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Examiners' report

PHYSICS A

H556

For first teaching in 2015

H556/02 Summer 2018 series

Version 1

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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. 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 can be downloaded from OCR.

Paper H556/02 series overview

H556/02 is one of the three assessed components of GCE Physics A. The component is worth 100 marks and is split into two sections. It assesses modules 1, 2, 4 and 6. Section A contains 15 multiple choice questions (MCQs) and allows the breadth coverage of the specification. 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 forms 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).

Overview of performance in Paper 1

The positive attributes of the candidates in this component were:

- Generally well-structured solutions with clear manipulation of equations, good substitution and expressing the final answers to appropriate significant figures.
- Good comprehension of command terms such as *describe*, *explain*, *show* etc.
- Good use was made of the spaces provided in the multiple choice questions; rough calculations were done and calculators used competently.
- Generally good analytical and graphical skills, especially in question **20(a)**.

There were some missed opportunities in this component, and candidates can maximise marks in future examinations by doing the following:

- Underline or circle key data within a question to aid calculations.
- Do **not** round, or truncate numbers in the middle of long calculations. Retain numbers on the calculator for subsequent stages of the calculations. This is the main cause of errors in calculations. The top-end candidates were exceptional in this area.
- Make good use of technical and scientific vocabulary in descriptions and explanations. For example, in **20(b)**, using terms such as *work function* and *threshold frequency* to get across ideas key to the photoelectric effect.
- Do not to use labels (e.g. ϕ, *f*, etc.) in explanations and descriptions - named quantities (e.g. *magnetic flux*, *work function*, *frequency*, etc.) are much better at communicating scientific ideas in extended writing.
- Use bullet points if it is easier to get your physics across. This alternative method could have been used in questions such as **20(b)** or **23(a)(ii)**.
- Finally, be aware of the information available in the Data, Formulae and Relationship booklet. In some questions, you need data from this booklet. For example, in **25(a)(ii)**, you need the value for the Planck constant *h* and the speed of light in vacuum *c* to calculate the minimum wavelength of the gamma-ray photon. These values are readily available, there is no need to recall them under the pressure of examination.

Section A overview

Section A has 15 MCQs from modules 1, 2, 4 and 6.

Space is provided on the question paper for any analysis or jottings. It is important for candidates to insert each correct response in the square box provided.

All questions showed a positive discrimination, and the less able candidates could access the easier questions. MCQs require careful inspection. A good strategy for making the questions accessible would be underline or circling key information. No detailed calculations are expected on the pages, so any shortcuts, or intuitiveness, can be employed to get to the correct answers.

Questions **1**, **2** and **6** proved to be particularly straightforward, allowing most of the candidates to demonstrate their knowledge and understanding of physics. The performance is questions **10** (circular motion of a charged particle in a uniform magnetic field) and **11** (percentage uncertainties) was far better than expected from candidates of all abilities. At the opposite end of the spectrum, questions **3**, **4**, **9** and **11**, were accessible by the top-end candidates.

Question 1

1 Which electrical quantity has S.I. units ampere-second (As)?

A charge

B current

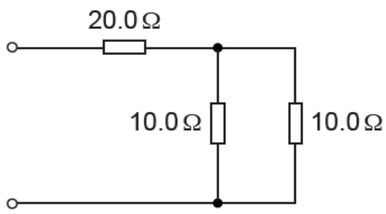
C resistance

D potential difference

Your answer [ ] **[1]**

Question 2

2 Three resistors are connected in a circuit.



The resistance of each resistor is shown in the circuit diagram.

What is the total resistance of this circuit?

A 10.0 Ω

B 20.2 Ω

C 25.0 Ω

D 40.0 Ω

Your answer [ ] **[1]**

This was a well-answered question with most candidates demonstrating excellent knowledge of resistors in series and parallel combination. On many scripts, there was hardly any working shown. The two 10.0 Ω resistors in parallel gave a combined resistance of 5.0 Ω. This added to the series resistor of 20.0 Ω gives the correct answer of 25.0 Ω. The most popular distractor was **D** – where all the resistance values were simply added together.

Question 3

3 An electron has a de Broglie wavelength equal to the wavelength of X-rays.

What is the **best** estimate of the momentum of this electron?

A $10^{-30}\,\text{kg m s}^{-1}$

B $10^{-27}\,\text{kg m s}^{-1}$

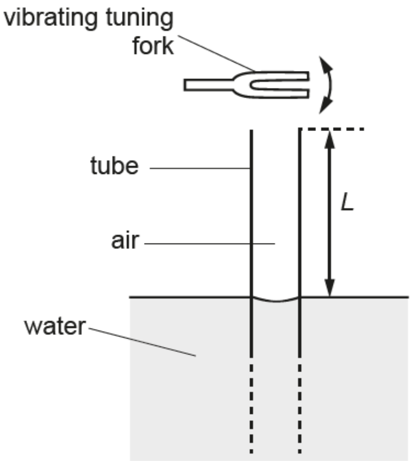
C $10^{-23}\,\text{kg m s}^{-1}$

D $10^{-18}\,\text{kg m s}^{-1}$

Your answer ☐ **[1]**

Question 4

4 A vibrating tuning fork is held above the open end of a long vertical tube. The other end of the tube, which is also open, is immersed in a tank of water. The length *L* of the air column within the tube is changed by raising or lowering the tube.



The wavelength of sound from the vibrating tuning fork is 150.0 cm.

What length *L* of air column will **not** produce a stationary wave within the tube?

A 37.5 cm

B 75.0 cm

C 112.5 cm

D 187.5 cm

Your answer ☐ **[1]**

Question 6

6 Which is the **best** value for the elementary charge *e* in terms of both accuracy and precision?

A $(1.5 \pm 0.5) \times 10^{-19}$ C

B $(1.5 \pm 0.4) \times 10^{-19}$ C

C $(1.7 \pm 0.2) \times 10^{-19}$ C

D $(1.8 \pm 0.2) \times 10^{-19}$ C

Your answer ☐ **[1]**

There was an erratum issues for this question. The term *precision* was replaced with *uncertainty*. The performance of the candidates was as expected with most opting for the correct answer **C**. A very small number of candidates opted for **D** because this value had the smallest **percentage uncertainty**.

Please note an erratum notice was issued for this question. You can view this at the end of the report.

Question 7

7 A small loudspeaker emits sound uniformly in all directions.
The amplitude of the sound is 12 μm at a distance of 1.5 m from the loudspeaker.

What is the amplitude of the sound at a distance of 4.5 m from the loudspeaker?

A 1.3 μm

B 4.0 μm

C 6.9 μm

D 12 μm

Your answer **[1]**

The emission of sound '*uniformly in all direction*' was the clue that the intensity of the wave followed an inverse square law relationship with distance from the source. The intensity is also directly proportional to amplitude^2. This meant that amplitude of the wave is inversely proportional to the distance from the source. The correct answer (key) for this question is **B**. The most popular distractor was **C**, where 12 μm was divided by √3.

Exemplar 1

A 1.3 μm

B 4.0 μm

C 6.9 μm

D 12 μm

$A = 12 \times 10^{-6}$ m

$I \propto \left(\frac{1}{r^2}\right)$

$I \propto A^2$

$A \propto \left(\frac{1}{r}\right)$

Your answer ~~A~~ B **[1]**

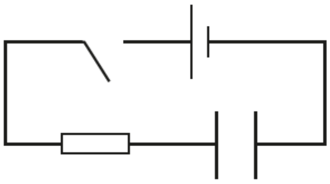
This exemplar illustrates the sensible strategy from a top-end candidate.

The key ideas are jotted down and analysis completed: $I \propto 1/r^2$ and $I \propto A^2$, therefore $A \propto 1/r$.

The distance r increases by a factor of 3, therefore the amplitude will decrease by a factor of 3. This makes the answer 4.0 μm. The final sum being done either in the head or calculator – this is of little significance. What is important here is that all the important ideas have been extracted competently from the question. A commendable technique.

Question 9

9 A capacitor is charged through a resistor.



The cell has e.m.f. 1.50 V and negligible internal resistance.
The capacitor is initially uncharged. The time constant of the circuit is 100 s.
The switch is closed at time $t = 0$.

What is the potential difference across the capacitor at time $t = 200$ s?

A 0.20 V

B 0.55 V

C 0.95 V

D 1.30 V

Your answer ☐ **[1]**

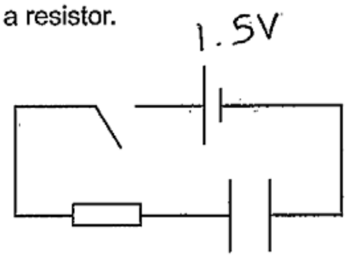
This question provided good discrimination with most to-end candidates scoring 1 mark for the correct answer **D**. Extracting all the information was the prerequisite for success. The potential difference across the capacitor is required. This could either be done by calculating the potential difference across the resistor (0.20 V), and then subtracting this from the e.m.f. of 1.50 V, or in one step using the equation

$$V = V_0(1 - e^{-t/CR}).$$

It is worth pointing out the answer 0.20 V proved to be the most popular distractor for low-scoring candidates.

Exemplar 2

9 A capacitor is charged through a resistor.



The cell has e.m.f. 1.50 V and negligible internal resistance.
The capacitor is initially uncharged. The time constant of the circuit is 100 s.
The switch is closed at time $t = 0$.

What is the potential difference across the capacitor at time $t = 200$ s?

A 0.20 V

B 0.55 V

C 0.95 V

D 1.30 V

$v = V_0(1 - e^{-t/CR})$

$v = 1.5(1 - e^{-\cancel{100}\,200/100})$

$= 1.296$

Your answer $\boxed{D}$ ✓ **[1]**

This exemplar illustrates the effortless strategy adopted by this A-grade candidate.

The circuit diagram has been annotated with the e.m.f. of 1.50 V, and the time constant *CR* of 100 s has been underlined. The correct equation has been used to get 1.30 V.

Compare and contrast this answer with the exemplar 3 below from a C-grade candidate.

Exemplar 3

A 0.20 V

B 0.55 V

C 0.95 V

D 1.30 V

$CR = 100s$

$V_0 = 1.5$

$V = 1.5e^{-\frac{200}{100}}$

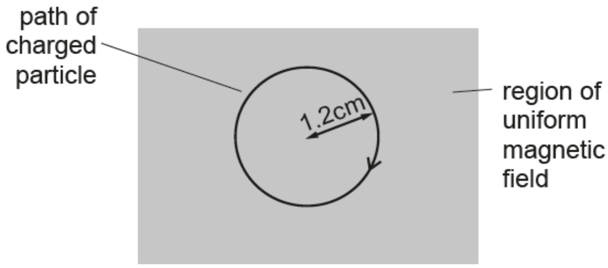
$= 0.2V$

Your answer $\boxed{A}$ ✗ **[1]**

The answer calculated here of 0.2 V, is the potential difference across the resistor and not the capacitor. This candidate was one step away from getting the correct answer – this value just had to be subtracted from the e.m.f. of 1.50 V. Deciphering the question is vital, as is the analysis that follows.

Question 10

10 A charged particle moves in a circular path of radius 1.2 cm in a uniform magnetic field.



The direction of the magnetic field is perpendicular to the plane of the paper.

The particle has mass m, charge $+Q$ and speed v.

Another particle of mass $3m$, charge $+2Q$ and speed v moves in a circular path of radius R in the same magnetic field.

What is the value of R?

A 0.8 cm

B 1.2 cm

C 1.8 cm

D 7.2 cm

Your answer ☐ **[1]**

Question 11

11 The acoustic impedance Z of a material in the shape of a cube can be determined using the equation

$$Z = \frac{Mc}{L^3}$$

where M is the mass of the material, L is the length of each side of the cube and c is the speed of ultrasound in the material.

The percentage uncertainty in L is 1.2% and the percentage uncertainty in c is 1.8%. The percentage uncertainty in M is negligible.

What is the percentage uncertainty in Z?

A 2.2%

B 3.0%

C 4.2%

D 5.4%

Your answer ☐ **[1]**

Question 15

15 A contrast material is used while taking an X-ray image of a patient.

Which statement is correct?

A Iodine is a contrast material.

B Technetium is a contrast material.

C A contrast material must have a short half-life.

D A contrast material is used for acoustic matching.

Your answer ☐ **[1]**

The majority of the candidates did get the correct answer **A**. A significant number of candidates opted for **C**, confusing contrast material with medical tracers.

Section B

Question 16(a)

16 (a) Derive the S.I. base units for resistance.

base units: .... **[2]**

This was a challenging question, which provided the ideal opportunity for top-end candidates to use a variety of methods to get the correct S.I. base units of kg m^2 A^{-2} s^{-3} for resistance. A significant number of candidates secured 1 mark for a partial answer with either charge $\rightarrow$ A s, or energy $\rightarrow$ kg m^2 s^{-2}. The rules for exponents were a bit perplexing for the low-scoring candidates. Many also misunderstood S.I. units.

Exemplar 4

16 (a) Derive the S.I. base units for resistance.

$V = IR \quad R = \frac{V}{I}. \qquad V = \frac{W}{Q} = \frac{F \times d}{I \times t} = \frac{mad}{It}$

$= \frac{kg\,m\,s^{-2} \times m}{A\,s}$

$R = \frac{kg\,m^2 s^{-2}}{A\,s} \div A$

$R = kg\,m^2 A^{-2} s^{-3}$

base units: $kg\,m^2 A^{-2} s^{-3}$ **[2]**

This exemplar illustrates a flawless answer from a top-end candidate.

The equations are clear to see and follow. The units of each physical quantities are clearly identified and the appropriate S.I. units for the quantities have been successfully manipulated to give the correct answer.

Compare this with the exemplar below which illustrates a common misconception.

Exemplar 5

$\rho = \frac{m}{V}$

$R = \frac{\rho L}{A} = \cancel{kg\,m^{-3}} \frac{\left(\frac{m}{V}\right) L}{A}$

$R = \frac{kg\,m^{-3}\,m}{m^2} = kg\,m^{-5}\,m = kg\,m^{-4}$

base units: ......$kg\,m^{-4}$...... **[2]**

This exemplar illustrates a common error made by some candidates across the ability spectrum.

?

The resistivity ρ in the equation for resistance has been mistaken for density (which unfortunately has the same label). There can be no credit for wrong physics. It is vital to know your equations.

Key:

? **Misconception**

Question 16(b)(i)

(b) Fig. 16.1 shows the I-V characteristics of two electrical components **L** and **R**.

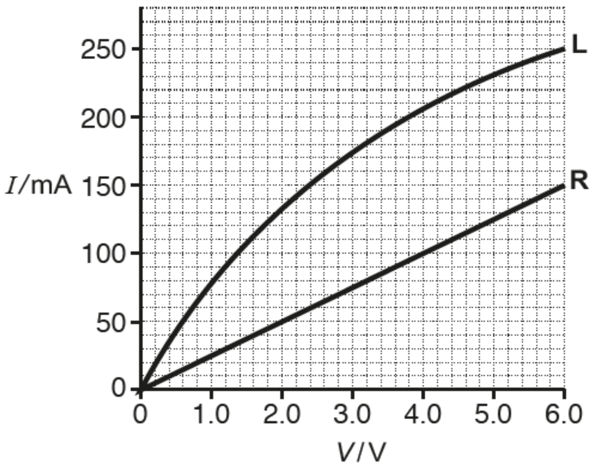


Fig. 16.1

The component **L** is a filament lamp and the component **R** is a resistor.

(i) Show that the resistance of **R** is 40 Ω.

[1]

The majority of the candidates scored 1 mark here for clearly using the graph to show the resistance of **R** to be 40 Ω. Most used a data point from the straight line. A significant number also used the idea that the gradient of the straight line is equal to the inverse of the resistance. However, candidates are reminded that resistance is equal potential difference divided by current, but in this context of a straight line through the origin, determining resistance from the gradient was allowed. Of course, determining the gradient of a curve is simply incorrect physics for determining resistance.

Question 16(b)(ii)(1)

(ii) Fig. 16.2 shows the components **L** and **R** connected in series to a battery of e.m.f. 6.0 V.

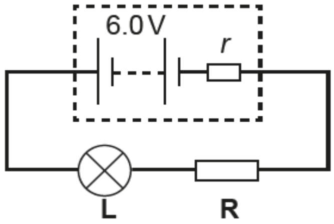


Fig. 16.2

The resistor **R** is a cylindrical rod of length 8.0 mm and cross-sectional area $2.4 \times 10^{-6}\,m^2$.
The current in the circuit is 100 mA.

1 Use Fig. 16.1 to determine the internal resistance *r* of the battery.

r = ... Ω **[3]**

This was a discriminating question with many of the top-end candidates effortless getting the correct answer of 6.0 Ω for the internal resistance *r*. The most common error was omitting the resistance of the filament lamp in the calculation. This gave an incorrect value of 20 Ω for the internal resistance. Candidates doing this still managed to pick up 1 mark for the total resistance of 60 Ω.

Question 16(b)(ii)(3)

3 There are 6.5×10^{17} charge carriers within the volume of **R**.

Calculate the mean drift velocity *v* of the charge carriers within the resistor **R**.

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

Turn over

The success in this question depended on understanding the term *n* in the equation *I* = *Anev* given in the Data, Formulae and Relationship booklet. A significant number of candidates took *n* to be the total number of charge carriers within the volume of **R**, instead of the number of charge carriers per unit volume (number density). Those who appreciated this had no problems coping with prefixes and powers of ten. The correct answer was 7.7×10^{-3} m s^{-1}.

Using 6.5×10^{17} for the number density, gave an answer of 4.0×10^{5} m s^{-1}; examiners credited 1 mark for this incorrect answer, mainly for the manipulating and using the equation *I* = *Anev*.

Exemplar 6

$I = Anev$

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

$$V = \frac{0.1}{2.4\times10^{-6} \times \frac{6.5\times10^{17}}{2.4\times10^{-6}\times8\times10^{-3}} \times 1.6\times10^{-19}} = \frac{1}{130}$$

v = 7.7×10^{-3} m s^{-1} **[3]**

This exemplar illustrates a perfect answer from a C-grade candidate.

The equation has been rearranged correctly and the substitution is all correct and easy to follow. The number density *n* has not been calculated separately – it forms an integral part of the whole calculation. The one big benefit of this is that you do not end up with rounding errors. A decent technique demonstrated here. All correct for 3 marks.

Question 17*

17* A metal circular plate is rotated at a constant frequency by an electric motor.
The plate has a small hole close to its rim.
Fig. 17.1 shows an arrangement used by a student to determine the frequency of the rotating plate.

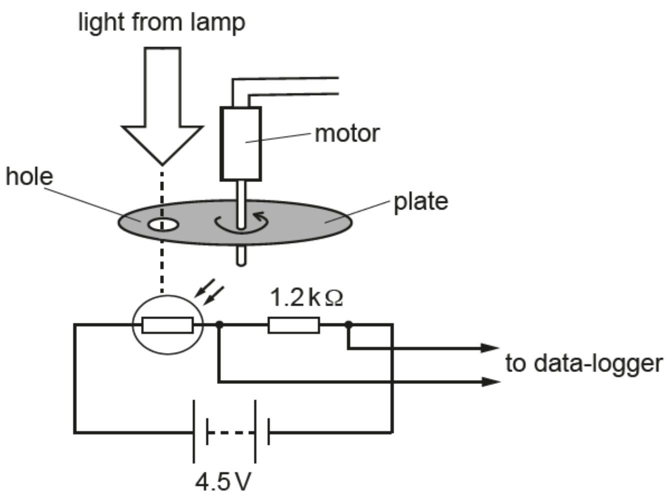


Fig. 17.1

A light-dependent resistor (LDR) and a fixed resistor of resistance 1.2 kΩ are connected in series to a battery. The battery has e.m.f. 4.5 V and has negligible internal resistance. The potential difference *V* across the resistor is monitored using a data-logger.

Fig. 17.2 shows the variation of *V* with time *t*.

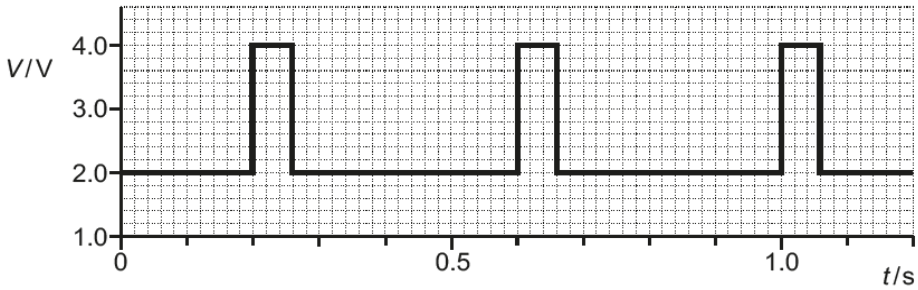


Fig. 17.2

Use your knowledge and understanding of potential divider circuits to explain the shape of the graph shown in Fig. 17.2. Include in your answer the maximum and minimum values of the resistance of the LDR.
Describe how the student can determine the frequency of the rotating plate.

....

....

....

.... **[6]**

This was one of the two LoR questions. It required understanding of potential dividers, light-dependent resistor and rotation frequency of a spinning plate.

Examiners expect varied responses, and two very dissimilar answers can score comparable marks as long as the criteria set out in the answers' section of the marking scheme are met. Level 3 answers had the correct maximum and minimum resistance values of the LDR, a decent description and explanation of the trace shown in Fig. 17.2, and an outline of how the frequency of the spinning plate was determined. As mentioned earlier, eclectic answers are inevitable – verbose and concise answers can be at Level 3.

In Level 2 answers there were generally missed opportunities. Half-done calculation and descriptions either with some errors or lacking in depth. Level 1 answers had some elements of calculations or descriptions.

The two exemplars below, illustrate a Level 3 response and a Level 1 response.

Exemplar 7

When the hole in the metal plate is directly above the LDR, light strikes the LDR. This causes the resistance on the LDR to decrease. This means that the total resistance of the circuit decreases, so the current flowing in the circuit increases. As the resistance of the fixed resistor is constant and current increases, the p.d. across it (V) must increase by $V = IR$. This can also be shown using the potential divider equation: $V_{out} = \frac{R_2}{R_1 + R_2} \times V_{in}$, where V_{out} is the p.d. across the fixed resistor (V). We can rearrange this equation to find the resistance of the LDR both when light is and isn't shining on it. For when light isn't shining on it: $(2.0) = \frac{(1.2 \times 10^3)}{R_{max} + (1.2 \times 10^3)} \times (4.5) \Rightarrow R_{MAX} = 1500\,\Omega$

For when light is shining on it: $(4.0) = \frac{(1.2 \times 10^3)}{R_{MIN} + (1.2 \times 10^3)} \times (4.5)$, $R_{MIN} = 150\,\Omega$

The frequency can be found by first finding the period, T. This is the time taken for the voltage p.d. (V) to return to the same value. This is $T = 0.4\,s$. Finding the inverse of this will give the frequency $f = 1/T = \frac{1}{0.4} = 2.5\,Hz$.

L3

This is a Level 3 response from a top-end candidate who scored 6 marks.

The description of the variation of the resistance of the LDR, the circuit current and the potential difference across the fixed resistor is perfect. The calculations of the LDR resistances are nicely embedded into the general explanation. The calculation of the frequency is all correct. This is a model answer for 6 marks.

Compare and contrast this with the Level 1 response below.

Exemplar 8

When the light shines through the hole onto the LDR, the resistance decreases, causing the pd across the fixed resistor to increase, and vice versa when the ~~lamp is taken away~~ light is blocked again.

Determine the frequency by seeing how long the plate takes to rotate, so from pd increase to pd increase, 0.4 seconds

frequency $= \frac{1}{T}$

frequency $= 2.5$

L1

This is a Level 1 response from an E-grade candidate.

The description of the variation of the resistance of the LDR is correct. However, there are no calculations of the resistance of the LDR, as required in the question. Hence, a significant part of the question has been omitted. According to the marking criteria, this could only score Level 1. The examiner credited 2 marks for this response.

Question 18(a)

18 A narrow beam of unpolarised light is incident at the boundary between air and glass.

Fig. 18 shows the incident ray, the reflected ray and the refracted ray at the air-glass boundary.

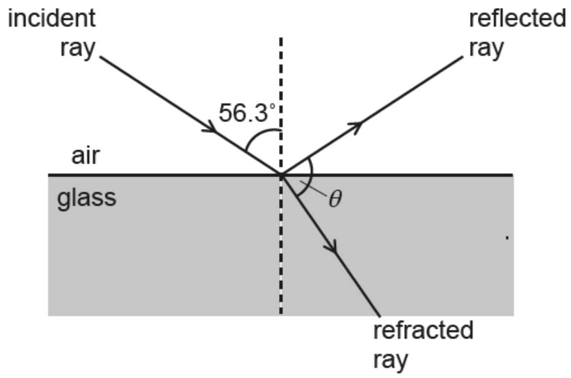


Fig. 18 (not to scale)

The refractive index of air is 1.00 and the refractive index of the glass is 1.50.
The angle of incidence of the light is 56.3°.

(a) Show that the angle θ between the refracted ray in the glass and the reflected ray in the air is 90.0°.

[3]

Generally, candidates answered this question well with most making a good start with the equation $n\sin\theta$ = constant. Most candidates correctly calculated the angle of refraction to be 33.7°; only a small proportion lost marks because of rounding errors. The final mark was reserved for steps clearly showing that the angle θ marked on the figure was equal to 90.0°. A pleasing number of candidates annotated the figure with angles and labels in order to ensure this last mark was picked up.

A very small number of candidates attempted to either use $\sin C = 1/n$ or omitted $n\sin\theta$ = constant altogether.

(b) Describe how you can demonstrate in the laboratory that the reflected light is plane polarised.

....

....

.... **[2]**

Question 18(b)

Most candidates scored well deserved 2 marks here for opting to use a polarising filter and rotating it to see variation in the intensity of the transmitted light. A small number of candidates chose the wrong equipment – the most common of these were diffraction grating, a single slit and microwave receiver.

Question 19(a)

19 **(a)** Fig. 19.1 shows the image from an experiment using a ripple tank.

Item removed due to third party copyright restrictions

Fig. 19.1

A straight ruler repeatedly hits the surface of water. Waves on the surface of the water travel in the direction shown by the two large upward white arrows. The waves are incident at a solid barrier.

Closely examine the image shown in Fig. 19.1.

State **two** wave phenomena (properties) that can be observed in this image. You may annotate Fig. 19.1 to support your answer.

....

....

.... **[2]**

Most candidates scored two marks for identifying any two from diffraction, superposition (or interference) and reflection. A few answers were spoilt by mentioning either *refraction* or *total internal reflection*.

Question 19(b)

(b) Two transmitters, **A** and **B**, emit coherent microwaves in all directions. A receiver is moved at constant speed along the line from **P** to **Q** which is parallel to the line joining the two transmitters, as shown in Fig. 19.2.

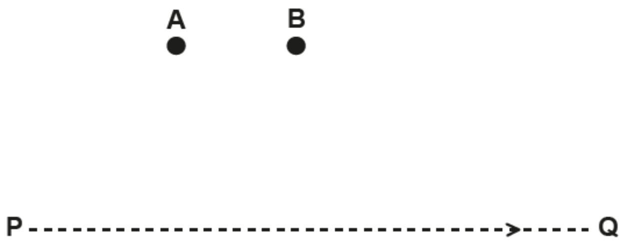


Fig. 19.2

Explain why the output signal from the receiver fluctuates between minimum and maximum values as the receiver moves from **P** to **Q**.

.... **[3]**

Many candidates made a start by defining coherence, this was not necessary. Most candidates realised that the maximum and minimum signals were linked to superposition, or interference, of the waves from **A** and **B**. The majority of the candidates equated *coherence* with '*in phase'* and gave explanations in terms of **path** difference instead of **phase** difference. Constructive interference could not be linked to an integer number of wavelengths but it could be linked to the waves being **in phase**. Similarly, for destructive interference, the apt explanation was that the waves are in **anti-phase** at points of minimum signal. Specific values of phase differences were allowed. For anti-phase, '**completely** out of phase' was allowed.

?

Some of the common misconceptions were:

- The maximum and minima signals were related to antinodes and nodes
- The variation in the signal was due to Doppler effect

Question 20(a)(i)

20 **(a)** An approximate value of the Planck constant h can be determined in the laboratory using light-emitting diodes (LEDs). An LED suddenly starts to conduct and emit monochromatic light when the potential difference across an LED exceeds a minimum value V_0.
The potential difference V_0 and the wavelength λ of the emitted light are related by the equation

$$V_0 = \left(\frac{hc}{e}\right) \times \frac{1}{\lambda}$$

where e is the elementary charge and c is the speed of light in a vacuum.

Fig. 20.1 shows some data points plotted by a student on a V_0 against $\frac{1}{\lambda}$ graph for five different LEDs.

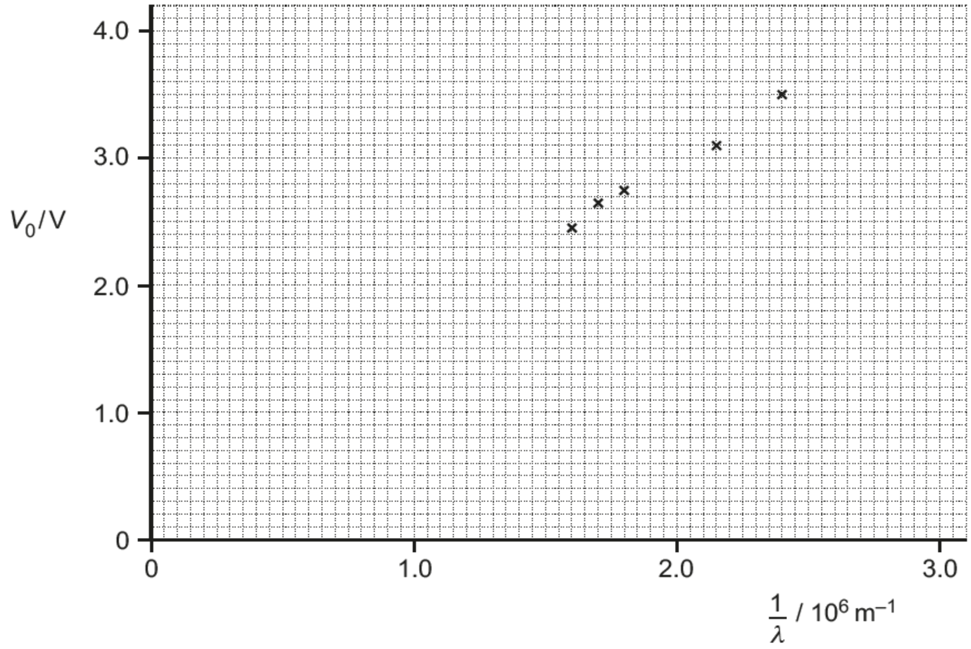


Fig. 20.1

The potential difference across each LED was measured using a digital voltmeter with divisions ±0.01 V. The values for the wavelengths are accurate and were provided by the manufacturer of the LEDs.

The value of V_0 was determined by directly observing the state of the LED in the **brightly** lit laboratory.

(i) Draw the straight line of best fit on Fig 20.1 and determine the gradient of the line.

gradient = ... V m **[2]**

Most candidates scored either 1 or 2 marks. The straight lines of best fit were generally well drawn. A significant number of the candidates forced their lines to go through the origin. The tolerance for the value of the gradient was deliberately made large. The ultimate penalty was the power of ten. Very few made two errors here – straight line through the origin and missing 10^{-6} factor.

Question 20(a)(ii)

(ii) Use your answer in **(i)** and the equation on page 20 to determine a value for *h* to 2 significant figures. Show your working.

h = ... J s **[3]**

This was not an easy question, but a good number of candidates did exceptionally well on this practical-style question. The first mark was for correctly identifying 'gradient = *hc*/*e*', and subsequent marks were for correct substitution and writing the final to 2 significant figures (SF). A significant number of candidates quoted their correct *h* value to more than the required SF. Many candidates were scoring full marks through the error carried forward rule.

Exemplar 9

$\frac{dy}{dx} = \frac{4.0}{\frac{1}{2.7} \times 1 \times 10^6}$

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gradient = 1.08×10^{-5} V m **[2]**

(ii) Use your answer in **(i)** and the equation on page 20 to determine a value for *h* to 2 significant figures. Show your working.

$v_0 = \left(\frac{hc}{e}\right) \times \frac{1}{\lambda}$

$v_0 \lambda e = hc$

$\frac{v_0 \lambda e}{c} = h$

$\cancel{\frac{4 \times 2.7 \times 10^6 \times 1.6 \times 10^{-19}}{3 \times 10^8}} = h$

$\cancel{h = 5.76 \times 10^{-21}}$

$\cancel{1.08 \times 10^6} = \frac{hc}{e}$

ECF

$\frac{1.08 \times 10^{-5} \times 1.6 \times 10^{-19}}{3 \times 10^8}$

h = 5.8×10^{-33} J s **[3]**

This exemplar illustrates how full marks can always be scored from error carried forward (ECF) rule.

The gradient of 1.08 × 10^{-5} was well outside the range allowed. This had already been penalised in the earlier part **20(b)(i)**. This erroneous value has been used correctly in this section. The answer is nowhere close to the Planck constant, but this is irrelevant – the physics has been applied correctly here, the answer is correctly written with 2 SF, so well deserved 3 marks for this E-grade candidate.

Question 20(a)(iii)

(iii) Calculate the percentage difference between your value in **(ii)** and the accepted value of the Planck constant.

difference = ... % **[1]**

Question 20(a)(iv)

(iv) Identify the two types of errors shown by the data in Fig. 20.1 and suggest how you could have refined the experiment to reduce or eliminate these errors.

....

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....

.... **[4]**

The two errors in this experiment were *systematic* and *random* errors (see learning outcome 2.2.1a in the H556 specification). Many candidates did not name these two errors, instead focussing on nebulous terms such as *human error*, *equipment error*, etc. Appropriate descriptions of these two errors were allowed. Only a small number of candidates appreciated that taking multiple readings of V_0 and averaging will lead to reduction in the random error. A pleasing number of candidates realised that the main reason for the non-zero intercept (systematic error) was the ambient light and switching off the lights would improve matters. Sorting out the zero-error on the voltmeter was an acceptable alternative.

Descriptions about using ‘precise instruments’ for measuring potential difference or light intensity often led to no credit.

Question 20(b)

(b) Fig. 20.2 shows a gold-leaf electroscope with a clean zinc plate.

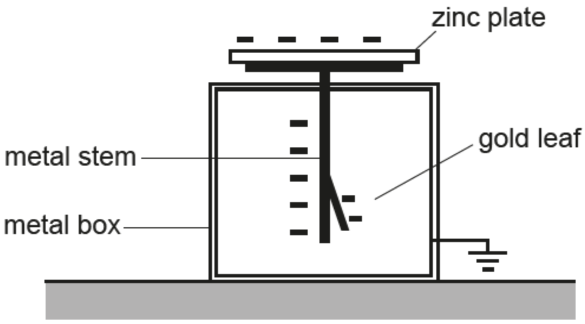

Fig. 20.2

The zinc plate, metal stem and the gold-leaf are given a negative charge by briefly connecting the zinc plate to the negative electrode of a high-voltage supply.

The gold leaf is fully diverged.

The position of the leaf is not affected by intense white light from a table lamp incident on the zinc plate. The gold leaf collapses very quickly when low-intensity ultraviolet radiation from a mercury lamp is incident on the zinc plate.

Explain these observations in terms of photons.

....

....

....

....

.... **[4]**

This question on the photoelectric effect was enthusiastically answered by candidates. Good discrimination enabled many of the top-end candidates to score full marks. The question was scrutinised well with many candidates explaining why the leaf fell with the ultraviolet radiation. The one-to-one interaction between UV photons and surface electrons was nicely embedded in the descriptions. Some of the candidates would have benefitted by writing their answers in bullet points.

?

There were a few missed opportunities and misconceptions, these are outlined below:

- Photons were emitted from the zinc plate (rather than electrons)
- Threshold frequency and work function were properties of the photons or electrons (and not zinc)
- Threshold frequency and work function were synonymous
- Intensity was linked to number of photons (rather than to the **rate** of photons)
- Referring to '*not enough energy*' instead of work function of the metal in the description

Question 21(a)(i)

21 Fig. 21.1 shows a coil of a simple generator rotating in a uniform magnetic field.

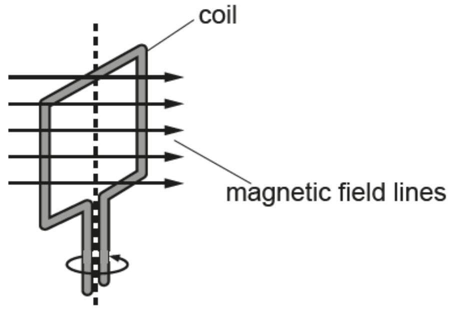

Fig. 21.1

The coil has 85 turns of insulated wire. The cross-sectional area of the coil is $14\,\text{cm}^2$.
Fig. 21.2 shows the variation of magnetic flux density B through the plane of the coil with time t as it rotates.

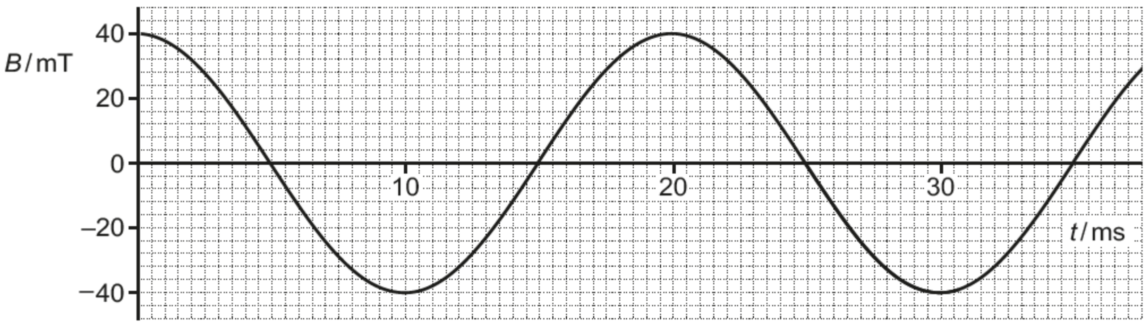

Fig. 21.2

(a) (i) Explain why the electromotive force (e.m.f.) induced across the ends of the coil is a **maximum** at the times when $B = 0$.

....

....

.... **[1]**

Although worth just 1 mark, this question did provide good opportunity for top-end candidates to pick up one mark. Many candidates quoted Faraday's law of electromagnetic induction, without mentioning that the **rate** of change of flux (linkage) was **maximum** at $B = 0$. Low-scoring candidates wrote about the orientation of the coil relative to the magnetic field or the '*cutting'* of field lines. None of the explanations led to any marks being credited.

Question 21(a)(ii)

(ii) Draw a tangent to the curve in Fig. 21.2 when *B* = 0, and hence determine the **maximum** e.m.f. induced across the ends of the coil.

maximum e.m.f. = ... V **[3]**

Most candidates followed the question and drew decent tangents on Fig. 21.2. Most of the tangents were acceptable, but a few either crossed the curve or had very thick pencil lines. A significant number of candidates quoted the maximum e.m.f. to be equal to the magnitude of the gradient of the tangent. Top-end candidates faced no obstacles here; the gradient was multiplied by [$85 \times 14 \times 10^{-4}$] to give an answer around 1.5 V. Once again, a good number of candidates were picking the odd mark through error carried. Converting the cross-sectional area of 14 cm^2 into 14×10^{-4} m^2 was a challenge for some of the candidates in the middle and lower quartiles.

Question 21(b)

(b) Fig. 21.3 shows the variation of the e.m.f. induced across the ends of the coil with time *t*.

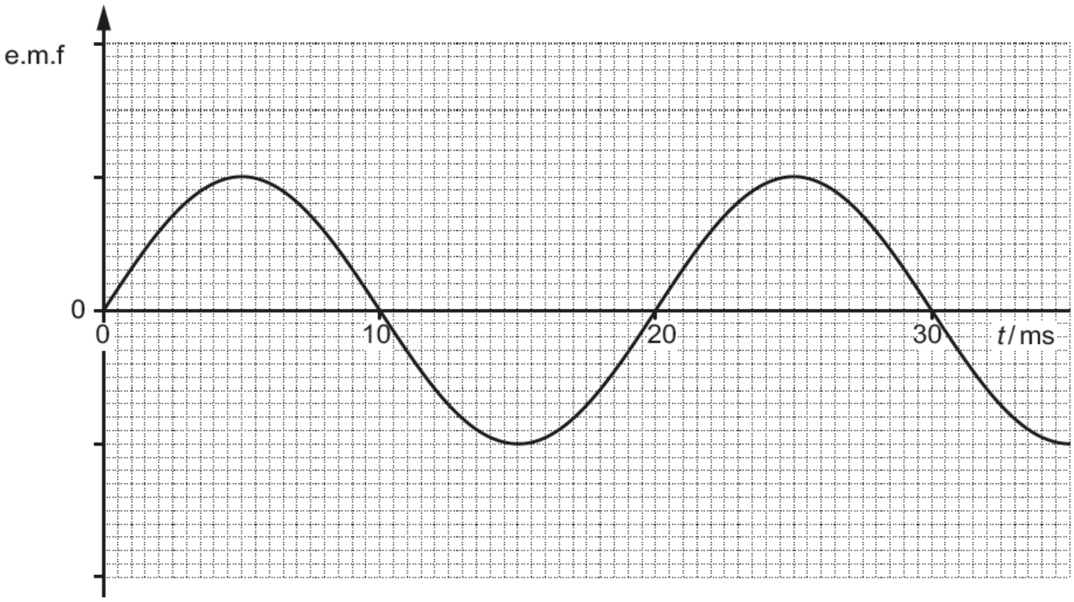

Fig. 21.3

The magnitude of the magnetic flux density of the uniform field is now halved and the coil is rotated at twice its previous frequency.

On Fig. 21.3 sketch the new variation of the e.m.f. induced with time *t*. **[2]**

Most candidates scored a mark for showing that the period of the new e.m.f. trace was halved. Only a small proportional had the peak e.m.f. unchanged; the most frequent incorrect trace showed the peak e.m.f. also being halved. The sinusoidal curves were generally well-sketched.

Question 22(a)

22 A student wishes to determine the permittivity ε of paper using a capacitor made in the laboratory.

The capacitor consists of two large parallel aluminium plates separated by a very thin sheet of paper.

The capacitor is initially charged to a potential difference V_0 using a battery. The capacitor is then discharged through a fixed resistor of resistance 1.0 MΩ.

The potential difference V across the capacitor after a time t is recorded by a data-logger. The student uses the data to draw the ln$V$ against t graph shown in Fig. 22.

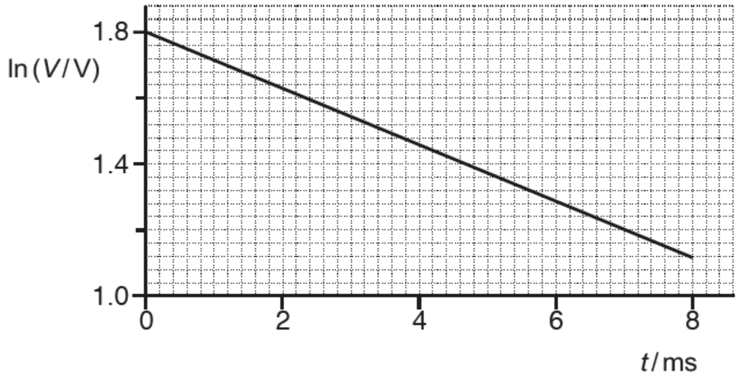

Fig. 22

(a) Show that the magnitude of the gradient of the line shown in Fig. 22 is equal to

$$\frac{1}{CR}$$

where C is the capacitance of the capacitor and R is the resistance of the resistor.

[2]

This question was successfully tackled by the high-scoring candidates, many of whom effortlessly derived the correct expression ln$V$ = lnV_0 – t/CR and demonstrated clearly how the equation of a straight line made the gradient equal to -1/CR.

?

The most common errors made by candidates were:

- Using the wrong expression $V = V_0(1 - e^{-t/CR})$
- Writing the equation as ln(V/V_0) = -t/CR and comparing this with $y = mx$, with y = ln(V/V_0) and $x = t$.
- Calculating the gradient of the line to be about -85; which proved to be helpful in the LoR question **22(b)**.

Question 22(b)*

(b)* Use Fig. 22 to determine the capacitance *C* of the capacitor. Describe how the student can then use this value of *C* to determine a value for ε.
In your description, mention any additional measurements required on the capacitor.

....

....

....

.... **[6]**

This was the second of the two LoR questions in this paper. It required application of practical skills from module 1.1 (Development of practical skills), knowledge of parallel plate capacitor and permittivity.

As with the other LoR question 17, examiners expect varied responses for the criteria for the three levels to be met. Unlike some of the analytical questions, there is no one perfect model answer for a specific question. For Level 3, correct value of the capacitance *C* was required together with a clear description of how to do the additional measurements that led to the determination of the permittivity of the paper. For Level 2, it was either clear description with some correct working or some description with the correct value for *C.* Level 1 required some description or some working.

As expected, there were diverse answers which demonstrated adequate experimental and practical skills. The thickness of the paper was invariably measured using a micrometer, but some candidates decided to measure the total thickness of a large number of sheets using a ruler and then calculating the thickness of each sheet. This technique was as good as using a micrometer or using Vernier calipers. Diverse answers are the characteristic of LoR questions.

?

The most common errors made were:

- Confusing permittivity with either relative permittivity or the permittivity of free space ε_0.
- Using $C = 4\pi\varepsilon R$ instead of $C = \varepsilon A/d$.
- Issues with powers of ten when determining the gradient – mainly because of the milli prefix on the time axis.

Exemplar 10

$$\frac{dy}{dx} = \frac{0.68}{8\times10^{-3}} = 85$$

$$85 = \frac{1}{CR}$$

$R = 1\times10^{6}$

$$CR = \frac{1}{85} \qquad C = \frac{1}{85(1\times10^{6})}$$

$= 1.18\times10^{-8}$ F

$$C = \frac{\varepsilon A}{d}$$

- would also need the area of the plates (A) on the capacitor and the separation between them (d)
- can then rearrange equation to give $\frac{Cd}{A} = \varepsilon$
- can use to figure out ε.

L2

This exemplar illustrates a Level 2 performance from this top-end candidate.

The analysis is perfect, but the description is basic and there are no details of the instruments needed to make the measurement. It would have taken a couple more lines to elevate this answer to Level 3.

Compare and contrast this with the exemplar below for a Level 3 response.

Exemplar 11

$|\mathrm{\ln}(V)| = 0.68$

$|\Delta t| = 8 \times 10^{-3}\ s$

$|m| = \frac{1}{CR} = \frac{0.68}{8 \times 10^{-3}}$

$= 85$

$85 = \frac{1}{C(10^6)}$

$C^{-1} = 8.5 \times 10^7$

$C = 1.176... \times 10^{-8}\ F$

$\approx \underline{12 nF}$

Via the equation $C = \frac{\varepsilon A}{d}$, to deduce ε, all the student must do is measure d (thickness of the paper) and A ~~Area~~ (Area of paper between ~~the~~ aluminium plates) to give $\underline{\frac{Cd}{A} = \varepsilon}$

To measure d, take 50 of the sheets of paper used and stack them ontop of eachother, using a micrometer screw gauge or a vernier caliper, measure this distance (ensuring not to crumple the paper) and divide by 50 for the d value.

To calculate A, simply measure the width and height of both of the aluminium plates with a ruler (if small enough use a vernier caliper). Taking an average of height and width, multiply these together for the A value. Then $\varepsilon = \frac{Cd}{A}$ gives the permitivity of paper **[6]**

18 Turn over

L3

This above is a typical Level 3 answer. Correct calculation and a description that has all the right ingredients. Notice how the appropriate measuring instruments are being used and how the uncertainty in the measurements is reduced.

Question 23(a)

23 (a) The structure of atoms was deduced in the early 1900s by Rutherford and his co-workers from the scattering of alpha-particles by a very thin sheet of gold.

Rutherford assumed that the scattering of the alpha-particles was due to electrostatic forces. Fig. 23 shows a detector used to record the number *N* of alpha-particles scattered through an angle θ.

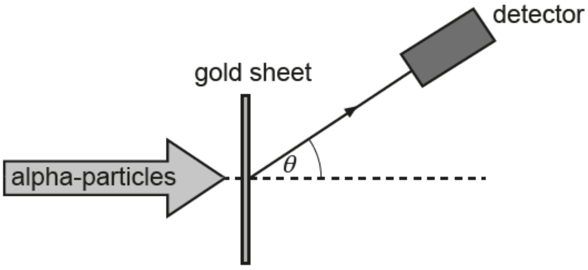

Fig. 23

At θ = 0°, *N* was too large to be measured. The table below summarises some of the collected data.

θ / °	lg (*N*)
150	1.5
75	2.3
60	2.7
30	3.9
15	5.1
0	*N* too large

Question 23(a)(ii)

(ii) Use the evidence from the table to explain the structure of the atom.

....

....

....

....

....

.... **[3]**

This question provided good discrimination. It is worth 3-marks, so the examiners were broadly looking for three key disparate points. The exemplar below, from a top-end candidate, illustrates a model answer. There is no ambiguity – full marks scored.

Exemplar 12

The majority of the alpha particles pass straight through which suggests that the majority of the atom is empty space. The fact that some ~~the~~ were scattered suggested there was a nucleus with a positive charge repelling the positive alpha particles away from it. **[3]**

It would be difficult to provide an improved answer. However, it is worth pointing out that the same ideas can also be presented in bullet-point form – three distinct points for the 3 available marks.

Question 23(b)(i)

(b) A proton with kinetic energy 0.52 MeV is travelling directly towards a stationary nucleus of cobalt-59 ($^{59}_{27}Co$) in a head-on collision.

(i) Explain what happens to the electric potential energy of the proton-nucleus system.

....

....

.... **[1]**

Question 23(b)(ii)

(ii) Calculate the **minimum** distance R between the proton and cobalt nucleus.

R = ... m **[3]**

The above question on electric potential energy provided excellent discrimination with middle and upper quartile candidates showing how to produce immaculate answers – identify the physics, write down the correct physical equation, do any necessary conversions (e.g. MeV to J), rearrange the equation, substitute correctly and then write the final answer in standard form to the correct number of significant figures. About a third of the candidates scored full marks.

?

Some of the missed opportunities or errors were:

- Using an incorrect equation with the distance squared
- Not correctly converting the kinetic energy 0.52 MeV into joule (J)
- Using the equation $r = r_0A^{1/3}$ for the mean radius of a nucleus to determine the minimum distance

Question 24(a)(ii)

(ii) the lead isotope.

$${}^{209}_{82}\text{Pb} \longrightarrow {}^{\dots\dots}_{83}\text{Bi} + {}^{0}_{-1}\text{e} + \dots\dots\dots\dots\dots\dots\dots\dots$$ **[2]**

Question 24(b)(i)

(b) A pure sample of polonium-213 is being produced in a research laboratory.

The half-life of ${}^{213}_{84}\text{Po}$ is very small compared with the half-life of ${}^{209}_{82}\text{Pb}$.

After a very short time, the ionising radiation detected from the sample is mainly from the beta-minus decay of the lead-209 nuclei.

(i) Briefly describe and explain an experiment that can be carried out to confirm the beta-minus radiation emitted from the lead nuclei.

....

....

....

.... **[2]**

This turned out to be a low-scoring question from candidates across the ability spectrum. Only a quarter of the candidates gained 2 marks for identifying aluminium as the absorber for the beta-minus radiation (electrons) and providing adequate description in terms of reduction in the count-rate. A small number of candidates opted for charged parallel plates and identified the electrons curving towards the positive plate. There were some baffling descriptions involving pointing the source at '*wires and measuring the current*'. Fluorescent screens and cloud chambers were not allowed as acceptable answers because both can be used to detect the presence of gamma-photons and alpha-particles.

Question 24(b)(ii)

(ii) The activity of the sample of ${}^{209}_{82}\text{Pb}$ after 7.0 hours is 12 kBq.

The half-life of ${}^{209}_{82}\text{Pb}$ is 3.3 hours.

Calculate the initial number of lead-209 nuclei in this sample.

number of nuclei = ... **[4]**

The question was multi-stepped calculation, requiring knowledge of radioactive decay equations, half-time and activity. The final stage of the calculation was dependent on the equation $A = \lambda N$ and working consistently in Bq for the activity and in s^{-1} for the decay constant. The number of nuclei N could not be calculated with the activity in Bq and the decay constant in either h^{-1} or min^{-1}.

About half of the candidates scored full marks. Those working with inconsistent units invariably ended up with the incorrect value 2.5×10^5 nuclei, but this still earned them 2 marks for the preceding steps.

Question 25(b)

(b) Describe how the components of a computerised axial tomography (CAT) scanner can produce high-quality images of the internal structures of a patient.

....

....

....

.... **[4]**

The majority of the candidates gave decent answers here for the CAT scanner. Answers were often very detailed and demonstrated a good understanding of the stages and the components used in the production of 3D X-rays images. Some even managed to give additional details on the absorption mechanisms. However, examiners only required simplistic answers in terms of a thin beam of rotating X-rays, which enabled cross-sectional scans (slices) of the patient and how computer software was used to generate 3D image of the patient.

A small number of candidates outlined hybrid scanners with mixture of MRI scanners, gamma camera and PET scanners. Most of descriptions here earned the mark just for '3D image'.

The omission rate for this last question was small enough for examiners to confidently say that there were no time issues with this H556/02 question paper.

Erratum notice

Turn to **page 4** of the **question paper** and look at question **6**.

In the first line, cross out 'precision' and replace with 'uncertainty'.

The question should now read:

Which is the **best** value for the elementary charge *e* in terms of both accuracy and uncertainty?

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