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# A LEVEL

*Examiners' report*

# *PHYSICS B (ADVANCING PHYSICS)*

**H557**
For first teaching in 2015

## H557/02 Summer 2018 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. 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 H557/02 series overview

Paper 2 – Scientific Literacy in Physics is a synoptic paper that includes questions on an Advance Notice article. The questions in Section A are of medium-length, usually contributing around ten marks each to the paper total. Section B comprises longer questions, including Level of Response questions. Section C is based on the Advance Notice article and can include both short and long questions.

The synoptic nature of the paper, relatively long questions and novel contexts can make this a challenging assessment. It was encouraging to see that a great proportion of the candidates completed all the questions and there was little evidence of candidates running out of time.

Generally, the more able candidates demonstrated the use of the physics of the course in the novel situations described in the questions. This is particularly evident in the Level of Response questions. All three questions required candidates to use relatively straightforward and familiar ideas in new contexts. Those candidates who scored well on the paper overall tended to gain marks in these questions by performing simple calculations relevant to the context. Less able candidates were more inclined to give simplistic or hopeful explanations which bore less resemblance to the context.

Seeing through the context of the question to the underlying physics is a skill that can be practised through past paper questions and class discussions.

***Candidate performance overview***

Candidates who performed well on this paper generally:

- Performed short calculations accurately.
- Showed clear and logical thinking in longer calculations such as questions 1 (d), 3 (a), 3 (b), 5 (b)(i) and 5 (b) (ii).
- Produced accurate and concise responses to the Level of Response questions on iterative modelling (4 (b) (ii)) and conductivity (6 (c)).
- Used clear and accurate technical vocabulary throughout the paper.

Candidate who did less well on this paper generally:

- Found unstructured calculations difficult to break down into individual steps.
- Wrote explanatory responses which did not use technical vocabulary accurately or lacked sufficient analysis of the situation. Examples of this include short explanations such as 1(a), 1 (b) and 5 (a) and longer responses including the Level of Response questions 4 (b) (ii), conductivity (6 (c) and 8.
- Did not always read the question with care and so did not address all the marking points. Responses to questions 1 (b) and 2 (d) often showed this lack of care.

## Section A overview

This 31-mark section comprises 3 short questions. Nearly all the candidates completed all the questions on this section and showed a reasonable understanding of the physics involved. Some responses showed a weaker grasp of technical vocabulary and so missed out on marks through lack of clarity. The shorter calculations proved accessible to nearly all candidates but longer, unscaffolded calculations proved to be more discriminating.

### Question 1 (a)

**1** This question is about investigating the polarisation of light.

**(a)** A student takes two polarising filters as shown in Fig. 1.1.

Unpolarised light is incident on the filter 1.

Filter 2 is initially set up to allow all the light passing through the first filter to be transmitted. The filter 2 is then rotated through 360°.

Describe and explain how the intensity of the transmitted light changes during the rotation of the second filter.

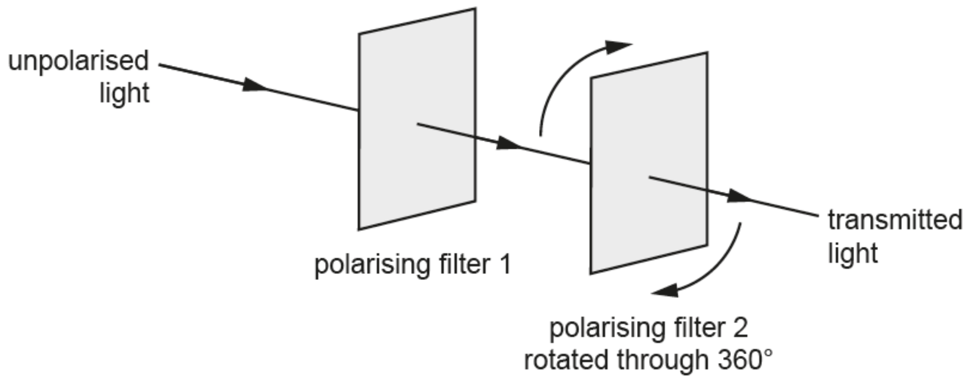


**Fig. 1.1**

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Nearly all responses showed a familiarity with the set up described in the question and gained the first mark for correctly describing the variation in intensity of transmitted light. The second marking point was more discriminating. Lower level responses did not clearly explain that the filters pass light in one plane of polarisation and so missed out on the second mark.

## Exemplar 1

Intensity will fluctuate between 0 and its max intensity value with a sin ~~sh gra~~ graph shape when plotted against time. The period would be the time for the second filter to rotate through an entire 360° rotation.
When filter 2 is at 90° to filter 1, no light gets through ∴ 0 intensity as both horizontal and vertical components are stopped. **[2]**

This explanation did not clearly explain the action of the filters, the candidate does not explain why 'horizontal and vertical components are stopped'.

## Question 1 (b)(i)

**(b)** The transmitted light strikes an LDR in the circuit shown in Fig. 1.2.

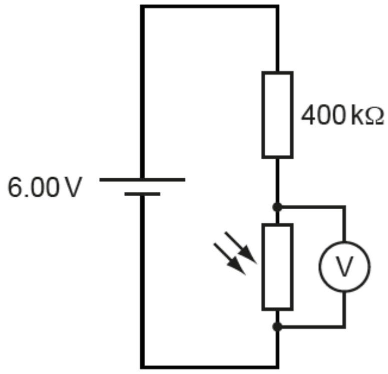


**Fig. 1.2**

**(i)** Describe and explain how the p.d. across the LDR changes as the second filter is rotated through 360° from its original orientation.

You do not need to give values for the p.d. but you should indicate the orientation of the filters which produce maximum and minimum p.d.s.

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This question proved challenging for some. A good answer linked the correct variation of resistance with intensity and the effect of this on the potential difference across the LDR in series with a fixed resistor. Lower ability candidates did not describe the variation of p.d. for a complete rotation, even though the question specified this. Many responses incorrectly suggested that the resistance of an LDR increases with light intensity. Although most responses made the link between maximum resistance and maximum p.d., only the best responses explained this using understanding of potential dividers.

## Exemplar 2

filters which produce maximum and minimum p.d.s.

As the light intensity increases, the resistance decreases and as a result the voltage over the LDR would also decrease as it would have a smaller resistance in proportion to the total resistance. Therefore the maximum pd across the LDR would be produced when the light intensity is at a minimum (90°, 270°) as at this point the resistance would be greatest and the minimum pd when the light intensity is at a maximum so (0°, 180° & 360°)

This response gives a clear description of the variation in potential difference, links resistance to light intensity and links potential difference across the LDR to the proportion it contributes to the total resistance the circuit.

## Question 1 (b)(ii)

**(ii)** The highest p.d. recorded by the voltmeter is 3.00 ± 0.01 V.

Calculate the **maximum** value of the resistance of the LDR at this point.

Assume that there is no uncertainty in the p.d. of the cell.

maximum value of resistance = ...................................................... Ω **[2]**

Most candidates recognised this as a potential divider calculation. Those candidates who realised that the greatest p.d. is 3.01 V and that there is no uncertainty in the p.d. of the cell gained both marks. The most common error was to take the maximum p.d. as 3.00 V.

## Question 2 (a)

**2** The equation shows a fission reaction.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{146}_{57}La + ^{87}_{35}Br + 3^{1}_{0}n$$

**(a)** Explain how this reaction can become a chain reaction and suggest how the rate of the reaction can be controlled.

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Although the majority of responses to this question showed that candidates had an understanding of what a chain reaction is, a reasonable proportion of the responses did not explain the process clearly enough to meet the marking point. The crucial element of the response is that neutrons released in one fission reaction can interact with uranium-235 nuclei to produce further neutron emissions.

## Question 2 (b)

**(b)** The graph in Fig. 2.1 shows the binding energies per nucleon of the nuclei involved in the reaction.

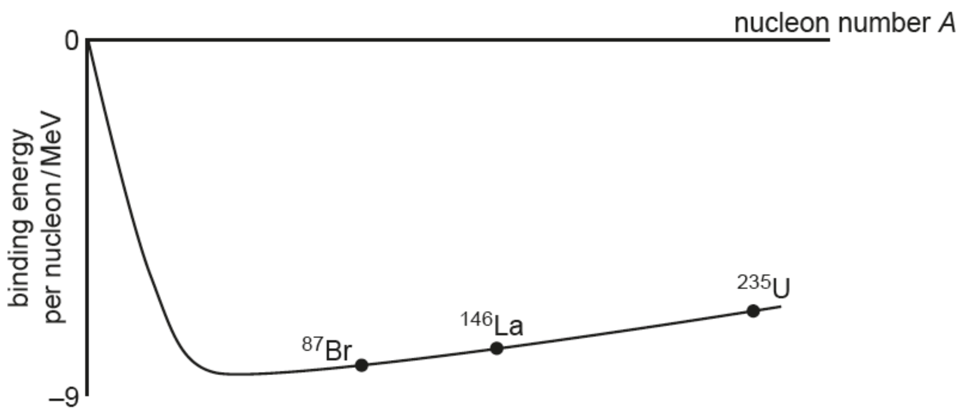


**Fig. 2.1**

Use the graph to explain why energy is released in the reaction.

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Many candidates gained one mark in this question for writing responses such as 'the binding energy of the products is less than the binding energy of the uranium'. This type of response ignored the y-axis label. Using the graph explain the energy release in the reaction needs a consideration of the difference in binding energies per nucleon.

Other errors included writing that Br-87 and La-146 have higher binding energies per nucleon. This is not shown in the graph.

## Question 2 (c)

**(c)** Each fission reaction releases about 16 MeV. Calculate the mass change in a single reaction.

mass change = ...................................................... kg **[3]**

This standard calculation was accurately answered by the majority of the candidates.

## Question 2 (d)

**(d)** Each year, fission reactors around the world produce about $1.4 \times 10^{18}$ J of useful energy. Use the data below to calculate an estimate of the time uranium reserves will last at the **current** rate of energy production. Suggest and explain why such an estimate may be inaccurate.

estimated mass of $^{235}$U available = $1.6 \times 10^{8}$ kg
mass of $^{235}$U atom = $3.9 \times 10^{-25}$ kg.
efficiency of power stations = 30%

time uranium reserves will last = ...................................................... years

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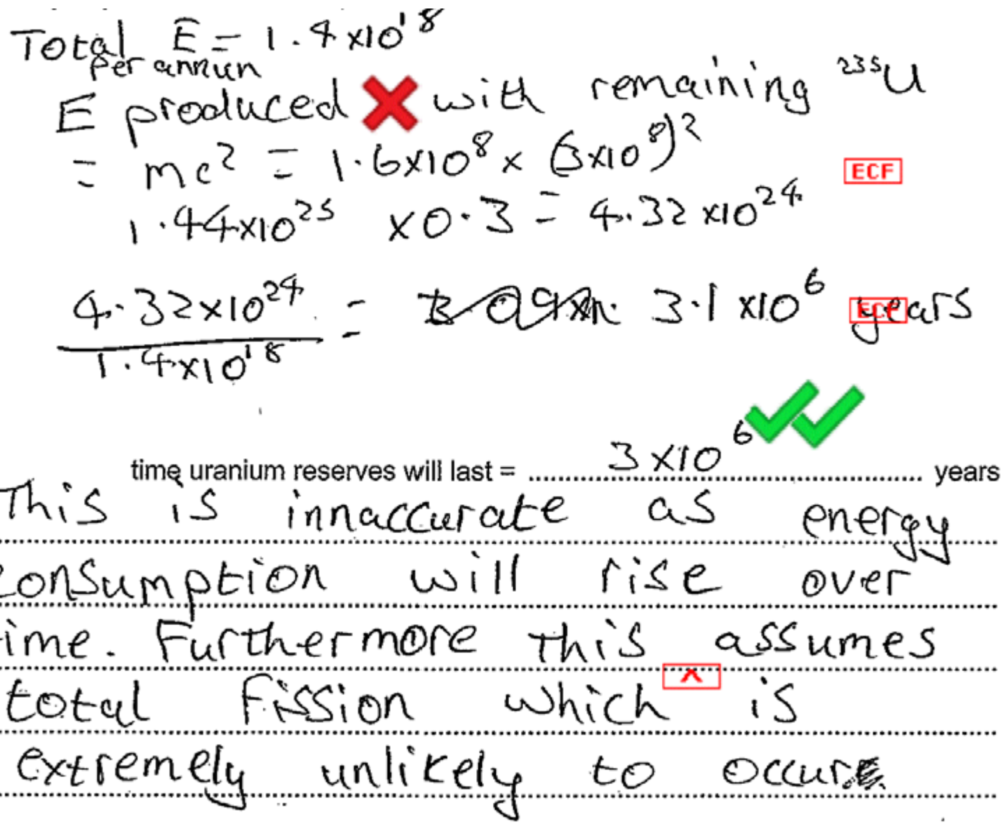
This question asks candidates to perform a novel, unstructured calculation. Encouragingly, most candidates gained marks for this with many reaching the required value of 225 years. A common error was to use the value $2.8 \times 10^{-29}$ kg in the calculation rather than $3.9 \times 10^{-25}$ kg (that is, using the mass defect rather than the mass of the uranium atom). Less able candidates reached values for the time until reserves are depleted ranging from a few weeks to considerably longer than the age of the universe.

The last mark of this part was for the comment about the estimate. Unfortunately, many candidates missed the emboldened point that they were to consider the current rate of energy production.

## Exemplar 3



Total E per annum = $1.4 \times 10^{18}$

E produced with remaining $^{235}U$

$= mc^2 = 1.6 \times 10^8 \times (3 \times 10^8)^2$ ECF

$1.44 \times 10^{25} \times 0.3 = 4.32 \times 10^{24}$

$\frac{4.32 \times 10^{24}}{1.4 \times 10^{18}} = 3.1 \times 10^6$ years

time uranium reserves will last = $3 \times 10^6$ years

This is innaccurate as energy consumption will rise over time. Furthermore this assumes total fission which is extremely unlikely to occure.

In the calculation this response assumes that all the mass of uranium is converted to energy. Using this incorrect assumption the candidate gains two marks for the correct method and evaluation. This shows the importance of giving working. The candidate misses the last marking point by commenting on a change of energy consumption, which indicates a change in the rate of production. The candidate has not considered the emboldened point in the stem of the question.

## Question 3 (a)

**3** This question is about beta radiation from the decay of potassium-40 ($^{40}_{19}K$) in bananas.

**(a)** An average banana contains about 5 × $10^{-4}$ kg of potassium. About 0.012% of this potassium is the beta-emitting isotope, potassium-40.

Show that a single banana will have an activity in the range 10 – 20 Bq.

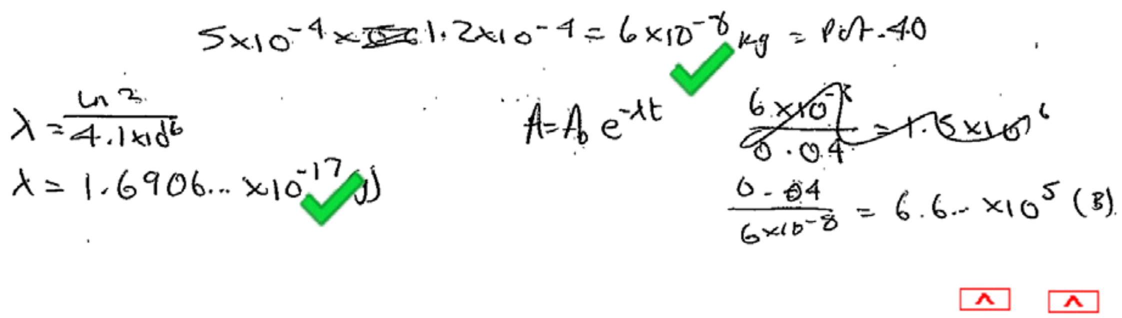
The mass of one mole of potassium-40 is 0.040 kg.

Potassium-40 decays with half-life 1.3 × $10^9$ years (4.1 × $10^{16}$ s).

**[4]**

It is once again encouraging that the majority of the candidates gained full marks for this novel, unstructured calculation. Some lower ability candidates gained marks for correctly calculating and recording elements of the answer. For example, gaining a mark for calculating the decay constant and/or the mass of $^{40}K$ in a banana. This shows how important it is for candidates to write down each stage of their answers, a lone number on the dotted line can gain full marks if it is correct but will score zero if incorrect.

## Exemplar 4




This gives an example of gaining marks even though the calculation is unfinished. The candidate correctly calculates the mass of potassium-40 in a banana (realising that 0.012% is a proportional factor of 1.2 x $10^{-4}$) and calculates the decay constant.

## Question 3 (b)

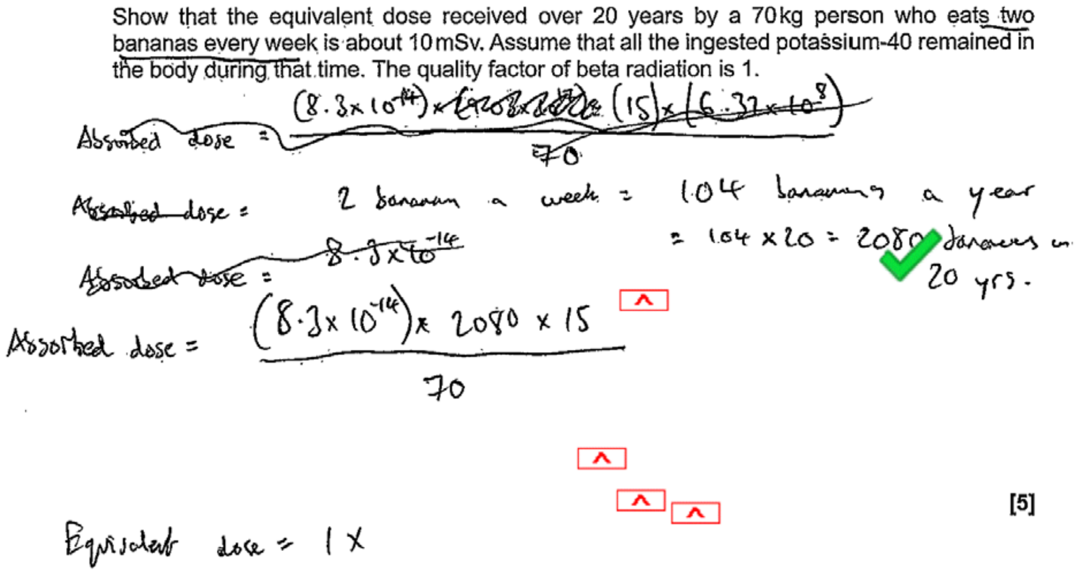
**(b)** The average energy of the beta particles emitted by potassium-40 is $8.3 \times 10^{-14}$ J.

Show that the equivalent dose received over 20 years by a 70 kg person who eats two bananas every week is about 10 mSv. Assume that all the ingested potassium-40 remained in the body during that time. The quality factor of beta radiation is 1.

**[5]**

This question was very discriminating and required candidates to work through a novel and open-ended problem step by step. Although there were lower level marks available, calculating the number of bananas consumed in 20 years, for example, lower ability candidates did not always know where to start on the problem and missed out on the early marking points. Some responses were difficult to follow as the working was not laid out very clearly but the higher ability candidates scored 3 marks or more. The question became much easier for those candidates who realised that the activity of a given banana would remain at about 15 Bq throughout the twenty-year period as the half-life of $^{40}$K is so much greater than twenty years. Only the highest ability candidates noticed that the dose over the twenty years can be calculated by assuming that 1040 bananas were present throughout that time (that is, half the number consumed by the end of the twenty-year period).

## Exemplar 5


Show that the equivalent dose received over 20 years by a 70 kg person who eats two bananas every week is about 10 mSv. Assume that all the ingested potassium-40 remained in the body during that time. The quality factor of beta radiation is 1.

~~Absorbed dose = $\frac{(8.3\times10^{-14}) \times (2080 \times 2080) (15) \times (6.32\times10^{8})}{70}$~~

~~Absorbed dose =~~ 2 bananas a week = 104 bananas a year

= 104 × 20 = 2080 bananas in 20 yrs.

~~Absorbed dose = 8.3 × 10^-14~~

Absorbed dose = $\frac{(8.3\times10^{-14}) \times 2080 \times 15}{70}$

[5]

Equivalent dose = 1 ×

This response gains one mark for calculating the number of bananas consumed over twenty years. The incomplete calculation of absorbed dose would give the dose given by 2080 per second, although the candidate has not made this clear. Had the candidate continued along this line of reasoning the response would have gained more marks. Many responses showed similar truncated answers.

## Question 3 (c)

**(c)** The risk of contracting cancer is about 5% per sievert. Calculate an estimate of the number of cancers produced in a population of 60 million over a period of twenty years from this equivalent dose.

**[1]**

The majority of candidates gained this mark.

## Question 3 (d)

**(d)** The amount of potassium-40 in the body is maintained at a steady level of about $2.0 \times 10^{-5}$ kg for a 70 kg adult. The excess is excreted.

Suggest and explain one reason why the Government should **not** recommend that people should limit the number of bananas they eat on the basis of radiation risk.

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This question was discriminating. Many candidates gained credit for explaining that any excess potassium would be excreted and that the amount of $^{40}K$ in the body represents about 330 bananas-worth, rather than the 2080 or 1040 bananas used in the earlier calculation. Some candidates wrote about the benefits of eating bananas but did not address the radiation risk.

# Section B overview

This section comprises three longer questions which contribute 40 marks to the paper. It includes two Level of Response questions. As expected, the section includes explanatory questions and multi-stage calculations. Lower ability candidates managed to gain marks in most areas but the multi-stage calculations in question 5 proved challenging. Higher ability candidates performed uniformly well in this section with no particular question appearing more accessible than others.

## Question 4 (a) (i)

**4** This question is about objects falling in a gravitational field.

**(a)** In 1589, the Italian physicist Galileo Galilei is said to have dropped different masses from the top of the Leaning Tower of Pisa (Fig. 4.1) to show that all objects accelerate towards the Earth at the same rate.

**Fig. 4.1**

**(i)** The height of the Leaning Tower is 56 m. Calculate the time for a mass to fall to the ground when released from rest at the top of the tower. Ignore the effects of air resistance.

time = ........................................................ s **[2]**

Nearly all the candidates reached the correct vale of 3.4 s

## Question 4 (a) (ii)

**(ii)** Explain why two objects of different masses dropped from the top of the tower should accelerate at the same rate if air resistance is ignored.

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This question was discriminating. Lower ability candidates simply stated that the acceleration due to gravity is independent of mass – which is given in the stem of the question. The best answers showed a clear understanding of the proportionality of the weight with mass and the inverse proportionality of acceleration and mass. This could be expressed algebraically or in words.

## Question 4 (b)(i)

**(b)** If Galileo had used two objects with very different masses, he would have observed that they did not both fall with the same acceleration. The air exerts a drag force on falling objects, decreasing their acceleration.

Taking into account the effects of drag, the acceleration $a$ of an object falling through air at velocity $v$ can be modelled using the equation

$$a = 9.81\,\mathrm{m\,s^{-2}} - Kv^2 \quad \text{where } K \text{ is a constant for the object.}$$

**(i)** The motion of a falling object, taking account of drag forces, can be modelled iteratively as shown below:

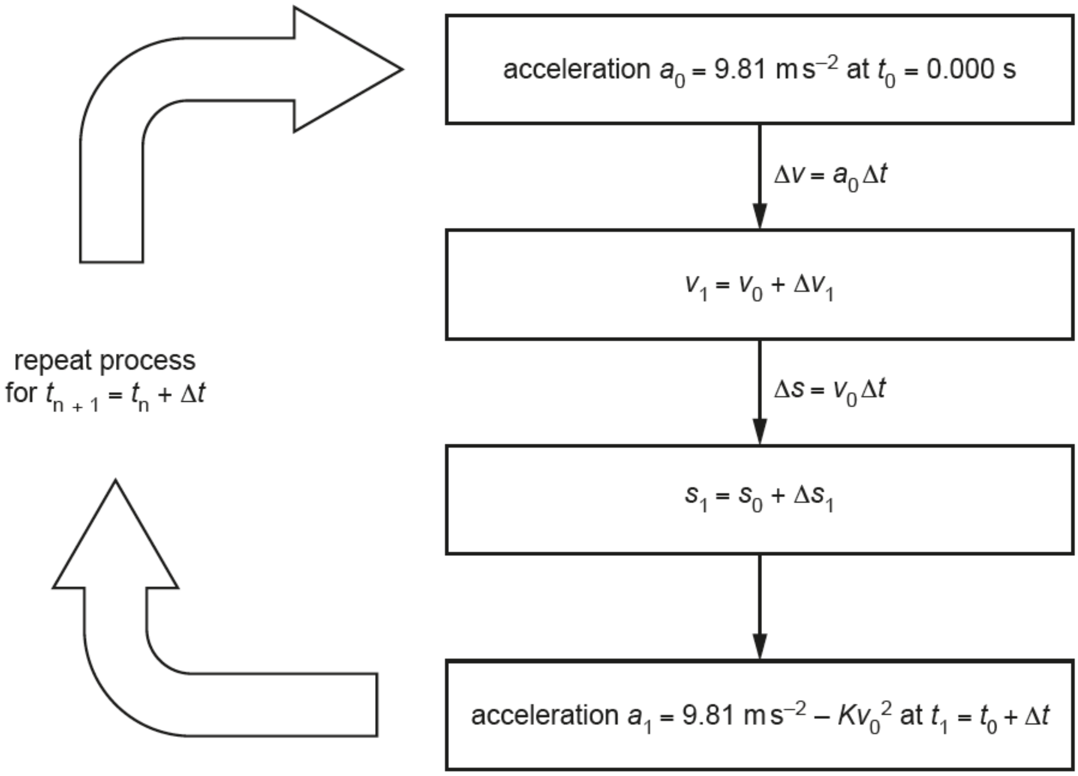


**Fig. 4.2**

The table below is for a ball with $K = 3.40 \times 10^{-3}\,\mathrm{m^{-1}}$, using $\Delta t = 0.200\,\mathrm{s}$. Complete the table.

| $n$ | $t$/ s | $a$/ m s$^{-2}$ | $\Delta v$/ m s$^{-1}$ | $v$/ m s$^{-1}$ | $\Delta s$/ m | $s$/ m |
|---|---|---|---|---|---|---|
| 0 | 0.000 | 9.81 | – | 0.00 | – | 0.00 |
| 1 | 0.200 | 9.81 | 1.96 | 1.96 | 0.00 | 0.00 |
| 2 | 0.400 | | | | | |

**[3]**

Nearly all candidates gained marks on this part. 9.81 was a common and incorrect value given for acceleration.

## Question 4 (b)(ii)

**(ii)*** Further iterations of the calculation produce the graph in Fig. 4.3.

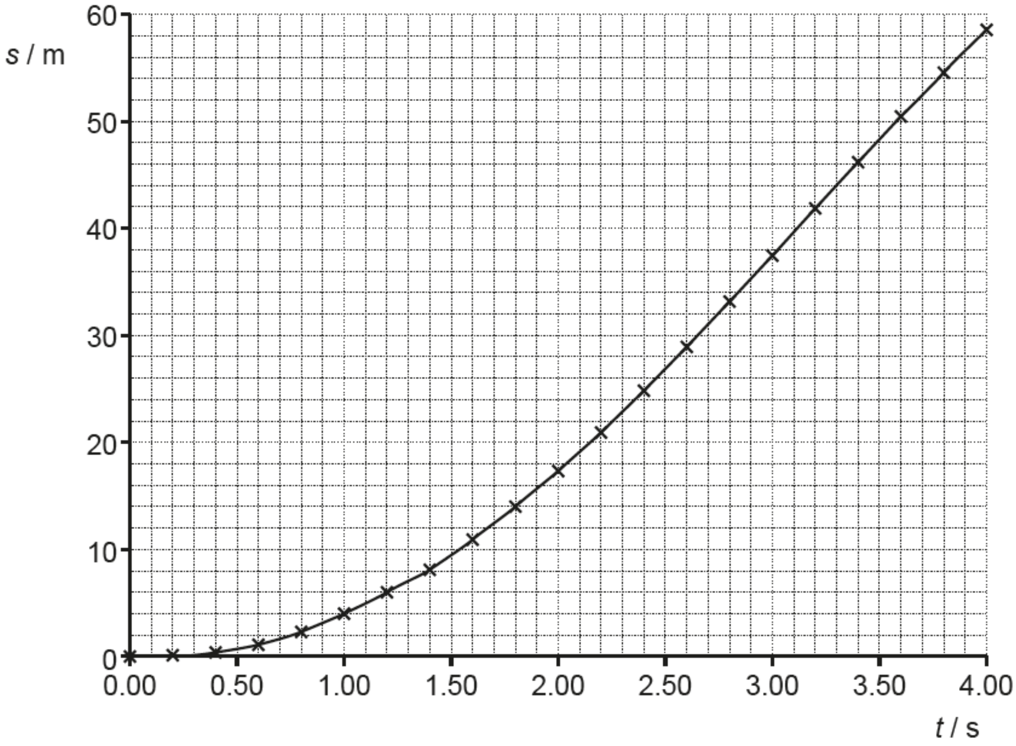


**Fig. 4.3**

Use data from the graph to estimate the time for this ball to fall from the top of the Leaning Tower to the ground.

Explain why the model may not give an accurate result and how the model could be improved.

Compare your estimate with your value from **(a)(i)** and use this to suggest and explain whether observers in 1589 would have been able to distinguish between the time of fall of relatively similar masses from the top of the tower. **[6]**

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This is the first of three Level of Response questions. The question requires candidates to consider the use of iterative modelling and its limitations and explain whether the difference in time of fall of different masses would be observed in 1589.

The majority of candidates produced Level 2 or Level 3 responses. The data from the graph was correctly interpreted in most responses and the limitations of iterative modelling were clearly described by most candidates. It was pleasing to see that many responses showed clear structure, linking the difference in time between the calculation in 4 (a) (i) with the value from the graph and considering this in terms of measurements in 1589. The better responses commented on the difference between the two values being less than would be observed for two masses with similar drag coefficients.

## Exemplar 6

1 • Use data from the graph to estimate the time for this ball to fall from the top of the Leaning Tower to the ground.

2 • Explain why the model may not give an accurate result and how the model could be improved.

3 • Compare your estimate with your value from **(a)(i)** and use this to suggest and explain whether observers in 1589 would have been able to distinguish between the time of fall of relatively similar masses from the top of the tower. **[6]**

1. Using the graph, the time taken to fall 56m L1 is ~3.86s.

2. The model may not give an accurate result because it assumes that during the interval of Δt, L1 the acceleration is constant and that the velocity only changes at the start (and end) of each interval. L2 This may be inaccurate because in reality, the acceleration and velocity are constantly changing.

In order to improve the model, small intervals of Δt could be used, eg 0.1s and this means taking more iterations. This improves the accuracy since it means that the acceleration has a smaller

L2

error and difference between the real and constant value. This means that the velocity is more accurate and so the path of The displacement will be more closer to the real data.

3. The graphs suggests that it would've taken 3.86s but the calculation suggests it would take 3.38s however the value in a(c) does

L3

not factor in the effects of air resistance which explains why it suggests that a shorter time is needed. Assuming that a massive object would have air resistance but a light object would have negligible, they would be able

L3

to see the difference of 0.4s over large heights like 50m. (For similar masses, they would not be able to if air resistance was the same).

This is a good example of a Level 3 response. The first thing to notice is that the candidate has annotated the question with '1', '2' and '3' to help him/her to cover all the points in the answer. The time of fall is correctly stated followed by a clear explanation of the limitations of the iterative model. This explanation includes an understanding of the constantly changing acceleration of the falling mass. The final paragraph clearly states that the time interval between the two values could be determined by observers at the time and comments that the time difference for similar masses would be more difficult to determine. There was not enough explanation of the last point to gain 6 marks for the response so the response gained 5 marks. Other responses to this question included comments about the value of *K* for different masses.

## Question 5 (a)(i)

**5** This question is about determining the diameter of the atomic nucleus.

**(a)** In 1909, a team led by Ernest Rutherford fired alpha particles at a thin sheet of gold. Most of the alpha particles passed through the sheet with little deflection but about one alpha particle in ten thousand 'bounced back'.

**(i)** Explain why such scattering experiments are carried out in a vacuum.

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This question required candidates to show an understanding of the properties of alpha particles. Nearly all responses gained at least one mark. Some of the marking points were missed by many candidates; for example, few responses considered energy loss in interactions. More encouragingly, a good proportion of candidates made well-argued comments for the effect of deflections on the experimental results.

## Question 5 (a)(ii)

**(ii)** We can assume that the alpha particles come to rest for an instant at the point where the electrical potential energy of the particle is equal to the kinetic energy of the particle at a large distance from the nucleus.

Calculate the distance of closest approach of a 4.5 MeV alpha particle ($^{4}_{2}He$) to a gold nucleus ($^{197}_{79}Au$) and explain why the use of more energetic alpha particles would result in a different value for the radius of the gold nucleus.

distance of closest approach = ............................................................ m

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This is a standard calculation and most responses reached the correct value for closest approach. Common errors included using the nucleon number in the calculation rather than the proton number and using $r^2$ as the denominator rather than $r$. The third marking point required candidates to explain why the value of the radius (closest approach) changes. The best answers showed understanding of the physics of the situation and linked initial kinetic energy to the electrical potential energy at closest approach. As in other questions, some responses did not explain the result but merely stated it; '*r* decreases' was not enough for the mark.

## Question 5 (b)(i)

**(b)** Accelerated electrons can also be scattered by atomic nuclei.

The electrons are diffracted by the nuclei giving a minimum at angle $\theta$ where $\sin\theta = \frac{1.2\lambda}{d}$ and $d$ is the diameter of the nucleus and $\lambda$ is the de Broglie wavelength of the electrons.

**(i)** Show that the velocity of an electron accelerated through $1.5 \times 10^8$ V is very close to the velocity of light.

rest energy of electron = 0.51 MeV

**[4]**

This question requires understanding of the gamma factor as well as the ability to identify the rest energy and kinetic energy of the electron from the data given. Successful responses worked through to the value of 295 for the gamma factor using 0.51 MeV and 150 MeV as rest energy and kinetic energy. Other candidates reached the value of 295 after unnecessarily converting the energies into joules.

An incorrect gamma factor of 294 was commonly found. In such cases candidates had misinterpreted the equation 'total energy = gamma factor x rest energy' to mean
'kinetic energy = gamma factor x rest energy'. Such responses often gained the last two marking points of the calculation.

A significant number of responses did not gain any marks for this question, perhaps due to its unstructured nature.

## Question 5 (b)(ii)

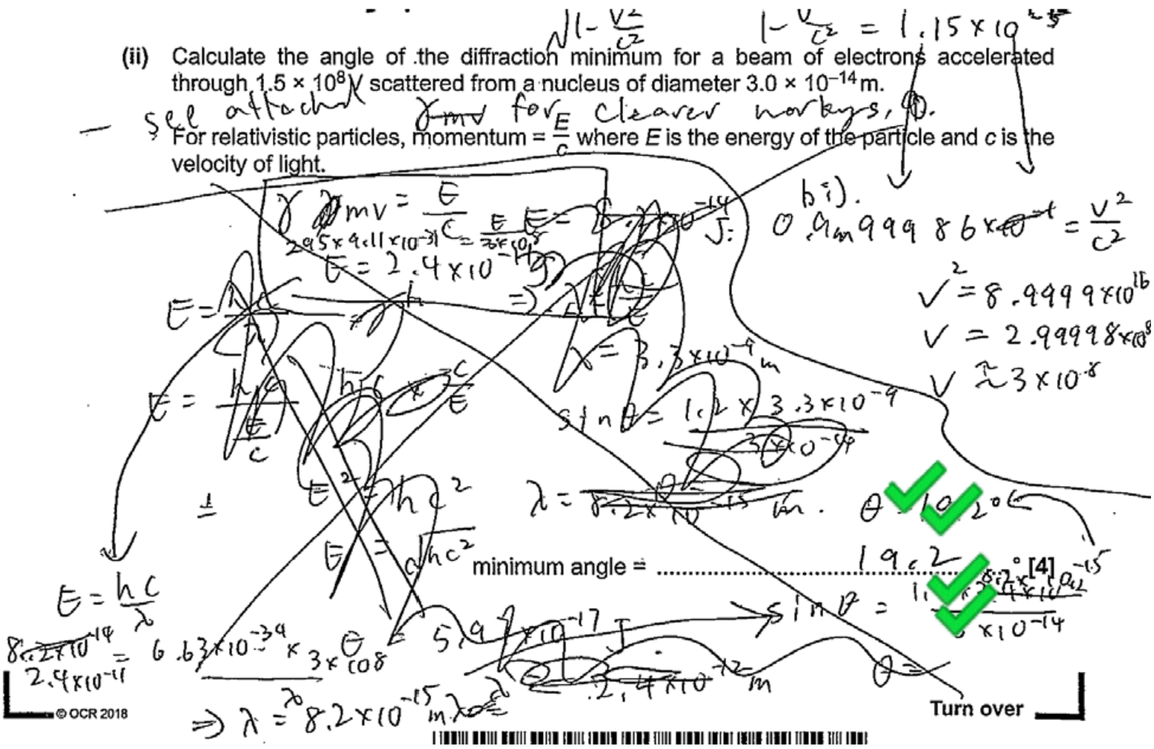
**(ii)** Calculate the angle of the diffraction minimum for a beam of electrons accelerated through $1.5 \times 10^{8}$ V scattered from a nucleus of diameter $3.0 \times 10^{-14}$ m.

For relativistic particles, momentum = $\frac{E}{c}$ where $E$ is the energy of the particle and $c$ is the velocity of light.

minimum angle = ........................................................ ° **[4]**

This is the second four-mark, unstructured calculation in the question. Although the stem of the question gives both the equations required to reach a value for minimum angle the question proved challenging. The best responses showed clarity and confidence in the calculation, often performing the calculation in one step having clearly written down the equation and showing the values used. Less impressive responses could still gain marks by correctly working out an angle from an incorrect value for wavelength. These marks were missed by candidates who chose not to show clear working or whose calculated wavelength value led to a value of sine of more than unity.

### Exemplar 7


(ii) Calculate the angle of the diffraction minimum for a beam of electrons accelerated through $1.5 \times 10^{8}$ V scattered from a nucleus of diameter $3.0 \times 10^{-14}$ m.

For relativistic particles, momentum = $\frac{E}{c}$ where $E$ is the energy of the particle and $c$ is the velocity of light.

minimum angle = ........................................ ° [4]

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Turn over

| | | |
|---|---|---|
| 5 | biii | $\gamma m v = \frac{E}{c}$ |
| | | $E = \gamma m v c = 295 \times 9.11 \times 10^{-31} \times (3\times10^{8})^2$ |
| | | $= 2.4 \times 10^{-11}$ J. |
| | | $E = \frac{hc}{\lambda}$ |
| | | $\lambda = \frac{hc}{E} = \frac{6.63\times10^{-34} \times 3\times10^{8}}{2.4\times10^{-11}} = 8.2\times10^{-15}$ m |
| | | $\Rightarrow \sin\theta = \frac{1.2 \times 8.2\times10^{-15}}{3\times10^{-14}} \approx$ |
| | | $\sin\theta = 0.33$ |
| | | $\theta = 19.2°$ |
| | | $\theta \approx 19°$ (2sf) |

This response shows conciseness and accuracy.

## Exemplar 8

For relativistic particles, momentum = $\frac{E}{c}$ where $E$ is the energy of the particle and $c$ is the velocity of light.

$\lambda = \frac{h}{p}$ $\lambda = \frac{hc}{E}$ $\lambda = \frac{(6.63\times10^{-34}) \times (3\times10^{8})}{2.4\times10^{-11}}$

$\lambda = 8.3\times10^{-15}$ m

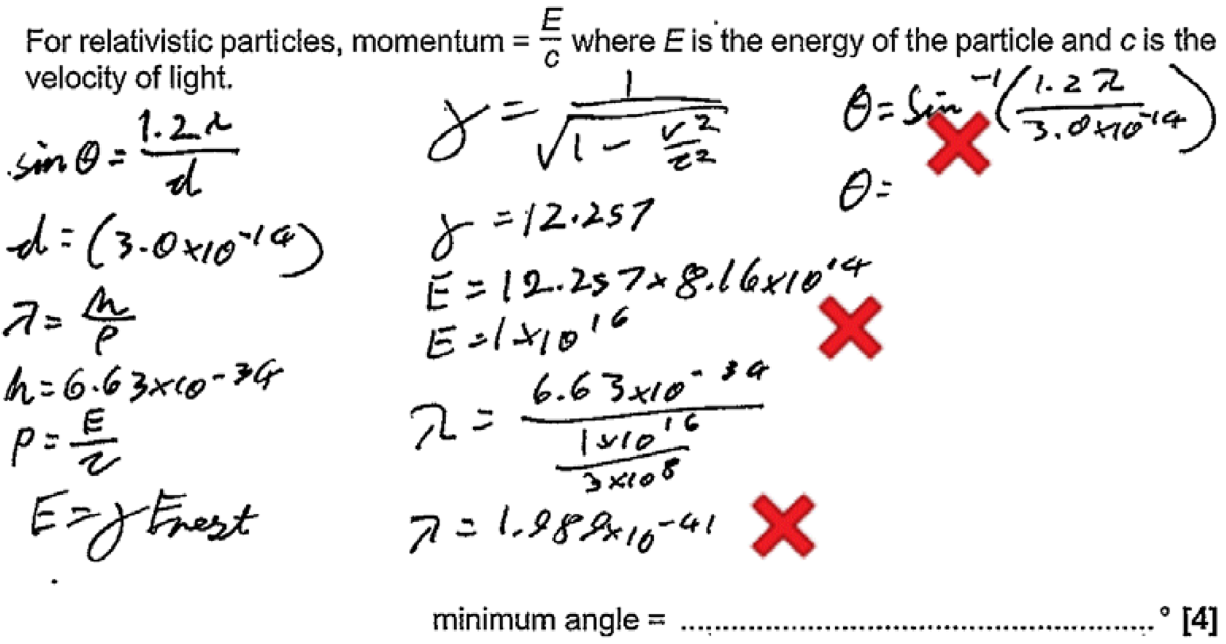
$\theta = \sin^{-1}\left(\frac{1.2 \times (8.3\times10^{-15})}{3\times10^{-14}}\right)$

$\theta = 19.4$

minimum angle = 19.4 ° **[4]**

This response is clear, accurate and concise.

## Exemplar 9


For relativistic particles, momentum = $\frac{E}{c}$ where $E$ is the energy of the particle and $c$ is the velocity of light.

$\sin\theta = \frac{1.2\lambda}{d}$

$d = (3.0\times10^{-14})$

$\lambda = \frac{h}{p}$

$h = 6.63\times10^{-34}$

$p = \frac{E}{c}$

$E = \gamma E_{rest}$

$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$

$\gamma = 12.257$

$E = 12.257\times8.16\times10^{14}$

$E = 1\times10^{16}$

$\lambda = \frac{6.63\times10^{-34}}{\frac{1\times10^{16}}{3\times10^{8}}}$

$\lambda = 1.989\times10^{-41}$

$\theta = \sin^{-1}\left(\frac{1.2\lambda}{3.0\times10^{-14}}\right)$

$\theta =$

minimum angle = .......................................................° [4]

This response shows a common lack of detail in the third marking point. This gives a description of the change in value of the gold nucleus rather than an explanation.

## Question 5 (c)

**(c)** Electron scattering experiments show that the radius $r$ of a nucleus of nucleon number $A$ is proportional to $\sqrt[3]{A}$.

This relationship suggests that the radius of a silver nucleus ($^{107}_{47}Ag$) is about four-fifths the radius of the gold nucleus. However, calculations similar to those in **(a)(ii)** suggest that the maximum radius of the silver nucleus is smaller than this.

Use the relationship $r \propto \sqrt[3]{A}$ to calculate the ratio $\frac{\text{radius of a silver atom}}{\text{radius of a gold atom}}$ and show that it is significantly greater than the ratio given by the closest approach method used in **(a)(ii)**.

**[4]**

This question requires candidates to compare ratios of atomic radii using electron scattering relationships and Rutherford scattering relationships. Many responses reached the expected ratio of 0.82 for electron scattering, although a significant minority lost marks by giving the ratio as 0.81 – a rounding error.

Surprisingly, only the highest ability candidates calculated the ratio of radii from Rutherford scattering from the ratio 'nuclear charge on silver/nuclear charge on gold nucleus'. A more common, complicated and error-prone method involved making a calculation of the distance of closest approach of a 4.5 MeV alpha particle to a silver nucleus and finding the ratio of this value to the value calculated in (a) (ii).

## Question 6 (a)

**6** This question is about conduction in metals and in semiconductors.

**(a)** A copper wire of length 1.5 m and radius $2.5 \times 10^{-4}$ m has a resistance of 0.13 Ω at 20 °C. Calculate the conductivity of copper at this temperature.

conductivity at 20 °C = ............................................... $S\,m^{-1}$ **[3]**

This standard calculation was accurately performed by most candidates.

## Question 6 (b)

**(b)** A simple model of conduction suggests that each copper atom in the wire contributes one or more electrons to a cloud of free electrons that behave rather like particles in a gas. These electrons drift through the wire under the influence of an electric field.

The current $I$ is given by the equation $I = nave$ where:

$n$ is the number of free electrons in the material per $m^3$
$a$ is the cross-sectional area of the wire
$v$ is the drift velocity of the electrons
$e$ is the electronic charge.

Calculate the drift velocity of the electrons when the copper wire in part **(a)** carries a current of 2.3A. The number of free electrons per $m^3$ in copper = $8.5 \times 10^{28}\,m^{-3}$

drift velocity = ............................................... $m\,s^{-1}$ **[2]**

This standard calculation was accurately performed by most candidates. Less able candidates incorrectly rearrange the equation given in the stem of the question.

## Question 6 (c)

**(c)*** The conductivity $\sigma$ of semiconductors such as ntc thermistors increases dramatically with temperature $T$. The relationship is given by the equation

$$\sigma = C\,e^{-E/kT}$$

where $C$ is a constant, $k$ is the Boltzmann constant and $E$ is the energy required to ionise an atom in the semiconductor.

Use the relationships given in the question to explain the effect of increasing temperature on the conductivity of metals and semiconductors, referring to the microscopic structure of the materials. No calculations are required. **[6]**

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This is the second Level of Response question on the paper. Candidates were required to explain the effect of increasing temperature on the conductivity of semiconductors and metals. A description of the microscopic structure of the materials was also required. Candidates could make use of the information in the stem of part (b) to help in this question.

The best responses clearly separated the conduction process in metals (free electrons travelling through the lattice of positive ions) from that in semiconductors (far fewer free electrons) and then described the effect of increasing temperature, bringing in the relationship given in the stem.

A significant proportion of responses considered the activation process as the most important factor in the conductivity of both semiconductors and metals. Other responses did not state which material was being discussed.

The best responses showed a greater knowledge of semiconductors than is required by the specification as well as a firm grasp of the mechanism of metallic conduction.

## Exemplar 10

Semiconductors:

• $e^{-\frac{E}{kT}}$ is the Boltzmann factor - it gives the fraction of particles with the extra energy E compared to those without. As temperature increases, $\frac{E}{kT}\downarrow$, and so $e^{-\frac{E}{kT}}$ increases - this means more electrons have the energy required to be ~~excited~~ liberated. L1

• In semiconductors, charge is carried by liberated electrons from ionised atoms. The more electrons there are, the more charge carriers there are, and so the higher the conductivity. This shows that as temperature increases in a semi-conductor, its conductivity increases. L2 The Boltzmann factor shows that as ~~the~~ temperature increases further, the conductivity plateaus. This is because all atoms become ionised.

Metals

• As the temperature of a metal increases, its atoms gain ~~heat~~ kinetic energy, causing them to vibrate more. This reduces the drift velocity v, as electrons' path is obstructed more, and their movements are more random. As $I = nAve$, a decrease in v causes a decrease in current, which causes a decrease in conductance. As $G = \frac{\sigma A}{L}$, and L and A are constant, a decrease in conductance means a ~~dec~~ decrease in conductivity has L3 occurred.

This response gained 6 marks. Note that it is not perfect and could be bettered but it answered the question posed to a level meriting the highest grade. Labelling sections of the answer 'semiconductors' and 'metals' immediately shows clarity. The discussion of conduction in semiconductors makes a clear connection to the equation given in the stem and shows a good application of the Boltzmann factor.

The discussion of conduction in metals is secure although it does not consider the average distance travelled by electrons between collisions. Taken as a whole this represents a good response to an open-ended question and combines analysis, knowledge and understanding.

# Section C overview

This section contributes 29 marks to the paper total. The four questions in the section are linked to the Advance Notice article 'Flying on sunshine' which focuses on solar cells used on the aircraft Solar Impulse 2 and the Juno spacecraft. There was little evidence of candidates running out of time in these later questions although the final question was left unanswered by more candidates than previous questions. Centres can prepare candidates for this section by discussing the article in class and suggesting possible areas for questions. As in previous years, there was evidence that candidates had used the Advance Notice article to inform their revision of aspects of the specification and application of theory to novel contexts.

## Question 7 (a)(i)

**7** In 1905, Einstein explained the photoelectric effect using the equation

maximum kinetic energy of photoelectrons emitted from a surface = $hf - \phi$

where $h$ is the Planck constant, $f$ is the frequency of light incident on the surface and $\phi$ is the work function of the surface. Fig. 7.1 shows this relationship for the metal rubidium.

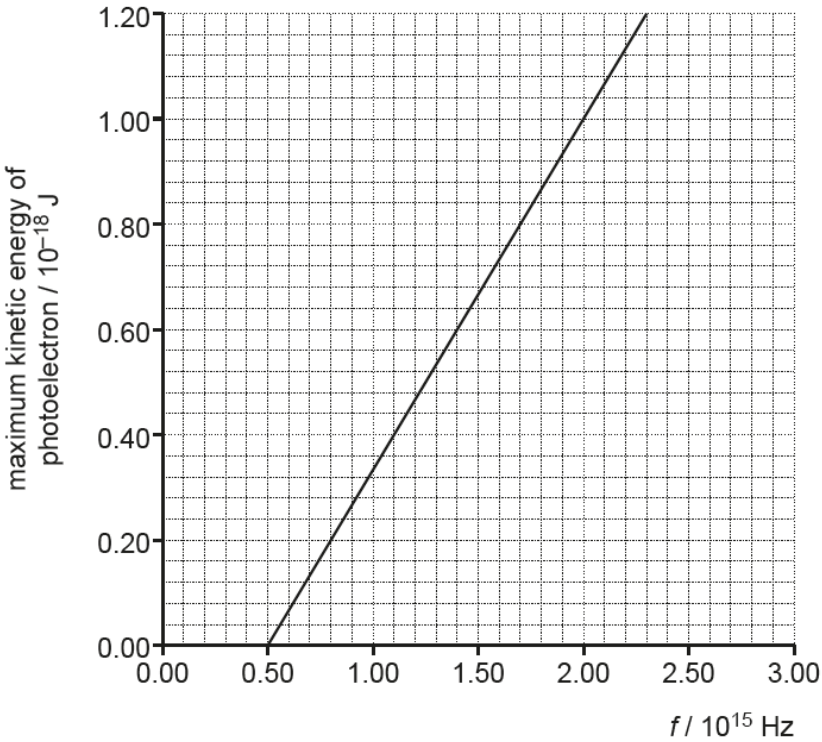


**Fig. 7.1**

**(a) (i)** Use the graph in Fig. 7.1 to find the work function of the metal.

work function = ........................................................ J **[2]**

This is a standard calculation and most candidates answered it correctly. This area of physics was flagged up in lines 14 – 17 of the article.

## Question 7 (a)(ii)

**(ii)** Explain the meaning of the term *work function* and explain why Einstein's equation gives the **maximum** kinetic energy of the electrons emitted for a particular frequency of incident light (lines 14 – 17 in the Article).

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Although most responses correctly gave the meaning of the term work function, a much smaller proportion gained the second mark, that photons might not be interacting with electrons on the surface of the metal and that these 'deeper' electrons will require more energy to escape. Any discussion of the concept of minimum energy to escape linking to maximum kinetic energy of the ejected electrons would gain the mark.

## Question 7 (b)

**(b)** Add a second line to the graph of Fig. 7.1 for a metal surface with a work function which is double that of the work function for rubidium. **[2]**

Most candidates gained both marks for this question. A common incorrect response was to draw a line of different gradient but with the same x-axis intercept. Some candidates were penalised for sloppy line drawing, when the line had the correct intercept but was not quite parallel to the first line. This was a wasted mark for these candidates.

## Question 8

**8*** The upper surface of a solar cell is represented in Fig. 8.1.

Use ideas about superposition of waves to explain why a transparent layer of silicon monoxide about 100 nm thick reduces the amount of reflection of light of wavelength 613 nm and increases the efficiency of the solar cell (lines 29 – 30 in the Article). **[6]**

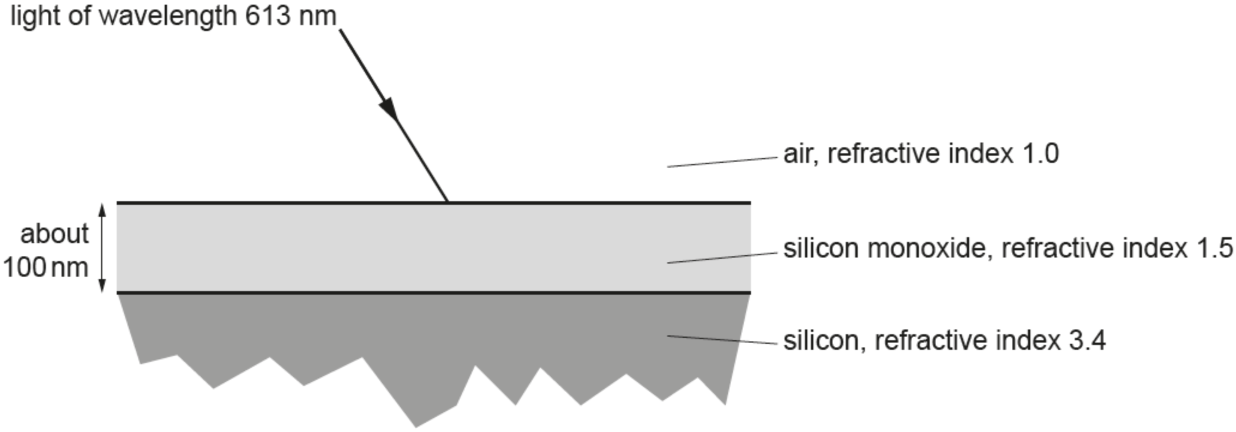


**Fig. 8.1**

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This last Level of Response question proved to be the most difficult on the paper. Many candidates concentrated on the refractive indices given in the diagram rather than the superposition at the upper surface from reflected waves at both surfaces. The indicative points listed in the mark scheme allowed such responses to gain merit but to reach the higher levels required an explanation of the physics of superposition in the context of the question.

Common errors included making the assumption that standing waves are set up in the silicon monoxide layer and that refraction in the layer somehow focuses and hence intensifies the light reaching the silicon layer.

The best answers calculated the wavelength of light in the silicon monoxide, showed that the layer was about one quarter of a wavelength thick and concluding that this introduces a path difference of half a wavelength at the surface.

## Exemplar 11

The superposition of waves means that waves in antiphase, a phase difference of $\pi$ or $\frac{\lambda}{2}$ will [L1] interfere destructively and have a very small amplitude, as the waves cancel out. If they have a phase difference of $2\pi$ or $\lambda$ then they will arrive in phase. A small amplitude means that [L1] there is a small probability of it occurring as probability $\propto A^2$ and so more of the light ~~refl~~ won't be reflected but instead absorbed.

[L2] As $\lambda_c = 613 \times 10^{-9}$ m, and the refractive index is 1.5, $\lambda$ inside the silicon monoxide will be $\frac{\lambda}{1.5} = 409 \times 10^{-9}$ m. In order to produce a phase difference of $\frac{\lambda}{2}$, the thickness [L2] should be $\frac{\lambda}{4}$ in order get $\frac{\lambda}{4} + \frac{\lambda}{4}$ each way (before and after reflection). Therefore the optimum thickness for reducing reflection is

$\frac{409 \times 10^{-9}}{4}$ = ~~100~~ 102 nm $\approx$ 100 nm.

Decreasing the reflection again means that they're in antiphase & so the probability of arrival is low. Therefore more of the light will [L3] be absorbed, making the cell more efficient because more of the light's energy is transferred into the cell to be converted into the electricity - a greater intensity means more electrons are [L3] excited, producing a greater charge and so greater efficiency.

This is an example of a high level response from a candidate who scored highly on the paper. A simple description of superposition and path difference is given as an introduction. The wavelength of the light in silicon monoxide is correctly calculated. The thickness of the monoxide layer is shown to provide a path difference of half a wavelength. The link between reduced reflection and increased absorption is made, though not particularly clearly. Finally, the candidate links this to the increased efficiency of the solar cell. The argument is clearly presented throughout.

## Question 9 (a)

**9** This question is about the effect of the gravitational slingshot on the motion of the Juno space probe (lines 45 – 57 in the Article).

Fig. 9.1 shows a simplified situation in which a space probe of mass *m* sweeps around a planet of mass *M*.

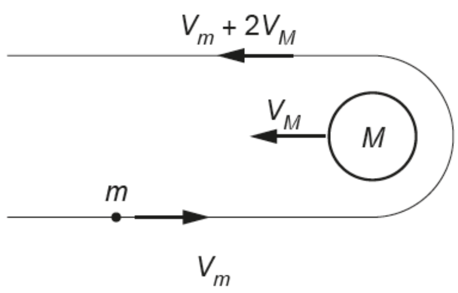


**Fig. 9.1**

**(a)** Show that the change in momentum of the space probe = $2m(V_m + V_M)$.

**[2]**

Candidates who recognised the vector nature of momentum and velocity were able to answer this question in a couple of lines of reasoning. Those candidates who didn't recognise that the final velocity of the probe is negative if the initial velocity is positive (or vice versa) could not gain marks. The question was highly discriminating with candidates who scored highly on the paper overall gaining both marks and less able candidates not scoring.

## Question 9 (b)

**(b)** The planet has a much greater mass than the space probe. Use the principle of conservation of momentum to describe the effect that the slingshot will have on the motion of the planet.

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Most responses to this part gained 1 or 2 marks. Some responses showed confusion between change in velocity and velocity; it was not uncommon to read that the planet would go backwards 'a little'. Once again, this question tested candidates' ability to use fundamental ideas from the course in a new context.

## Question 9 (c)

**(c)** Use the data below to show that the Juno probe has sufficient energy per kg to move from 1AU to 5.2AU after its gravitational slingshot (see lines 58 – 60 in the Article).

mass of Sun = $2.0 \times 10^{30}$ kg
1 AU = $1.5 \times 10^{11}$ m
velocity of Juno after slingshot = $4.2 \times 10^{4}$ m s$^{-1}$

**[4]**

This question proved more discriminating than expected. It may be that candidates were tiring a little at this stage, or rushing. It is also an unstructured calculation about a novel idea. Some confident responses suggested a familiarity with the concepts that may be due to thorough revision of the topics identified in the article. Correct responses calculated the change in gravitational potential and compared this to the kinetic energy per kg of the probe. Some candidates calculated potential energy change rather than potential change.

Many candidates gained marks for calculating the kinetic energy per kg of Juno but did not correctly calculate the change in gravitational potential. Common errors included confusing a factor of (1/5.2 AU – 1/1AU) with a factor of (1/4.2AU) and calculating the potential at 5.2 AU rather than the change in potential.

## Question 10

**10** Solar Impulse 2 recharges its batteries during the day as it climbs from 1500 m to 8500 m. The solar cells produce an output power of 62.1 kW.

Use data from page 3 of the Article to show that the energy produced by the solar cells over eight hours of daylight is sufficient to lift the plane from 1500 m to 8500 m and fully recharge the batteries.

Make your reasoning clear.

**[4]**

Candidates answered this question with more confidence than they showed in the previous question. Nearly all gained some marks and approached the problem in the same manner as the mark scheme. Some responses calculated the power required during the day and compared this to the useful power received from sunlight. Both approaches could gain four marks. The most common error was to ignore the energy required to charge the batteries, thus limiting the possible marks to 2. This is another example of applying standard physics to new contexts and taking the question step by step.

## Question 11

**11** The intensity of solar radiation at 1 AU from the Sun is 1.4 kW m$^{-2}$. At a distance of 5.2 AU from the Sun, the solar cells on the Juno probe produce a power of 500 W. Use data from page 4 of the Article to calculate an estimate of the efficiency of the solar cells.

efficiency = ...................................................... % **[3]**

This is a relatively straightforward question to finish the paper. The only common cause of error was miscalculating the intensity at 5.2 AU. This error would only cost one mark if the candidate clearly and correctly worked through to a value based on the error earlier in the question. Unfortunately, some responses continued to show errors beyond the first marking point, or did not clearly show how the final value was reached.

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Section B, Q4, Fig. 4.1

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