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Examiners' report

PHYSICS B
(ADVANCING PHYSICS)

H557

For first teaching in 2015

H557/02 Summer 2022 series

Version 1

Contents

Introduction

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

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

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

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

Advance Information for Summer 2022 assessments

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

Paper 2 series overview

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 10 marks each to the paper total. Section B comprises longer questions, including a level of response question. Section C is based on the Advance Notice article and includes short and long questions and a level of response question.

The Advance Notice information gave candidates some idea of the major areas tested but this is a challenging examination. It is encouraging that the majority of the candidates attempted all the questions. There was little evidence of candidates running out of time. An erratum was given with the paper that highlighted an unnecessary answer line in Question 7. Some candidates crossed this out. There is little evidence to show that those candidates who did not cross out the answer line were disadvantaged although not all the candidates completed this question.

Generally, as usual the more able candidates demonstrated the ability to apply physics to novel areas, accurately used technical vocabulary and had prepared carefully for the questions on the Advance Notice article.

Candidates who did well on this paper generally did the following:	Candidates who did less well on this paper generally did the following:
• Showed full working to all calculations • Used correct technical vocabulary • Provided full written explanations when required • Applied physics to novel situations • Showed familiarity with the physics covered in the Advance Notice article	• Did not give their own value for 'show that' questions • Misused technical vocabulary • Gave incomplete arguments or did not clearly explain reasoning • Did not show working in calculations

Section A overview

Section A comprises three questions of about 10 marks each. These can be taken from any area of the course.

Question 1 (a), (b)

1 This question is about the experiment to measure the charge on an electron performed by American physicists Robert Millikan and Harvey Fletcher in the early years of the twentieth century.

Consider the forces on an oil drop falling at terminal velocity through air, as shown in **Fig. 1.1**.

Fig. 1.1

(a) Ignoring any upthrust forces, state why the drag force D must be equal and opposite to the weight W of the drop when it is falling at terminal velocity.

....

.... **[1]**

(b) The drag force is given by the equation $D = 6\pi\eta_{air}rv$ where r is the radius of the oil drop and v is the terminal velocity. The symbol η_{air} represents the viscosity of air; this is a measure of the resistance that air has to the motion of objects in it.

Show that the terminal velocity of a drop of mass 1.8×10^{-15} kg is about 7×10^{-5} m s^{-1}. The buoyancy of air may be ignored.

density of oil = 8.7×10^{2} kg m^{-3}

viscosity of air = 1.8×10^{-5} Pa s

[2]

The first question on the paper opens with a consideration of drag forces. Part (a) requires candidates to recognise that there will be no acceleration when forces are balanced. Part (b) is a straightforward calculation with a given equation. Common errors here included failing to convert grams intro kilograms and using mass rather than weight for the drag force. Candidates who performed well across the paper often made the calculation of the radius of the drop a separate calculation.

Question 1 (c) (i)

(c) The oil drop is given a negative charge and falls into a region of uniform electric field, as shown in the diagram.

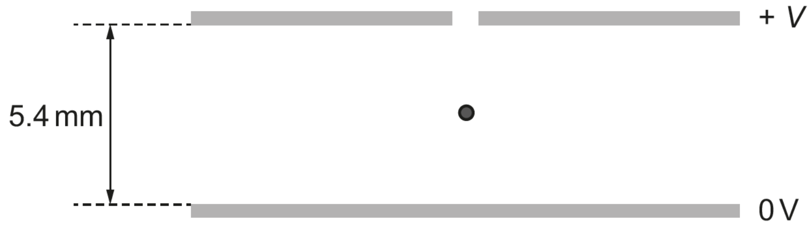


Fig. 1.2 (not to scale)

(i) Draw six lines on **Fig. 1.2** to represent the uniform field between the plates. Assume that the oil drop does not distort the field. **[2]**

Most candidates included the (correct) direction of field lines but many did not take enough care with their diagram and did not draw equally spaced field lines. Some of the less successful candidates confused field lines with equipotential lines.

Question 1 (c) (ii)

(ii) The drop of mass 1.8×10^{-15} kg is held stationary between the plates when the p.d. V between the plates is 200 V. The plate separation is 5.4 mm.
Calculate the charge on the oil drop.

charge = ... C **[2]**

This standard calculation proved quite discriminatory with some candidates using mass rather than weight in the calculation or choosing the wrong equation to use.

Question 1 (c) (iii)

(iii) When Millikan and Fletcher performed this experiment with many oil drops, they found that the charge on the drop was always a multiple of about 1.6×10^{-19} C (to two significant figures). Why does this suggest that there is a fundamental quantity of electric charge and how does the modern model of the structure of hadrons suggest that 1.6×10^{-19} C may not be the smallest quantity of charge that a particle can possess?

....

....

....

....

.... **[2]**

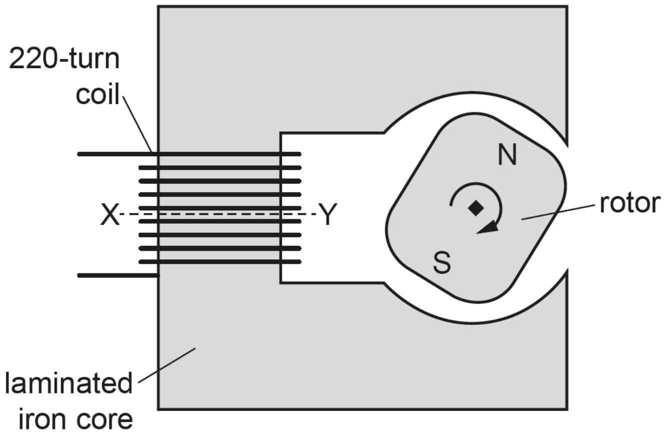
Only the most successful candidates suggested that a continuous range of charge would be observed if charge does not have a minimum value.

Misconception

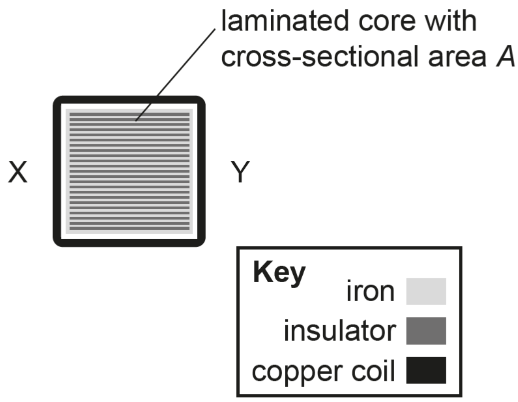
? A significant proportion of candidates stated that electrons are composed of quarks.

Question 2 (a) (i)

2 This question is about a simple generator as shown in **Fig. 2.1**.



Face view
Fig. 2.1a



Section through X-Y
Fig. 2.1b

(a) (i) The core is made of sheets of iron which have been laminated (separated by thin sheets of electrically insulating material). The layers of iron and insulator are all parallel to the plane of **Fig. 2.1a** and stacked as shown in **Fig. 2.1b**.

Explain why iron is used in the core and why laminating the core improves the performance of the generator.

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....

.... **[4]**

The second question on the paper focuses on electromagnetic induction. The first part of the question revealed some misunderstandings of vocabulary. Most candidates gained marks in the second part of the question for their understanding of the role of laminations, correctly linking laminations to eddy-current reduction and hence greater efficiency.

Misconception

Some candidates confused permeance (a property of a particular magnetic circuit or a particular component within a magnetic circuit) and permeability (a property of a material such as iron or air).

Assessment for learning

It is helpful to compare the difference between permeability and permeance with that between resistivity and resistance or conductivity and conductance – as is suggested in part (a) (ii) of the question.

Question 2 (a) (ii)

(ii) The permeance of a magnetic circuit can be compared to the conductivity of an electrical circuit. Suggest and explain a change to the generator in **Fig. 2.1** which would increase the permeance of the magnetic circuit.

....

....

....

.... **[2]**

Less successful candidates suggested increasing the number of turns on the coil to increase the permeance of the circuit. Most candidates gained at least one mark for a realistic suggestion to increase the permeance but only the most successful gave clear reasoning which explained their suggestion. The marking scheme shows examples of the linked suggestions and explanations that were seen in the best responses.

Question 2 (b) (i)

Fig. 2.2 shows how the flux density in the iron core within the coil changes as the magnet rotates.

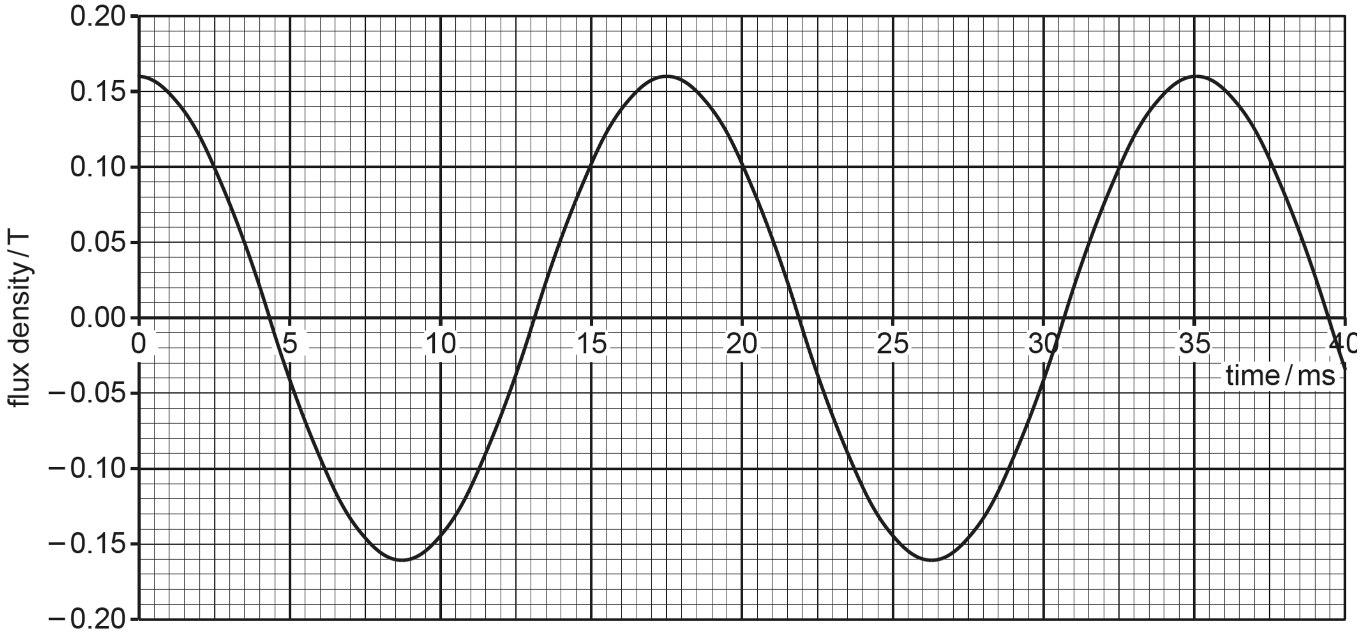

Fig. 2.2

(b) (i) The cross-sectional area A of the iron core inside the coil is $1.5 \times 10^{-4}\,m^2$.

Explain, without calculation, how the maximum emf across the 220-turn coil can be estimated from the cross-sectional area of the coil and the data in **Fig. 2.2**.

....

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....

....

.... **[3]**

A significant proportion of candidates did not gain any marks for this part of the question. This was because the responses made no mention of gradient or maximum gradient. Typical incorrect responses included suggestion that the maximum emf can be found by multiplying maximum flux density by cross-sectional area and number of turns. This will be a useful question to use in class to clarify the role of rate of change of flux density in developing an emf.

Question 2 (b) (ii)

(ii) The emf ε across each turn of the coil is given by the equation

$\varepsilon = 2\pi f \phi_{max} \sin 2\pi ft$

Use the equation and data from **Fig. 2.2** and part **(b) (i)** to calculate the **maximum** emf induced across the coil.

maximum emf = ... V **[2]**

This question required candidates to recognise that the largest value of the sine function is +/- 1. Most candidates who recognised this gained both marks but some forgot to multiply by the number of turns to find the emf generated across the coil as a whole.

Question 3 (a) (i)

3 This question is about using the change in resistance of a wire to measure strain.

Strain gauges use extremely thin wire to give a measurable change in resistance for a small increase in strain.

(a) A strain gauge has the structure shown in **Fig. 3.1**. It has 14 strands of wire connected by thicker strips of negligible resistance.

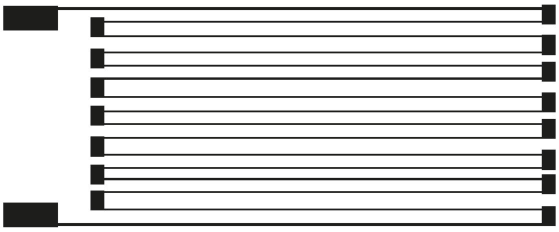

Fig. 3.1

A student places the gauge in a potential divider circuit as shown. The gauge has a resistance of 310 Ω when it is not stretched or compressed. This is called its unstrained resistance.

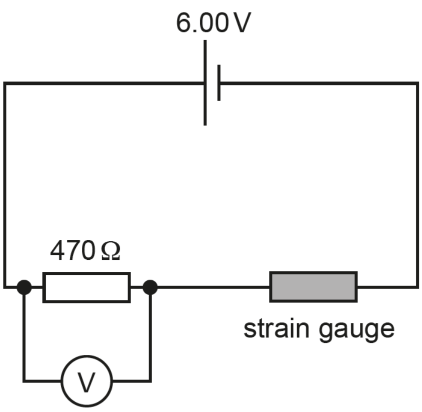

Fig. 3.2

(i) The student had a choice of three resistors for the strain potential divider; 100 Ω, 470 Ω and 2000 Ω. Suggest and explain why they chose the 470 Ω resistor.

....

....

....

.... **[2]**

The final question in Section A is based around the standard potential divider circuit. Candidates may not have used a strain gauge before. This question is written in the understanding that this particular use of a potential divider is unfamiliar to candidates. It was encouraging to see such a high proportion of responses linking similar resistance of the two components in the circuit with sensitivity of the sensor.

Question 3 (a) (ii)

(ii) Show that the p.d. across the resistor when the gauge is not under strain is about 3.6 V

[2]

This is a standard calculation and was performed correctly by the majority of candidates. Some did not gain the second mark for not giving their own value from the calculation – a necessity in 'show that' questions.

Assessment for learning

When a question asks the candidate to show that a value is 'about' a given figure it is crucial that the candidate gives their own value to show that this is 'about' the given figure and not precisely the same.

Question 3 (a) (iii)

(iii) The p.d. across the resistor drops to 3.57 V when the gauge experiences a tensile force. Calculate the resistance of the gauge in this case.

resistance = ... Ω **[2]**

Some candidates tried to calculate the resistance using current and p.d. values across the circuit. This is a legitimate method but requires the correct current value. Candidates using this approach often used a current value calculated in part (a) (ii) which does not apply in this situation. Candidates using the standard potential divider equation generally gained both marks.

Question 3 (b)

(b) Two gauges are fixed on a beam, clamped at one end, as indicated in **Fig. 3.3a**.

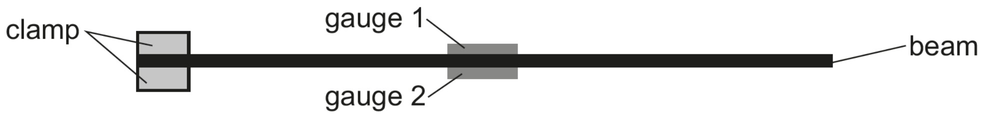

Fig. 3.3a (not to scale)

Fig. 3.3b (not to scale)

When the beam is bent down, as shown in **Fig. 3.3b**, gauge 1 stretches, increasing its resistance, and gauge 2 compresses, decreasing its resistance. The two resistances change by the same amount.

The two gauges are connected into the potential divider circuit as indicated in **Fig. 3.4**.

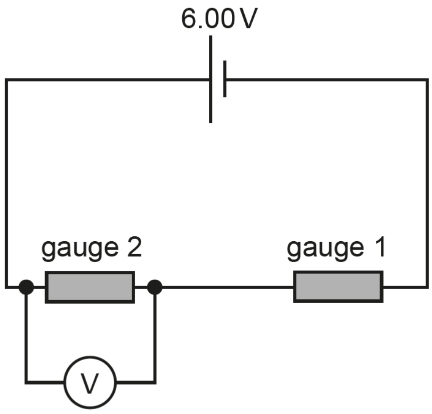

Fig. 3.4

When the wires in the gauges are stretched or compressed the volume of the wire remains the same; shortening the wire increases its cross-sectional area and lengthening the wire decreases its cross-sectional area.

Calculate the reading on the voltmeter when the strain on each gauge = ± 0.01 (1%). Assume the resistivity remains constant.

Data:

total length of unstrained wire in each gauge: 0.118 m

initial cross-sectional area of wire: 1.84×10^{-10} m

resistivity of wire: $4.83 \times 10^{-7}\,\Omega$ m

voltmeter reading = ... V **[4]**

Successful candidates usually calculated the new resistance of each gauge using the data. Some realised that if the strain changes by a factor of 0.01, so will the length. Few candidates who took this approach realised that this will also result in a change in cross-sectional area by the same factor. Two

marks were available for correct use of the potential divider equation irrespective of the resistance values calculated. This highlights the importance of showing all working.

Erratum notice

Turn to **page 9** of the **question paper** and look at **question 3**.

Look at **Data:**

In the second line of Data add the 'squared symbol' to the units 'm'

The sentence should now read:

'**initial** cross-sectional area of wire: 1.84×10^{-10} m^2'

Section B overview

Section B comprises three questions of around fifteen marks each. These questions tend to have longer sections and are typically more challenging than Section A questions.

Question 4 (a) (i)

4 This question is about the force on a current-carrying wire in a magnetic field.

A student sets up an experiment to measure the field strength between a pair of magnets as shown in **Fig. 4.1a**. A stiff copper wire experiences a force when it carries a current. The magnetic field when no current is flowing through the wire is represented in **Fig. 4.1b**.

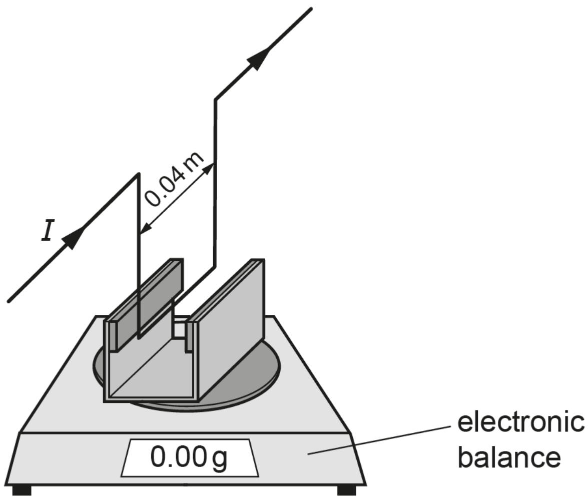

Fig. 4.1a

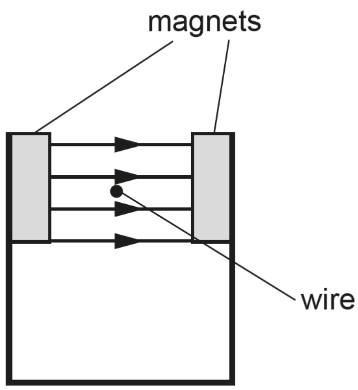

Fig. 4.1b

(a) (i) The reading on the electronic balance changes when the current in the wire changes. Explain why this is an example of Newton's Third Law of motion.

....

....

.... **[2]**

The majority of the candidates recalled Newton's Third Law accurately. More successful candidates explained the idea of the same type of force acting on two bodies. The mark scheme allows for this explanation to be based around the situation given in the question. Less successful candidates gave imprecise explanations, for example, by not making it clear that the forces considered are in opposing directions.

Question 4 (a) (ii)

(ii) 0.040 m of the copper wire is within the uniform magnetic field which acts perpendicularly to the wire.

The reading on the balance changes by 1.4 gram when the wire carries a current of 3.1 A.

Calculate the strength *B* of the magnetic field.

field strength = ... T **[2]**

This standard calculation was correctly worked through by most candidates. Once again, some lower performance responses omitted to convert a mass in grams to a force in newtons.

Question 4 (a) (iii)

(iii) The student records the balance reading for a range of current values. She plots a graph of balance reading (*y*-axis) against current (*x*-axis). Explain how she can use the graph to find a value for the field strength. Describe why this can give a more reliable result than finding the mean value from a number of estimates of field strength using a range of current values.

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....

.... **[3]**

Only a small proportion of responses gained 3 marks for this question. It is important that candidates record each stage of an explanation. In this case, it is important to state what the gradient represents as the basis of the explanation of finding field strength. Many responses correctly identified the benefits of establishing field strength using the gradient rather than the mean of the values although lower performance responses suggested that the gradient gives a better average, without saying why.

Question 4 (b) (i)

(b) (i) A wire of length 0.90 m carries an alternating current of frequency 50 Hz. The tension in the wire can be changed using weights as indicated in **Fig. 4.2**.

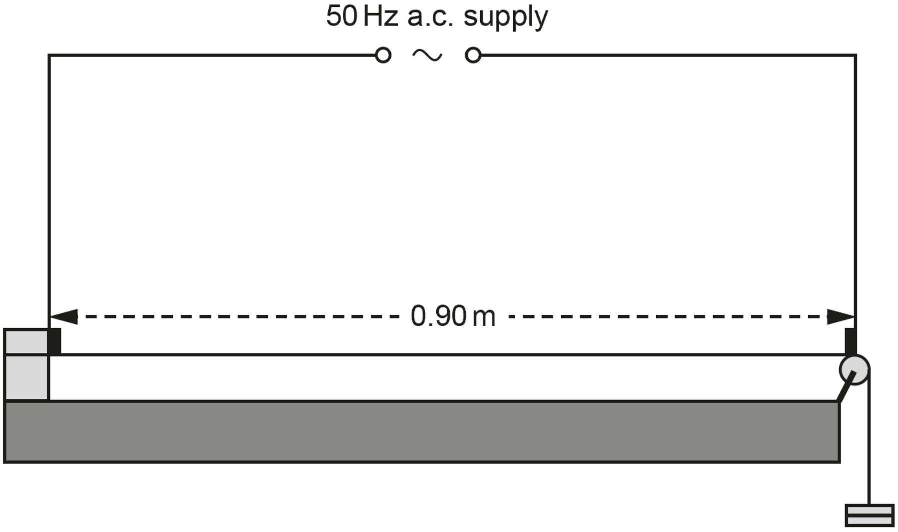

Fig. 4.2

The Earth's magnetic field exerts a force on the current carrying wire. Explain why this makes the wire oscillate at frequency of 50 Hz.

....

....

.... **[2]**

Although the majority of candidates gave responses to this part of the question, many did not gain marks because their explanations were not detailed enough. Responses such as 'the force changes because of the alternating current' are not incorrect but not a full explanation. Examiners were looking for a clear link between a stated change in direction of current leading to a change in direction of the force.

Some responses focused on why the wire experienced a force, rather than why the wire oscillates.

Question 4 (b) (ii)*

(ii)* The 0.90 m wire has mass per unit length, $\mu = 0.0046\,\text{kg}\,\text{m}^{-1}$.

The velocity c of transverse waves in a wire is given by the equation

$$c = \sqrt{\frac{T}{\mu}}$$

where T is the tension in the wire.

The amplitude of the 50 Hz oscillations reaches a maximum when $T = 37$ N.

Explain this observation, including relevant calculations and the underlying physics of the phenomenon.

....

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....

....

....

.... **[6]**

This is a challenging level of response question. Candidates are required to perform a calculation with little scaffolding and link this clearly to a resonant phenomenon. A good proportion of responses included correct calculations, for example of the speed of the wave along the wire, but only a small minority went on to show that this gives a frequency of about 50 Hz for a wavelength of 1.80 m – that of the fundamental vibration mode of the wire. Descriptions of resonance tended to be superficial and rarely went beyond a statement that the natural frequency matches the driving frequency at resonance.

Assessment for learning

It is helpful to discuss resonance in energy terms. The oscillator gains energy each cycle during the early stages of a resonant response and its amplitude increases. The amplitude stops increasing when the energy lost (transferred away) per cycle is equal to the energy gained (transferred to the oscillator) per cycle.

Exemplar 1

12

(ii)* The 0.90 m wire has mass per unit length, μ = 0.0046 kg m^{-1}.

The velocity c of transverse waves in a wire is given by the equation

$$c = \sqrt{\frac{T}{\mu}}$$

where T is the tension in the wire.

The amplitude of the 50 Hz oscillations reaches a maximum when T = 37 N.

Explain this observation, including relevant calculations and the underlying physics of the phenomenon.

$c = \sqrt{\frac{37}{0.0046}} = 89.7\ ms^{-1}$

$\lambda = 2l = 2 \times 0.9 = 1.8\ m$

$c = f\lambda \Rightarrow f = \frac{c}{\lambda} = \frac{89.7}{1.8} = 49.8\ Hz \approx 50\ Hz$

$F = ma$ $\quad T = \frac{1}{f} = \frac{1}{50} = 0.02\ s$

$F = m\left(\frac{\Delta v}{\Delta t}\right) = \frac{1.8 \times 0.0046 \times 89.7}{0.02} = 37.1\ N$

Amplitude reaches a maximum when the system goes into resonance - this is when the driving frequency from the AC supply matches the natural frequency of the wire from the Earth's magnetic field, leading to large amplitude oscillations

As the transverse wave travels down the wire, it will reflect off of the fixed end. It will interfere with a wave travelling in the opposite direction & the superposition will lead to the creation of nodes (0 amplitude) & antinodes (max. amplitude).

This exemplar highlights a number of points. You can see from the candidate's annotations that they have thought carefully about how to respond to the question. The wavelength of the fundamental mode is clearly stated and is used with the calculated velocity to give the natural frequency of the oscillation. The explanation is not complete, with no explanation of why large amplitude oscillations develop and the calculation is not sufficiently linked to the explanation.

Question 5 (a)

5 In the seventeenth century, the astronomer Johannes Kepler published a relationship between the period of a planet's orbit and the radius of the orbit.

This can be expressed mathematically as $T^2 = kr^3$ where T is the period and r the radius of the orbit.

(a) Use the equation for centripetal force and the equation giving the gravitational force between two bodies, to show that the constant k in Kepler's relationship is equal to $\frac{4\pi^2}{GM}$.

Make each step of your reasoning clear.

[3]

Question 5 opens with a standard derivation made a little different by requiring a constant to be derived. It was interesting that many candidates tackled the question through angular velocity, omega rather than instantaneous velocity. Candidates who did not work through the derivation typically became muddled with the negative value for gravitational force.

Question 5 (b)

(b) Ganymede is the largest moon of the planet Jupiter.
It orbits Jupiter at a distance of 1.07×10^9 m. The period of the orbit is 6.18×10^5 s.
Use Kepler's relationship to show that the mass of Jupiter is about 2×10^{27} kg.

[2]

Most candidates gained full marks for this question, a matter of substituting values into a given equation.

Question 5 (c) (i)

In December 2016, the spacecraft Juno went into orbit around Jupiter.
It followed the highly elliptical orbit as shown in **Fig. 5.1**.

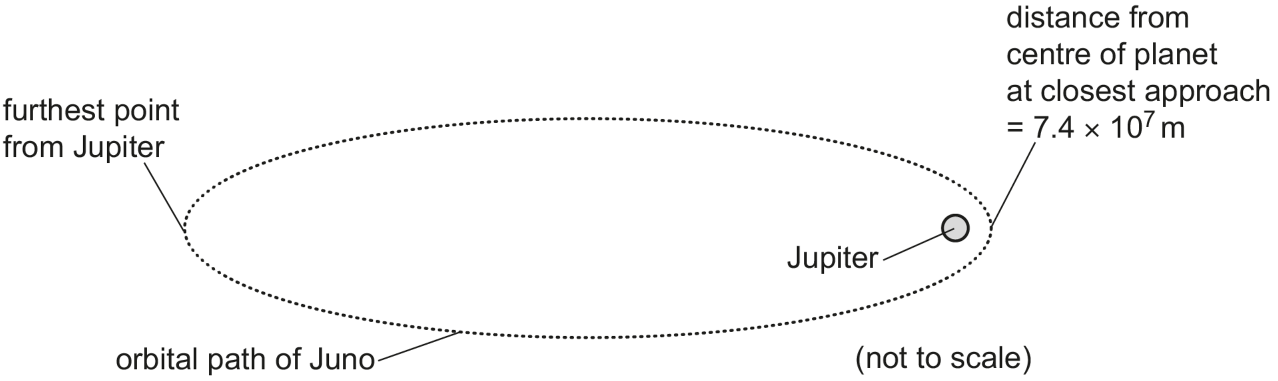

Fig. 5.1

(c) (i) Use ideas of energy transfer to explain why the spacecraft moves faster when it is nearer to Jupiter. The spacecraft motors are not used when it is orbiting the planet.

....

....

....

.... **[3]**

Once again, less successful candidates did not gain full marks for the question because their explanations were incomplete. The majority gained the mark for a transfer of gravitational potential energy to kinetic but a smaller proportion stated that the total energy is constant, an important part of the argument. Only the higher performance candidates stated that the gravitational potential energy becomes more negative as Juno approaches the Sun. Some responses did not follow the instructions in the stem of the question and considered force rather than energy.

Question 5 (c) (ii)

(ii) The spacecraft Juno travels at $5.8 \times 10^4\,\mathrm{m\,s^{-1}}$ at its closest approach to the planet.

At its furthest point from Jupiter, the spacecraft is $1.0 \times 10^9\,\mathrm{m}$ from the centre of Jupiter. Use information in **Fig. 5.1** and the mass of Jupiter from part **(b)** to calculate the speed of the spacecraft.

speed = ... $\mathrm{m\,s^{-1}}$ **[4]**

This proved to be the most challenging question on the paper. The question requires a clear understanding of the negative nature of gravitational potential. The more successful candidates correctly calculated the total energy/kg from the data available for Juno at closest approach and then calculated the potential at Juno's greatest distance from the Sun. A small minority of the responses continued to calculate the velocity. Many candidates struggled with not being given the mass of Juno. As in part (a) the negative nature of gravitational potential proved problematic for many and led to incorrect calculations. This was particularly evident in otherwise confident candidates who attempted to reach the answer in one step.

Question 5 (d)

(d) The spacecraft fired motors to slow it down before it entered orbit with Jupiter. Suggest and explain why this was necessary.

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....

.... **[3]**

The majority of responses gained at least one mark for this part of the question by suggesting that the spacecraft would have too much kinetic energy to be 'captured' by Jupiter unless it slowed down. More successful responses did use the idea of escaping from Jupiter's potential well or that if the magnitude of the spacecraft's kinetic energy was greater than the magnitude of the potential energy during the approach the spacecraft would not orbit the planet.

Question 6 (a) (i), (ii), (iii)

(ii) Draw a curve on **Fig. 6.1** showing how the velocity of the oscillator varies with time. Label this line 'v'. **[1]**

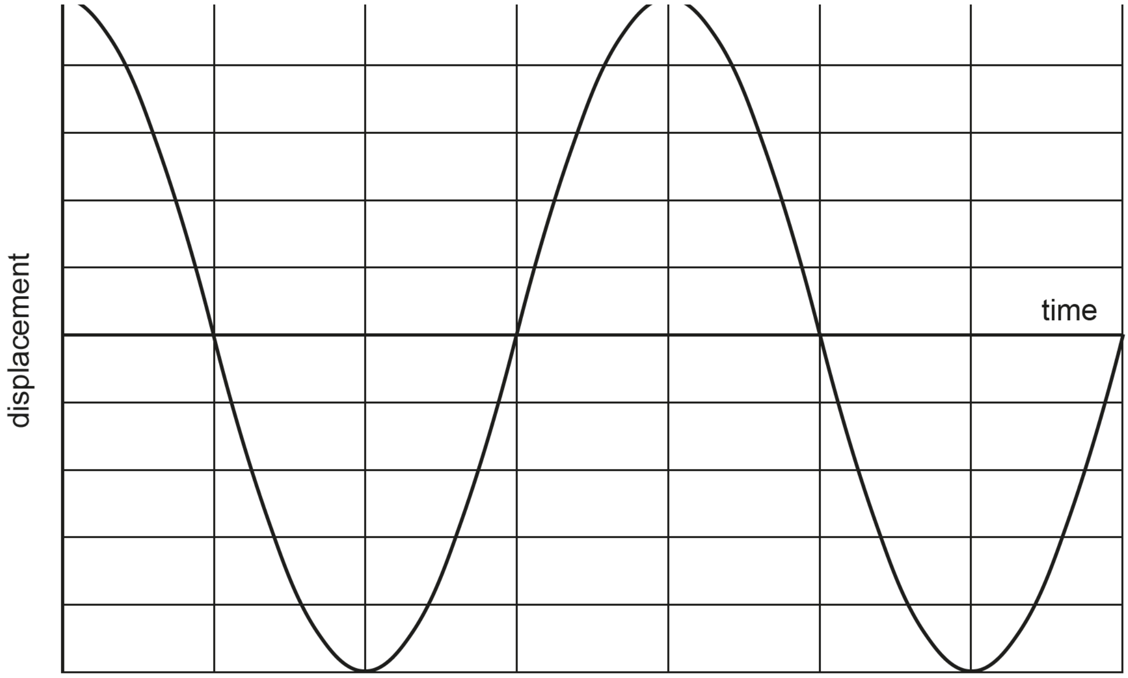

Fig. 6.1

(a) (i) State how the graph shows that the oscillator is undamped.

....

.... **[1]**

(ii) Draw a curve on **Fig. 6.1** showing how the velocity of the oscillator varies with time. Label this line 'v'. **[1]**

(iii) Draw a curve on **Fig. 6.1** showing how the acceleration of the oscillator varies with time. Label this line 'a'. **[1]**

Many candidates gained all 3 marks for the (a) section of the question, an exercise in recall and careful drawing.

Question 6 (b) (i)

The oscillation of a mass held between springs can be iteratively modelled.

Fig. 6.2 shows the model together with the data for the system.

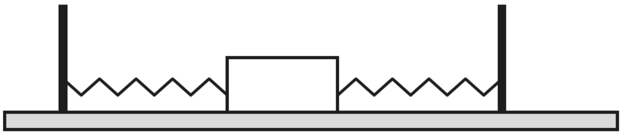

Fig. 6.2

Data:

force (spring) constant k of system = 18 N m^{-1}

mass of oscillator m = 0.60 kg

amplitude of oscillation = 0.12 m

time interval between calculations (iterations) Δt = 0.05 s

Fig. 6.3 shows the flowchart for the iterative calculations.

x represents the displacement from the equilibrium position.

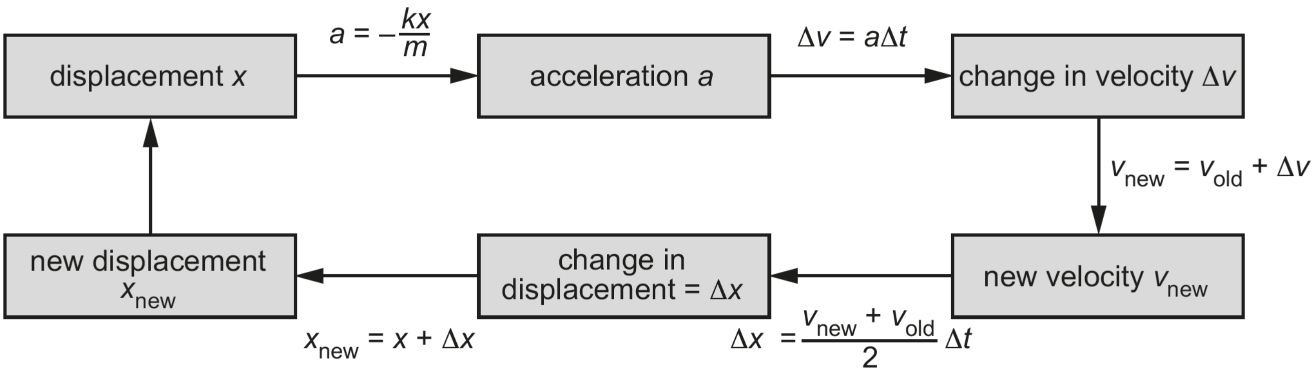

Fig. 6.3

(b) (i) State why the change in displacement during an iteration is given by

$$\Delta x = \frac{v_{new} + v_{old}}{2}\Delta t$$

....

.... **[1]**

This was an accessible challenge for most candidates who recognised that mean velocity is used in the model.

Question 6 (b) (ii)

(ii) The model starts at t = 0 s with x = 0.1200 m at a velocity v_{new} = 0.000 m s^{-1}. The table below has the first two rows filled in.
Use the flow chart to complete the third row of the table.

time / s	***x* / m**	***a* / m s^{-2}**	**Δv / m s^{-1}**	**v_{new} / m s^{-1}**	**Δx / m**	**x_{new} / m**
0.0	0.1200			0.000	0.0000	0.1200
0.05	0.1200	–3.600	–0.180	–0.180	–0.0045	0.1155
0.10	0.1155					

[3]

Most responses gained full marks for this part of the question, those that did not gain 3 marks often did not give the values to the required precision or forgot the negative sign after the first calculation.

Question 6 (b) (iii)

Further iterations of the model produce the graph shown in **Fig. 6.4**.

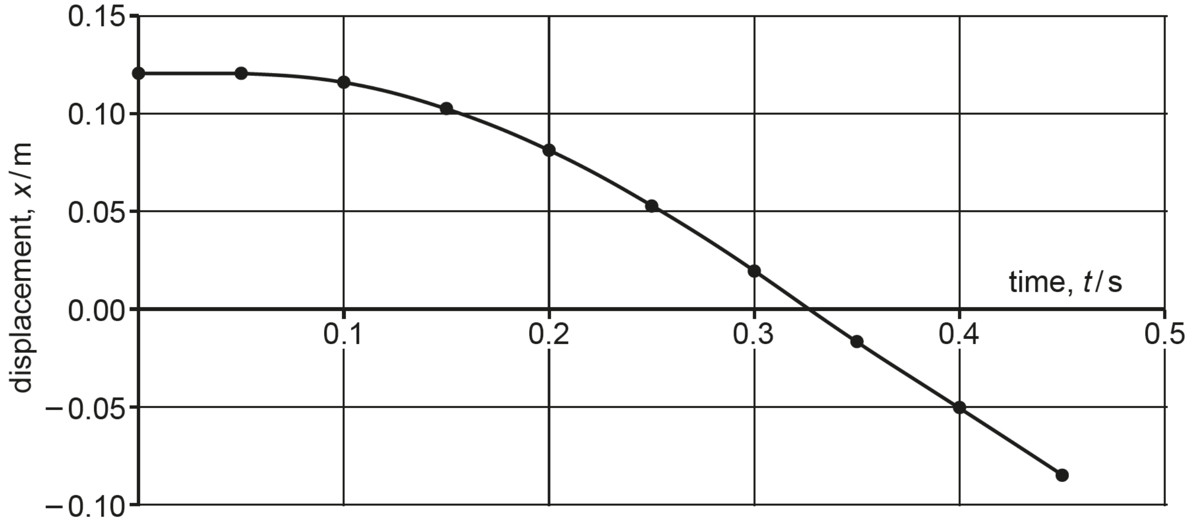

Fig. 6.4

(iii) Use the graph to estimate the frequency of the oscillation and compare this to the result found using the equation for the time period of a mass-spring oscillator. Suggest and explain any difference in the two values.

frequency obtained from the graph = ... Hz

frequency calculated from equation = ... Hz

....

....

....

.... **[4]**

The majority of candidates correctly calculated the two values of frequency. Some candidates suggested that the graphical result was inaccurate because the velocity was assumed to be constant in the model. This is not the case as the model produces a mean velocity which takes into account the change in velocity to a limited extent. The crucial assumption is that the acceleration is kept constant during each iteration. Many candidates explained how the model could be improved – but this is not what the question required. Some candidates also noted the practical difficulty of reading the time period from the graph.

Misconception

A significant proportion of responses suggested that the iterative model was inaccurate as it did not take into account drag or other empirical factors – making the implicit assumption that the equation for a mass-spring oscillator does take these factors into account

Question 6 (c)

(c) When the model is run over many more iterations, the graph in **Fig. 6.5** is produced.

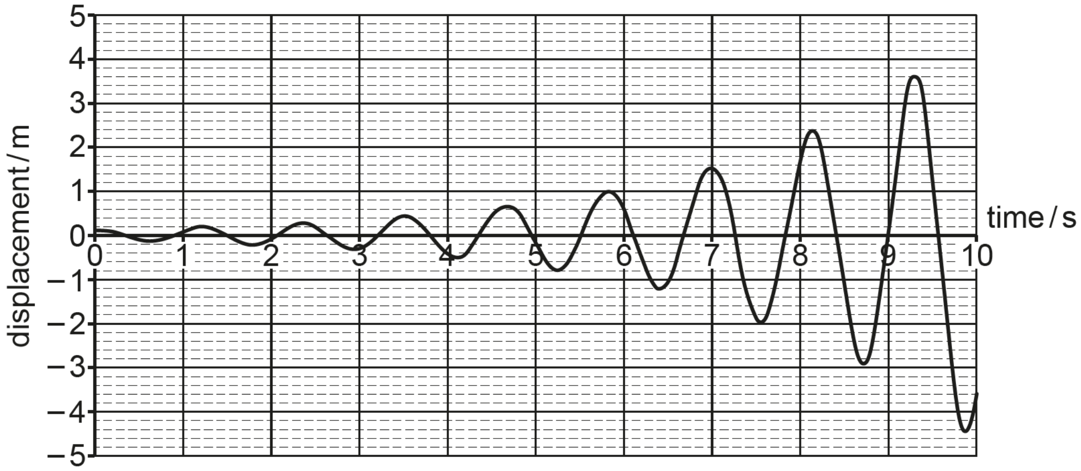

Fig. 6.5

The model incorrectly predicts that the amplitude of the oscillation increases over time. A student suggests that the model shows that the energy of the oscillator increases by a constant factor during each oscillation. Perform calculations to test this suggestion, stating your conclusion. Explain your method and reasoning.

[4]

Although most responses recognised that the energy of an oscillator is proportional to amplitude squared, many of the calculations relied on a comparison of amplitudes rather than their squares. Less successful responses considered the difference in amplitudes rather than the ratio of amplitudes (or, correctly, the ratio of the squares).

Assessment for learning

Only a small proportion of responses gave clear explanations of the reasoning behind the test undertaken on the data. It is useful to discuss such tests with candidates and give them opportunities to explain tests verbally before setting their ideas down on paper. Candidates can be remined that instructions such as 'explain your method' imply that one or more of the marks for the question is given for explanation.

Section C overview

Section C is based on the Advance Notice article. Many of the candidates seemed well-prepared for the section, with clear familiarity with the context of the questions set. There was little evidence of candidates running out of time at the end of the paper.

Question 7

7 This question is about the movement of energy through the radiative zone (lines 53 – 60).

Use the equation given in the article (line 58) to estimate the number of steps required for a photon to make a displacement of 3.5×10^8 m through the radiative zone. Use this value to calculate the total distance travelled by a photon as it passes through the radiative zone and show that this suggests that radiation takes about 100 000 years to travel through the zone.

distance between photon-electron interactions, $x = 1.2 \times 10^{-4}$ m

1 year = 3.2×10^7 s

number of steps = ... **[3]**

Although not all candidates crossed out the answer line as instructed in the erratum notice the majority gained all 3 marks available, using information in the article to reach the correct value.

Erratum notice

Turn to **page 20** of the **question paper** and look at **question 7**.

Cross out the answer line 'number of steps = ……………………' and use the blank space on the page to answer the question.

Question 8 (a)

8 This question is about the aurorae (lines 15 – 26).

(a) Explain the mechanism that produces light from aurorae and calculate the energy associated with photons of the green light of wavelength 558 nm that is often seen in aurorae.

....

....

....

....

....

....

photon energy = ... J **[3]**

Most responses correctly calculated the energy of the photons emitted. Although many candidates had a grasp of the energy changes involved in the interaction between cosmic ray particles and electrons in atmospheric atoms, explanations were not always clear. For example, some discussions involved the absorption of photons, confusing this situation with the photoelectric effect. Some candidates wrote of the cosmic ray particles being absorbed by atmospheric atoms or producing ionisation. Both these mechanisms are plausible but do not explain photon release.

Question 8 (b) (i)

(b) **(i)** The article states that the charged particles in the solar wind 'spiral down the magnetic field near the poles'. Consider an electron in the solar wind moving with a velocity of $5.0 \times 10^5\,\mathrm{m\,s^{-1}}$ perpendicular to a uniform field of strength $40\,\mu\mathrm{T}$ as shown in **Fig. 8.1**.

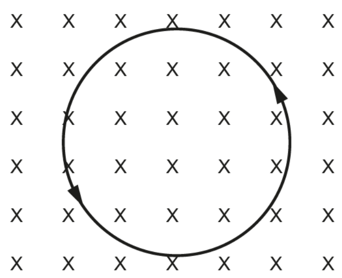

Fig. 8.1

Show that the electron will travel in a circle of approximately 7 cm radius. Show your method.

[2]

The majority of responses gained both marks for this standard calculation. Some candidates were only given one mark because they did not give their own value of the radius.

Question 8 (b) (ii)

(ii) Consider the situation represented in **Fig. 8.2**.

An electron is travelling at $5.0 \times 10^5\,\mathrm{m\,s^{-1}}$ at an angle of 25° to the direction of the magnetic field of strength 40 μT (**Fig. 8.2a**). It forms a spiral of radius $r = 0.029\,\mathrm{m}$ (**Fig. 8.2b**).

By considering horizontal and vertical components of its velocity, calculate the vertical distance d the electron travels between each full rotation around the field line.

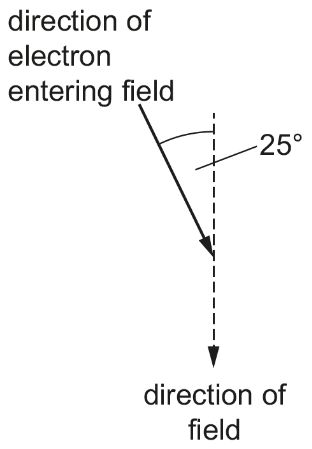

Fig. 8.2a

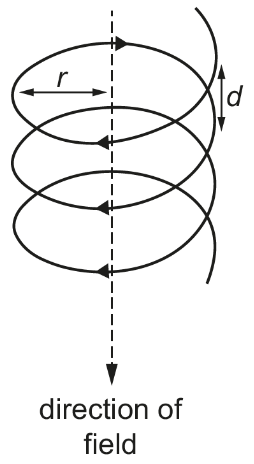

Fig. 8.2b

distance d = ... m **[4]**

This is a more challenging question and it was encouraging to see that the majority of responses gained at least one mark. Two marks can be gained by carrying forward errors in the horizontal and vertical components of velocity. As always, some candidates find the trigonometry involved in resolving components rather difficult and reverse the two components. More successful candidates gained all 4 marks and often showed very clear working indicating confidence in the method and familiarity with the context from the Advance Notice article.

Question 8 (b) (iii)

(iii) Suggest and explain how the spiral might change as the electron moves nearer to the pole, considering the strengthening field and the energy transferred to particles in the atmosphere.

....

....

....

.... **[2]**

This proved to be an accessible question with the majority of responses gaining both marks and few misconceptions evident. Those candidates that only scored one mark did not clearly link an explanatory statement (for example, strengthening field) with the stated change to the spiral.

Question 9*

9* This question is about the slow rate of fusion in the Sun (lines 33 – 47).

The temperature of the core of the Sun is 1.5×10^7 K. Assuming that two protons need to come to within 10^{-14} m of each other to fuse, show that, on average, protons in the core do not have enough kinetic energy to fuse.

Explain, using calculations, why the Boltzmann factor for the process shows that fusion of any two protons at this temperature is extremely unlikely and that it cannot account for the 3.7×10^{38} protons which fuse in the Sun each second.

The total mass of the Sun is 2×10^{30} kg.

[6]

The second level of response question on the paper produced a wide range of marks. Many candidates successfully calculated the Boltzmann factor by calculating the average energy per particle and the energy required to overcome the potential barrier between particles. More successful candidates estimated the number of fusions required per second and then compared this value with the number calculated from the Boltzmann factor. However, only very few considered that both protons in the reaction, on average, will have the average energy which therefore doubles the energy of the collision. Nevertheless, the quality of the work of the best candidates near the end of a long paper was most impressive.

Exemplar 2

$kT = 1.5\times10^{7} \times k = 2.07\times10^{-16}$

$E = \frac{kqQ}{r}$ $= 2.31\times10^{-14}$ (A)

$2.07\times10^{-16} < 2.31\times10^{-14}$

$E_A = 2.31\times10^{-14}$

$f = e^{-\frac{E_A}{kT}} = 3.57\times10^{-49}$, this number is the fraction of particles that can be expected to reach the activation energy, it is very low

Assuming all mass of sun of protons; since it is mostly hydrogen

$\frac{2\times10^{30}}{1.673\times10^{-27}} = 1.195\times10^{57}$ protons

$1.195\times10^{57} \times 3.57\times10^{-49} = 4.27\times10^{8}$, which is nowhere close to the 3.7×10^{38}, almost a magnitude of 30 off; and this is even assuming that all of the mass of the sun is protons, which it isn't.

This exemplar, from a candidate who performed well across the paper, is a typical Level 3 response.

In addition to correct calculations the candidate has included explanations of what the Boltzmann factor shows, why assuming the mass of the Sun is mostly composed of protons – but noting that this is not completely accurate. The candidate writes clearly and concisely about the situation but omits to consider the combined energy of the interacting protons.

Question 10 (a)

10 This question is about the Parker Solar Probe mission (lines 114 – 138).

(a) The Earth orbits the Sun at a distance of 1.5×10^{11} m. At this distance the intensity of solar radiation is $1400\,\text{W m}^{-2}$. Calculate the intensity at the distance of 1.4×10^{10} m – the close approach that the Parker probe made to the Sun in January 2021.

intensity = ... W m^{-2} **[2]**

This part of the last question on the paper tests the candidates understanding of the inverse-square law for intensity and their familiarity with the ideas in the article. Early on in the article (line 13) the radiant power of the Sun is described as spreading over a sphere. Candidates can use this method of arriving at the intensity at the close approach of the Parker probe or use simple ratio. The majority of the candidates correctly performed the calculation using one of these approaches.

Question 10 (b)

(b) Use your answer to **(a)** and Stefan's Law (line 125) to estimate the temperature of a body in thermal equilibrium at 1.4×10^{10} m from the Sun.

temperature = ... K **[1]**

Most candidates gained the mark here, sometimes through bringing forward an error from part (a). This again showed familiarity with the context of the question.

Question 10 (c)

(c) Explain why missions investigating the Sun such as the Parker Solar Probe can have an importance beyond scientific discovery.

....

....

....

.... **[2]**

Many candidates correctly suggested that forecasting coronal mass ejections was a use beyond scientific discovery. Fewer candidates gave specific examples of the dangers of such events and some simply quoted the article.

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