# PHYSICS

**Paper 9702/11**
**Multiple Choice**

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

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

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

| Question Number | Key |
|---|---|
| 31 | D |
| 32 | C |
| 33 | A |
| 34 | A |
| 35 | D |
| 36 | D |
| 37 | C |
| 38 | A |
| 39 | A |
| 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.

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.

Candidates generally performed better on problems involving a calculation and found questions involving algebraic representations or verbal reasoning more challenging.

In general, candidates found **Questions 12**, **13**, **25**, **26**, **34** and **35**, relatively difficult. Candidates found **Questions 11**, **17**, **18**, **21**, **22**, **24**, **31**, **37** and **38** relatively easy.

## Comments on specific questions

### Question 1

This was answered correctly by the majority of candidates. A small minority of candidates selected incorrect option **B**, which identified charge as a vector. Candidates are reminded to carefully check all the columns in each option.

**Question 3**

This was straightforward for stronger candidates. For weaker candidates the most popular incorrect option was **A**, indicating some confusion between SI units and SI base units.

**Question 4**

This question was also straightforward for stronger candidates. Weaker candidates chose incorrect option **A** as frequently as the correct option **C**. This suggest that candidates think a force is required to 'close' the triangle presented, confusing this with an equilibrium problem.

**Question 7**

Candidates found this more challenging. Fewer than half selected the key **B**. Incorrect options **A** and **C** were the most popular. Incorrect option **A** tested the misconception that the horizontal distance travelled is independent of the vertical distance travelled. Candidates who selected incorrect option **C** thought that as the vertical distance had increased by a factor of **4**, the horizontal distance must also have increased by a factor of **4**. The easiest way to solve this problem was by using $4y = \frac{1}{2}gt^2$, meaning that the time for the second object to reach the ground was twice the time for the initial object to reach the ground. As the initial horizontal speeds are the same the second object would travel twice as far as the first.

**Question 8**

The majority of candidates correctly selected the correct option **C**. Option **D** was the most popular incorrect option, with these candidates perhaps confusing a decreasing acceleration with a negative acceleration.

**Question 9**

This was straightforward for most, but a significant minority selected incorrect option **A**, indicating that many candidates do not understand the requirement for an isolated system in the conservation of momentum, even when that option is presented to them.

**Question 11**

A large majority of candidates correctly selected option **A**. Even if candidates were unfamiliar with Newton's second law, the obvious presentation of $5000\,\text{kg m s}^{-1}$ and $10\,\text{s}$ will have encouraged many to find a ratio.

**Question 12**

Candidates found this very challenging, with the correct option **A** and two incorrect options **B** and **C** proving equally popular. To solve this problem, candidates needed to recognise that the upward force would be equal to the resultant force + weight. Many candidates assumed the upward force would be equal to the resultant force only (option **B**) or the resultant force minus the weight (option **C**).

**Question 13**

Stronger candidates found this moments question straightforward. Weaker candidates overwhelmingly selected incorrect options **C** (component of weight parallel to the rod) and **D** (component of weight perpendicular to the rod), neglecting to account for the different distances of the weight and $F$ to the pivot.

**Question 18**

This was generally answered correctly, demonstrating that most candidates had a good understanding of the conservation of energy. A few candidates selected each of the three incorrect options, but even amongst the weakest candidates the correct option (**C**) was the most popular choice.

**Question 19**

Many candidates found this question challenging. Having been provided with a velocity and asked for 'work done per unit time', candidates were expected to realise they were determining power and recall the power equation $P = Fv$. Many candidates selected incorrect option **B** (distance travelled per unit time, i.e. the velocity they already had), suggesting that they did not understand what was required.

**Question 25**

This was a very challenging question. All the options were frequently selected, with **A** being the most common incorrect choice. Candidates should be familiar with graphical representations of longitudinal waves, so this topic would benefit from more practice.

**Question 26**

Candidates found this application of Malus's law challenging. The most commonly selected incorrect option was **C**, which is a result of using 20° (the angle to the vertical) rather than 30° (the angle between the transmission axes of the first and second filters) for the second use of Malus's law. Candidates are reminded to carefully read the question as this information was clearly presented in the question text.

**Question 28**

Stronger candidates found this question straightforward. The weakest candidates appeared to be guessing, and so perhaps did not recognise that this was a problem in which Young's double-slit equation could be applied. The most popular incorrect option was **B**, which results from incorrect determining the fringe spacing as $(34 \times 10^{-3} / 5)$ rather than the correct $(34 \times 10^{-3} / 4)$.

**Question 29**

This was another question requiring candidates to interpret the graphical presentation of a wave, and candidates again struggled. All the options were selected fairly often, suggesting candidates are not confident of the differences between progressive and stationary waves.

**Question 33**

A majority of candidates correctly selected option **A**, with the stronger candidates finding this straightforward. For the weaker candidates incorrect options **B** and **C** were roughly equally as popular as the key, suggesting that most candidates could identify one correct diagram, but were then guessing between the remaining options. Knowledge of the I-V characteristics of both a filament lamp and a diode is a specific learning outcome on the syllabus and should be practiced.

**Question 34**

This was a challenging question. Even amongst the strongest candidates only around half correctly selected the key **A**.

The most straightforward approach to solving this problem was to determine the p.d. across the 2.0 Ω resistor ($3.0 \times 2.0 = 6.0$ V) and then apply Kirchoff's law to the left-hand loop to determine the p.d. across resistor P ($9.0 - 6.0 - 1.0 = 2.0$ V). Candidates could then apply Kirchoff's first law to the middle branch to get the current through P ($2.0 + 3.0 = 5.0$A) and then use $R = V / I$ for P ($2.0 / 5.0 = 0.40\ \Omega$).

**Question 37**

Candidates found this straightforward, with the majority selecting the key, **C**, indicating a good understanding of Kirchhoff's first law as applied to a circuit diagram.

**Question 39**

This question was easy for most candidates. A small number of very weak candidates opted for incorrect option B, confusing or misreading the charge on W as $-1.96 \times 10^{-19}$ C. Incorrect options **C** and **D** were not selected very often, indicating candidates are confident of the difference between proton number and nucleon number.

**Question 40**

The majority of candidates correctly identified the positron as a lepton. A significant minority chose one of the incorrect options, with all three incorrect options selected roughly equally suggesting that candidates who were unsure were guessing. Candidates should be able to identify the main classes of particle, and examples of each, as stated in the syllabus.

# PHYSICS

**Paper 9702/12**
**Multiple Choice**

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

## 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 apply a common-sense check to their answers to ensure they are a sensible magnitude. Candidates commonly forget powers of 2 and factors of half and should be aware of these common mistakes.

Candidates often struggle with graphical representations of waves, and whilst this was true on this paper for weaker candidates, the stronger candidates did well on these questions.

Candidates should be familiar with the definitions of physical quantities in the syllabus.

Candidates found the circuits questions challenging and might benefit from more practical experience constructing and taking measurements from a variety of circuits.

Candidates found the questions on subatomic particles and nuclear decay challenging. More understanding of these concepts is required.

In general, candidates found **Questions 11**, **12**, **14**, **19**, **32**, **34**, **35** and **46** relatively difficult. Candidates found **Questions 1**, **5**, **8**, **13**, **15**, **16**, **18**, **21** and **25** relatively easy.

**Comments on specific questions**

**Question 1**

This question was answered correctly by the vast majority of candidates. Only very weak candidates chose incorrect options **A** (confusing mass with weight) and **C** (confusing mass with weight and also confusing grams with kg).

**Question 4**

Candidates found this quite challenging, with a little over half correctly identifying the correct option (**C**). Candidates needed to recall the formula $a = 2s / t^2$ and then recognise that the percentage error in $a = 2 \times$ percentage error in $t$ (as the error in displacement is negligible). **B** was the most popular incorrect option, a result of neglecting the factor of 2. Candidates should be familiar with calculating percentage and absolute uncertainties.

**Question 6**

This was straightforward for the stronger candidates, but weaker candidates found it more challenging. The question required candidates to first determine the acceleration of the bicycle and then apply that acceleration to find the further distance travelled, using an initial velocity of $7\,\text{m}\,\text{s}^{-1}$ and a final velocity of 0. The most popular incorrect option was **D**, which results from candidates assuming that as the change in velocity to come to rest is three times as large, the distance travelled must also be three times as large.

**Question 7**

Although most candidates correctly selected option **A**, some chose incorrect option **C** indicating that these candidates do not know the difference between distance travelled and displacement. Candidates should be able to identify the key quantities within the syllabus.

**Question 10**

This question was straightforward for most candidates. The most popular incorrect option was **A**. This suggests that some candidates think a momentum vector is required to "close" the triangle presented, confusing this with an equilibrium problem.

**Question 11**

This was a challenging question. Overall incorrect option **B** was the slightly more popular choice, with the correct option **A**, and incorrect options **C** and **D** selected roughly equally. Candidates are perhaps used to questions where the drag force increases with increasing speed, and so selected incorrect option **B** on the basis that the speed was greatest at $t_1$. However, this reasoning does not account for the fact that at both $t_3$ and $t_1$ the skydiver is experiencing zero resultant force, and so at both instants the drag force must be equal to her weight. Candidates are encouraged to deal with unfamiliar problems by starting from first principles and working forward from these.

**Question 12**

A little under half of candidates correctly selected the correct option (**D**). Without being given the masses of P and Q it was not possible to solve this problem using conservation of momentum. Those who recalled that for an elastic collision the relative speed of approach must equal the relative speed of separation could quickly narrow down the options to **C** or **D**. Candidates could then rule out **C** as these initial velocities would not lead to a collision.

**Question 13**

This was relatively easy for most candidates, with almost all selecting **A**, showing a good understanding of representations of a couple.

**Question 18**

On the whole candidates found this question straightforward. There were however a small number of candidates who selected incorrect option **D**, adding the two heights rather than finding the difference. Candidates are encouraged to always consider whether they are working with scalar or vector quantities, and to draw diagrams to help interpret written problems.

**Question 21**

Around three quarters of candidates correctly selected 'compression' as the answer. However, a significant number selected one of the three incorrect options. Candidates should know the correct meaning of all the terms listed in the syllabus.

**Question 25**

Phase difference is a topic that candidates often find challenging, but this was generally well answered, with most candidates selecting the correct option (**B**). Incorrect options **A** and **C** were selected roughly equally, with candidates perhaps mistaking the initial position of particle B and thinking that phases differences of 180° and 540° are the same.

**Question 26**

This proved challenging for weaker candidates. The stronger candidates correctly applied intensity is proportional to amplitude$^2$ and arrived at the correct option **D**. Many candidates simply took the ratio of the amplitudes and selected **C**. A similar number took the inverse ratio of the amplitudes, and did not realise that as Y has a large amplitude it must also have a larger intensity, so selected **B**. **A** was popular with the weakest candidates, suggesting that many were guessing.

**Question 29**

This question was straightforward for the stronger candidates. The most popular incorrect answer was **C**, 'order of intensity maximum'. It is possible that candidates confused the diffraction grating equation with Young's double-slit equation and so thought that the correct option could not be **A**. Candidates should know what each quantity represents in all the equations listed in the syllabus.

**Question 30**

A majority of candidates chose the correct answer (**C**), but all three incorrect options were selected frequently. Candidates selecting **D** confused nodes and antinodes. Candidates selecting **A** and **B** are demonstrating a common misconception about the formation of stationary waves, perhaps confusing this with the formation of interference fringes.

**Question 31**

Some candidates incorrectly selected incorrect option **B** 'doppler shift', perhaps confusing varying loudness with vary frequency. Candidates are reminded to carefully read the question.

**Queston 32**

Weaker candidates found this question challenging. Roughly equal numbers of candidates selected incorrect option **C** and the correct option **D**. Candidates selecting **D** had realised that the resistance remained constant, and so the correct power formula was $P = I^2R$, meaning the new power depended on the ratio of the **square** of the currents. Those selecting **C** had perhaps assumed a constant potential difference and so scaled the new power by the ratio of the currents.

**Question 34**

This question tested the distinction between e.m.f. and terminal p.d. Fewer than half of candidates correctly selected the correct option **D**, with a large number of candidates selecting **A** (neglecting the energy dissipated in the internal resistance) or **B** (neglecting the energy dissipated in the external circuit). Students should be aware of the distinction between these key ideas.

**Question 35**

Candidates found this question challenging, particularly the weaker candidates. Those who recognised an increase in temperature would lead to a decrease in the resistance of the thermistor, and so an increase in p.d. on the voltmeter could eliminate options **A** and **B**. Candidates then had to recognise that the ratio of resistances had become 2:1 and so the p.d. on the voltmeter would be $2 / 3 \times 60 = 40\,\text{V}$.

Weaker candidates struggled to manipulate the ratios of resistances correctly, and or became confused by the change to the resistance.

**Question 36**

Candidates found this question challenging. The use of a galvanometer to determine the EMF of a cell is an example of a null method. Approximately half of the stronger candidates correctly selected the correct option (**D**), but most candidates appeared to be guessing. Candidates would benefit from practical experience constructing circuits to help understand how this method works in practice.

**Question 37**

Stronger candidates found this simple definition easy, but nearly a quarter of candidates overall selected option **B**, confusing voltage and energy. It is essential that candidates know the definitions of the key terms in the syllabus.

**Question 38**

Candidates found this challenging. The most popular incorrect option was **A**, which gave the change in the magnitude of the charge, but not the magnitude of the change in the charge. Incorrect options **B** and **D** were also popular indicating a lack of confidence in the charges on quarks.

# PHYSICS

**Paper 9702/13**
**Multiple Choice**

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

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.

Candidates generally performed better on problems involving a calculation and found questions involving algebraic representations or verbal reasoning more challenging.

In general, candidates found **Questions 12**, **13**, **25**, **26**, **34** and **35**, relatively difficult. Candidates found **Questions 11**, **17**, **18**, **21**, **22**, **24**, **31**, **37** and **38** relatively easy.

## Comments on specific questions

### Question 1

This was answered correctly by the majority of candidates. A small minority of candidates selected incorrect option **B**, which identified charge as a vector. Candidates are reminded to carefully check all the columns in each option.

**Question 3**

This was straightforward for stronger candidates. For weaker candidates the most popular incorrect option was **A**, indicating some confusion between SI units and SI base units.

**Question 4**

This question was also straightforward for stronger candidates. Weaker candidates chose incorrect option **A** as frequently as the correct option **C**. This suggest that candidates think a force is required to 'close' the triangle presented, confusing this with an equilibrium problem.

**Question 7**

Candidates found this more challenging. Fewer than half selected the key **B**. Incorrect options **A** and **C** were the most popular. Incorrect option **A** tested the misconception that the horizontal distance travelled is independent of the vertical distance travelled. Candidates who selected incorrect option **C** thought that as the vertical distance had increased by a factor of **4**, the horizontal distance must also have increased by a factor of **4**. The easiest way to solve this problem was by using $4y = \frac{1}{2}gt^2$, meaning that the time for the second object to reach the ground was twice the time for the initial object to reach the ground. As the initial horizontal speeds are the same the second object would travel twice as far as the first.

**Question 8**

The majority of candidates correctly selected the correct option **C**. Option **D** was the most popular incorrect option, with these candidates perhaps confusing a decreasing acceleration with a negative acceleration.

**Question 9**

This was straightforward for most, but a significant minority selected incorrect option **A**, indicating that many candidates do not understand the requirement for an isolated system in the conservation of momentum, even when that option is presented to them.

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A large majority of candidates correctly selected option **A**. Even if candidates were unfamiliar with Newton's second law, the obvious presentation of $5000\,\text{kg m s}^{-1}$ and $10\,\text{s}$ will have encouraged many to find a ratio.

**Question 12**

Candidates found this very challenging, with the correct option **A** and two incorrect options **B** and **C** proving equally popular. To solve this problem, candidates needed to recognise that the upward force would be equal to the resultant force + weight. Many candidates assumed the upward force would be equal to the resultant force only (option **B**) or the resultant force minus the weight (option **C**).

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**Question 19**

Many candidates found this question challenging. Having been provided with a velocity and asked for 'work done per unit time', candidates were expected to realise they were determining power and recall the power equation $P = Fv$. Many candidates selected incorrect option **B** (distance travelled per unit time, i.e. the velocity they already had), suggesting that they did not understand what was required.

**Question 25**

This was a very challenging question. All the options were frequently selected, with **A** being the most common incorrect choice. Candidates should be familiar with graphical representations of longitudinal waves, so this topic would benefit from more practice.

**Question 26**

Candidates found this application of Malus's law challenging. The most commonly selected incorrect option was **C**, which is a result of using 20° (the angle to the vertical) rather than 30° (the angle between the transmission axes of the first and second filters) for the second use of Malus's law. Candidates are reminded to carefully read the question as this information was clearly presented in the question text.

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Stronger candidates found this question straightforward. The weakest candidates appeared to be guessing, and so perhaps did not recognise that this was a problem in which Young's double-slit equation could be applied. The most popular incorrect option was **B**, which results from incorrect determining the fringe spacing as $(34 \times 10^{-3} / 5)$ rather than the correct $(34 \times 10^{-3} / 4)$.

**Question 29**

This was another question requiring candidates to interpret the graphical presentation of a wave, and candidates again struggled. All the options were selected fairly often, suggesting candidates are not confident of the differences between progressive and stationary waves.

**Question 33**

A majority of candidates correctly selected option **A**, with the stronger candidates finding this straightforward. For the weaker candidates incorrect options **B** and **C** were roughly equally as popular as the key, suggesting that most candidates could identify one correct diagram, but were then guessing between the remaining options. Knowledge of the I-V characteristics of both a filament lamp and a diode is a specific learning outcome on the syllabus and should be practiced.

**Question 34**

This was a challenging question. Even amongst the strongest candidates only around half correctly selected the key **A**.

The most straightforward approach to solving this problem was to determine the p.d. across the 2.0 Ω resistor $(3.0 \times 2.0 = 6.0\,\text{V})$ and then apply Kirchoff's law to the left-hand loop to determine the p.d. across resistor P $(9.0 - 6.0 - 1.0 = 2.0\,\text{V})$. Candidates could then apply Kirchoff's first law to the middle branch to get the current through P $(2.0 + 3.0 = 5.0\text{A})$ and then use $R = V / I$ for P $(2.0 / 5.0 = 0.40\,\Omega)$.

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This question was easy for most candidates. A small number of very weak candidates opted for incorrect option B, confusing or misreading the charge on W as $-1.96 \times 10^{-19}$ C. Incorrect options **C** and **D** were not selected very often, indicating candidates are confident of the difference between proton number and nucleon number.

**Question 40**

The majority of candidates correctly identified the positron as a lepton. A significant minority chose one of the incorrect options, with all three incorrect options selected roughly equally suggesting that candidates who were unsure were guessing. Candidates should be able to identify the main classes of particle, and examples of each, as stated in the syllabus.

# PHYSICS

**Paper 9702/14**
**Multiple Choice**

| Question Number | Key | Question Number | Key | Question Number | Key | Question Number | Key |
|---|---|---|---|---|---|---|---|
| 1 | C | 11 | B | 21 | B | 31 | B |
| 2 | B | 12 | C | 22 | A | 32 | A |
| 3 | B | 13 | D | 23 | C | 33 | A |
| 4 | C | 14 | C | 24 | D | 34 | D |
| 5 | A | 15 | C | 25 | A | 35 | D |
| 6 | B | 16 | A | 26 | B | 36 | C |
| 7 | D | 17 | B | 27 | C | 37 | A |
| 8 | C | 18 | C | 28 | C | 38 | D |
| 9 | A | 19 | B | 29 | C | 39 | A |
| 10 | D | 20 | D | 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 would benefit from being able to recognise common mistakes with definitions, for example confusing definitions for units and quantities.

Candidates overall performed very well on questions involving a calculation, even where the calculation was quite complex, but performed poorly on questions involving definitions or descriptions of physical concepts.

Candidates were very strong on some electrical topics, and very weak on others. Candidates should be familiar with all parts of the syllabus.

In general, candidates found **Questions 9**, **16**, **22**, **25**, **34** and **37** difficult. Candidates found **Questions 7**, **8**, **21** and **23** relatively easy.

## Comments on specific questions

### Question 1

Most candidates selected either the correct option **C**, or incorrect option **D**. Candidates should pay close attention to the difference between the options and should bear in mind that whilst the SI system is the preferred system of measurement, it is not the only system.

**Question 3**

Candidates typically find determining a percentage uncertainty for a calculated quantity challenging, but this question was answered correctly by the majority of candidates.

**Question 5**

A small majority of candidates selected the correct option **A**. Incorrect option **B** was the most common incorrect answer, with candidates confusing a varying acceleration with a varying velocity. Projectile motion is a very common topic, and candidates should be familiar with the motion of an object with uniform velocity in one direction and uniform acceleration in a perpendicular direction as stated in the syllabus.

**Question 7**

All Candidates found this question straight-forward, suggesting a secure knowledge of graphical representations of motion.

**Question 9**

Candidates found this question extremely challenging, with even the strongest candidates struggling to identify the correct option (**A**). Most candidates selected incorrect option **B**, which can only be true in the absence of a drag force, but the question states the sphere is moving downwards at terminal velocity so this cannot be the case. Weaker candidates appeared to be guessing. Candidates are reminded in unfamiliar problems to start from first principles and work forward from there.

**Question 11**

This question discriminated well between the strong and weaker candidates. Many stronger candidates correctly identified the correct option as **B**, recognising the distinction between relative speed and relative velocity. The weakest candidates were split fairly evenly across all the options. **A** was the most frequently selected incorrect option, with candidates confusing the magnitude of the force with the vector nature of the force. Candidates are reminded to pay careful attention to the distinction between scalars and vectors, especially in the context of collisions.

**Question 15**

This question was answered well, with a majority of candidates correctly selecting the correct option, **C**. Even amongst weaker candidates nearly half were able to correctly use the principle of moments to determine the correct answer.

**Question 16**

This question was conceptually difficult for many. Slightly fewer than half of candidates selected the correct option (**A**), with **D** being the most popular incorrect option. This suggests that most candidates were capable of identifying the gain in gravitational potential energy of block P, but fewer recognised that this was equal in magnitude to the product of tension force and velocity.

**Question 19**

Although a majority of candidates correctly selected **B**, a significant minority selected each of the three incorrect options. Candidates are typically able to recall the formula $\Delta E_P = mg\Delta h$ but should also be familiar with the conditions under which the formula is valid.

**Question 22**

This question discriminated effectively, with many of the strongest candidates able to identify that each spring would experience a force of F / 2 and combine this with the formula $E_P = \frac{1}{2}Fx$. Many weaker candidates selected incorrect option **B**, correctly recalling the formula but not accounting for both springs. Incorrect option **C** was also very popular, with candidates recalling $E_P = \frac{1}{2}kx^2$ but incorrectly assuming the spring constant of each spring had become $k / 2$.

**Question 24**

This proved challenging, with fewer than half of candidates selecting the correct option **D**. Incorrect option **A** was the most popular incorrect choice, indicating that many candidates believe the particles in a transverse wave move in the direction of travel of the wave. Candidates would benefit from more practice interpreting graphical representations of both transverse and longitudinal waves.

**Question 25**

This question was answered poorly, with fewer than half able to recall key facts about electromagnetic waves. Nearly a third of candidates selected option **D**, suggesting that candidates do not have a good understanding of the difference between electromagnetic waves and mechanical waves. Candidates should be able to describe the key features of electromagnetic waves as given in the syllabus.

**Question 31**

The majority of candidate selected the correct option (**B**), but a significant minority chose incorrect options **A** and **D**, both of which demonstrate persistent misunderstandings. Candidates should be confident of the conditions required for coherence and should be aware that a constant phase difference need not be a constant phase difference of zero.

**Question 33**

This question was answered correctly by most candidates, indicating a good understanding of the connection between physical circuits and circuit diagrams.

**Question 34**

This proved challenging, even for the stronger candidates. Candidates needed to use $R = \rho L / A$ to determine the resistance in the thinner section of wire was four times the resistance in the thicker section of wire, and then apply $P = I^2 R$ with a constant current to determine the correct option **D**. Weaker candidates apparently guessed at the answer to this question. All four options were selected frequently, suggesting many candidates struggled to recognise or manipulate the equations required.

**Question 36**

This question was very straight-forward, with a majority of candidates correctly determining the correct option **C**. Candidates were clearly well-prepared to analyse resistor networks.

**Question 37**

Conversely, candidates found this question harder than expected. Considering the relative success on **Question 36**, this is challenging to explain, as many of the same physical principles apply. Candidates frequently selected incorrect options **B** and **C**, suggesting that the effect of introducing a parallel resistor is not well understood, nor the effect of internal resistance on the terminal p.d. of a source.

**Question 38**

Stronger candidates found this simple recall question trivial, but weaker candidates appeared to be guessing. Candidates should be able to recall the changes involved in alpha and beta decays.

# PHYSICS

**Paper 9702/21**
**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 rearranged. In some questions, credit can be awarded for correct statements of physical equations, but only where the whole equation is clearly shown. Candidates should not rely on the examiner to infer a subject for an expression given in the working.
- Candidates should pay attention to the units and powers of ten in which information is presented to avoid transcription errors and ensure that they are converting answers into SI base units where appropriate.
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- When describing mathematical relationships, candidates should be careful to use precise mathematical language. In particular, the words 'into' and 'by' are used to mean both multiply and divide in different parts of the world making it impossible to infer which meaning is intended. Candidates should explicitly state when they are referring to multiplication or division.

## General comments

Candidates generally presented the quantitative 'show that' questions with well-presented working and the necessary detail. Many candidates found the algebraic 'show that' question more demanding.

A significant number of the weaker candidates found it difficult to give correct definitions. The words used often needed to be more accurate or detailed.

Candidates found **Questions 1(a)**, **1(b)**, **1(c)(i)**, **1(c)(ii)**, **2(a)(i)**, **2(b)(i)**, **3(a)**, **3(b)(i)**, **3(d)(i)**, **4(b)(i)**, **4(b)(ii)**, **5(a)**, **6(a)** and **6(b)** to be relatively straightforward.

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

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

## Comments on specific questions

### Question 1

**(a)** The majority of the candidates gave an appropriate definition of acceleration. A small number gave 'the rate of change of velocity per unit time' which is not acceptable as it implies the *second* derivative of velocity. Some weaker candidates gave 'velocity / time' which is incorrect.

**(b) (i)** The majority of the candidates correctly obtained the acceleration using the gradient of the velocity–time graph.

**(ii)** The majority of the candidates gave full working for this 'show that' question using an equation of uniform acceleration or the area under the velocity–time graph.

**(c) (i)** Most candidates used the correct expression for the gravitational potential energy. A small number used the change in height in kilometres instead of metres.

**(ii)** Most candidates used the correct expression for the change in kinetic energy. A small number did not square the velocity in their calculation. Most read the correct velocity from the graph. The most common incorrect value used for the velocity was $20\,m\,s^{-1}$, which was the time of flight.

**(iii)** The majority of the candidates started with a correct expression for power, in this case work done / time or change in energy / time. The correct average power was determined by the more able candidates. A significant number attempted to use $P = Fv$ with $F = ma$ without success. A similar number only included the change in gravitational potential energy or only the change in kinetic energy. A small number divided the change in energy by two to determine the average power.

**Question 2**

**(a) (i)** The definition of pressure was given by most candidates. A small number gave a statement where the ratio of force to area was not clear. 'Force by area' and 'force on area' were two common incorrect answers.

**(ii)** Candidates found this question difficult. A small number of candidates were able to identify that upthrust is a result of a difference in pressure between the top and bottom surfaces of the object, and fewer clearly linked this difference in pressure to a difference in the force acting on the top and bottom of the object.

Very weak candidates sometimes confused upthrust with drag or thought that Newton's third law of motion meant that the weight of the object and the upthrust were equal and opposite. Some candidates only stated that the upthrust was equal to the weight of displaced liquid without any further explanation. Others demonstrated misconceptions by stating that upthrust was the reaction to weight or stating that upthrust was a resistive force.

**(b) (i)** The majority of the candidates drew correct arrows for weight and either the drag force or the upthrust. A significant number showed the drag force acting downwards when the ball was travelling downwards in the oil. There were a significant number of diagrams where the arrows were not vertical and some that were not labelled. A small number of candidates labelled the viscous drag force as air resistance. A similar number labelled the weight force as simply 'gravity' which was not credited.

**(ii)** The SI base units of $\eta$ were determined by more able candidates. Some left newtons in their final answer or made arithmetic errors when cancelling the powers for seconds in the units of acceleration or velocity.

**(c) (i)** The stronger candidates were able to substitute all the values required in the formula for upthrust (which is given on the data and formulae page of the question paper). The weaker candidates were unable to show the working for the volume of a sphere, and sometimes attempted to determine the volume of the sphere by using the density of the liquid and the mass of the sphere.

**(ii)** Stronger candidates determined the terminal speed of the ball by relating the three forces acting on the ball. Many candidates equated the drag force with the weight or equated the drag force with the upthrust.

**Question 3**

**(a)** The definition of the Young modulus was given by most candidates. Some candidates did not give a statement that indicated a ratio between stress and strain. 'Stress by strain' or 'stress on strain' were not accepted. Candidates are reminded that 'by' could mean 'multiplied by' or 'divided by' and so precise mathematical language should be used.

**(b) (i)** The stronger candidates gave the expression that links resistance with resistivity. Weaker candidates often tried to use all four quantities listed in the question.

**(ii)** The stronger candidates gave the expression for the definition of the spring constant $k$ and then used expressions for stress and strain to obtain the required relationship between $k$ and $E$. Weaker candidates were often unable to link the expression for the spring constant with that for the Young modulus.

**(c) (i)** The correct straight-line graph was drawn by the strongest candidates. A significant number did not start the resistance at $R_0$ when the force was zero or had the resistance decreasing with increased force. Many candidates gave the resistance as zero when the force was zero and the wire was at its original length. A nonlinear graph was often drawn by weaker candidates.

**(ii)** Many candidates did not draw a graph indicating that the spring constant is constant. There were many straight-line graphs with positive or negative gradients and many that started from the origin.

**(d) (i)** Stronger candidates gave the full substitution of the quantities required to calculate the length of the wire. There were some that did not show the calculation of the area, used the diameter instead of the radius or did not convert from millimetres to metres.

**(ii)** There were many good answers. Some of the candidates gave no response even though the question directs them to the correct formula. A significant number of candidates made an error in the calculation of the area or used a value for the area rounded early to one or two significant figures, leading to an incorrect final answer.

**Question 4**

**(a)** Many candidates found it difficult to describe diffraction. There were many answers that described a wave bending after passing through obstacles. The bending or change of direction of the wave suggests refraction rather than diffraction.

**(b) (i)** The majority of the candidates started with the correct equation for a diffraction grating. Most candidates were able to convert the wavelength in nanometres into metres.

**(ii)** Most candidates obtained the angle for the second-order fringe. A small number of candidates did not know the equation that is applied to a diffraction grating. A significant number doubled the answer from **(b)(i)**.

**(iii)** Only the strongest candidates drew the peak intensities of bright fringes at the angles determined in the previous parts with zero intensity in between.

**(c)** The reduction to half the original intensity was given by the strongest candidates. Some candidates stated that there would be a decrease in intensity without qualifying their answer. The question specified the filter being rotated by 45° and not just being moved from the vertical. A comment describing the fringes at the same angle of deflection was very rarely seen. Many weaker candidates did not give a response.

**Question 5**

**(a)** Most candidates gave an acceptable statement of Kirchhoff's first law. There were some answers that omitted the 'sum of' the currents or omitted that the currents were entering and leaving a 'junction' in the circuit. A small minority stated Kirchhoff's second law.

**(b) (i)** The majority of the candidates started a line at $R_0$. There were a significant number that drew a line with positive gradient. A significant number drew a line that unrealistically reached zero resistance before or at a temperature of 100 °C. There were many lines drawn with a large horizontal section suggesting that the resistance is constant for a range of temperatures.

**(ii)** There were many descriptions that did not give an answer *with reference to the current in the cell*. Many answers described the resistance of the thermistor decreasing and then stated that more current passes through the thermistor and less through the resistor R. The effect of the reduction in the thermistor resistance on the total resistance of the circuit and hence the current in the cell was only stated by a small number of candidates. The effect of an increased current on the 'lost volts' in the cell, the terminal potential difference of the cell and the potential difference across R was only mentioned by a very small number of stronger candidates.

**(c) (i)** The calculation of the current in the cell was generally only completed by the more able candidates. Many candidates used the e.m.f. of the cell as the potential difference across the internal resistance. Very few candidates calculated the terminal potential difference or the potential difference across the internal resistance.

**(ii)** The calculation of the resistance of the thermistor was determined by the more able candidates. Many candidates used the e.m.f. of the cell as the potential difference across the thermistor, which mean that the effect of the internal resistance of the cell on the circuit was ignored.

**Question 6**

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

**(ii)** This question was well answered by most candidates. There were some diagrams in which the protons and neutrons were not labelled, or where individual particles were not shown.

**(b) (i)** This question was well answered by most candidates. There were a significant number of answers where the values given for the helium and beta particle did not balance with those of the tritium nucleus.

**(ii)** There were many correct answers. A common error was to state the particle as an anti-electron neutrino or a neutrino.

**(c)** There were a significant number of correct answers. Some candidates gave incorrect numbers of protons and neutrons or made errors when quoting the number of quarks for each particle in the nucleus of tritium. Some included quarks for an electron. A small number of candidates stated the number of up and down quarks without any working and so no credit could be awarded if the final answer was incorrect.

# 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 rearranged. In some questions, credit can be awarded for correct statements of physical equations, but only where the whole equation is clearly shown. Candidates should not rely on the examiner to infer a subject for an expression given in the working.

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

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- When describing mathematical relationships, candidates should be careful to use precise mathematical language. In particular, the words 'into' and 'by' are used to mean both multiply and divide in different parts of the world making it impossible to infer which meaning is intended. Candidates should explicitly state when they are referring to multiplication or division.

## General comments

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

Candidates would benefit from improving their presentation of working, as it was sometimes challenging to follow the reasoning. This is especially significant in 'show that' questions, where the flow of the working is a key part of presenting the answer.

Candidates found questions **2(c)(ii)**, **3(b)(ii)** and **6(c)(i)** relatively easy. They found questions **1(b)(ii)**, **3(a)**, **4(c)** and **5(b)(iv)** particularly difficult.

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

## Comments on specific questions

### Question 1

**(a)** Only the strongest candidates gave fully correct answers. Many candidates thought that pressure is a vector, possibly confusing pressure with force. Many candidates gave the units for pressure as Pa, confusing SI units with SI base units. It was also common to see the SI base unit of temperature given as °C rather than K.

**(b) (i)** This question was generally answered well. Most candidates correctly transcribed the upthrust formula from the formula page. Many candidates could not recall the formula for the volume of a sphere. It is essential that candidates are fully able to meet the Mathematical Requirements section of the syllabus.

**(ii)** Only the strongest candidates were able to identify that upthrust is a result of a difference in pressure between the top and bottom surfaces of the balloon, and few candidates clearly linked this difference in pressure to a difference in the force acting on the top and bottom of the balloon.

A common misconception was that the upthrust was due to the difference between the pressure acting on the inside and the outside of the balloon. Other candidates compared the density of the gas inside the balloon with the density of the air outside the balloon, which was irrelevant to the question.

Very weak candidates sometimes confused upthrust with air resistance or thought that Newton's third law of motion meant that the weight of the balloon and the upthrust were equal and opposite. Some candidates only stated that the upthrust was equal to the weight of displaced air without any further explanation. Others demonstrated misconceptions by stating that upthrust was the reaction to weight or stating that upthrust was a resistive force or due to drag.

**(iii)** Strong candidates correctly calculated the resultant force and the mass of the balloon, and were able to find the acceleration. Weaker candidates typically omitted one of the intermediate steps. It was common for candidates to use the upthrust rather than the resultant force. It was also common for candidates to calculate the mass of the displaced air rather than the mass of the balloon.

**(c)** This question was generally well answered. Most candidates correctly determined the percentage uncertainty. A small number of candidates gave the percentage uncertainty as the final answer. A common error for weaker candidates was to attempt to calculate a value for $c$ but substitute the percentage uncertainties as values for the measured quantities.

**Question 2**

**(a) (i)** The majority of the candidates were able to calculate the moment about the centre of gravity of one of the two forces. Stronger candidates correctly subtracted the moments to find the resultant moment. Many candidates added the moments, neglecting to account for their opposite directions.

A very large number of candidates attempted to combine the moments using a vector triangle and Pythagoras theorem. Candidates would benefit from practising problems involving non-parallel moments.

**(ii)** Most candidates could give a correct justification for the forces from A and C not being a couple. The most common correct response was to say that the forces are not a couple because they do not have equal magnitude.

A common misconception was to state that as the forces acted at different perpendicular distances from the centre of gravity they could not be a couple.

Some of the weakest candidates seemed to confuse moments with forces. For example, some appeared to think that the forces are not a couple because the clockwise moment is not equal to the anticlockwise moment. Others said that the forces were a couple because the moments act in opposite directions.

**(b)** Most candidates correctly identified that the speed of the spacecraft would increase from $t_1$ to $t_2$. A straight line from the origin was the most common response. Stronger candidates correctly gave a line from the origin with an increasing positive gradient, often with some reasoning written in the margins. Very weak candidates sometimes drew a straight line from a non-zero value of speed, suggesting that they had not carefully read the question.

**(c) (i)** This standard definition was generally well recalled. Common errors were to omit the idea of 'total' momentum, or to not mention the requirement for an isolated system. Very weak candidates confused momentum with moment, and in some cases there was an overlap, with candidates correctly stating the principle of conservation of momentum but also stating that it applies to a system in equilibrium. Candidates should be familiar with the key definitions required in the syllabus.

**(ii)** This question was straightforward for most candidates.

**(iii)** Stronger candidates found this question straightforward, and often gave concise, well-presented working. Most candidates identified conservation of momentum as an effective solution strategy.

It was common for candidates to use the mass of the payload and arrive at an answer of $8.6\,\mathrm{m\,s^{-1}}$. Many realised that this was not correct and so attempted to subtract the increase in velocity of the payload ($8.5\,\mathrm{m\,s^{-1}}$) to get a change in velocity for the carrier.

Some candidates attempted to find a final velocity, using an unknown (or $8.5\,\mathrm{m\,s^{-1}}$) initial velocity. It was rare for these candidates to manage the algebra correctly to get the final answer for the change in velocity.

**Question 3**

**(a)** A significant number of candidates could not correctly identify the direction of the forces acting on the pulley, frequently showing *F* and *T* acting opposite to the correct directions. This demonstrated confusion between the forces acting on the pulley (from the spring and cable) and the forces acting on the spring and cable (from the pulley).

Many candidates showed a force of *F* acting to the left. Only the strongest candidates correctly identified the fact that there were two forces of magnitude *T* acting to the right, with most simply giving a single arrow labelled *T*.

Some candidates drew *T* acting in both parts of the cable in Fig. 3.1, but then did not show this in Figure 3.2.

Candidates often created their own labels for the forces, rather than using the information from the question stem. Where the labels were accurate they were given credit, but often candidates used vague terms such as ‘force’ which was not credited, and frequently the arrows were unlabelled.

Very weak candidates sometimes drew an arrow pointing down the page labelled ‘weight’ due to misinterpreting the diagram as a side view rather than a view from above.

**(b) (i)** Many candidates gave an answer of 110 N. This mistake was due to the incorrect assumption that the rightwards force on the pulley was *T* instead of 2*T.*

**(ii)** Most candidates correctly calculated the extension as 0.44 m. Only very weak candidates could not recall the relevant equation.

**(c) (i)** Many candidates correctly gave an answer of 0.22 m. A common incorrect answer was 0.88 m, usually a result of candidates incorrectly thinking that two springs would mean twice the force, or that the combined spring constant would be half (rather than double) the spring constant of a single spring. Candidates would benefit from practising problems involving springs in parallel and in series.

**(ii)** Nearly all candidates correctly recalled the equation for elastic potential energy, and many were able to apply this to both sets of springs. The most common error was to neglect the fact that there were two springs in Fig. 3.3 and so only calculate the elastic potential energy for one spring, leading to a ratio of 4.

**Question 4**

**(a)** Typically, candidates could identify that the interference pattern was a result of superposition of two waves. Stronger candidates often gave full and precise descriptions of the path or phase difference at both bright and dark fringes, and the role of the double slit in diffracting the waves. Many candidates omitted to describe the diffraction at the double slit.

Candidates were more frequently able to describe a bright fringe as the result of waves meeting ‘in phase’, but often gave the vague description ‘out of phase’ for dark fringes. Candidates should be reminded that ‘out of phase’ does not necessarily mean a phase difference of 180°.

Weaker candidates often confused phase and path difference, or wrote about the meeting of crests and troughs, or ‘constructive’ or ‘destructive’ interference without sufficient detail.

Very weak candidates confused the formation of interference fringes with the formation of a stationary wave and so attempted to describe the light reflecting off the screen. Another common error amongst very weak candidates was to suggest that the dark fringes were formed by light not reaching the screen, assuming the pattern was a shadow of the double slit.

**(b)** Most candidates were able to correctly recall the formula for the double slit and the wave equation. Weaker candidates often attempted to introduce an *n* term into the double-slit equation and so obtained an incorrect wavelength. A very common error was to round the wavelength to $6.9 \times 10^{-7}$ m and so get an incorrect final answer for frequency to two significant figures. Candidates are reminded to only round the final answer, and to either keep intermediate working in their calculator memory or to record intermediate answers to more significant figures than the final answer. A few very weak candidates attempted to use the speed of sound in air, rather than the speed of light in a vacuum.

**(c)** Many candidates found it difficult to answer this question. Stronger candidates were able to identify the lack of coherence between the two distinct laser sources, but many gave vague answers such as ‘different wavelengths’ or ‘different frequencies’ which was already stated in the question. Many candidates simply said that the steady pattern would not be formed because there was no diffraction without the double slit or because the light waves cannot interfere.

**Question 5**

**(a)** This question was generally well answered. A common mistake was to refer to ‘current’ instead of the ‘sum of currents’. Sometimes candidates tried to state Kirchhoff’s second law instead of the first law. Some candidates produced a statement that was a hybrid of Kirchhoff’s first and second laws. Weak candidates occasionally confused current with charge.

**(b) (i)** This question was generally answered well with sufficient working shown. Weaker candidates typically presented a circular argument by calculating the required total resistance using 4.8 V / 38 mA and then used this to ‘show’ that the p.d. was 4.8 V.

Another common error was to calculate the terminal potential difference of the battery using the resistance of Z, for example $V = 38 \times 10^{-3} \times 120 = 4.56$ V or $V = 38 \times 10^{-3} \times (120 + 4.7) = 4.74$V and then suggest that this was equal to 4.8 V.

**(ii)** Candidates found this question difficult. Many candidates correctly read the resistance of Z from the graph, although this often had to be inferred from the working. Candidates are encouraged to explicitly identify values taken from the graph within their working. Weaker candidates often used only a single resistance combined with the e.m.f. of the battery (rather than the terminal p.d.) to find a current which they presented as their final answer. It was also common for candidates to find $I_1$ and present this as a final answer. There were many possible approaches to solving this problem, but most used the first method in the mark scheme. Candidates who attempted to find the parallel resistance combination typically got lost in the working.

**(iii)** Many candidates were able to gain full credit. It was again common for candidates to assume that the p.d. across resistor Y was the battery’s e.m.f. of 5.0 V rather than the terminal p.d. of 4.8 V.

**(iv)** Many candidates identified that the resistance of the LDR would increase. Many went on to describe that the terminal p.d. would increase, but relatively few were able to give a sufficiently detailed explanation of why this occurs.

Throughout, many candidates referred only vaguely to ‘resistance’, ‘current’ and ‘potential difference’. It is important that candidates explicitly specify which resistance, which current and which potential difference they are referring to. For example, they should refer to resistance *of the LDR*, the *total* resistance of the circuit, the current *in the battery* or the *terminal* potential difference.

**Question 6**

**(a)** There were many correct statements. However, other statements were often vague and ambiguous, such as ‘fundamental particles are small particles used to make other particles’. A small number of candidates seemed to think that only quarks (and nothing else) are fundamental particles. Others thought that any sub-atomic particle was a fundamental particle.

**(b) (i)** This question was also generally well answered. The most common correct answer was up and antiup. Some candidates just gave ‘a quark and antiquark’, having not carefully read the question. Very weak candidates typically gave the composition of a proton or a neutron, suggesting that they did not understand the question.

**(ii)** Stronger candidates typically found this straightforward. Neglecting the power of two in the velocity was common, leading to an answer of $3.8 \times 10^{11}\,m\,s^{-1}$. Candidates should recognise that a speed greater than the speed of light must indicate that they have made an error in their working.

Weaker candidates sometimes found it difficult to convert the mass of particle Q to kg. Some candidates confused the unified atomic mass unit (u) with the charge of an up quark and so thought that it was equal to +(2/3) kg. Others confused the unified atomic mass unit (u) with the micro symbol and so thought it was equal to $10^{-6}$ kg. Some candidates omitted the unified atomic mass unit altogether and so assumed that particle Q had a mass of 0.67 kg.

**(c) (i)** This question was generally answered correctly. A small number of candidates incorrectly thought that there were 140 electrons (which is the number of neutrons in the Ra atom rather than the number of electrons).

**(ii)** This question proved to be challenging. There were many different ways of achieving an incorrect number of protons and an incorrect number of neutrons in nucleus X. A common incorrect value for the number of protons was 74, which is achieved by wrongly assuming that a $\beta^-$ particle has a proton number of +1 instead of –1. A common incorrect value for the number of neutrons was 208, which is the number of nucleons in nucleus X rather than the number of neutrons.

# PHYSICS

**Paper 9702/23**
**AS Level Structured Questions**

## Key messages

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## General comments

Candidates generally presented the quantitative 'show that' questions with well-presented working and the necessary detail. Many candidates found the algebraic 'show that' question more demanding.

A significant number of the weaker candidates found it difficult to give correct definitions. The words used often needed to be more accurate or detailed.

Candidates found **Questions 1(a)**, **1(b)**, **1(c)(i)**, **1(c)(ii)**, **2(a)(i)**, **2(b)(i)**, **3(a)**, **3(b)(i)**, **3(d)(i)**, **4(b)(i)**, **4(b)(ii)**, **5(a)**, **6(a)** and **6(b)** to be relatively straightforward.

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

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

## Comments on specific questions

### Question 1

**(a)** The majority of the candidates gave an appropriate definition of acceleration. A small number gave 'the rate of change of velocity per unit time' which is not acceptable as it implies the *second* derivative of velocity. Some weaker candidates gave 'velocity / time' which is incorrect.

**(b) (i)** The majority of the candidates correctly obtained the acceleration using the gradient of the velocity–time graph.

**(ii)** The majority of the candidates gave full working for this 'show that' question using an equation of uniform acceleration or the area under the velocity–time graph.

**(c) (i)** Most candidates used the correct expression for the gravitational potential energy. A small number used the change in height in kilometres instead of metres.

**(ii)** Most candidates used the correct expression for the change in kinetic energy. A small number did not square the velocity in their calculation. Most read the correct velocity from the graph. The most common incorrect value used for the velocity was $20\,\text{m}\,\text{s}^{-1}$, which was the time of flight.

**(iii)** The majority of the candidates started with a correct expression for power, in this case work done / time or change in energy / time. The correct average power was determined by the more able candidates. A significant number attempted to use $P = Fv$ with $F = ma$ without success. A similar number only included the change in gravitational potential energy or only the change in kinetic energy. A small number divided the change in energy by two to determine the average power.

**Question 2**

**(a) (i)** The definition of pressure was given by most candidates. A small number gave a statement where the ratio of force to area was not clear. 'Force by area' and 'force on area' were two common incorrect answers.

**(ii)** Candidates found this question difficult. A small number of candidates were able to identify that upthrust is a result of a difference in pressure between the top and bottom surfaces of the object, and fewer clearly linked this difference in pressure to a difference in the force acting on the top and bottom of the object.

Very weak candidates sometimes confused upthrust with drag or thought that Newton's third law of motion meant that the weight of the object and the upthrust were equal and opposite. Some candidates only stated that the upthrust was equal to the weight of displaced liquid without any further explanation. Others demonstrated misconceptions by stating that upthrust was the reaction to weight or stating that upthrust was a resistive force.

**(b) (i)** The majority of the candidates drew correct arrows for weight and either the drag force or the upthrust. A significant number showed the drag force acting downwards when the ball was travelling downwards in the oil. There were a significant number of diagrams where the arrows were not vertical and some that were not labelled. A small number of candidates labelled the viscous drag force as air resistance. A similar number labelled the weight force as simply 'gravity' which was not credited.

**(ii)** The SI base units of $\eta$ were determined by more able candidates. Some left newtons in their final answer or made arithmetic errors when cancelling the powers for seconds in the units of acceleration or velocity.

**(c) (i)** The stronger candidates were able to substitute all the values required in the formula for upthrust (which is given on the data and formulae page of the question paper). The weaker candidates were unable to show the working for the volume of a sphere, and sometimes attempted to determine the volume of the sphere by using the density of the liquid and the mass of the sphere.

**(ii)** Stronger candidates determined the terminal speed of the ball by relating the three forces acting on the ball. Many candidates equated the drag force with the weight or equated the drag force with the upthrust.

**Question 3**

**(a)** The definition of the Young modulus was given by most candidates. Some candidates did not give a statement that indicated a ratio between stress and strain. 'Stress by strain' or 'stress on strain' were not accepted. Candidates are reminded that 'by' could mean 'multiplied by' or 'divided by' and so precise mathematical language should be used.

**(b) (i)** The stronger candidates gave the expression that links resistance with resistivity. Weaker candidates often tried to use all four quantities listed in the question.

**(ii)** The stronger candidates gave the expression for the definition of the spring constant $k$ and then used expressions for stress and strain to obtain the required relationship between $k$ and $E$. Weaker candidates were often unable to link the expression for the spring constant with that for the Young modulus.

**(c) (i)** The correct straight-line graph was drawn by the strongest candidates. A significant number did not start the resistance at $R_0$ when the force was zero or had the resistance decreasing with increased force. Many candidates gave the resistance as zero when the force was zero and the wire was at its original length. A nonlinear graph was often drawn by weaker candidates.

**(ii)** Many candidates did not draw a graph indicating that the spring constant is constant. There were many straight-line graphs with positive or negative gradients and many that started from the origin.

**(d) (i)** Stronger candidates gave the full substitution of the quantities required to calculate the length of the wire. There were some that did not show the calculation of the area, used the diameter instead of the radius or did not convert from millimetres to metres.

**(ii)** There were many good answers. Some of the candidates gave no response even though the question directs them to the correct formula. A significant number of candidates made an error in the calculation of the area or used a value for the area rounded early to one or two significant figures, leading to an incorrect final answer.

**Question 4**

**(a)** Many candidates found it difficult to describe diffraction. There were many answers that described a wave bending after passing through obstacles. The bending or change of direction of the wave suggests refraction rather than diffraction.

**(b) (i)** The majority of the candidates started with the correct equation for a diffraction grating. Most candidates were able to convert the wavelength in nanometres into metres.

**(ii)** Most candidates obtained the angle for the second-order fringe. A small number of candidates did not know the equation that is applied to a diffraction grating. A significant number doubled the answer from **(b)(i)**.

**(iii)** Only the strongest candidates drew the peak intensities of bright fringes at the angles determined in the previous parts with zero intensity in between.

**(c)** The reduction to half the original intensity was given by the strongest candidates. Some candidates stated that there would be a decrease in intensity without qualifying their answer. The question specified the filter being rotated by 45° and not just being moved from the vertical. A comment describing the fringes at the same angle of deflection was very rarely seen. Many weaker candidates did not give a response.

**Question 5**

**(a)** Most candidates gave an acceptable statement of Kirchhoff's first law. There were some answers that omitted the 'sum of' the currents or omitted that the currents were entering and leaving a 'junction' in the circuit. A small minority stated Kirchhoff's second law.

**(b) (i)** The majority of the candidates started a line at $R_0$. There were a significant number that drew a line with positive gradient. A significant number drew a line that unrealistically reached zero resistance before or at a temperature of 100 °C. There were many lines drawn with a large horizontal section suggesting that the resistance is constant for a range of temperatures.

**(ii)** There were many descriptions that did not give an answer *with reference to the current in the cell*. Many answers described the resistance of the thermistor decreasing and then stated that more current passes through the thermistor and less through the resistor R. The effect of the reduction in the thermistor resistance on the total resistance of the circuit and hence the current in the cell was only stated by a small number of candidates. The effect of an increased current on the 'lost volts' in the cell, the terminal potential difference of the cell and the potential difference across R was only mentioned by a very small number of stronger candidates.

**(c) (i)** The calculation of the current in the cell was generally only completed by the more able candidates. Many candidates used the e.m.f. of the cell as the potential difference across the internal resistance. Very few candidates calculated the terminal potential difference or the potential difference across the internal resistance.

**(ii)** The calculation of the resistance of the thermistor was determined by the more able candidates. Many candidates used the e.m.f. of the cell as the potential difference across the thermistor, which mean that the effect of the internal resistance of the cell on the circuit was ignored.

**Question 6**

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

**(ii)** This question was well answered by most candidates. There were some diagrams in which the protons and neutrons were not labelled, or where individual particles were not shown.

**(b) (i)** This question was well answered by most candidates. There were a significant number of answers where the values given for the helium and beta particle did not balance with those of the tritium nucleus.

**(ii)** There were many correct answers. A common error was to state the particle as an anti-electron neutrino or a neutrino.

**(c)** There were a significant number of correct answers. Some candidates gave incorrect numbers of protons and neutrons or made errors when quoting the number of quarks for each particle in the nucleus of tritium. Some included quarks for an electron. A small number of candidates stated the number of up and down quarks without any working and so no credit could be awarded if the final answer was incorrect.

# PHYSICS

**Paper 9702/24**
**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 rearranged. In some questions, credit can be awarded for correct statements of physical equations, but only where the whole equation is clearly shown. Candidates should not rely on the examiner to infer a subject for an expression given in the working.
- Candidates should pay attention to the units and powers of ten in which information is presented to avoid transcription errors 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 the data used in the calculation.
- When describing mathematical relationships, candidates should be careful to use precise mathematical language. In particular, the words ‘into’ and ‘by’ are used to mean both multiply and divide in different parts of the world making it impossible to infer which meaning is intended. Candidates should explicitly state when they are referring to multiplication or division.

## General comments

Candidates generally presented the quantitative ‘show that’ questions with well-presented working and the necessary detail. Many candidates found the ‘show that’ question on hadrons more demanding.

A significant number of the weaker candidates found it difficult to give correct definitions. The words used often needed to be more accurate or detailed.

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

There were more demanding parts in many of the questions where application of basic knowledge was required. Examples of these are **1(a)(iv)**, **1(b)(ii)**, **2(c)(i)**, **2(d)**, **2(e)**, **3(d)**, **4(b)(i)**, **5(a)(ii)**, **5(b)(iii)**, **5(b)(iv)**, **6(c)(i)** and **6(c)(ii)**.

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

## Comments on specific questions

### Question 1

**(a)(i)** The majority of the candidates calculated the two components of velocity. A small number of candidates gave the components in the reverse order.

**(ii)** Most of the candidates used $v = u + at$ with the initial vertical component of velocity and the fact that this component was zero at the maximum height to show the time taken. A small number of candidates made an error and had the acceleration and the initial velocity in the same direction and showed working that gave a negative time. A significant number determined the maximum height and then calculated the time to reach this point. Some candidates calculated the maximum height and gave this as their answer. These candidates seemed to have misread the question.

Some candidates used an equation that resulted in a quadratic equation. The answer was then quoted without showing how the equation was solved. It is essential in 'show that questions' that full accurate working is presented.

**(iii)** The majority of candidates drew a horizontal line at the required horizontal velocity. A significant number of candidates did not label the line. A small number of candidates showed the velocity decreasing at a constant rate, perhaps confusing the horizontal and vertical motions. Some candidates did not answer the question.

**(iv)** There were many good answers to show the variation with time of the vertical component of velocity. A small number of candidates showed the velocity increasing positively (upwards) with time after the ball reached the maximum height at 1.6 s. There were many unlabelled lines despite the explicit instructions to label both lines.

**(b) (i)** The majority of the candidates gave the correct definition. There were some answers where it was not clearly stated that momentum is the product of mass and velocity. Candidates are reminded to use clear mathematical language when describing relationships between quantities. A small number gave speed instead of velocity. Some gave an incorrect definition of momentum = force × time.

**(ii)** The stronger candidates linked the force with the rate of change of momentum. Weaker candidates often tried to link force with mass and acceleration, often without success.

**(iii)** The more able candidates linked the force on the ball (the weight of the ball) with the acceleration to determine the mass. Weaker candidates generally used inappropriate equations linking the initial velocity with the change in momentum or gave no response.

**Question 2**

**(a)** Candidates found it difficult to give the definition of the torque of a couple. Some gave a definition for moment of a force. Many candidates did not include the *perpendicular* distance between the lines of action of the forces. A significant number described a couple and did not give the definition of the torque of a couple.

**(b)** Most of the candidates gave a correct response and drew a straight line from the rod to the lower corner of the sheet. A significant number of candidates did not draw the line all the way to the corner. The weaker candidates did not give a line vertically below the rod or gave a point in the rod. A common error was for candidates to draw an arrow from the rod labelled 'weight' or '*mg*', suggesting that they had not understood the question.

**(c) (i)** The more able candidates explained why the torque applied to the rod was anticlockwise. There were many answers that gave no explanation and therefore did not gain credit. Candidates should be familiar with requirements of the command words as described in the syllabus.

**(ii)** This question was well answered by the more able candidates. Weaker candidates often did not give a response.

**(d)** The stronger candidates gave a well-presented solution to this 'show that' question. A small number of candidates did not show the conversion of the thickness from millimetres to metres. The weaker candidates were generally unable to link the volume with the side length. Some of these candidates were only able to calculate the volume using the density and mass.

**(e)** The more able candidates were able to indicate the position of the centre of gravity. Many candidates were unable to use the information given in the previous questions to locate the centre of gravity. Many had drawn a line from the rod to the right-hand corner in **(b)** to show the possible location of the centre of gravity, but then gave a point in this part that was not on their original line.

**Question 3**

**(a)** This question was well answered by the candidates with stronger ability. The weaker candidates often gave no response or gave an equation that linked the force with the spring constant and the extension which is a consequence of Hooke's law. Candidates should avoid using the word 'length' in their answers as it often led to ambiguous statements that could not be given credit e.g. 'extended length' rather than 'extension'.

**(b) (i)** This question was well answered and there were very few misreads from the graph.

**(ii)** The majority of candidates the calculated the spring constant from the gradient of the graph. There were a small number of misreads from the graph and some candidates used a point on the line instead of the gradient. A small number of candidates did not know the required formula.

**(c) (i)** This question was well answered by most candidates. The weaker candidates often used an inappropriate equation for the change in gravitational potential energy. A small number did not show the value used for *g*. Candidates are reminded that in 'show that' questions all the values used must be shown in the working.

**(ii)** This question was well answered by many candidates. A small number of candidates did not show all their working in this 'show that' question. The most common error was to omit the working for the extension, jumping straight to 83 m without showing the calculation. The less able candidates often did not use an appropriate equation or equated the loss in gravitational potential energy with the gain in elastic potential energy.

**(d)** Many responses did not give a full explanation for why the kinetic energy would be zero and hence the speed of the jumper would be zero. Many suggested that gravitational potential energy was converted to elastic potential energy but did not state that *all* was converted. The amount converted to kinetic energy was often stated as zero but this was not linked to the given statement in the question that the initial kinetic energy was zero.

**Question 4**

**(a)** The principle of superposition was given by the stronger candidates. A significant number of candidates described two or more waves overlapping. Many candidates did not describe waves meeting but suggested waves of the same frequency and wavelength were required. The effect on the waves was often poorly described. Many candidates gave ambiguous statements such as 'the sum of the displacement is equal to the sum of the displacement' or 'the resultant displacement is equal to the individual displacement'. A small number of candidates stated that the resultant amplitude was the sum of the individual amplitudes, which is incorrect.

**(b) (i)** Many answers did not refer to the overlapping of the waves from the transmitter and the reflected waves from the metal sheet. Often the explanation was not related to the question and the general description of waves travelling in opposite directions was often stated. The description of a node and an antinode in terms of resultant amplitudes was given by the very able candidates. Weaker candidates described the antinode as the point of maximum displacement, which is not correct. Some candidates focused on the phase difference between the incident and reflected waves at the node and antinode, suggesting that at a node the phase difference is always 180° and at a node it is always 0°. This explanation is incorrect.

**(ii)** This question was well answered by the majority of the candidates. There were some answers that used the speed of sound for the electromagnetic wave.

**(iii)** There were many answers that were not part of the electromagnetic spectrum. Many candidates did not provide a response.

**(iv)** The stronger candidates generally knew the relationship between the wavelength and the distance between a node and an antinode. There were many incorrect answers with half a wavelength being the most common.

**Question 5**

**(a) (i)** Most of the candidates gave the definition of resistance. A small number of candidates gave units in their definition, and some candidates gave an incorrect definition in terms of the resistivity.

**(ii)** There were many well drawn circuit diagrams. A significant number of candidates did not draw the correct symbol for a resistor to represent the nichrome wire as requested in the question. Less able candidates often placed the ammeter and voltmeter in wrong positions. A small number of candidates drew a potential divider circuit and some drew a variable resistor.

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

**(ii)** The stronger candidates calculated the resistivity and gave an answer to three significant figures as required in the question. A significant number of candidates made a power-of-ten error as they did not convert the diameter of the wire given in millimetres into metres. A small number used the diameter to calculate the area instead of the radius. Many candidates gave an answer to only two significant figures.

**(iii)** The more able candidates calculated the percentage uncertainty correctly. Most candidates gave at least one correct fractional or percentage uncertainty for the quantities. Many candidates made arithmetic errors in their calculation or were unable to use the information given in the table. A significant number of candidates did not double the percentage uncertainty in the diameter.

**(iv)** The stronger candidates calculated the absolute uncertainty without error. A significant number of candidates were able to calculate the absolute uncertainty from their percentage uncertainty and gained credit.

**Question 6**

**(a) (i)** The majority of the candidates drew the deflection for particle W as upwards. A small number showed the deflection to be similar to that of particle X. A significant number showed particle Y to be deflected much less than particle X or like that of particle Z.

There were many candidates that appeared not to use the deflections given for particles X and Z as a guide for particles W and Y. Weaker candidates often drew lines that showed deflections for particle W that were well before or well after that of X. Similarly, deflections for particle Y often started well before that of X or well after X.

**(ii)** There were many answers that did not refer to the nucleus of the gold atom. A small number of candidates described the nucleus having most of the mass of an atom. Many suggested that the nucleus had a large mass without any comparison. A small number stated that the nucleus was charged. Some suggested that the *atom* was charged. A few candidates described the structure of the alpha particle and had not read the question carefully.

**(iii)** Many answers did not give the detail required for a clear indication of the structure of an atom. The nucleus being small was often stated without any comparison with the size of the atom. The atom having empty spaces was often stated without suggesting that the atom was mostly empty space. The empty spaces were often described as being in the nuclei or between nuclei or between atoms.

**(b)** This question was well answered by the more able candidates. Weaker candidates often did not seem to know the structure of an alpha particle. Some candidates gave their answers as absolute values instead of in terms of u and *e*.

**(c) (i)** Stronger candidates usually gave a correct response. There were many candidates that did not know this type of hadron. There were many spelling mistakes for the baryon particle.

**(ii)** A significant number of candidates gave the charge on an up and down quark as 2/3 and –1/3 respectively instead of (2/3)*e* and –(1/3)*e*. The correct combinations of charge for the proton and neutron were given by only the strongest candidates. Many weaker candidates did not seem to know which particles were hadrons in the alpha particle.

# PHYSICS

**Paper 9702/31**
**Advanced Practical Skills 1**

## Key messages

- Consideration of regular and sensible numerical scales on the graph axes.
- Positioning of line of best fit of plotted points.
- Consideration of detailed and clear limitations in the evaluation section.
- Provision of a set of Supervisor's Results.

## 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 'extra' equipment should be available to the candidates. In some cases, this may disadvantage candidates.

Any help given to a candidate should be detailed in 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. Candidates demonstrated good skills in the generation and handling of data and in their responses to improvements to the limitations in **Question 2** and 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 $m$ = 270 g with a unit.

**(ii)** Many candidates stated a final value in range and with a unit. Some candidates stated two repeated values of at least 5 or more oscillations.

**(b)** Many candidates stated $T_2$ greater than $T_1$ in **(a)(ii)**.

**(c)** Many candidates were able to collect six sets of values of $m$ and $T_1$ and $T_2$ without assistance from the Supervisor with the correct trend.

Some candidates did not state all their values of time to the nearest 0.01s or all to the nearest 0.1s when the timer can be read to the nearest 0.01s or, taking into account reaction time error, all to the nearest 0.1s. Some candidates stated time to the nearest second or added trailing zeros.

Many candidates did not extend their range low enough (equal to or below 220 g) or high enough (equal to or above 350 g). Candidates are encouraged to use the whole range available to them.

Many candidates gave both the quantity and correct unit for each heading separated by a solidus or brackets around the unit. Candidates are encouraged to remember a separating mark between the quantity and unit. Some candidates wrote the column heading of $\sqrt{T}$ as $\sqrt{T}$/s incorrectly. Candidates are encouraged to use conventional scientific notation e.g. $\sqrt{T}/\sqrt{s}$ or $T^{0.5}/s^{0.5}$.

Many candidates correctly stated their calculated values of $\sqrt{T}$. Candidates are encouraged not to truncate the value and to round their answers appropriately.

The table work was done well by candidates.

**(d) (i)** Some candidates plotted the correct graph with quantities labelled, sensible and regular scales such that all the data occupy over half the graph grid available. Awkward, irregular or offset scales were often the reason for not awarding the axes mark. For example, $\sqrt{T_2}$ incrementing in steps of 0.5 along the axis with the scale offset to the bold lines 0.12, 0.62, 1.12, 1.62, 2.12...

Many plots were drawn as neat crosses such that the plot 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 very often the reasons for not awarding the plotting mark.

**(ii)** Some 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. Common reasons for not awarded this mark include: lines needing a rotation or a shift to get a better fit; kinked lines.

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. The judgement of the line of best fit mark can be made on the remaining plots.

**(iii)** Some candidates correctly used a large triangle to calculate the gradient, used correct read-offs and substituted into $\frac{\Delta y}{\Delta x}$ correctly. Candidates then went on to read off from the graph at $x = 0$ or used a correct read off into $y = mx + c$ to find the y-intercept. Some of the reasons for not awarding the gradient mark included: too small a gradient triangle; substitution into $\frac{\Delta x}{\Delta y}$ ; plots incorrectly read off; points used from the table which were not on the line of best fit; read offs and triangle not shown. Reasons for not awarding the *y*-intercept included reading the *y*-intercept off the graph when there was a false origin or substitution into a wrongly arranged equation e.g. $\frac{y}{mx} = c$ .

**(e)** Some candidates recognised that *P* and *Q* were equal to the gradient and the intercept respectively and gave the correct unit for *Q*, $s^{0.5}$ (or $\sqrt{s}$) and no unit for *P*. Some candidates omitted units for *Q* or stated an incorrect unit e.g. s.

**Question 2**

**(a)** Many candidates measured and stated repeated values of *d* to the nearest mm and in range. Some candidates omitted to repeat their readings. A few candidates set *d* up to be out of range.

**(b) (i)** Many candidates measured and stated raw values of *y* to the nearest mm and in range.

**(ii)** Some correctly estimated the uncertainty in *y* to be in range, considering the awkward nature of this reading. Other candidates, having repeated their readings, correctly showed the uncertainty as half the range and then calculated the percentage uncertainty. 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.

**(c) (i)** Nearly all candidates correctly stated a value for *p* that was less than *y.*

**(ii)** Nearly all candidates correctly calculated ($y - p$).

**(d)** Nearly all candidates stated *w*, *d, y* and *p* correctly. Most candidates correctly stated their second *p* value to be lower than their first.

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

**(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 *w* and ($y – p$). Common reasons for not awarding this mark were stating 'raw readings', 'previous measurements', 'values used in calculation' without detailing the quantities involved or only mentioned the quantity deemed to have the fewest significant figures.

**(f)** Some candidates calculated the per cent difference between their values of *k*, testing it against the stated 10 per cent criterion and provided a valid statement. Some candidates omitted a per cent difference calculation, gave a different criterion e.g. compared to 20 per cent or gave an invalid statement inconsistent with their findings.

**(g) (i), (ii)** 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 and/or chronologically and systematically go through the experiment. Candidates should explain clearly what the difficulties are and then suggest corresponding solutions that address each difficulty. Candidates are encouraged add detail to gain credit addressing questions like: 'What measurement is difficult and why?', 'How does the solution solve the difficulty?' or 'What additional equipment do I need to improve the measurement?

Problems commonly awarded were 'two sets of data were not enough to draw a valid conclusion'; 'difficult to measure *p* as there is parallax error'; 'difficult to set *d* because the clips flatten one side' or 'difficult to squash the cylinder as it does not squash evenly'.

Improvements that were commonly seen were 'take more readings and plot a graph', 'use a vernier caliper (or pointers on a ruler)' or 'wrap around a proforma and tape' or 'clamp the ruler' to measure *y.*

The evaluation section proved to be challenging.

Please refer to the mark scheme for more examples of acceptable limitations and improvements.

# PHYSICS

**Paper 9702/33**
**Advanced Practical Skills 1**

## Key messages

- Consideration of regular and sensible numerical scales on the graph axes.
- Positioning of line of best fit of plotted points.
- Consideration of detailed and clear limitations in the evaluation section.
- Provision of a set of Supervisor's Results.

## 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 'extra' equipment should be available to the candidates. In some cases, this may disadvantage candidates.

Any help given to a candidate should be detailed in 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. Candidates demonstrated good skills in the generation and handling of data and in their responses to improvements to the limitations in **Question 2** and can improve by giving more thought to expressing clearly the limitations of the experiment.

## Comments on specific questions

### Question 1

**(a)** Most candidates stated $S$ in range.

**(b)** Many candidates stated $T$ in range. Some candidates repeated and stated their raw times of two or more oscillations more than once.

**(c)** Many candidates were able to collect six sets of values of $h$ and $T$ without assistance from the Supervisor 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. Many of these candidates stated $h$ to the nearest cm or added and extra zero.

Many candidates did not extend their range low enough (below 15.0 cm) or high enough (above 33.0 cm). Candidates are encouraged to use the whole range available to them. Some candidates increased $h$ from their initial value of around 22.0 cm without going below.

Many candidates gave both the quantity and correct unit for each heading separated by a solidus or brackets around the unit. Candidates are encouraged to remember a separating mark between the quantity and unit. Many candidates correctly omitted the unit for $S/h$. Some candidates wrote the unit of $S/h$ as (cm/cm) incorrectly as a unit is not conventional scientific notation.

Many candidates correctly stated their calculated values of *S/h* to the number of significant figures (or one more) consistent with their raw readings of *S* or *h* (whichever quantity has the least number of significant figures). Candidates are encouraged not to truncate the value and round their answers appropriately.

The table work was done well by candidates.

**(d) (i)** Some candidates plotted the correct graph with quantities labelled, sensible and regular scales such that all the data occupy over half the graph grid available. Awkward, irregular or offset scales were often the reason for not awarding the axes mark. For example, S/h incrementing in steps of 0.5 along the axis with the scale offset to the bold lines 1.13, 1.63, 2.13, 2.63, 3.13...

Many plots were drawn as neat crosses such that the plot 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 very often the reasons for not awarding the plotting mark.

**(ii)** Some 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. Common reasons for not awarded this mark include: lines needing a rotation or a shift to get a better fit; kinked lines.

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. The judgement of the line of best fit mark can be made on the remaining plots.

**(iii)** Some candidates correctly used a large triangle to calculate the gradient, used correct read-offs and substituted into $\frac{\Delta y}{\Delta x}$ correctly. Candidates then went on to read off from the graph at $x = 0$ or used a correct read off into $y = mx + c$ to find the y-intercept. Some of the reasons for not awarding the gradient mark included: too small a gradient triangle; substitution into $\frac{\Delta y}{\Delta x}$; plots incorrectly read off; points used from the table which were not on the line of best fit; read offs and triangle not shown. Reasons for not awarding the *y*-intercept included reading the *y*-intercept off the graph when there was a false origin or substitution into a wrongly arranged equation e.g. $y/mx = c$.

**(e) (i)** Some candidates recognised that *A* and *B* were equal to the gradient and the intercept respectively and gave correct units, s^2. Some candidates omitted units or occasionally used different units.

**(ii)** Many candidates were able to calculate g with consistent units. Some candidates worked in cm and did not convert to metres before stating $\text{m s}^{-2}$ as their unit.

**Question 2**

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

**(ii)** Some correctly estimated the uncertainty in *d* to be in range, considering the awkward nature of this reading. Other candidates, having repeated their readings, correctly showed the uncertainty as half the range and then calculated the percentage uncertainty using the correct method. 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.

**(b)** Many candidates stated *V* and *R* in range and with a correct unit. Many candidates stated *R* in terms of ohms when it should have been kohms on their scale up to max 20 kohms. Other candidates omitted a unit. Some centres had difficulty with the scale being too low and either changed the scale to get a reading or gave the reading as 1. This was taken into account in the marking as long as this was also the case in the Supervisor's Results.

**(c)** Many candidates stated *L*, *V* and *R* correctly. Many candidates correctly stated their second *R* value to be higher than their first.

**(d) (i)** Some candidates were able to calculate *k* for the two sets of data, showing their working clearly. Some candidates incorrectly rearranged the equation to calculate *k*. Others forgot to take forward their power of ten (1000) on the kΩ or substituted L instead of d.

**(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 *R*, *d* and *V* (and *Z*). Common reasons for not awarding this mark were stating 'raw readings', 'previous measurements', 'values used in calculation' without detailing the quantities involved or only mentioned the quantity deemed to have the fewest significant figures.

**(e)** Some candidates calculated the per cent difference between their values of *k*, testing it against the stated 5 per cent criterion and provided a valid statement. Some candidates omitted a per cent difference calculation, gave a different criterion e.g. 10 per cent or 20 per cent or gave an invalid statement inconsistent with their findings.

**(f)** Many candidates calculated a correct value of wavelength.

**(g) (i), (ii)** 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 and/or chronologically and systematically go through the experiment. Candidates should explain clearly what the difficulties are and then suggest corresponding solutions that address each difficulty. Candidates are encouraged add detail to gain credit addressing questions like: 'What measurement is difficult and why?', 'How does the solution solve the difficulty?' or 'What additional equipment do I need to improve the measurement?

Problems commonly awarded were 'two sets of data were not enough to draw a valid conclusion'; 'difficult to measure *d* as there is parallax error'; 'difficult to align the LDR above the LED' or 'the *R* value was affected by the surrounding light'.

Improvements that were commonly seen were 'take more readings and plot a graph', 'use a vernier caliper (or pointers on a ruler)' or 'do the experiment in a dark room' or 'clamp the ruler' to measure *d.*

The evaluation section, once again, proved to be challenging.

Please refer to the mark scheme for more examples of acceptable limitations and improvements.

# PHYSICS

**Paper 9702/34**
**Advanced Practical Skills 2**

## Key messages

- Candidates should be familiar with carrying out experiments. The importance of setting up apparatus in accordance with instructions and diagrams given should be emphasised, to ensure that the correct range of values or operation of the apparatus is as expected. For experiments of the type in **Question 2**, suitable problems and suggestions for improvement for those experiments can be discussed.
- Candidates should be able to draw best-fit lines, using 30 cm rulers, and checking using a least-squares fit on their calculator or in a spreadsheet such as Excel.
- Candidates should be aware of the resolution of measuring instruments and the correct precision of recorded values, distinguishing this from significant figures in calculated values. The number of decimal places in a measured value should never be forced to give the number of significant figures consistent with a calculated value.
- In **Question 2**, candidates should be advised to concentrate on measured values and start their answer with '*It was difficult to measure x because …..*'. Candidates should follow the advice in the question, in this case *'… state the quantity being measured and a reason for the uncertainty*.' Comments regarding the suitability of apparatus, rather than the method of use, apart from measuring apparatus, are unlikely to get credit.
- Candidates should recognise that units should be included on all answer lines that do not have a printed unit. Units for calculated quantities should be checked to be consistent with the units of measured values.

## General comments

The general standard of the work done by the candidates was good, and there were many excellent scripts. Candidates demonstrated good skills in the generation and handling of data but can improve by giving more thought to the analysis and evaluation of experiments.

Candidates did not seem to be short of time and both questions were attempted in full by almost all the candidates. There were a few candidates with no response in **Question 1(c)(iii) and (d),** but with **Question 2** fully answered; candidates should be reminded that they are only allowed access to apparatus for each question for one hour and should allocate their time to each question accordingly.

Where a centre has a problem with providing the apparatus required, they should note this in their Supervisor's Report, and this report must be sent with the scripts to Cambridge so that the Examiners can take this into consideration when marking. No 'extra' equipment should be available to the candidates. In some cases, this may disadvantage candidates.

## Comments on specific questions

### Question 1

This experiment worked well, with a large majority of candidates able to set up the apparatus and obtain results with the correct trend.

**(a) (i)** Candidates are expected to set up apparatus as required, with instructions such as 'set the length *a* to be about 25 cm'. Here the required arrangement was shown in a diagram. In this case the nail is shown in the fifth hole from the right-hand end of the wooden strip. The 'range' mark for *W* checked if candidates had followed this instruction.

**(ii)** Some candidates mis-read the equation and included their value of *L*, resulting in an incorrect calculation of *Z*.

**(b)** Almost all candidates were able to measure the required six sets of values, with results that followed the correct trend. Stronger candidates used both the first and eighth holes to give the widest range of the independent variable possible and were given credit for this. Candidates should be advised to ensure that their values of the independent variable include both the smallest and largest values possible within the limitations of the apparatus and the instructions given.

Candidates were using rulers with millimetre scales, so all measured values need to be given to this precision. Weaker candidates gave *N* values only to the nearest centimetre. Some candidates added trailing zeros to their values, often to show their *L* values as three significant figures. Measured values should always show a resolution determined by the measuring instrument used.

A significant minority of candidates showed *Z* values to two significant figures, although determined from *W* and *N* values with three significant figures.

Units were usually shown correctly with unit separators of the 'solidus' (/) or using brackets. Candidates, however, need to consider carefully the units of calculated quantities. In this case *Z* has no units but it was common to see units of cm or, less frequently, $cm^{-1}$.

**(c) (i)** Many candidates gained credit for drawing appropriate axes, with labels and sensible scales covering at least half the graph grid and plotting their six points accurately. There was, however, a large number of poor graphs with compressed scales (typically starting the *Z* axis at zero), imprecise points (blobs) and poorly-drawn best-fit lines.

There were some awkward scales used, typically where candidates had tried to maximise the spread of points on that scale. Candidates should be advised that it is only necessary for their plotted points to cover at least half the available grid, so it is better to have a sensible scale. Errors in plotting, or reading values from the graph, were more common with awkward scales.

If candidates identify an anomalous point, they should first check the plotting of that point, then the calculation and then, if possible, to use the apparatus to repeat the measurements for that point. If necessary, a single anomalous point can be indicated and ignored when drawing the line of best fit.

**(ii)** Many candidates were able to draw a straight line of best fit. There was, however, a large number of lines requiring rotation to give a good spread of points along the line. Some lines were drawn so that the maximum number of plotted points were on the line and ignored the points not on the line or were drawn to join two points (typically the first and last). A significant number of lines were drawn in two sections, or distorted at one end, so that the line was kinked. Candidates should use a transparent, non-folding 30 cm ruler to draw a single, clear line.

**(iii)** Candidates can either draw a triangle on their line or indicate two points on the line used to determine the gradient. Typical errors were using a small triangle for gradient or reading the intercept value from the y-axis when a false origin was used on the x-axis.

Stronger candidates clearly showed a gradient calculation as $(y_2 - y_1)/(x_2 - x_1)$, with the points shown on the line. Candidates should be advised that this approach is less prone to error.

There were cases of incorrect read-offs substituted into the gradient calculation, particularly when awkward scales were used. Candidates should be encouraged to use one of the gradient read-offs substituted into the equation for intercept, rather than using another point and a further chance of reading error. The common mistake was to use values from the table for a point that was not on the line.

**(d)** The majority of candidates recognised that their gradient and intercept values should be transferred as *a* and *b* values respectively. There were, however, many missing or incorrect units. Candidates should be encouraged to ensure that each term in an equation has a consistent unit. In this case both *aZ* and *b* need to have the same units as *L*.

**Question 2**

Most candidates were able to complete this question and to obtain results within the ranges expected.

**(a)** Candidates should be reminded that answer lines without units need to have units quoted with their value. Some candidates used, for example, $x$ in cm and $d$ in mm and this caused issues in calculations. Candidates should be encouraged to use consistent units where units are not given on the answer line.

**(b) (i)** Most candidates measured $h$ to the nearest mm, as expected. There was a significant number of low values, often from candidates making a comment in **2(g)** about the ball stopping rolling before reaching the box. Candidates should check they have followed all instructions carefully and, as in this case, use any diagrams to help ensure that the apparatus is set up correctly.

**(ii)** The metre rule can touch the end of the track so parallax error is not an issue here and the uncertainty could be ±1 mm. Some candidates used an uncertainty of ±0.5 mm but did not show this as ½ range of their repeated values. Candidates should repeat measurements and show the calculation of percentage uncertainty as ½range/mean × 100 per cent.

**(c) (i)** There was a wide range of values of ball diameter, $d$, with many out-of-range.

**(ii)** Only the weaker candidates did not follow the good practice of repeating and averaging measurements of time. A small number of candidates appeared to be unfamiliar with the display on a digital stopwatch, recording, for example, 4.23 s as 4 minutes 23 seconds. Candidates should be using apparatus, particularly measuring equipment, with which they are familiar.

**(d)** Most candidates were able to give a second set of results for a larger ball, with the correct trend. Some candidates gave a second $t$ greater than their first, showing the wrong trend.

**(e) (i)** Most candidates were able to correctly calculate a value for $k$. Weaker candidates found it difficult to deal with the $1 - (x/d)^2$ expression when rearranging the equation and there were other mistakes making $k$ the subject of the equation. One error from a number of candidates was to substitute the value of $1 - (x/d)^2$ as $(x/d)^2$. It would be easier to substitute values and simplify each numerical part, particularly as the value of $1 - (x/d)^2$ had been previously calculated. Candidates should be familiar with this approach and also to not to round intermediate values. This can result in a final value that is out-of-tolerance at the second significant figure.

**(ii)** Many candidates recognised that the measurement of $h$ had the fewest significant figures and that this would limit the number of significant figures given for $k$. Only the strongest candidates realised that it was necessary to refer not only to $h$ but also to the significant figures in the other measured values (or in this case to $1 - (x/d)^2$) in order to get credit. Weaker responses made reference to 'raw data' or 'measured values' without stating the quantities involved.

**(f)** Candidates should calculate the percentage *difference* between their $k$ values and compare this to the suggested percentage *uncertainty*. There were many clear answers but some vague statements such as, *'the percentage uncertainty was less than the percentage uncertainty, so the results support the relationship'*. There were also answers showing confusion over the requirement, such as: '*My results do support the relationship as their difference (33 per cent) is close to 30 per cent', 'Percentage difference does not equal 30 per cent so results do not support the relationship' or 'Percentage difference is nowhere near the suggested percentage uncertainty of 30 per cent so results do not support the relationship'*

It is expected that there will be a numerical comparison with the suggested uncertainty given, in this case 30 per cent, and a statement such as, *'The percentage difference between my k-values* ***is less than*** *the suggested percentage uncertainty of 30 per cent so my results* ***support*** *the relationship.'*.

**(g) (i)** Most candidates described four sources of uncertainty or problems, but many suggestions were too vague or did not refer to the measurement affected. Difficulty judging the point at which the ball reached the end of the track needed to be linked to the measurement of $t$, for example.

Many candidates recognised that two sets of data were insufficient to draw a valid conclusion.

Parallax was an issue identified by many candidates, but in this experiment was only relevant to measurements of *d* and/or judging when the ball reaches the end of the track. Parallax is a problem only if there is an unavoidable gap between the scale or marker and the item being measured. Candidates should apply the problem of parallax only to these situations. In this experiment many candidates referred to parallax error in the measurement of *h*, but the ruler could be held so that it was touching the end of the track, without any gap.

**(ii)** Most candidates described four improvements but, as in **(i)** there were many vague answers. There were also many suggestions such as ‘read the ruler at right angles’ or ‘take repeat measurements and calculate the average’ that should be standard practice, and so could have been done in this experiment.

Stronger candidates were able to suggest taking more sets of readings (for different diameter balls) and plotting a graph, using a micrometer or vernier calipers for the measurement of diameter and recording a video with a timer in view that would be replayed frame-by-frame.

Some candidates made reference to bending of the trunking or track. However just stating ‘use stiffer track’ will not gain credit unless the way of achieving this is described, such as using a metal track.

Candidates should be aware that stating, ‘larger track’ could mean ‘longer track’ or ‘wider track’ unless this is made clear with ‘to allow greater value of length’, for example.

The key to this section is for candidates to identify genuine problems associated with setting up the experiment and in obtaining measured values. Candidates are encouraged to suggest practical solutions that either improve technique or give more reliable data. More successful candidates will select relevant problems and describe them clearly, linking to relevant measurements and will suggest improvements that are workable and expressed clearly.

# PHYSICS

**Paper 9702/35**
**Advanced Practical Skills 1**

## Key messages

- Consideration of the range of readings available (**Question 1**).
- An understanding of when to record data to consistent decimal places and when to record to consistent significant figures.
- Recognising the effect of a false origin on the y-intercept value on the graph.
- Accuracy of the drawn line of best fit on the graph.
- In last part of **Question 2** (limitations and improvements) candidates need to ensure that their answers are specific in linking their comments to the procedure or quantity being referred to. General responses such as 'measuring the time was difficult due to human error' or 'use more precise measuring instruments' will not gain credit without further clarification.

## General comments

Most centres did not appear to have difficulty in providing the equipment requested for both experiments. In **Question 1** there was some variation in the masses provided to candidates which in some instances affected setting the rod horizontal using the stated string angle of 45°.

In general, any deviation between the requested equipment and that provided to the candidates should be written down clearly in the Supervisor's Report and this report <u>must</u> be sent with the scripts to Cambridge so that the Examiners can take this into consideration when marking. No 'extra' equipment should be available to the candidates as, in some cases, this may disadvantage them.

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 was a large selection of very good responses produced. Candidates did not seem to be short of time and both questions were attempted by almost all of them. Overall, candidates demonstrated competent skills in the generation and handling of data but could improve in several areas:

**1.** Before carrying out their data collection candidates are reminded to ensure they have read very carefully the instructions regarding what is required from the setup and use of the apparatus. In this particular paper, **Question 1** required some fairly precise control of the apparatus involved and it was clear that, in some cases, candidates had not adhered to the instructions set out in the paper.

**2.** By ensuring the presentation of their tabulated work is legible and conforms to scientific convention. For example, some candidates produced very cramped data tables despite having a large white space in which to set out a clear table. Such cramping of work can make interpretation of the candidates' information difficult. Others had some data tabulated and other data 'scattered' around the white space on page 4 and thus did not conform to correct scientific principles.

Candidates are encouraged to <u>plan</u> the layout of their data table before then using a <u>ruler</u> to set out clear rows and columns with sufficient space to legibly enter their data.

**3.** In the last part of **Question 2**, candidates are reminded that for the 'limitations' section they should, for each point, identify a measured quantity that has an associated 'difficulty' (in ensuring accuracy) <u>and</u> provide some detail as to the reason(s) why this difficulty exists. A similar approach should be taken in the 'improvements' section where candidates are encouraged to identify improvements <u>but should also</u> link these to the relevant quantity that it is intended to improve.

**Comments on specific questions**

**Question 1**

**(a)** Most candidates had appropriate values for *S*, *θ*, *p* and *q*. In general, candidates are reminded that in using a protractor to measure an angle this can only sensibly be done to the nearest whole degree. Where no unit is pre-given for a quantity on the answer, candidates should always provide an appropriate unit.

**(b)** Virtually all candidates were able to collect six sets of values of *p* and *q* without assistance from the Supervisor. However, a significant number did not obtain the correct trend in their data. In some instances, this appeared to be due to incorrect following of instructions in the use of the apparatus and/or incorrect use of a ruler to measure *p* and *q* (e.g. using the ruler from the 100 cm marker rather than the 0 cm marker). In general, candidates are encouraged to check their results as they proceed and, if one value is out of trend with the rest, to repeat the collection of that data point.

A number of candidates did not extend their range of *q* values to a low enough and/or high enough value. Candidates are reminded to use the whole range available to them which will often imply using lower <u>and</u> higher values than the initial value used in the very first part of the question (**Question 1(a)(i)** in this instance).

In their table, the majority of candidates gave both the quantity and correct unit for each heading separated by a solidus or brackets around the unit.

Many candidates correctly wrote their calculated values of $T_P$ and $T_Q$ to an appropriate number of significant figures based on their values of *p* and *q* and on the given value of *W*. Candidates are encouraged to be aware that changes in the number of significant figures in their raw (collected) data can have an effect on the number of significant figures in their calculated values. For example, if collected data spans both single digit and double-digit numbers.

**(c)** Many candidates plotted the correct graph with quantities labelled correctly on the corresponding axes. For the most part, they used sensible and regular scales such that all the data occupied over half the graph grid available. The majority of candidates are setting up graph axes using sensible (non-awkward) scales and this consequently enables awarding of marks for plotting points, reading off for the gradient and for the intercept.

Many plots 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 not awarding the plotting mark Candidates are encouraged to use a sharpened pencil for the graph work.

**(ii)** Some candidates were able to draw a carefully considered line of best fit that had a balanced distribution of points either side of the line along the entire length. This was especially the case if they had taken care at the experimental stage in collecting accurate data. Common reasons for not awarding this mark included: lines needing a rotation or a shift to get a better fit; lines with kinks, joins or that had been drawn with a damaged straight edge. Some candidates think that a best fit line must have some points ‘above’ and some points ‘below’ their line once drawn and they artificially skew their line to make this so. The line of best fit mark is only awarded if it is clear candidates have given due consideration to the spread of their data points and the corresponding appropriate balance of those points about the resulting line drawn.

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)** Most candidates correctly used a large triangle to calculate the gradient, used correct read-offs and substituted into $\frac{\Delta y}{\Delta x}$ correctly. Candidates then went on to use a correct read off and correctly substitute into $y = mx + c$ to find the y-intercept. A relatively large number of candidates were not awarded the y-intercept mark due to not recognising the 'false origin' which frequently occurred on the graphs from this experiment. Candidates are reminded that, if they use this method to find the y-intercept, they should double-check their x-axis scale to ensure that it does not have a false origin.

Some further reasons for not awarding the gradient and/or y-intercept mark included: too small a gradient triangle (less than half the length of the drawn line); substitution into $\frac{\Delta x}{\Delta y}$ ; plots incorrectly read off (especially if awkward scales had been used); points used from the table which were not on the line of best fit; substitution into a wrongly arranged equation e.g. $c = y/mx$ for the y-intercept.

**(d) (i)** Candidates needed to be mindful of the format of the equation presented here. A significant number cited *A* as the gradient and *B* as the y-intercept and so were not awarded the first mark. For the most part, units were correctly identified.

**(ii)** Stronger candidates correctly rearranged the equation, maintained power of ten consistency in the values of *A* and *S* and found a correct value for *R* along with providing a correct unit.

**Question 2**

**(a) (i)** The majority of candidates correctly measured a value of *d* as required.

**(ii)** Where centres have provided sufficient opportunity for candidates to practice working with percentage uncertainties, this question presented no difficulties. However, there are a substantial number who struggle with this part of **Question 2** and candidates are encouraged to work with 'half range' estimates of uncertainty AND making sensible estimates of absolute uncertainty that takes account of the inherent difficulties in making the required measurement(s). As a general rule, the latter approach will not be awarded the mark if a candidate simply uses the smallest measurement division on the piece of apparatus being used e.g. +/–1 mm if using a millimetre ruler

**(b)** Values of *L* were almost all in range. A few candidates obtained a value for *L* that was greater than the length of the metre ruler provided.

**(c) (i)** The majority correctly measured *h* to the nearest millimetre with many repeating readings (although this was not required in this instance). Measurements of *t* were done well by the majority, including repeating of readings. The majority also gave correct units for both *h* and *t*.

**(ii)** Almost all candidates were awarded this mark, using correct substitution of values to obtain the acceleration of the bottle.

**(iii)** This was done well by most candidates who correctly justified the number of significant figures they had given for the value of *a* with reference to the number of significant figures used in *L* and *t*. The most common reasons for not awarding this mark were for bald references to 'raw readings', 'previous measurements' or 'values used in the calculation' without detailing the what the individual <u>raw</u> quantities concerned were. Some candidates incorrectly focused on the number of decimal places involved in the data.

**(d)** The majority of candidates successfully took further readings of *h* and *t* and also showed good experimental technique in obtaining a second value of *t* that was larger than the first.

**(e)** Mathematically stronger candidates were able to calculate the *k* values for their two sets of data, showing their working clearly. Weaker candidates rearranged the equation incorrectly or were inconsistent in their powers of ten e.g. using a value of *a* in $\text{m s}^{-2}$ and then *d* and/or *h* in cm. In this instance, such an error leads to an incorrect calculation.

**(f)** This was done well by lots of candidates who calculated the percentage difference between their values of *k*, tested it against the stated 15 per cent criterion <u>and</u> provided a valid statement in conclusion. Some candidates omitted a percentage difference calculation, gave a different criterion (e.g. 10 per cent, 20 per cent or the uncertainty from **(a)(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.

Candidates are reminded that there are three parts required for successfully answering this section of **Question 2**: a calculation to show the percentage difference in the *k* values; a comparison to the stated percentage criterion; a statement to say whether their calculation supports or rejects the relationship.

**(g)** Candidates need to identify difficulties associated with setting up and obtaining the required readings. They can do this by writing about the different measurements taken and/or chronologically going through the experiment in a systematic way to identify where 'limitations' are to be found. Candidates should then think of corresponding 'improvements' that address each difficulty. With both limitations and improvements candidates are encouraged to be specific and add detail in order to gain credit by addressing questions such as: 'How does this solution solve a specific difficulty?' or 'What measurement is difficult/subject to uncertainty and why?'.

Problems commonly awarded marks were: 'two sets of data were not enough to draw a valid conclusion'; 'difficult to measure *t* as it is difficult to identify the point at which the bottle reaches the end of the rulers'; '*h* was difficult to measure because of parallax error'

Improvements that were commonly credited included: 'take more readings and plot a graph' and 'use a caliper to measure d'.

With both limitations and improvements candidates should be encouraged to state what the relevant quantity is **AND** give a reason for it having uncertainty. In general, a clear way for candidates to express the limitations is to use a format such as '*it was difficult to measure* (stated quantity) ***because*** (stated reason)'.

For example, 'it was difficult to measure *x* because there was no vertical reference line (or mark) to measure it from'. Such statements are concise, clear and show good awareness of the experimental difficulties typically inherent in the **Question 2** experiments.

Similarly, for the 'improvements', statements such as '*the measurement of* (stated quantity) *could be improved by* (appropriate approach taken)' offer a precise approach to tackling this section of the paper.

For example, 'the measurement of *x* could be improved by using a plumbline to act as a vertical reference line'.

# PHYSICS

**Paper 9702/36**
**Advanced Practical Skills 2**

## Key messages

- Ensure all quantities listed in the question are included in the table of results.
- Record all measured values according to the resolution of the measuring instrument.
- Positioning of the line of best fit and use of a sufficiently long ruler to draw a continuous straight line.
- When suggesting possible limitations and improvements in **Question 2**, ensure the measured quantity is quoted as part of the response.

## 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 'extra' equipment should be available to the candidates. In some cases, this may disadvantage candidates.

Any help given to a candidate should be detailed in 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. Candidates demonstrated good skills in the generation and handling of data and in their responses to improvements to the limitations in **Question 2** and can improve by giving more thought to expressing clearly the limitations of the experiment.

## Comments on specific questions

### Question 1

**(a)** Most candidates recorded repeated readings of *P* and had a final value within the expected range. A correct unit was provided by most candidates. A small number of candidates recorded *P* values that were smaller than 1.0 s, suggesting that the stopwatch was misread. Others appeared to have calculated frequency rather than time. As such, their final value was outside the expected range.

**(b)** Almost all candidates recorded six sets of readings. Some did not include columns in their table for all the quantities listed in the question stem and so could not gain full access to the marks for this question.

Whilst many candidates made best use of the range of masses available, some were not awarded the range mark because they did not extend their range high enough to include 70 g or low enough to include 10 g. Instead, such candidates only recorded data for masses of 10 g to 60 g, or 20 g to 70 g, in 10 g intervals.

Most candidates provided column headings consisting of a quantity and unit separated by either a solidus or brackets around the units. Candidates not awarded this mark often omitted units or provided incorrect units for $1 / P$ and/or $1 / \sqrt{M}$ .

For the consistency mark, candidates were expected to record all values of *P* to the nearest 0.01 s or all values to the nearest 0.1 s. Although many did this, some seemed to want to preserve the number of significant figures in the column and so reduced the number of decimal places when the time changed from 9 s to 10 s.

Many candidates gave values of $1/\sqrt{M}$ to an appropriate number of significant figures.

The calculation of $1/\sqrt{M}$ was correct in most cases. Candidates not awarded this mark had either presented their value with a rounding error or performed an incorrect calculation, e.g., $1 / M$.

**(c)(i)** Many candidates were able to select sensible scales for their graph axes which allowed the plotted points to occupy at least half the grid in both the *x* and *y* directions.

Whilst few awkward scales (e.g., 3:10) were seen, some candidates made poor choices when deciding upon a suitable scale for their axes. For example, taking the lowest and highest table values and using these as the first and last scale markings on each axis. Then dividing the range by the number of grid squares to arrive at the interval. This inevitably led to awkward scales and so the mark for graph axes could not be awarded. In such cases, candidates often misread their own awkward scales when plotting points and taking read-offs for the gradient and *y*-intercept calculations. As such, this should be heavily discouraged.

Several candidates, in trying to achieve a true origin on the *x*-axis, selected scales that resulted in their data occupying too few large squares in the horizontal direction.

Most candidates were able to draw plots as crosses using a fine line that meant the positioning of the centre of the cross could be judged using the tolerance of half a small square. Some candidates used plots with diameters greater than half a small square. As such, the accuracy of these plots could not be judged, and the plotting mark could not be awarded.

**(ii)** Some candidates were able to draw a straight, thin, line of best fit with an even distribution of points either side of the line along the full length. Lines not credited were often kinked or poorly jointed. Other lines would have achieved a better fit via a rotation or translation.

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. The judgement of the line of best fit mark can be made on the remaining plots.

**(iii)** Some candidates correctly used a large triangle to calculate the gradient, used correct read-offs and substituted into $\Delta y/\Delta x$ correctly. Candidates then went on to read off from the graph at $x = 0$ or used a correct read off into $y = mx + c$ to find the *y*-intercept. Some of the reasons for not awarding the gradient mark included: too small a gradient triangle; substitution into $\Delta x/\Delta y$; plots incorrectly read off; points used from the table which were not on the line of best fit; read offs and triangle not shown. Due to the nature of the *x*-axis data, the most common reason for not awarding the *y*-intercept was reading the *y*-intercept directly off the graph when there was a false origin.

**(d)** Most candidates recognised that *a* was their gradient value and *b* their *y*-intercept value. A small number were not awarded this mark because at least one of the values was given to only one significant figure. Some candidates recalculated new gradient and intercept values in **(d)** to arrive at values of *a* and *b*. The new values, if not the same as those in **(c)(iii)**, were not credited.

Many candidates either omitted units for *a* and *b* or were unable to determine a correct unit for *a* with several candidates incorrectly stating the units as $\text{g s}^{-1}$ or $g^{-\frac{1}{2}}\,\text{s}^{-1}$ instead of $g^{\frac{1}{2}}\,\text{s}^{-1}$.

**Question 2**

**(a)** Most candidates stated a value for *d* that was within the expected range and to the nearest mm. Some, rather than measuring *d* directly, measured the heights of the two rods from the bench and then calculated the difference. This method was acceptable provided that the two heights were measured to the nearest mm.

**(b)** Almost all candidates were able to correctly calculate a value of $T$ and give their answer to 3 or 4 significant figures. Those not awarded this mark used too few significant figures when presenting their value i.e., fewer significant figures than the values used in the calculation.

**(c) (i)** Successful candidates recorded repeated readings of $x$ and quoted all raw readings to the nearest mm.

**(ii)** Given the limitations involved in measuring $x$, e.g., judging where to begin and end the measurement, parallax, the absolute uncertainty was not solely determined by the resolution of the measuring instrument. Many candidates we able to suggest a suitable absolute uncertainty for $x$ but some incorrectly used the smallest reading on the ruler i.e. $\pm$ 1 mm rather than accounting for the practical difficulties. Some candidates correctly used half the range of repeated readings as their absolute uncertainty, and this was credited where working was clearly shown and repeated readings were seen.

**(iii)** Almost all candidates were able to correctly calculate $y$. Some had values with rounding errors which meant that the mark could not be awarded.

**(d)** Almost all candidates provided second values of $T$ and $x$. In most cases, the second value of $x$ was smaller than the first and so met the quality criterion for this question.

**(e) (i)** Most candidates were able to correctly calculate two values of $k$.

**(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 $T$, $x$ and $y$ (or $d$). Common reasons for not awarding this mark were stating 'raw readings', 'previous measurements', 'values used in calculation' without detailing the quantities involved or only referencing the quantity deemed to have the least significant figures.

**(f)** Many candidates correctly calculated the % difference between their values of $k$, then tested their value against the stated 20% criterion, and provided a valid conclusion. Some candidates omitted a % difference calculation, gave a different criterion e.g. 15% or gave an invalid statement inconsistent with their findings. Candidates should be aware that when testing against a criterion, stating that their calculated % difference is 'close to' the criterion is not an acceptable way of comparing the two. Candidates should instead clearly state whether their % difference is 'less than the criterion' or 'greater than the criterion'.

**(g) (i),(ii)** Many candidates did not gain full credit in this section because they did not follow the advice in the question stem and state the quantity being measured alongside the difficulty associated with the measurement of that quantity.

Candidates should use phrasing such as, e.g., 'difficulty with $x$ because...' to begin responses.

When suggesting solutions to problems, the candidate should reiterate the quantity being measured. Examiners are unable to make links between the suggested improvements in **(ii)** and limitations in **(i)** and so without sufficient detail in **(ii)** candidates may not gain credit.

Commonly awarded limitations were 'two sets of readings are insufficient to draw a valid conclusion', 'difficult to measure $x$ due to a parallax error', 'difficult to maintain the value of 5.0 N when pulling the string' and 'difficult to measure $x$ as it is hard to hold the ruler steady'.

Commonly awarded improvements were 'take more readings and plot a graph', 'clamp the ruler when measuring $x$', 'clamp the newton meter' and 'use a vertical reference when measuring $x$'.

Although some candidates recognised the large uncertainty in the measurement of $x$, this was not often correctly expressed as a large % uncertainty in $x$.

Many candidates suggested recording the experiment to overcome the difficulty of checking two measurements simultaneously. Few, however, referred to both measuring instruments (metre rule and newton meter) being in view when filming.

Please refer to the mark scheme for more examples of acceptable limitations and improvements.

# PHYSICS

**Paper 9702/37**
**Advanced Practical Skills 1**

## Key messages

- Consideration of the range of readings available (**Question 1**).
- An understanding of when to record data to consistent decimal places and when to record to consistent significant figures.
- Recognising the effect of a false origin on the y-intercept value on the graph.
- Accuracy of the drawn line of best fit on the graph.
- In last part of **Question 2** (limitations and improvements) candidates need to ensure that their answers are specific in linking their comments to the procedure or quantity being referred to. General responses such as 'measuring the time was difficult due to human error' or 'use more precise measuring instruments' will not gain credit without further clarification.

## General comments

Most centres did not appear to have difficulty in providing the equipment requested for both experiments. In **Question 1** there was some variation in the masses provided to candidates which in some instances affected setting the rod horizontal using the stated string angle of 45°.

In general, any deviation between the requested equipment and that provided to the candidates should be written down clearly in the Supervisor's Report and this report must be sent with the scripts to Cambridge so that the Examiners can take this into consideration when marking. No 'extra' equipment should be available to the candidates as, in some cases, this may disadvantage them.

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 was a large selection of very good responses produced. Candidates did not seem to be short of time and both questions were attempted by almost all of them. Overall, candidates demonstrated competent skills in the generation and handling of data but could improve in several areas:

**1.** Before carrying out their data collection candidates are reminded to ensure they have read very carefully the instructions regarding what is required from the setup and use of the apparatus. In this particular paper, **Question 1** required some fairly precise control of the apparatus involved and it was clear that, in some cases, candidates had not adhered to the instructions set out in the paper.

**2.** By ensuring the presentation of their tabulated work is legible and conforms to scientific convention. For example, some candidates produced very cramped data tables despite having a large white space in which to set out a clear table. Such cramping of work can make interpretation of the candidates' information difficult. Others had some data tabulated and other data 'scattered' around the white space on page 4 and thus did not conform to correct scientific principles.

Candidates are encouraged to plan the layout of their data table before then using a ruler to set out clear rows and columns with sufficient space to legibly enter their data.

**3.** In the last part of **Question 2**, candidates are reminded that for the 'limitations' section they should, for each point, identify a measured quantity that has an associated 'difficulty' (in ensuring accuracy) and provide some detail as to the reason(s) why this difficulty exists. A similar approach should be taken in the 'improvements' section where candidates are encouraged to identify improvements but should also link these to the relevant quantity that it is intended to improve.

**Comments on specific questions**

**Question 1**

**(a)** Most candidates had appropriate values for $S$, $\theta$, $p$ and $q$. In general, candidates are reminded that in using a protractor to measure an angle this can only sensibly be done to the nearest whole degree. Where no unit is pre-given for a quantity on the answer, candidates should always provide an appropriate unit.

**(b)** Virtually all candidates were able to collect six sets of values of $p$ and $q$ without assistance from the Supervisor. However, a significant number did not obtain the correct trend in their data. In some instances, this appeared to be due to incorrect following of instructions in the use of the apparatus and/or incorrect use of a ruler to measure $p$ and $q$ (e.g. using the ruler from the 100 cm marker rather than the 0 cm marker). In general, candidates are encouraged to check their results as they proceed and, if one value is out of trend with the rest, to repeat the collection of that data point.

A number of candidates did not extend their range of $q$ values to a low enough and/or high enough value. Candidates are reminded to use the whole range available to them which will often imply using lower and higher values than the initial value used in the very first part of the question (**Question 1(a)(i)** in this instance).

In their table, the majority of candidates gave both the quantity and correct unit for each heading separated by a solidus or brackets around the unit.

Many candidates correctly wrote their calculated values of $T_P$ and $T_Q$ to an appropriate number of significant figures based on their values of $p$ and $q$ and on the given value of $W$. Candidates are encouraged to be aware that changes in the number of significant figures in their raw (collected) data can have an effect on the number of significant figures in their calculated values. For example, if collected data spans both single digit and double-digit numbers.

**(c)** Many candidates plotted the correct graph with quantities labelled correctly on the corresponding axes. For the most part, they used sensible and regular scales such that all the data occupied over half the graph grid available. The majority of candidates are setting up graph axes using sensible (non-awkward) scales and this consequently enables awarding of marks for plotting points, reading off for the gradient and for the intercept.

Many plots 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 not awarding the plotting mark Candidates are encouraged to use a sharpened pencil for the graph work.

**(ii)** Some candidates were able to draw a carefully considered line of best fit that had a balanced distribution of points either side of the line along the entire length. This was especially the case if they had taken care at the experimental stage in collecting accurate data. Common reasons for not awarding this mark included: lines needing a rotation or a shift to get a better fit; lines with kinks, joins or that had been drawn with a damaged straight edge. Some candidates think that a best fit line must have some points ‘above’ and some points ‘below’ their line once drawn and they artificially skew their line to make this so. The line of best fit mark is only awarded if it is clear candidates have given due consideration to the spread of their data points and the corresponding appropriate balance of those points about the resulting line drawn.

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)** Most candidates correctly used a large triangle to calculate the gradient, used correct read-offs and substituted into $\frac{\Delta y}{\Delta x}$ correctly. Candidates then went on to use a correct read off and correctly substitute into $y = mx + c$ to find the y-intercept. A relatively large number of candidates were not awarded the y-intercept mark due to not recognising the 'false origin' which frequently occurred on the graphs from this experiment. Candidates are reminded that, if they use this method to find the y-intercept, they should double-check their x-axis scale to ensure that it does not have a false origin.

Some further reasons for not awarding the gradient and/or y-intercept mark included: too small a gradient triangle (less than half the length of the drawn line); substitution into $\frac{\Delta x}{\Delta y}$ ; plots incorrectly read off (especially if awkward scales had been used); points used from the table which were not on the line of best fit; substitution into a wrongly arranged equation e.g. $c = y/mx$ for the y-intercept.

**(d) (i)** Candidates needed to be mindful of the format of the equation presented here. A significant number cited *A* as the gradient and *B* as the y-intercept and so were not awarded the first mark. For the most part, units were correctly identified.

**(ii)** Stronger candidates correctly rearranged the equation, maintained power of ten consistency in the values of *A* and *S* and found a correct value for *R* along with providing a correct unit.

**Question 2**

**(a) (i)** The majority of candidates correctly measured a value of *d* as required.

**(ii)** Where centres have provided sufficient opportunity for candidates to practice working with percentage uncertainties, this question presented no difficulties. However, there are a substantial number who struggle with this part of **Question 2** and candidates are encouraged to work with 'half range' estimates of uncertainty AND making sensible estimates of absolute uncertainty that takes account of the inherent difficulties in making the required measurement(s). As a general rule, the latter approach will not be awarded the mark if a candidate simply uses the smallest measurement division on the piece of apparatus being used e.g. +/–1 mm if using a millimetre ruler

**(b)** Values of *L* were almost all in range. A few candidates obtained a value for *L* that was greater than the length of the metre ruler provided.

**(c) (i)** The majority correctly measured *h* to the nearest millimetre with many repeating readings (although this was not required in this instance). Measurements of *t* were done well by the majority, including repeating of readings. The majority also gave correct units for both *h* and *t*.

**(ii)** Almost all candidates were awarded this mark, using correct substitution of values to obtain the acceleration of the bottle.

**(iii)** This was done well by most candidates who correctly justified the number of significant figures they had given for the value of *a* with reference to the number of significant figures used in *L* and *t*. The most common reasons for not awarding this mark were for bald references to 'raw readings', 'previous measurements' or 'values used in the calculation' without detailing the what the individual <u>raw</u> quantities concerned were. Some candidates incorrectly focused on the number of decimal places involved in the data.

**(d)** The majority of candidates successfully took further readings of *h* and *t* and also showed good experimental technique in obtaining a second value of *t* that was larger than the first.

**(e)** Mathematically stronger candidates were able to calculate the *k* values for their two sets of data, showing their working clearly. Weaker candidates rearranged the equation incorrectly or were inconsistent in their powers of ten e.g. using a value of *a* in $\text{m s}^{-2}$ and then *d* and/or *h* in cm. In this instance, such an error leads to an incorrect calculation.

**(f)** This was done well by lots of candidates who calculated the percentage difference between their values of *k*, tested it against the stated 15 per cent criterion <u>and</u> provided a valid statement in conclusion. Some candidates omitted a percentage difference calculation, gave a different criterion (e.g. 10 per cent, 20 per cent or the uncertainty from **(a)(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.

Candidates are reminded that there are three parts required for successfully answering this section of **Question 2**: a calculation to show the percentage difference in the *k* values; a comparison to the stated percentage criterion; a statement to say whether their calculation supports or rejects the relationship.

**(g)** Candidates need to identify difficulties associated with setting up and obtaining the required readings. They can do this by writing about the different measurements taken and/or chronologically going through the experiment in a systematic way to identify where 'limitations' are to be found. Candidates should then think of corresponding 'improvements' that address each difficulty. With both limitations and improvements candidates are encouraged to be specific and add detail in order to gain credit by addressing questions such as: 'How does this solution solve a specific difficulty?' or 'What measurement is difficult/subject to uncertainty and why?'.

Problems commonly awarded marks were: 'two sets of data were not enough to draw a valid conclusion'; 'difficult to measure *t* as it is difficult to identify the point at which the bottle reaches the end of the rulers'; '*h* was difficult to measure because of parallax error'

Improvements that were commonly credited included: 'take more readings and plot a graph' and 'use a caliper to measure d'.

With both limitations and improvements candidates should be encouraged to state what the relevant quantity is **AND** give a reason for it having uncertainty. In general, a clear way for candidates to express the limitations is to use a format such as '*it was difficult to measure* (stated quantity) ***because*** (stated reason)'.

For example, 'it was difficult to measure *x* because there was no vertical reference line (or mark) to measure it from'. Such statements are concise, clear and show good awareness of the experimental difficulties typically inherent in the **Question 2** experiments.

Similarly, for the 'improvements', statements such as '*the measurement of* (stated quantity) *could be improved by* (appropriate approach taken)' offer a precise approach to tackling this section of the paper.

For example, 'the measurement of *x* could be improved by using a plumbline to act as a vertical reference line'.

# PHYSICS

**Paper 9702/38**
**Advanced Practical Skills 2**

## Key messages

- Ensure all quantities listed in the question are included in the table of results.
- Record all measured values according to the resolution of the measuring instrument.
- Positioning of the line of best fit and use of a sufficiently long ruler to draw a continuous straight line.
- When suggesting possible limitations and improvements in **Question 2**, ensure the measured quantity is quoted as part of the response.

## 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 'extra' equipment should be available to the candidates. In some cases, this may disadvantage candidates.

Any help given to a candidate should be detailed in 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. Candidates demonstrated good skills in the generation and handling of data and in their responses to improvements to the limitations in **Question 2** and can improve by giving more thought to expressing clearly the limitations of the experiment.

## Comments on specific questions

### Question 1

**(a)** Most candidates recorded repeated readings of *P* and had a final value within the expected range. A correct unit was provided by most candidates. A small number of candidates recorded *P* values that were smaller than 1.0 s, suggesting that the stopwatch was misread. Others appeared to have calculated frequency rather than time. As such, their final value was outside the expected range.

**(b)** Almost all candidates recorded six sets of readings. Some did not include columns in their table for all the quantities listed in the question stem and so could not gain full access to the marks for this question.

Whilst many candidates made best use of the range of masses available, some were not awarded the range mark because they did not extend their range high enough to include 70 g or low enough to include 10 g. Instead, such candidates only recorded data for masses of 10 g to 60 g, or 20 g to 70 g, in 10 g intervals.

Most candidates provided column headings consisting of a quantity and unit separated by either a solidus or brackets around the units. Candidates not awarded this mark often omitted units or provided incorrect units for $1/P$ and/or $1/\sqrt{M}$.

For the consistency mark, candidates were expected to record all values of *P* to the nearest 0.01 s or all values to the nearest 0.1 s. Although many did this, some seemed to want to preserve the number of significant figures in the column and so reduced the number of decimal places when the time changed from 9 s to 10 s.

Many candidates gave values of $1/\sqrt{M}$ to an appropriate number of significant figures.

The calculation of $1/\sqrt{M}$ was correct in most cases. Candidates not awarded this mark had either presented their value with a rounding error or performed an incorrect calculation, e.g., $1 / M$.

**(c)(i)** Many candidates were able to select sensible scales for their graph axes which allowed the plotted points to occupy at least half the grid in both the *x* and *y* directions.

Whilst few awkward scales (e.g., 3:10) were seen, some candidates made poor choices when deciding upon a suitable scale for their axes. For example, taking the lowest and highest table values and using these as the first and last scale markings on each axis. Then dividing the range by the number of grid squares to arrive at the interval. This inevitably led to awkward scales and so the mark for graph axes could not be awarded. In such cases, candidates often misread their own awkward scales when plotting points and taking read-offs for the gradient and *y*-intercept calculations. As such, this should be heavily discouraged.

Several candidates, in trying to achieve a true origin on the *x*-axis, selected scales that resulted in their data occupying too few large squares in the horizontal direction.

Most candidates were able to draw plots as crosses using a fine line that meant the positioning of the centre of the cross could be judged using the tolerance of half a small square. Some candidates used plots with diameters greater than half a small square. As such, the accuracy of these plots could not be judged, and the plotting mark could not be awarded.

**(ii)** Some candidates were able to draw a straight, thin, line of best fit with an even distribution of points either side of the line along the full length. Lines not credited were often kinked or poorly jointed. Other lines would have achieved a better fit via a rotation or translation.

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. The judgement of the line of best fit mark can be made on the remaining plots.

**(iii)** Some candidates correctly used a large triangle to calculate the gradient, used correct read-offs and substituted into $\Delta y/\Delta x$ correctly. Candidates then went on to read off from the graph at $x = 0$ or used a correct read off into $y = mx + c$ to find the *y*-intercept. Some of the reasons for not awarding the gradient mark included: too small a gradient triangle; substitution into $\Delta x/\Delta y$; plots incorrectly read off; points used from the table which were not on the line of best fit; read offs and triangle not shown. Due to the nature of the *x*-axis data, the most common reason for not awarding the *y*-intercept was reading the *y*-intercept directly off the graph when there was a false origin.

**(d)** Most candidates recognised that *a* was their gradient value and *b* their *y*-intercept value. A small number were not awarded this mark because at least one of the values was given to only one significant figure. Some candidates recalculated new gradient and intercept values in **(d)** to arrive at values of *a* and *b*. The new values, if not the same as those in **(c)(iii)**, were not credited.

Many candidates either omitted units for *a* and *b* or were unable to determine a correct unit for *a* with several candidates incorrectly stating the units as $g\,s^{-1}$ or $g^{-\frac{1}{2}}\,s^{-1}$ instead of $g^{\frac{1}{2}}\,s^{-1}$.

**Question 2**

**(a)** Most candidates stated a value for *d* that was within the expected range and to the nearest mm. Some, rather than measuring *d* directly, measured the heights of the two rods from the bench and then calculated the difference. This method was acceptable provided that the two heights were measured to the nearest mm.

**(b)** Almost all candidates were able to correctly calculate a value of $T$ and give their answer to 3 or 4 significant figures. Those not awarded this mark used too few significant figures when presenting their value i.e., fewer significant figures than the values used in the calculation.

**(c) (i)** Successful candidates recorded repeated readings of $x$ and quoted all raw readings to the nearest mm.

**(ii)** Given the limitations involved in measuring $x$, e.g., judging where to begin and end the measurement, parallax, the absolute uncertainty was not solely determined by the resolution of the measuring instrument. Many candidates we able to suggest a suitable absolute uncertainty for $x$ but some incorrectly used the smallest reading on the ruler i.e. $\pm$ 1 mm rather than accounting for the practical difficulties. Some candidates correctly used half the range of repeated readings as their absolute uncertainty, and this was credited where working was clearly shown and repeated readings were seen.

**(iii)** Almost all candidates were able to correctly calculate $y$. Some had values with rounding errors which meant that the mark could not be awarded.

**(d)** Almost all candidates provided second values of $T$ and $x$. In most cases, the second value of $x$ was smaller than the first and so met the quality criterion for this question.

**(e) (i)** Most candidates were able to correctly calculate two values of $k$.

**(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 $T$, $x$ and $y$ (or $d$). Common reasons for not awarding this mark were stating ‘raw readings’, ‘previous measurements’, ‘values used in calculation’ without detailing the quantities involved or only referencing the quantity deemed to have the least significant figures.

**(f)** Many candidates correctly calculated the % difference between their values of $k$, then tested their value against the stated 20% criterion, and provided a valid conclusion. Some candidates omitted a % difference calculation, gave a different criterion e.g. 15% or gave an invalid statement inconsistent with their findings. Candidates should be aware that when testing against a criterion, stating that their calculated % difference is ‘close to’ the criterion is not an acceptable way of comparing the two. Candidates should instead clearly state whether their % difference is ‘less than the criterion’ or ‘greater than the criterion’.

**(g) (i),(ii)** Many candidates did not gain full credit in this section because they did not follow the advice in the question stem and state the quantity being measured alongside the difficulty associated with the measurement of that quantity.

Candidates should use phrasing such as, e.g., ‘difficulty with $x$ because...’ to begin responses.

When suggesting solutions to problems, the candidate should reiterate the quantity being measured. Examiners are unable to make links between the suggested improvements in **(ii)** and limitations in **(i)** and so without sufficient detail in **(ii)** candidates may not gain credit.

Commonly awarded limitations were ‘two sets of readings are insufficient to draw a valid conclusion’, ‘difficult to measure $x$ due to a parallax error’, ‘difficult to maintain the value of 5.0 N when pulling the string’ and ‘difficult to measure $x$ as it is hard to hold the ruler steady’.

Commonly awarded improvements were ‘take more readings and plot a graph’, ‘clamp the ruler when measuring $x$’, ‘clamp the newton meter’ and ‘use a vertical reference when measuring $x$’.

Although some candidates recognised the large uncertainty in the measurement of $x$, this was not often correctly expressed as a large % uncertainty in $x$.

Many candidates suggested recording the experiment to overcome the difficulty of checking two measurements simultaneously. Few, however, referred to both measuring instruments (metre rule and newton meter) being in view when filming.

Please refer to the mark scheme for more examples of acceptable limitations and improvements.

# 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.

Most candidates showed their working. Some candidates would benefit from presenting their calculations more clearly. In particular, it is important to write numbers clearly so that they are unambiguous (e.g. 2 and 3, or 5, 6 and 8). This particularly applies to powers of ten.

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

**Comments on specific questions**

**Question 1**

**(a)** Most candidates appreciated that velocity and acceleration were always perpendicular to each other in circular motion. A smaller number of candidates appreciated that the magnitude of the velocity (speed) was constant. It was rarely written that the magnitude of the acceleration was also constant.

**(b) (i)** This question was generally answered correctly.

**(ii)** Most candidates understood the relationship between acceleration and either angular or linear velocity. Some candidates did not identify that the question required a relationship to be given that included all three of those quantities.

**(c) (i)** Most candidates recognised that a sine term needed to be used in the expression.

**(ii)** This question was generally answered correctly.

**(iii)** This 'show that' question required candidates to include both equations from the two earlier parts of **(c)** before they made the substitution to match the given answer.

**(iv)** Many candidates ignored the requirement to refer to the given equation in **(c)(iii)**. Instead, correct relationships were often given between acceleration and displacement. Such answers were not able to gain credit as they did not answer the question that was asked.

**(d) (i)** This question was generally answered correctly, with most candidates understanding what is meant by amplitude.

**(ii)** Most candidates knew the relationship between angular frequency/velocity and period.

**(iii)** Successful responses made clear that the acceleration and displacement were the maximum values, by the inclusion of a subscript ($a_0$, $x_0$) in the equation used.

**(e)** This question considered the movement of the shadow on the screen. Only the strongest candidates appreciated that drawing the shadow as a whole gave a greater opportunity to correctly identify the position of maximum positive acceleration. A significant minority of candidates did not follow the instruction in the question to label the shadow with the letter 'A'. Stronger candidates appreciated that the maximum positive acceleration would occur at the extreme left-hand edge of the movement of the shadow.

**Question 2**

**(a)** Stronger candidates clearly described the context of a system or gas, and were able to identify that work being done or thermal energy being added or removed would change the internal energy of that system. A significant number of candidates mistakenly appeared to believe that changes of work or changes of thermal energy were required to change the internal energy.

**(b) (i)** Some candidates did not mention a system or gas, making their descriptions inaccurate. Stronger candidates understood that the change was too quick to allow thermal energy to be involved. Weaker answers confused thermal energy with internal energy or temperature.

**(ii)** Many answers did not refer to molecular energies directly. Descriptions of bonds being broken were common, but stronger candidates explained that both molecular separation and molecular potential energy increased. The link between molecular kinetic energy and temperature was generally well understood.

**Question 3**

**(a)** In general, the ratio of force per unit mass was clearly expressed.

**(b) (i)** The word 'derive' in the question implied a starting point of the expression for gravitational force due to a point mass. Stronger candidates correctly combined this with their answer in **(a)**, and also identified the gravitational constant symbol.

**(ii)** The drawing of the gravitational field direction on Fig. 3.1 was improved by the use of a ruler to ensure that the field direction extrapolated through both the test mass at P and mass *M*. Where lines were inaccurately drawn, this prevented candidates from gaining credit. Weaker answers mistakenly considered the gravitational field of the test mass at P.

**(iii)** The majority of the candidates understood the inverse-square nature of the gravitational field and were able to deduce the factor of four as being the difference between the fields at P and Q. Stronger candidates also identified that the fields were in opposite directions.

**(c)** In general, the graph was well drawn. Credit could be gained for showing the correct start and end points, the correct point at which the field strength was zero, and the increasing steepness of the curve away from the midpoint. Candidates who used a pencil, and could therefore adjust their sketch where it was inaccurate, were at an advantage.

**Question 4**

**(a)** Weaker candidates confused the temperature scales in **(i)** and **(ii)**, reversing their answers. Some candidates incorrectly rounded their answer in **(i)** to a whole number.

**(b) (i)** Candidates were generally able to identify the gas as being an ideal gas. Weaker answers simply gave an expression in symbols without indicating anything about the nature of the gas.

**(ii)** This question was well answered.

**(iii)** This question was well answered, with candidates generally using the correct expression, then showing their working in full before expressing their answer to the correct number of significant figures.

**(c)** Stronger candidates laid out their working clearly, appreciating that an answer in kilograms required conversion to atomic mass units. The final answer was not exactly 4 u, so two significant figures were required. Weaker candidates often did not recognise that an r.m.s. speed was given, which needed to be squared to obtain the mean-square speed. Some candidates were incorrect in the way they expressed the mean-square speed in symbol form, creating an incorrect meaning to their expression.

**Question 5**

**(a)** Most candidates had some recall of the definition. Where full credit was not awarded, this was usually due to one of two omissions, either not making the ratio clear or not clarifying that the charge being moved from infinity was positive.

**(b) (i)** This 'show that' question required the working to be clearly set out, showing the addition of the two contributory potentials. Stronger candidates clearly showed all the values used and the sign of those contributory potentials.

**(ii)** Most candidates were able to successively replicate their method from **(i)** to the new situation. Some weaker candidates did not realise that the distances to both charges would change, or only considered one charge.

**(iii)** Many candidates were able to position the cross correctly.

**(iv)** Credit could be gained for identifying the key elements of a correct start and end point, an increasing steepness of the curve away from the midpoint where there was a sign change, and the correct plotting of a potential at 30 pm and 90 pm. Candidates who used a pencil, and could therefore adjust their sketch where it was inaccurate, were at an advantage.

**Question 6**

**(a)** This question highlighted where candidates had a confused understanding of the relationships for charge and for p.d. in the arrangements of series and parallel capacitors. Candidates generally found this question more difficult than the following questions that concerned only a single capacitor.

**(b) (i)** This question was generally well answered.

**(ii)** There were a number of ways that candidates could answer this question, depending on the equation they chose to use. Candidates generally performed well on this question.

**(iii)** Stronger candidates understood that the charge value obtained in **(ii)** was the same for this arrangement of two capacitors. Weaker candidates often believed that the p.d. value obtained in **(i)** was the same for this arrangement, and so attempted to use the same equation as they used in **(i)**.

**Question 7**

**(a)** Faraday's law was generally recalled accurately. Occasional confusion was seen between the terms flux linkage and flux density.

**(b) (i)** Leading on from the statement in **(a)**, the relationship between e.m.f. and magnetic flux was generally applied successfully in this question. Weaker candidates found difficulty in identifying an appropriate unit for their numerical answer.

**(ii)** This question was well answered by most candidates.

**(iii)** The involvement of the width of the aircraft's wings led to some confusion over the application of two basic equations: speed = distance travelled × time and area = width × distance travelled for a significant number of weaker candidates.

**(iv)** Candidates found this question difficult. Better answers were written in stages, first considering the direction of the force to oppose the motion of the aircraft, then describing the application of Fleming's left-hand rule to identify the direction of current flow from wingtip Q to P. The strongest candidates appreciated that this current was inside an e.m.f. source and then gave the correct answer.

**Question 8**

**(a)** There was a good understanding of the nature of the photon amongst most candidates.

**(b) (i)** To successfully answer this question, candidates needed to maintain the use of six decimal places in their calculations to match the data provided. Most candidates attempted to use the equation $E = mc^2$ but only stronger candidates converted the energy released into a mass in u to then be added to the other two masses.

**(ii)** The correct equation was used by most candidates. Stronger candidates were able to follow through the subtraction of energies that gave the value for the energy of the gamma photon.

**(ii)** Stronger candidates identified that they should be describing the energy of a gamma photon and its relationship to wavelength.

**(c)** Candidates who mentioned another product of the decay usually knew the correct product. Weaker candidates were unaware of the impact of the energy sharing between the products on the energy available to each gamma photon. Stronger candidates appreciated that each decay involved a single gamma photon.

**Question 9**

**(a)** The relationship between temperature and wavelength was generally understood. Some candidates omitted reference to the *surface* temperature or did not mention a star or black body.

**(b)** Many candidates wrote at least one answer that, although factually correct, was not a *conclusion* that could be drawn from the data. Some were simply readings of the data itself, put into words. This would suggest that candidates would benefit from exercises in differentiating between the data itself and the conclusions available from it. Candidates who correctly calculated quantitative answers such as the surface temperature, luminosity or radius of star X needed to include a unit with their answers for credit.

**(c)** Candidates were more able to identify the visible change to the line in Fig. 9.2 than to identify what was being redshifted to cause the change. A minority of candidates incorrectly described the star as being redshifted.

**Question 10**

**(a)** Specific acoustic impedance was generally defined correctly by candidates. Some candidates were not specific enough about the speed, and did not identify it as being that of (ultra)sound or that the speed was specifically that within the medium.

**(b)** Many candidates wasted time by describing the production process of ultrasound, and this did not gain credit as it was not what the question asked for. Where the detection was described, most candidates described ultrasound waves as the cause of crystal vibration. Fewer candidates identified those vibrations as the cause of an induced e.m.f. across the crystal.

**(c) (i)** The equation to calculate the intensity reflection coefficient was applied correctly by the majority of the candidates.

**(ii)** Candidates often used vague or general terms such as ‘most’, ‘less’ or ‘quite’ throughout. Successful responses used precise wording to describe the very similar $Z$ values, which meant almost all the ultrasound was transmitted.

# 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) (i)** This question was generally well answered, with most candidates able to show the relevant trigonometry relating the radius of the Earth and the radius of the circle.

**(ii)** Stronger candidates had little difficulty with this question, but many of the weaker candidates found it difficult. Common mistakes were either to try to use an equation derived from equating gravitational force with resultant force, or to take the period of the circular motion as one year rather than one day.

**(b) (i)** Most candidates knew the correct starting equation for the resultant force $F = mv^2 / R$, and many were able to achieve full credit. Other than errors in arithmetic such as forgetting to square the speed, the common mistake of physics was to use the radius of the Earth rather than the radius of the circular motion.

**(ii)** Many candidates thought that the resultant force causing circular motion is towards the centre of the Earth rather than towards the centre of the circle.

**(iii)** Many candidates knew that one of the forces acting on the candidate is the weight towards the centre of the Earth. Very few candidates were able to deduce that the other force is the contact force from the surface of the Earth upwards from the surface and slightly to the left. Candidates were allowed credit for splitting this contact force into its normal and frictional components, provided those components were labelled correctly.

**Question 2**

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

**(b)** Whilst candidates generally had a reasonable understanding of what the assumptions of the kinetic theory are, many did not articulate clearly enough that they were discussing the molecules of the gas rather than the gas itself. For example, responses such as 'gases have negligible volume' and 'gases undergo elastic collisions' were common incorrect answers. There was no credit available to candidates for repeating the assumption that was stated in the question.

**(c) (i)** Most candidates knew the correct starting equation and were able to use it. Some candidates did not notice that the data provided in the question was given to three significant figures and that therefore three significant figures should be given in the answer.

**(ii)** Many candidates realised that the starting point for this question was to determine the number of molecules in the sample. Many candidates then stopped after determining the effective volume occupied per molecule, without converting the volume into an effective distance of separation. In carrying out this last step, candidates could treat the effective space occupied by each molecule as a cube or a sphere, leading to an effective mean separation of the order of $10^{-9}$ m.

Many answers were seen that were many orders of magnitude away from being plausible, and this was a good example of a question in which taking time to consider whether the answer makes sense can lead to detection of an error in the working. For example, a candidate that stops at the volume and arrives at an answer of $10^{-27}$ m ought to realise that it cannot make sense for the effective separation to be smaller than the diameter of the nucleus of an atom.

**(d) (i)** Most candidates that obtained an answer in **(c)(ii)** were able to use their separation with Newton's law of gravitation to determine the gravitational force between adjacent molecules. Some weaker candidates used the equation for gravitational field strength rather than gravitational force and omitted to square the mass in the numerator.

**(ii)** The hint in the question was that candidates needed to determine an order of magnitude for the weight of a molecule. Those that determined the $10^{-26}$ N figure and then drew a consistent conclusion about the validity of the assumption based on comparing $10^{-26}$ N with their answer in **(d)(i)** were awarded credit.

**Question 3**

**(a)** The meaning of the term thermal equilibrium was generally well understood. It is important for candidates to understand that the temperatures of two objects do not need to be constant for them to be in thermal equilibrium; they simply need to be equal to each other.

**(b) (i)** Most candidates were able to draw on their knowledge of hydrostatic pressure from AS Level to realise that the quantity needed was the density of the liquid.

**(ii)** Many candidates did not appreciate the significance of the information in the question, that the system needs to reach equilibrium before the measurement can be made.

**(iii)** Candidates found this question difficult. This question effectively built on the understanding tested in **(b)(ii)**, with the idea that a constant volume gas thermometer could be used to measure temperatures that are not rapidly changing or temperatures of fluids with large mass (or heat capacity).

**(iv)** Stronger candidates tended to have little difficulty in establishing the correct answer to this question. Many candidates overlooked the information in the question, that the value of $\Delta h$ is proportional to the *thermodynamic* temperature of the gas, and attempted to work through the question with the temperature left in °C.

**Question 4**

**(a)** Many candidates were able to give a partially correct answer, but fully correct statements of the first law were only given by the strongest candidates.

**(b) (i)** Only the strongest candidates were able to conclude, when comparing Fig. 4.1 and Fig. 4.2, that the internal energy at each of the stages A, B, C and D is given by $U = (3/2)pV$.

**(ii)** Some candidates deduced the correct equation $U = (3/2)NkT$. Many of these did so from knowledge of the mean kinetic energy of a molecule as $(3/2)kT$ and the definition of internal energy for an ideal gas. Partial credit was available for this approach. For full credit, candidates needed to show how this equation follows from the answer in **(b)(i)**.

**(c) (i)** Many candidates obtained the correct answer for this question using the knowledge that work done is equal to the product of pressure and change in volume. Some candidates who were using the correct starting equation stopped short of completing the algebra, and others had the wrong sign for the answer.

**(ii)** The most common mistake in this question was to not realise that the work done on the gas in stage CD must be negative.

**(d)** Many of the weaker candidates were confused between the concepts of internal energy and transfer of thermal energy, and thought that the net transfer of thermal energy over a complete cycle must be zero. Stronger candidates were generally able to apply the fact that the internal energy returns to its original value and to deduce at least the correct magnitude for the transfer of thermal energy. Again, there were some difficulties over the sign of the answer. For full credit, candidates needed to explain that the work done on the gas during stages BD and DA is zero, but many omitted this part of the explanation.

**Question 5**

**(a) (i)** Many candidates gave a statement of the characteristic properties of simple harmonic motion without answering the question that asked how the graph demonstrates these properties.

**(ii)** This question was generally well answered, with full credit awarded to many candidates.

**(b) (i)** The meaning of damping was generally well known.

**(ii)** Many candidates began their graphs at the correct starting point, but many candidates drew curves for light damping rather than heavy damping.

**Question 6**

**(a)** The definition of electric field as force per unit positive charge was generally well known.

**(b)** The electric field pattern around the sphere was generally well drawn. The numerical questions that followed in the remaining parts of **(b)** were generally well answered, with many candidates obtaining the correct answers.

**(c)** This was a difficult question, but many candidates obtained the correct answer. Weaker candidates generally made no attempt to use the exponential equation and were therefore unable to make a start with the question.

**Question 7**

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

**(b)** The main challenges with drawing the sketch graph (aside from the skill of being able to draw a sinusoidal variation) were establishing the correct phase and the correct amplitude. Common errors were to draw sine curves rather than cosine curves, and to draw curves with an amplitude of 16 V rather than 18 V.

**(c)** It is important for candidates to understand, when answering this type of open question about conclusions that may be drawn from a graphical representation, that there is no credit available for simply describing the graphs. Credit is available for doing something with the data that goes beyond simply reading a value from the axis. There were many ways in which candidates could access credit for this question.

One common misconception concerns using the phrase 'r.m.s. power' to describe mean power. Whilst determining r.m.s power is beyond the expectations of the syllabus (given that it involves integrating a $\sin^4 \theta$ function and in any case has no physical significance), candidates ought to appreciate that the mean value of a variation and the r.m.s. value of a variation are different concepts. For a.c. power, the quantity that candidates are expected to know about is mean power.

**Question 8**

**(a)** Many candidates attempted to explain why the photoelectric effect has a threshold frequency rather than answering the question that was asked.

**(b) (i)** Common reasons for credit not being awarded in this question were either giving an answer that was positive rather than negative, or giving an answer to fewer than the three significant figures warranted by the data in the question.

**(ii)** This question was well answered by many candidates. Some of the weaker candidates thought they had to work out a difference in the energies represented by two frequencies, rather than appreciating that the frequency of each line relates to a difference in energy levels.

**(iii)** Some candidates were able to determine one column correctly but not the other, leading to partial credit. Stronger candidates in general were able to achieve full credit.

**Question 9**

**(a)** The definition of mass defect seems to be less well known than other definitions. Some candidates appeared to have the right idea but did not use the terminology correctly (particularly with nucleus/nuclei/nuclide/nucleons/neutrons). Many of the candidates that did identify mass defect as the difference in mass between the nucleus and its constituent nucleons did not make the point that the latter mass is when the nucleons are infinitely separated. Common misconceptions among weaker candidates were either that mass defect is a change in mass during a reaction, or that mass defect is an energy.

**(b)** Many of the more able candidates obtained credit for determining the energy release from the formation of one nucleus of helium, but then stopped short of extending that to one mole.

**(c) (i)** Most candidates found this question difficult and attempted to use an equation for which the information was not available. The question was a test of their understanding of what is meant by luminosity (as the rate of emission of energy from the star) and they needed to realise that this could be obtained by applying $E = c^2 \Delta m$ to the rate of loss of mass.

**(ii)** Many candidates were able to obtain full credit here using their value for luminosity from **(c)(i)**.

**(d)** Most candidates made the point that standard candles have known luminosity. The use of the equation $F = L / 4\pi d^2$ to calculate $d$ was also articulated well by many candidates. Many candidates found it difficult to explain the use of the radiant flux intensity (including naming the quantity correctly).

**Question 10**

**(a)** Many candidates gave responses dealing with how contrast is achieved rather than the meaning of the term.

**(b) (i)** This question was generally well answered.

**(ii)** Many candidates found this a challenging question and found it difficult to set up the starting equation. Of those who did start correctly, most then went on to calculate the correct answer. Some made the correct start but then had difficulty with the arithmetic.

**(iii)** A common mistake was for candidates to compare the linear attenuation coefficients rather than the detected intensities. Other candidates compared the detected intensities with the incident intensity, or thought that it was the absolute values of the detected intensities rather than their relative values that determined the contrast.

**(c)** Many candidates found it difficult to articulate the notion that the structure is scanned in sections, and that the images of the sections are compiled together to form the 3D image. The word ‘slice’ was used frequently, but often inappropriately as ‘slices of the image’. Many candidates knew that the scanning was from multiple angles.

# 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.

Most candidates showed their working. Some candidates would benefit from presenting their calculations more clearly. In particular, it is important to write numbers clearly so that they are unambiguous (e.g. 2 and 3, or 5, 6 and 8). This particularly applies to powers of ten.

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

## Comments on specific questions

### Question 1

**(a)** Most candidates appreciated that velocity and acceleration were always perpendicular to each other in circular motion. A smaller number of candidates appreciated that the magnitude of the velocity (speed) was constant. It was rarely written that the magnitude of the acceleration was also constant.

**(b) (i)** This question was generally answered correctly.

**(ii)** Most candidates understood the relationship between acceleration and either angular or linear velocity. Some candidates did not identify that the question required a relationship to be given that included all three of those quantities.

**(c) (i)** Most candidates recognised that a sine term needed to be used in the expression.

**(ii)** This question was generally answered correctly.

**(iii)** This 'show that' question required candidates to include both equations from the two earlier parts of **(c)** before they made the substitution to match the given answer.

**(iv)** Many candidates ignored the requirement to refer to the given equation in **(c)(iii)**. Instead, correct relationships were often given between acceleration and displacement. Such answers were not able to gain credit as they did not answer the question that was asked.

**(d) (i)** This question was generally answered correctly, with most candidates understanding what is meant by amplitude.

**(ii)** Most candidates knew the relationship between angular frequency/velocity and period.

**(iii)** Successful responses made clear that the acceleration and displacement were the maximum values, by the inclusion of a subscript ($a_0$, $x_0$) in the equation used.

**(e)** This question considered the movement of the shadow on the screen. Only the strongest candidates appreciated that drawing the shadow as a whole gave a greater opportunity to correctly identify the position of maximum positive acceleration. A significant minority of candidates did not follow the instruction in the question to label the shadow with the letter 'A'. Stronger candidates appreciated that the maximum positive acceleration would occur at the extreme left-hand edge of the movement of the shadow.

### Question 2

**(a)** Stronger candidates clearly described the context of a system or gas, and were able to identify that work being done or thermal energy being added or removed would change the internal energy of that system. A significant number of candidates mistakenly appeared to believe that changes of work or changes of thermal energy were required to change the internal energy.

**(b) (i)** Some candidates did not mention a system or gas, making their descriptions inaccurate. Stronger candidates understood that the change was too quick to allow thermal energy to be involved. Weaker answers confused thermal energy with internal energy or temperature.

**(ii)** Many answers did not refer to molecular energies directly. Descriptions of bonds being broken were common, but stronger candidates explained that both molecular separation and molecular potential energy increased. The link between molecular kinetic energy and temperature was generally well understood.

### Question 3

**(a)** In general, the ratio of force per unit mass was clearly expressed.

**(b) (i)** The word 'derive' in the question implied a starting point of the expression for gravitational force due to a point mass. Stronger candidates correctly combined this with their answer in **(a)**, and also identified the gravitational constant symbol.

**(ii)** The drawing of the gravitational field direction on Fig. 3.1 was improved by the use of a ruler to ensure that the field direction extrapolated through both the test mass at P and mass *M*. Where lines were inaccurately drawn, this prevented candidates from gaining credit. Weaker answers mistakenly considered the gravitational field of the test mass at P.

**(iii)** The majority of the candidates understood the inverse-square nature of the gravitational field and were able to deduce the factor of four as being the difference between the fields at P and Q. Stronger candidates also identified that the fields were in opposite directions.

**(c)** In general, the graph was well drawn. Credit could be gained for showing the correct start and end points, the correct point at which the field strength was zero, and the increasing steepness of the curve away from the midpoint. Candidates who used a pencil, and could therefore adjust their sketch where it was inaccurate, were at an advantage.

**Question 4**

**(a)** Weaker candidates confused the temperature scales in **(i)** and **(ii)**, reversing their answers. Some candidates incorrectly rounded their answer in **(i)** to a whole number.

**(b) (i)** Candidates were generally able to identify the gas as being an ideal gas. Weaker answers simply gave an expression in symbols without indicating anything about the nature of the gas.

**(ii)** This question was well answered.

**(iii)** This question was well answered, with candidates generally using the correct expression, then showing their working in full before expressing their answer to the correct number of significant figures.

**(c)** Stronger candidates laid out their working clearly, appreciating that an answer in kilograms required conversion to atomic mass units. The final answer was not exactly 4 u, so two significant figures were required. Weaker candidates often did not recognise that an r.m.s. speed was given, which needed to be squared to obtain the mean-square speed. Some candidates were incorrect in the way they expressed the mean-square speed in symbol form, creating an incorrect meaning to their expression.

**Question 5**

**(a)** Most candidates had some recall of the definition. Where full credit was not awarded, this was usually due to one of two omissions, either not making the ratio clear or not clarifying that the charge being moved from infinity was positive.

**(b) (i)** This 'show that' question required the working to be clearly set out, showing the addition of the two contributory potentials. Stronger candidates clearly showed all the values used and the sign of those contributory potentials.

**(ii)** Most candidates were able to successively replicate their method from **(i)** to the new situation. Some weaker candidates did not realise that the distances to both charges would change, or only considered one charge.

**(iii)** Many candidates were able to position the cross correctly.

**(iv)** Credit could be gained for identifying the key elements of a correct start and end point, an increasing steepness of the curve away from the midpoint where there was a sign change, and the correct plotting of a potential at 30 pm and 90 pm. Candidates who used a pencil, and could therefore adjust their sketch where it was inaccurate, were at an advantage.

**Question 6**

**(a)** This question highlighted where candidates had a confused understanding of the relationships for charge and for p.d. in the arrangements of series and parallel capacitors. Candidates generally found this question more difficult than the following questions that concerned only a single capacitor.

**(b) (i)** This question was generally well answered.

**(ii)** There were a number of ways that candidates could answer this question, depending on the equation they chose to use. Candidates generally performed well on this question.

**(iii)** Stronger candidates understood that the charge value obtained in **(ii)** was the same for this arrangement of two capacitors. Weaker candidates often believed that the p.d. value obtained in **(i)** was the same for this arrangement, and so attempted to use the same equation as they used in **(i)**.

**Question 7**

**(a)** Faraday's law was generally recalled accurately. Occasional confusion was seen between the terms flux linkage and flux density.

**(b) (i)** Leading on from the statement in **(a)**, the relationship between e.m.f. and magnetic flux was generally applied successfully in this question. Weaker candidates found difficulty in identifying an appropriate unit for their numerical answer.

**(ii)** This question was well answered by most candidates.

**(iii)** The involvement of the width of the aircraft's wings led to some confusion over the application of two basic equations: speed = distance travelled × time and area = width × distance travelled for a significant number of weaker candidates.

**(iv)** Candidates found this question difficult. Better answers were written in stages, first considering the direction of the force to oppose the motion of the aircraft, then describing the application of Fleming's left-hand rule to identify the direction of current flow from wingtip Q to P. The strongest candidates appreciated that this current was inside an e.m.f. source and then gave the correct answer.

**Question 8**

**(a)** There was a good understanding of the nature of the photon amongst most candidates.

**(b) (i)** To successfully answer this question, candidates needed to maintain the use of six decimal places in their calculations to match the data provided. Most candidates attempted to use the equation $E = mc^2$ but only stronger candidates converted the energy released into a mass in u to then be added to the other two masses.

**(ii)** The correct equation was used by most candidates. Stronger candidates were able to follow through the subtraction of energies that gave the value for the energy of the gamma photon.

**(ii)** Stronger candidates identified that they should be describing the energy of a gamma photon and its relationship to wavelength.

**(c)** Candidates who mentioned another product of the decay usually knew the correct product. Weaker candidates were unaware of the impact of the energy sharing between the products on the energy available to each gamma photon. Stronger candidates appreciated that each decay involved a single gamma photon.

**Question 9**

**(a)** The relationship between temperature and wavelength was generally understood. Some candidates omitted reference to the *surface* temperature or did not mention a star or black body.

**(b)** Many candidates wrote at least one answer that, although factually correct, was not a *conclusion* that could be drawn from the data. Some were simply readings of the data itself, put into words. This would suggest that candidates would benefit from exercises in differentiating between the data itself and the conclusions available from it. Candidates who correctly calculated quantitative answers such as the surface temperature, luminosity or radius of star X needed to include a unit with their answers for credit.

**(c)** Candidates were more able to identify the visible change to the line in Fig. 9.2 than to identify what was being redshifted to cause the change. A minority of candidates incorrectly described the star as being redshifted.

**Question 10**

**(a)** Specific acoustic impedance was generally defined correctly by candidates. Some candidates were not specific enough about the speed, and did not identify it as being that of (ultra)sound or that the speed was specifically that within the medium.

**(b)** Many candidates wasted time by describing the production process of ultrasound, and this did not gain credit as it was not what the question asked for. Where the detection was described, most candidates described ultrasound waves as the cause of crystal vibration. Fewer candidates identified those vibrations as the cause of an induced e.m.f. across the crystal.

**(c) (i)** The equation to calculate the intensity reflection coefficient was applied correctly by the majority of the candidates.

**(ii)** Candidates often used vague or general terms such as ‘most’, ‘less’ or ‘quite’ throughout. Successful responses used precise wording to describe the very similar *Z* values, which meant almost all the ultrasound was transmitted.

# 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.

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

**Comments on specific questions**

**Question 1**

**(a)** Generally, this question was answered well and most candidates were awarded full credit. Some candidates stated that the force was proportional to the 'masses' rather than the product of the masses. Some candidates stated the force was inversely proportional to the 'distance' or 'radius' squared, rather than the 'separation' or 'distance of separation' of the masses squared. A small number of candidates referred to 'indirect' rather than 'inverse' proportion regarding the separation squared or omitted 'squared'. A small number of candidates did not refer to force and gained no credit.

**(b) (i)** The majority of the candidates gained full credit. The most common error involved using the incorrect distance for the separation of the stars.

**(ii)** A large proportion of candidates gave the correct answer. Some candidates did not realise that the radius of the path of star A was one-third of the separation of the stars, and a small number of candidates did not correctly identify appropriate starting equations.

**(iii)** Candidates were guided to use their answer from **(b)(ii)**. Those who ignored this were generally unsuccessful in reaching the correct answer.

**(iv)** The majority of the candidates placed their ticks in the correct cells of the table. Almost all candidates were able to gain at least partial credit.

**Question 2**

**(a) (i)** A common error was giving the meaning of $T$ as 'thermal dynamic' temperature. Less common errors were giving the meaning of $N$ as the number of moles and the value of $k$ instead of its meaning.

**(ii)** A significant number of candidates were careless with regard to the symbols used for mean-square speed, writing $\langle c \rangle^2$ instead of $\langle c^2 \rangle$ or $\bar{c}^2$ instead of $\overline{c^2}$ . An incorrect final answer was often $E_K = \frac{3}{2}NkT$, having not cancelled $N$ following the use of the correct starting equation. Some candidates gave two correct starting equations ($pV = NkT$ and $pV = \frac{1}{3}Nm\langle c^2 \rangle$) but did not clearly show in their derivations how these were combined.

**(b)** Most candidates gained at least partial credit. Common incorrect final answers were 1/4 and 16, both of which implied that the average kinetic energies of a particle in both gases were the same.

**Question 3**

**(a)** Some candidates did not mention random motion and/or 'total' when referring to kinetic energy. The fact that the molecular potential energy is zero in an ideal gas was well known. Some candidates did not refer to molecules or particles at all in their answers.

**(b) (i)** The equation $\frac{3}{2}kT$ was commonly assumed to be the correct equation to use, as the candidate had just derived it in **Question 2**. Many candidates calculated $E_K$ for only one molecule, omitting to calculate and use $N$.

**(ii)** Most candidates gave the correct answer.

**(iii)** Most candidates gave the correct answer. A minority made a power-of-ten error.

**(iv)** A significant proportion of candidates incorrectly drew a straight line from B to C for line Y. Most candidates placed B and C in the correct positions and drew the correct line for X.

**Question 4**

**(a)** Some candidates did not make the ratio number of oscillations *per* unit time clear or specified 'per second', so did not gain credit.

**(b) (i)** Many candidates did not explicitly reference the graph in Fig. 4.2 or kinetic energy, and so their attempts at explanations did not answer the question that had been asked.

**(ii)** Most candidates gained full credit.

**(iii)** A significant number of candidates identified the features in Fig. 4.1 but did not state that the oscillations were simple harmonic as a conclusion. Some candidates did not pay enough attention to the wording of the question and gave conclusions regarding period, frequency or angular frequency. Direct readings from the graphs such as maximum displacement, maximum acceleration and maximum kinetic energy were considered to be readings rather than drawn conclusions and were ignored. Many otherwise correct numerical answers had insufficient significant figures to gain credit.

**(iv)** Incorrect or inaccurate terminology was frequently used such as 'at maximum amplitude' or 'at amplitude' (for 'at maximum displacement') and 'minimum' kinetic energy or potential energy (for 'zero' kinetic energy or potential energy). Only the strongest candidates mentioned that kinetic energy + potential energy is constant.

**Question 5**

**(a)** Many candidates correctly quoted the definition of electric potential, but this alone was not awarded credit. Many stronger candidates correctly stated that the potential at infinity is defined as zero. Many candidates stated that the force was repulsive without explaining that this was because the charge on a proton is positive. Very few candidates distinguished between 'work done <u>on</u> the charges' and 'work done <u>by</u> the charges'.

**(b) (i)** Although the majority of the candidates gained credit, many candidates were careless in drawing the arrow (e.g. curved arrows, arrows that did not pass through Q or did not pass sufficiently close to the centre of the sphere when extended), and some candidates had arrows which were pointing towards the centre of the sphere.

**(ii)** The curves drawn were usually partly or approximately correct but often they did not have precise detail. Examples included not using data to determine values of $E$ (e.g. at $x = 2R$ and $x = -2R$) despite a clear numerical scale, allowing the curve to become horizontal or straight in sections and not showing that $E$ was negative for negative values of $x$.

**(c)** The majority of the candidates obtained the correct magnitude, but many candidates omitted the minus sign. Typical errors were omitting one of the charges and dividing by the separation squared. Some weaker candidates substituted the sum of the charges instead of the product.

**Question 6**

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

**(ii)** Most candidates gave the correct answer.

**(iii)** Some candidates drew correct diode symbols but did not show them connected into the circuit. A significant minority of candidates had incorrect orientations of one or more of the diodes.

**(b) (i)** Most candidates gained full credit. As always with a 'show that' question, credit is not awarded for the numerical answer, but for showing the working that leads to the answer. The full substitution $T = 2\pi/18$ was required for a complete answer.

**(ii)** Most candidates gave the correct answer.

**(iii)** Most candidates gained full credit, but some candidates showed inaccurate peak values and some weaker candidates drew unrectified waveforms.

**(c) (i)** The majority of the candidates gave the correct answer. Many candidates placed the capacitor connected in parallel with $V_{IN}$ and a small number drew a symbol which was more like the symbol for a cell.

**(ii)** Most candidates gave the correct answer.

**(iii)** Most candidates gave the correct answer. A common mistake was to substitute the r.m.s. voltage instead of the peak voltage into the correct equation.

**Question 7**

**(a)** The majority of the candidates gained full credit, but some candidates specified a particular change causing the induced e.m.f. (e.g. a force or a flux change).

**(b) (i)** Most candidates identified the correct starting equation for flux, but then a significant number used an incorrect method to calculate the area. Some candidates did not give a correct unit.

**(ii)** The majority of the candidates gained full credit. Many candidates inappropriately included the number of blades in their calculations and so their answers were incorrect by a factor of 4.

**(iii)** Lenz's law was often not used to explain that a force or moment was needed to oppose the rotation of the rotor. When this was mentioned, the direction of that force or moment was often not stated. The answer X and reference to current in the rotor blade was required. Those who used Fleming's left-hand rule to correctly determine the current direction often forgot that the rotor is an e.m.f. source with current flowing from lower to higher potential within the source.

**Question 8**

**(a)** Candidates found it difficult to give a complete and correct meaning of a tracer. The radioactive substance was often referred to, but was stated without mention of the need to introduce it into the body. Some candidates implied the substance or the positrons were already inside the body. Absorption into the tissue 'being studied' or equivalent wording was rarely stated.

**(b) (i)** The majority of the candidates gained full credit.

**(ii)** The most common incorrect answer was 'neutron'.

**(c) (i)** Candidates found it difficult to give a correct definition of activity. Common incomplete answers were versions of 'rate of decay of nuclei'.

**(ii)** Some candidates gave answers with less than three significant figures, especially those giving answers in $min^{-1}$. Some candidates gave the unit as Bq instead of $s^{-1}$.

**(iii)** The candidates who used the method in the mark scheme often gained full credit, but some gave insufficient significant figures in their final answers or made premature rounding errors. Candidates who calculated the number of moles of oxygen-15 and multiplied by the Avogadro constant to find the number of nuclei frequently made the power-of-ten error of not converting kg to g before dividing by 15 u.

**(d) (i)** Many candidates gave incomplete answers such as 'photons', 'gamma rays', 'gamma particles', 'gamma radiation' etc. Others gave incorrect answers, most commonly 'electrons'.

**(ii)** The description of gamma photon production often missed out that it is the total mass of the positron and electron that is converted. Candidates often either did not mention mass at all, or wrote that 'mass' was converted without making it clear that it is the mass of the particles. It was not always clear that the mass is converted into the energy of photons (and not just energy in general).

**Question 9**

**(a)** The majority of the candidates gained full credit. Some specified that the incident radiation was light, and others referred to electrons being excited but not emitted.

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

**(ii)** Most candidates gave the correct answer. Some stated the value of the Planck constant rather than giving an expression.

**(c)** Many candidates gained full credit. Some candidates incorrectly showed the lines extending with negative kinetic energy, although dashed lines were treated as construction lines to demonstrate the intercept on the $E_K$ axis of the extrapolated line and ignored. Some candidates did not label the lines X and Y. Some candidates drew only one line and gained no credit.

**Question 10**

**(a)** Many candidates gave incomplete answers, e.g. stating that 'wavelength' has increased without adding that this is the observed wavelength of light from a galaxy. Some candidates referred to planets moving away from the observer.

**(b)** The stronger candidates made the connection that, if all (or most) galaxies are moving away from the observer (or our galaxy), they are moving away from each other, and therefore the universe is expanding. Some candidates referred to planets rather than galaxies, and some to the universe receding rather than expanding.

**(c)** Many candidates stated Hubble's law without further explanation. A significant proportion of candidates correctly described that more distant galaxies are receding faster. A common conclusion was that galaxies were closer together in the past, but often candidates did not develop this to the idea that all matter (or contents of the universe) was in a very small space a long time ago, i.e. before the formation of stars and galaxies. This is ultimately the reasoning that supports the Big Bang theory.

# 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 powers of ten in logarithmic quantities 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 often did not suggest a suitable graph, or were not explicit in how the relationship could be proved or how the constants *n* and *Y* were determined. 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 link the extreme ends of error bars correctly or coordinates were wrongly read off when determining the gradient and/or *y*-intercept. Some candidates made the mistake of joining the top point to the bottom point for the line of best fit. Another common mistake was to give *H* to an incorrect power of ten and/or with incorrect units.

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 *x* would be kept constant. Some candidates misunderstood what *x* represented. Candidates should be encouraged to re-read the question to check their understanding of the variables given. There was additional credit for also stating that *k* and *r* would 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'.

There was also credit for how *x* was kept constant, such as by placing a marker at the compressed position. Candidates should be reminded that there will often be credit for how variables are kept constant and how they are measured or determined if appropriate.

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 how the spring was fixed in place to prevent it moving when compressed. Good diagrams often showed a block clamped to the bench with a G-clamp so that the spring could be placed against it. Resting or attaching the spring to a wall was also accepted. The diagram also required point P to be marked and a light gate positioned there since the purpose of the experiment was to measure *v* at point P for different *r* values. It was important for the equipment to be shown on a bench since the block will need to be clamped to the bench and the ball requires a flat horizontal surface to move along.

The measurement of *r* required the use of calipers or a micrometer to measure the diameter of the ball and then a calculation of *r* from that diameter. Some candidates described a direct measurement of *r*, which is not possible. Other candidates described the use of a ruler, which is not appropriate unless blocks are also used. Additional credit was awarded for suggesting taking multiple measurements of the diameter of the ball in different directions and calculating an average.

Candidates gained credit for describing a method to determine *v* at point P. Candidates had to make it clear that they were dividing the diameter of the ball by the time for the diameter to pass through the light gate (the time given on the timer). Some candidates incorrectly determined *v* as the average speed of the ball during its journey from the spring to point P and attempted to determine *v* by dividing distance travelled by the ball by a measured time. This highlights the need to ensure that the quantities in the experiment are correctly understood before writing an answer. Some candidates incorrectly described an interrupt card attached to the ball; this method is not workable. Candidates who have practically used interrupt cards would be less likely to make this mistake.

Candidates gained credit for suggesting measuring *x* 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.

Many candidates suggested correct axes for a graph. There were many different acceptable log–log graphs and candidates were awarded credit if they gave axis quantities that would result in a straight line. Some candidates could not be awarded credit here or for subsequent analysis because they gave a graph where one or both axis quantities were not logarithmic quantities. 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 each of the constants *n* and *Y* from the experimental results using the gradient and *y*-intercept. To gain credit, the constants *n* and *Y* 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 were stopping the ball rolling onto the floor or using eye protection to prevent being struck in the eye by the ball or the spring. Trays or cushions placed on the floor were not awarded credit since the best safety precautions would stop the ball while it is still on the bench.

Additional detail credit was awarded for describing how the constants were determined. To determine *k*, a separate experiment should have been described where the spring is extended using a measured weight and the weight is divided by the measured extension. To determine $\rho$, the mass of the ball should be measured using a balance and the volume calculated using the measured diameter of the ball, and these quantities divided to obtain $\rho$. Many candidates did not gain credit either because of an incorrect formula for the volume of a sphere or for not giving the density equation with $\rho$ as the subject. Some candidates named a 'scale' as the measuring device for mass, and this is not credited as a scale is a vague term that describes many different measuring devices.

**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 calculated $\frac{d}{c}$ correctly. Many candidates also calculated the uncertainty in $\frac{d}{c}$ correctly. A minority of candidates gave one or more of the values to too few significant figures. Since the value of *c* was given to three significant figures and the values of *d* were recorded to two or three significant figures, the values of $\frac{d}{c}$ should have been recorded to the same number of significant figures as the corresponding *d* value (or one more). For example, with *d* recorded to three significant figures, then values of $\frac{d}{c}$ should have been recorded to three or four significant figures.

**(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 their 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 points. The worst acceptable line was drawn well in general, and many stronger candidates drew a line which passed through all error bars and hit the extreme top and bottom of error bars to make the difference in the gradients of the lines as large as possible while still remaining within the 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 coordinates on the line of best fit which are easy to read, i.e. the coordinates are on grid lines. It is worth making it clear to students that the coordinates used for the gradient calculation should not be plotted points and should instead be coordinates from the line that are clearly on a grid line.

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 were seen to incorrectly divide the *y* value by *mx* or use a plotted point that did not lie on the line of best fit in their calculation.

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 determine the uncertainty in the *y*-intercept by calculating the *y*-intercept of the worst acceptable line using the gradient of the line of best fit, or the same coordinate that was used when determining the *y*-intercept of the line of best fit. A small number of candidates attempted to calculate the uncertainty using a fractional method and their uncertainty in the gradient, and this is not a correct method.

**(d)** Stronger candidates showed clear working for their determination of $\lambda_0$ and *H*. A clear method for $\lambda_0$ often included a statement that $\lambda_0$ = *y*-intercept followed by the *y*-intercept value. A clear method for *H* often included a statement that gradient = $H\lambda_0$ then a substitution and rearrangement leading to the correct value of *H*. Some candidates calculated these values correctly but then did not gain credit since the answers were not recorded to an appropriate number of significant figures.

The value of *H* or $\lambda_0$ was often given to an incorrect power of ten or with incorrect units. Candidates should be careful to use powers of ten from the graph axes and from the given data. Both axes had powers of ten to deal with since the *y*-axis quantity was given in nm.

**(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.

Most candidates achieved credit for taking the reciprocal of their value for *H*. The most able candidates could calculate the uncertainty in *T*. The most straightforward method was to use the sum of the percentage uncertainties of the *y*-intercept and gradient and then use this to determine the uncertainty in *T* directly. Some candidates attempted to use a maximum or minimum method; errors often occurred where candidates did not understand that if the maximum gradient was chosen then the $\lambda_0$ value had to be minimum or vice versa. Candidates often chose the more complicated maximum and minimum method as they did not make the connection that the percentage uncertainty in *H* had to be the same as the percentage uncertainty in *T*.

# 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 powers of ten in logarithmic quantities 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 graph could be used to identify whether the given relationship was true or how the constant *Q* 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 by calculating values and determining the uncertainty in each value. Many candidates did not understand that in a logarithmic quantity the number of decimal places should correspond to the original number of significant figures in the quantity. 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. A common difficulty was in determining the absolute uncertainty in *k*. Candidates often found determining the mean distance *r* of Titan from the centre of Saturn challenging because they were not confident in using the correct powers of ten in the quantities.

In question parts requiring mathematical manipulation, stronger candidates clearly stated the equation used with correct substitution of numbers, and then calculated the answer. 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 *A* and *R* would be kept constant. There was additional credit for also stating that *P* and *T* would be kept constant. Credit is 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. Diagrams should be drawn of the workable experiment. In this experiment, it was expected that candidates would show a fan resting on the bench directed towards the turbine. Stronger candidates also indicated that the fan and the turbine were clamped to the bench.

Candidates needed to show a correct circuit diagram with an ammeter and a resistor connected in series to the two terminals on the turbine. Candidates should be encouraged to use correct circuit symbols. Three common errors were placing the ammeter in parallel with the resistor, connecting a power supply into the circuit or adding an ohmmeter to the circuit.

Stronger candidates often gained credit by drawing a separate circuit to determine the resistance $R$ of the resistor.

Many candidates gave good explanations of how the speed $v$ of the moving air could be changed. Creditworthy answers included changing the distance from the fan to the turbine, changing the power settings on the fan or showing a circuit connected to the fan with a variable resistor so that $v$ could be changed by adjusting the variable resistor.

Many candidates correctly suggested the use of a thermometer to measure $T$. Additional detail credit was awarded for candidates who explained how the thermodynamic temperature in kelvin was determined from the temperature measured in °C.

Candidates also needed to explain how $A$ was determined. Candidates needed to identify an appropriate measuring instrument, e.g. ruler or calipers to measure $L$, and then to explain how $L$ was used (e.g. $\pi L^2$) to determine $A$. Credit was not awarded for the use of a micrometer. Candidates who just stated $\pi r^2$ or $\pi d^2/4$ did not gain credit. Additional credit was awarded for candidates who described either measuring from the tip of one blade to the tip of the diagonally opposite blade and dividing by two, or for measuring $L$ for each of the four blades of the turbine and finding the average value for $L$.

Candidates also needed to describe how the measurements of $v$ and $P$ were taken. Many candidates were able to suggest the use of an anemometer or air speed meter for $v$ and the use of a barometer, manometer or pressure gauge for $P$.

Many candidates suggested correct axes for a graph. Most candidates correctly suggested $I^2$ against $v^3$. Other acceptable graphs included $I$ against $v^{3/2}$ or log $I$ against log $v$. Candidates must explicitly state the quantities to be plotted on each axis either in the text or on drawn axes – credit is not given for just writing $y = mx + c$ 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 and give an indication of the straight line passing through the origin. Credit was not awarded to candidates who did not correctly identify appropriate axes for a graph to plot. Candidates who suggested plotting log $I$ against log $v$ needed to specify the gradient of the line.

Candidates needed to explain how they would determine a value for the constant $Q$ from the experimental results using the gradient (or $y$-intercept for log $I$ against log $v$). To gain credit, the constant $Q$ 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 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 were avoiding contact with the moving fan blades or the use of goggles to prevent the air stream or dust particles entering the eyes. Credit was not awarded for the use of gloves as the hands should not be near the moving blades. 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. Many different correct forms of the *y*-intercept were seen, e.g. lg 2π – lg *k*. Candidates should use the white space on the question paper to rearrange the equation into an equation of a straight line.

**(b)** Candidates found the calculation of the values of lg ($r$ / $10^8$ m) and the values of lg ($T$ / $10^3$ s) challenging. Candidates need to understand that the number of decimal places in the logarithmic value should correspond to the number of significant figures in the quantity. Since values of *r* were recorded to three significant figures, it was expected that values of lg ($r$ / $10^8$ m) would be recorded to three (or four) decimal places. Similarly, values of *T* were recorded to two significant figures and it was expected that values of lg ($T$ / $10^3$ s) would be recorded to two (or three) decimal places. Other common mistakes were observed in rounding lg ($r$ / $10^8$ m), e.g. 0.376 instead of 0.377.

The majority of the candidates correctly calculated the absolute uncertainties in lg *T*.

**(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.

**(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. the points are on grid lines.

When determining the uncertainty in the gradient, candidates need to show their working, including the coordinates that they have used from the worst acceptable line and 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 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 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)** Most candidates gained credit for identifying that *n* was equal to the gradient and correctly recording their answers to two or three significant figures.

Stronger candidates clearly demonstrated the use of the *y*-intercept in the equation to determine *k*. A common error was to attempt to determine the answer by using $e^{y\text{-intercept}}$ as opposed to $10^{y\text{-intercept}}$.

Most candidates correctly stated the absolute uncertainty in *n*. To determine the absolute uncertainty in *k*, candidates needed to show their method. Stronger candidates clearly demonstrated the substitution of the *y*-intercept from the worst acceptable line into the equation to determine *k* and then found the difference between this value and *k*. Many weaker candidates attempted an incorrect fractional method.

**(e)** This question was difficult. The most common error was not correctly determining the logarithm of *T*. Many candidates did not understand that the values of *k* and *n* were for specific quantities lg ($r$ / $10^8$ m) and lg ($T$ / $10^3$ s). The strongest candidates correctly took the logarithm of $1.38 \times 10^3$ and then allowed for the $10^8$.

# PHYSICS

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

## Key messages

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## 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 often did not suggest a suitable graph, or were not explicit in how the relationship could be proved or how the constants $n$ and $Y$ were determined. 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 link the extreme ends of error bars correctly or coordinates were wrongly read off when determining the gradient and/or $y$-intercept. Some candidates made the mistake of joining the top point to the bottom point for the line of best fit. Another common mistake was to give $H$ to an incorrect power of ten and/or with incorrect units.

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 $x$ would be kept constant. Some candidates misunderstood what $x$ represented. Candidates should be encouraged to re-read the question to check their understanding of the variables given. There was additional credit for also stating that $k$ and $r$ would 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'.

There was also credit for how $x$ was kept constant, such as by placing a marker at the compressed position. Candidates should be reminded that there will often be credit for how variables are kept constant and how they are measured or determined if appropriate.

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 how the spring was fixed in place to prevent it moving when compressed. Good diagrams often showed a block clamped to the bench with a G-clamp so that the spring could be placed against it. Resting or attaching the spring to a wall was also accepted. The diagram also required point P to be marked and a light gate positioned there since the purpose of the experiment was to measure $v$ at point P for different $r$ values. It was important for the equipment to be shown on a bench since the block will need to be clamped to the bench and the ball requires a flat horizontal surface to move along.

The measurement of $r$ required the use of calipers or a micrometer to measure the diameter of the ball and then a calculation of $r$ from that diameter. Some candidates described a direct measurement of $r$, which is not possible. Other candidates described the use of a ruler, which is not appropriate unless blocks are also used. Additional credit was awarded for suggesting taking multiple measurements of the diameter of the ball in different directions and calculating an average.

Candidates gained credit for describing a method to determine $v$ at point P. Candidates had to make it clear that they were dividing the diameter of the ball by the time for the diameter to pass through the light gate (the time given on the timer). Some candidates incorrectly determined $v$ as the average speed of the ball during its journey from the spring to point P and attempted to determine $v$ by dividing distance travelled by the ball by a measured time. This highlights the need to ensure that the quantities in the experiment are correctly understood before writing an answer. Some candidates incorrectly described an interrupt card attached to the ball; this method is not workable. Candidates who have practically used interrupt cards would be less likely to make this mistake.

Candidates gained credit for suggesting measuring $x$ 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.

Many candidates suggested correct axes for a graph. There were many different acceptable log–log graphs and candidates were awarded credit if they gave axis quantities that would result in a straight line. Some candidates could not be awarded credit here or for subsequent analysis because they gave a graph where one or both axis quantities were not logarithmic quantities. 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 each of the constants $n$ and $Y$ from the experimental results using the gradient and $y$-intercept. To gain credit, the constants $n$ and $Y$ 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 were stopping the ball rolling onto the floor or using eye protection to prevent being struck in the eye by the ball or the spring. Trays or cushions placed on the floor were not awarded credit since the best safety precautions would stop the ball while it is still on the bench.

Additional detail credit was awarded for describing how the constants were determined. To determine *k*, a separate experiment should have been described where the spring is extended using a measured weight and the weight is divided by the measured extension. To determine $\rho$, the mass of the ball should be measured using a balance and the volume calculated using the measured diameter of the ball, and these quantities divided to obtain $\rho$. Many candidates did not gain credit either because of an incorrect formula for the volume of a sphere or for not giving the density equation with $\rho$ as the subject. Some candidates named a 'scale' as the measuring device for mass, and this is not credited as a scale is a vague term that describes many different measuring devices.

**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 calculated $\frac{d}{c}$ correctly. Many candidates also calculated the uncertainty in $\frac{d}{c}$ correctly. A minority of candidates gave one or more of the values to too few significant figures. Since the value of *c* was given to three significant figures and the values of *d* were recorded to two or three significant figures, the values of $\frac{d}{c}$ should have been recorded to the same number of significant figures as the corresponding *d* value (or one more). For example, with *d* recorded to three significant figures, then values of $\frac{d}{c}$ should have been recorded to three or four significant figures.

**(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 their 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 points. The worst acceptable line was drawn well in general, and many stronger candidates drew a line which passed through all error bars and hit the extreme top and bottom of error bars to make the difference in the gradients of the lines as large as possible while still remaining within the 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 coordinates on the line of best fit which are easy to read, i.e. the coordinates are on grid lines. It is worth making it clear to students that the coordinates used for the gradient calculation should not be plotted points and should instead be coordinates from the line that are clearly on a grid line.

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 were seen to incorrectly divide the *y* value by *mx* or use a plotted point that did not lie on the line of best fit in their calculation.

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 determine the uncertainty in the *y*-intercept by calculating the *y*-intercept of the worst acceptable line using the gradient of the line of best fit, or the same coordinate that was used when determining the *y*-intercept of the line of best fit. A small number of candidates attempted to calculate the uncertainty using a fractional method and their uncertainty in the gradient, and this is not a correct method.

**(d)** Stronger candidates showed clear working for their determination of $\lambda_0$ and *H*. A clear method for $\lambda_0$ often included a statement that $\lambda_0$ = *y*-intercept followed by the *y*-intercept value. A clear method for *H* often included a statement that gradient = $H\lambda_0$ then a substitution and rearrangement leading to the correct value of *H*. Some candidates calculated these values correctly but then did not gain credit since the answers were not recorded to an appropriate number of significant figures.

The value of *H* or $\lambda_0$ was often given to an incorrect power of ten or with incorrect units. Candidates should be careful to use powers of ten from the graph axes and from the given data. Both axes had powers of ten to deal with since the *y*-axis quantity was given in nm.

**(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.

Most candidates achieved credit for taking the reciprocal of their value for *H*. The most able candidates could calculate the uncertainty in *T*. The most straightforward method was to use the sum of the percentage uncertainties of the *y*-intercept and gradient and then use this to determine the uncertainty in *T* directly. Some candidates attempted to use a maximum or minimum method; errors often occurred where candidates did not understand that if the maximum gradient was chosen then the $\lambda_0$ value had to be minimum or vice versa. Candidates often chose the more complicated maximum and minimum method as they did not make the connection that the percentage uncertainty in *H* had to be the same as the percentage uncertainty in *T*.

# 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 powers of ten in logarithmic quantities 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. Candidates should be specific about quantities discussed, e.g. 'measure the period of rotation with a stopwatch' rather than the more general 'measure time with a stopwatch'. Using terms defined in the question minimises confusion, e.g. 'measure length $r$ with a rule'. Weaker candidates tended to suggest a suitable graph to draw but were not explicit in how the graph could be used to identify whether the given relationship was true or how the constants $\beta$ and $K$ would be 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 by calculating values and determining the uncertainty in each value. Many candidates did not understand that in a logarithmic quantity the number of decimal places should correspond to the original number of significant figures in the quantity. 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.

In question parts requiring mathematical manipulation, stronger candidates clearly stated the equation used with correct substitution of numbers and then calculated the answer. 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. Some weaker candidates identified $m$ as the independent variable but then contradicted this by stating that $m$ would be kept constant. 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 $f_0$ would be kept constant. There was additional credit for also stating that $r$ would be kept constant. Credit is not given for stating 'control' since this is just repeating the stem of the question and does not indicate what is meant by 'control'. There was additional credit available for candidates who explained a method to keep $f_0$ constant. A small minority of candidates stated that the current in the motor should be kept constant by adjusting a variable resistor.

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 the turntable base and motor on the bench. Stronger candidates indicated that the motor and turntable base were clamped to the bench.

Further credit was given for the correct circuit diagram showing a d.c. power supply connected to the two terminals of the motor. Candidates should be encouraged to use correct circuit symbols.

Candidates needed to describe a method to determine $f$ and $f_0$. Candidates generally understood the need to use a stopwatch to determine the period of rotation. Candidates should be encouraged to avoid vague responses such as 'use a stopwatch to measure time' but relate their descriptions to quantities in their answer. Many candidates chose to measure the period of rotation of the turntable using a cathode-ray oscilloscope but gave no detail of exactly how this would be done. Other descriptions that were not given credit were 'use a 'phone to measure the time for one revolution' (timing app on the phone needed to be specified) and 'make a video and analyse it frame by frame' (a timer would be needed to be in view of the video, otherwise there is no time reference that can be used). Having determined the period for several rotations, credit was awarded to candidates who described how $f$ and $f_0$ would be calculated.

Many candidates correctly identified the need to take repeat readings of $f$ (or the period of rotation) for each value of $m$, and to calculate the average value of $f$. Some weaker candidates identified the need for repeat readings but made a vague statement like 'repeat and average the results' which was not sufficiently specific to this experiment to gain credit.

Credit was also given where candidates stated the use of a balance to measure $m$ and the use of a rule or calipers to determine $r$. A micrometer did not gain credit as it was not an appropriate instrument.

Many candidates suggested correct axes for a graph. Candidates who suggested the use of logarithms did not gain credit. 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 needed to explain how they would determine a value for each of the constants $\beta$ and $K$ from the experimental results using the gradient and $y$-intercept. To gain credit, the constants $\beta$ and $K$ 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.

Candidates also needed to explain how the graph would confirm the suggested relationship. Candidates need to use the words 'relationship is valid if' and the word 'straight' to describe the line. Some candidates did not gain credit because they stated 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.

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, candidates could describe precautions to avoid injury from the mass leaving the turntable.

**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)** Most candidates gave correctly calculated values of $1/s$ and $y$. Some weaker candidates incorrectly recorded their values of $y$ to two significant figures. Since $w$ was recorded to three significant figures, it was expected that $y$ would be recorded to three (or four) significant figures. Some candidates truncated their values of 1/*s* rather than rounding them, e.g. 4.167 was written as 4.16 rather than 4.17.

The majority of the candidates correctly calculated the absolute uncertainties in 1/*s*.

**(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 their 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 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. the points are on grid lines.

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

**(d)** Most candidates gained credit. A small number of candidates did not correctly calculate the value of 0.921 m, but most errors were made in calculating the uncertainty. It appeared that incorrect answers were generally caused by numerical errors rather than a lack of understanding.

**(e) (i)** Most candidates correctly gained credit for calculating $\lambda$. A significant number of candidates found the units and powers of ten challenging. Values used in the calculation must be taken from the gradient; credit was not gained for substituting data values from the table.

**(ii)** Stronger candidates clearly demonstrated the method to determine the percentage uncertainty in $\lambda$.

**(f)** Most candidates attempted to determine a value for *s*. It was essential that candidates showed their method of working and correct substitution of values. Most answers used powers of ten that were consistent with their earlier answers.

Clear working had to be shown to gain credit for calculating the uncertainty in *s*, and the working had to be consistent with the method used to calculate *s*.