed to recognise that the difference between the internal and external diameters was equal to twice the wall thickness, so the thickness must be 1.0 mm. They also had to recognise that the uncertainty in the difference between the diameters was 0.2 mm and so the absolute uncertainty in the thickness must be halved to give 0.1 mm. Many candidates selected either option **B** or option **D** and so had not understood one or both of these points.

Question 5

Most candidates answered this correctly. Option **B** was the most popular incorrect answer suggesting that some candidates had not read the axis label or are not confident of the difference between distance and displacement. Candidates need to carefully check the axes in graphs to ensure they are answering the right question.

Question 8

Slightly over half of the candidates correctly selected option **B**. All three incorrect options were popular, especially among weaker candidates. Candidates needed to recognise that in this problem the skydiver started at terminal velocity and after the parachute was opened approaches a new, lower terminal velocity. Those candidates selecting **A** had assumed a skydiver falling from rest. Those selecting **C** or **D** had not accounted for air resistance, which must be significant, given the initial terminal velocity of the skydiver. Candidates need to carefully read the question.

Question 9

As the collision is elastic the relative speed of approach must equal the relative speed of separation and so options **A** and **B** can be ruled out. Stronger candidates found it straightforward to solve the conservation of momentum problem and determine the correct answer as **C**. Weaker candidates selected all four options equally suggesting high levels of guessing. Candidates need to consider all the information presented in the question, and in momentum questions to be particularly aware of the directions of the momentums involved.

Question 10

A significant minority selected incorrect option **A**. Candidates should know the definitions of the key physical quantities in the syllabus.

Question 18

This was a challenging question on elastic potential energy. Candidates could solve this with a number of different methods. The most efficient was to find the spring constant for the spring using $k = F/x$ and then use the formula $\Delta E = ½\Delta(F^2)/k$. Most candidates selected either option **C** or option **D** indicating a good understanding of the situation. A number of errors could lead to option **C**, for instance candidates calculating the **total** energy stored if the **total** force was 4.0 N.

Question 21

This proved to be a challenging question with only the strongest candidates choosing the correct answer **A**. Some candidates chose incorrect option **C**, despite the question clearly stating that the graph represented an instant in time.

Candidates need to be familiar with different graphical representations of waves.

Question 33

Candidates found this challenging with roughly half selecting the correct option **A**. Incorrect options **C** and **D** were popular, especially with weaker candidates, demonstrating a lack of understanding that changing the variable resistance will affect the total resistance, and thus the current through the lamp.

Question 35

In contrast to **Question 33**, this was answered correctly by the majority of candidates. This suggests that candidates are confident using Kirchhoff's laws to solve circuit problems when values are given and are less familiar with the conceptual relationship between quantities.

Question 38

Slightly over half of the candidates correctly chose option **D**. Weaker candidates appeared to be guessing, indicating that either the composition of alpha and beta particles is not well known, or that candidates were not confident of the meaning of 'element' and 'nucleon number'. It is important for candidates to recall the definitions of key terms in the syllabus.

PHYSICS

Paper 9702/21
AS Level Structured Questions

Key messages

- Candidates need to be able to accurately recall the definitions, laws, principles, standard formulae and factual information given in the syllabus.
- Candidates should be aware that rounding an intermediate answer in a numerical question can lead to an inaccurate final answer. Candidates should either retain all the significant figures on their calculators or record more significant figures for intermediate answers.
- Candidates should understand the command words given in the syllabus. In a question that uses the command words 'state and explain', candidates can only be awarded credit for an answer supported by a valid explanation.
- Candidates should know the SI unit prefixes (for example cm and km) and make the appropriate power-of-ten conversions in calculations.

General comments

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

The stronger candidates were generally successful in applying their knowledge in the questions. Some of the weaker candidates could have significantly improved their responses by being able to recall basic facts, for example standard formulae and definitions in the syllabus.

In **Question 1(b)** candidates needed to ensure that all values had the correct signs when substituted into the appropriate equation of uniformly accelerated motion – a significant number of candidates were awarded partial credit due to making an error here.

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

Comments on specific questions

Question 1

(a) Most candidates found this question straightforward. In some cases, candidates gave a description of acceleration rather than a definition. Some candidates gave the definition of *velocity*. Other common errors were for candidates to mention 'speed' instead of velocity or to write 'velocity over time' which could imply a duration rather than a ratio.

Definitions must be expressed carefully. For example: 'rate of change of velocity *per unit time*' is incorrect as it implies a rate of change of a rate of change.

(b) (i) The vast majority of candidates were able to calculate the time correctly. Incorrect answers often involved use of the wrong vertical displacement of 3.6 m. Weaker candidates often attempted to use an incorrect formula, such as $v = u + at$ with $v = 0$. A few answers were awarded partial credit as candidates needed to execute the square root in the final step of their calculation.

(ii) This question was challenging. Candidates who set out their working carefully and took a systematic approach to identifying the correct equation of uniformly accelerated motion were more often successful. Incorrect answers frequently arose from inconsistent signs for *s* and *g*. Some answers used the wrong displacement of 14 – 3.6 = 10.4 m.

(c) (i) Many candidates were awarded partial credit for stating that object B would take less time to reach the ground when projected at an angle. Relatively few were able to articulate a valid explanation and so were not awarded full credit. A common misconception was that the time would be greater because there was a horizontal distance to cover in addition to a vertical distance. A significant proportion of candidates gave answers that simply mentioned 'vertical velocity' or 'initial velocity' instead of initial vertical velocity. Some candidates mistakenly wrote that the initial vertical component of velocity was $v\sin\theta$, or just discussed 'speed'.

(ii) Only a small minority of candidates gave correct answers to this question. Candidates needed to apply the principle of conservation of energy and understand how the initial conditions for objects A and B meant that the two objects would have the same final kinetic energy (and thus the same speed) upon reaching the ground. Some responses were merely a description of energy changes taking place. Many incorrect responses referred to object B reaching a lower maximum height and so having a lower final kinetic energy, showing a misunderstanding of the physics involved.

Question 2

(a) A lot of candidates understood this concept.

Common errors included omitting 'sum', 'about a point' or 'in equilibrium'. Some candidates confused momentum with moments; the phrase 'in a closed system' was often seen. Some candidates merely defined the moment of a force. Candidates should be aware that 'in balance' is not an adequate alternative for 'in equilibrium'.

(b) Generally, this was well answered. Of those candidates awarded partial credit, many selected the wrong distances about the pivot (e.g., 3 – x for object B). Candidates needed to include *g* when calculating a moment. There were several instances where an invalid final answer of 4/3 was given. Candidates should be aware that (unless explicitly stated in the question) answers given in surd or fractional form are not acceptable.

(c) (i) Most candidates identified $F = kx$ as the relevant formula and correctly determined $x = 0.21$ m. The most common error was related to the value of *F*, which was either calculated by an invalid method involving multiple forces or moments or by using the incorrect object. Candidates needed to realise that the force applied was equivalent to the weight of object A, which had been replaced by the spring. A significant number of candidates used an incorrect value of 0.80 m or 0.59 m for *x*.

(ii) Many candidates were awarded full credit in this question. The weakest candidates often started with a wrong equation, for example: $E = kx^2$, $E = ½kx$ or $E = mgh$.

Candidates need to take care in setting out their working and executing their calculations – sometimes only partial credit could be awarded due to candidates mixing up the value for *k* with the value for *F* from **(c)(i)** and by forgetting to square the value for *x*.

Question 3

(a) This was usually answered correctly. A few candidates tried to define power via the wrong equation, such as $P = Fv$ or $P = VI$. Some candidates attempted to *describe* power. Some candidates wrote both 'rate' and 'per unit time' in their definition.

(b) (i) Most candidates found this question straightforward and were awarded full credit. The most common error was using the incorrect equation $P = F / v$.

(ii) This was usually answered correctly. The most straightforward approach was to use the equation $W = Fs$ and candidates adopting this method gained credit, although making a power-of-ten error on the value for distance was a common mistake.

(iii) The stronger candidates managed to obtain the correct final answer. Many candidates were awarded partial credit for giving the equation $P = VI$. Other responses needed to follow this up with a correct formula for efficiency. The most common mistake was substituting the power from **(b)(i)** for the *total input* power.

Many candidates gave an abbreviated formula for efficiency (i.e. with no mention of energy or power), alongside incorrectly identifying 61 000 W as the total input power, leading to partial credit for $P = VI$. There were many instances of candidates applying the efficiency formula directly to 600 V to get 510 V and some instances of efficiency being omitted entirely. A small number of candidates attempted to use the value of work done from **(b)(ii)** in the efficiency formula.

(c) (i) The vast majority of answers just stated air resistance 'increases' / 'decreases' / 'stays the same' without an explanation. Some candidates mentioned that the speed of the car would increase. Candidates need to read the question carefully. Candidates should know that air resistance is dependent upon speed.

(ii) Only a small proportion of candidates gave complete correct answers. Some answers incorrectly stated that the current would be the same since the speed was the same. A few answers referred to the current being less because the motor has to do less work, which was insufficient for credit.

Question 4

(a) There were many good answers which were concise and clearly expressed. There were also answers which were imprecise or incomplete, often because candidates used the wrong keywords – e.g., 'superpose' / 'interfere' / 'interact' instead of 'meet' / 'overlap' or 'amplitude' instead of 'displacement'.

(b) (i) Most candidates could recall the equation $\lambda = ax / D$ for double-slit interference. Candidates needed to determine the fringe separation x from **Fig. 4.2**. Some candidates incorrectly divided 3.2 cm by 9 or 16 instead of 8. The conversion of cm to m was also a common source of error. A small number of candidates attempted to apply the diffraction grating formula $n\lambda = d\sin\theta$.

(ii) The strongest candidates produced very good curved lines that passed through the expected points. Most candidates who were awarded partial credit drew a straight line of negative gradient passing through (0.16, 0.4). Straight lines with a positive gradient were incorrect responses that were commonly seen.

Candidates are expected to use the mathematical skills and knowledge referred to in the syllabus, which includes the sketching of graphs of simple relationships, such as the inverse proportionality between x and a in this question.

Question 5

(a) This question proved to be challenging for most candidates. Only a small proportion of candidates were awarded full credit, usually because λ was only defined as 'distance'. The best answers gave concise definitions of wavelength and frequency in words, as well as 'speed = distance/time' and either put them together to show $v = f\lambda$, or related these to symbol equations followed by algebraic reasoning leading to $v = f\lambda$.

(b) (i) There were many correct answers. Candidates needed to understand that the frequency could be determined from the time period of the CRO trace in **Fig 5.1**. A common error was overlooking the unit prefix of the time-base and getting a final answer to the wrong power-of-ten. Some candidates attempted to use the Doppler equation.

(ii) Many candidates realised that the Doppler equation was required. Common mistakes included substituting 250 Hz as f_s instead of f_o, mixing up v with v_s and using the wrong sign in the denominator of the equation.

Question 6

(a) (i) This question was usually answered correctly.

(ii) This was generally answered well. Most candidates identified the correct equation. When substituting numerical values into the formula, some candidates made an error in transcribing the data (often writing the wrong power-of-ten).

(iii) This was generally answered well. The weakest candidates sometimes made an error rearranging the equation. A small number of candidates used non-standard symbols in the equation. Candidates should be aware that credit cannot be awarded for an equation with non-standard symbols unless those symbols are clearly defined either in words or by a subsequent correct substitution of values.

(b) (i) Only a qualitative answer was required here. Candidates needed to understand the effect of combining resistances in parallel and Kirchhoff's laws to answer this correctly. A common error was to state that the current would be unchanged since the ammeter is 'before' the junction and so the current would not have split at this point. Some candidates stated that total resistance would increase since more resistance had been added and therefore current would decrease. Some candidates gave answers without a supporting explanation.

(ii) This question was challenging, and only the strongest candidates were awarded full credit. The majority of responses stated what happened to the average drift speed without an explanation. Many candidates stated that the current *increased*, considering the current in the ammeter rather than the current in wire X.

Question 7

(a) This question involved completing and balancing a simple nuclear equation. Candidates needed to realise that the decay was by beta-plus emission. There were many good answers. Some candidates misidentified the decay as beta-minus. The neutrino was frequently omitted, or an antineutrino was given instead.

(b) (i) Many candidates answered this correctly. The most common incorrect answers were stating the charge to be –1 or 1.6×10^{-19}.

(ii) This was generally answered correctly, although incorrect classifications were often seen.

(iii) This was generally answered correctly. Stronger candidates were usually awarded full credit. Weaker candidates often gave incorrect combinations of antiquark flavours or gave incorrect charges; a common wrong answer was giving the quark charges for the proton rather than the antiproton.

PHYSICS

Paper 9702/22
AS Level Structured Questions

Key messages

Candidates should explicitly state the subject of any numerical or algebraic equations they use. This is especially important where more than one equation is used in a question, and when equations are stated and then re-arranged. In some questions, credit can be awarded for correct statements of physical equations, if the whole equation is clearly shown.

Candidates should pay attention to the units and powers of ten in which information is presented and ensure that they are converting answers into SI base units where appropriate.

Candidates should ensure that they avoid rounding interim values in a calculation, as this can lead to incorrect final answers. Candidates should also give their answers to an appropriate number of significant figures, based on their data used in the calculation.

Candidates should be prepared to draw accurate diagrams. It was clear that many candidates did not have a ruler or protractor in the exam.

When describing mathematical relationships, candidates should be careful to use precise mathematical language. In particular, the words ‘into’ and ‘by’ can mean multiply or divide, so it is not possible to infer which meaning is intended. Candidates should explicitly state when they are referring to multiplication or division.

General comments

There was no evidence that candidates were short of time for this examination.

Candidates are expected to use the standard symbols for the quantities given in the AS Level part of the syllabus. These symbols are shown in the relevant syllabus topics and are also given in the syllabus summary of key quantities, symbols and units. This is especially relevant in ‘show that’ questions.

Most candidates answered questions involving the recall and use of formulae well. Definitions were not always well known, and many either missed out key words or used wording which changed the meaning of the definition.

There were a number of ‘state and explain’ questions in this paper. These require both a statement and an explanation to award full credit.

Candidates found **Question 1(b)(iii)**, **3(a)**, **3(b)(i)** and **6(b)(i)** relatively easy. They found **Question 1(b)(iv)**, **2(b)(i)**, **2(b)(ii)**, and **6(c)** particularly difficult.

Comments on specific questions

Question 1

(a) Most candidates correctly identified acceleration and displacement as vectors. A common misconception among weaker candidates was that gravitational potential energy is a vector, perhaps due to candidates associating a change in gravitational potential energy with displacement in the vertical direction.

(b) (i) Successful candidates clearly laid out each step of their derivation and used the appropriate symbols. Most candidates were able to state that $W = Fs$. Weaker candidates often used non-standard symbols; '*Wd*' instead of '*W*' for the work done; '*d*' instead of '*s*' for displacement; '*s*' instead of '*v*' for speed. As this was a 'show' question candidates needed to explicitly state or substitute the initial value of the speed as zero.

Weaker candidates frequently made the incorrect assumption that $s = vt$ instead of $s = ½vt$. This then led to an expression that did not contain ½ and so some candidates introduced an unexplained factor of ½ at the end of their working.

A small minority used base units to check the homogeneity of the given equation which was not relevant to the question.

(ii) The symbol formula for kinetic energy was well known. A significant number of weaker candidates did not square the value of the speed at the substitution stage and so got an incorrect answer.

(iii) The appropriate symbol equation for power was usually stated correctly.

Most candidates did not realise that the increase in kinetic energy of the car needed to be added to the work done against the resistive forces. Some candidates made the mistake of subtracting them. The most common error was to use only the work done against the resistive forces on its own to calculate the average output power of the car.

Some candidates attempted to use $P = Fv$. These candidates typically made no progress as the velocity of the car is not constant during the period in question.

(iv) This question proved challenging for candidates. Most responses stated that the output power was either less than or the same as the output power just before $t = 5.8\,s$. Only very strong candidates could give a full explanation of why the output power was less. Sometimes only a partial explanation that lacked the required detail was provided, such as explaining only that the resultant force or acceleration decreases to zero. A common misconception was that the car had reached terminal velocity, and so explanations often incorrectly focused on this.

Question 2

(a) Many candidates were able to provide a correct definition of the moment of a force. Common errors included confusing 'displacement' with 'distance' (perhaps confusing the definition of work done with that of moment) or referring vaguely to only 'distance' instead of 'perpendicular distance'. Very weak candidates sometimes stated only that the moment is the turning effect of the force. A small number of candidates gave the principle of moments, rather than the definition of moment. A number of very weak candidates gave the definition of momentum.

(b) (i) This was a 'show' question and so it was essential for the candidates to explicitly show all the key steps in the calculation of the angle θ. Some candidates were able to show the correct expression for the moment due to the weight of the tree. Only a small minority were able to show the correct expression for the moment due to the force applied by the post on the tree. Many candidates incorrectly gave the moment due to the post as $1800 \times 1.6 \times \cos\theta$.

It was clear that candidates found determining the moment due to a force that was not horizontal or vertical significantly challenging.

(ii) This straightforward question required candidates to draw a scale vector diagram. Most candidates were able to draw a triangle of forces. Candidates needed to show arrows that correctly represented zero resultant force on the tree.

It was common for the arrows for *F* and *R* to be drawn so that their tails were touching. Many candidates neglected to label one or both vectors, and it was very common for one of the vectors to be labelled 'resultant force' demonstrating a lack of understanding of the conditions for equilibrium.

Stronger candidates typically drew *F* in the right direction. It was common for *R* to be perpendicular to *F*, suggesting that the magnitude of *F* had not been calculated. It appeared that very few candidates had a protractor, as it was common for the angle between the weight and *F* to be labelled '25°' and to be very different to 25° on the page.

(iii) Most candidates correctly stated the symbol formula for pressure. Many of the weaker candidates substituted the wrong value of force into the formula. Candidates that did not convert, or incorrectly converted, the value of the pressure from kPa to Pa often calculated an area that had a clearly unrealistic magnitude. Candidates are encouraged to apply a sense check to their answers to identify whether their values are reasonable.

Question 3

(a) The vast majority of candidates correctly gave the amplitude of wave X. Very occasionally the amplitude of wave Y (20 cm) was given instead.

(b) (i) Nearly all candidates correctly recalled $v = f\lambda$, with only a few weak candidates attempting to use $f = 1 / T$ instead. Weaker candidates occasionally used the value of amplitude as the wavelength.

(ii) Candidates found this challenging. A large number of candidates either stated the waves were coherent or explained that the phase difference was constant. Candidates needed to provide both a statement and an explanation.

A common incorrect answer was for candidates to state that the waves had 'the same' phase difference, implying that phase difference is a property possessed by each wave, rather than a comparison between two waves.

A common misconception was that the waves needed to be in phase to be coherent. A significant number of candidates explained only that the waves had the same frequency or wavelength, without relating this to a constant phase difference.

(c) The majority of the candidates were able to correctly apply the principle of superposition and sketch the correct resultant wave. A small number of candidates sketched a positive sine wave instead of a negative one. There were some excellent curves, as well as some that were less accurate. Candidates should draw a curve that is a single line, not a collection of disconnected 'feathered' strokes.

(d) Stronger candidates found this straightforward, often showing a correct symbol formula and a single substitution line with the correct answer. Weaker candidates sometimes quoted the correct relationship between intensity and amplitude then inverted the ratio (leading to an answer of 4.0) or assumed that the ratio of the intensities was equal to the ratio of the amplitudes (giving a final answer of 0.50).

Question 4

(a) Most candidates explained correctly that the collision was inelastic in terms of kinetic energy. Some candidates referred only to 'energy' not kinetic energy. Many candidates alternatively explained in terms of the change in (relative) speed, though use of the term 'relative' was rare. Very weak candidates thought that it was an elastic collision simply because the ball bounced upwards rather than sticking to the ground.

(b) (i) The formula for the momentum of an object was well known. Many candidates did not consider the change in direction of the velocity and so made the mistake of subtracting the magnitudes of the velocities instead of adding them.

(ii) A significant number of very weak candidates thought that the average force on the ball during the collision would be equal to the weight of the ball. A few weak candidates thought that force was equal to momentum over time rather than change in momentum over time.

(c) Stronger candidates typically presented clear working, with h_1 and h_2 clearly identified in the calculations. Weaker candidates often presented many lines of disordered calculation, using '*s*' for both h_1 and h_2.

It was common for candidates to get confused in the working as to which values were the initial and final height, and so the inverse ratio (2.1) was a common incorrect answer.

Most candidates made use of $v^2 = 2as$. Other equations of motion were also common, and a few candidates used $½mv^2 = mgh$. Candidates using other equations of motion often used incorrect values, such as $t = 0.18$ s (the contact time for the collision) or $6^2 – 5.2^2 = 2 \times 9.81 \times h_2$. Very weak candidates sometimes treated this as a constant velocity problem and so attempted to use the ratio of the speeds for the ratio of the heights.

Another very common error was for candidates to prematurely round the value of h_2. In general, candidates should always avoid early rounding of interim answers within a calculation as this can lead to an incorrect final answer on the answer line.

Candidates also frequently gave their final answer to this question to only 1SF.

Question 5

(a) Most candidates correctly gave the definition of Young modulus. Some candidates gave extra information by also defining stress and strain, which was not required. A few candidates gave the definition only as a symbol equation, and those that did rarely defined the symbols and so were not awarded credit.

(b) (i) Many candidates were able to determine the cross-sectional area of the wire, making use of a point from the graph to 'fill in' the force and extension variables. Some candidates attempted to first find the spring constant for the wire and those that did were often successful. Common errors were neglecting the 10^{-3} factor in the value of extension and having a power-of-ten error in the value of the Young modulus. Candidates need to check whether their answers are of a sensible magnitude, as these errors typically led to implausible values for the area.

It was also common for arithmetic errors to occur when candidates changed the subject of the numerical equation. A small number of very weak candidates tried to calculate the cross-sectional area of the wire by finding the area under the graph.

(ii) Many candidates were able to recall a correct formula for the elastic potential energy in an extended wire. A significant number of weaker candidates tried to apply the incorrect expression of $W = Fx$ instead of $½Fx$. The most successful candidates either directly calculated the appropriate area under the graph or applied the expression $W = ½F_2x_2 – ½F_1x_1$. A common error was to incorrectly assume that the work done could be calculated by applying the expression $W = ½ (F_2 – F_1) (x_2 – x_1)$ or $W = ½k (x_2 – x_1)^2$. Candidates should be aware that the difference of squared values is not the same as the square of the difference in values.

Candidates should consider the number of significant figures of the data used to judge the appropriate number of significant figures in their answers.

Question 6

(a) Many candidates gave the correct definition of potential difference. The most common mistake was to define electric potential difference as the energy transferred to 'move' a unit charge, instead of the energy transferred per unit charge. Candidates needed to clearly express this definition as a ratio of two quantities. Relatively few candidates confused potential difference with electromotive force. A small number of very weak candidates simply stated $V = IR$ in symbols or in words.

(b) (i) A large proportion of candidates were awarded full credit on this question. Candidates typically recalled $Q = It$, though very weak candidates often gave $Q = I / t$ instead. The most common error was for candidates to forget to convert the value of the time from units of minutes to seconds.

(ii) The vast majority of candidates recalled $I = V / R$. Many candidates correctly substituted the total p.d. and the total resistance of 430 W + 240 W. Some weaker candidates substituted only one of the values of resistance.

(iii) Most candidates were able to correctly apply Kirchhoff's first law to determine the unknown current. Some weaker candidates incorrectly assumed that the current was equal to 8 V/210 Ω leading to an incorrect answer of 0.038 A.

(iv) This was challenging for candidates. Many candidates were able to determine the total resistance in the top branch. It was reasonably common for this total resistance to be given as the final answer.

Candidates who attempted to apply a parallel resistance formula often made arithmetic errors, the most common of which was to state 267 = 1/(210 + *R*) + 1/670.

(c) This question was very challenging, with many candidates unfamiliar with the use of a galvanometer in a null method. Weaker candidates tended to omit this question or give vague responses in term of a potential divider circuit, perhaps confusing this with a different circuit containing a potentiometer wire. A number of candidates referred to the idea that the potential difference across the galvanometer was zero. Candidates then needed to explain that this was known because the current in the galvanometer was zero. Some candidates did not state that the current in the galvanometer was zero, instead referring vaguely to the galvanometer 'pointing up' rather than reading 0. Some candidates wrongly assumed that the galvanometer gave a reading of potential difference, instead of current.

It was also common for candidates to give only a partial explanation by equating the ratio of the variable resistance and the resistance of X to either a ratio of currents or a ratio of potential differences (instead of to the ratio of the 210 Ω and 430 Ω resistors). Some incorrectly assumed that the galvanometer could be used to show that the resistances of the top and bottom branches were equal, rather than considering the ratios of resistances.

Those candidates who did succeed typically explained the ratio mathematically with an equation, rather than in words.

Question 7

(a) Candidates found this simple definition challenging. Candidates often gave vague answers such as 'they are the smallest particles' or 'the simplest/most basic particles' or 'subatomic particles' or 'particles that are used to make other particles'. A common misconception was that a fundamental particle is any particle that is used to make up an atom or nucleus. Candidates sometimes named quarks or (less commonly) leptons as examples of fundamental particles, which was not required.

(b) (i) This proved very challenging. Many candidates did not convert the nucleon number into a mass, or did not account for the value of the elementary charge.

A common error for candidates was to confuse '14 nucleons' with '14 neutrons' and so calculate a final answer of 10 protons instead of 6 protons.

Some candidates simply guessed that the nucleus would have an equal number of neutrons and protons and therefore gave a final answer of 7 protons.

(ii) The beta-minus term in the equation was usually given correctly. Many candidates were also able to determine the nucleus Z term correctly. A small number of candidates incorrectly stated that nucleus Z had a proton number of 7*e* (instead of 7) and a nucleon number of 14u (instead of 14). Those candidates confused proton number with charge and nucleon number with mass. Many candidates found it difficult to give the antineutrino term correctly and a significant number gave the symbol for a neutrino rather than an antineutrino. A number of weaker candidates gave both a beta minus particle and a beta plus particle in their answer, despite the question clearly stating that the nucleus undergoes beta-minus decay. A significant minority of candidates did not know how to structure their answer using the lines given, suggesting the standard notation for nuclear decay is unfamiliar.

(c) There were some excellent responses to this question, with clear deductive reasoning being shown by some of the strongest candidates, as well as frequent additional explanation of why the beta-plus particles had a continuous range of kinetic energy. Most candidates were able to identify that the decay was beta-plus decay. Candidates then needed to give a supporting explanation. Weaker candidate sometimes incorrectly stated that the decay was alpha decay, perhaps because they knew that alpha particles were positive. It was also common for weaker candidates to state that the decay was beta-minus, perhaps confusing this question with part **(b)(ii)**.

PHYSICS

Paper 9702/23
AS Level Structured Questions

Key messages

Candidates should be advised to read the whole question carefully before attempting to answer any part.

Candidates should be encouraged to show their working clearly in calculations. This is particularly essential where candidates make an error and arrive at the incorrect answer, as partial credit can be awarded for the working.

Candidates should know the definitions required in the syllabus.

Candidates should be familiar with the basic relationships between quantities in electrical circuitry.

General comments

Most candidates answered questions involving the recall and use of formulae well. Definitions were only well known by the stronger candidates. The weaker candidates either missed out key words or used wording which changed the meaning of the definition.

There were many opportunities for the weaker candidates to show their understanding in straightforward questions, such as in **Questions 1(a)**, **2(a), 2(b)(i)** and **2(b)(ii)**, **3(c)(i)** and **3(c)(ii), 4(a)**, **4(b)(i)**, **5(a)**, **6(a)**, **6(b)(i)**, **7(a)** and **8(a)**.

There were more demanding parts in many of the questions where application of basic knowledge was required. For example: **1(b)**, **1(c)(i)** and **1(c)(ii)**, **2(b)(iii)**, **3(b)(i)** and **3(b)(ii)**, **4(b)(ii)**, **5(b)(i)** and **5(b)(ii)**, **6(b(ii)** and **6(b)(iii)** and **7(b)(iii)**.

There did not appear to be a time problem that prevented the candidates from completing the paper.

Comments on specific questions

Question 1

(a) Most of the candidates gave an acceptable definition of velocity. There were many attempts that used vague terms such as 'speed in a given direction'.

(b) A significant number of candidates were able to determine the time taken for object A to reach the ground using an equation of uniform acceleration. The stronger candidates substituted this time into an equation applied to the motion of object B to determine *h*. The weaker candidates made errors with the signs used for the velocity and acceleration of object B. A number attempted to determine the maximum height reached by object B and then determine *h.*

(c) (i) The stronger candidates recognised that the vertical component of the velocity was the same in both cases and hence the time taken to reach the ground was the same. The weaker candidates suggested that the time would be greater as the horizontal component of velocity would cause the object to take longer to fall to the ground. Some calculated the vertical component to be greater than in the first case using an incorrect equation. Some gave no explanation even though one was asked for in the question.

(ii) The stronger candidates gave answers that used energy to explain why the speed in the second case was greater than in the first case. The weaker candidates did not consider energy as asked for in the question.

Question 2

(a) Some candidates gave a correct definition of the moment of a force. A significant number omitted 'perpendicular' when describing the distance from the line of action of the force to a point or pivot. Some implied that the distance was perpendicular to the point or pivot rather than perpendicular to the line of action of the force. A small number used displacement instead of perpendicular distance and a similar number referred to momentum rather than moments. A significant number gave answers that were not related to the moment of a force.

(b) (i) The majority of candidates were able to apply the principle of moments and obtain the mass of the block. A small number made errors when calculating the perpendicular distance of the weights of blocks A and B from the pivot.

(ii) Most of the candidates started with the correct expression for the Young modulus. Many went on to calculate the cross-sectional area. A small number used the diameter as the radius when calculating the area. The main error was in selecting a value for the force applied to the wire.

(iii) The strongest candidates were able to give a correct explanation of why the strain increases in terms of a greater moment required from the wire to maintain equilibrium. The weaker candidates frequently suggested the force on the wire would be less as B had moved further away from the wire.

Question 3

(a) The proof of $P = Fv$ was only shown by the strongest candidates. A significant number were unable to show a link between work and power in terms of the force acting.

(b) (i) A large number of candidates gave the correct expression for gravitational potential energy. Only the strongest were able to show the value given for the increase in gravitational potential energy. The main difficulty appeared to be in calculating the height h when the velocity given was up the slope.

(ii) There were very few complete answers. A small number gave the power needed to overcome the resistive forces. An even smaller number included the gain in gravitational potential energy shown in the previous part.

(c) (i) This question part was challenging for most candidates.

(ii) Most of the candidates correctly stated that the power would increase due to the increase in mass.

Question 4

(a) A minority of candidates gave a statement of the principle of conservation of momentum that included all the necessary details. A significant number omitted 'the sum/total momentum before' or 'the sum/total momentum after'.

(b) (i) This part was well answered by the majority of candidates.

(ii) Most of the candidates were able to calculate the kinetic energy before and after the collision. There were a number that made arithmetic errors in their calculations. A common error was to give the percentage of energy that remained as kinetic energy as the final answer.

Question 5

(a) A small majority knew that sound waves cannot be polarised as they are longitudinal waves. A significant number did not know that only transverse waves can be polarised and that sound waves are longitudinal waves.

(b) (i) A small number of candidates knew the relationship between the intensity and the position of the transmission axis of the filter. There were some attempts to draw a sketch that showed the intensity varying from zero to a maximum I_0 twice over the 360°. The majority of sketches were inaccurate, showing maximum and minimum in the wrong places or indicating a poor $\sin^2\alpha$ shape.

(ii) This was a very challenging question. The strongest candidates obtained the correct solution. A significant number only gave the relationship between the intensity and amplitude and the intensity and the transmission angle. There were some that used 20° for the angle between the planes of polarisation of the light and the filter instead of 70°.

Question 6

(a) There were very few correct responses. The majority referred to the bending of the waves which can be associated with refraction, or the splitting of the waves into various wavelengths (colours) which is associated with dispersion.

(b) (i) There were many correct answers. Some candidates started with the correct equation and then made an arithmetic error in the calculation or substituted an incorrect value for the speed of light.

(ii) The majority of candidates gained credit for the diffraction grating equation $d\sin\theta = n\lambda$. Many candidates then used 52° instead of 26° for θ and gave the line spacing instead of the number of lines per unit length for their answer.

(iii) The strongest candidates obtained the correct answer. The majority could not equate the two different orders and wavelengths for the same angle of diffraction. Those that started with $d\sin\theta = n\lambda$ often made arithmetic errors or used incorrect values for d or θ.

Question 7

(a) Well answered by a large number of candidates. Some gave only two significant figures although the question asked for three. There were very few arithmetic errors in the calculation.

(b) (i) There were very few correct answers. Some referred to the potential difference across the balance length of the wire being equal to the e.m.f. of the cell without mentioning that the galvanometer reading was zero.

(ii) Many candidates were familiar with the potentiometer experiment and correctly determined the e.m.f. of cell X. Many weaker candidates could not relate the ratio of lengths of wire with the e.m.f.s of the cells. A few attempted to calculate the current in the wire and the resistance of the balance length of wire to calculate the p.d. across the balance length then made errors in the working.

(iii) There were a small number of correct answers. The weaker candidates stated a direction of movement for the position of the null point with no explanation. There were some answers that referred to a decrease in the current in the circuit due to the addition of a cell with internal resistance. This statement was seldom related to the change in the p.d. across the balance length or the full length of wire. The weaker candidates referred to a need to decrease the resistance of the balance length as the resistance of the circuit was increased.

Question 8

(a) Many candidates gave the correct flavours for the quarks present in an antineutron. A significant number gave incorrect charges for these flavours.

(b) A minority of candidates gave correct responses. Many confused the particle and the antiparticle or had little idea of the decay process for a neutron.

PHYSICS

Paper 9702/24
AS Level Structured Questions

Key messages

Candidates should read the whole question carefully before attempting to answer any part.

Candidates are encouraged to show their working clearly in calculations. This is particularly essential where candidates make an error and arrive at the incorrect answer, as partial credit can be awarded for the working.

Candidates should learn definitions as required on the syllabus.

Candidates should be familiar with the basic relationships between quantities in electrical circuitry.

General comments

Most candidates answered questions involving the recall and use of formulae well. Definitions were well known by the strongest candidates. The weaker candidates either missed out key words or used wording which changed the meaning of the definition.

There were many opportunities for the weaker candidates to show their understanding in straightforward questions, such as **Questions 1(a)** and **1(b)(iii)**, **2(a), 2(b)** and **2(c)**, **3(a)**, **3(b)**, **3(c)**, **3(e)(i)** and **3(e)(ii), 4(a)(i)**, **4(b)(i)** and **4(b)(ii)**, **5(b)(i)** and **5(b)(ii)**, **7(a)**, **7(b)** and **7(c)**.

There are more demanding parts in many of the questions where application of basic knowledge is required, for example **1(b)(ii)**, **2(d)**, **2(e)** and **2(f)**, **3(d)**, **4(a)(ii)**, **4(b)(iii)** and **4(b)(iv)**, **5(a)(ii)** and **6**.

There did not appear to be a time problem that prevented the candidates completing the paper.

Comments on specific questions

Question 1

(a) The majority of candidates gave a satisfactory definition of the moment of a force. A significant number omitted ‘perpendicular’ when describing the distance from the line of action of the force to a point or pivot. Some implied that the distance was perpendicular to the point or pivot rather than perpendicular to the line of action of the force. A small number used displacement instead of perpendicular distance and a similar number referred to momentum rather than moments.

(b) (i) A minority of candidates gave a statement of the principle of moments that included all the necessary details. A significant number omitted ‘the sum of’ the clockwise moments or ‘the sum of’ the anticlockwise moments. A similar number omitted that the moments were to be taken about ‘the same point or pivot’. A large number omitted the condition that the object must be in equilibrium for the principle to apply. A number included a condition of the system being isolated or closed for the principle to apply which is not relevant.

(ii) A large majority of candidates gave the correct component of weight. A significant minority calculated the component parallel to the slope.

(iii) This part was answered well. Most candidates obtained an answer for the force by applying the principle of moments correctly.

Question 2

(a) The majority of candidates gave the definition of momentum. A small number gave incorrect expressions such as force × time which is change in momentum, mass × change in velocity or mass × speed.

(b) Well answered by the majority of candidates. A small number misread the graph or made errors in their calculation by not taking the momentum at a time of 12.0 s as <u>negative</u> 1.4 kg m s^{-1}.

(c) Well answered by the majority of candidates. A significant number recognised the connection between the gradient of the graph and the force. The weaker candidates started with p/t rather than $\Delta p/\Delta t$ or attempted to use $F = ma$ without success.

(d) Only a small number of candidates gave a sufficiently detailed answer. Many referred to a deceleration without a clear link to the variation in the speed or described a decrease in speed without noting that it was a <u>uniform</u> decrease.

(e) The stronger candidates were able to explain that the force could not be air resistance, as the force shown by the graph was constant while the speed of the object was decreasing. A very small number stated that the force was not zero when the speed was zero. Only a minority of candidates stated that the force shown by the graph was constant.

(f) The stronger candidates were able to demonstrate their understanding and drew an appropriate curve. The weaker candidates drew straight lines as if the object was travelling at a constant speed. Some did not start their lines at the origin and some showed the object having an increased displacement after 8.0 s.

Question 3

(a) Well answered by the majority of candidates.

(b) Well answered by the majority of candidates. The working was required and very few candidates were unable to show the link between the compression and the change in gravitational potential energy.

(c) Well answered by most candidates. A significant number showed no working even though this was asked for in the question.

(d) Well answered by the majority of candidates. There were many well-presented answers using the equation $E = ½kx$. A minority of answers used $E = Fx$ and then without explanation doubled their answer to get the required force of 700 N.

(e) (i) The stronger candidates realised that the force from the spring on the block and the weight of the block acted in opposite directions and gave the correct resultant force. A significant number added the weight to the force from the spring. These candidates gained credit if they showed the working for calculating the weight of the block.

(ii) Well answered by the majority of candidates. Most were able to quote $F = ma$ and use their answer from **e(i)**.

Question 4

(a) (i) The idea of the transfer of energy by waves was described by the stronger candidates. The weaker candidates described the oscillations in transverse or longitudinal waves without mentioning energy.

(ii) A minority of candidates gave correct answers for both the distance and the time in terms of the given quantities.

(iii) Correct answers were given by a small minority of candidates who obtained the expression for the speed of the wave.

(b) (i) Generally well answered by most candidates. The majority of errors were power-of-ten errors. One was converting cm into m for the wavelength, the other when converting the frequency in Hz to GHz.

(ii) Well answered by the majority of candidates.

(iii) Correct answers were given by a small minority of candidates. The majority did not state the correct intensity at Q. Very few were able to give explanations in terms of path difference and phase difference for the two waves coming from sources X and Y. A significant number stated the quantities such as amplitude, intensity and path difference as quantities that could be deduced without providing an explanation. Many attempted to use $I \propto A^2$ which was not relevant here. There were many references to destructive interference. Candidates then needed to develop the explanation in terms of phase difference.

(iv) There were very few correct answers. A significant number did not state that at the starting point P there was a maximum. Many candidates referred only to intensity. Only the strongest candidates realised that there would be more than one minimum between P and Q. A large majority described the amplitude as decreasing or increasing and not that there was a minimum or maximum.

Question 5

(a) (i) Very few candidates described the resistance decreasing due to a decrease in temperature. The question asked for an explanation and many did not provide one. The weaker candidates used $V = IR$ and suggested R was $\propto 1/I$ and therefore increased.

(ii) A significant number knew the correct shape of the graph. A number only gave a sketch in the first quadrant and some had the curve increasing in gradient from the origin. A common error was to draw the curve horizontal at the end or to take the curve below the horizontal with a negative gradient.

(b) (i) Well answered by the majority of candidates. A small number calculated the correct value for the potential difference across a lamp, then doubled their answer when giving *E*. This was most likely due to incorrectly interpreting the lamps to be in series and not in parallel.

(ii) Well answered by the majority of candidates. A common error was to use an incorrect current value for lamp B such as 3.3 A or 1.5 A. A few did not subtract 1.5 from 3.3 and others did not insert a correct value for the charge (e).

Question 6

(a) The majority of candidates were able to calculate the circuit current. A significant number then incorrectly used the p.d. of 6.0 V (across the battery) or 2.4 V (the p.d. across the wire) for the p.d. across the resistor *R*. The stronger candidates tended to use the ratio of potential differences to the ratio of resistances, as the current was constant through the series circuit.

(b) The stronger candidates were able to give the equations that linked the potential difference across the wire with the resistance of the wire and then the resistance of the wire with the length of wire. A small number gave the explanation required. Many answers merely stated that as the length increased the resistance increased and therefore the p.d. increased.

(c) (i) Many candidates realised that the p.d. across XP was equal to the e.m.f. *E* of the cell. A significant number gave the correct ratio of lengths for the wire. The ratio of the p.d.s did not match the ratio of the lengths in many solutions. The p.d. across the wire XY was often given as 6.0 V (the p.d. across the battery). Some correctly calculated the resistance of XP, then used an incorrect resistance or p.d. for wire XY.

(ii) There were many correct answers. The weaker candidates stated a direction of movement for the position P with no explanation. There were many answers that referred to an increase in current in the circuit due to the decrease in the value of resistor R. This statement was seldom related to the change in the p.d. across XP or XY. The weaker candidates referred to a need to increase the resistance of XP as the resistance R was decreased.

Question 7

(a) Well answered by a large number of candidates. Some answers were given as symbols and these were not awarded credit as the question asks for the names of leptons.

(b) The majority of candidates gave the two correct answers. A significant number only gave one response or combinations of incorrect responses.

(c) Most candidates gave the correct quark composition of the proton. Some omitted the value of e in the charge given for each quark.

PHYSICS

Paper 9702/31
Advanced Practical Skills 1

Key messages

- Measurements should always be recorded to the precision of the measuring device. Candidates should consider carefully whether it would be advantageous to repeat their measurements.
- In the table work, the number of significant figures in the calculated quantity should relate to the number of significant figures in the raw data with the least number of significant figures. Each calculated quantity should be checked row by row. It is unnecessary, and often incorrect, to force the number of significant figures to be constant down a column of calculated values.
- When plotting graphs, candidates should carefully consider the selection of consistent and regular numerical scales for the graph axes. Many candidates would benefit from more practice in the drawing of lines of best fit.
- To be successful answering **Question 2**, candidates should be reminded that their identified limitations and suggestions for improvement must be focused on the particular experiment being carried out. General points such as 'measurements were difficult' or 'use more precise measuring instruments' will not usually gain credit without further detail.

General comments

Most centres did not have difficulties in providing the equipment requested for both experiments. In **Question 1** there was some variation in the smallest masses that were able to be provided to candidates. Where a supervisor's report and sample results were supplied, these variations were accommodated within the marking process to allow all candidates fair access to credit for this part of the experiment.

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 on the paper was good, and there were many excellent scripts. The candidates did not seem to be short of time and both questions were attempted in full by almost all candidates.

Candidates could improve in three main areas:
- giving due consideration to the nature of an experiment to decide whether repeated readings for measurements should be taken, e.g. those related to manual use of a stopwatch
- recording the data in the table in **Question 1** more tidily and clearly
- being more specific about how their suggested limitations and improvements at the end of **Question 2** relate to the relevant quantity needing to be measured in the experiment.

Comments on specific questions

Question 1

(a) Most candidates had an appropriate value for n_0 within the range required.

(b) Most candidates obtained values of n and N appropriately.

(c) Most candidates were able to collect five sets of values of *M* and *n* without assistance from the supervisor and obtained the correct trend. Some candidates misread the instructions and recorded values of (*M* + mass of S) which, in most cases, meant they went on to plot the incorrect graph. A few candidates confused *N* and *n* and so again went on to plot an incorrect graph.

Many candidates did not extend their range to a low enough and/or high enough value of *M*. Candidates are expected to always use the whole range of data values available to them. There is no requirement for the independent variable to be evenly spaced.

Many candidates gave both the quantity and the correct unit for each heading in the table. Some candidates attempted to give 'units' such as $(n_0 - n)$ in the heading for *n* and/or *N* and this could not be awarded credit for a correct column heading.

The calculation of N^3 was largely completed well and many candidates correctly wrote their values correctly to three significant figures as required in the question. Some candidates seemed confused between decimal places and significant figures, and this resulted in an inconsistent number of significant figures.

Overall, the table work was done well by candidates. Candidates are encouraged to take the time to construct a clear, well laid-out table in which to enter their data.

(d) (i) The majority of the candidates plotted the correct graph, labelling axes with the correct quantities and using sensible and regular scales such that all the data occupy over half the graph grid available. Plotting and reading off points is then an easy task for them to carry out. Awkward or irregular scales (including, in a few cases, the use of fractions) were the main reason for not awarding credit for the axes and these errors often led candidates to give incorrect read-offs from their line of best fit due to difficulty in processing from a non-regular scale. Candidates should be advised that trying to fit the range of their data values *exactly* to the 12 by 6 squares of the graph paper almost always leads to awkward scales that are impossible to work with.

Many points were drawn as neat crosses such that the centre was no more than half a square thick, and were plotted correctly so that the position is within half a small square in both the *x* and *y* directions. Candidates are reminded that any point whose diameter is greater than half a small square will not be given credit. Candidates are encouraged to use a sharpened pencil for the graph work and to produce clear, well-defined crosses to identify the location of their plotted points.

(ii) Candidates found it difficult to draw a line of best fit. Common reasons for not awarding credit included lines needing a rotation or a shift to get a better fit and lines with kinks or joins or that have been drawn with a damaged straight edge. Candidates are reminded that care should be taken when drawing the line of best fit in order to get an even distribution of points about the line. Many candidates try to draw a line that passes through as many plotted points as possible without giving due regard to the overall distribution of points on their graph.

Candidates are encouraged not to have anomalies. If a point is anomalous on the graph, candidates are encouraged to check the plotting first, then check their reading with the equipment available. If there is still an anomalous point, then this can be identified by ringing or labelling that point as 'anomalous'.

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

Common mistakes with the gradient were using too small a gradient triangle, substitution into $\Delta x / \Delta y$, values incorrectly read off and points used from the table which were not on the line of best fit. For the *y*-intercept, common mistakes were reading the *y*-intercept from the graph when there was a false origin and substitution into a wrongly arranged equation e.g. $c = y / mx$.

(e) The majority of the candidates correctly identified *P* as being the gradient and *Q* as the *y*-intercept. Some candidates omitted the unit for *P* or gave an incorrect unit such as g rather than g^{-1}.

Question 2

(a) The majority of the candidates correctly used repeated readings to obtain final values for *d*. A relatively common error was inconsistency of precision in the measurements given, and it was not uncommon to see data recorded such as 5.9, 6, 6.1. Candidates are reminded to ensure they maintain appropriate precision in measured quantities in accordance with the equipment being used.

(b) (i) The majority of the candidates correctly measured a value of T_A that was in the accepted range. A number of candidates did not repeat their readings.

(ii) Many candidates did not use a value of absolute uncertainty that took into account the nature of the experiment and that factors beyond stopwatch precision and human reaction time needed to be considered. Those who showed repeated readings for T_A often correctly used a half-range calculation, although some candidates incorrectly used the whole range as the uncertainty.

(c) (i) Most candidates were awarded credit.

(ii) Although the calculation for *W* was usually done correctly, some candidates inappropriately included a unit (often seconds) for what should be a dimensionless quantity.

(iii) Many candidates answered this question well and referred specifically to the quantities of raw data involved. Weaker candidates often referred simply to ‘raw data’ or ‘raw values’ or discussed decimal places rather than significant figures and were not awarded credit.

(d) The majority of candidates successfully repeated the experiment and obtained second values of *d*, T_A, T_B and *w* that followed the expected trend.

(e) Many candidates correctly calculated two values of *k* for their two sets of data, showing their working clearly. Weaker candidates rearranged the equation incorrectly (e.g. using $k = d / W^2$) and so obtained an incorrect value for *k*. A minority of candidates incorrectly stated their values of *k* to only one significant figure.

(f) Stronger candidates successfully carried out the three (standard) required steps for this question, correctly calculating the percentage difference between their values of *k*, comparing it against the stated 20% criterion and providing a valid statement of conclusion for supporting or not supporting the relationship.

Some candidates omitted a percentage difference calculation, made a comparison with a different criterion (e.g. 10%, 15% or the uncertainty from **(b)(ii)**) or gave a statement that was inconsistent with their findings. Some candidates also confused ‘percentage difference’ with ‘percentage uncertainty’ meaning their conclusion was unclear. A minority of candidates attempted to calculate their own percentage uncertainty using estimates of, for example, the uncertainty in T_A and T_B and so were not awarded credit.

(g) (i) Candidates are encouraged to identify difficulties associated with setting up and obtaining specific readings. They can do this by writing about the different measurements taken or chronologically and systematically going through the experiment. Candidates should explain clearly what the difficulties are and then suggest corresponding solutions that address each difficulty. Candidates should then try to think of solutions that address each problem.

Credit is awarded in this question for specifying the nature of the problem and giving a reason for it. Candidates are encouraged to use expressions such as ‘difficult to measure *T* <u>because</u> the stopwatch has to be started at the same time as placing the paper on the water’.

(ii) An improvement that was commonly seen was ‘take more readings and plot a graph’. In general, candidates are encouraged to explain *how* a problem will be solved, detailing what additional equipment is necessary. It is often helpful for candidates to think about which quantity they are referencing their improvement to <u>and</u> the nature of that improvement.

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

PHYSICS

Paper 9702/32
Advanced Practical Skills 2

Key messages

- Measurements should always be recorded to the precision of the measuring device. Candidates should consider carefully whether it would be advantageous to repeat their measurements.
- In the table work, the number of significant figures in the calculated quantity should relate to the number of significant figures in the raw data with the least number of significant figures. Each calculated quantity should be checked row by row. It is unnecessary, and often incorrect, to force the number of significant figures to be constant down a column of calculated values.
- When plotting graphs, candidates should carefully consider the selection of consistent and regular numerical scales for the graph axes. Many candidates would benefit from more practice in the drawing of lines of best fit.
- To be successful answering **Question 2**, candidates should be reminded that their identified limitations and suggestions for improvement must be focused on the particular experiment being carried out. General points such as ‘measurements were difficult’ or ‘use more precise measuring instruments’ will not usually gain credit without further detail.

General comments

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

Candidates in some centres experienced difficulties in gaining the expected measurements from their apparatus. If this occurs, centres should provide a description of the difficulties encountered, and any mitigating steps they might have taken, in the supervisor’s report, so that this can be taken into account during marking.

Some candidates would benefit from further understanding of the importance of a relevant unit to go with a numerical value. At the simplest level, this was shown in the omission of units for **Question 1(a)**, in column headings in the table in **Question 1(b)**, and in different parts of **Question 2**. Some candidates did not appreciate the significance of prefixes such as ‘milli-’. In **Question 1(a)**, for example, a unit of ampere suggested a candidate did not appreciate the small magnitude of the current flowing or that the candidate did not understand the use of prefixes for units. In **Question 2(b)(i)** a unit of centimetres suggested a candidate did not appreciate the small value of the diameter being measured.

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

Comments on specific questions

Question 1

(a) Most candidates were able to record a value of x within the range expected by the mark scheme, with an appropriate unit. Nearly all candidates were able to record a non-zero numerical value for I.

Some candidates could improve by providing a unit for current with an appropriate prefix, e.g. mA for milliampere rather than A for ampere. Responses that gave a value for I outside the expected range nearly all gave A as the unit when the numerical values were likely to have been mA.

(b) Many candidates used a wide enough range of *x* values to gain credit for the range of values. A number of candidates did not use a sufficiently high value of *x* at the top end of their range of values, and this was the most common reason for not gaining credit. In this paper, a range of values of *x* was indicated in the question, and candidates should be encouraged to use the maximum and minimum values stated when this is the case.

Most candidates were able to present their values of *x* to the correct precision. Candidates who did not gain credit generally did so because they presented values of *x* only to the nearest cm rather than to the nearest 0.1 cm. Occasionally candidates gave values to the nearest 0.01 cm or adjusted their values to ensure the same number of significant figures for their *x* values rather than the same precision (same number of decimal places). Candidates should be encouraged to recognise that, for measured values, it is the precision (number of decimal places) that needs to be presented consistently.

Many candidates were able to gain credit for the column headings, with the most common reasons for not gaining credit being the omission a unit for $\sqrt{I}$ or giving the unit as A or mA.

The majority of the candidates were able to record values of *x* and I that followed the expected trend. At large values of *x* (and so small values of I), candidates sometimes found it difficult to achieve reliable values of I.

Most candidates were able to calculate correct numerical values for $\sqrt{I}$ and to give their values to an appropriate number of significant figures. Occasionally, candidates incorrectly or inappropriately rounded their numerical answers and were not able to gain credit for one or other of these marking points.

(c) (i) The expected range of values of *x* meant that the majority of the candidates chose sensible scales for the axes of their graphs, with a 2 cm to one large square scale on the *x*-axis typical of most responses. Some candidates chose a scale based on multiples of 3 and so were not able to gain credit. Candidates generally understood the expectation that they should place regularly spaced numerical labels at least every 2 cm (1 large square) on the axes of their graph. Where an interval of 4 cm (two large squares) between scale markings occurred, it was usually on the $\sqrt{I}$ axis.

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 and to use either clear crosses or points that are smaller than half a small square.

Many candidates were able to gain credit for the quality of their data.

(ii) Candidates' data very often produced a slightly curved trend in their plotted points. The extent of this curvature was less when the data gained was of good quality. Most candidates correctly attempted to draw a straight line through their data. The stronger candidates were able to draw a line that showed a balanced distribution of points either side of the line along the entire length. A common reason for not awarding credit was a line that needed a rotation to get a better fit. Candidates who draw a line joining the top and bottom points on their grid are very unlikely to draw the line of best fit and therefore are likely not to gain credit.

For many candidates, one point on their graph may have appeared anomalous compared with other points, perhaps because it was off trend compared to the other points. If this occurs, candidates are encouraged to check their readings for this point. If they still have one anomalous point, they can identify the point as such by ringing it or stating the point as 'anomalous'. This allows the candidate to then use the remaining points (usually five) to draw their line.

(iii) Many candidates were able to successfully use read-offs from points on their drawn lines to calculate a gradient value. A small number of candidates omitted the negative sign from their gradient value, and so were not able to gain credit. Candidates who used points from their table usually did not gain credit as one or other of the points did not lie on their drawn line. A small number of candidates chose points from their line that were closer together than half the length of the line, and these candidates also did not gain credit.

Candidates who calculated their intercept value by substituting a read-off into $y = mx + c$ or a similar expression were generally able to gain credit. Many candidates who determined the intercept by reading off the intercept on their $\sqrt{I}$ axis did not gain credit because their graph showed a false origin (i.e. not $x = 0$).

(d) The majority of the candidates were able to correctly transfer their gradient and intercept values from **(c)(iii)** to the values of *a* and *b*. A small number of candidates calculated new values of *a* and *b* different from those in **(c)(iii)**, and these candidates were not able to gain credit. Candidates who presented one or other of their two values to only one significant figure were also unable to gain credit.

Many candidates found it difficult to give correct units. This occurred mostly when the unit for $\sqrt{I}$ in the candidate's table and on the graph axis was given as A or mA, with this unit being carried through to the units for *a* and *b*. When candidates did provide a unit of, for example, $mA^{1/2}\,cm^{-1}$ for their value of *a*, it was expected that this unit be consistent with the unit used for their table or graph axes.

Question 2

(a) (i) Most candidates were able to record a value for *B* that was within the range expected by the mark scheme. Many of these candidates recognised that a value recorded to the nearest mm was expected from the use of a rule with mm markings. Most responses that did not gain credit presented a value of *B* only to the nearest cm.

(ii) The strongest candidates used an appropriate absolute uncertainty of 2–5 mm to correctly calculate the percentage uncertainty. Many candidates used unrealistically small values for the absolute uncertainty, often appearing to use the smallest scale division (or half the smallest scale division) on the rule as their value for the absolute uncertainty. Candidates who gained credit here appeared to be candidates with practical experience who had a good sense of a realistic value for absolute uncertainty. A small number of candidates calculated half the difference between maximum and minimum repeated values *B* to use as their absolute uncertainty, and this was also accepted.

(b) (i) Most candidates were able to record a value of *d* that was within the range expected by the mark scheme. Candidates were expected to use calipers to record this value, and therefore to record it to the nearest 0.1 mm (if using vernier calipers) or to the nearest 0.01 mm if using digital calipers capable of that precision. Centres should allow candidates to gain experience of using calipers during their course. Occasionally a candidate provided a clearly incorrect unit such as cm with their numerical answer.

(ii) Almost all candidates were able to record a value of *L* in the range expected by the mark scheme. A small number of candidates did not give a unit with their value, and so were not able to gain credit.

(iii) A significant number of candidates experienced difficulty in achieving rotational oscillations that could be used successfully to determine the time period. Candidates should measure the time for several oscillations, and then repeat that measurement an appropriate number of times. Typically, a minimum of five oscillations is expected, but in this experiment (in which the rotational oscillations decayed quickly) a minimum of two oscillations was accepted.

(c) The majority of the candidates were able to record values that gained credit.

(d) (i) Many candidates were able to correctly calculate two values of *k*. A significant number of candidates rounded their values of *k* to two or three significant figures, and this was acceptable.

Some weaker candidates in effect calculated values of 1 / *k* as a result of a mistake in rearranging their formula. Candidates who substituted their numerical values into an expression that had already been rearranged to make *k* the subject were less likely to have made a mistake in rearranging the formula. Candidates whose substitution involved writing *k* multiplied by their value of T^2 on the left-hand side before calculating intermediate values for the right-hand side of the expression appeared more prone to rearrangement or calculational errors.

Candidates should be encouraged to substitute values into a formula after rearranging it, or to rearrange their substituted numerical values before carrying out intermediate steps of a calculation.

(ii) Nearly all the candidates who gained credit in this question did so by quoting a number of significant figures for each of *B, L, d* and *T*, and then identifying the appropriate number of significant figures for the values of *k*. Candidates need to recognise that their justification of the number of significant figures in *k* must refer to the significant figures in all of the quantities used in the calculation of *k*, identifying each of those quantities explicitly. A number of candidates referred only to the significant figures in one or two of the quantities involved, and so were not able to gain credit. Generalised references to choosing a number of significant figures for 'accuracy', or generalised references to the significant figures of the 'quantities used in the calculation' will not gain credit.

(e) Many candidates were able to calculate a percentage difference between the two values of *k* and compare it to the 20% criterion given in the question, with a correct conclusion being drawn. Some candidates adopted a process of estimating a percentage uncertainty in each of the quantities *B*, *L*, *d* and *T* and then using those individual uncertainties to determine an uncertainty in *k*. This approach is not able to gain credit because it does not use the given value of 20%. A small number of candidates used a different percentage criterion, usually one of their own choosing such as 10%, and these candidates were also not able to gain credit. A small number of weaker candidates appeared to understand the criterion as requiring a percentage difference equal to 20% (rather than less than or equal to 20%) and so incorrectly stated that the relationship was not supported when their calculated value of the percentage difference was less than 20%.

The syllabus indicates the expectations for responding to this question: the calculation of a percentage difference, the comparison of that difference to the given suggested uncertainty value, and the statement of a conclusion consistent with the comparison. In order to gain credit, candidates' responses need to include all three of these elements.

(f) (i) Many candidates stated limitations in an incomplete way, either stating the difficulty without giving a reason, or stating a reason without identifying the quantity involved. 'Difficult to measure *L*' (without saying why) is an example of the first type of problem, and 'difficult to tell when an oscillation starts or ends' (without mentioning *T*) is an example of the second type. Candidates can be encouraged to look at each of the quantities used in the calculation of *k* to identify possible sources of uncertainty or limitation. Candidates should be encouraged to read the stem of this question carefully, as it states that they 'should state the quantity being measured and a reason for the uncertainty'.

Candidates should be encouraged to think in terms of how the start and end point of oscillations can be judged. Responses that refer to just 'reaction time' as a reason for inaccuracy in time values are unlikely to gain credit.

Some candidates made only very general suggestions of limitations, such as 'inaccurate to use a metre rule to measure *B*' or 'air conditioning affects oscillations', and these were not able to gain credit. Candidates should be aware that they need to describe uncertainties and limitations that arise from the specific experiment being carried out. Difficulties such as wind from open windows or cooling fans and generalised references to inaccurate equipment are unlikely to gain credit.

(ii) Candidates who achieved high marks in this question appeared to be familiar with previous experiments and had good practical experience.

Many candidates considered the collection of more sets of data. To gain credit, such responses need to link the collection of more sets of data to the plotting of a graph or to the comparison of several *k* values to each other. Responses such as 'take more measurements and find an average' are not able to gain credit, as this is something that candidates could have done when carrying out the experiment.

Candidates who attempted to describe an improved method to measure *B* needed to describe carefully how they took account of the width of the masses in their measurement. Candidates could gain credit by describing, for example, the subtraction of the thickness of the mass from a measurement made to the outside edges of both masses. Responses such as ‘mark the centres of the masses’ without an explanation of how that is to be achieved were not able to gain credit.

Responses that referred to the use of a fiducial marker to improve the measurement of *T* needed to carefully describe the positioning of the marker at the midpoint of the oscillations in order to gain credit. Responses such as ‘use a fiducial marker’ without further detail, or responses that described a marker being placed at the end of the oscillations, were not able to gain credit.

PHYSICS

Paper 9702/33
Advanced Practical Skills 1

Key messages

- Measurements should always be recorded to the precision of the measuring device. Candidates should consider carefully whether it would be advantageous to repeat their measurements.

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

- When plotting graphs, candidates should carefully consider the selection of consistent and regular numerical scales for the graph axes. Many candidates would benefit from more practice in the drawing of lines of best fit.

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

General comments

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

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

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

Comments on specific questions

Question 1

(a) Most candidates stated E with a unit and to the nearest 0.001 V.

(b) Most candidates stated L in the accepted range and with an appropriate unit, and gave a value of that was V smaller than E.

(c) Many candidates were able to collect six sets of values of L and V without assistance from the Supervisor and with the correct trend.

Some candidates did not state their values of L to the nearest mm when the ruler used can be read to the nearest mm. These candidates often stated values only to the nearest cm instead.

Many candidates did not extend their range of values of *L* low enough or high enough. Candidates are encouraged to use the whole range available to them. There was no penalty for candidates who ignored the instruction to increase *L* from the initial value of around 30.0 cm, but their graphs often showed a curved trend and this made it more difficult to draw the straight line of best fit.

Many candidates gave both the quantity and correct unit for each heading, separated by a solidus or with brackets around the unit. Candidates are encouraged to remember a separating mark between the quantity and unit. Some candidates omitted the unit for $(E – V) / L$ or gave cm^{-1} instead of $V\,cm^{-1}$.

Many candidates correctly stated their calculated values of $(E – V) / L$ to three or four significant figures. Candidates are encouraged not to truncate the values and to round their answers accordingly.

(d) (i) Stronger candidates plotted the correct graph with quantities labelled, and chose sensible and regular scales such that all the data occupied over half the graph grid available. Awkward or irregular scales were a common reason for not awarding credit for the axes. This was especially the case when there was a change in the power of ten along the scale, e.g. 0.094, 0.096, 0.098, 0.100, 0.12, 0.14.

Many points were drawn as neat crosses such that the centre was no more than half a square thick and were plotted correctly so that the position is within half a small square in both the *x* and *y* direction. 'Blobs' (diameter greater than half a small square) and points plotted more than half a square out from the correct position were often the reasons for credit not being awarded.

(ii) Stronger candidates were able to draw carefully a considered line of best fit that had a balanced distribution of points either side of the line along the entire length. Many lines needed to be rotated or shifted to get a better fit, and some lines were kinked, i.e. not drawn as a single straight line.

Candidates are encouraged not to have anomalies. If a point is anomalous on the graph, candidates should check the plotting first, then check their reading with the equipment available. If there is still an anomalous point, then this can be identified by ringing or labelling.

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

Common mistakes with the gradient were using too small a gradient triangle, substitution into $\Delta x / \Delta y$, values incorrectly read off and points used from the table which were not on the line of best fit. For the *y*-intercept, common mistakes were reading the *y*-intercept from the graph when there was a false origin and substitution into a wrongly arranged equation e.g. $c = y / mx$.

(e) Candidates needed to recognise that *P* and *Q* were equal to the gradient and the negative of the *y*-intercept respectively and give correct units consistent with those used in the experiment. Some candidates omitted units or occasionally used different units to those used in the experiment.

(f) Candidates found it difficult to place line W so that it had a steeper gradient to reflect a larger value of $(E – V) / L$ for any value of *V* (consistent with a lower resistance in the circuit). The line W also needed to be placed to the left of the original line to reflect that the intercept would be the same had the true origin been drawn. Many candidates placed parallel or shallower lines to the right of the line of best fit. Some candidates did not attempt this question.

Question 2

(a) (i) Most candidates measured values of *d* to the nearest mm and in the accepted range.

(ii) Some candidates, having repeated their readings, correctly showed the uncertainty as half the range and then calculated the percentage uncertainty using the correct method. Others correctly made a sensible estimate of the uncertainty in *d*, considering the awkward nature of this reading. Many candidates incorrectly stated the absolute uncertainty as the smallest reading on the ruler (i.e. 1 mm) without considering the difficulty in the reading owing to parallax error and the inconsistent diameter of the modelling clay 'sphere'.

(b) (i) Many candidates stated *x* in the accepted range and to the nearest mm. Some candidates stated their measurement to the nearest cm instead.

(ii) Many candidates calculated *N* correctly. Some rounded their value incorrectly or stated it to a number of significant figures other than the three that were asked for in the question.

(c) Many candidates were able to repeat at least two sets of at least 5 oscillations and give a final value in the accepted range and with a unit. Common mistakes were to incorrectly work out the frequency rather than the period, taking only one measurement, omitting to divide the final answer by the number of repeats, or omitting units.

(d) The majority of the candidates stated a second value of *d* and *x* with the second value of *T* smaller than the first value.

(e) (i) Many candidates were able to calculate *k* for the two sets of data, showing their working clearly. A few candidates incorrectly stated their values to one significant figure.

(ii) Many 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 time, *d* and *x*. Common reasons for not awarding credit were stating 'raw readings', 'previous measurements' or 'values used in calculation' without detailing the quantities involved, or only mentioning the quantity deemed to have the least number of significant figures.

(f) Some candidates calculated the percentage difference between their values of *k*, testing it against the stated 15% criterion and providing a valid statement of conclusion. Some candidates omitted a percentage difference calculation, gave a different criterion of their own choosing (e.g. 10% or 20%), or gave an invalid statement inconsistent with their findings.

(g) (i) Candidates are encouraged to identify difficulties associated with setting up and obtaining specific readings. They can do this by writing about the different measurements taken or chronologically and systematically going through the experiment. Candidates should explain clearly what the difficulties are and then suggest corresponding solutions that address each difficulty. Candidates should then try to think of solutions that address each problem.

Problems commonly awarded credit were 'two sets of data were not enough to draw a valid conclusion', 'difficult to measure *d* as there is parallax error', 'difficult to measure time as hard to judge the end of the oscillation' and 'difficult to roll the ball into a perfect sphere'.

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

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

PHYSICS

Paper 9702/34
Advanced Practical Skills 2

Key messages

- Measurements should always be recorded to the precision of the measuring device. Candidates should consider carefully whether it would be advantageous to repeat their measurements.

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

- When plotting graphs, candidates should carefully consider the selection of consistent and regular numerical scales for the graph axes. Many candidates would benefit from more practice in the drawing of lines of best fit.

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

General comments

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

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

The general standard of the work done by the candidates was good, and there were many excellent scripts. Candidates did not seem to be short of time and both questions were attempted by almost all the candidates. They demonstrated good skills in the generation and handling of data and in describing experimental improvements in **Question 2**, but can improve by giving more thought to expressing clearly the limitations of the experiment.

Comments on specific questions

Question 1

(a) (i) Most candidates stated values of L_1 and L_2 with units and with L_2 in the range 15.0–18.0 cm. Some candidates mixed up their values of L_1 and L_2 and might have benefited from reading the instructions in the question paper more carefully.

(ii) Most candidates stated T in the accepted range and with an appropriate unit. Some candidates had a final value of T outside the accepted range because the final value they gave was actually nT rather than T.

Many candidates took repeated readings of nT with $n \geq 5$. Some candidates may have recorded nT but could not be given credit because the value of n was neither stated nor evidenced in the working.

(b) Many candidates were able to collect six sets of values of L_1, L_2 and T without assistance from the supervisor and with the correct trend. Some candidates did not follow instructions, resulting in L_1 or L_2 values that did not change. The resulting data then did not show the correct trend.

Some candidates included a value of $L_2 \leq 6.0$ cm, but many did not use the full range of L_2 values that the apparatus allowed. Candidates should be encouraged to make best use of the apparatus given.

Many candidates gave both the quantity and a correct unit for each heading, separated by a solidus or with brackets around the unit. Candidates are encouraged to remember to include the separating mark between the quantity and unit. The most common error seen was an incorrect or omitted unit for $\sqrt{L_1} + \sqrt{L_2}$.

Most candidates stated values of L_1 and L_2 to the nearest mm. Some candidates were not awarded credit because they attempted to maintain the number of significant figures rather than recording values to the precision of the measuring instrument. A common situation was where one value had been recorded to three significant figures (e.g. 10.3 cm) and the next (e.g. 9.4 cm) should be two significant figures but was erroneously recorded to three significant figures as 9.40 cm.

Most candidates followed the instruction in the question and stated all values of $\sqrt{L_1} + \sqrt{L_2}$ to three significant figures. Some candidates did not follow this instruction and instead followed the significant figures in their values of L_1 or L_2, and this resulted in the inclusion of values with an incorrect number of significant figures.

Most candidates were able to correctly calculate values of $\sqrt{L_1} + \sqrt{L_2}$. Some candidates made rounding errors or incorrectly added L_1 and L_2 before taking the square root.

(c) (i) Stronger candidates plotted the correct graph with quantities labelled, and with sensible and regular scales such that all the data occupied over half the graph grid available. Awkward or irregular scales were common reasons for not awarding credit. This was especially the case when there was a change in the power of ten along the scale, e.g. 0.094, 0.096, 0.098, 0.100, 0.12, 0.14.

Many points were drawn as neat crosses such that the centre was no more than half a square thick and were plotted correctly so that the position was within half a small square in both the x and y directions. 'Blobs' (diameter greater than half a small square) and points plotted more than half a square out from the correct position were often the reasons for credit not being awarded.

Most candidates collected data that allowed a straight line to be drawn that was within ± 0.5 $cm^{1/2}$ of all plotted points in the $\sqrt{L_1} + \sqrt{L_2}$ direction.

(ii) Stronger candidates were able to draw carefully a considered line of best fit that had a balanced distribution of points either side of the line along the entire length. Many lines needed to be rotated or shifted to get a better fit, and some lines were kinked, i.e. not drawn as a single straight line.

Candidates are encouraged not to have anomalies. If a point is anomalous on the graph, candidates should check the plotting first, then check their reading with the equipment available. If there is still an anomalous point, then this can be identified by ringing or labelling.

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

Common mistakes with the gradient were using too small a gradient triangle, substitution into $\Delta x / \Delta y$, values incorrectly read off and points used from the table which were not on the line of best fit. For the y-intercept, common mistakes were reading the y-intercept from the graph when there was a false origin and substitution into a wrongly arranged equation e.g. $c = y / mx$.

(d) Most candidates recognised that *a* and *b* were equal to the gradient and *y*-intercept respectively. A common reason for credit not being awarded was the presentation of values as fractions or to only one significant figure. Although most candidates plotted graphs with the correct axes (*T* on the *y*-axis and $\sqrt{L_1} + \sqrt{L_2}$ on the *x*-axis), some inverted their axes resulting in the need for additional processing to make the equation in **(d)** fit the graph. Many candidates with inverted axes could not be awarded credit because they did not make the necessary corrections.

Stronger candidates were able to give correct units for *a* (e.g. $\text{s cm}^{-½}$) and *b* (s). Many omitted units or gave incorrect units that could not be given credit.

(e) Most candidates were able to use their value of *a* correctly in the equation and provide a consistent unit. The most common reason for credit not being awarded was a missing or incorrect unit. Some candidates, being aware of the usual SI unit of *g*, gave a dimensionally correct unit that was inconsistent with their value, i.e. m s^{-2} when they had actually worked in cm and calculated a value in cm s^{-2}.

Question 2

(a) (i) Most candidates took measurements of *D* that were within the expected range and stated a consistent unit. Where candidates' values were outside of range, the supervisor's value was referenced to see whether credit could be awarded.

Some candidates evidenced repeated readings in their working. A significant number only took one reading of *D* and so were not awarded credit for repeated readings.

(ii) Many candidates stated a value of *d* that was in the accepted range, with a consistent unit and to the nearest 0.1 mm or better. Some candidates were not awarded credit as they gave a value to the nearest mm which was not consistent with the measuring instrument provided. Others took measurements to the nearest 0.1 mm but incorrectly reduced the precision in the final answer.

(b) (i) Most candidates measured a value of *t* within the accepted range, with a unit and to the nearest 0.1 s or better.

Most candidates recognised the need to take repeated readings of the time *t*.

(ii) Most candidates were able to select a suitable absolute uncertainty and use this to correctly calculate the percentage uncertainty. Candidates taking repeated readings of *t* in **(b)(i)** or **(b)(ii)** were awarded credit if they used half the range as their absolute uncertainty provided working was shown.

(c) Most candidates stated a second value of *d* and *t* with the second value of *t* smaller than the first value in **(b)(i)**.

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

A significant number of candidates incorrectly substituted a value of *d* (diameter of the ball) in place of *D* (internal diameter of the tube). Candidates are reminded to read the question carefully and be aware that values determined earlier in the question may be required in later calculations.

A small number of candidates incorrectly stated their values to one significant figure.

(ii) Many 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 time *t* and ($D^2 - d^2$). A significant number of candidates were not awarded credit because they stated 'raw readings' or 'values used in calculation' without detailing the quantities involved. Others only mentioned the quantity deemed to have the fewest number of significant figures. This is not given credit as it is not clear that all relevant quantities have been considered by the candidate.

(e) Many candidates calculated the percentage difference between their values of *k*, testing it against the stated 10% criterion and providing a valid statement of conclusion. Some candidates omitted a percentage difference calculation, gave a different criterion e.g. 20%, or gave an invalid statement inconsistent with their findings. Some candidates wrote a correct method for calculating a percentage difference but did not multiply by 100. Candidates should be encouraged to estimate the percentage difference in their two *k* values to get a feel for what is a sensible answer. Some had values that were very far apart and a percentage difference of less than 1%. This then led to a comparison with 10% that was not valid.

(f) (i) Candidates are encouraged to identify difficulties associated with setting up and obtaining specific readings. They can do this by writing about the different measurements taken or chronologically and systematically going through the experiment. Candidates should explain clearly what the difficulties are and then suggest corresponding solutions that address each difficulty. Candidates should then try to think of solutions that address each problem.

Problems commonly awarded credit were 'two sets of data were not enough to draw a valid conclusion', 'difficult to measure *D* as the tube distorts on measuring' and difficulties linked to the fall of the ball, e.g. 'ball hits sides of tube'.

(ii) Many candidates were more successful in suggesting improvements than they were in describing the difficulties with the experiment. Candidates are encouraged to explain *how* a problem will be solved, detailing what additional equipment is necessary.

Improvements that were commonly seen were 'take more readings and plot a graph', 'use a longer tube', 'use a rigid tube', 'use a micrometer for measuring *d*' and 'use video with a timer in view to measure the time *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 ruler at right angles'.

PHYSICS

Paper 9702/35
Advanced Practical Skills 1

Key messages

- Measurements should always be recorded to the precision of the measuring device. Candidates should consider carefully whether it would be advantageous to repeat their measurements.
- In the table work, the number of significant figures in the calculated quantity should relate to the number of significant figures in the raw data with the least number of significant figures. Each calculated quantity should be checked row by row. It is unnecessary, and often incorrect, to force the number of significant figures to be constant down a column of calculated values.
- When plotting graphs, candidates should carefully consider the selection of consistent and regular numerical scales for the graph axes. Many candidates would benefit from more practice in the drawing of lines of best fit.
- To be successful answering **Question 2**, candidates should be reminded that their identified limitations and suggestions for improvement must be focused on the particular experiment being carried out. General points such as 'measurements were difficult' or 'use more precise measuring instruments' will not usually gain credit without further detail.

General comments

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

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

The general standard of the work done by the candidates was good, and there were many excellent scripts. Candidates did not seem to be short of time and both questions were attempted by almost all the candidates. They demonstrated good skills in the generation and handling of data and in the suggested improvements in **Question 2**, but can improve by giving more thought to expressing clearly the limitations of the experiment.

Comments on specific questions

Question 1

(a) Many candidates were able to repeat at least two sets of at least 5 oscillations and give a final value in the accepted range and with a unit. Some candidates incorrectly worked out the frequency (rather than the period), took only one set of readings, omitted to divide the final answer by the number of repeats, or omitted units.

(b) Most candidates recorded T to be smaller than T_0.

(c) Many candidates were able to collect six sets of values of h and time without assistance from the supervisor and with the correct trend.

Some candidates did not state their values of *h* to the nearest mm when the ruler used can be read to the nearest mm. These candidates stated *h* to the nearest cm instead.

Many candidates chose their values of *h* so that they were in the range specified. Some candidates did not extend their range low enough or high enough. Candidates are encouraged to use the whole range of *h* available to them.

Many candidates gave both the quantity and correct unit for each heading, separated by a solidus or with brackets around the unit. Candidates are encouraged to remember a separating mark between the quantity and unit. Many candidates correctly omitted the unit for the dimensionless quantity T / T_0.

Many candidates correctly calculated the values of T / T_0.

(d) (i) Stronger candidates plotted the correct graph with quantities labelled, and used sensible and regular scales such that all the data occupied over half the graph grid available. Awkward or irregular scales were a common reason for not awarding credit for the axes. This was especially the case when there was a change in the power of ten along the scale.

Many points were drawn as neat crosses such that the centre was no more than half a square thick and were plotted correctly so that the position is within half a small square in both the *x* and *y* direction. 'Blobs' (points with diameter greater than half a small square) and points plotted more than half a square out from the correct position were often the reasons for credit not being awarded.

(ii) Stronger candidates were able to draw carefully a considered line of best fit that had a balanced distribution of points either side of the line along the entire length. Many lines needed to be rotated or shifted to get a better fit, and some lines were kinked, i.e. not drawn as a single straight line.

Candidates are encouraged not to have anomalies. If a point is anomalous on the graph, candidates should check the plotting first, then check their reading with the equipment available. If there is still an anomalous point, then this can be identified by ringing or labelling.

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

Common mistakes with the gradient were using too small a gradient triangle, substitution into $\Delta x / \Delta y$, values incorrectly read off and points used from the table which were not on the line of best fit. For the *y*-intercept, common mistakes were reading the *y*-intercept from the graph when there was a false origin and substitution into a wrongly arranged equation e.g. $c = y / mx$.

(e) Stronger candidates recognised that *P* and *Q* were equal to the gradient and the *y*-intercept respectively and gave correct units as those used in the experiment. Some candidates omitted units or occasionally used different units from those used in the experiment.

Question 2

(a) Most candidates measured values of *t* to the nearest 0.01 mm or 0.001 mm and in the accepted range. Candidates are encouraged to state their readings to the precision of the measuring instrument. Some candidates rounded or truncated their answer on the answer line.

(b) (i) Many candidates stated *x* in the accepted range and to the nearest mm. Some candidates stated their measurement to the nearest cm instead.

(ii) Many candidates stated *y* in the accepted range and to the nearest mm. Some candidates stated their measurement to the nearest cm instead. Both *x* and *y* can be read to the nearest mm as a ruler was used.

(iii) Stronger candidates, having repeated their readings, correctly showed the uncertainty as half the range and then calculated the percentage uncertainty using the correct method. Others correctly estimated the uncertainty in *y* in the accepted range, considering the awkward nature of this reading. Many weaker candidates incorrectly stated the absolute uncertainty as the smallest reading on the ruler (1 mm) without considering the difficulty in obtaining the centre of gravity points to get the reading.

(iv) Many candidates calculated y^2 / m^2 correctly. Some rounded their value incorrectly, truncating their answer instead.

(v) Many candidates correctly justified the number of significant figures they had given for the value of y^2 / m^2 with reference to the number of significant figures used in the measurements of *y* and *m*. Common reasons for not awarding credit were stating 'raw readings', 'previous measurements' or 'values used in calculation' without detailing the quantities involved, or only mentioning the quantity deemed to have the smallest number of significant figures.

(c) The majority of the candidates stated a second value of *t, m*, *x* and *y* with the second value of *y* larger than the first value.

(d) Most candidates were able to calculate *k* for the two sets of data, showing their working clearly. A few candidates incorrectly stated their values to one significant figure.

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

(f) (i) Candidates are encouraged to identify difficulties associated with setting up and obtaining specific readings. They can do this by writing about the different measurements taken or chronologically and systematically going through the experiment. Candidates should explain clearly what the difficulties are and then suggest corresponding solutions that address each difficulty. Candidates should then try to think of solutions that address each problem.

Problems commonly awarded credit were 'two sets of data were not enough to draw a valid conclusion', 'difficult to measure *x* as difficult to judge the centre of the mass', 'the mass of the putty was not taken into account' and 'difficult to draw the lines whilst the card was hanging up'.

(ii) Many candidates were more successful in suggesting improvements than they were in describing the difficulties with the experiment. Improvements that were commonly seen were 'take more readings and plot a graph', 'clamp a ruler vertically' and 'measure the mass of the putty and add to the masses'. A solution, like the problem, needs detail to gain credit. Candidates are encouraged to explain *how* a problem will be solved, detailing what additional equipment is necessary.

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

PHYSICS

Paper 9702/37
Advanced Practical Skills 1

Key messages

- Measurements should always be recorded to the precision of the measuring device. Candidates should consider carefully whether it would be advantageous to repeat their measurements.
- In the table work, the number of significant figures in the calculated quantity should relate to the number of significant figures in the raw data with the least number of significant figures. Each calculated quantity should be checked row by row. It is unnecessary, and often incorrect, to force the number of significant figures to be constant down a column of calculated values.
- When plotting graphs, candidates should carefully consider the selection of consistent and regular numerical scales for the graph axes. Many candidates would benefit from more practice in the drawing of lines of best fit.
- To be successful answering **Question 2**, candidates should be reminded that their identified limitations and suggestions for improvement must be focused on the particular experiment being carried out. General points such as 'measurements were difficult' or 'use more precise measuring instruments' will not usually gain credit without further detail.

General comments

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

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

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

Comments on specific questions

Question 1

(a) Most candidates stated *E* with a unit and to the nearest 0.001 V.

(b) Most candidates stated *L* in the accepted range and with an appropriate unit, and gave a value of that was *V* smaller than *E*.

(c) Many candidates were able to collect six sets of values of *L* and *V* without assistance from the Supervisor and with the correct trend.

Some candidates did not state their values of *L* to the nearest mm when the ruler used can be read to the nearest mm. These candidates often stated values only to the nearest cm instead.

Many candidates did not extend their range of values of L low enough or high enough. Candidates are encouraged to use the whole range available to them. There was no penalty for candidates who ignored the instruction to increase L from the initial value of around 30.0 cm, but their graphs often showed a curved trend and this made it more difficult to draw the straight line of best fit.

Many candidates gave both the quantity and correct unit for each heading, separated by a solidus or with brackets around the unit. Candidates are encouraged to remember a separating mark between the quantity and unit. Some candidates omitted the unit for $(E – V) / L$ or gave cm^{-1} instead of $V\,cm^{-1}$.

Many candidates correctly stated their calculated values of $(E – V) / L$ to three or four significant figures. Candidates are encouraged not to truncate the values and to round their answers accordingly.

(d) (i) Stronger candidates plotted the correct graph with quantities labelled, and chose sensible and regular scales such that all the data occupied over half the graph grid available. Awkward or irregular scales were a common reason for not awarding credit for the axes. This was especially the case when there was a change in the power of ten along the scale, e.g. 0.094, 0.096, 0.098, 0.100, 0.12, 0.14.

Many points were drawn as neat crosses such that the centre was no more than half a square thick and were plotted correctly so that the position is within half a small square in both the x and y direction. 'Blobs' (diameter greater than half a small square) and points plotted more than half a square out from the correct position were often the reasons for credit not being awarded.

(ii) Stronger candidates were able to draw carefully a considered line of best fit that had a balanced distribution of points either side of the line along the entire length. Many lines needed to be rotated or shifted to get a better fit, and some lines were kinked, i.e. not drawn as a single straight line.

Candidates are encouraged not to have anomalies. If a point is anomalous on the graph, candidates should check the plotting first, then check their reading with the equipment available. If there is still an anomalous point, then this can be identified by ringing or labelling.

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

Common mistakes with the gradient were using too small a gradient triangle, substitution into $\Delta x / \Delta y$, values incorrectly read off and points used from the table which were not on the line of best fit. For the y-intercept, common mistakes were reading the y-intercept from the graph when there was a false origin and substitution into a wrongly arranged equation e.g. $c = y / mx$.

(e) Candidates needed to recognise that P and Q were equal to the gradient and the negative of the y-intercept respectively and give correct units consistent with those used in the experiment. Some candidates omitted units or occasionally used different units to those used in the experiment.

(f) Candidates found it difficult to place line W so that it had a steeper gradient to reflect a larger value of $(E – V) / L$ for any value of V (consistent with a lower resistance in the circuit). The line W also needed to be placed to the left of the original line to reflect that the intercept would be the same had the true origin been drawn. Many candidates placed parallel or shallower lines to the right of the line of best fit. Some candidates did not attempt this question.

Question 2

(a) (i) Most candidates measured values of d to the nearest mm and in the accepted range.

(ii) Some candidates, having repeated their readings, correctly showed the uncertainty as half the range and then calculated the percentage uncertainty using the correct method. Others correctly made a sensible estimate of the uncertainty in d, considering the awkward nature of this reading. Many candidates incorrectly stated the absolute uncertainty as the smallest reading on the ruler (i.e. 1 mm) without considering the difficulty in the reading owing to parallax error and the inconsistent diameter of the modelling clay 'sphere'.

(b) (i) Many candidates stated *x* in the accepted range and to the nearest mm. Some candidates stated their measurement to the nearest cm instead.

(ii) Many candidates calculated *N* correctly. Some rounded their value incorrectly or stated it to a number of significant figures other than the three that were asked for in the question.

(c) Many candidates were able to repeat at least two sets of at least 5 oscillations and give a final value in the accepted range and with a unit. Common mistakes were to incorrectly work out the frequency rather than the period, taking only one measurement, omitting to divide the final answer by the number of repeats, or omitting units.

(d) The majority of the candidates stated a second value of *d* and *x* with the second value of *T* smaller than the first value.

(e) (i) Many candidates were able to calculate *k* for the two sets of data, showing their working clearly. A few candidates incorrectly stated their values to one significant figure.

(ii) Many 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 time, *d* and *x*. Common reasons for not awarding credit were stating 'raw readings', 'previous measurements' or 'values used in calculation' without detailing the quantities involved, or only mentioning the quantity deemed to have the least number of significant figures.

(f) Some candidates calculated the percentage difference between their values of *k*, testing it against the stated 15% criterion and providing a valid statement of conclusion. Some candidates omitted a percentage difference calculation, gave a different criterion of their own choosing (e.g. 10% or 20%), or gave an invalid statement inconsistent with their findings.

(g) (i) Candidates are encouraged to identify difficulties associated with setting up and obtaining specific readings. They can do this by writing about the different measurements taken or chronologically and systematically going through the experiment. Candidates should explain clearly what the difficulties are and then suggest corresponding solutions that address each difficulty. Candidates should then try to think of solutions that address each problem.

Problems commonly awarded credit were 'two sets of data were not enough to draw a valid conclusion', 'difficult to measure *d* as there is parallax error', 'difficult to measure time as hard to judge the end of the oscillation' and 'difficult to roll the ball into a perfect sphere'.

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

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

PHYSICS

Paper 9702/38
Advanced Practical Skills 2

Key messages

- Measurements should always be recorded to the precision of the measuring device. Candidates should consider carefully whether it would be advantageous to repeat their measurements.

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

- When plotting graphs, candidates should carefully consider the selection of consistent and regular numerical scales for the graph axes. Many candidates would benefit from more practice in the drawing of lines of best fit.

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

General comments

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

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

The general standard of the work done by the candidates was good, and there were many excellent scripts. Candidates did not seem to be short of time and both questions were attempted by almost all the candidates. They demonstrated good skills in the generation and handling of data and in describing experimental improvements in **Question 2**, but can improve by giving more thought to expressing clearly the limitations of the experiment.

Comments on specific questions

Question 1

(a) (i) Most candidates stated values of L_1 and L_2 with units and with L_2 in the range 15.0–18.0 cm. Some candidates mixed up their values of L_1 and L_2 and might have benefited from reading the instructions in the question paper more carefully.

(ii) Most candidates stated T in the accepted range and with an appropriate unit. Some candidates had a final value of T outside the accepted range because the final value they gave was actually nT rather than T.

Many candidates took repeated readings of nT with $n \geq 5$. Some candidates may have recorded nT but could not be given credit because the value of n was neither stated nor evidenced in the working.

(b) Many candidates were able to collect six sets of values of L_1, L_2 and T without assistance from the supervisor and with the correct trend. Some candidates did not follow instructions, resulting in L_1 or L_2 values that did not change. The resulting data then did not show the correct trend.

Some candidates included a value of $L_2 \leq 6.0$ cm, but many did not use the full range of L_2 values that the apparatus allowed. Candidates should be encouraged to make best use of the apparatus given.

Many candidates gave both the quantity and a correct unit for each heading, separated by a solidus or with brackets around the unit. Candidates are encouraged to remember to include the separating mark between the quantity and unit. The most common error seen was an incorrect or omitted unit for $\sqrt{L_1} + \sqrt{L_2}$.

Most candidates stated values of L_1 and L_2 to the nearest mm. Some candidates were not awarded credit because they attempted to maintain the number of significant figures rather than recording values to the precision of the measuring instrument. A common situation was where one value had been recorded to three significant figures (e.g. 10.3 cm) and the next (e.g. 9.4 cm) should be two significant figures but was erroneously recorded to three significant figures as 9.40 cm.

Most candidates followed the instruction in the question and stated all values of $\sqrt{L_1} + \sqrt{L_2}$ to three significant figures. Some candidates did not follow this instruction and instead followed the significant figures in their values of L_1 or L_2, and this resulted in the inclusion of values with an incorrect number of significant figures.

Most candidates were able to correctly calculate values of $\sqrt{L_1} + \sqrt{L_2}$. Some candidates made rounding errors or incorrectly added L_1 and L_2 before taking the square root.

(c) (i) Stronger candidates plotted the correct graph with quantities labelled, and with sensible and regular scales such that all the data occupied over half the graph grid available. Awkward or irregular scales were common reasons for not awarding credit. This was especially the case when there was a change in the power of ten along the scale, e.g. 0.094, 0.096, 0.098, 0.100, 0.12, 0.14.

Many points were drawn as neat crosses such that the centre was no more than half a square thick and were plotted correctly so that the position was within half a small square in both the x and y directions. 'Blobs' (diameter greater than half a small square) and points plotted more than half a square out from the correct position were often the reasons for credit not being awarded.

Most candidates collected data that allowed a straight line to be drawn that was within ± 0.5 $\text{cm}^{1/2}$ of all plotted points in the $\sqrt{L_1} + \sqrt{L_2}$ direction.

(ii) Stronger candidates were able to draw carefully a considered line of best fit that had a balanced distribution of points either side of the line along the entire length. Many lines needed to be rotated or shifted to get a better fit, and some lines were kinked, i.e. not drawn as a single straight line.

Candidates are encouraged not to have anomalies. If a point is anomalous on the graph, candidates should check the plotting first, then check their reading with the equipment available. If there is still an anomalous point, then this can be identified by ringing or labelling.

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

Common mistakes with the gradient were using too small a gradient triangle, substitution into $\Delta x / \Delta y$, values incorrectly read off and points used from the table which were not on the line of best fit. For the y-intercept, common mistakes were reading the y-intercept from the graph when there was a false origin and substitution into a wrongly arranged equation e.g. $c = y / mx$.

(d) Most candidates recognised that *a* and *b* were equal to the gradient and *y*-intercept respectively. A common reason for credit not being awarded was the presentation of values as fractions or to only one significant figure. Although most candidates plotted graphs with the correct axes (*T* on the *y*-axis and $\sqrt{L_1} + \sqrt{L_2}$ on the *x*-axis), some inverted their axes resulting in the need for additional processing to make the equation in **(d)** fit the graph. Many candidates with inverted axes could not be awarded credit because they did not make the necessary corrections.

Stronger candidates were able to give correct units for *a* (e.g. $\text{s cm}^{-½}$) and *b* (s). Many omitted units or gave incorrect units that could not be given credit.

(e) Most candidates were able to use their value of *a* correctly in the equation and provide a consistent unit. The most common reason for credit not being awarded was a missing or incorrect unit. Some candidates, being aware of the usual SI unit of *g*, gave a dimensionally correct unit that was inconsistent with their value, i.e. m s^{-2} when they had actually worked in cm and calculated a value in cm s^{-2}.

Question 2

(a) (i) Most candidates took measurements of *D* that were within the expected range and stated a consistent unit. Where candidates' values were outside of range, the supervisor's value was referenced to see whether credit could be awarded.

Some candidates evidenced repeated readings in their working. A significant number only took one reading of *D* and so were not awarded credit for repeated readings.

(ii) Many candidates stated a value of *d* that was in the accepted range, with a consistent unit and to the nearest 0.1 mm or better. Some candidates were not awarded credit as they gave a value to the nearest mm which was not consistent with the measuring instrument provided. Others took measurements to the nearest 0.1 mm but incorrectly reduced the precision in the final answer.

(b) (i) Most candidates measured a value of *t* within the accepted range, with a unit and to the nearest 0.1 s or better.

Most candidates recognised the need to take repeated readings of the time *t*.

(ii) Most candidates were able to select a suitable absolute uncertainty and use this to correctly calculate the percentage uncertainty. Candidates taking repeated readings of *t* in **(b)(i)** or **(b)(ii)** were awarded credit if they used half the range as their absolute uncertainty provided working was shown.

(c) Most candidates stated a second value of *d* and *t* with the second value of *t* smaller than the first value in **(b)(i)**.

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

A significant number of candidates incorrectly substituted a value of *d* (diameter of the ball) in place of *D* (internal diameter of the tube). Candidates are reminded to read the question carefully and be aware that values determined earlier in the question may be required in later calculations.

A small number of candidates incorrectly stated their values to one significant figure.

(ii) Many 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 time *t* and ($D^2 - d^2$). A significant number of candidates were not awarded credit because they stated 'raw readings' or 'values used in calculation' without detailing the quantities involved. Others only mentioned the quantity deemed to have the fewest number of significant figures. This is not given credit as it is not clear that all relevant quantities have been considered by the candidate.

(e) Many candidates calculated the percentage difference between their values of *k*, testing it against the stated 10% criterion and providing a valid statement of conclusion. Some candidates omitted a percentage difference calculation, gave a different criterion e.g. 20%, or gave an invalid statement inconsistent with their findings. Some candidates wrote a correct method for calculating a percentage difference but did not multiply by 100. Candidates should be encouraged to estimate the percentage difference in their two *k* values to get a feel for what is a sensible answer. Some had values that were very far apart and a percentage difference of less than 1%. This then led to a comparison with 10% that was not valid.

(f) (i) Candidates are encouraged to identify difficulties associated with setting up and obtaining specific readings. They can do this by writing about the different measurements taken or chronologically and systematically going through the experiment. Candidates should explain clearly what the difficulties are and then suggest corresponding solutions that address each difficulty. Candidates should then try to think of solutions that address each problem.

Problems commonly awarded credit were ‘two sets of data were not enough to draw a valid conclusion’, ‘difficult to measure *D* as the tube distorts on measuring’ and difficulties linked to the fall of the ball, e.g. ‘ball hits sides of tube’.

(ii) Many candidates were more successful in suggesting improvements than they were in describing the difficulties with the experiment. Candidates are encouraged to explain *how* a problem will be solved, detailing what additional equipment is necessary.

Improvements that were commonly seen were ‘take more readings and plot a graph’, ‘use a longer tube’, ‘use a rigid tube’, ‘use a micrometer for measuring *d*’ and ‘use video with a timer in view to measure the time *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 ruler at right angles’.

PHYSICS

Paper 9702/41
A Level Structured Questions

Key messages

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

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

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

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

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

General comments

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

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

Comments on specific questions

Question 1

(a) Most candidates gave a correct definition of gravitational potential. Some candidates' responses did not make the ratio work done per unit mass clear or specified a unit of mass as part of their definition, and so were not able to gain full credit.

(b) (i) A common mistake was to equate the change in gravitational potential with the potential energy in the higher orbit (omitting the potential energy in the lower orbit). This resulted in the same numerical value for the mass of Mars but only earned partial credit.

(ii) Most candidates were awarded credit for the correct substitution of values into the correct equation. Many candidates were not awarded full credit because they omitted the minus sign or had an incorrect unit.

(c) (i) Most candidates were awarded credit for this question. Some weaker candidates confused rotation with orbit.

(ii) Common answers which did not earn credit described the orbit as geostationary (which describes an orbit around Earth) or as 'on' the equator of Mars rather than above it.

Question 2

(a) Generally, this question was answered well and most candidates earned full credit. A few candidates referred to 'indirect' rather than 'inverse' proportion regarding the distance of separation squared or omitted the word 'squared'.

(b) (i) The most common error was to respond with a value in coulomb rather than in terms of the elementary charge, but most candidates were awarded credit.

(ii) As always with a 'show that' question, marks are not awarded only for the answer, but for showing the working that leads to the answer. The common reason for credit not being awarded was not showing the full substitution by not substituting values for e and/or ε_0.

(c) (i) Most candidates used the correct starting equation for centripetal force and correctly calculated the speed. Some candidates were not familiar with the power of ten indicated by the prefix 'p' for pico.

(ii) Again, most candidates used the correct starting equation or equations and earned full credit.

(d) (i) Although many stronger candidates earned full credit, a significant number approached the question with the correct method but did not reach the correct answer for reasons including the omission of one or both of the differences in charge and radius.

(ii) A common incorrect answer was that the radius of the orbit would change, but the question gave a constant value for the orbital radius. Stronger candidates correctly explained that the change in resultant force would result in a lower speed or longer period.

Question 3

(a) The definition of specific latent heat was generally well known, although some candidates did not include the detail that the temperature remains constant to earn full credit.

(b) A comparison of the change in volume or molecular separation and the corresponding change in potential energy of the molecules between vaporisation and fusion was rarely explained well by candidates. Incorrect explanations involving breaking bonds between molecules were common. Very few candidates who had an explanation in terms of volume and potential energy change referred to the kinetic energy of molecules being unchanged.

(c) Most candidates identified the correct equations for heat transfer during temperature change and during state change. However, many candidates did not consider the three processes involved (one state change and two temperature changes). The strongest candidates earned full credit.

Question 4

(a) (i) The definition of internal energy was generally well known, although some of the weaker candidates confused this definition with the first law of thermodynamics and the change in internal energy.

(ii) Most candidates correctly stated that the potential energy of molecules in an ideal gas is zero. Some went on to state that internal energy was therefore proportional to the total kinetic energy of the molecules rather than equal to it. Most candidates also correctly stated that the kinetic energy of the molecules is proportional to the thermodynamic temperature.

(b) Only the strongest candidates obtained full credit for this question, but many candidates earned partial credit for the work done and the increase in internal energy during cooling. Weaker candidates sometimes gave responses which were dimensionally incorrect, e.g. including temperature T as a quantity of energy.

Question 5

(a) (i) Most candidates gave the correct answer.

(ii) Most candidates gave the correct answer.

(b) Despite the question being clear that quantitative conclusions were required, many candidates gave qualitative descriptions that could gain no credit. Some candidates obtained correct numerical values but then presented the value without a unit. Candidates should be encouraged to check whether a unit is required whenever they give a numerical answer.

(c) Many candidates earned full credit, but often the curves were drawn with insufficient care. For example, common mistakes were for candidates to draw a curve with the correct maximum potential energy at depth h = 0.8 m but this would not be matched at h = 2.0 m, or the minimum of the curve was not close enough to h = 1.4 m.

Question 6

(a) (i) Most candidates gave the correct answer.

(ii) Most candidates gave the correct answer.

(b) (i) Most candidates gave the correct answer for A, but many candidates left the answer for B as a multiple of π rather than calculating the numerical answer.

(ii) Most candidates gave the correct answer.

(iii) Most candidates had the correct symbols for four diodes, but only the strongest candidates drew a circuit diagram which would work as a full-wave rectifier, with all of the diodes in the correct orientation.

(iv) Most candidates knew the correct starting equation(s). Many candidates substituted times which were larger than the discharge time shown in Fig. 6.2. Some weaker candidates made a power-of-ten error.

(c) Most candidates gave the correct answer, including those given credit on the basis of an error carried forward from **(b)(iv)**.

Question 7

(a) The definition of magnetic flux density was generally well known, so full credit was common. Some candidates' answers were ambiguous with regard to what needed to be perpendicular to the field (whether the force or the length/current). Some also referred to specific units for length and/or current as part of their definition.

(b) (i) Most candidates gave the correct answer.

(ii) Most candidates gave the correct answer. Some weaker candidates drew arrows far from point Y and in some cases well outside the region of the magnetic field.

(iii) Most candidates gave the correct answer, although some curves were carelessly drawn with changes in curvature or discontinuities.

(c) (i) Some candidates' responses relied upon a diagram for some of the credit. This was acceptable, but candidates should be reminded the diagrams are only ever likely to be given credit when they are labelled. Many diagrams were not labelled sufficiently for it to be clear what was being shown. Written descriptions of the required direction of the electric field were frequently insufficiently precise.

(ii) Most candidates gave a correct derivation and the correct answer.

Question 8

(a) The majority of the candidates gave the correct textbook or syllabus answer. Some attempted a definition based upon the equation for the de Broglie wavelength. A significant number of candidates specified a particle (commonly an electron) or in a few cases referred to a photon.

(b) Most candidates knew the equation and gave the correct answer.

(c) Most candidates correctly identified a similarity and a difference. A small number of candidates stated a difference as the charges being 'different' rather than 'opposite', and this was considered to be incomplete as it could refer to the magnitude of the charge and thus be incorrect.

(d) (i) Most candidates gave the correct answer.

(ii) Candidates did not always make it clear that the mass–energy conversion was the origin of the energy of the gamma-ray photons. Some responses incorrectly suggested that the photons were produced in addition to the energy released by the annihilation of the electron–positron pair.

(iii) Most candidates identified conservation of momentum as the reason, but not all of these candidates explained that this was achieved by the photons travelling in opposite directions. A significant number of weaker candidates gave the fact that there were two particles annihilated as the reason for two photons being produced.

(iv) This should have been a straightforward 'show that' question using a familiar starting equation for kinetic energy. A significant number of candidates made errors with an incorrect mass or power of ten, or not showing the substituted speed being squared.

(v) Only the strongest candidates recognised that the sum of the kinetic energy and the energy of the mass of the particles was required. Most candidates only gained partial credit for one of the two starting equations.

Question 9

(a) A significant proportion of candidates were unable to give a clear and unambiguous definition.

(b) Only strong candidates were able to gain full credit. Most candidates could not explain the nature of an exponential change, for example as a particular fractional change taking the same amount of time or as the rate of change of *N* being proportional to *N*. Some attempts at explanations referring to half-life were incomplete.

(c) (i) The majority of the candidates gave the correct answer

(ii) Most candidates gave the correct answer, some with the benefit of an error carried forward from **(i)**.

(iii) Although many candidates gained full credit, most gained partial credit because the curve was drawn without sufficient care, sometimes resulting in zero gradient or a positive gradient at some times.

Question 10

(a) Most candidates earned partial credit by stating that speed and distance were proportional, but many were not awarded full credit due to muddled details regarding the what the speed and distance referred to. Some candidates referred to ‘celestial bodies’ instead of galaxies (a celestial body could be a planet among other irrelevant objects).

(b) (i) Common errors were failing to clearly identify the observed and emitted wavelengths in comparisons and using wording which suggests that the observed wavelength is continuing to increase.

(ii) Use of the incorrect wavelength as the denominator in the equation prevented some candidates from gaining credit.

(iii) Most candidates gained partial credit by showing that they were aware of the inverse proportionality between wavelength and temperature, but many did not gain full credit due to incomplete statements to justify their conclusion.

(c) Most candidates gave the correct answer, some with the benefit of an error carried forward from **(b)(ii)**.

PHYSICS

Paper 9702/42
A Level Structured Questions

Key messages

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

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

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

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

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

General comments

The question paper contained questions of a variety of levels of difficulty, enabling candidates at different levels of ability to show what they know. Candidates who knew the theory, 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.

Comments on specific questions

Question 1

(a) The definition of the radian was generally well known and successfully stated by the majority of the candidates.

(b) (i) Most candidates knew that the starting equation for this question was $v = r\omega$, and many candidates calculated the correct angular velocity. A common mistake was to use the speed of the wheel of the bicycle with the radius of the small cog rather than the radius of the wheel.

(ii) Most candidates knew one or other of the valid starting equations, and many realised that they just needed to use the angular velocity calculated in **(b)(i)**. Weaker candidates attempted to find a different angular velocity before using $T = 2\pi / \omega$.

(iii) Most candidates realised that this question was effectively asking them to determine the circumference of the small cog, and were able to show that using the equation circumference = $2\pi r$. Some candidates used an incorrect answer to **(b)(ii)** together with the speed of the bicycle to obtain what was a numerically correct answer using speed = distance × time. The idea that the circumference of the small cog is related to the period of rotation via the speed of the bicycle was taken by examiners to be fundamentally incorrect physics.

(iv) This was another question in which most candidates knew the correct starting equation, $s = r\theta$. A smaller number of candidates realised that the correct radius needed to determine the angle turned by the large cog was the radius of the large cog.

(c) This was a challenging question set in the context of the effect of changing a bicycle's gear on the rate at which the pedals rotate. It discriminated well among the most able candidates, with the strongest candidates able to give very convincing explanations for the decrease in angular velocity of the pedals.

Question 2

(a) (i) Many candidates attempted to answer a different question from the one asked, and either gave the definition of gravitational field or an explanation of what is meant by a gravitational field. Of those candidates that did address the question of what is represented by a gravitational field line, many correctly stated that a field line represents the direction of the force exerted on a test mass. Other candidates incorrectly thought that a single field line represents the magnitude of the field. Another weak answer was that a field line represents the direction in which a test mass will move or accelerate, not appreciating that the motion of a particle depends on the resultant of all the forces acting on it, not just the gravitational force.

(ii) This question was generally well answered, with most candidates making an attempt to draw a radial field pattern towards the centre of the planet.

(b) (i) Many candidates did not know that magnetic field lines point away from magnetic N poles and towards magnetic S poles.

(ii) Many candidates found it difficult to apply their knowledge of the magnetic field pattern due to a solenoid to the scenario of the magnetic field due to the Earth. Candidates should remember that magnetic field lines cannot cross each other.

(c) (i) Many candidates answered a different question from the one asked here, and gave explanations of how the Earth's gravitational field varies with height above the surface for small changes in height. This question was about how the gravitational field around the surface varied around the surface, and many candidates missed this. Since gravitational field is a vector quantity, examiners were looking for an explanation for the constant magnitude (in terms of uniform spacing of field lines at the surface), and for an explanation of constant direction by observing that the gravitational field is downwards wherever one stands on the surface of the Earth.

(ii) Again, magnetic field is a vector quantity, and so, for full credit, candidates needed to address both the variation in magnitude of the magnetic field around the surface and the variation in its direction.

Only the strongest candidates addressed the issue of direction, but many were able to achieve partial credit by observing that the magnitude of the Earth's magnetic field is strongest at the poles and weakest at the Equator. As with **(c)(ii)**, some candidates discussed the variation with altitude above the surface rather than variation around the surface.

Question 3

(a) Many candidates defined a quantity that is an energy (often mixing up units with the definition of the quantity), but candidates that gave a dimensionally correct definition of specific heat capacity were usually able to achieve full credit.

(b) (i) This question was generally well answered, though a significant minority of candidates gave an answer to only two significant figures when the data justified four significant figures.

(ii) There were two possible approaches to answering this question, one that used only the primary data in the question, and the other that used the answer in **(b)(i)**. Candidates choosing the latter route needed to appreciate that the volume to be shown was to four significant figures, and that therefore to correctly 'show' this volume, the mass used also had to be given to at least four significant figures.

(iii) This question was generally well answered. Of candidates that knew the correct starting equation, the main reasons for not achieving full credit were either substituting a volume rather than the change in volume, or giving the answer to fewer significant figures than justified by the data in the question.

(iv) Many candidates had the right idea, but there was much confusion between the block, the gas involved (which is the atmosphere), and the 'system' (which is both the block and the atmosphere).

(v) Achieving full credit in this question required evidence of correct application of the first law of thermodynamics, correct substitution of data, an answer calculated to the correct number of significant figures, and an answer given with correct unit. Many candidates achieved full credit, but many others did not meet one or more of these requirements. It is particularly worth noting that some candidates were confused between degrees Celsius and coulombs as the unit of temperature change.

(c) This question discriminated well amongst stronger candidates. Candidates were required to observe that, since the work done (whether doubled or not) is negligible compared with the increase in internal energy, the three significant figure value for specific heat capacity asked for in **(b)(v)** will be unaffected by the pressure change.

Question 4

(a) (i) Most candidates were able to identify the meaning of T as thermodynamic or absolute temperature.

(ii) Many candidates were able to correctly deduce the meaning of B as the molar gas constant in this question. Common misconceptions were that B represented either the Boltzmann constant or magnetic flux density.

(b) (i) Some candidates were confused in this part over whether they were dealing with a single molecule or all the molecules. The symbol m had to be identified as the mass of a single molecule, and $\langle c^2 \rangle$ as the mean-square speed of all the molecules.

(ii) This question was generally well answered, although some candidates converted the question in their minds into the derivation of $E_K = (3/2)kT$ without substituting back for the expression in terms of A and B.

(c) Most responses seen warranted at least partial credit. Straight lines or curves curving the wrong way were usually the reasons for not achieving full credit.

Question 5

(a) The definition of simple harmonic motion was generally well known.

(b) (i) This question was generally well answered, with most candidates realising that the angular frequency was 16 rad s^{-1} and using that correctly with $T = 2\pi / \omega$. A significant minority of weaker candidates had difficulty with the arithmetic and gave a two significant figure answer of 0.40 s.

(ii) Weaker candidates found this a more difficult question and could not determine the relationship between maximum velocity and maximum displacement. Stronger candidates were generally successful in getting to the correct answer.

(iii) A significant minority of candidates did not realise that this question required more than simply reproducing the general equation for velocity in terms of displacement from the formula sheet. The instruction that v is in m s^{-1} and x is in m made clear that numerical values of ω and x_0 needed to be substituted into this equation. Some candidates gave trigonometric expressions in attempting to give the variation of v with time, and others attempted to calculate a numerical answer. Many more able candidates did successfully substitute the appropriate values into the general equation but omitted the important $\pm$ symbol.

(iv) This question was generally well answered, with most candidates able to draw an oval-shaped loop passing within tolerance through the correct crossing points of the axes. Examiners allowed error-carried-forward from **(b)(ii)** for the crossing points of the x-axis, provided the candidate's value for x_0 lay within the range of the axis. A minority of weaker candidates attempted to sketch the variation of acceleration with displacement or the variation of velocity with time, but most candidates realised the correct shape for the variation of velocity with displacement.

Question 6

(a) This question was generally well answered, with most candidates recognising that negatively charged electrons accelerate from the negative plate to the positive plate.

(b) (i) This question was also generally well answered, with most candidates able to calculate the correct value and give it with a correct unit.

(ii) The more able candidates were generally able to calculate the acceleration correctly. Many of the weaker candidates equated the product of mass and acceleration with an energy or the electric field strength instead of the electric force, and others attempted to use an equation of uniform acceleration.

(c) (i) Most candidates knew the relationship between photon energy and wavelength. Many were unsure of how to determine the photon energy from the energy of the electron. Some candidates calculated the energy by working backwards from the wavelength value. Of candidates that did correctly show the working for the wavelength, some had difficulty in showing the final conversion from m to pm.

(ii) Most candidates were able to identify the electromagnetic waves as X-rays, from a combination of the order of magnitude of the wavelength and the method of production of the radiation.

(iii) Many candidates found it difficult to answer the question that was asked here, with many accounts given of how X-rays are produced. The idea that the image is formed by the differences in transmitted intensities of X-rays that are detected after passing through different parts of the body structure was not well articulated.

Question 7

(a) Many weaker candidates were unable to state that V_C and V_R must be equal to each other.

(b) (i) The majority of the candidates knew the correct starting equation, but some had difficulty with the unit conversion into μF.

(ii) As with **(b)(i)**, most candidates knew the correct starting equation, but some had difficulty with the unit conversion into kΩ.

(iii) Some weaker candidates were unsure how to answer this question, but most candidates knew that time constant is the product of resistance and capacitance and were able to use their answers in the previous two parts correctly.

(c) Candidates found this question difficult. The idea of variations with time that are exponential occurs in two places within the syllabus, in the capacitance topic and the topic of radioactive decay, and candidates should appreciate that exponential variations occur when the rate of change of a quantity is directly proportional to the quantity itself. In the case of capacitor discharge, candidates were expected to make the points that, because the current in the resistor is proportional to V_R and the charge on the capacitor is proportional to V_C, and because $V_C = V_R$, it follows that the current in the circuit is proportional to the charge on the capacitor. And since the current in the circuit is the rate of decrease of charge, it then follows that the rate of decrease of charge is proportional to the charge, hence the variation of charge with time is exponential.

Question 8

(a) (i) Most candidates were able to identify the type of rectification as half-wave from the circuit in Figure 8.1.

(ii) This question was generally well answered, with most candidates able to calculate the peak value of a sinusoidal alternating voltage from its r.m.s. value.

(b) (i) Again this question was generally well answered, with most candidates able to use the peak voltage correctly with $P = V^2 / R$ to calculate the peak power.

(ii) Whilst most candidates were able to achieve at least partial credit for this graph, full credit was relatively rare. The two common mistakes were to draw the power–time graph for full-wave rectification rather than for half-wave rectification, and to not draw the correct shaped curve, particularly in the region close to the time axis. Most of the graphs seen, whether full- or half-wave rectified, were based on |sin| curves rather than $\sin^2$ curves, without smooth troughs at the base.

(iii) This was a challenging question that required candidates to explain the two relevant ×½ factors, one from the symmetry of the non-zero power sections giving a mean power of $\frac{1}{2}P_0$ within those sections, and the other from the removal of half of the power by the half-wave rectification. Common misconceptions were that the whole power–time graph was symmetrical about $\frac{1}{4}P_0$, and that the effect of half-wave rectification was to halve the peak power.

(iv) Candidates who understood the concept of r.m.s. voltage were able to use the information that the mean power is a quarter of the peak power together with their value of the peak power to calculate the correct r.m.s. voltage. Many candidates found this question challenging.

Question 9

(a) This question was generally well answered, with most candidates able to state that the photoelectric effect is the emission of electrons from a metal surface when electromagnetic radiation is incident upon it. Some weaker candidates confused the roles of the photons and the electrons in the process.

(b) (i) Many candidates misunderstood the point of this question and discussed in detail why a threshold frequency exists for photoelectric emission. Candidates who realised that this question was all about the maximum kinetic energy of the electrons after emission were more successful in gaining credit. Many candidates were too vague in their discussion of ‘energy’, often just using the term generically despite there being three different energies involved in the process (photon energy, work function energy and electron kinetic energy). To achieve credit, candidates needed to be clear which of these energies they were referring to when discussing ‘energy’.

(ii) Many candidates found this question difficult, either giving qualitative rather than quantitative conclusions, or simply giving descriptions of the graphs rather than drawing conclusions from them. Quantities that candidates could calculate from the graph data to achieve credit included the threshold frequency of the metal, the threshold wavelength, the work function, a value for the Planck constant, the number per unit time of incident photons and the power of the incident radiation. In answering this type of question, candidates should be advised that they need to give all calculated values with a correct unit and to an appropriate number of significant figures.

Question 10

(a) Most candidates were able to give the correct meaning of the term spontaneous, although some weaker candidates conflated it with the term random.

(b) (i) Most candidates successfully determined the correct half-lives from the graph, but many of them found it difficult to give dimensionally correct answers for the decay constants and the values of N_0.

(ii) A significant number of candidates determined the correct value of t as $12T$ for full credit. Of those that were not able to determine the correct answer, partial credit was available for correct substitution into $A = A_0 \exp(-\lambda t)$ and then for equating the two expressions for activity. Candidates needed to take care with their use of t and T in the substitution, because t and T have different meanings in this question and both are required in the substitution. Some candidates equated values of N rather than A, which examiners took as an incorrect starting point for the question.

(c) Most candidates realised that the underlying reason for the difference in measured count rate and activity was that the detector does not detect all of the radiation emitted during the radioactive decay process. Weaker candidates often were not able to give reasons why the detector does not detect all the radiation.

PHYSICS

Paper 9702/43
A Level Structured Questions

Key messages

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

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

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

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

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

General comments

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

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

Comments on specific questions

Question 1

(a) Most candidates gave a correct definition of gravitational potential. Some candidates' responses did not make the ratio work done per unit mass clear or specified a unit of mass as part of their definition, and so were not able to gain full credit.

(b) (i) A common mistake was to equate the change in gravitational potential with the potential energy in the higher orbit (omitting the potential energy in the lower orbit). This resulted in the same numerical value for the mass of Mars but only earned partial credit.

(ii) Most candidates were awarded credit for the correct substitution of values into the correct equation. Many candidates were not awarded full credit because they omitted the minus sign or had an incorrect unit.

(c) (i) Most candidates were awarded credit for this question. Some weaker candidates confused rotation with orbit.

(ii) Common answers which did not earn credit described the orbit as geostationary (which describes an orbit around Earth) or as 'on' the equator of Mars rather than above it.

Question 2

(a) Generally, this question was answered well and most candidates earned full credit. A few candidates referred to 'indirect' rather than 'inverse' proportion regarding the distance of separation squared or omitted the word 'squared'.

(b) (i) The most common error was to respond with a value in coulomb rather than in terms of the elementary charge, but most candidates were awarded credit.

(ii) As always with a 'show that' question, marks are not awarded only for the answer, but for showing the working that leads to the answer. The common reason for credit not being awarded was not showing the full substitution by not substituting values for e and/or ε_0.

(c) (i) Most candidates used the correct starting equation for centripetal force and correctly calculated the speed. Some candidates were not familiar with the power of ten indicated by the prefix 'p' for pico.

(ii) Again, most candidates used the correct starting equation or equations and earned full credit.

(d) (i) Although many stronger candidates earned full credit, a significant number approached the question with the correct method but did not reach the correct answer for reasons including the omission of one or both of the differences in charge and radius.

(ii) A common incorrect answer was that the radius of the orbit would change, but the question gave a constant value for the orbital radius. Stronger candidates correctly explained that the change in resultant force would result in a lower speed or longer period.

Question 3

(a) The definition of specific latent heat was generally well known, although some candidates did not include the detail that the temperature remains constant to earn full credit.

(b) A comparison of the change in volume or molecular separation and the corresponding change in potential energy of the molecules between vaporisation and fusion was rarely explained well by candidates. Incorrect explanations involving breaking bonds between molecules were common. Very few candidates who had an explanation in terms of volume and potential energy change referred to the kinetic energy of molecules being unchanged.

(c) Most candidates identified the correct equations for heat transfer during temperature change and during state change. However, many candidates did not consider the three processes involved (one state change and two temperature changes). The strongest candidates earned full credit.

Question 4

(a) (i) The definition of internal energy was generally well known, although some of the weaker candidates confused this definition with the first law of thermodynamics and the change in internal energy.

(ii) Most candidates correctly stated that the potential energy of molecules in an ideal gas is zero. Some went on to state that internal energy was therefore proportional to the total kinetic energy of the molecules rather than equal to it. Most candidates also correctly stated that the kinetic energy of the molecules is proportional to the thermodynamic temperature.

(b) Only the strongest candidates obtained full credit for this question, but many candidates earned partial credit for the work done and the increase in internal energy during cooling. Weaker candidates sometimes gave responses which were dimensionally incorrect, e.g. including temperature T as a quantity of energy.

Question 5

(a) (i) Most candidates gave the correct answer.

(ii) Most candidates gave the correct answer.

(b) Despite the question being clear that quantitative conclusions were required, many candidates gave qualitative descriptions that could gain no credit. Some candidates obtained correct numerical values but then presented the value without a unit. Candidates should be encouraged to check whether a unit is required whenever they give a numerical answer.

(c) Many candidates earned full credit, but often the curves were drawn with insufficient care. For example, common mistakes were for candidates to draw a curve with the correct maximum potential energy at depth h = 0.8 m but this would not be matched at h = 2.0 m, or the minimum of the curve was not close enough to h = 1.4 m.

Question 6

(a) (i) Most candidates gave the correct answer.

(ii) Most candidates gave the correct answer.

(b) (i) Most candidates gave the correct answer for A, but many candidates left the answer for B as a multiple of π rather than calculating the numerical answer.

(ii) Most candidates gave the correct answer.

(iii) Most candidates had the correct symbols for four diodes, but only the strongest candidates drew a circuit diagram which would work as a full-wave rectifier, with all of the diodes in the correct orientation.

(iv) Most candidates knew the correct starting equation(s). Many candidates substituted times which were larger than the discharge time shown in Fig. 6.2. Some weaker candidates made a power-of-ten error.

(c) Most candidates gave the correct answer, including those given credit on the basis of an error carried forward from **(b)(iv)**.

Question 7

(a) The definition of magnetic flux density was generally well known, so full credit was common. Some candidates' answers were ambiguous with regard to what needed to be perpendicular to the field (whether the force or the length/current). Some also referred to specific units for length and/or current as part of their definition.

(b) (i) Most candidates gave the correct answer.

(ii) Most candidates gave the correct answer. Some weaker candidates drew arrows far from point Y and in some cases well outside the region of the magnetic field.

(iii) Most candidates gave the correct answer, although some curves were carelessly drawn with changes in curvature or discontinuities.

(c) (i) Some candidates' responses relied upon a diagram for some of the credit. This was acceptable, but candidates should be reminded the diagrams are only ever likely to be given credit when they are labelled. Many diagrams were not labelled sufficiently for it to be clear what was being shown. Written descriptions of the required direction of the electric field were frequently insufficiently precise.

(ii) Most candidates gave a correct derivation and the correct answer.

Question 8

(a) The majority of the candidates gave the correct textbook or syllabus answer. Some attempted a definition based upon the equation for the de Broglie wavelength. A significant number of candidates specified a particle (commonly an electron) or in a few cases referred to a photon.

(b) Most candidates knew the equation and gave the correct answer.

(c) Most candidates correctly identified a similarity and a difference. A small number of candidates stated a difference as the charges being 'different' rather than 'opposite', and this was considered to be incomplete as it could refer to the magnitude of the charge and thus be incorrect.

(d) (i) Most candidates gave the correct answer.

(ii) Candidates did not always make it clear that the mass–energy conversion was the origin of the energy of the gamma-ray photons. Some responses incorrectly suggested that the photons were produced in addition to the energy released by the annihilation of the electron–positron pair.

(iii) Most candidates identified conservation of momentum as the reason, but not all of these candidates explained that this was achieved by the photons travelling in opposite directions. A significant number of weaker candidates gave the fact that there were two particles annihilated as the reason for two photons being produced.

(iv) This should have been a straightforward 'show that' question using a familiar starting equation for kinetic energy. A significant number of candidates made errors with an incorrect mass or power of ten, or not showing the substituted speed being squared.

(v) Only the strongest candidates recognised that the sum of the kinetic energy and the energy of the mass of the particles was required. Most candidates only gained partial credit for one of the two starting equations.

Question 9

(a) A significant proportion of candidates were unable to give a clear and unambiguous definition.

(b) Only strong candidates were able to gain full credit. Most candidates could not explain the nature of an exponential change, for example as a particular fractional change taking the same amount of time or as the rate of change of N being proportional to N. Some attempts at explanations referring to half-life were incomplete.

(c) (i) The majority of the candidates gave the correct answer

(ii) Most candidates gave the correct answer, some with the benefit of an error carried forward from **(i)**.

(iii) Although many candidates gained full credit, most gained partial credit because the curve was drawn without sufficient care, sometimes resulting in zero gradient or a positive gradient at some times.

Question 10

(a) Most candidates earned partial credit by stating that speed and distance were proportional, but many were not awarded full credit due to muddled details regarding the what the speed and distance referred to. Some candidates referred to 'celestial bodies' instead of galaxies (a celestial body could be a planet among other irrelevant objects).

(b) (i) Common errors were failing to clearly identify the observed and emitted wavelengths in comparisons and using wording which suggests that the observed wavelength is continuing to increase.

(ii) Use of the incorrect wavelength as the denominator in the equation prevented some candidates from gaining credit.

(iii) Most candidates gained partial credit by showing that they were aware of the inverse proportionality between wavelength and temperature, but many did not gain full credit due to incomplete statements to justify their conclusion.

(c) Most candidates gave the correct answer, some with the benefit of an error carried forward from **(b)(ii)**.

PHYSICS

Paper 9702/44
A Level Structured Questions

Key messages

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

General comments

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

Questions asking for an explanation or reason were often answered by weaker candidates in a way that just described the information that was given in the question, diagram or graph, thereby gaining little or no credit. Candidates should be advised to read questions and command words carefully to ensure that they provide an answer that can be given credit.

A number of questions required freehand drawing of lines, including sinusoidal waves, curves and straight lines. Some candidates would have achieved more credit by the appropriate use of a pencil, ruler and eraser, thereby allowing them to easily and clearly correct or clarify their work. Statements written next to diagrams describing how the drawing should look do not compensate for inaccurate drawing.

There was no evidence that candidates had insufficient time in which to complete the paper.

Comments on specific questions

Question 1

(a) Most candidates correctly provided the correct ratio of force per unit mass. A significant number described qualitatively a general region in which a gravitational force occurs, which is not a definition. Some candidates gave both of these descriptions.

(b) (i) More candidates were able to give the correct direction of the gravitational field lines than the correct pattern.

(ii) Candidates usually used appropriate wording to compare the small change in vertical height with the radius of the planet. Stronger candidates understood that the field lines were approximately (or could be assumed to be) parallel. Weaker candidates often thought that the planet mass was the relevant quantity to compare with, rather than the planet radius. The minimal impact of squaring the two distances was rarely mentioned.

(c) (i) A high proportion of candidates correctly read the question and gave their answer to exactly three significant figures.

(ii) In addition to the need to express their answer to at least three significant figures to match that of the given data, stronger candidates also appreciated that the gravitational potential had a negative value.

(d) Most candidates understood the importance of infinity as a reference point for gravitational potential. Fewer candidates appreciated that any mention of 'work done' required them to say what was doing the work, and in what direction the masses were moving relative to each other.

Question 2

(a) This question was generally well answered. Where candidates were unable to achieve full credit, it was usually because of an essential missing word in their description, such as 'net transfer' or 'thermal' (energy).

(b) Most candidates correctly answered all three parts of this question. The most difficult part was **(ii)** because the question asked for the energy *lost* by the water, requiring a positive answer.

(c) This 'show that' question required candidates to begin their answer by equating the three energy changes from **(b)**. Stronger candidates did so before rearranging their equation. Attempts to work backwards from the given equation did not meet the requirements of the question.

Question 3

(a) This question was generally well answered. Many weaker candidates did not identify the temperature used in the relationship as being thermodynamic temperature.

(b) (i) Stronger candidates ensured that the correct symbol $\langle c^2 \rangle$ was used throughout their answer. Weaker candidates did not use $\langle c^2 \rangle$ for root-mean-square speed or used it incorrectly. Many candidates showed confusion over mass and density, believing the density was the mass of one molecule divided by the volume of the gas.

(ii) The use of the ideal gas equation $pV = NkT$ to form an equation involving molecular kinetic energy illustrated a better understanding in general than the relationships tested in **(i)**. More candidates achieved full credit here than in **(i)**.

(c) The calculation of the internal energy was the part of this question that was most successfully answered, and there were also many candidates who a gave good explanation of the reason for ignoring molecular potential energy in their calculations. Weaker candidates often confused the number of moles with the number of molecules.

Question 4

(a) The proportionality between acceleration and displacement was well understood, but the opposite direction of the two quantities was less clearly explained by some candidates. Candidates should ensure that they explain each term used if they quote an equation as part of their answer to this type of question.

(b) (i) This question tested the candidates' ability to match the velocity–time graph to the actual movement of the sphere, both in terms of speed and direction. Key to a producing a successful answer to this question was an appreciation of the direction of travel of the sphere during its oscillations.

(ii) Weaker candidates often confused the terms frequency and angular frequency.

(c) Where the starting equation of $\omega = v_0 / x_0$ was used, the identification of maxima for *v* and *x* using subscripts was not always made. A minority of candidates took the alternative (longer) route of using a tangent drawn on Fig. 4.2 to calculate the maximum acceleration and hence the amplitude. However, for most of those candidates, this graphical method introduced too great a degree of inaccuracy for full credit.

Question 5

(a) As well as defining electric potential in terms of movement of charge to or from infinity (depending on the sign of the charge) stronger candidates were also aware of the required ratio between work done and charge.

(b) (i) Candidates used a number of different methods to compare the two positions (*r* and 3*r* from the sphere's centre) and the relative electric field strength and potential values at each position. Each method was equally creditworthy in deriving the field strength at the surface of the sphere. The most common error was to invert the relationships and get a smaller value of electric field strength at the surface than further away at distance 3*r*.

(ii) In this 'show that' question, equations for electric field strength and potential needed to first be shown and then compared in order to progress to the final relationship between *E*, *V* and sphere radius *r*. Most candidates missed this beginning and started from that final relationship, into which values were substituted. The calculation produced a value in metres, which needed to be clearly converted into centimetres. Some weaker candidates wrongly used the equation for parallel plates, including an unexplained symbol *d*.

(iii) The rearrangement of the equation for electric field strength or for electric potential did not prove problematic to most candidates. Weaker candidates were not able to recognise that the precise value of the capacitance was not exactly 0.5 μC, and so they gave their answer to only one significant figure instead of the required minimum of two.

(iv) The majority of the candidates were able to successfully use the data provided to calculate the capacitance of the sphere.

Question 6

(a) (i) The equation $F = BIL$ was stated and used by the majority of the candidates, although there was often some confusion as to the need to include the number of turns, resulting in a reduced force. Weaker candidates found more difficulty in identifying which side of the coil was being referred to as *L* in their equation.

(ii) The torque was often described as $F \times d$ with no explanation or clarification of the symbols used. Stronger candidates identified the requirement for a perpendicular distance to be identified, and hence the inclusion of a cosine term. Some weaker candidates took the symbol τ as being a time constant, despite it being defined as torque in the question.

(iii) Only the strongest candidates were able to sketch the sinusoidal curve without error, despite some allowance being given for a freehand drawing. Stronger candidates marked intermediate points on their graph to aid their drawing of the curves. The most common errors involved an excessively sharp start and finish to the curve at $\theta = 0°$ or at $\theta = 360°$, and a line that was wrongly or insufficiently curved between the peaks and troughs. The skill of accurately drawing a correct sinusoidal shape is one that would have been of significant benefit in this question. The labelling of the *y*-axis with values regularly showed number positioning that was imprecise. Few candidates marked the exact position of their values on the grid line, and it was not uncommon to see the negative labels missing a minus sign. Repetition of the power of ten on the axis numbers was also a common error. These two errors appeared across the full range of overall candidate performance.

(b) Only the strongest candidates realised that adding a ferrous core would increase the magnetic flux density.

Question 7

(a) (i) Stronger candidates identified both the change to the oscillations and the cause of that change. Weaker candidates confused the resistive force on the bar magnet with the resistance in the circuit.

(ii) The words ‘oscillation’, ‘displacement’, ‘amplitude’, ‘time’ and ‘period’ were often confused with each other by weaker candidates when describing the gradual reduction in amplitude over time. ‘Maximum amplitude’ was also an incorrect phrase seen.

(iii) This was one of the more difficult questions on the paper. Candidates were expressly required to focus on conservation of energy, and needed to link two parts of the process in their description, such as magnetic flux change and induced e.m.f., or current and thermal energy dissipation in the resistor. Only the strongest candidates were able to do so, with many candidates focusing instead on the impact of Lenz’s law and opposing forces. Whilst many candidates described a change of magnetic flux inducing an e.m.f., there was significant confusion over the process.

(b) Most candidates understood the effect of the increase in resistance, and correctly described the reduction in damping or the increase in the number of oscillations. Few candidates identified the lower thermal energy dissipation or lower resistive force caused by the reduction in the current.

Question 8

(a) The four diodes were correctly and carefully drawn by most candidates. The correct diode directions were identified less often, and incomplete connections to the diodes were occasionally seen.

(b) (i) Many candidates of all abilities drew an incomplete graph, omitting the charging section of the curve from the minima to the peaks. The decay sections of the graph curved the correct way in most answers. More careful reading of the question might have prevented the incorrect choice of $V_0 / 3$ as the minimum voltage.

(ii) This question highlighted the importance of showing every step of the working clearly. Here, evidence of the derivation of the decay period from the graph was often missing. This meant that, if the final answer was also incorrect, there was no opportunity to award credit for the working.

(iii) Stronger candidates were able to identify both that the time constant increased and that this reduced the difference between minimum and maximum output voltage. Weaker candidates often wrongly implied that the output voltage was always increased (including the maximum V_0).

Question 9

(a) (i) Candidates were more likely to discuss examples exclusively, rather than describe the general picture of wave–particle duality. The particle-like behaviour of an electromagnetic wave was the half of the required answer that was most successfully described. It was rarely mentioned that a particle needed to be moving to show wave-like properties.

(ii) This question was generally well answered.

(b) (i) Candidates who focused on what wave nature entailed were more successful in this question. The opportunity to compare the pattern shown with that of other waves was rarely taken. Interference was mentioned by some candidates but often without identifying that the light and dark rings represented regions of constructive and destructive interference.

(ii) The reduction of the de Broglie wavelength was well understood by most candidates, and descriptions of how that occurred were often very accurate. Descriptions of the change to the pattern, on the other hand, were often too imprecise to be given credit, weaker examples being the use of the words ‘pattern’ or ‘lines’ rather than ‘rings’ or ‘circles’.

Question 10

(a) Many candidates were well prepared for this question, and it was common to see a full answer covering all the marking points. Reading the question carefully would have shown that this question was only asking for a description of the method of generation of ultrasound at the natural frequency of the crystal. Additional descriptions of the pathway of the ultrasound in the body, and the reception of the returning waves were not assessed. Some candidates wrongly described a current passing through the crystal.

(b) (i) The product of density and speed was mostly well known by candidates, but fewer were specific about what had the speed and where that speed occurred.

(ii) Answering this question required a careful choice of words. It was clear that the general picture of the physics involved when ultrasound meets a boundary between two media was understood by many candidates. Any errors were usually because of imprecision in the use of words, such as describing the two specific acoustic impedances as being just ‘different’ rather than ‘very different’ (for example). Likewise, the reflected fraction α was often described as ‘big’ or ‘small’ rather than relating it to the extreme values of 1 or 0.

(c) This question was generally well answered, and most candidates were able to give a correct unit consistent with their value.

Question 11

(a) (i) The correct spelling of the technical term ‘fusion’ was required to ensure that there was no possible ambiguity with ‘fission’. Many candidates either misspelled the term fusion or believed that the nuclear reaction given was fission.

(ii) Most candidates appreciated that this was a ‘show that’ question, and so they laid out their derivation and substitutions clearly. Occasionally, the conversion of the mass defect from atomic mass units to kg was not shown, but most candidates were successful in this question.

(b) (i) Only stronger candidates were able to identify that the mass of helium (whether one atom or one mole) was the quantity to be used in the calculation. Most candidates appreciated that three significant figures were required for their answers. Weaker candidates wrongly attempted to use the Stefan–Boltzmann law.

(ii) Most candidates were able to process the data provided to give the star’s surface temperature to three significant figures. Occasionally the fourth root proved a source of arithmetical error.

PHYSICS

Paper 9702/51
Planning, Analysis and Evaluation

Key messages

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

General comments

In **Question 1**, it is advisable that candidates should think carefully about how they would perform the experiment in the laboratory using the bullet points given to aid their answer. Planning a few key points before answering **Question 1** is useful. In particular, candidates should be encouraged to draw circuit diagrams with correct circuit symbols. Weaker candidates tended to suggest a suitable graph to draw but were not explicit in how the relationship could be proved or how the constant *K* was determined. To be awarded credit for additional detail, candidates should take care to describe exactly how each measurement will be obtained, including both the equipment used and the method to take the measurement. It is essential for candidates to have experienced practical work in preparation for answering this question.

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

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 logically so that it can be understood.

Comments on specific questions

Question 1

Most candidates correctly identified the independent and dependent variables. A small number of candidates incorrectly identified *N* or *E*. Candidates should then consider the control of variables and to explicitly state the quantities that need to be kept constant to make the experiment a fair test. In this experiment, it was expected that candidates would state that *E* would be kept constant. There was an additional credit for also stating that *N*, *A*, l and *S* would also be kept constant. Credit was not given for stating 'control' since this is just repeating the stem of the question and does not indicate what is meant by 'control'.

Candidates were awarded credit for a clearly labelled diagram. The drawing of workable circuit diagrams appeared to be challenging. Common errors included voltmeters or oscilloscopes connected in series with the circuit, an a.c. supply not being specified, and an ohmmeter being connected in series or parallel with the circuit. The need for a variable frequency supply or a signal generator was generally only described by the strongest candidates.

Candidates needed to be able to describe the methods to determine *V*, *E* and *f*. Stronger candidates related their descriptions to the display of the waveform on the oscilloscope. Some candidates referred to '*y*-base' rather than '*y*-gain' or 'voltage gain' and did not refer to the maximum height or amplitude of the waveform. Similarly, many candidates did not refer to the horizontal distance of one cycle before multiplying this distance by the time-base to determine the period of the cycle when determining frequency. Some stronger candidates gained additional credit for explaining that they would adjust the *y*-gain to have a large maximum amplitude, adjust the time-base for the maximum horizontal distance of one cycle, or measure the distance across *n* cycles and dividing this distance by *n* to determine the horizontal distance of one wave.

Many candidates correctly suggested the use of a ruler or calipers to measure *l*. Candidates should carefully consider which measuring instrument is suitable for the measurement of a length. A micrometer should only be suggested if the measurement is likely to be small. To determine *A*, candidates gained credit by stating the use of calipers or a micrometer to measure the diameter of the coil and then showing how *A* was calculated. There was additional credit for describing repeating the measurements of diameter along the coil and finding the mean diameter.

Many candidates suggested correct axes for a graph. Candidates must explicitly state the quantities to be plotted on each axis either in the text or on drawn axes – credit is not given for just writing $y = mx + c$ below 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. In this experiment, candidates needed to state that the straight line would pass through the origin. Credit was not awarded to candidates who did not correctly identify appropriate axes for a graph to plot.

Candidates needed to explain how they would determine a value for the constant *K* from the experimental results using the gradient. To gain credit, the constant *K* had to be the subject of the relevant equation. Credit was not awarded to candidates who did not correctly identify appropriate axes for a graph to plot.

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. Vague responses were not credited. It is essential that candidates' answers are relevant to the planned experiment rather than general 'textbook' rules for working in the laboratory. Statements like 'ensure all apparatus is working correctly' or 'check all connections are properly made' will not gain credit as this is just normal good experimental procedure.

When describing safety precautions, candidates should be encouraged to explain how the precaution proposed is relevant to the experiment. In this experiment, precautions when working with the hot coil or hot resistors were relevant and gained credit.

There was additional detail credit for determining the resistance *S*. Stronger candidates often drew a separate circuit with either the resistor connected to an ohmmeter or the resistor connected to a power supply, ammeter and voltmeter.

Question 2

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

(b) The majority of candidates correctly calculated $1 / I$. Some weaker candidates incorrectly recorded their values of $1 / I$ to two significant figures. Since I was recorded to three significant figures, it was expected that $1 / I$ would be recorded to three (or four) significant figures. Some candidates recorded 2.19 instead of 2.20 because they had truncated their answer rather than rounding it correctly.

The absolute uncertainties in $1 / I$ were usually calculated correctly. Some mistakes included writing all the uncertainties as ± 0.005 or ± 0.1.

(c) (i) The data points were straightforward to plot. It is expected that the data points plotted should be clearly represented. The plotting needed to be within half a small square. A common error was in plotting (0.111, 1.46) as (0.101, 1.46). 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 about the plotted data point. A clear small line should be drawn at the end of each bar.

(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 data points. The worst acceptable line was drawn well in general, and many stronger candidates drew a line which passed through all error bars. Candidates should clearly label the lines drawn as required by the question. Clear labelling should also assist candidates when they determine the gradient and *y*-intercept. Where a dashed line represents the worst acceptable line, the dashed parts of the line should cross each of the error bars.

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

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

(iv) The majority of the candidates who were awarded full credit set out their working clearly. Stronger candidates often substituted data from the gradient calculation in **(c)(iii)** into $y = mx + c$. Other errors seen included candidates incorrectly dividing the y value by mx or calculating $mx - y$.

When determining the uncertainty in the *y*-intercept, candidates needed to show the correct substitution from the worst acceptable line of both the gradient and a data point into $y = mx + c$. 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. Many weaker candidates incorrectly attempted to determine the uncertainty in the *y*-intercept by either assuming that the fractional uncertainty in the gradient was the same as the fractional uncertainty in the *y*-intercept or by adding fractional uncertainties.

(d) (i) Credit was not gained for substituting data values from the table. Most candidates realised that the constant R was equal to 5.8 × gradient and that constant Z was equal to 5.8 × *y*-intercept. Some candidates did not gain credit because they did not give their values of R and Z to an appropriate number of significant figures. Since the number of significant figures in E is two, R and Z should be given to two (or three) significant figures. Candidates found the power of ten for R and Z and the units for R and Z to be challenging.

(ii) To gain credit in this part, candidates needed to show their method. Firstly, candidates needed to determine the absolute uncertainty in *E.* Since these were repeated readings, the absolute uncertainty was equal to half the range. Many candidates realised that the percentage uncertainty in the gradient needed to be added to the percentage uncertainty in *E.* A significant minority of candidates incorrectly included the percentage uncertainty in the *y*-intercept.

A small number of candidates used either a maximum or a minimum method. Clear working showing how each of the maximum or minimum values were obtained was needed for credit.

(e) It was essential that candidates showed their method of working. Stronger candidates wrote down the equation and clearly substituted in their values. Most answers used powers of ten that were consistent with earlier answers.

PHYSICS

Paper 9702/52
Planning, Analysis and Evaluation

Key messages

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

General comments

In **Question 1**, it is advisable that candidates should think carefully about how they would perform the experiment in the laboratory using the bullet points given to aid their answer. Planning a few key points before answering **Question 1** is useful. In particular, candidates should be encouraged to draw diagrams showing an arrangement of the apparatus with key measurements shown. Some weaker candidates tended to suggest a suitable graph to draw but were not explicit in how the relationship could be proved or how the constants *P* and *Q* were determined. To be awarded credit for additional detail, candidates should take care to describe exactly how each measurement will be obtained, including both the equipment used and the method to take the measurement. It is essential for candidates to have experienced practical work in preparation for answering this question.

In **Question 2**, candidates should be familiar with completing a results table for quantities and their uncertainty, and with finding the gradient and *y*-intercept of a graph. For several candidates, credit was not awarded because the plotted points were not balanced about the line best fit, the worst acceptable line did not pass through the error bars correctly or coordinates were wrongly read off when determining the gradient and/or *y*-intercept. Some candidates were confused by the negative value of the gradient. Another common difficulty was determining the percentage uncertainty in *C*.

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

Comments on specific questions

Question 1

Most candidates correctly identified the independent and dependent variables. Candidates should then consider the control of variables and to explicitly state the quantities that need to be kept constant to make the experiment a fair test. In this experiment, it was expected that candidates would state that *h* would be kept constant. There was additional credit for stating that *r* and *z* would also need to be kept constant. Credit is not given for simply stating 'control' since this is just repeating the stem of the question and does not indicate what is meant by 'control'.

Candidates were awarded credit for a clearly labelled diagram. Diagrams should be drawn of the workable experiment. In this experiment, it was expected that candidates would show that the axle would be supported at both ends by resting the axle on clamps attached to a stand on the bench. It was also expected that the distance *h* would be indicated with one light gate correctly positioned at the lower position of *h*.

Only the strongest candidates were able to explain the method to determine *v* using one light gate. The strongest candidates stated that they would measure the vertical height of the block and divide this by the time to pass through the light gate. A common mistake was to state that *v* was equal to *h* / *t*. This would give the average speed of the block as it falls through distance *h* but not the required speed after the block has fallen through distance *h*.

Many candidates correctly suggested the use of a balance to measure *m*. Similarly, most candidates suggested the use of a micrometer to measure *z*.

Many candidates stated measuring *r* using a rule without describing how the measurement should be made. Only a small minority of candidates were able to describe measuring the diameter and dividing by two or measuring the distance to the axle and adding half the diameter of the axle.

Many candidates suggested correct axes for a graph. Candidates must explicitly state the quantities to be plotted on each axis either in the text or on drawn axes – credit is not given for just writing $y = mx + c$ below 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. In this experiment, credit was not given for stating that the straight line would pass through the origin since there would be a *y*-intercept. Stronger candidates often stated the *y*-intercept that the line would pass through. Credit was not awarded to candidates who did not correctly identify appropriate axes for a graph to plot.

Candidates needed to explain how they would determine values for the constants *P* and *Q* from the experimental results using the gradient and *y*-intercept. To gain credit, the constants *P* and *Q* had to be the subject of the relevant equations. Credit was not awarded to candidates who did not correctly identify appropriate axes for a graph to plot.

The additional detail section had a maximum of six marks that could be awarded. Candidates should be encouraged to write their plans including appropriate detail. Vague responses were not credited. It is essential that candidates’ answers are relevant to the planned experiment rather than general ‘textbook’ rules for working in the laboratory. Statements such as ‘ensure all apparatus is working correctly’ or ‘check all connections are properly made’ will not gain credit as this is just normal good experimental procedure.

When describing safety precautions, candidates should be encouraged to explain how the precaution proposed is relevant to the experiment. In this experiment, relevant precautions would prevent damage to the block or the bench. Some candidates gained credit by suggesting the use of G-clamps to prevent the stands from falling. Vague answers such as ‘to prevent damage to apparatus’ did not gain credit.

Question 2

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

(b) The majority of the candidates correctly calculated both *V* and 1 / *V* correctly. A significant minority of weaker candidates incorrectly recorded their values of 1 / *V* to two significant figures. Since both V_1 and V_2 were recorded to three significant figures, it was expected that both *V* and 1 / *V* would be recorded to three (or four) significant figures. Another common mistake was recording the last value of 1 / *V* as 4.235 instead of 4.236, which comes from truncating the answer rather than rounding it correctly.

To determine the absolute uncertainties in *V*, it was expected that candidates would halve the range of V_1 and V_2. A common mistake was just finding the range and giving the uncertainty as ± 0.1. Most candidates who determined the uncertainty in *V* correctly then determined the absolute uncertainties in 1 / *V* correctly.

(c) (i) The data points were straightforward to plot. It is expected that the data points plotted should be clearly represented. The plotting needed to be within half a small square. 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 about the plotted data point. A clear small line should be drawn at the end of each bar. For example, for the uncertainty of ± 0.007, the error bar should be three and a half small squares in each direction from the plotted data point.

(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 data points. The worst acceptable line was drawn well in general, and many candidates drew a line which passed through all error bars. Candidates should clearly label the lines drawn as required by the question. Clear labelling should also assist candidates when they determine the gradient and *y*-intercept. Where a dashed line represents the worst acceptable line, the dashed parts of the line should cross each of the error bars.

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

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

(iv) The majority of the candidates who were awarded full credit set out their working clearly. Stronger candidates often substituted data from the gradient calculation in **(c)(iii)** into $y = mx + c$. Other errors seen included candidates incorrectly dividing the y value by mx or calculating $mx - y$.

When determining the uncertainty in the *y*-intercept, candidates needed to show the correct substitution from the worst acceptable line of both the gradient and a data point into $y = mx + c$. 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. Many weaker candidates incorrectly attempted to determine the uncertainty in the *y*-intercept by either assuming that the fractional uncertainty in the gradient was the same as the fractional uncertainty in the *y*-intercept or by adding fractional uncertainties.

(d) (i) Credit was not gained for substituting data values from the table. Most candidates realised that the constant *E* was equal to 1 / *y*-intercept. Some candidates did not gain credit because they did not give their values of *E* and *C* to an appropriate number of significant figures. Since the number of significant figures in *A* is two, *C* should be given to two (or three) significant figures. Most candidates were able to calculate a value for *C* using the gradient and either the *y*-intercept or *E*. Candidates found the power of ten for *C* and the units for both *E* and *C* to be challenging.

(ii) To gain credit, candidates needed to show their method. Many candidates realised that the percentage uncertainty in the gradient needed to be added to the percentage uncertainty in the *y*-intercept and the percentage uncertainty in *A*. Many weaker candidates did not include the percentage uncertainty in *A.* Other errors included using the uncertainty in the *y*-intercept with the value of *E* or not showing how the absolute uncertainty in *E* was determined. A small number of candidates used either a maximum or a minimum method. Clear working showing how each of the maximum or minimum values was obtained was needed for credit.

(e) It was essential that candidates showed their method of working. Stronger candidates wrote down the equation and clearly substituted in their values.

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

General comments

In **Question 1**, it is advisable that candidates should think carefully about how they would perform the experiment in the laboratory using the bullet points given to aid their answer. Planning a few key points before answering **Question 1** is useful. In particular, candidates should be encouraged to draw circuit diagrams with correct circuit symbols. Weaker candidates tended to suggest a suitable graph to draw but were not explicit in how the relationship could be proved or how the constant *K* was determined. To be awarded credit for additional detail, candidates should take care to describe exactly how each measurement will be obtained, including both the equipment used and the method to take the measurement. It is essential for candidates to have experienced practical work in preparation for answering this question.

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

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 logically so that it can be understood.

Comments on specific questions

Question 1

Most candidates correctly identified the independent and dependent variables. A small number of candidates incorrectly identified *N* or *E*. Candidates should then consider the control of variables and to explicitly state the quantities that need to be kept constant to make the experiment a fair test. In this experiment, it was expected that candidates would state that *E* would be kept constant. There was an additional credit for also stating that *N*, *A*, l and *S* would also be kept constant. Credit was not given for stating 'control' since this is just repeating the stem of the question and does not indicate what is meant by 'control'.

Candidates were awarded credit for a clearly labelled diagram. The drawing of workable circuit diagrams appeared to be challenging. Common errors included voltmeters or oscilloscopes connected in series with the circuit, an a.c. supply not being specified, and an ohmmeter being connected in series or parallel with the circuit. The need for a variable frequency supply or a signal generator was generally only described by the strongest candidates.

Candidates needed to be able to describe the methods to determine V, E and f. Stronger candidates related their descriptions to the display of the waveform on the oscilloscope. Some candidates referred to 'y-base' rather than 'y-gain' or 'voltage gain' and did not refer to the maximum height or amplitude of the waveform. Similarly, many candidates did not refer to the horizontal distance of one cycle before multiplying this distance by the time-base to determine the period of the cycle when determining frequency. Some stronger candidates gained additional credit for explaining that they would adjust the y-gain to have a large maximum amplitude, adjust the time-base for the maximum horizontal distance of one cycle, or measure the distance across n cycles and dividing this distance by n to determine the horizontal distance of one wave.

Many candidates correctly suggested the use of a ruler or calipers to measure l. Candidates should carefully consider which measuring instrument is suitable for the measurement of a length. A micrometer should only be suggested if the measurement is likely to be small. To determine A, candidates gained credit by stating the use of calipers or a micrometer to measure the diameter of the coil and then showing how A was calculated. There was additional credit for describing repeating the measurements of diameter along the coil and finding the mean diameter.

Many candidates suggested correct axes for a graph. Candidates must explicitly state the quantities to be plotted on each axis either in the text or on drawn axes – credit is not given for just writing $y = mx + c$ below 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. In this experiment, candidates needed to state that the straight line would pass through the origin. Credit was not awarded to candidates who did not correctly identify appropriate axes for a graph to plot.

Candidates needed to explain how they would determine a value for the constant K from the experimental results using the gradient. To gain credit, the constant K had to be the subject of the relevant equation. Credit was not awarded to candidates who did not correctly identify appropriate axes for a graph to plot.

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. Vague responses were not credited. It is essential that candidates' answers are relevant to the planned experiment rather than general 'textbook' rules for working in the laboratory. Statements like 'ensure all apparatus is working correctly' or 'check all connections are properly made' will not gain credit as this is just normal good experimental procedure.

When describing safety precautions, candidates should be encouraged to explain how the precaution proposed is relevant to the experiment. In this experiment, precautions when working with the hot coil or hot resistors were relevant and gained credit.

There was additional detail credit for determining the resistance S. Stronger candidates often drew a separate circuit with either the resistor connected to an ohmmeter or the resistor connected to a power supply, ammeter and voltmeter.

Question 2

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

(b) The majority of candidates correctly calculated $1 / I$. Some weaker candidates incorrectly recorded their values of $1 / I$ to two significant figures. Since I was recorded to three significant figures, it was expected that $1 / I$ would be recorded to three (or four) significant figures. Some candidates recorded 2.19 instead of 2.20 because they had truncated their answer rather than rounding it correctly.

The absolute uncertainties in $1 / I$ were usually calculated correctly. Some mistakes included writing all the uncertainties as ± 0.005 or ± 0.1.

(c) (i) The data points were straightforward to plot. It is expected that the data points plotted should be clearly represented. The plotting needed to be within half a small square. A common error was in plotting (0.111, 1.46) as (0.101, 1.46). 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 about the plotted data point. A clear small line should be drawn at the end of each bar.

(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 data points. The worst acceptable line was drawn well in general, and many stronger candidates drew a line which passed through all error bars. Candidates should clearly label the lines drawn as required by the question. Clear labelling should also assist candidates when they determine the gradient and *y*-intercept. Where a dashed line represents the worst acceptable line, the dashed parts of the line should cross each of the error bars.

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

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

(iv) The majority of the candidates who were awarded full credit set out their working clearly. Stronger candidates often substituted data from the gradient calculation in **(c)(iii)** into $y = mx + c$. Other errors seen included candidates incorrectly dividing the y value by mx or calculating $mx - y$.

When determining the uncertainty in the *y*-intercept, candidates needed to show the correct substitution from the worst acceptable line of both the gradient and a data point into $y = mx + c$. 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. Many weaker candidates incorrectly attempted to determine the uncertainty in the *y*-intercept by either assuming that the fractional uncertainty in the gradient was the same as the fractional uncertainty in the *y*-intercept or by adding fractional uncertainties.

(d) (i) Credit was not gained for substituting data values from the table. Most candidates realised that the constant R was equal to 5.8 × gradient and that constant Z was equal to 5.8 × *y*-intercept. Some candidates did not gain credit because they did not give their values of R and Z to an appropriate number of significant figures. Since the number of significant figures in E is two, R and Z should be given to two (or three) significant figures. Candidates found the power of ten for R and Z and the units for R and Z to be challenging.

(ii) To gain credit in this part, candidates needed to show their method. Firstly, candidates needed to determine the absolute uncertainty in E. Since these were repeated readings, the absolute uncertainty was equal to half the range. Many candidates realised that the percentage uncertainty in the gradient needed to be added to the percentage uncertainty in E. A significant minority of candidates incorrectly included the percentage uncertainty in the *y*-intercept.

A small number of candidates used either a maximum or a minimum method. Clear working showing how each of the maximum or minimum values were obtained was needed for credit.

(e) It was essential that candidates showed their method of working. Stronger candidates wrote down the equation and clearly substituted in their values. Most answers used powers of ten that were consistent with earlier answers.

PHYSICS

Paper 9702/54
Planning, Analysis and Evaluation

Key messages

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

General comments

In **Question 1**, it is advisable that candidates should think carefully about how they would perform the experiment in the laboratory using the bullet points given to aid their answer. Planning a few key points before answering **Question 1** is useful. Many candidates were successful in both the planning and the analysis sections, and often there was clear identification of how the constants could be determined. Weaker candidates tended to suggest a suitable graph to draw but were not explicit in how the relationship could be proved or how the constants *P* and *Q* were determined. To be awarded credit for the method and additional detail, candidates should take care to describe exactly how each quantity will be obtained, including both the equipment used and the method to take the measurement or, for a calculated quantity, the method required. It is essential for candidates to have experienced practical work in preparation for answering this question.

In **Question 2**, candidates should be familiar with completing a results table for quantities and their uncertainty, and with finding the gradient and *y*-intercept of a graph. For several candidates, credit was not awarded because the plotted points were not balanced about the line of best fit, the worst acceptable line did not pass through the error bars correctly or coordinates were wrongly read off when determining the gradient and/or *y*-intercept. Some candidates were not awarded credit because they joined the top point to the bottom point rather than drawing the line of best fit. A common mistake was to attempt to determine the absolute uncertainty in *K* using a percentage uncertainty method.

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

Comments on specific questions

Question 1

Most candidates correctly identified the independent and dependent variables. Candidates should then consider the control of variables and to explicitly state the quantities that need to be kept constant to make the experiment a fair test. In this experiment, it was expected that candidates would state that *z* would be kept constant. There was additional credit for also stating that *v* would be kept constant. Credit is not given for simply stating 'control' *z* since this is just repeating the stem of the question and does not indicate what is meant by 'control'.

Candidates were awarded credit for a clearly labelled diagram. Diagrams should be drawn of the workable experiment. In this experiment, it was important to show the sheet positioned on a bench and clearly supported in some way, for example using a stand and clamp or a block for the sheet to rest on. The path of the ball or distance *d* also needed to be shown on the diagram since the purpose of the experiment is to measure *d* for each value of θ. The expected impact position of the ball is important for the positioning of a rule and camera for accurate measurement of *d*. Ideally, candidates also included a clamped vertical rule positioned to measure *z*. This rule would need to move every time θ is changed to ensure that *z* remains constant. Additional credit was available for a drawn set square positioned to check that the rule was vertical.

The accurate measurement of *d* required a rule and a method to measure the impact point of the ball on the bench. There were many valid methods seen for this, such as the use of a video camera with slow motion playback or the use of paint or sand to more easily determine the impact point. The measurement of θ could either be done with a protractor correctly positioned (shown on the diagram) or by correct measurements to determine θ by trigonometry.

Candidates gained credit for suggesting measuring *d* with a rule and *z* with a rule or calipers. Candidates should carefully consider which measuring instrument is suitable for the measurement of a length. A micrometer should only be suggested if the measurement is likely to be small and it was not practical in this experiment.

Candidates gained credit for recognising that *v* should remain constant, but stronger candidates also went on to describe how this would be achieved, for example by keeping the height between the release point of the ball and the sheet constant. Candidates who stated that this height should be constant without linking it to *v* remaining constant were not awarded credit. Some candidates gave a relevant equation to calculate *v* but did not define the quantities in that equation. For example, $v = gt$ could be used to calculate *v*, but to gain credit *t* needed to be defined as the time for the ball to fall to the sheet. Some candidates proposed using light gates to determine *v*, but this was not a workable method for measuring *v* due to difficulty in ensuring the diameter of the ball passing through the beam and in positioning the light gate above the sheet. Some weaker candidates incorrectly determined *v* as the average speed of the ball during its fall and attempted to determine *v* by dividing the fall height by the time taken to fall, or by using two light gates.

Many candidates suggested correct axes for a graph. Candidates must explicitly state the quantities to be plotted on each axis either in the text or on drawn axes – credit is not given for just writing $y = mx + c$ below 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. In this experiment, credit was not given for stating that the straight line would pass through the origin since there would be a *y*-intercept. Stronger candidates often stated the *y*-intercept that the line would pass through. Credit was not awarded to candidates who did not correctly identify appropriate axes for a graph to plot.

Candidates needed to explain how they would determine a value for the constants *P* and *Q* from the experimental results using the gradient and *y*-intercept. To gain credit, the constants *P* and *Q* had to be the subject of the relevant equations. Credit was not awarded to candidates who did not correctly identify appropriate axes for a graph to plot.

The additional detail section had a maximum of six marks that could be awarded. Candidates should be encouraged to write their plans including appropriate detail; some candidates’ answers suggested that they did not have sufficient practical experience. Vague responses were not credited. It is essential that candidates’ answers are relevant to the planned experiment rather than general ‘textbook’ rules for working in the laboratory. Statements such as ‘ensure all apparatus is working correctly’ or ‘check all connections are properly made’ will not gain credit as this is just normal good experimental procedure.

When describing safety precautions, candidates should be encouraged to explain how the precaution proposed is relevant to the experiment. In this experiment, relevant precautions would be ways to stop the ball rolling onto the floor or using eye protection to prevent being struck in the eye by the ball or sand. Trays or cushions placed on the floor were not given credit; the best safety precautions would stop the ball while it is still on the bench.

Two marks that were difficult to obtain were for describing a method to maintain a constant value for *z* and a method to ensure that the ball impacted the sheet at the measured *z* position. These were both very specific to this experiment and those candidates who had carefully thought through how they would practically carry out this experiment were more successful.

Question 2

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

(b) The majority of the candidates correctly calculated lg μ and lg λ correctly. Many candidates also correctly calculated the uncertainty in lg μ. A minority of candidates gave one or more of the values to too few decimal places. Some candidates appeared to be trying to match the significant figures in the calculated log values to the original data, not realising that the decimal places in a calculated log value must match the number of significant figures in the data used. Since the values of μ were all given to two significant figures, the values of lg μ should have been recorded to two (or three) decimal places.

(c) (i) The data points were straightforward to plot. It is expected that the data points plotted should be clearly represented. The plotting needed to be accurate to less than half a small square in both the *x* and *y* directions. 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 about the plotted data point. A clear small vertical line should be drawn at the end of each bar.

(ii) Most candidates appear to be using a sharp pencil and a transparent 30 cm ruler. For correctly plotted data, the line of best fit did not pass through both the highest and lowest points. The worst acceptable line was drawn well in general, and many stronger candidates drew a line which passed through all error bars. Candidates should clearly label the lines drawn as required by the question. Clear labelling should also assist candidates when they determine the gradient and *y*-intercept. Where a dashed line represents the worst acceptable line, the dashed parts of the line should cross each of the error bars.

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

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

(iv) The majority of the candidates who were awarded full credit set out their working clearly. Stronger candidates often substituted data from the gradient calculation in **(c)(iii)** into $y = mx + c$. Some weaker candidates incorrectly read off the *y*-intercept when the *x*-axis reading was 0.6. Other errors seen included candidates incorrectly dividing the *y* value by *mx* or the use of a plotted point that did not lie on the line of best fit.

When determining the uncertainty in the *y*-intercept, candidates needed to show their working including both the gradient and a coordinate 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. Many candidates incorrectly attempted to calculate the *y*-intercept of the worst acceptable line using the gradient of the line of best fit, or used the same coordinate that they used when finding the *y*-intercept of the line of best fit.

(d) Stronger candidates showed clear working for their determination of *k* and *n*. A clear method for *n* often included a statement that *n* = gradient followed by their gradient value and finally *n*. A clear method for *k* often included a statement that *y*-intercept = lg *k* then a substitution and rearrangement leading to the correct value of *k*. Some candidates calculated these values correctly but were not awarded credit because they gave one or both to an incorrect number of significant figures. The original data in the question is given to a minimum of two significant figures and so both *n* and *k* should be given to two or three significant figures.

Candidates also needed to determine the uncertainty in both *n* and *k*. The uncertainty in *n* should be equal to the uncertainty in the gradient, but the uncertainty in *k* had to be calculated using the maximum and/or minimum values of *k*. Candidates who were awarded credit clearly showed how the uncertainty in *k* was calculated with a clear method and full substitution of data from **(c)(iv)** including a subtraction to give the uncertainty. Some candidates incorrectly attempted to determine the uncertainty via a fractional or percentage method.

(e) It was essential that candidates showed their method of working. Stronger candidates wrote down the equations and clearly substituted in their values before carefully showing the working in steps.