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Examiners' report

PHYSICS A

H556

For first teaching in 2015

H556/02 Summer 2022 series

Version 1

Contents

Introduction

Our examiners' reports are produced to offer constructive feedback on candidates' performance in the examinations. They provide useful guidance for future candidates.

The reports will include a general commentary on candidates' performance, identify technical aspects examined in the questions and highlight good performance and where performance could be improved. A selection of candidate answers are also provided. The reports will also explain aspects which caused difficulty and why the difficulties arose, whether through a lack of knowledge, poor examination technique, or any other identifiable and explainable reason.

Where overall performance on a question/question part was considered good, with no particular areas to highlight, these questions have not been included in the report.

A full copy of the question paper and the mark scheme can be downloaded from OCR.

Advance Information for Summer 2022 assessments

To support student revision, advance information was published about the focus of exams for Summer 2022 assessments. Advance information was available for most GCSE, AS and A Level subjects, Core Maths, FSMQ, and Cambridge Nationals Information Technologies. You can find more information on our website.

Paper 2 series overview

H556/02 is one of the three assessed components of the GCE Physics Specification A, A Level, and assesses modules 1, 2, 4 and 6 from this specification. The component is worth 100 marks and is split into two sections; section A contains 15 multiple choice questions (MCQs) and allows the breadth coverage of the specification and section B includes short-answer style questions, two level of response (LoR) questions, problem-solving, calculations and practical. The assessment of practical skills, as outlined in module 1 (Development of practical skills in physics) and module 2 (Foundations of physics), forms an integral part of the assessment. The Data, Formulae and Relationships booklet is a valuable resource in examination and allows candidates to demonstrate their knowledge and application of physics without the need to rote learn physical data, equations and mathematical relationships. The weighting of this component is 37% and duration of the examination paper is 2 hours 15 minutes. H556/01 Component has weighting 37%. It assesses material from modules 1, 2, 3 and 5. H556/03 Component has weighting 26% and is synoptic. It assesses material from all modules (1 to 6).

Candidates who did well on this paper generally did the following:	Candidates who did less well on this paper generally did the following:
• Answering all of the MCQs and showing helpful and supportive working where necessary. • Good use of calculators and careful consideration of unit conversions. • Showing working in calculations and clear demonstration of methods, especially in "show that" questions. • Good use of logarithms and manipulation of exponential equations. • Detail and careful analysis in Level of Response (LoR) questions, paying particular attention to the specifics of the question. • Clear appreciation of command words. • Careful use of scientific language and appropriate terms. • Consideration of significant figures in calculation.	• Not attempting all of the MCQs, which did not appear to be a lack of time issue. • Limited working in extended calculations, which means it may be difficult to award method marks. • Lack of detail in LoR questions. For example, not stating how the wavelength is determined in Question 17 (b) or not discussing quark changes in Question 20 (b). • Misreading graph scales, particularly in Question 22 (b) (ii) 1 and 24 (b) (i). • Poor use of scientific terminology, especially in Questions 21 (a) and 24 (a). • Lack of use of bullet points in extended writing which could help clearly identify specific points. • Error analysis was poorly done in Question 21 (b) (iii).

Section A overview

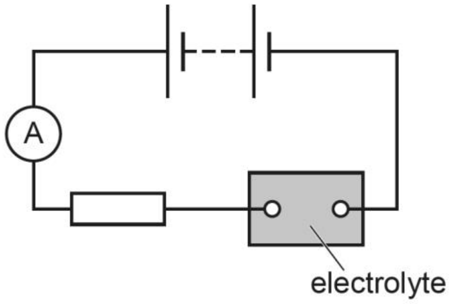
Section A has 15 multiple choice questions (MCQs) from modules 1, 2, 4 and 6. Each of the MCQs has four possible alternatives, of which only one is correct. The MCQs are worth one mark each, giving a maximum possible mark of 15 for section A.

Candidates are requested to insert their response into the square box provided and it is important for this to be done carefully to avoid any ambiguity. Space is provided on the exam paper for candidates' working and they may annotate text or diagrams if it is found to be helpful. Only the response in the box is marked and so candidates may make use of any shortcuts or ingenuity to reach their answer.

Questions 1, 3, 10, 11, 12 and 13 proved to be accessible to most candidates, while Questions 2, 6 and 8 were more challenging and only accessible to the higher end candidates.

Question 1

1 A current is present in the circuit below.



The resistor is made from a length of wire.

Which row gives the correct charge carriers in the resistor and in the electrolyte?

	Charge carriers in the resistor	**Charge carriers in the electrolyte**
A	Electrons	Electrons
B	Electrons	Ions
C	Electrons and protons	Ions and electrons
D	Electrons and ions	Ions and protons

Your answer ☐ **[1]**

The vast majority of candidates were able to correctly recall the correct charge carriers in the resistor and the electrolyte. **A** proved to be the most common distractor, possibly as the others contained "protons".

Question 2

2 The half-life of fluorine-18 isotope is T.
After time $t = 4T$ the number of fluorine-18 nuclei in a source is N.

How many fluorine-18 nuclei have decayed in the time interval from $t = 0$ to $t = 4T$?

A $3N$

B $4N$

C $15N$

D $16N$

Your answer ☐ **[1]**

Only around one third of candidates were able to give the correct response of **C**. Many candidates showed a variety of correct working to produce the correct initial number of nuclei as 16 N, however then gave the incorrect response of **D**. This highlights the need to read each question carefully.

Question 3

3 The activity of an alpha-emitting source is 120 kBq. The kinetic energy of each alpha-particle is 4.0 MeV.

What is the rate of energy released by the source?

A 6.4×10^{-13} W

B 4.8×10^{-8} W

C 7.7×10^{-8} W

D 1.2×10^{5} W

Your answer ☐ **[1]**

Although a little over two thirds of candidates selected the correct response, this question discriminated well between candidates of differing abilities. Potential errors in this question included two unit prefix conversions and the conversion between eV and joules. Incorrect responses were fairly well spread across the other distractors.

Question 4

4 Which of the following statement(s) correctly describe radioactive decay?

1 Radioactive decay can be modelled using dice.
2 Radioactive decay of nuclei is random.
3 Radioactive decay of nuclei is spontaneous.

A Only 1

B Only 2

C 2 and 3

D 1, 2 and 3

Your answer [ ] **[1]**

This question proved to be relatively straightforward with most candidates selecting the correct response. By far the most common incorrect response was C, suggesting that the idea of modelling using dice was not known, despite it being specification point 6.4.3f(ii).

Question 5

5 A gamma-ray photon of frequency 6.76×10^{22} Hz creates a particle-antiparticle pair. The particle-antiparticle pair have zero kinetic energy.

What is the mass of the particle?

A 2.49×10^{-28} kg

B 4.98×10^{-28} kg

C 7.47×10^{-20} kg

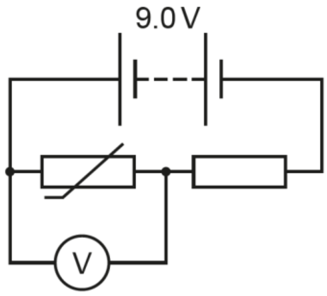
D 4.48×10^{-11} kg

Your answer [ ] **[1]**

This question was answered correctly by approximately half of the candidates. Most showed written working, often as $hf = 2mc^2$ or the equivalent in numerical form. **B** was by far the most common incorrect response, and it is clear from candidates working that the factor of 2 had simply been missed out.

Question 6

6 A potential divider circuit is shown below.



The battery has electromotive force (e.m.f.) 9.0 V and negligible internal resistance.
At room temperature the potential difference (p.d.) across the thermistor is 4.5 V.
The temperature of the thermistor is increased and its resistance decreases by 20% from its previous value.

What is the p.d. across the thermistor now?

A 3.6 V

B 4.0 V

C 5.0 V

D 5.4 V

Your answer **[1]**

This proved to be a challenging question with only around a quarter of the candidates able to obtain the correct response. It was likely that written working was helpful here and many candidates set out some form of a potential divider calculation. Some did this in ratios and others made up a value for the two resistances (e.g. 10 Ω) which they then decreased to 8.0 Ω for the thermistor. The incorrect responses were spread fairly evenly across the distractors, which is maybe surprising as it would be expected that candidates should have appreciated that the p.d. across the thermistor would now be less than the initial 4.5 V.

Question 7

7 A particle is moving at right angles to a uniform magnetic field of flux density B. The particle has mass m, charge q and moves in a circular arc of radius r in the region of the magnetic field.

What quantities are required to determine the momentum of this particle?

A B, q and r

B B, q and m

C B, q, r and m

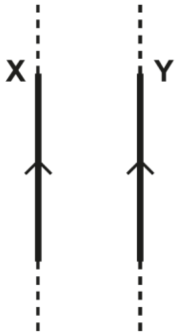
D q, r and m

Your answer [ ] **[1]**

Most candidates who successfully answered this question showed working equating the magnetic force to the centripetal force to show that $mv = rBq$. Some had possibly learnt the formula $r = mv/Bq$ as this was also a common starting point.

Question 8

8 The diagram below shows two long current-carrying conductors **X** and **Y**.



The conductors are parallel to each other.
Y experiences a force because it is in the magnetic field of **X**.

Which row gives the correct direction of the magnetic field at **Y** due to **X**, and the direction of the force experienced by **Y** due to this field?

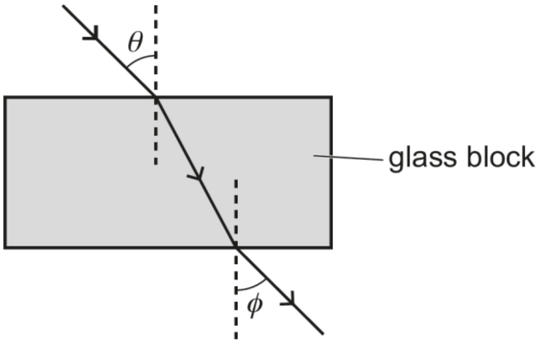
	Direction of magnetic field	**Direction of force**
A	Down into the plane of paper	To the right
B	Up from the plane of paper	To the right
C	Down into the plane of paper	To the left
D	Up from the plane of paper	To the left

Your answer [ ] **[1]**

Most candidates appear to know that the force between the two wires would be attractive, and circled C or D as their options. A few used the diagram and the right hand rule to draw arrows to help with the direction. Both of these are good practice in this style of question. A little less than half of the candidates selected the correct response with the vast majority of incorrect responses being D.

Question 9

9 A student is investigating the refraction of light by a rectangular glass block. The glass block is surrounded by air.
The diagram below shows the path of the light as it enters the block, when it is refracted within the block and when it exits the block.



Which statement is correct?

A The angles θ and ϕ are the same because the glass block is surrounded by air.

B The product of sin θ and the refractive index of glass is a constant.

C The refractive index of glass is less than the refractive index of air.

D The speed of light is the same in both air and glass.

Your answer **[1]**

This question was correctly answered by the majority of candidates. The distractor B was the most common incorrect response and several candidates wrote out $n\sin\theta$ = constant on their diagram.

Question 10

10 A proton of mass 1.67×10^{-27} kg is travelling at a speed of 2.0×10^{5} m s^{-1}.

The table below shows the mass and speed of four particles **A**, **B**, **C** and **D**.

Particle	**Mass / kg**	**Speed / 10^5 m s^{-1}**
A	9.11×10^{-30}	5.0
B	8.80×10^{-28}	3.0
C	2.49×10^{-28}	2.0
D	3.34×10^{-27}	1.0

Which particle has the same de Broglie wavelength as the proton?

Your answer **[1]**

Many candidates were able to correctly calculate the wavelength of the two particles and show that the correct response was D. Some calculated the wavelength of all of the particles from A to D, but the most elegant solutions were done through a variety of methods to determine some ratio or constant factor.

Question 11

11 A beam of sound of intensity I_0 is reflected off the surface of water.
The amplitude of the reflected sound is $\frac{1}{4}$ the amplitude of the incident sound.

What is the intensity of the reflected sound in terms of I_0?

A $\frac{I_0}{16}$

B $\frac{I_0}{8}$

C $\frac{I_0}{4}$

D I_0

Your answer **[1]**

The vast majority of candidates were able to reach the correct response and appreciated that the intensity of a wave is proportional to the (amplitude)^2 as given in the specification point 4.4.1(g). The most common incorrect response was, as expected, C.

Question 12

12 A small sample of muscle has volume 1.0 cm^3 and mass 1.10 g.
The speed of ultrasound in the muscle is 1600 $m s^{-1}$.

What is the acoustic impedance of the muscle?

A $1.76 \times 10^3 kg m^{-2} s^{-1}$

B $1.76 \times 10^4 kg m^{-2} s^{-1}$

C $1.76 \times 10^6 kg m^{-2} s^{-1}$

D $1.76 \times 10^{12} kg m^{-2} s^{-1}$

Your answer [1]

This question involves several stages, the most critical being the correct conversion of the volume units to m^3. Very encouragingly, the majority were able to do this correctly and work through to the correct response. A was a common distractor for those who made no conversion from g and cm^3.

Question 13

13 The mass of a proton is m_p, the mass of a neutron is m_n, and the mass of a hydrogen-3 (^3_1H) nucleus is M. The speed of light in a vacuum is c.

Which expression is correct for the binding energy (B.E.) of the hydrogen-3 nucleus?

A B.E. = $M \times c^2$

B B.E. = $(m_n + m_p - M) \times c^2$

C B.E. = $(m_n + 2m_p - M) \times c^2$

D B.E. = $(2m_n + m_p - M) \times c^2$

Your answer [1]

This question can correctly be answered by over three quarters of the candidates. Most appeared to be able to evaluate the composition of the nucleus correctly and then work forward from that. A was the most common incorrect response, presumably as less successful responses were able to recognise a variation of $E = mc^2$.

Question 14

14 A wire in a circuit obeys Ohm's law.

Which statement about the wire is linked to this law?

A The current in the wire is directly proportional to the potential difference across it.

B The current in the wire is inversely proportional to its resistance.

C The resistance of the wire is directly proportional to its length.

D The resistance of the wire is inversely proportional to its cross-sectional area.

Your answer **[1]**

This question was correctly answered by a majority of candidates. Although many candidates wrote out $V = IR$ or some other version of Ohm's law, they seemed unable to relate this to the statements. There was evidently some uncertainty as to what Ohm's law exactly was, and the writing of the resistivity formula inevitably led several candidates to responses C and D.

Question 15

15 An electron has both mass and charge. The electron has a gravitational field and an electric field around it.

Which statement is **not** correct?

A Both field patterns look the same.

B Both field patterns show parallel field lines around the electron.

C Both field strengths obey an inverse square law with distance from the electron.

D The direction of both fields is the same at any point around the electron.

Your answer **[1]**

This was a challenging question; candidates often drew a radial field diagram as a starting point and many candidates helpfully "ticked" the correct responses to help them eliminate these from their response. It is important that candidates read the questions carefully, as it was evident that some were looking for a correct statement.

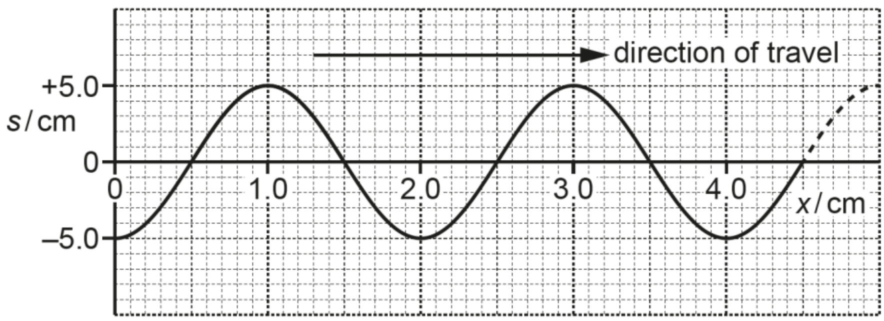
Section B overview

Section B consists of 9 short-answer style questions containing problem-solving, calculations and practical style questions; it also includes two level of response (LoR) questions each of has a maximum of 6 marks. This section is worth a total of 85 marks and candidates are expected to spend about 1 hour 45 minutes on this.

There was no real evidence of candidates having time issues on this paper; although there were several questions not answered by some candidates, these tended to be on the more challenging questions and generally spread throughout the paper.

Question 16 (a) (i)

16 **(a)** A graph of displacement *s* against distance *x* for a **progressive** wave at time *t* = 0 is shown below.



Determine:

(i) the phase difference ϕ in radians between the points on the wave at *x* = 1.5 cm and *x* = 2.5 cm

ϕ = ... rad **[1]**

The first question can generally be expected to be accessible to most candidates and many were able to gain a mark on this. Common errors included $\pi/2$ and giving responses in terms of wavelengths.

Although there is no requirement to show working for this question, many candidates converted from complete cycles (using wavelengths or 360°) to help them convert to radians.

Question 16 (a) (ii)

(ii) the displacement s at time $t = \frac{3}{4}T$ at x = 1.5 cm, where T is the period of the oscillations of the wave.

s = ... cm **[1]**

This proved to be a challenging question; it appears many candidates were unable to appreciate the progressive nature of the wave on a displacement-distance graph.

By far the most common response was 0, where it is likely the candidates ignored the inclusion of time and simply gave the displacement at 1.5cm.

Question 16 (b)

(b) A beam of coherent light of wavelength λ is incident normally at two parallel slits (double-slit). A series of bright and dark fringes are formed on a distant screen placed parallel to the line joining the slits.
The location of some of these fringes is shown in **Fig. 16.1**.

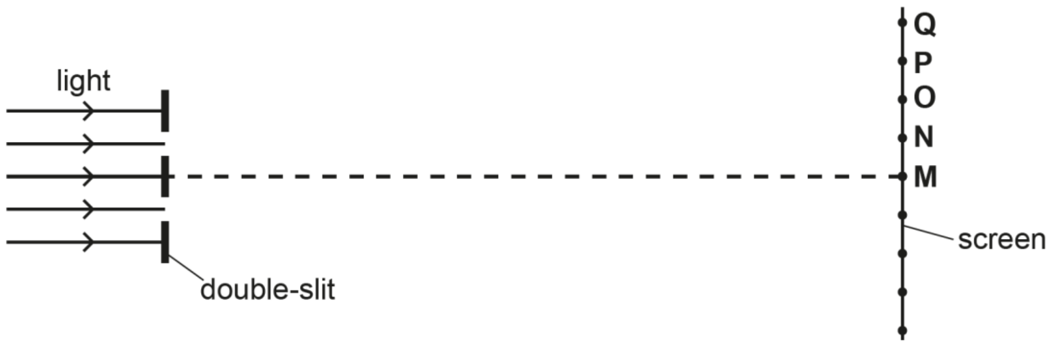


Fig. 16.1 (not to scale)

The bright fringes are seen at points **M**, **O** and **Q**. The dark fringes are seen at points **N** and **P**.

State the phase difference ϕ in degrees, and the path difference d in terms of wavelength λ, for the waves from the two slits meeting at point **P**.

ϕ = ... ° **[1]**

d = ... λ **[1]**

This was a well done question overall; most candidates were able to appreciate that destructive interference resulted from a half number of cycles. Generally, the phase difference seemed to be better understood than the path difference, where incorrect responses for the path difference included a common response of *(n+1/2)*λ, or sometimes 0.5, showing an understanding of destructive interference but not applying it correctly to this situation.

Question 16 (c) (i)

(c) A student is doing an experiment to determine the speed of sound in air by producing stationary waves inside a horizontal glass tube.

Fine powder is sprinkled inside the tube. A loudspeaker is placed close to the open end of the tube. The other end of the tube is closed. The loudspeaker is connected to a signal generator producing a frequency of 2.72 kHz.
The powder inside the tube forms piles at certain locations inside the tube, see **Fig. 16.2**.

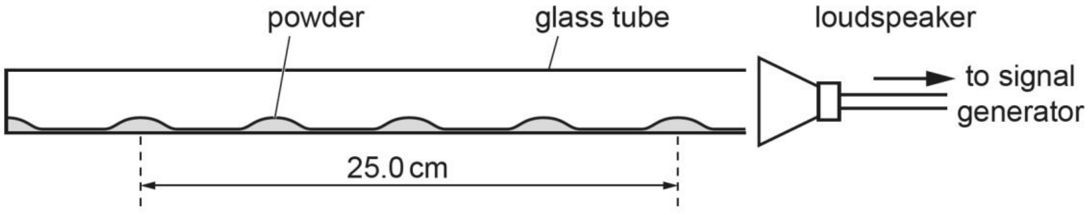


Fig. 16.2 (not to scale)

(i) Suggest why the powder piles up at the nodes within the tube.

....

.... **[1]**

Most candidates were able to appreciate that the stationary wave has nodes and antinodes and correctly relate them to the movement of the particles. Candidates were expected to give their responses in terms of the nodes, and responses in terms of the antinodes – such as powder is displaced from the antinodes – does not really answer the question.

Several candidates drew a stationary wave on the diagram, with nodes and antinodes at the correct places. As the exemplar below shows, this helps confirm in the candidates mind the variation of the oscillations of the stationary wave. It also helps with subsequent questions; although cannot be given marks itself, candidates are always to be encouraged to make additions to diagrams to help them in supporting their responses.

Exemplar 1

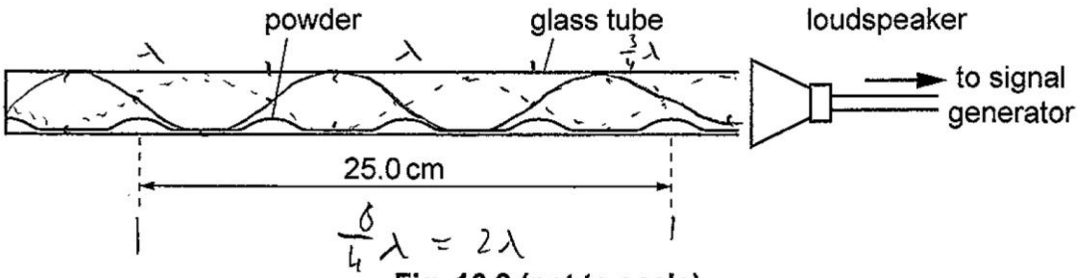


Fig. 16.2 (not to scale)

(i) Suggest why the powder piles up at the nodes within the tube.

At nodes the air molecules have no net movement, so the light powder isn't pushed away, unlike at the antinodes **[1]**

A candidate drawing on the diagram to assist them to appreciate the vibrations at the nodes and antinodes.

Question 16 (c) (ii)

(ii) Use **Fig. 16.2** to determine the speed of sound *v*.

v = ... $m\,s^{-1}$ **[3]**

This question was well answered by most candidates who were able to correctly appreciate that the given distance of 25cm corresponded to two complete wavelengths of the stationary wave. Encouragingly, very few candidates did not make the cm to m conversion. A small number of candidates thought that the wavelength was the distance between two nodes resulting in an answer of 170 $m\,s^{-1}$.

Many candidates structured their responses clearly and were able to explain their reasoning.

Question 16 (c) (iii)

(iii) Determine the fundamental (minimum) frequency f_0 of the stationary wave that can be formed within this tube.

f_0 = ... Hz **[2]**

This proved to be a challenging question and only around one fifth of the candidates were able to score any marks. Most successful candidates appreciated that there were 11 quarter wavelengths of the initial wave in the tube and used this to determine the length of the tube, from which they were able to determine the fundamental wavelength and hence the frequency. There are many potential errors in this question, however a common incorrect response was 680Hz, calculated from treating the wavelength of the fundamental wave as twice the given distance of 25cm.

Question 17 (a)

17 A light-emitting diode (LED) can be used to determine the Planck constant *h*. When the LED just starts to emit light, the equation below is valid

$$eV = \frac{hc}{\lambda}$$

where *V* is the potential difference (p.d.) across the LED, λ is the wavelength of the light emitted, *c* is the speed of light in vacuum and *e* is the elementary charge.

(a) In the equation above, $\frac{hc}{\lambda}$ is the energy of a photon emitted from the LED.

Determine the S.I. base units for *h*.

base units = ... **[2]**

This question was done correctly by around half of the candidates. The most common method was to use an equation for energy or work to give the base units of the joule. From this, multiplying it by s would lead to the correct response. Most candidates used $KE = ½ mv^2$ to determine the base units of the joule directly, although others used work done = force × distance and force = mass × acceleration. Encouragingly, there were relatively few arithmetic errors even with the negative indices.

Some candidates got into difficulties attempting to use the given equation and struggled with the volt, attempting to use $V = IR$ in a variety of ways. A very common error was to give the units simply as Js, often using $h = E\lambda/c$ to show [J × m / m s^{-1}] gives J s. There was a clear misconception (see below) about what constitutes a base unit.

Misconception

Candidates are reminded that base units are kg, m, s, A, K and mol. Other units are derived units.

Question 17 (b)*

(b)* Describe how an experiment can be carried out in the laboratory to determine *h* from a graph. Your description must include how *V* and λ are accurately determined. Assume that the values of *e* and *c* are known. **[6]**

This level of response (LoR) question was designed to assess practical skills of planning, implementation, analysis and evaluation from module 4 of the specification, specifically 4.5.1(e). A holistic approach to marking is used, with marks given according to answers matching the descriptors for the various levels. No one answer is perfect for this question, examiners were expecting a varied approach which would lead to a correct determination of *h*. The nature of the question is such that it can be conveniently separated into a description of the experiment and an analysis of it.

The key points in the description that examiners were looking for were: - a suitable circuit diagram allowing the potential difference across the LED to be both varied and measured – a description of the method used, specifically measuring the potential difference across the LED at the point at which it just lights – a statement or description of how the wavelength of the emitted light is determined or measured – use of a range of different wavelengths (or colours) of LEDs.

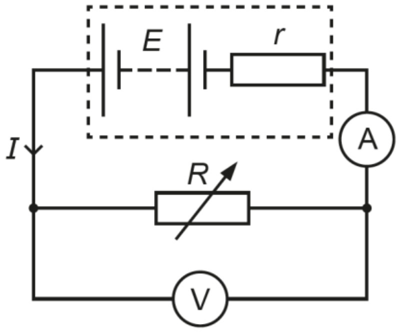
The key points in the analysis that examiners were looking for were: - a suitable graph with appropriate variables on the correct axes – a description of how the graph will appear and what the gradient corresponds to – how the value of *h* can be determined from the gradient.

It was clear that many candidates had carried out this experiment and were able to give good descriptions and analysis. The very best was detailed and well-structured and made every attempt to fully answer each section of the question. It was anticipated that the determination of the wavelength would come from an experimental method, but it was evident that many candidates who had carried this experiment out had used the manufacturer's data which is a perfectly acceptable response. It was important that candidates described how the potential difference across the LED was to be measured as this was specifically asked in the question and several candidates drew circuit diagrams which would not have worked in the required way, often with the variable resistor across the LED. Many candidates gave extra experimental details, such as using a darkroom, to help build up a detailed response.

For the most part, the analysis was done better than the description and candidates were generally able to describe the correct graph and how to determine *h*. Several candidates plotted an incorrect graph, such as *V* against λ, which meant that they would not be able to determine *h*. Some of the responses were brief and used symbols with little explanation about how the analysis was to be carried out.

Question 18 (a)

18 A battery is connected to a variable resistor.



The variable resistor is made from a length of wire. The resistance of the variable resistor is *R*. The battery has electromotive force (e.m.f.) *E* and internal resistance *r*. The current in the circuit is *I*.

(a) Compare the e.m.f. of the battery and the potential difference (p.d.) across the variable resistor in terms of energy transfers or changes.

....

.... **[1]**

The important word in this question is energy and so any response needs to be framed with this in mind. This is directly from the specification point 4.2.2 (e). Many candidates stated differences between the magnitudes of the e.m.f. and p.d. without referring to energy and so could not be given a mark. There were many good responses, and the simplest was to state how the electrical energy is transferred in each case.

Question 18 (b)

(b) State which physical quantity of the variable resistor is changed to alter its resistance.

.... **[1]**

This was correctly answered by the majority of candidates; it was clear that some had not read the question and answered along the lines of changing the number of turns/coils, presumably thinking about a rheostat. Another common incorrect answer was temperature.

Question 18 (c) (i)

(c) A student connects up the circuit above to determine *r*.

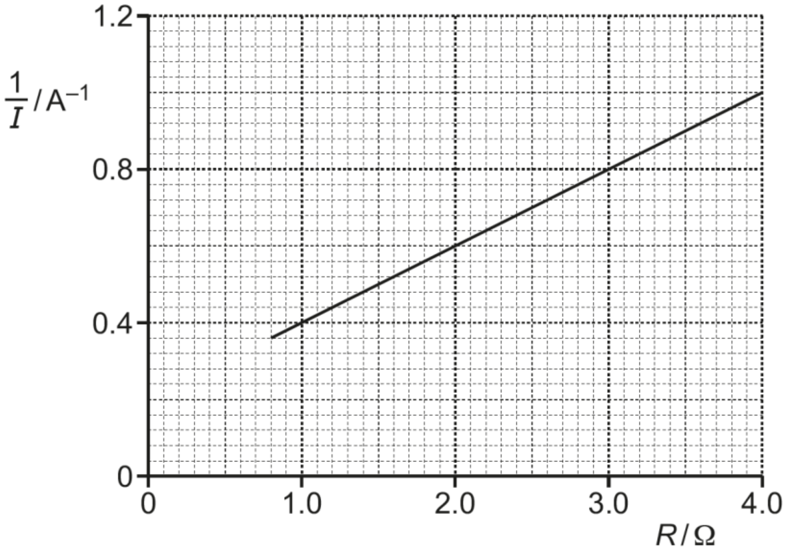
(i) Show that $\frac{1}{I} = \frac{R}{E} + \frac{r}{E}$.

[2]

Many candidates were able to do this relatively simple manipulation. The circuit diagram should alert the candidates that this question is based on internal resistance and allow them to select one of the appropriate starting points. Some less successful responses chose other routes, such as $I = I_1 + I_2$, but then quickly found themselves unable to go further, unless by using incorrect algebra.

Question 18 (c) (ii)

(ii) The student varies R and measures the current I.
The student plots a graph of $\frac{1}{I}$ against R.



1 Use the graph to determine the power dissipated in the variable resistor when $R = 3.0\,\Omega$.

power = ... W **[2]**

2 The e.m.f. E of the battery is 5.0 V.

Determine r from the intercept of the line with the vertical axis.

r = ... Ω **[2]**

The vast majority of candidates were able to complete 1 correctly – there were few misreads from the graph, although some candidates took the reading of 0.8 as the current rather than the inverse of the current. There were also a few arithmetic slips with some candidates correctly setting out their calculation, such as $P = 1.25^2 \times 3.0$, but then not squaring the current. 2 was answered slightly less successfully and although the reading of the intercept was taken, some candidates could go no further.

Question 19 (a)

19 The diagram below shows two parallel plates, **E** and **C**, in an evacuated glass tube.

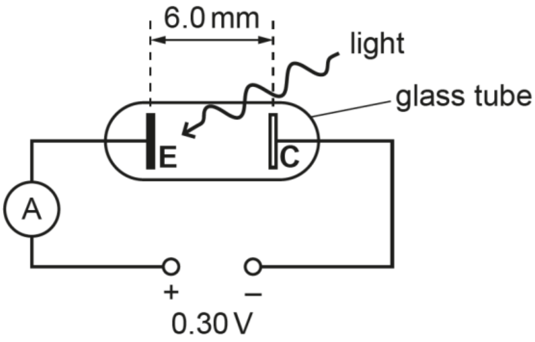


Plate **E** is made from potassium, which is sensitive to light. Plate **C** is not sensitive to light.

The separation between the plates is 6.0 mm and the potential difference between the plates is 0.30 V.

Light of frequency 6.3×10^{14} Hz is incident on plate **E**. The photoelectrons emitted from this plate have **maximum** kinetic energy 0.30 eV (4.8×10^{-20} J). The photoelectrons are repelled by the negative plate **C**. The ammeter reading is zero because these photoelectrons reach plate **C** with zero kinetic energy.

(a) Calculate the work function of potassium in eV.

work function = ... eV **[3]**

This question was successfully completed by many candidates. It was clear that the use of Einstein's equation was well known, and the conversion to eV (generally done at the end) only caused a few candidates difficulties, mostly by multiplying their work function (in J) by *e*. Several candidates wrote down the answer with no working – while this will score full marks here, it is a risky tactic should an arithmetic error occur on their calculator.

Question 19 (b) (i)

(b) This question is about a photoelectron emitted perpendicular to plate **E** and with an initial kinetic energy of 4.8×10^{-20} J.

(i) Show that the magnitude of deceleration of this photoelectron is $8.8 \times 10^{12}\,\mathrm{m\,s^{-2}}$.

[3]

There were many different routes to showing the acceleration, and marks were given for each method or part method. No one method was seen significantly more than others, and some candidates used a variety of pathways to come to their answer.

The main principle in the question (and the subsequent one) where the candidate is being asked to "show that" a given value is correct is that the examiner must be convinced that the candidate has clearly demonstrated that they have carried out the calculation and evaluated it on their calculator. The instructions which examiners used was: first marking point for providing one (or two) equations that would lead to the solution, or calculation of an intermediate value; second marking point for a full substitution into one or more equations; third marking point for using this full substitution to produce an answer to more sf than given in the question. As the second marking point was deemed to be an M mark, the full substitution needed to be seen to gain the A mark.

A small number of (often higher end) candidates did not show the full substitution, often missing out the value of m_e in their calculation, and another common error was to not show the extra significant figure.

Over half of the candidates were able to achieve full marks on this question and it generally discriminated well.

Assessment for learning

When a question asks a candidate to "show that" a given value is correct, the following two points should be considered:

- Each stage of the calculation should be clearly shown. Preferably setting out any equation first, and then showing a full substitution of all values into that equation
- If the value calculated by the candidate would correctly round to the given value, then the candidate should show their calculated value to at least one more significant figure than the given value.

Both of these are evidence that the complete calculation has taken place and that the candidate has not somehow artificially generated the required value. This advice should be viewed as "best practice" rather than a rigid set of rules.

Reverse arguments are often possible where a candidate can work backwards from their given value, however this is not the advised approach.

Question 19 (b) (ii)

(ii) Show that the initial speed of the photoelectron is about $3 \times 10^5\,\text{m}\,\text{s}^{-1}$.

[2]

The vast majority of candidates were able to clearly show that the speed of the photoelectron could be calculated as $3.2 \times 10^5\,\text{m}\,\text{s}^{-1}$, most often through substitution into the kinetic energy formula. As in Question 19 (b) (i), it is important to show all variables and constants used in the equation for full marks and to give the answer to at least one more d.p. than given in the question, to show the calculation has taken place. An alternative solution using an equation of motion and the acceleration given (or calculated) in Question 19 (b) (i) would yield the same result.

Question 19 (b) (iii)

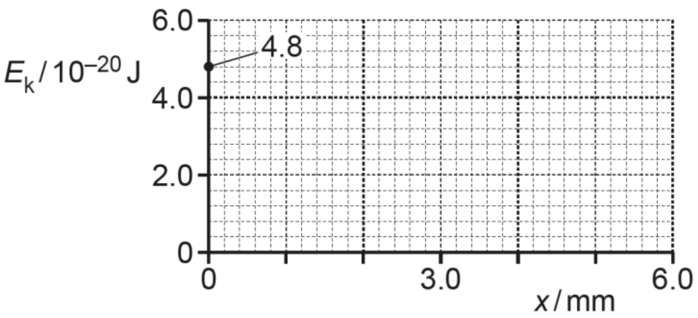
(iii) Calculate the time *t* taken by the photoelectron to travel from plate **E** to plate **C**.

t = ... s **[2]**

Only around half of the candidates were able to obtain answers within the required range. Candidates used a variety of rounded or none-rounded values from prior calculations, so a generous range of responses was given to allow for this. A common error among less successful responses was to simply use speed = distance/time usually leading to 2.0×10^{-8} s. Those using $s = ut + ½ at^2$ often encountered problems in solving the equation as it could lead to imaginary roots and tended to produce solutions way outside of the accepted values. However, marks could be given for setting up the calculation correctly.

Question 19 (b) (iv)

(iv) Using the axes shown below, sketch a graph of kinetic energy E_k against distance *x* from plate **E**.



[2]

Nearly all candidates appreciated that this line would start at 4.8×10^{-20} J and decrease to zero at 6.0 mm. However, the vast majority drew a curved line of decreasing gradient. This may well have come from a confusion from $KE \propto v^2$ and attempting to draw a parabola.

Question 19 (c)

(c) Explain, in terms of photons, what happens to the ammeter reading when light of frequency greater than 6.3×10^{14} Hz is now incident on plate **E**.

....

....

.... **[2]**

There were several misconceptions in candidates' responses to this question. Many candidates did not appreciate that the increased frequency would result in electrons of greater KE and thought that it was the increased energy of the photons crossing the 6.0mm gap that caused an ammeter reading. A significant number of candidates also described increasing frequency causing an increase in *kinetic* energy of photons, and some also linked the increasing frequency to a greater number of photons or photoelectrons.

Question 20 (a)

20 **(a)** Deuterium is an isotope of hydrogen.
A nucleus of deuterium has a proton and a neutron.

Describe the nature and range of the **two** forces acting between these two hadrons.

....

....

....

....

....

.... **[4]**

There were many superb answers to this question, with candidates giving plenty of correct detail in describing these forces. The vast majority appreciated the strong nuclear force was one of the forces and were able to give correct numerical values in terms of attractive and repulsive distances. Some stated that it was a purely attractive force, up to about 3fm, which could not be given the nature/range mark.

Those who selected gravitational force as their second force were generally able to score the nature/range mark as this was simpler than that required for the strong force.

A number of candidates stated that the electromagnetic force acted on the two hadrons and tried to justify the charge of the neutron in terms of its quarks.

Question 20 (b)*

(b)* Here is some data for a nucleus of carbon-14 ($^{14}_{6}C$) and a nucleus of uranium-235 ($^{235}_{92}U$).

	Carbon-14 nucleus	**Uranium-235 nucleus**
Decay mode	Beta-minus decay	Alpha decay
Mass of nucleus / u	14.0	235.0
Radius of nucleus / 10^{-15} m	2.9	7.4

Use the data to:

- describe the composition of the nuclei before and after the decay in terms of hadrons and quarks
- show that both nuclei have the same density. **[6]**

This is the second level of response (LoR) question in this paper, and was designed to assess nuclear and particle physics, specifically sections 6.4.1 and 6.4.2 of the specification. In particular, there are two parts (description and analysis) relating to two radioisotopes, and some given data. As previous, there are no specific marking points and examiners use a "best-fit" approach to the marking. Indicative scientific points are given in the mark scheme as a guidance what to expect, but not all need to be satisfied to be given full marks. Incorrect physics can be expected to be penalised however. Candidates should always be encouraged to structure their answers carefully and in calculations aim to give explanation of each stage rather than just producing a number. The two separate sections can be separated into a description of the decays, and an analysis of the data to show the two nuclear densities are the same.

The key points in the description that examiners were looking for were: - numbers of protons before and after each decay – a description of the change in quark structure during beta decay – correctly balanced equations for alpha and beta-minus decay – the nature of the emissions in each decay.

The key points in the analysis that examiners were looking for were: - calculation of volumes of nuclei, using $(4/3\pi)\ r^3$ – correct use of the density formula – numerical evaluation of the densities of the nuclei and a comparison.

The descriptions of the decays varied hugely both in quality and quantity. Most candidates were aware that a beta particle is an electron, but several seemed to think it was an orbiting one which had no structural changes on the nucleus. Those who did know it was from a neutron to proton change often mixed up the nucleon numbers afterwards. Alpha decay was generally done better with most candidates knowing the nature of an alpha particle and correctly stating the structure of the remaining nucleus. Attempts were generally made to changes in quark structures (mostly for beta decay) and the structure of a neutron and proton were known, although strangely several candidates stated the change was from an up quark to a down quark. Candidates who did not give any descriptions of the quark structures were limited to Level 2.

For the most part, the analysis was done better than the description and candidates were generally able to correctly evaluate the two densities and make a suitable comparison. Units of density were not penalised here, with many candidates using the mass (in u) in the calculation but giving the units of density as kg m^{-3}, although many stating u m^{-3}. However, many did correctly calculate the mass of the nucleus using the correct factor coming out with densities of approximately 2.3×10^{17} kg m^{-3}. Those who took an approach to algebraically show that the density of every nucleus is independent of the nucleon number (using a standard method to get to some variation of $3u/4\pi r^3$) alone were unable to reach Level 3 as they had not used the data. The use of r_0 as 1.2×10^{-15} m was commonly seen.

Exemplar 2

β^{-} = $^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e + \overline{V_e}$

~~Proton → neutron~~

neutron → proton

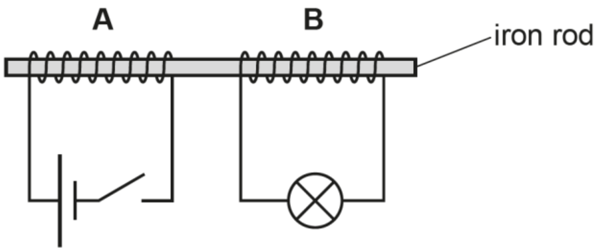
neutron = ~~udd~~ UDD ~~p~~ proton = UUD

In the beta minus decay 1 down quark turns to a up quark and one ~~prot~~ neutron turns into a proton

A candidate who provides some description and analysis which places it in Level 2, but the confusion over alpha decay and general lack of clarity means it would be at the lower point (3 marks).

Question 21 (a)

21 (a) The diagram below shows two insulated-copper coils **A** and **B** connected in circuits.



Both coils are individually wrapped around the same iron rod.
Coil **A** is connected to a cell and a switch. Coil **B** is connected to a filament lamp.

The switch is initially closed and the lamp is off.

The switch is then opened. The lamp flashes on for a brief time, and then remains off.

Explain these observations in terms of magnetic flux.

....

....

....

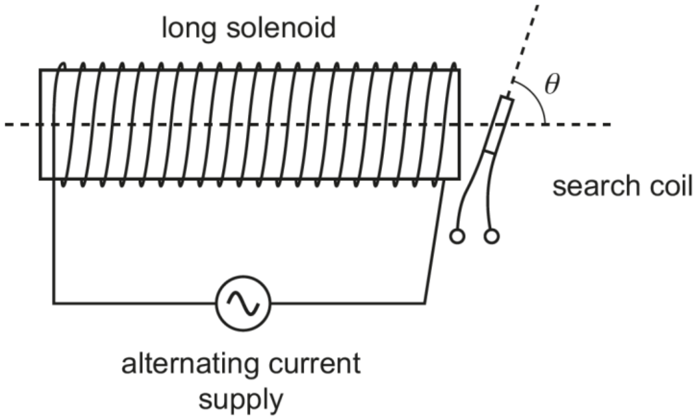
....

.... **[3]**

Many candidates found difficulties in appreciating what was required. A major confusion arose from a misunderstanding of the actual process, in that it was the opening of the switch which caused the lamp to light. Many knew Faraday's law, and were able to quote it, but not able to put it correctly into the context of this question. A common error included a misunderstanding of the role of the rod. With a large number of less successful responses stating that it conducted current to the lamp. A large number of candidates did not discuss the process in the terms of magnetic flux (as was required in the question) but talked in vague terms about "magnetism". Despite this being a challenging question, many candidates were able to score marks, and those at the top end were able to give clear and well-structured responses.

Question 21 (b) (i)

(b) A student is carrying out an experiment using a search coil.



A long solenoid is connected to an alternating current supply.

The search coil is placed at one end of the solenoid. The plane of the search coil is tilted such that it makes an angle θ with the central axis of the solenoid. The maximum alternating induced electromotive force (e.m.f.) across the ends of the search coil is E_0.

(i) Name an instrument that can be used to determine E_0.

.... **[1]**

Most candidates appreciated that a voltage was to be measured, however it was evident that only a small proportion realised that it would be alternating and so a simple "voltmeter" would not be sufficient. Candidates putting the correct response of "oscilloscope" may well be those who have carried out practical work using search coils.

Question 21 (b) (ii)

(ii) The equation for E_0 is:

$E_0 = KI_0ANf\sin\theta$

where I_0 = maximum current in the solenoid, A = cross-sectional area of the search coil, N = number of turns of the search coil, f = frequency of the alternating current in the solenoid and $K = 4.0 \times 10^{-3}\ \text{VA}^{-1}\,\text{m}^{-2}\,\text{s}$.

The magnitude of the induced e.m.f. in the search coil can be determined using Faraday's law of electromagnetic induction:

e.m.f. = rate of change of magnetic flux linkage

In the experiment, angle θ is changed and E_0 measured.

Suggest the quantity, or quantities, in the equation $E_0 = KI_0ANf\sin\theta$ linked to

1 the 'rate' part of the law

.... **[1]**

2 the 'change of magnetic flux linkage' part of the law.

.... **[1]**

Part 1 was answered better than part 2 in general. For part 1, the majority of candidates appreciated that the "rate" will have included the frequency although many included other irrelevant (and therefore incorrect) terms too. In part 2, the concept of what causes the magnetic flux linkage to "change" did not appear to be well understood; *A* and/or *N* were often an incorrect response, presumably as the candidate was aware that these terms are included in a calculation for flux linkage.

Question 21 (b) (iii)

(iii) The student plots a straight-line graph of E_0 against $\sin\theta$.

Determine *f*, including the absolute uncertainty. Write your value of *f* to **2** significant figures.

$I_0 = (8.0 \pm 0.2)\,\text{A}$
$A = (7.8 \pm 0.1) \times 10^{-5}\,\text{m}^2$
$N = 5000$
gradient of line $= KI_0ANf = (0.62 \pm 0.03)\,\text{V}$

f = ... ± .... Hz **[4]**

A good fraction of candidates were able to score full marks on this question. It is clear that many had been well prepared in treatment of errors, and 8.6% was seen often in the working. A common mistake among more successful responses was giving the error as 4.3, rather than 4. Less successful often simply added the raw uncertainties, giving 0.33, which was often then placed on the answer line. Some candidates missed out the factor of 10^{-5} in their calculation of *f*. Other approaches to obtain errors, such as calculating maximum and minimum values for *f* were seen and these can also lead to full marks.

Question 22 (a) (i)

22 (a) The diagram below shows a simple capacitor.

The capacitor consists of two horizontal metal plates in a vacuum. The magnitude of the charge on each plate is Q_0. The potential difference (p.d.) between the plates is V_0. The capacitor plates have capacitance C_0. The separation between the plates is d. The energy stored by the capacitor is E_0.

The top plate is moved vertically upwards. The new separation between the plates is $2d$. The charge on each plate remains the **same**.
The energy stored by the capacitor **increases**.

(i) Determine the new:

1 capacitance in terms of C_0

capacitance = ... C_0 **[1]**

2 p.d. between the plates in terms of V_0

p.d. = ... V_0 **[1]**

3 energy stored in terms of E_0.

energy = ... E_0 **[1]**

Around two thirds of candidates were able to score all of these marks. Most showed some limited (but helpful) working, such as writing the equation for the parallel plate capacitor and $C = Q/V$, to assist them in appreciating how each of the factors change. For this question, there is a quite large amount of introductory text and the bold text is there as a supportive guide. The most common incorrect responses were a simple reversal of the correct responses.

Question 22 (a) (ii)

(ii) Explain, in terms of forces between the plates, why the energy stored increases.

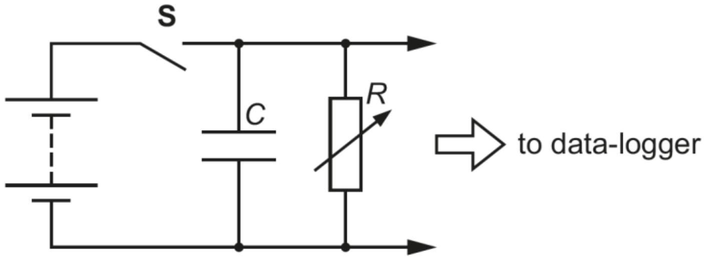
....

.... **[1]**

This proved to be a challenging question and only the higher end candidates were able to give a clear and correct response. The question stated, "in terms of forces" and most candidates did not explain the idea of attraction between the plates. Common incorrect responses included using $E = ½ QV$ or using $W = F \times d$ as a starting point.

Question 22 (b) (i)

(b) A student discharges a capacitor of capacitance *C* through a variable resistor of resistance *R* using the arrangement below.



The capacitor is made from two parallel metal plates separated by a sheet of paper of thickness 8.0×10^{-5} m. The area of overlap between the plates is 3.1×10^{-2} m^2.

The capacitor is charged fully by closing switch **S**. At time $t = 0$, **S** is opened and the capacitor discharges through the resistor. After $t = T$, the potential difference across the capacitor is halved. The student repeats this for several values of *R*.

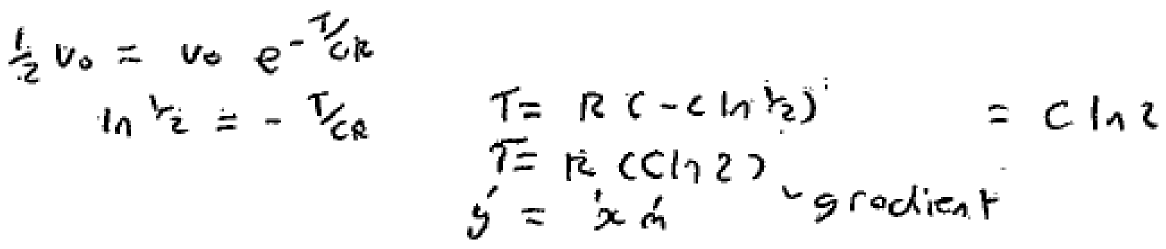
(i) The student decides to plot *T* against *R* to obtain a straight-line graph.

Show that the line has gradient = $C\ln 2$.

[2]

The treatment of natural logs was generally well done across the ability range and those who started from a correct exponential equation were generally able to score the first mark. There was some confusion among the less successful responses about the role of the negative sign, without them appreciating that ln(2) = - ln (½) and it was evident that some simply ignored it. Although many candidates were able to get to the correct equation, few linked it appropriately to the equation of a straight line and did not show that the gradient was *C*ln2, as required. Exemplar 3 shows a candidate producing elegant solution.

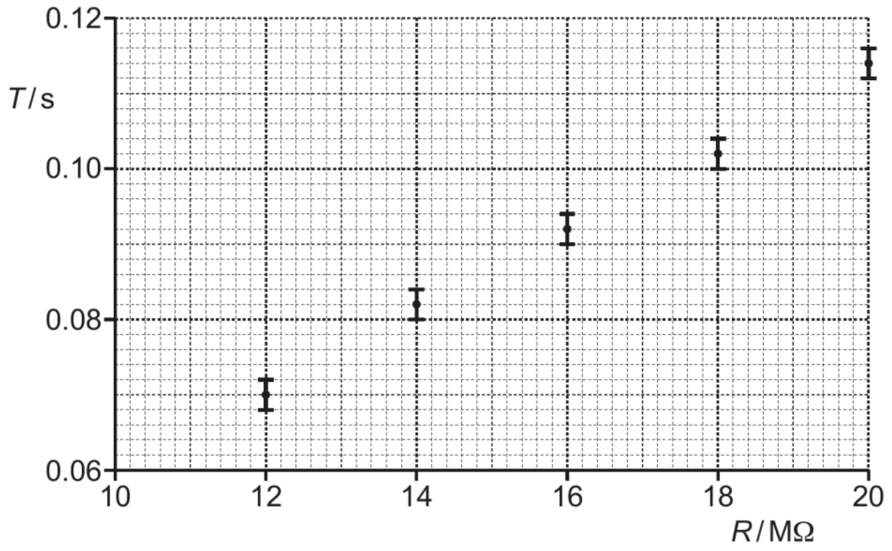
Exemplar 3



A response that works through the logs clearly and then relates it well to the form of y = mx + c.

Question 22 (b) (ii)

(ii) The data points plotted by the student are shown below.



1 Draw a best-fit straight line through the data points and use the gradient of this line to determine *C*.

C = ... F **[3]**

2 Use your answer in **(ii)1** to calculate the permittivity ε of the paper.

ε = ... F m^{-1} **[2]**

In part 1, nearly all the candidates were able to draw a correct straight best-fit line which passed through all the error bars. It was actually rather difficult not to do this, although several candidates did multiple lines (assuming they were unable to remove an original) and if any fell outside of the error bars, then it could not be given marks. In calculating the gradient, misreads from the graph were common either from the vertical scale or often assuming that the horizontal scale started from zero. A common mistake among the range of abilities was to miss out the 10^6 in the denominator of the gradient. Several candidates may have interpreted the question as meaning that the gradient was *C*, as they calculated the gradient but took it no further.

Part 2 was generally well done by many candidates. Some of the less successful responses were unable to rearrange the capacitance equation correctly, often swapping over the *d* and *A* values. A small proportion calculated the relative permittivity and as long as this was done correctly, it could score the first mark. A common error was to attempt to use $C = 4\pi\varepsilon r$ which proved to be unproductive.

Assessment for learning

Good practice for straight best-fit lines includes:

- A single straight line – not a line drawn in two or more parts.
- Use of a sharp pencil – once a line is drawn in pen, it is almost impossible to correct.
- Aiming to have an equal number of data points above and below the line – not always possible due to potential variations in data, but this should be a general aim.
- Looking for anomalous points – should not form part of the best-fit.
- Being aware of a false origin – if present then the line should not necessarily be expected to go through this point.
- Drawing a line through the origin – would (0,0) be expected to be a data point, and consideration of a potential systematic error in the data.
- Use of error bars – if present (generally in the dependent data), then the line must pass through the vertical error bars on every point.

Question 23 (a)

23 A gamma camera has several important components including a collimator, scintillator and photomultiplier tubes.

(a) Suggest why the collimator needs to be long and narrow.

....

.... **[1]**

This question was well answered by around half of the candidates who appreciated that the long, narrow collimator would allow only gamma rays which were parallel to each other to be received by the scintillator. This can be expressed in a number of ways and marks were given to candidates who were able to state this using alternative descriptions. A common confusion appeared between using the terms perpendicular and parallel, with some candidates incorrectly stating that the collimator allowed photons perpendicular to the tubes to pass. Essentially, the collimator allows for a clearer image to form and so this is an acceptable response.

Question 23 (b)

(b) State the function of the scintillator.

....

.... **[1]**

Around half of the candidates were able to correctly explain that the gamma photons produced visible light in the scintillator. Several candidates thought that the scintillator produced electrons or a voltage when the gamma photons were incident on it instead. Many candidates gave the extra correct information that many visible photons are produced from one gamma photon, although this was not a required detail on this occasion.

Question 23 (c)

(c) In a single photomultiplier tube, a photon of light produces a 0.32 μA pulse of current for a duration of 1.2 ns.

Calculate the number of electrons responsible for this pulse of current.

number of electrons = ... **[2]**

This calculation was done well by a large majority of candidates. There were few errors in the unit prefixes, with the most common one being 1.2 ns as 1.2×10^{-12} s. A small number of candidates calculated the charge correctly, but then took it no further to determine the number of electrons.

Question 23 (d)

(d) State one diagnostic application of a gamma camera.

....

.... **[1]**

The key word here was "diagnostic" and responses were expected to state any reasonable diagnostic use of a gamma camera and a wide variety of responses were given and accepted. Common responses included checking for brain tumours and observing kidney failure. Although a gamma camera may be used in a PET scanner, this alone was not acceptable as it does not explain the diagnostic use. Candidate should be encouraged to write in a clear sentence structure as simple responses such as "cancer" cannot be given marks.

Question 24 (a)

24 **(a)** Describe, in terms of X-ray photons, the attenuation mechanism of Compton scattering.

....

....

.... **[2]**

The Compton effect is part of the X-ray attenuation section of the specification 6.5.1(d). It appeared that some candidates were unfamiliar with this process and attempted to describe the photoelectric effect. There was a noticeable use of casual language in the description of the electron being removed from the atom and several candidates described the electron as moving up energy levels. Those who were able to obtain both marks generally gave clear and succinct responses.

Question 24 (b) (i)

(b) A parallel beam of X-rays is incident normally on a tissue as shown in **Fig. 24.1**.

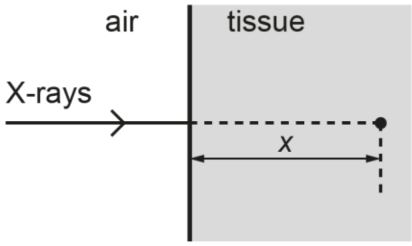


Fig. 24.1

The variation of the intensity I of the X-rays with depth x in the tissue is shown in **Fig. 24.2**.

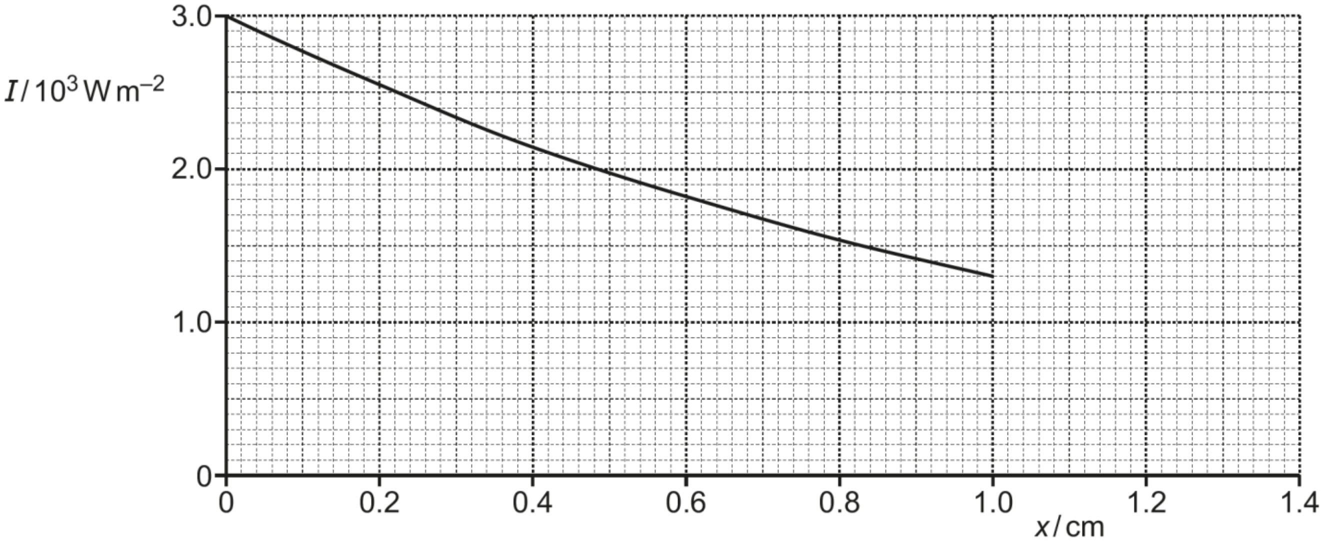


Fig. 24.2

The tissue has uniform structure between x = 0 and x = 1.0 cm.

(i) Use the graph to determine the attenuation (absorption) coefficient μ in cm^{-1} of the tissue.

μ = ... cm^{-1} **[2]**

The treatment of the logs was well done here (again, as with 22bi) and most of the candidates chose 0.0 and 1.0 cm to produce their values. The factor of 10^3 in the intensity was not needed for this calculation, so candidates who chose to ignore it (or did not see it) were unlikely to be penalised. The negative sign caused a problem if I and I_0 were reversed and candidates deliberately ignoring it would not score the second mark.

There was a common alternative to using the 0.0 and 1.0 cm points where candidates used the "half-thickness" value at approximately 0.83 cm which would produce the same answer.

As the graph scale on the vertical axis was simple, values which could have been from a "misread" would not be given further marks.

Although readings were taken from a graph in the calculation, several candidates gave their final answer to 1sf despite calculating it correctly throughout.

Question 24 (b) (ii)

(ii) Use the graph to determine the exposure time *t* for the total radiant energy incident per cm^2 at a depth of 1.0 cm to be 2.6 J.

t = ... s **[3]**

Many candidates made a good attempt at this question, however the conversion between cm^2 to m^2 and missing the 10^3 on the intensity reading caused two potential power of ten errors.

Question 24 (b) (iii)

(iii) Beyond $x = 1.0$ cm, the tissue has a larger attenuation coefficient than the value calculated in **(i)**.

On **Fig. 24.2**, sketch the variation of I with x beyond $x = 1.0$ cm. **[2]**

Most candidates appreciated that a larger attenuation coefficient would lead to a line which would lead to a lower intensity than a continuation of the original line. Common (and understandable) errors included the line touching the x axis and a continuation of the original line of increasing gradient. Some candidates may have misinterpreted the question as they drew a second line from the (3.0, 0.0) point beneath the original line.

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