IB DIPLOMA PROGRAMME
PROGRAMME DU DIPLÔME DU BI
PROGRAMA DEL DIPLOMA DEL BI

M05/4/PHYSI/HP2/ENG/TZ1/XX+

22056508

PHYSICS
HIGHER LEVEL
PAPER 2

Thursday 19 May 2005 (afternoon)

2 hours 15 minutes

Candidate session number

0	0							

INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all of Section A in the spaces provided.
- Section B: answer two questions from Section B in the spaces provided.
- At the end of the examination, indicate the numbers of the questions answered in the candidate box on your cover sheet.

SECTION A

*Answer **all** the questions in the spaces provided.*

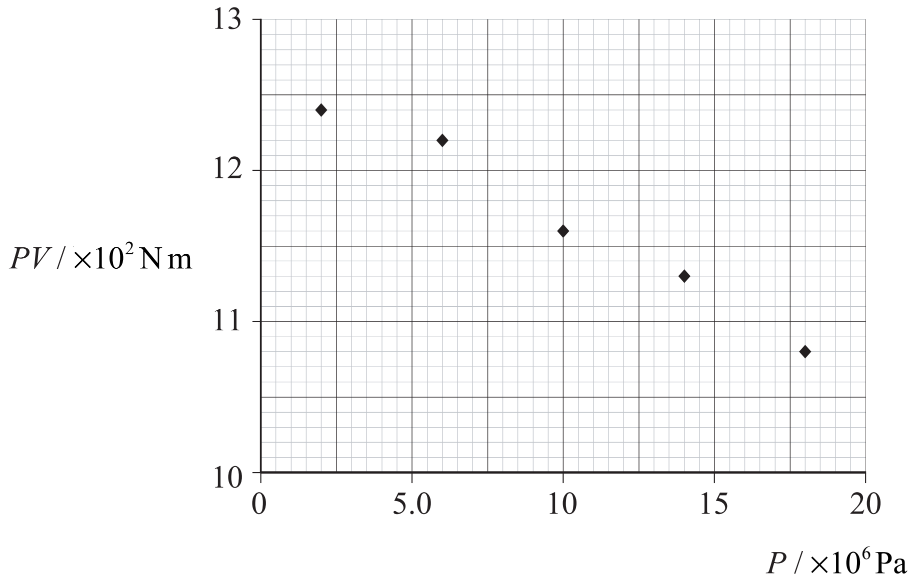
A1. Data analysis question

At high pressures, a real gas does not behave as an ideal gas. For a certain range of pressures, it is suggested that the relation between the pressure P and volume V of one mole of the gas at constant temperature is given by the equation

$$PV = A + BP$$

where A and B are constants.

In an experiment to measure the deviation of nitrogen gas from ideal gas behaviour, 1 mole of nitrogen gas was compressed at a constant temperature of 150 K. The volume V of the gas was measured for different values of the pressure P. A graph of the product PV of pressure and volume was plotted against the pressure P and is shown below. (Error bars showing the uncertainties in measurements are not shown).



(a) Draw a line of best fit for the data points. *[1]*

(This question continues on the following page)

(Question A1 continued)

(b) Use the graph to determine the values of the constants A and B in the equation

$$PV = A + BP\,.$$ *[5]*

Constant A . . . .

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Constant B . . . .

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(c) State the value of the constant B for an ideal gas. *[1]*

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(d) The equation $PV = A + BP$ is valid for pressures up to 6.0×10^{7} Pa.

(i) Determine the value of PV for nitrogen gas at a pressure of 6.0×10^{7} Pa. *[2]*

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(ii) Calculate the difference between the value of PV for an ideal gas and nitrogen gas when both are at a pressure of 6.0×10^{7} Pa. *[2]*

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(e) In the original experiment, the pressure P was measured to an accuracy of 5% and the volume V was measured to an accuracy of 2%. Determine the absolute error in the value of the constant A. *[3]*

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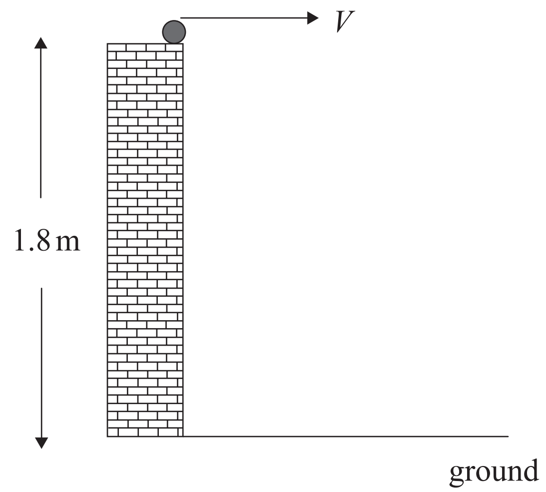
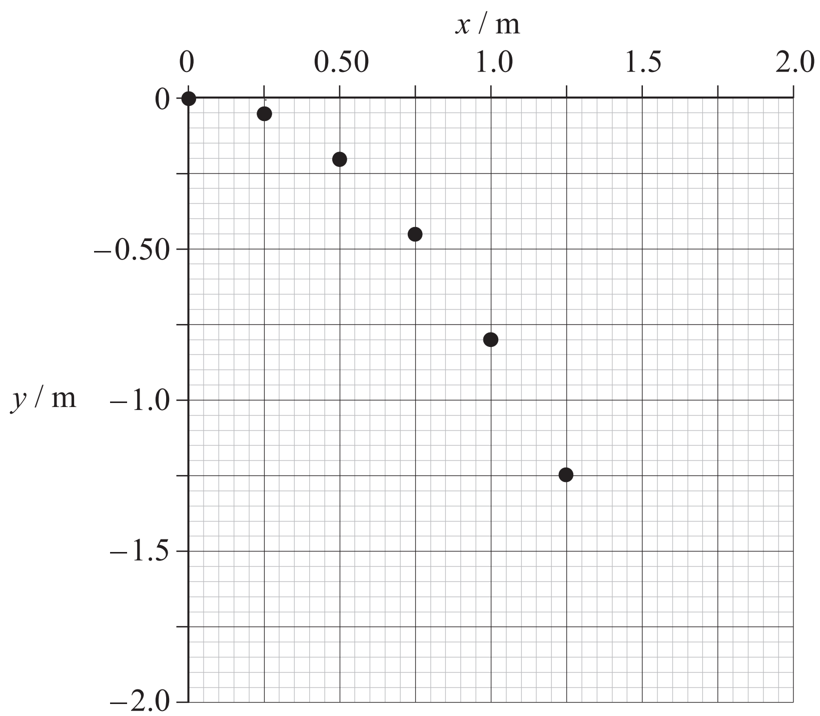
A2. This question is about projectile motion.

A marble is projected horizontally from the edge of a wall 1.8 m high with an initial speed V.



A series of flash photographs are taken of the marble. The photographs are combined into a single photograph as shown below. The images of the marble are superimposed on a grid that shows the horizontal distance x and vertical distance y travelled by the marble.

The time interval between each image of the marble is 0.10 s.



(a) On the images of the marble at $x = 0.5$ m and $x = 1.0$ m, draw arrows to represent the horizontal velocity V_H and vertical velocity V_V. *[2]*

(This question continues on the following page)

(Question A2 continued)

(b) On the photograph, draw a suitable line to determine the horizontal distance *d* from the base of the wall to the point where the marble hits the ground. Explain your reasoning. *[3]*

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(c) Use data from the photograph to calculate a value of the acceleration of free fall. *[3]*

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A3. This question is about an experiment to measure the temperature of a flame.

(a) Define *heat (thermal) capacity* *[1]*

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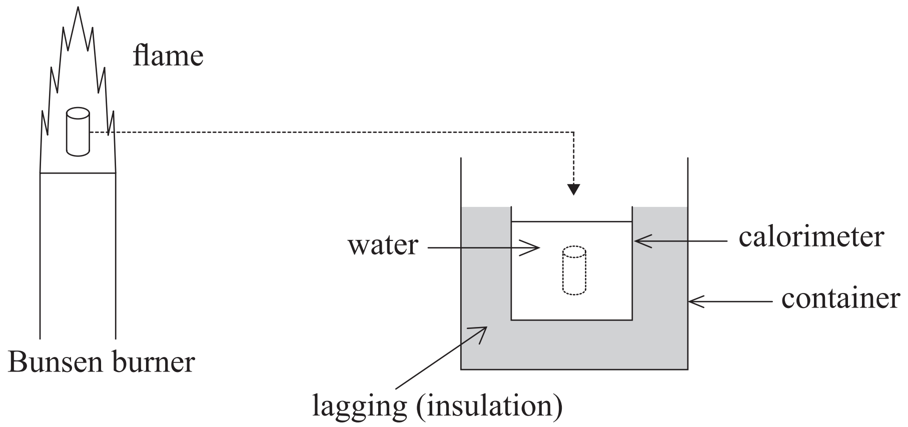
A piece of metal is held in the flame of a Bunsen burner for several minutes. The metal is then quickly transferred to a known mass of water contained in a calorimeter.



The water into which the metal has been placed is stirred until it reaches a steady temperature.

(b) Explain why

(i) the metal is transferred as quickly as possible from the flame to the water. *[1]*

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(ii) the water is stirred. *[1]*

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(This question continues on the following page)

(Question A3 continued)

The following data are available:

heat capacity of metal	$= 82.7\,\text{J K}^{-1}$
heat capacity of the water in the calorimeter	$= 5.46 \times 10^{2}\,\text{J K}^{-1}$
heat capacity of the calorimeter	$= 54.6\,\text{J K}^{-1}$
initial temperature of the water	$= 288\,\text{K}$
final temperature of the water	$= 353\,\text{K}$

(c) Assuming negligible energy losses in the processes involved, use the data to calculate the temperature T of the Bunsen flame. *[4]*

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A4. This question is about the photoelectric effect.

The following are two observations relating to the emission of electrons from a metal surface when light of different frequencies and different intensities is incident on the surface.

I. There exists a frequency of light (the threshold frequency) below which no electrons are emitted whatever the intensity of the light.

II. For light above the threshold frequency, the emission of the electrons is instantaneous whatever the intensity of the light.

Explain why the wave model of light is unable to account for these observations. *[6]*

Observation I . . . .

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Observation II . . . .

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SECTION B

This section consists of four questions: B1, B2, B3 and B4. Answer ***two*** *questions.*

B1. This question is in **two** parts. **Part 1** is about momentum and the kinematics of a proposed journey to Jupiter. **Part 2** is about radioactive decay.

Part 1 Momentum and kinematics

(a) State the law of conservation of momentum. *[2]*

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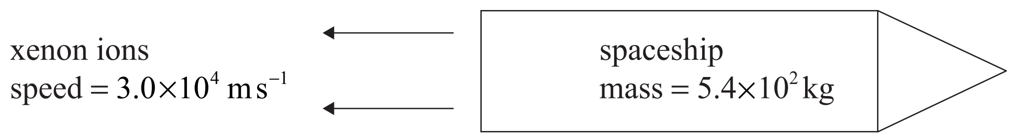
A solar propulsion engine uses solar power to ionise atoms of xenon and to accelerate them. As a result of the acceleration process, the ions are ejected from the spaceship with a speed of $3.0\times10^{4}\ \mathrm{m\,s^{-1}}$.



(b) The mass (nucleon) number of the xenon used is 131. Deduce that the mass of one ion of xenon is $2.2\times10^{-25}\ \mathrm{kg}$. *[2]*

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(c) The original mass of the fuel is 81 kg. Deduce that, if the engine ejects 7.7×10^{18} xenon ions every second, the fuel will last for 1.5 years. (1 year = 3.2×10^{7} s) *[2]*

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(Question B1, part 1 continued)

(d) The mass of the spaceship is 5.4×10^{2} kg. Deduce that the initial acceleration of the spaceship is $8.2\times10^{-5}\,\mathrm{m\,s^{-2}}$. *[5]*

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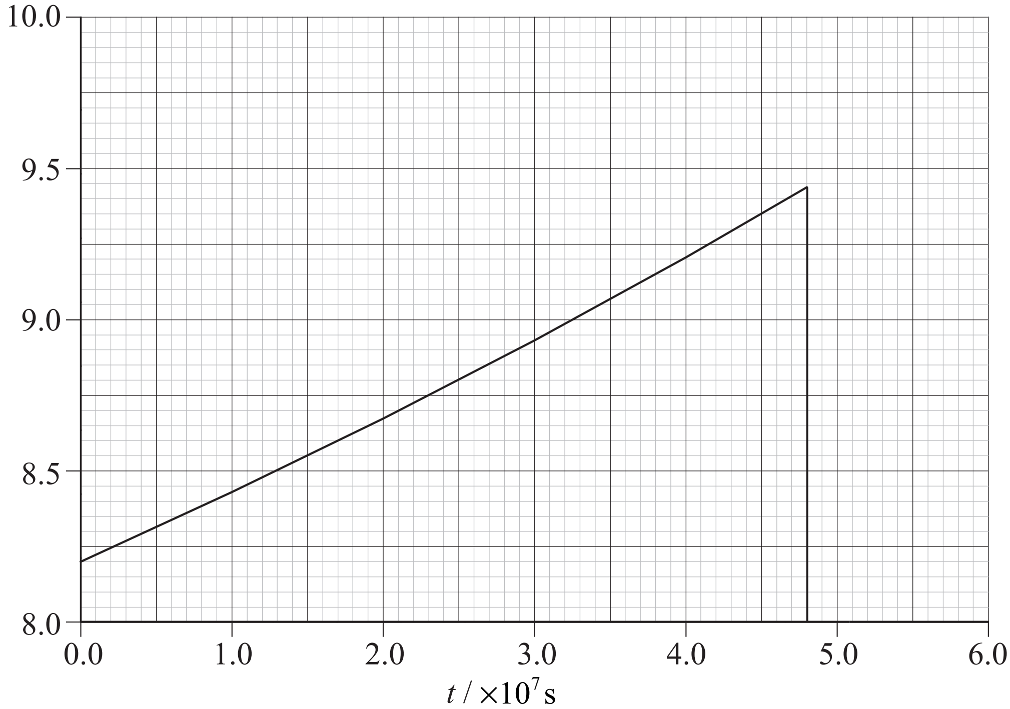
(Question B1, part 1 continued)

The graph below shows the variation with time t of the acceleration a of the spaceship. The solar propulsion engine is switched on at time $t = 0$ when the speed of the spaceship is $1.2\times10^3\,\text{m s}^{-1}$.



(e) Explain why the acceleration of the spaceship is increasing with time. *[2]*

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(f) Using data from the graph, calculate the speed of the spaceship at the time when the xenon fuel has all been used. *[4]*

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(Question B1, part 1 continued)

(g) The distance of the spaceship from Earth when the solar propulsion engine is switched on is very small compared to the distance from Earth to Jupiter. The fuel runs out when the spaceship is a distance of 4.7×10^{11} m from Jupiter. Estimate the total time that it would take the spaceship to travel from Earth to Jupiter. *[2]*

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(Question B1 continued)

Part 2 Radioactive decay

A nucleus of the isotope xenon, Xe – 131, is produced when a nucleus of the radioactive isotope iodine I-13 decays.

(a) Explain the term *isotopes*. *[2]*

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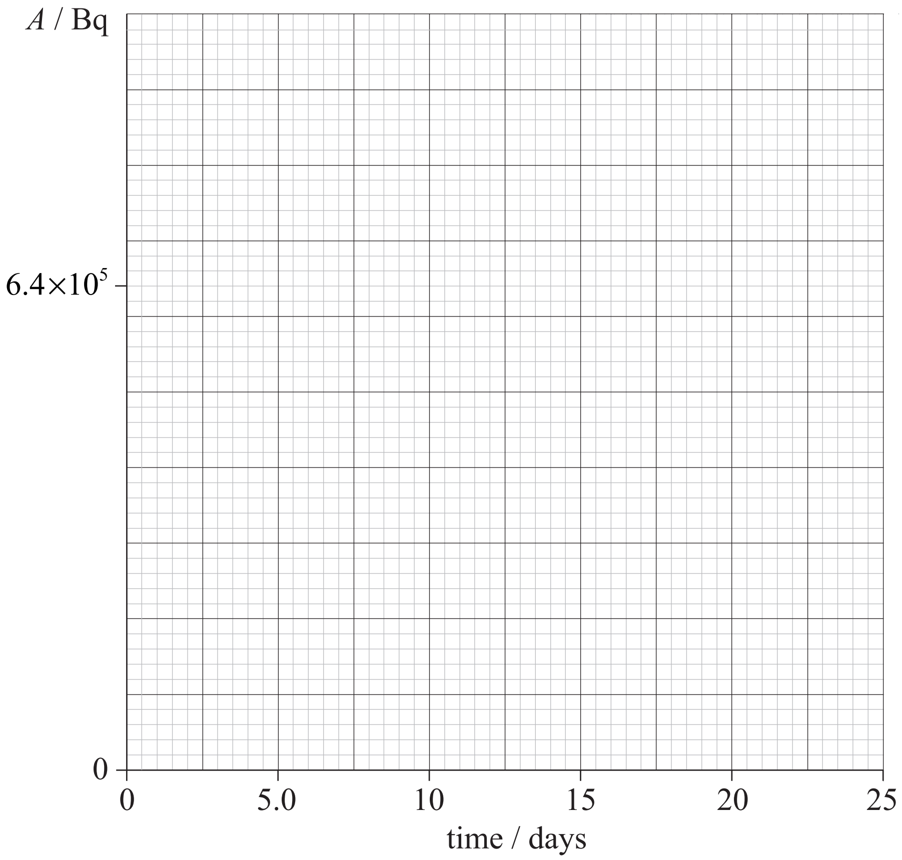
(b) Fill in the boxes below in order to complete the nuclear reaction equation for this decay. *[2]*

$$^{131}_{\square}\mathrm{I} \rightarrow {}^{131}_{54}\mathrm{Xe} + \beta^{-} + \square$$

The activity A of a freshly prepared sample of the iodine isotope is 6.4×10^{5} Bq and its half-life is 8.0 days.

(c) Using the axes, draw a graph to illustrate the decay of this sample. *[3]*



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Question B1, part 2 continued)

(d) Determine the decay constant of the isotope I-131. *[2]*

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The sample is to be used to treat a growth in the thyroid of a patient. The isotope should not be used until its activity is equal to 0.5×10^{5} Bq.

(e) Calculate the time it takes for the activity of a freshly prepared sample to be reduced to an activity of 0.5×10^{5} Bq. *[2]*

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B2. This question is in **two** parts. **Part 1** is about waves and wave motion. **Part 2** is about the possibility of generating electrical power using a satellite orbiting the Earth.

Part 1 Waves and wave motion

(a) Describe, by reference to the propagation of energy, what is meant by a transverse wave. *[2]*

Transverse wave

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(b) State **one** example, other than a wave on a string, of a transverse wave. *[1]*

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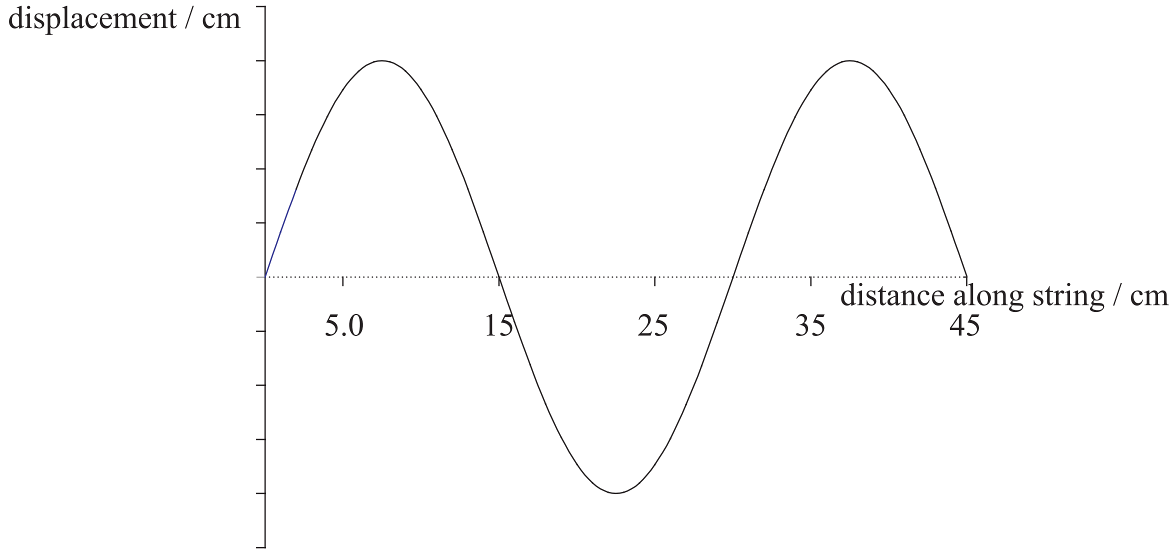
(Question B2, part 1 continued)

A transverse wave is travelling along a string that is under tension. The diagram below shows the displacement of part of the string at time $t = 0$. The dotted line shows the position of the string when there is no wave travelling along it.



(c) On the diagram, draw lines to identify for this wave

(i) the amplitude (label this A). *[1]*

(ii) the wavelength (label this λ). *[1]*

(d) The period of the wave is 1.2×10^{-3} s. Deduce that the speed of the wave is $250\,\text{m s}^{-1}$. *[2]*

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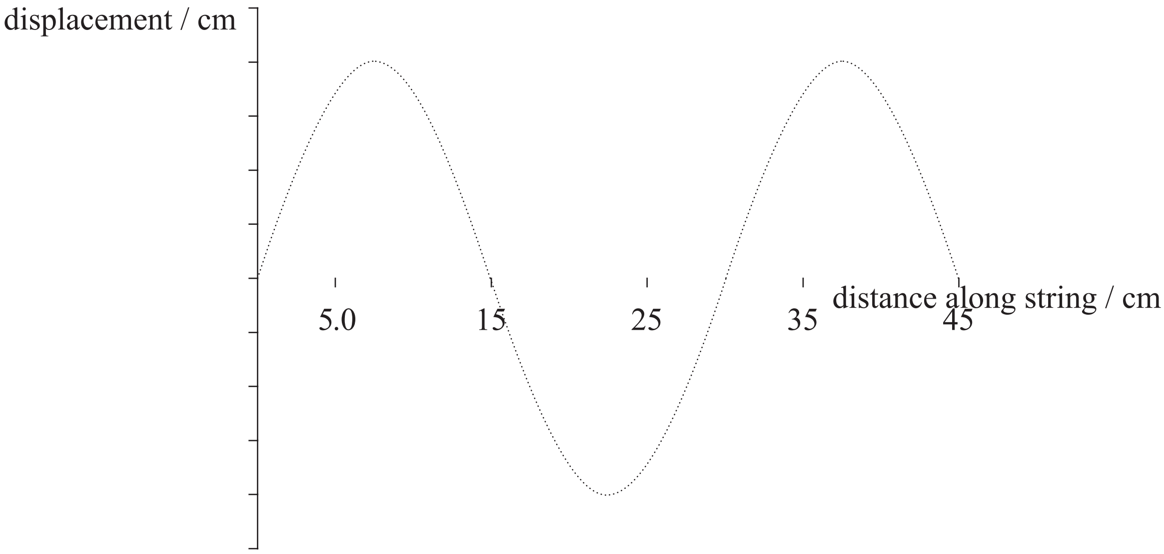
(Question B2, part 1 continued)

(e) Using the axes below, draw the displacement of the string when $t = 3.0 \times 10^{-4}$ s. (The displacement of the string at $t = 0$ is shown as a dotted line.) *[3]*



The string is maintained at the same tension and is adjusted in length to 45 cm. It is made to resonate at its first harmonic (fundamental) frequency.

(f) Explain what is meant by resonance. *[2]*

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(g) Describe how the string can be made to resonate at its first harmonic frequency only. *[2]*

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(h) Determine the frequency of the first harmonic of the string. *[2]*

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(Question B2 continued)

Part 2 The satellite and electrical power generation

(a) Define *gravitational field strength*. *[2]*

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(b) Use the definition of gravitational field strength to deduce that

$$GM = g_0 R^2$$

where M is the mass of the Earth, R it's radius and g_0 is the gravitational field strength at the surface of the Earth. (You may assume that the Earth is a uniform sphere with its mass concentrated at its centre.) *[2]*

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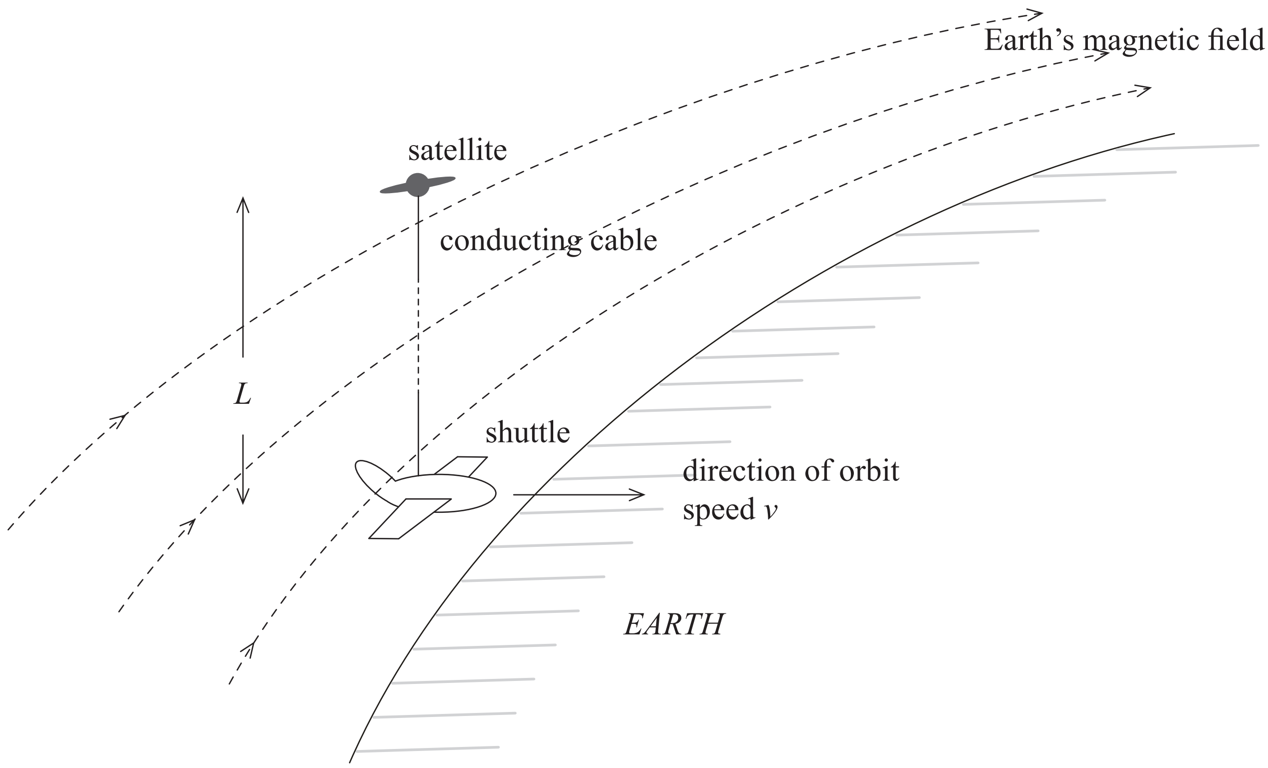
(Question B2, part 2 continued)

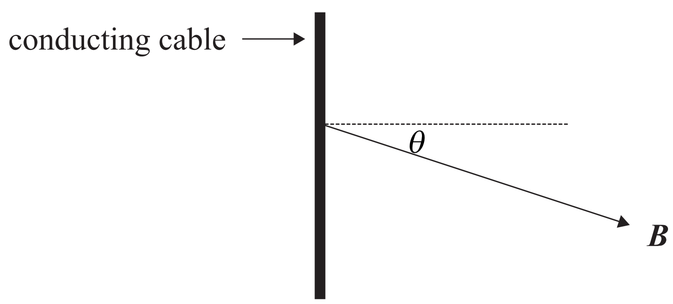
A space shuttle orbits the Earth and a small satellite is launched from the shuttle. The satellite carries a conducting cable connecting the satellite to the shuttle. When the satellite is a distance L from the shuttle, the cable is held straight by motors on the satellite.

Diagram 1



As the shuttle orbits the Earth with speed v, the conducting cable is moving at right angles to the Earth's magnetic field. The magnetic field vector $\boldsymbol{B}$ makes an angle θ to a line perpendicular to the conducting cable as shown in diagram 2. The velocity vector of the shuttle is directed out of the plane of the paper.

Diagram 2



(c) On diagram 2, draw an arrow to show the direction of the magnetic force on an electron in the conducting cable. Label the arrow F. *[1]*

(This question continues on the following page)

(Question B2, part 2 continued)

(d) State an expression for the force F on the electron in terms of B, v, e and θ, where B is the magnitude of the magnetic field strength and e is the electron charge. *[1]*

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(e) Hence deduce an expression for the e.m.f. E induced in the conducting wire. *[3]*

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(f) The shuttle is in an orbit that is 300 km above the surface of the Earth. Using the expression

$$GM = g_0 R^2$$

and given that $R = 6.4\times10^6$ m and $g_0 = 10\,\text{N kg}^{-1}$, deduce that the orbital speed v of the satellite is $7.8\times10^3\ \text{m s}^{-1}$. *[3]*

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(g) The magnitude of the magnetic field strength is 6.3×10^{-6} T and the angle $\theta = 20^\circ$. Estimate the length L of the cable required in order to generate an e.m.f. of 1 kV. *[2]*

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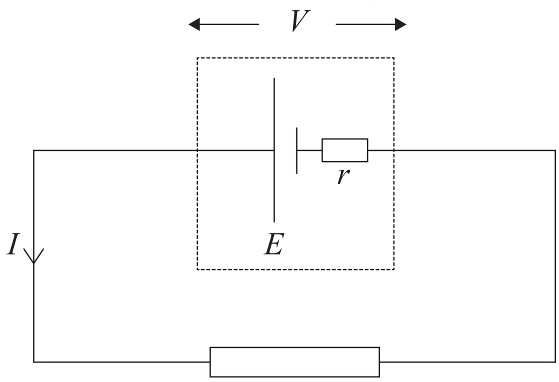
B3. This question is in **two** parts. **Part 1** is about e.m.f. and internal resistance. **Part 2** is about the wave properties of light and electrons.

Part 1 e.m.f. and internal resistance

A dry cell has an e.m.f. E and internal resistance r and is connected to an external circuit. There is a current I in the circuit when the potential difference across the terminals of the cell is V.



(a) State expressions, in terms of E, V, r and I where appropriate, for

(i) the total power supplied by the cell. *[1]*

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(ii) the power dissipated in the cell. *[1]*

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(iii) the power dissipated in the external circuit. *[1]*

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(b) Use your answers to (a) to derive a relationship between V, E, I and r. *[2]*

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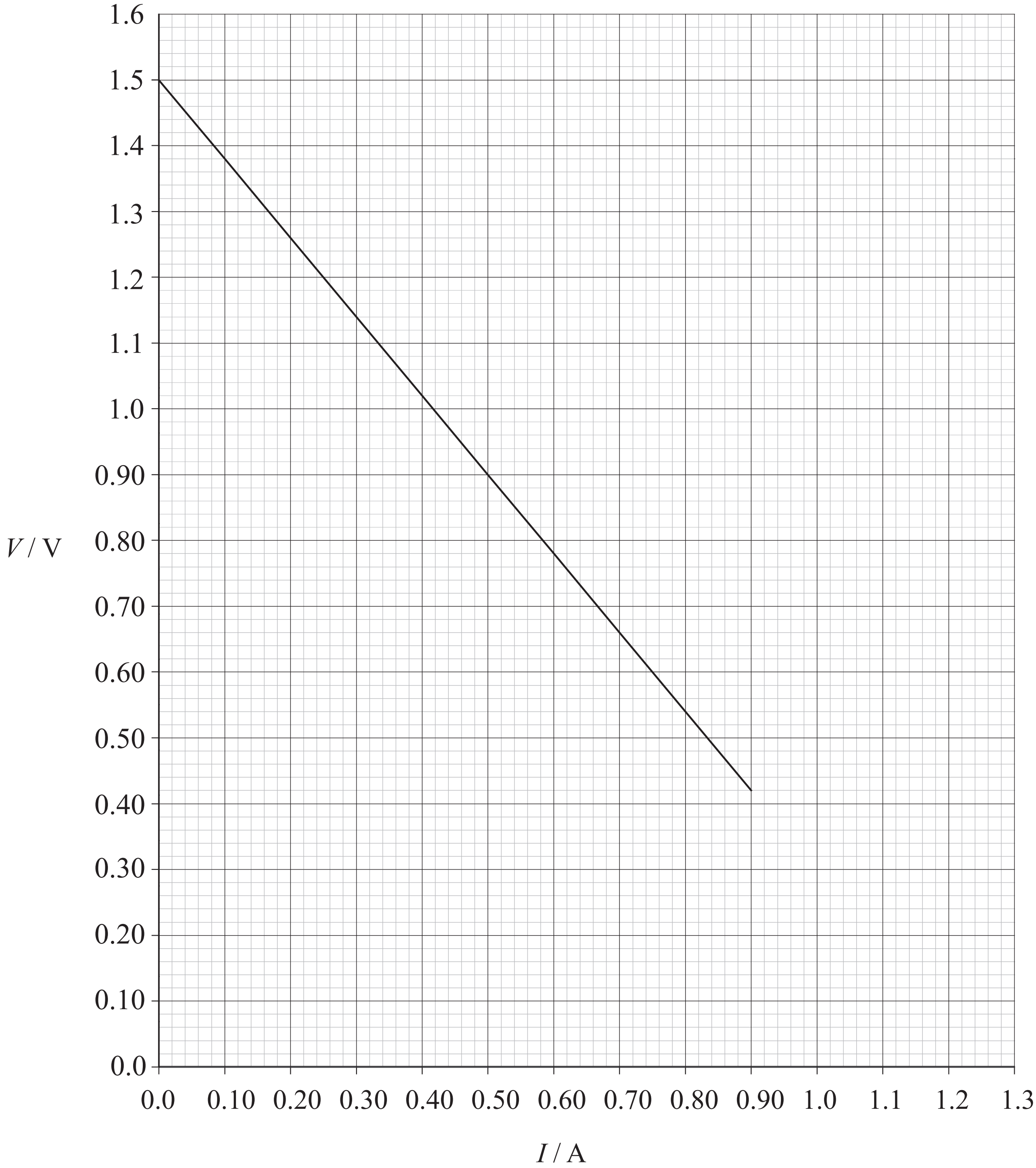
(Question B3, part 1 continued)

The graph below shows the variation of V with I for the dry cell.



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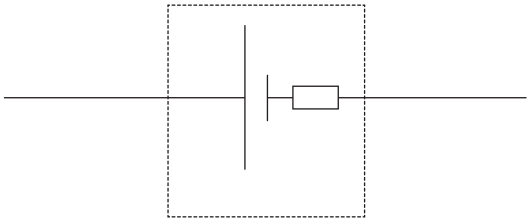
(Question B3, part 1 continued)

(c) Complete the diagram below to show the circuit that could be used to obtain the data from which the graph was plotted. *[3]*



(d) Use the graph, explaining your answers, to

(i) determine the e.m.f. E of the cell. *[2]*

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(ii) determine the current in the external circuit when the resistance R of the external circuit is very small. *[2]*

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(iii) deduce that the internal resistance r of the cell is about $1.2\,\Omega$. *[3]*

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(Question B3, part 1 continued)

(e) The maximum power dissipated in the external circuit occurs when the resistance of the external circuit has the same value as the internal resistance of the cell. Calculate the maximum power dissipation in the external circuit. *[3]*

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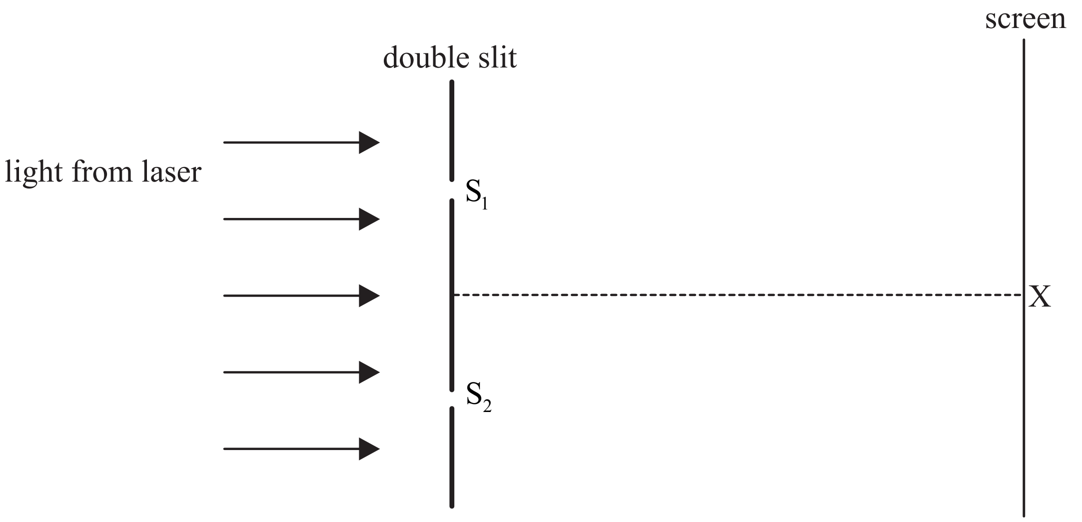
(Question B3 continued)

Part 2 Light and electrons

The diagram below (not to scale) is an arrangement for observing the interference pattern produced on a screen when the light from two narrow slits S_1 and S_2 overlaps. A beam of light from a laser is incident on the slits and after passing through the slits, the light is incident on a screen. The separation between the slits is large compared to the width of the slits and the distance between the slits and the screen is large compared to the slit separation.

The point X on the screen is equidistant from S_1 and S_2.



(a) Explain why an interference pattern will not be observed on the screen if the laser is replaced with a tungsten filament lamp. *[2]*

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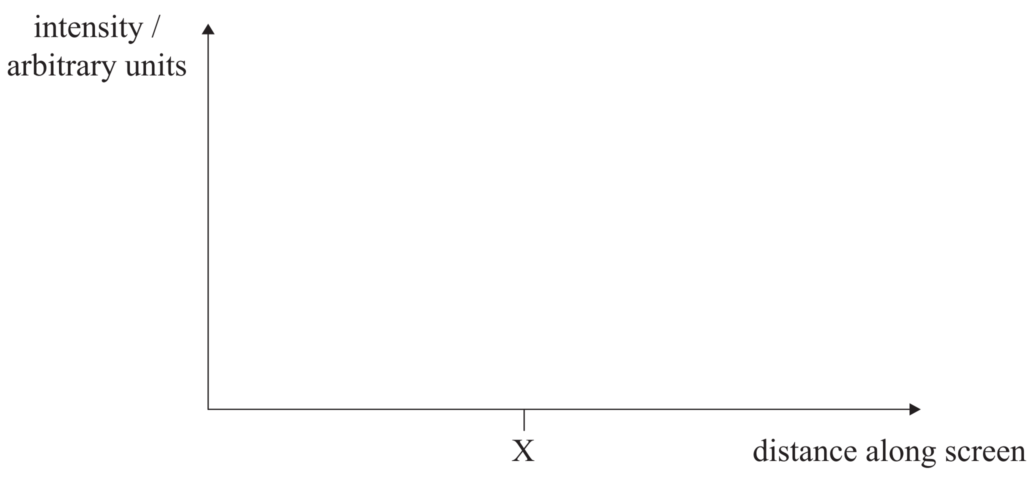
(b) On the axes below, draw a sketch-graph to show how the intensity of the observed interference pattern varies with distance along the screen. *[2]*



(This question continues on the following page)

(Question B3, part 2 continued)

(c) The wavelength of the light from the laser is 633 nm and the angular separation of the bright fringes on the screen is 4.00×10^{-4} rad. Calculate the distance between S_1 and S_2. *[3]*

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(d) Consider now a "thought" experiment in which the light from the laser is replaced by a beam of electrons that has been accelerated from rest through a potential difference V.

Deduce that the de Broglie wavelength λ of the electrons is

$$\lambda = \frac{h}{\sqrt{2m_e Ve}}$$

where h is the Planck constant, m_e the electron mass and e the electron charge. *[3]*

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(e) The electron beam is accelerated from rest through a potential difference of 400 V. Calculate the separation of S_1 and S_2 such that the angular separation of the electron interference fringes is 4.00×10^{-4} rad. *[2]*

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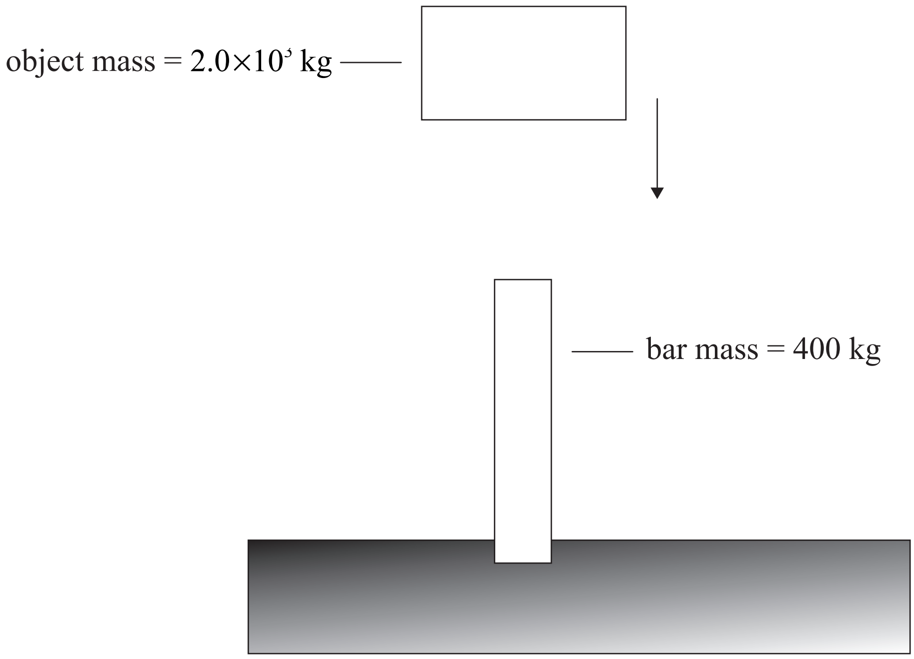
B4. This question is in **two** parts. **Part 1** is about driving a metal bar into the ground and the engine used in the process. **Part 2** is about the force between current-carrying wires.

Part 1 The metal bar

Large metal bars can be driven into the ground using a heavy falling object.



In the situation shown, the object has a mass 2.0×10^3 kg and the metal bar has a mass of 400 kg.

The object strikes the bar at a speed of $6.0\,\mathrm{m\,s^{-1}}$. It comes to rest on the bar without bouncing. As a result of the collision, the bar is driven into the ground to a depth of 0.75 m.

(a) Determine the speed of the bar immediately after the object strikes it. *[4]*

(This question continues on the following page)

(Question B4, part 1 continued)

(b) Determine the average frictional force exerted by the ground on the bar. *[3]*

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(c) The object is raised by a diesel engine that has a useful power output of 7.2 kW.

In order that the falling object strikes the bar at a speed of $6.0\,\text{m}\,\text{s}^{-1}$, it must be raised to a certain height above the bar. Assuming that there are no energy losses due to friction, calculate how long it takes the engine to raise the object to this height. *[4]*

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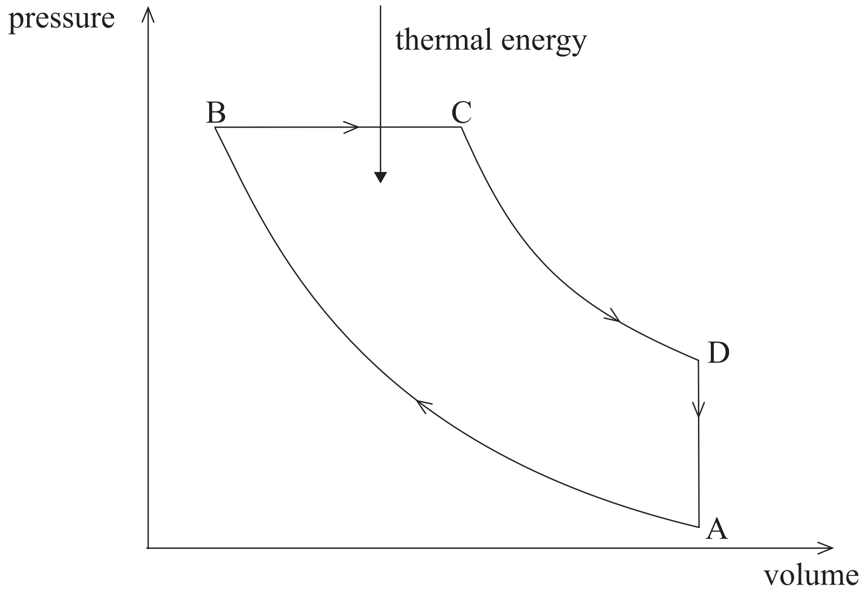
(Question B4, part 1 continued)

The diagram below shows the relation between the pressure and the volume of the air in the diesel engine for one cycle of operation of the engine. During the cycle there are two adiabatic processes, an isochoric process and an isobaric process.



(d) Explain what is meant by

(i) an adiabatic process. *[2]*

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(ii) an isochoric process. *[1]*

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(iii) an isobaric process. *[1]*

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(Question B4, part 1 continued)

(e) Identify, from the diagram, the following processes.

(i) Adiabatic processes *[1]*

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(ii) Isochoric process *[1]*

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(iii) Isobaric process *[1]*

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During the process B $\rightarrow$ C thermal energy is absorbed.

The diesel engine has a total power output of 8.4 kW and an efficiency of 40 %. The cycle of operation is repeated 40 times every second.

(f) State what quantity is represented on the diagram by the area ABCD. *[1]*

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(g) Determine the value of the quantity that is represented by the area ABCD. *[1]*

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(h) Determine the thermal energy absorbed during the process B $\rightarrow$ C. *[2]*

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(Question B4 continued)

Part 2 Force between current-carrying wires

Diagram 1 below shows two long, parallel vertical wires each carrying equal currents in the same direction. The wires pass through a horizontal sheet of card. Diagram 2 shows a plan view of the wires looking down onto the card.

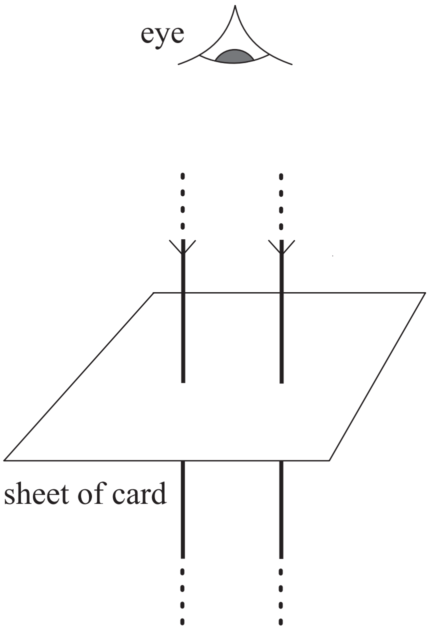

Diagram 1

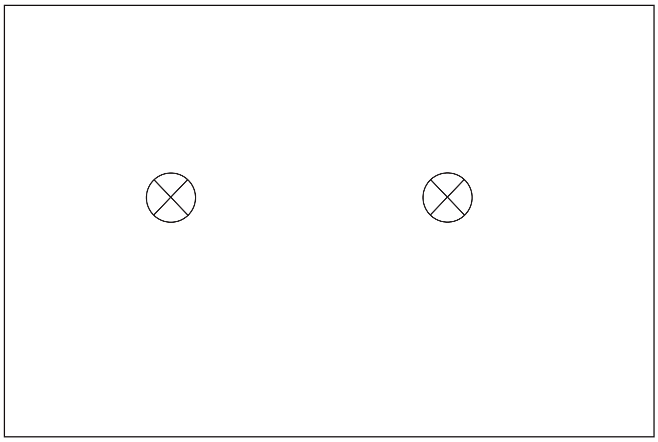

Diagram 2

(a) Draw on diagram 2 the magnetic field pattern due to the currents in the wire. *[3]*

(b) Outline how two current carrying conductors may be used to define the ampere. *[2]*

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(c) The card is removed and one of the two wires is free to move. Describe and explain, the changes in the velocity and in acceleration of the moveable wire. *[3]*

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