OCR
Oxford Cambridge and RSA

Friday 10 June 2022 – Afternoon

A Level Physics B (Advancing Physics)

H557/02 Scientific literacy in physics

Time allowed: 2 hours 15 minutes

You must have:
- a clean copy of the Advance Notice Article (inside this document)
- the Data, Formulae and Relationships Booklet

You can use:
- a scientific or graphical calculator
- a ruler (cm/mm)

Please write clearly in black ink. **Do not write in the barcodes.**

Centre number | | | | | | Candidate number | | | | |

First name(s) ____________________

Last name ____________________

INSTRUCTIONS
- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined pages at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- **Use the Insert to answer questions in Section C.**
- Where appropriate, your answer should be supported with working. Marks might be given for using a correct method, even if your answer is wrong.

INFORMATION
- The total mark for this paper is **100**.
- The marks for each question are shown in brackets **[ ]**.
- Quality of extended response will be assessed in questions marked with an asterisk (*).
- This document has **28** pages.

ADVICE
- Read each question carefully before you start your answer.

SECTION A

Answer **all** the questions.

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.

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.... **[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]

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

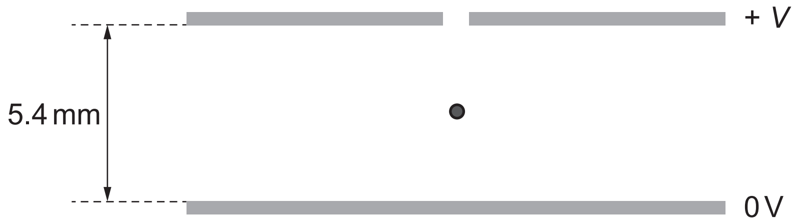

Fig. 1.2 (not to scale)

(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]**

(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]**

(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?

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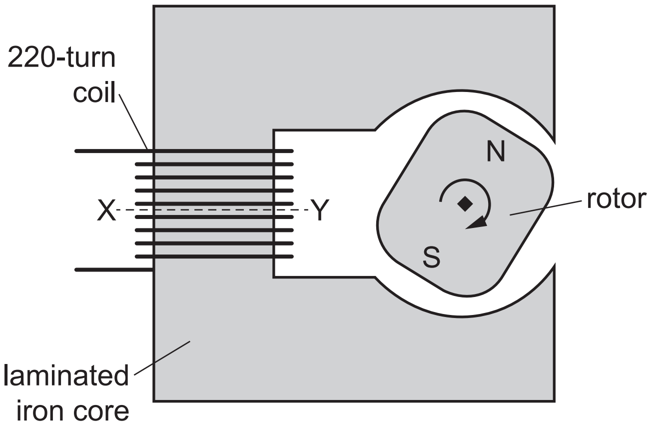
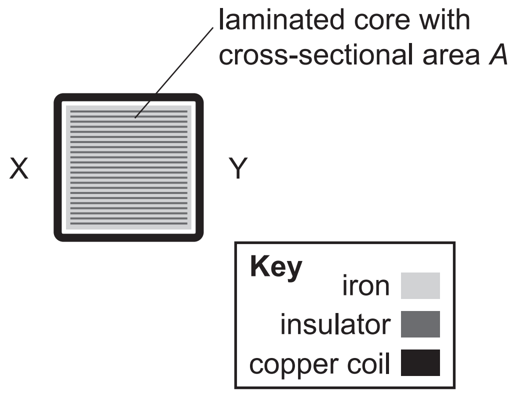
.... **[2]**

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]**

(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.

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.... **[2]**

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

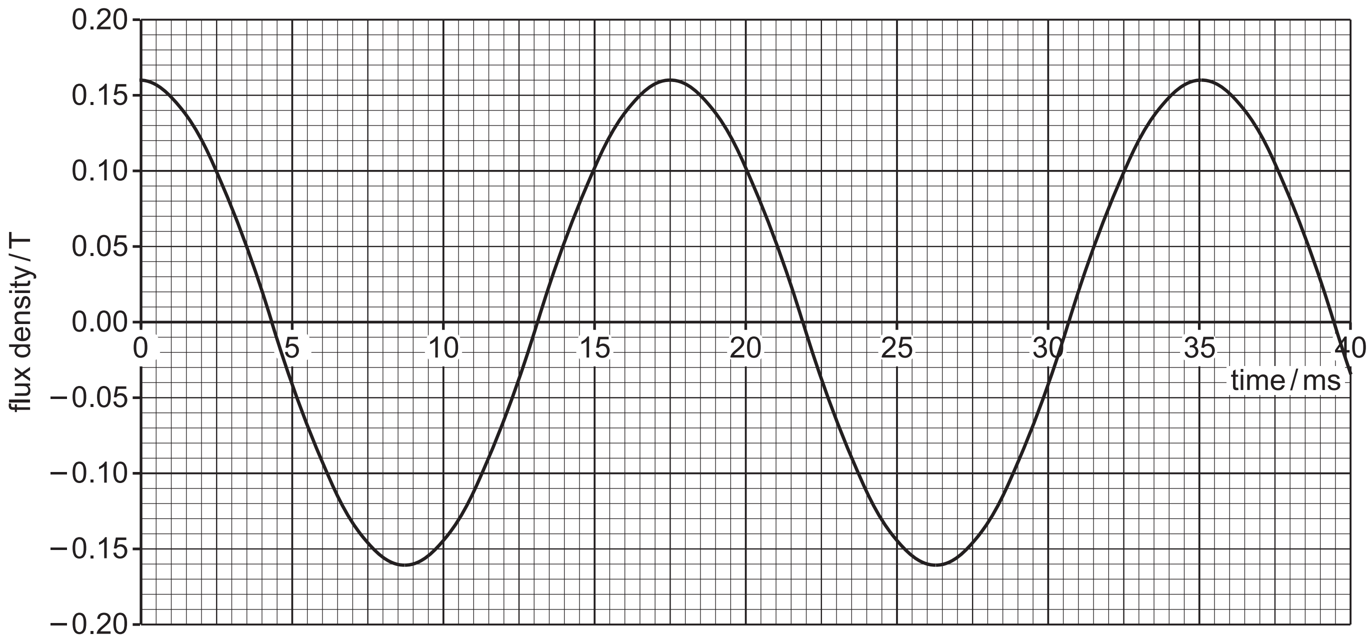

Fig. 2.2

(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]**

(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]**

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.

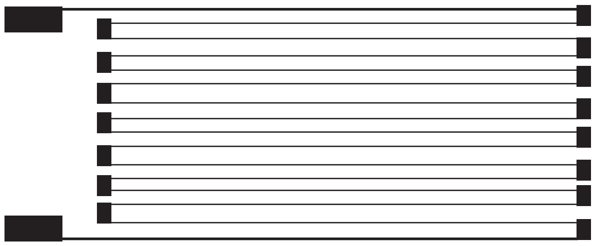

Fig. 3.1

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.

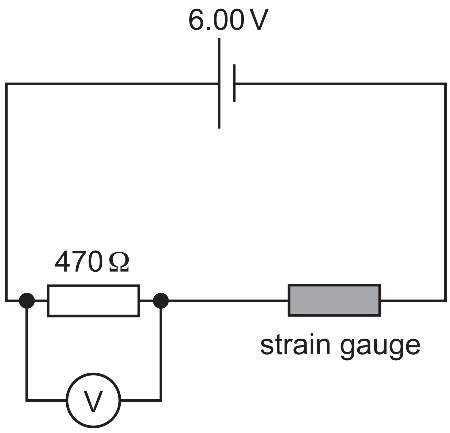

Fig. 3.2

(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.

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.... **[2]**

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

[2]

(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]**

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

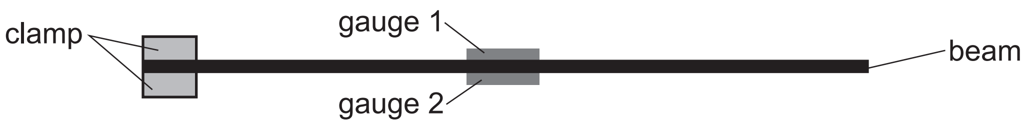

Fig. 3.3a (not to scale)

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**.

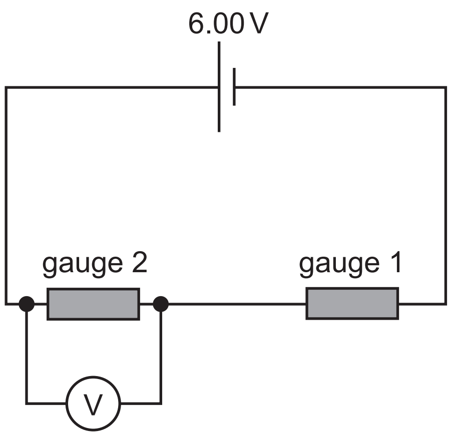

Fig. 3.4

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]**

SECTION B

Answer **all** the questions.

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**.

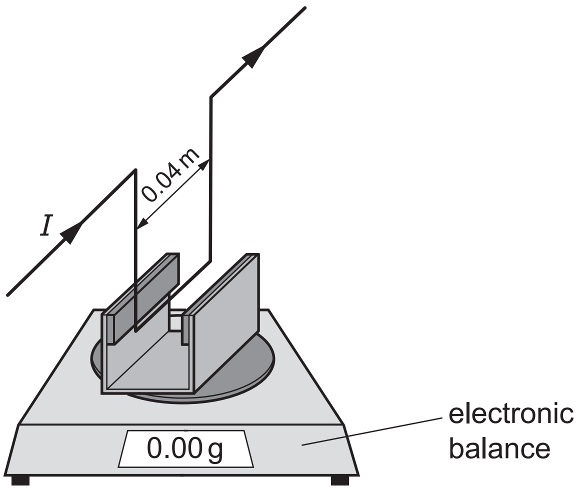

Fig. 4.1a

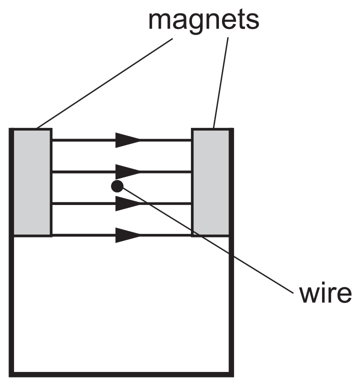

Fig. 4.1b

(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.

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.... **[2]**

(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]**

(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]**

(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**.

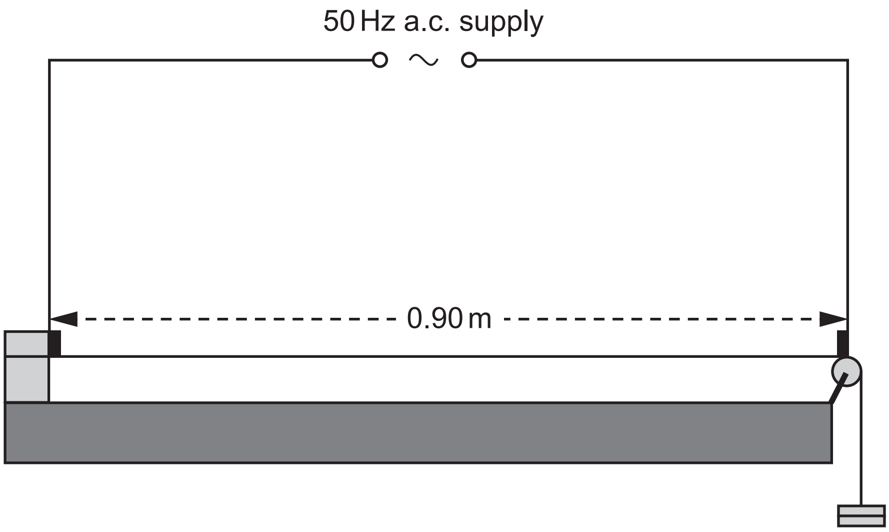

Fig. 4.2

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.

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.... **[2]**

(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.

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.... **[6]**

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]

(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]

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.

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.... **[3]**

(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 1.0×10^9 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]**

(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]**

6 **Fig. 6.1** shows how the displacement of an oscillator varies with time.

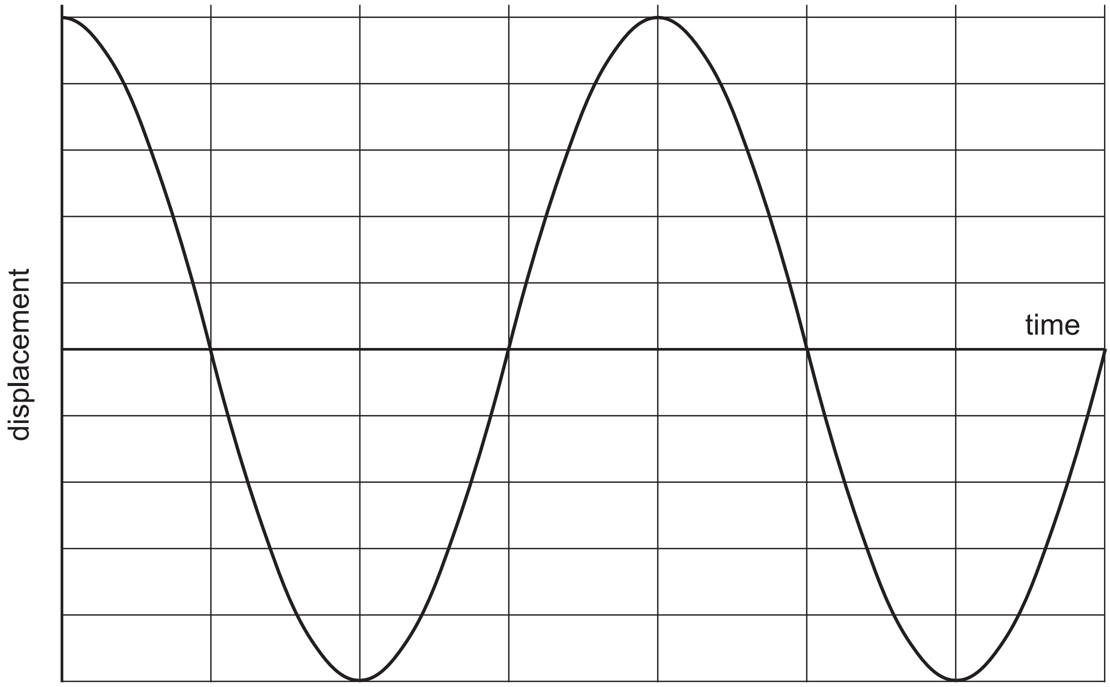

Fig. 6.1

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

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.... **[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]**

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.

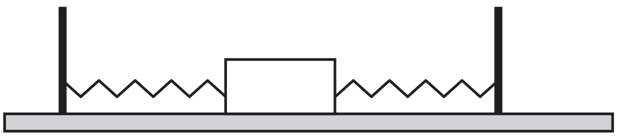

Fig. 6.2

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.

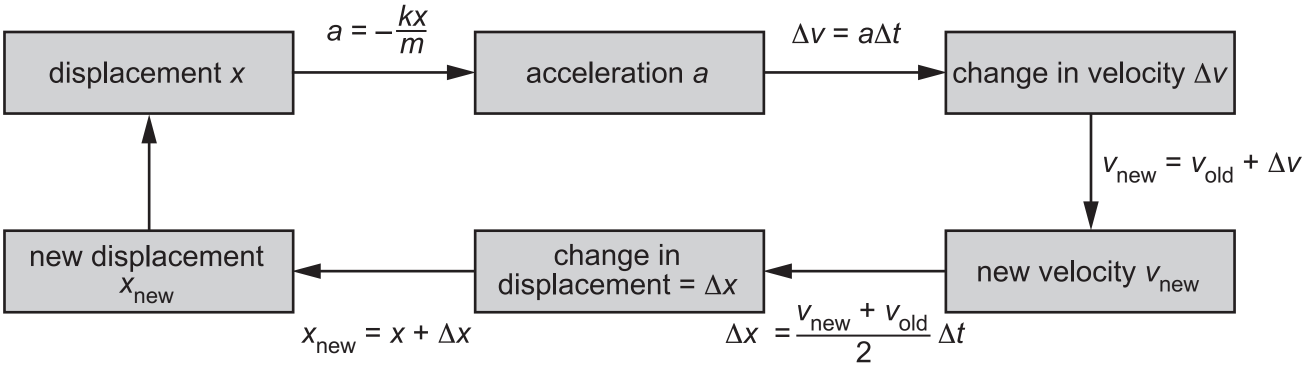

Fig. 6.3

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

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

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.... **[1]**

(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]

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

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.... **[4]**

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

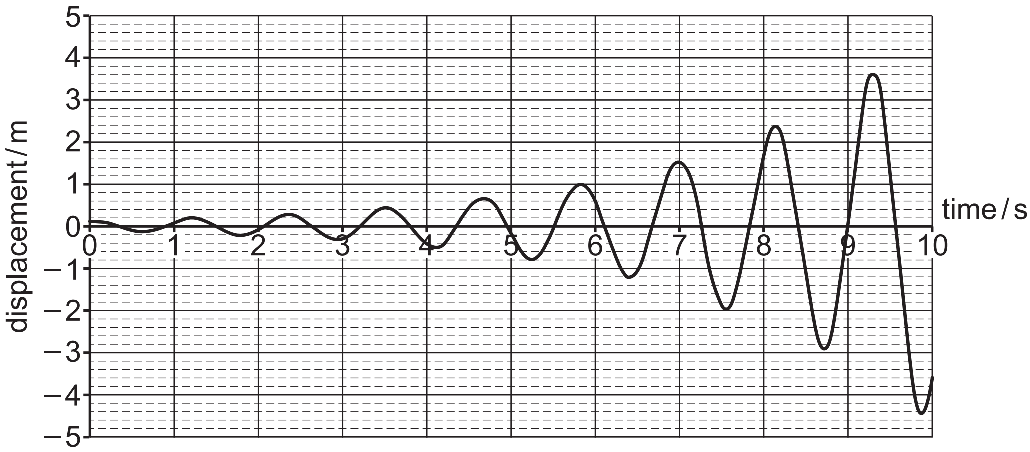

Fig. 6.5

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]

SECTION C

Answer **all** the questions.

This section is based on the Advance Notice Article, which is an insert.

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]**

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.

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

(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 $5.0 \times 10^5\,\text{m}\,\text{s}^{-1}$ perpendicular to a uniform field of strength 40 μT as shown in **Fig. 8.1**.

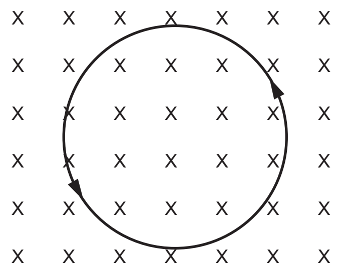

Fig. 8.1

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

[2]

(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 $40\,\mu\mathrm{T}$ (**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.

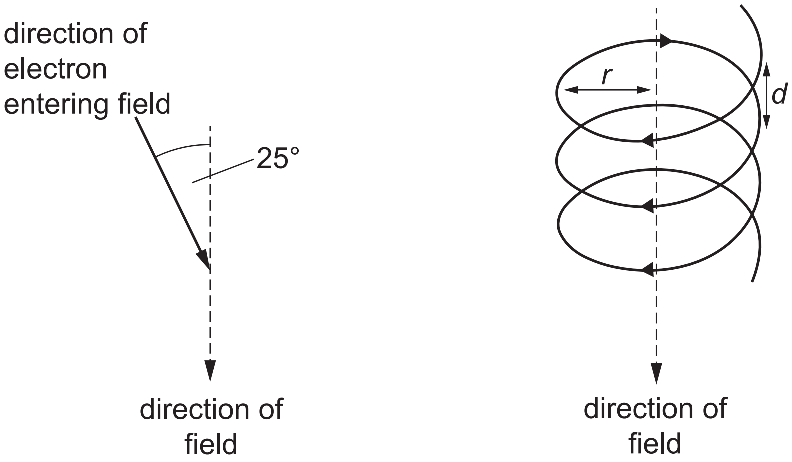

Fig. 8.2a **Fig. 8.2b**

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

(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.

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.... **[2]**

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]

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 $1400\,\text{W}\,\text{m}^{-2}$. 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 = ... $\text{W}\,\text{m}^{-2}$ **[2]**

(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]**

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

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.... **[2]**

END OF QUESTION PAPER

ADDITIONAL ANSWER SPACE

If additional space is required, you should use the following lined page(s). The question number(s) must be clearly shown in the margin(s).