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

M06/4/PHYSI/HP2/ENG/TZ1/XX+

22066508

PHYSICS
HIGHER LEVEL
PAPER 2

Tuesday 9 May 2006 (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.

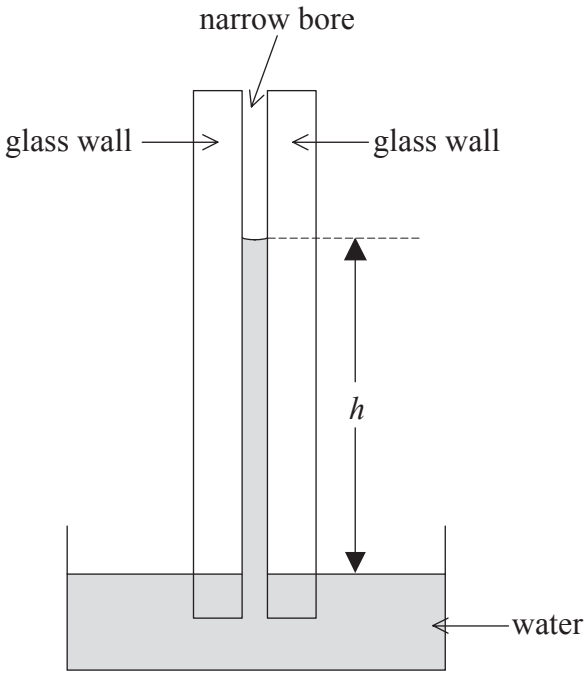
0136

SECTION A

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

A1. This question is about the rise of water in a capillary tube.

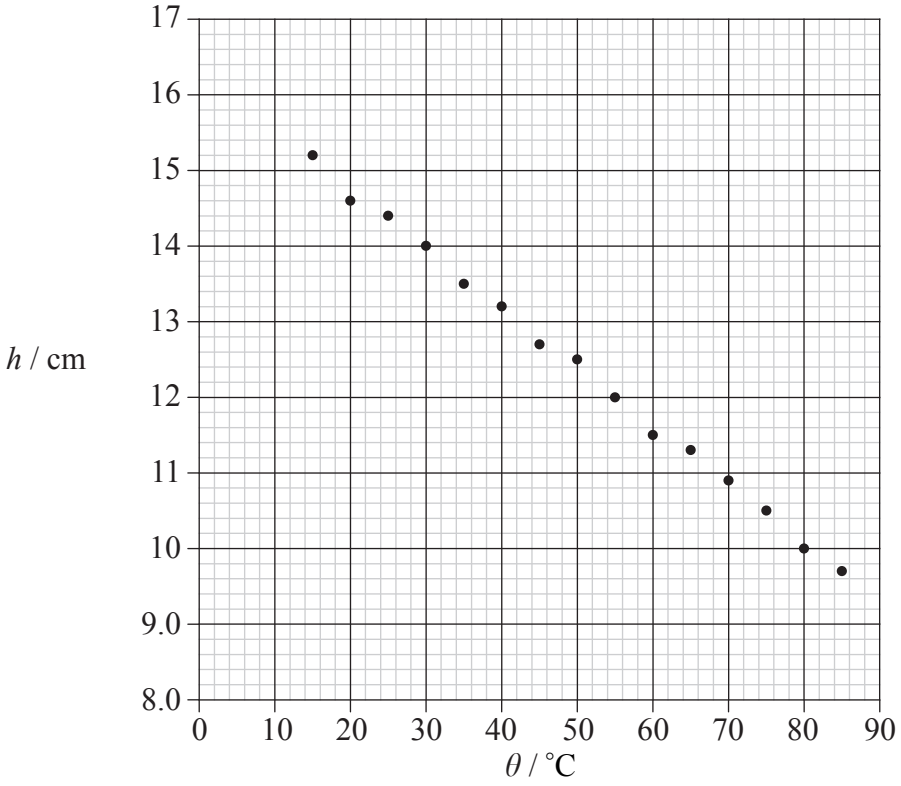
A capillary tube is a tube that is open at both ends and has a very narrow bore. A capillary tube is supported vertically with one end immersed in water. Water rises up the tube due to a phenomenon called capillary action. The water in the bore of the tube forms a column of height *h* as shown below.



(This question continues on the following page)

(Question A1 continued)

(a) The height h, for a particular capillary tube was measured for different temperatures of the water. The variation with temperature θ of the height h is shown below. Uncertainties in the measurements are not shown.



(i) On the graph above, draw a best-fit line for the data points. *[1]*

(ii) Determine the height h_0 of the water column at temperature $\theta = 0°C$. *[1]*

. . . . . .

. . . . . .

(This question continues on the following page)

(Question A1 continued)

(b) Explain why the results of this experiment suggest that the relationship between the height h and temperature θ is of the form

$$h = h_0(1 - k\theta)$$

where k is constant. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(c) Deduce that the value of k is approximately 4.8×10^{-3} deg C^{-1}. *[3]*

. . . . . .

. . . . . .

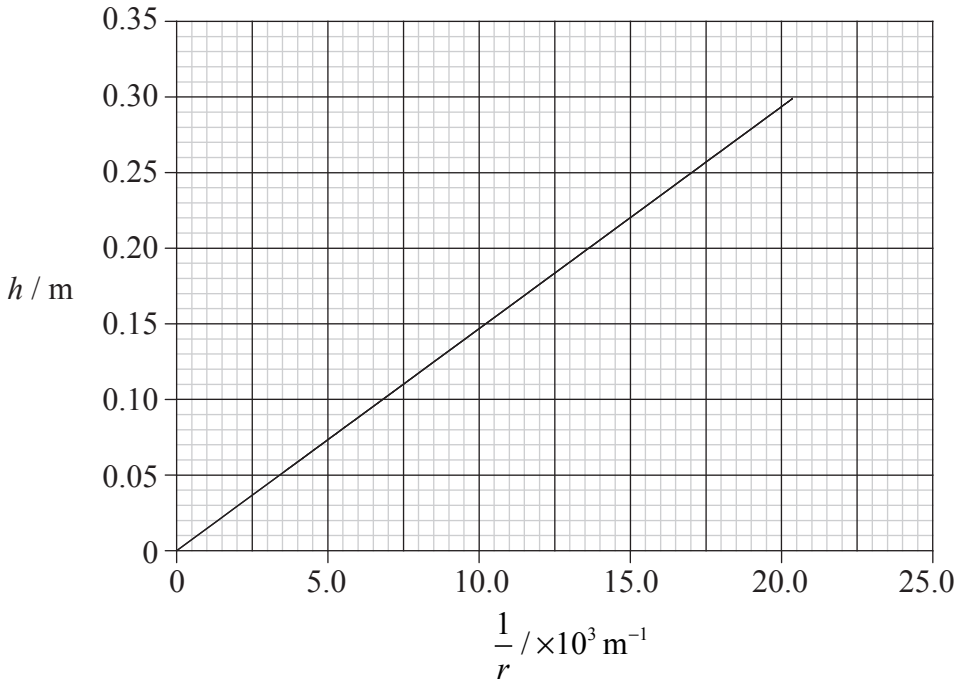
. . . . . .

. . . . . .

(This question continues on the following page)

(Question A1 continued)

(d) The experiment is repeated using tubes with bores of different radii r but keeping the water temperature constant. The graph below shows the variation with $\frac{1}{r}$ of the height h for capillary tubes of different radii r for a water temperature of 20°C.



It is suggested that capillary action is one of the means by which water moves from the roots of a tree to the leaves. A particular tree has a height of 25 m.

Use the graph to estimate the radius of the bore of the tubes that would enable water to be raised by capillary action from ground level to the top of the tree. Comment on your answer. *[4]*

Estimate: . . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

Comment: . . . . . .

. . . . . .

. . . . . .

A2. This question is about the forces exerted at the supports of a bridge.

(a) State the conditions for a body to be in translational and in rotational equilibrium. *[2]*

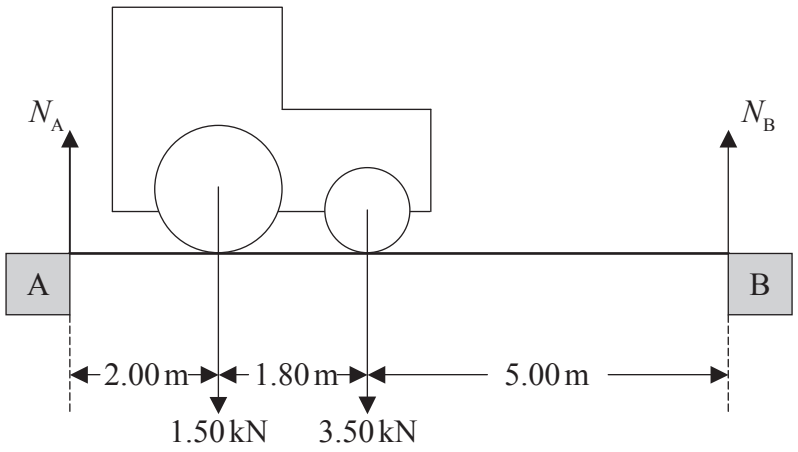
Translational equilibrium: . . . . . .

. . . . . .

Rotational equilibrium: . . . . . .

. . . . . .

(b) A simple bridge consists of a rigid roadway supported at ends A and B. A tractor is in the position shown in the diagram below.



The total load on the rear wheels of the tractor is 1.50 kN and on the front wheels, 3.50 kN. The distance between the front and rear wheels is 1.80 m. The rear wheels are 2.00 m from A and the front wheels 5.00 m from B.

The vertical forces at the supports A and B of the bridge due to the tractor are N_A and N_B respectively.

(i) State the value of the sum $N_A + N_B$. *[1]*

. . . . . .

(ii) Determine the value of N_A and of N_B. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

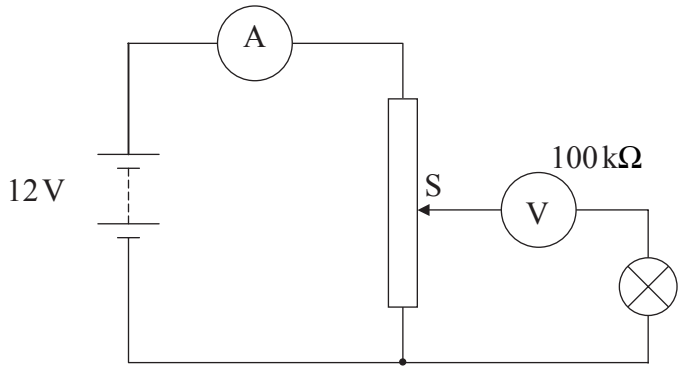
. . . . . .

Blank page

A3. This question is about an electric circuit.

A particular filament lamp is rated at 12 V, 6.0 mA. It just lights when the potential difference across the filament is 6.0 V.
A student sets up a electric circuit to measure the *I*-*V* characteristics of the filament lamp.

In the circuit, shown below, the student has connected the voltmeter and the ammeter into the circuit **incorrectly**.



The battery has e.m.f. 12 V and negligible internal resistance. The ammeter has negligible resistance and the resistance of the voltmeter is 100 kΩ.

The maximum resistance of the variable resistor is 15 Ω.

(a) Explain, without doing any calculations, whether there is a position of the slider S at which the lamp will be lit. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Estimate the maximum reading of the ammeter. *[2]*

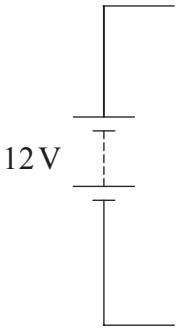
. . . . . .

. . . . . .

(This question continues on the following page)

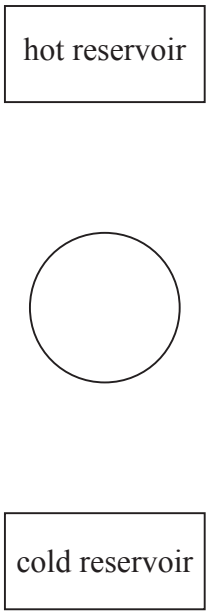
(Question A3 continued)

(c) Complete the circuit diagram below showing the correct position of the voltmeter and of the ammeter in order to determine the *I-V* characteristics of the filament lamp. *[2]*



A4. This question is about thermodynamic processes.

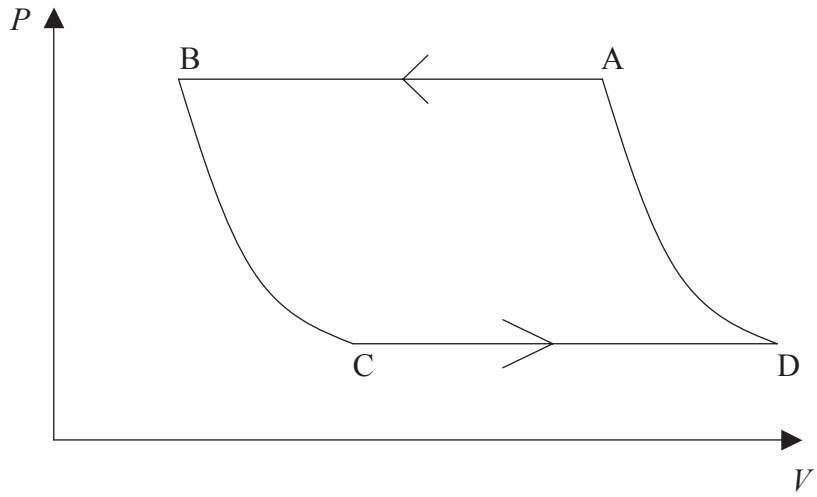
(a) On the diagram below, draw arrows to show the energy transfers associated with a heat pump. *[3]*



(This question continues on the following page)

(Question A4 continued)

(b) The diagram below, shows the relation between the pressure P and the volume V of the working substance of the heat pump for one cycle of its operation.



(i) The working substance at point C of the cycle is in the liquid phase.

State the reason why both the changes from C→D and A→B are isothermal isobaric changes. *[2]*

C→D: . . . . . .

. . . . . .

A→B: . . . . . .

. . . . . .

(ii) State during which process of the cycle energy is absorbed from the cold reservoir and during which process energy is transferred to the hot reservoir. *[2]*

Energy absorbed from cold reservoir

. . . . . .

Energy transferred to hot reservoir

. . . . . .

(iii) State how the value of the work done during one cycle may be determined from the PV diagram. *[1]*

. . . . . .

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 Kepler's third law. **Part 2** is about heating water electrically.

Part 1 Kepler's third law.

(a) Kepler's third law states that the period T of the orbit of a planet about the Sun is related to the average orbital radius R of the planet by the relationship

$$T^2 = KR^3$$

where K is a constant.

(i) Suggest why the law specifies the average orbital radius. *[1]*

. . . . . .

. . . . . .

(ii) State the name of the force that causes the acceleration of the planets orbiting the Sun. *[1]*

. . . . . .

(iii) State an expression for the magnitude F of the force in (ii) in terms of the mass M_S, of the Sun, the mass m of the planet, the radius R of the orbit and the universal gravitational constant G. *[1]*

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B1, part 1 continued)

(iv) Hence deduce, explaining your working, that the constant K is given by the expression

$$K = \frac{4\pi^2}{GM_S}.$$ *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Ganymede is one of the moons of Jupiter and the following data are available.

Average orbital radius of Ganymede $= 1.1 \times 10^9\,\text{m}$

Orbital period of Ganymede $= 6.2 \times 10^5\,\text{s}$

Universal gravitational constant G $= 6.7 \times 10^{-11}\,\text{N m}^2\,\text{kg}^{-2}$

(i) Deduce that the gravitational field strength of Jupiter at the surface of Ganymede is approximately $0.1\,\text{N kg}^{-1}$. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Estimate the mass of Jupiter. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

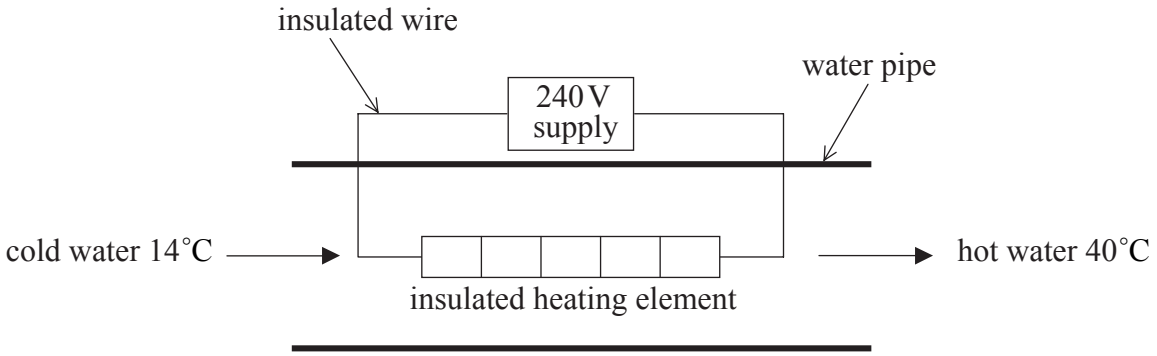
. . . . . .

(This question continues on the following page)

(Question B1 continued)

Part 2 Heating water electrically

The diagram below shows part of the heating circuit of a domestic shower.



Cold water enters the shower unit and flows over an insulated heating element. The heating element is rated at 7.2 kW, 240 V. The water enters at a temperature of 14°C and leaves at a temperature of 40°C. The specific heat capacity of water is $4.2\times10^{3}\,\text{J kg}^{-1}\,\text{K}^{-1}$.

(a) Describe how thermal energy is transferred from the heating element to the water. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Estimate the flow rate in kg s^{-1} of the water. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B1, part 2 continued)

(c) Suggest **two** reasons why your answer to (b) is only an estimate. *[2]*

1. . . . . .

. . . . . .

2. . . . . .

. . . . . .

(d) Calculate the current in the heating element when the element is operating at 7.2 kW. *[2]*

. . . . . .

. . . . . .

. . . . . .

(e) Explain why, when the shower unit is switched on, the initial current in the heating element is greater than the current calculated in (d). *[2]*

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B1, part 2 continued)

(f) In some countries, shower units are operated from a 110 V supply. A heating element operating with a 240 V supply has resistance R_{240} and an element operating from a 110 V supply has resistance R_{110}.

(i) Deduce, that for heating elements to have identical power outputs

$$\frac{R_{110}}{R_{240}} = 0.21.$$ *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Using the ratio in (i), describe and explain **one** disadvantage of using a 110 V supply for domestic purposes. *[2]*

. . . . . .

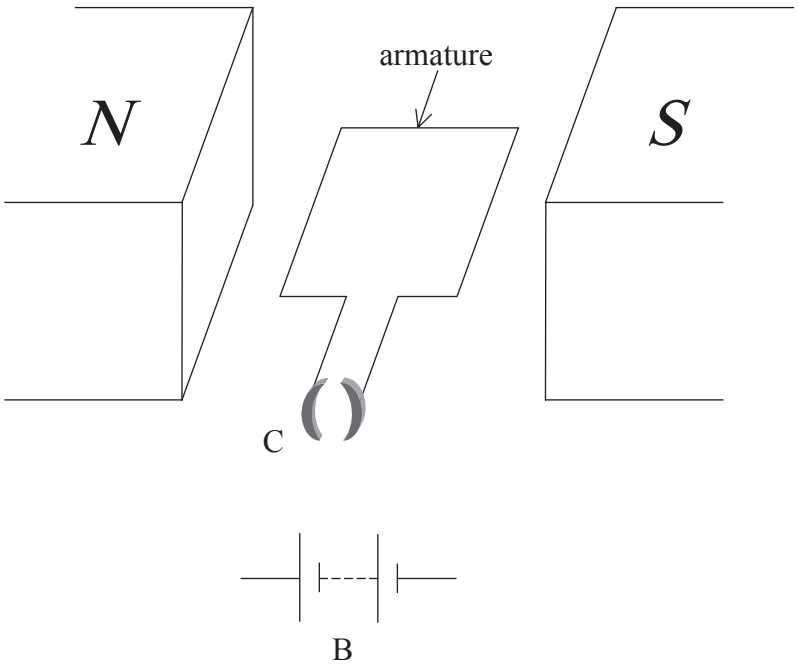
. . . . . .

. . . . . .

. . . . . .

B2. This question is about electric motors and generators.

(a) The diagram below is a representation of a simple dc electric motor. The armature consists of a single rectangular coil and rotates between the poles of a permanent magnet. The connections between the coil and the battery B are not shown. The split-ring is labelled C.



(i) On the diagram above, draw connections from the battery B to the split-ring so that the coil will rotate continuously in one direction. *[1]*

(ii) On the diagram above, draw arrows to show the direction of the forces acting on the coil when connection to the battery is made and the coil is in the position shown in the diagram. *[1]*

(iii) Describe how these connections enable the coil to rotate continuously in one direction. *[3]*

. . . . . .

. . . . . .

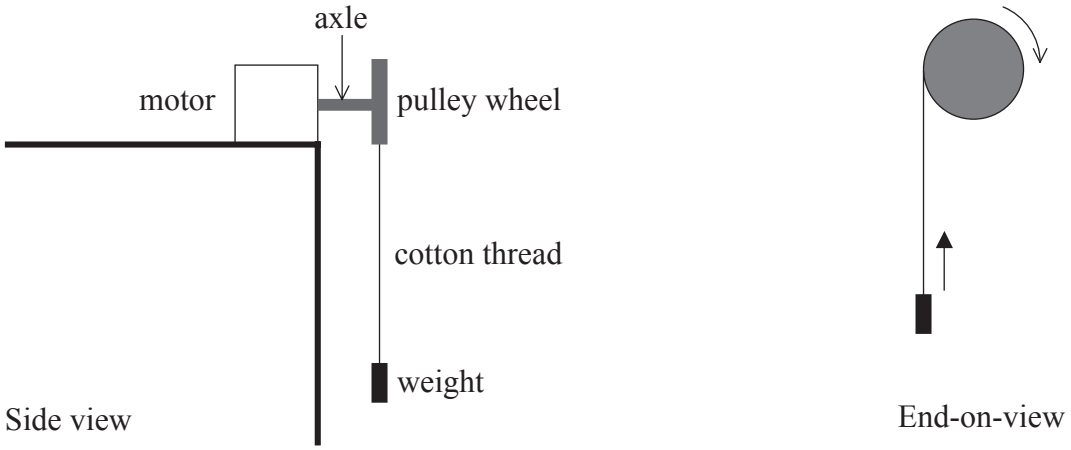
. . . . . .

. . . . . .

(This question continues on the following page)

(Question B2 continued)

(b) In an experiment to measure the efficiency of a small dc electric motor, the motor is clamped to the edge of a bench. The motor is used to raise a small weight that is attached to a pulley wheel by cotton thread. The pulley wheel is rotated by the motor. The thread wraps around the pulley wheel, so raising the weight.



The time taken for the motor to raise the weight through a certain height is measured. It is assumed that the weight accelerates uniformly whilst being raised. The weight of the cotton thread is negligible.

(i) Draw a labelled, free-body force diagram of the forces acting on the accelerating weight. *[3]*

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B2 continued)

(ii) The weight has a mass of 15 g and it takes 2.2 s to raise it from rest through a height of 0.84 m. Calculate the tension in the thread as the weight is being raised. (Acceleration of free fall $g = 10\,\text{m}\,\text{s}^{-2}$.) *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(c) In a second experiment, the current is adjusted so that the weight of mass 15 g is raised at constant speed. The motor is connected to a 6.0 V supply and it now takes the motor 3.4 s to raise the weight through 0.84 m.

(i) Suggest how it might be determined that the weight is being raised at constant speed. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Determine the power delivered to the weight by the motor. (Acceleration of free fall $g = 10\,\text{m}\,\text{s}^{-2}$.) *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(iii) The current in the motor is 45 mA. Estimate the efficiency of the motor. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B2 continued)

(d) It is suggested that the efficiency E of the motor is related to the current I in the motor by the expression

$$E = kI^n$$

where k and n are constants.

State and explain what graph you would plot in order to determine a value of n. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(e) Explain why

(i) as the coil rotates, an e.m.f. is induced in the coil. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) the faster the coil rotates, the greater the value of the induced e.m.f. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(iii) the induced e.m.f. is not constant even when the speed of rotation of the coil is constant. *[1]*

. . . . . .

. . . . . .

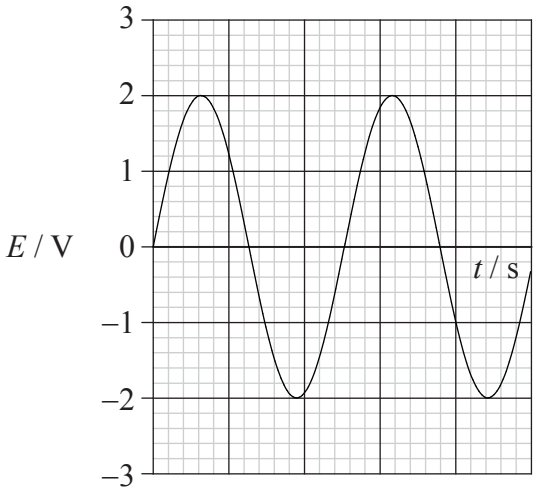
. . . . . .

(This question continues on the following page)

(Question B2 continued)

(f) An e.m.f. is also induced in a coil that is rotated mechanically in a magnetic field. This is the principle of a simple alternating current generator.

For a particular generator, the graph below shows the variation with time t of the induced (generated) e.m.f. E.



(i) On the graph above, label with the letter P, one point that corresponds to a time when the coil is parallel to the magnetic field. *[1]*

(ii) Determine the root mean square value of the induced e.m.f. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

Blank page

B3. This question is in **two** parts. **Part 1** is about sound waves. **Part 2** is about radioactive decay.

Part 1 This question is about sound waves

Production of sound waves

(a) Distinguish, in terms of the propagation of energy, the difference between a *transverse* travelling wave and a *longitudinal* travelling wave. *[3]*

. . . . . .

. . . . . .

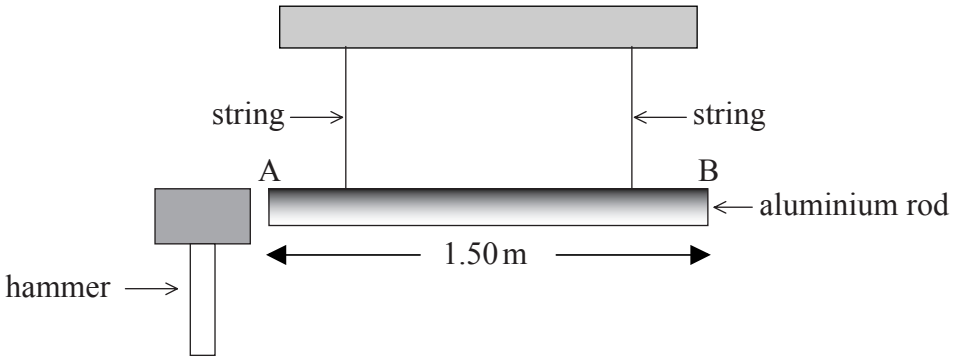
. . . . . .

. . . . . .

(This question continues on the following page)

(Question B3, part 1 continued)

(b) The diagram below shows an aluminium rod AB of length 1.50 m hanging horizontally from two strings.



End A of the rod is hit gently with a hammer. As a result, a wave pulse travels down the rod and is reflected from end B. The hammer remains in contact with the rod until the pulse reflected from end B reaches A. This pulse causes the hammer to rebound from the end of the rod.

(i) Suggest, giving a reason, whether the wave pulse is longitudinal or transverse. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) The hammer is in contact with end A of the rod for 6.00×10^{-4} s. Calculate the speed of the pulse in the rod. *[2]*

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B3, part 1 continued)

(iii) As a result of the rod being hit with the hammer, a sound is heard. Suggest how this sound arises. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(iv) The sound produced in the air consists of waves of many different frequencies and intensities. The loudest sound corresponds to a wave of frequency 1.67×10^3 Hz. Deduce that this frequency is due to the rod vibrating in its fundamental (first harmonic) mode. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

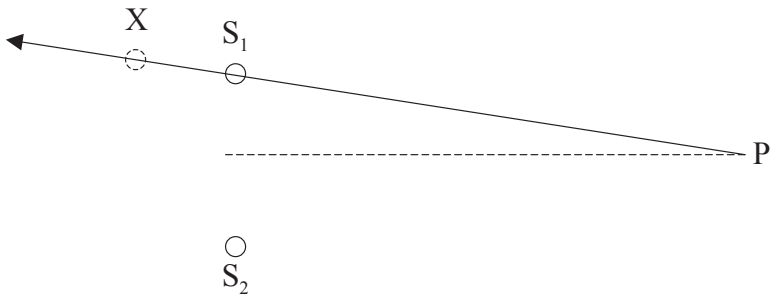
. . . . . .

(This question continues on the following page)

(Question B3, part 1 continued)

Interference of sound waves

(c) In the diagram below, S_1 and S_2 are two small loudspeakers. They are connected to the same sound source such that they emit sound waves of the same intensity and wavelength. An instrument for detecting sound intensity is placed at point P such that $S_1P = S_2P$.



The speaker S_1 is moved slowly away from P along the line PS_1. As S_1 is moved, the sound detected at P decreases and increases in intensity.

(i) Explain this observation. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) In moving the source from S_1 to point X, the intensity of the sound at P changes from a maximum to a minimum. The distance $S_1X = 0.082\,\text{m}$.

Calculate the value of the wavelength of the sound emitted by the sources. *[2]*

. . . . . .

(iii) S_1 remains at the point X and the frequency f of the sound emitted from both S_1 and S_2 is changed until a maximum of sound intensity is detected at P. This occurs when $f = 4100\,\text{Hz}$.

Estimate a value for the speed of sound. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B3 continued)

Part 2 Radioactive decay

(a) Carbon-14 is a radioactive isotope and is produced in the atmosphere by neutron bombardment of nitrogen. The equation for this reaction is

$$^{14}_{7}\mathrm{N} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{14}_{6}\mathrm{C} + \mathrm{X}.$$

Identify the particle X. *[1]*

. . . . . .

(b) Living trees contain atoms of carbon-14. The activity per gram of carbon from a living tree is 9.6 disintegrations per minute. The activity per gram of carbon in burnt wood (charcoal) found at an ancient campsite is 2.1 disintegrations per minute.

(i) A living tree continuously takes in carbon dioxide from the atmosphere. Suggest why the activity of the carbon from the charcoal is less than that of the living wood. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) The half-life of carbon-14 is 5500 years. Calculate the decay constant for carbon-14 and use this value to estimate the age of the carbon found at the campsite. *[5]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B3, part 2 continued)

(iii) Suggest **one** reason why radioactive dating of carbon samples that are more than 20 000 years old is unreliable. *[1]*

. . . . . .

. . . . . .

Blank page

B4. This question is in **two** parts. **Part 1** is about momentum. **Part 2** is about the quantum nature of radiation.

Part 1 Momentum

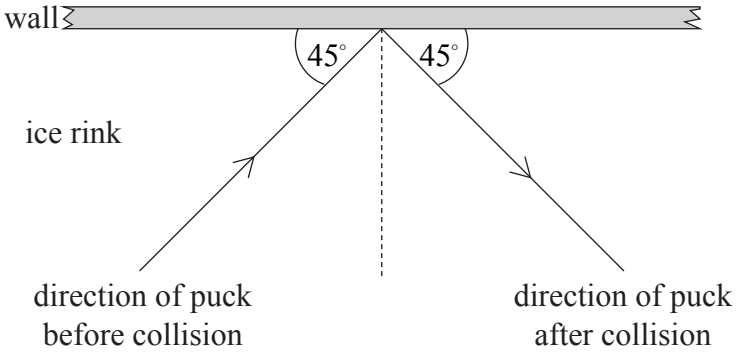
(a) State the law of conservation of momentum. *[2]*

. . . . . .

. . . . . .

. . . . . .

(b) An ice hockey puck collides with the wall of an ice rink. The puck is sliding along a line that makes an angle of 45° to the wall.



The collision between the wall and the puck is perfectly elastic.

(i) State what is meant by an *elastic collision*. *[1]*

. . . . . .

. . . . . .

(ii) Discuss how the law of conservation of momentum applies to this situation. *[2]*

. . . . . .

. . . . . .

. . . . . .

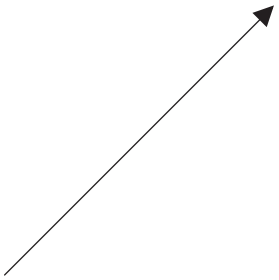
. . . . . .

(This question continues on the following page)

(Question B4, part 1 continued)

(c) The diagram below is a scale diagram that shows the vector representing the momentum of the puck before collision.

Scale: 1.0 cm = 0.10 N s

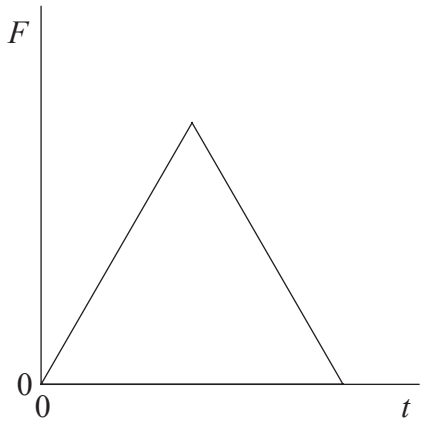


By adding appropriate vectors to the diagram, deduce that the magnitude of the change in momentum of the puck as a result of the collision is 0.71 N s. *[4]*

(This question continues on the following page)

(Question B4, part 1 continued)

(d) The sketch-graph below shows the variation with time t of the force F exerted by the wall on the puck.



The total contact time is 12 ms. Estimate, explaining your reasoning, the magnitude of the maximum force exerted by the wall on the puck. *[3]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on page 34)

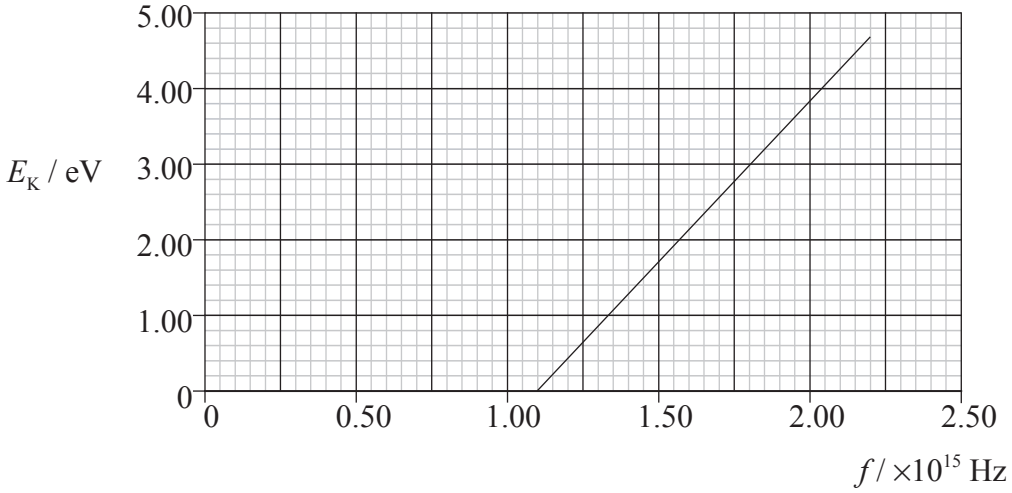
Blank page

(Question B4 continued)

Part 2 The quantum nature of radiation.

The photoelectric effect

A metal is placed in a vacuum and light of frequency f is incident on its surface. As a result, electrons are emitted from the surface. The graph below shows the variation with frequency f of the maximum kinetic energy E_K of the emitted electrons.



(a) The graph shows that there is a threshold frequency of the incident light below which no electrons are emitted from the surface. With reference to the Planck constant and the photoelectric work function, explain how Einstein's photoelectric theory accounts for this threshold frequency. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B4, part 2 continued)

(b) Use the graph opposite to determine the

(i) threshold frequency. *[1]*

. . . . . .

(ii) Planck constant. *[4]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(iii) work function of the metal. *[2]*

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question B4, part 2 continued)

X-rays

(c) Electrons are accelerated from rest through a potential difference of 25 kV. After acceleration the electrons strike a metal target and X-ray photons are emitted from the target.

Deduce

(i) that the speed of the electrons just before striking the target is of the order of $10^8\,\text{m}\,\text{s}^{-1}$. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) that the minimum wavelength of the emitted photons is about $5\times10^{-11}\,\text{m}$. *[2]*

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(d) On the axes below, draw a sketch graph of a typical X-ray spectrum produced by electrons bombarding a metal target. (Note: this is a sketch graph, you do not need to add any values to the axes.) *[3]*