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

M06/4/PHYSI/HP2/ENG/TZ2/XX+

22066514

PHYSICS
HIGHER LEVEL
PAPER 2

Tuesday 9 May 2006 (afternoon)

2 hours 15 minutes

Candidate session number

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INSTRUCTIONS TO CANDIDATES

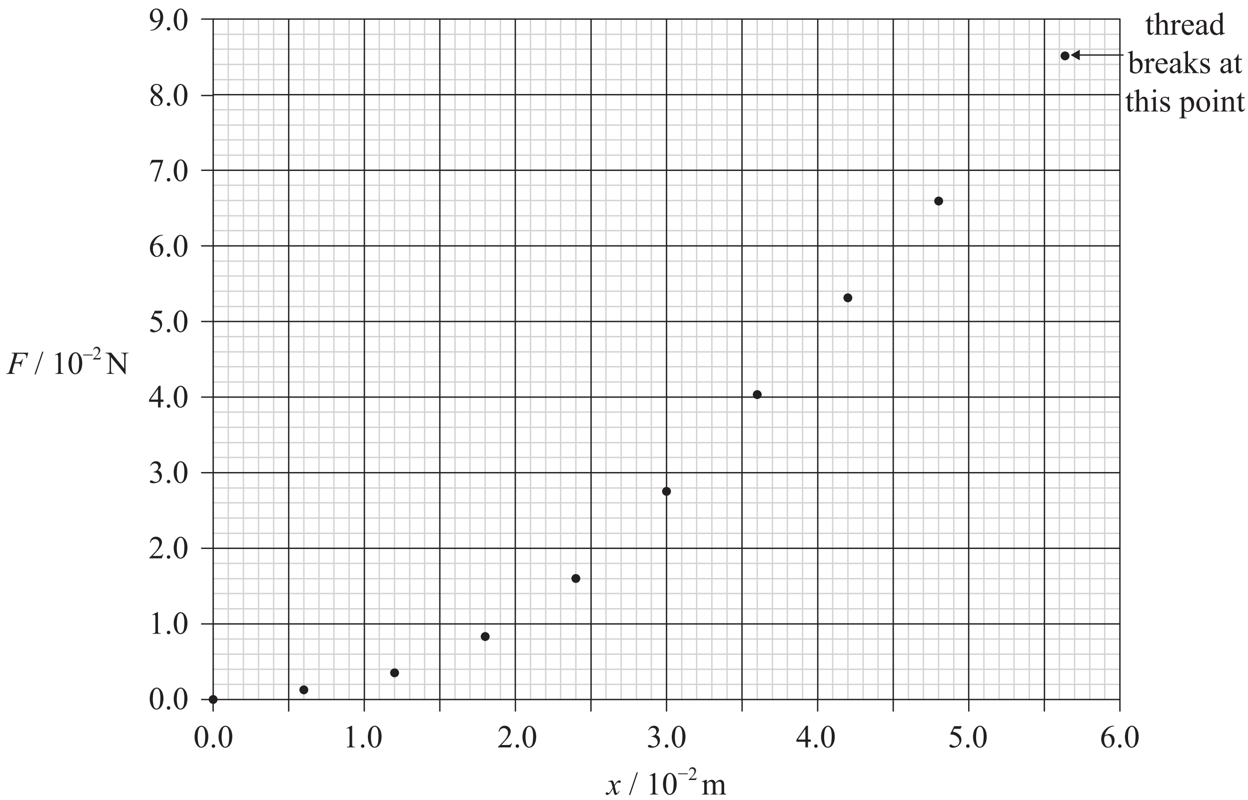
- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all of Section A in the spaces provided.
- Section B: answer two questions from Section B in the spaces provided.
- At the end of the examination, indicate the numbers of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

SECTION A

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

A1. This question is about a spider's web.

An experiment was carried out to measure the extension x of a thread of a spider's web when a load F is applied to it. The results of the experiment are shown plotted below. Uncertainties in the measurements are not shown.



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

(b) The relationship between F and x is of the form $F = kx^n$.

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

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(Question A1 continued)

(c) When a load is applied to a material, it is said to be under "stress". The magnitude P of the stress is given by

$$P = \frac{F}{A}$$

where, A is the area of cross-section of the sample of the material.

Use the graph and the data below to deduce that the thread used in the experiment has a greater breaking stress than steel. *[3]*

Breaking stress of steel $= 1.0 \times 10^{9}\ \mathrm{N\,m^{-2}}$

Radius of spider web thread $= 4.5 \times 10^{-6}\ \mathrm{m}$

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(d) The uncertainty in the measurement of the radius of the thread is $\pm 0.1 \times 10^{-6}$ m. Determine the percentage uncertainty in the value of the area of the thread. *[2]*

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(This question continues on the following page)

(Question A1 continued)

(e) In a particular web, one thread has the same original length as the thread used in the experiment. In the making of this web, the original length of the thread is extended by 2.4×10^{-2} m.

(i) Use the graph to deduce that the amount of work required to further extend the thread to the length at which it just breaks, is about 1.6×10^{-3} J. Explain your working. *[3]*

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(ii) If the thread is not to break due to the impact of a flying insect, then the thread must be capable of absorbing all the kinetic energy of the insect as it is brought to rest by the impact. Determine the impact speed that an insect of mass 0.15 g must have in order that it just breaks the thread. *[3]*

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A2. This question is about gravitational potential.

(a) Define *gravitational potential* at a point in a gravitational field. *[3]*

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(b) A planet has mass M and radius R_0. The magnitude g_0 of the gravitational field strength at the surface of a planet is

$$g_0 = G\frac{M}{R_0^{\ 2}}$$

where G is the gravitational constant.

Use this expression to deduce that the gravitational potential V_0 at the surface of the planet is given by

$$V_0 = -\,g_0 R_0.$$ *[2]*

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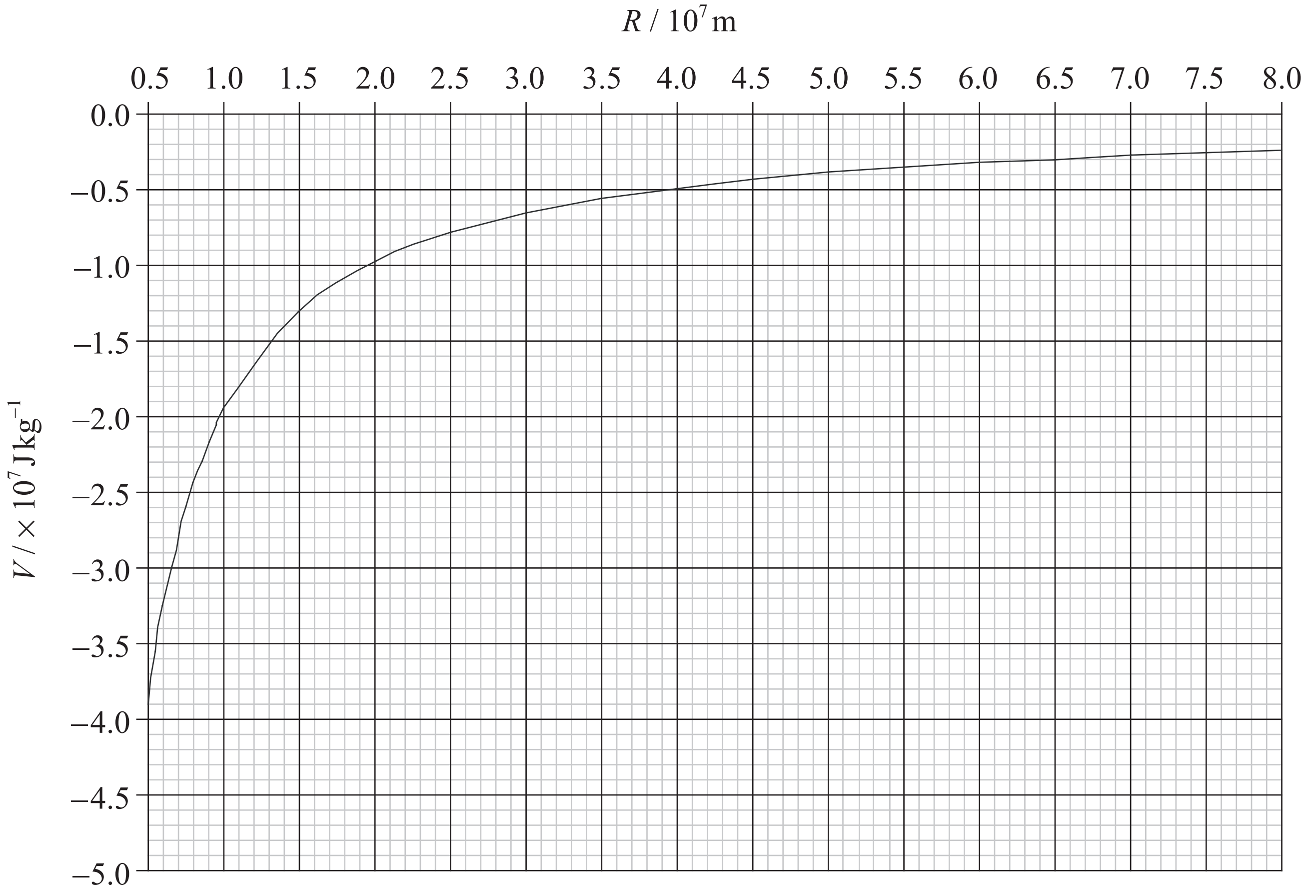
(This question continues on the following page)

(Question A2 continued)

(c) The graph below shows the variation with distance R from the centre of the planet of the gravitational potential V. The radius R_0 of the planet = 5.0×10^{6} m. Values of V are not shown for $R < R_0$.



Use the graph to determine the magnitude of the gravitational field strength at the surface of the planet. *[3]*

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(Question A2 continued)

(d) A satellite of mass 3.2×10^3 kg is launched from the surface of the planet. Use the graph to estimate the minimum launch speed that the satellite must have in order to reach a height of 2.0×10^7 m above the surface of the planet. (You may assume that it reaches its maximum speed immediately after launch.) *[4]*

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A3. This question is about an ideal gas.

(a) The pressure P of a fixed mass of an ideal gas is directly proportional to the kelvin temperature T of the gas. That is,

$$P \propto T.$$

State

(i) the relation between the pressure P and the volume V for a change at constant temperature. *[1]*

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(ii) the relation between the volume V and kelvin temperature T for a change at a constant pressure. *[1]*

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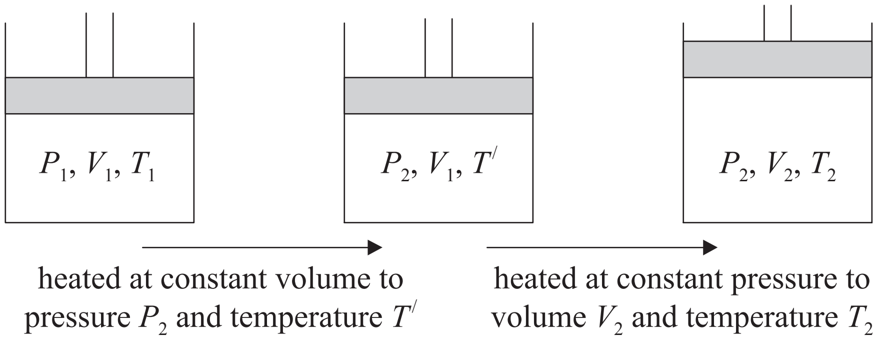
(This question continues on the following page)

(Question A3 continued)

(b) The ideal gas is held in a cylinder by a moveable piston. The pressure of the gas is P_1, its volume is V_1 and its kelvin temperature is T_1.

The pressure, volume and temperature are changed to P_2, V_2 and T_2 respectively. The change is brought about as illustrated below.



State the relation between

(i) P_1, P_2, T_1 and $T^{/}$. *[1]*

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(ii) V_1, V_2, $T^{/}$ and T_2. *[1]*

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(c) Use your answers to (b) to deduce, that for an ideal gas

$$PV = KT$$

where K is a constant. *[4]*

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SECTION B

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

B1. This question is about mechanical power and heat engines.

Mechanical power

(a) Define *power*. *[1]*

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(b) A car is travelling with constant speed v along a horizontal straight road. There is a total resistive force F acting on the car.

Deduce that the power P to overcome the force F is

$$P = Fv.$$ *[2]*

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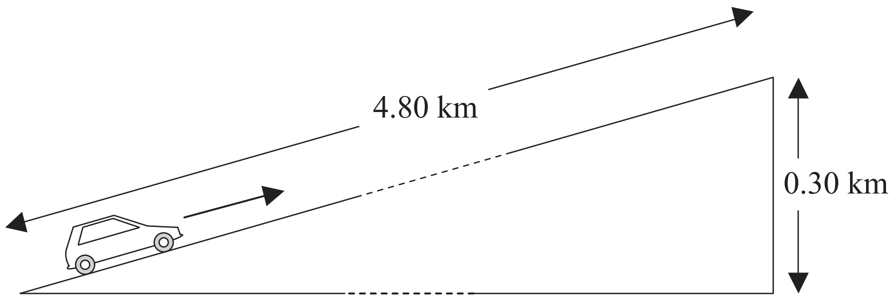
(Question B1 continued)

(c) A car drives up a straight incline that is 4.80 km long. The total height of the incline is 0.30 km.



The car moves up the incline at a steady speed of $16\,\text{m s}^{-1}$. During the climb, the average resistive force acting on the car is 5.0×10^{2} N. The total weight of the car and the driver is 1.2×10^{4} N.

(i) Determine the time it takes the car to travel from the bottom to the top of the incline. *[2]*

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(ii) Determine the work done against the gravitational force in travelling from the bottom to the top of the incline. *[1]*

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(iii) Using your answers to (i) and (ii), calculate a value for the minimum power output of the car engine needed to move the car from the bottom to the top of the incline. *[4]*

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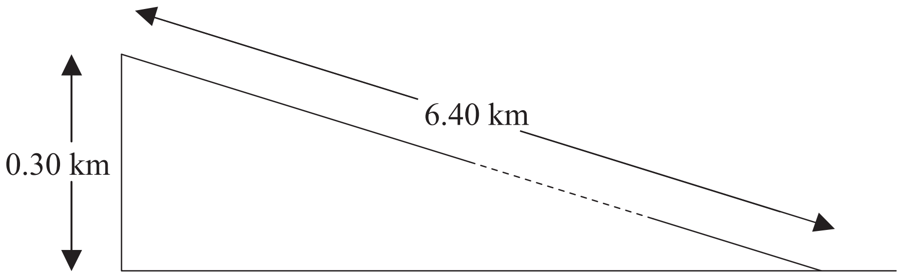
(Question B1 continued)

(d) From the top of the incline, the road continues downwards in a straight-line. At the point where the incline starts to go downwards, the driver of the car in (c) stops the car to look at the view. In continuing his journey, the driver decides to save fuel. He switches off the engine and allows the car to move freely down the incline. The car descends a height of 0.30 km in a distance of 6.40 km before levelling out.



The average resistive force acting on the car is 5.0×10^2 N.

Estimate

(i) the acceleration of the car down the incline. *[5]*

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(ii) the speed of the car at the bottom of the incline. *[2]*

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(e) In fact, for the last few hundred metres of its journey down the incline, the car travels at constant speed. State the value of the frictional force acting on the car whilst it is moving at constant speed. *[1]*

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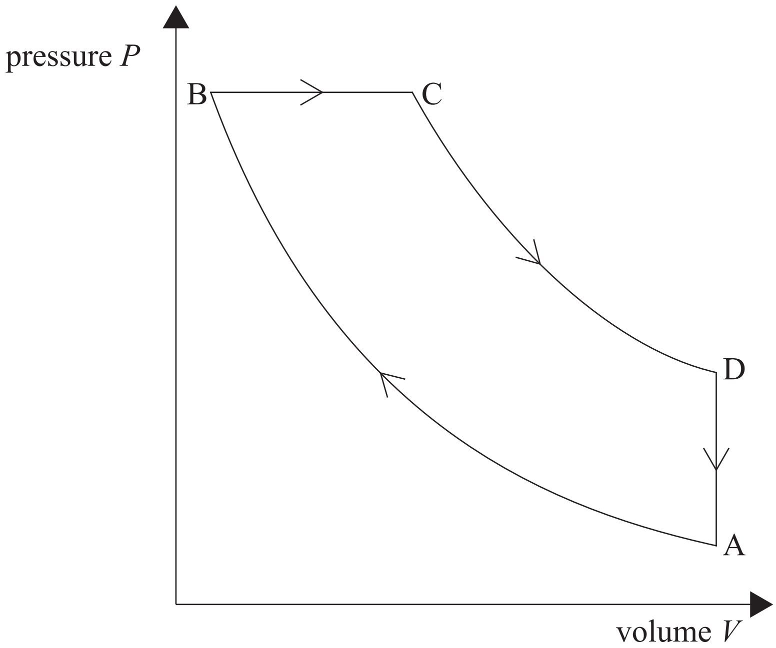
(This question continues on the following page)

(Question B1 continued)

The heat engine

(f) The diagram below shows the idealised pressure-volume (*P*-*V*) diagram for one cycle of the gases in an engine similar to that used in the car.



The changes A → B and C → D are adiabatic changes.

(i) Explain what is meant by an *adiabatic change*. *[2]*

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(ii) State the name given to the change B → C. *[1]*

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(This question continues on the following page)

(Question B1 continued)

(g) During the cycle of the gas in the engine, Q_H units of thermal energy are transferred to the gas and Q_C units are transferred from the gas.

(i) On the diagram in (f), draw labelled arrows to represent these energy transfers. *[2]*

(ii) State the value of the area ABCD in terms of Q_H and Q_C. *[1]*

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(iii) Explain whether, for a Carnot engine operating between the same temperatures as the car engine, the area ABCD is greater, smaller or the same. *[3]*

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(h) The useful power output of the engine is 20 kW and the overall efficiency of the engine is 32 %. The car engine completes 50 cycles every second. Deduce that $Q_H = 1.3$ kJ. *[3]*

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B2. This question is about waves and wave properties.

Travelling and standing (stationary) waves

(a) State **two** differences between a travelling wave and a standing (stationary) wave. *[2]*

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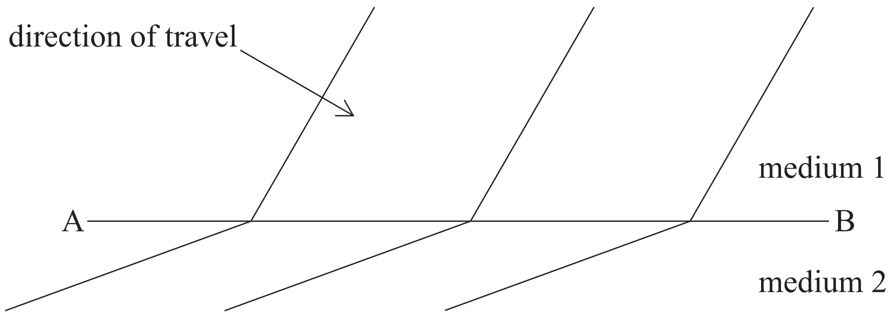
(b) In the scale diagram below, plane wavefronts travel from medium 1 to medium 2 across the boundary AB.



State and explain in which medium the wavefronts have the greater speed. *[3]*

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(c) By taking measurements from the diagram, determine the ratio

$$\frac{\text{speed of wave in medium 1}}{\text{speed of wave in medium 2}}.$$ *[3]*

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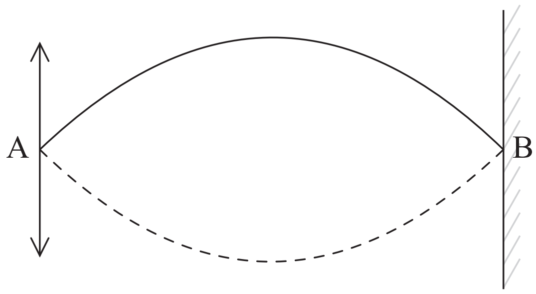
(Question B2 continued)

(d) To demonstrate the production of a standing wave, Samantha attaches the end B of a length AB of rubber tubing to a rigid support. She holds the other end A of the tubing, pulls on it slightly and then shakes the end A in a direction at right angles to AB. At a certain frequency of shaking, the tubing is seen to form the standing wave pattern shown below.



Explain how this pattern is formed. *[5]*

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(Question B2 continued)

(e) The speed v with which energy is propagated in the tubing by a travelling wave depends on the tension T in the tubing. The relationship between these quantities is

$$v = k\sqrt{T}$$

where k is a constant.

In an experiment to verify this relationship, the fundamental (first harmonic) frequency f was measured for different values of tension T.

(i) Explain how the results of this experiment, represented graphically, can be used to verify the relationship $v = k\sqrt{T}$. *[4]*

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(ii) In the experiment, the length of the tubing was kept constant at 2.4 m. The fundamental frequency for a tension of 9.0 N in the tubing was 1.8 Hz. Calculate the numerical value of the constant k. *[3]*

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(Question B2 continued)

The Doppler effect

(f) A source S emits sound waves at constant frequency. In the diagram below, S is moving at constant speed in the direction shown, along a straight-line between two stationary observers A and B.

(i) Draw, on the above diagram, **three** wavefronts representing the waves emitted by S. *[2]*

(ii) Use your sketch to explain any difference in the frequency of the sound as heard by observer A and by observer B. *[2]*

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(This question continues on the following page)

(Question B2 continued)

(g) Some speed detectors make use of the Doppler effect and the beat frequency between a transmitted wave and a reflected wave.

(i) Explain, with reference to sound waves, the term *beat frequency*. *[2]*

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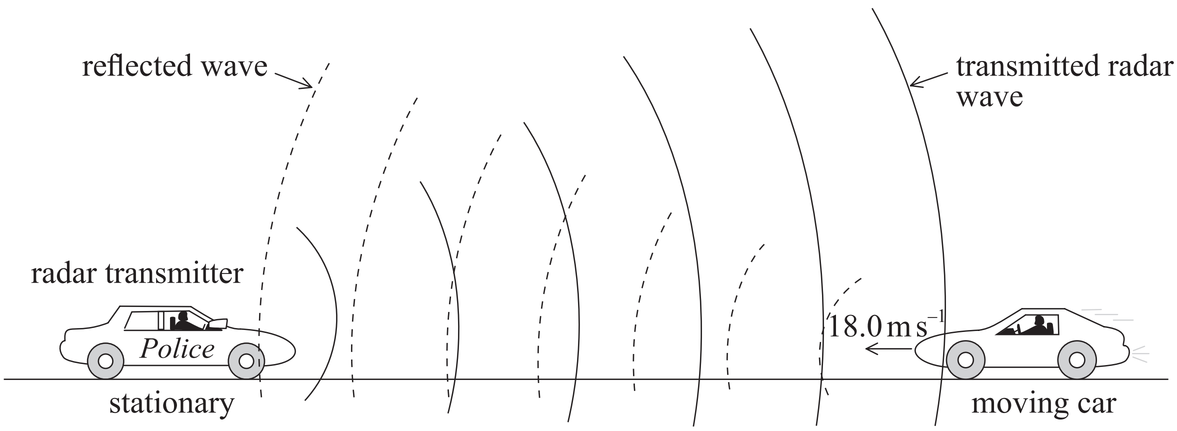
(ii) Some speed detectors transmit microwaves rather than sound. In this situation, the Doppler equations that apply to sound can also be assumed to apply to microwaves.

In the diagram below, a speed detector in a stationary police car emits microwaves of frequency 10.6 GHz. The waves are reflected off an approaching car.



The car is travelling in a direct line towards the police car with a speed $18.0\,\text{m}\,\text{s}^{-1}$. The reflected waves are Doppler shifted and interfere with the transmitted waves to produce beats. The speed of the microwaves is $3.00 \times 10^{8}\,\text{m}\,\text{s}^{-1}$.

Calculate the beat frequency measured at the speed detector. *[4]*

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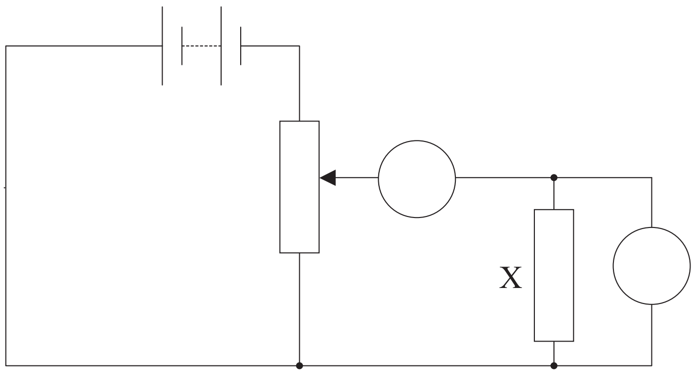
B3. This question is about electric current and the effects of electric current.

Electric current

(a) The diagram below shows the circuit used to measure the current-voltage (I-V) characteristic of an electrical component X.



On the diagram above,

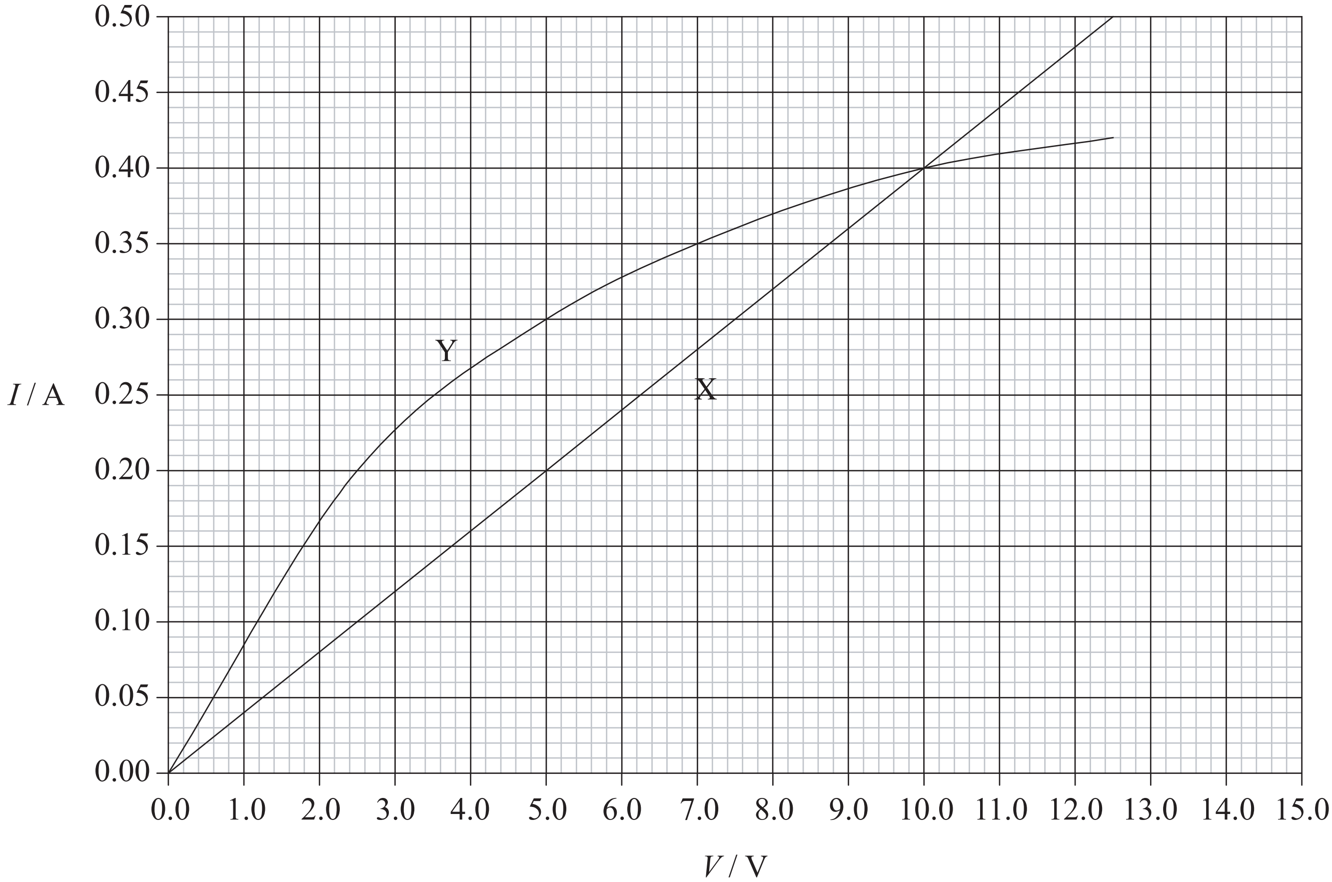
(i) label the ammeter A and the voltmeter V. *[1]*

(ii) mark the position of the contact of the potentiometer that will produce a reading of zero on the voltmeter. Label this position P. *[1]*

(This question continues on the following page)

(Question B3 continued)

(b) The graph below shows the current-voltage (*I-V*) characteristics of two different conductors X and Y.



(i) State the value of the current for which the resistance of X is the same as the resistance of Y and determine the value of this resistance. *[2]*

Current: . . . .

Resistance: . . . .

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(ii) Describe and suggest an explanation for the *I-V* characteristic of conductor Y. *[3]*

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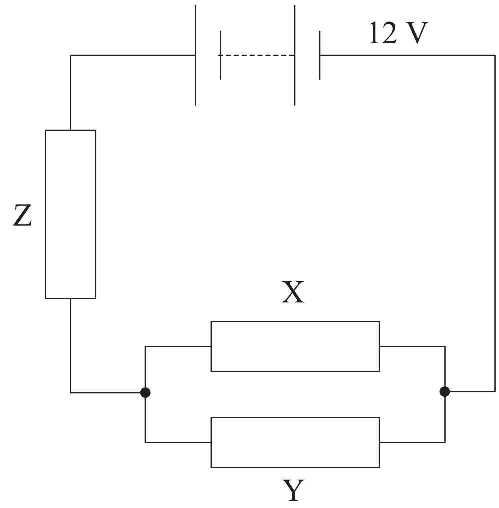
(Question B3 continued)

(c) The two conductors X and Y are connected in the circuit as shown below.



The cell has e.m.f. 12 V and negligible internal resistance. The resistor Z has resistance *R* and the potential difference across the conductors X and Y is 5.0 V.

(i) Use the graph in (b) to determine the total current in the circuit. *[2]*

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(ii) Determine the resistance *R* of the resistor Z. *[2]*

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(iii) Determine the total resistance of the parallel combination of X and Y. *[2]*

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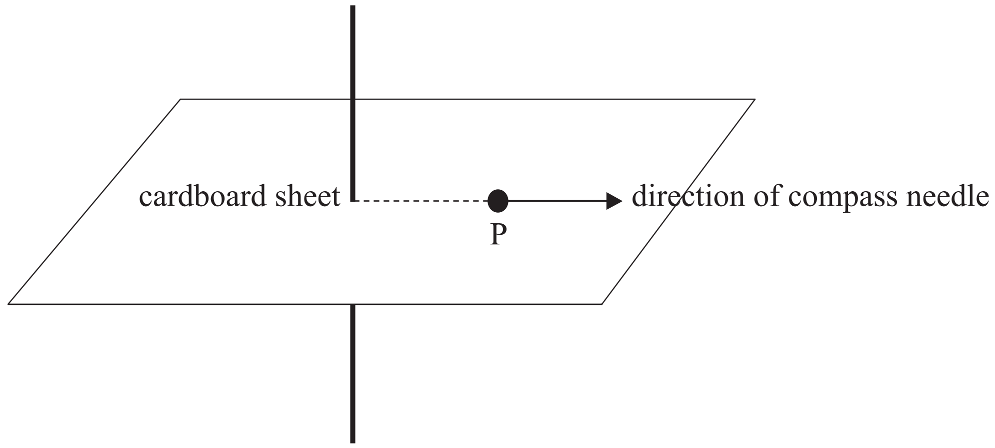
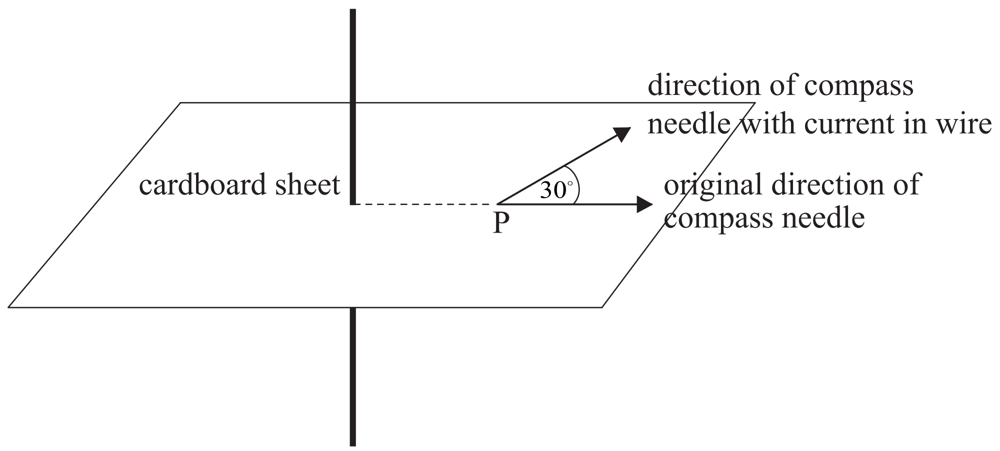
(Question B3 continued)

Electromagnetic effects associated with steady electric currents

(d) A long vertical wire passes through a sheet of cardboard that is held horizontal. A small compass is placed at the point P and the needle points in the direction shown.



A current is passed through the wire and the compass needle now points in a direction that makes an angle of 30° to its original direction as shown below.



(i) Draw an arrow on the wire to show the direction of current in the wire. Explain why it is in the direction that you have drawn. *[2]*

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(Question B3 continued)

(ii) The magnetic field strength at point P due to the current in the wire is B_W and the strength of the horizontal component of the Earth's magnetic field is B_E.

Deduce, by drawing a suitable vector diagram, that

$$B_E = B_W \tan 60^\circ.$$ *[2]*

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(iii) The point P is 2.0 cm from the wire and the current in the wire is 4.0 A. Calculate the strength of the horizontal component of the Earth's magnetic field at point P. *[2]*

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(Question B3 continued)

Electromagnetic effect due to time-changing currents

(e) State

(i) Faraday's law of electromagnetic induction. *[2]*

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(ii) Lenz's law. *[1]*

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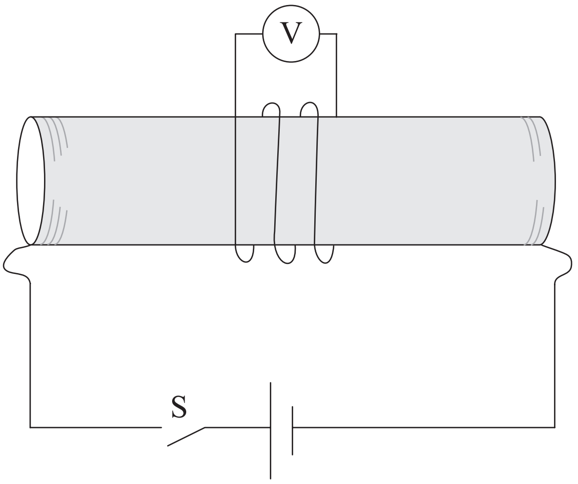
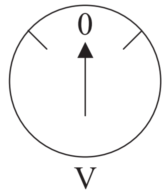
(Question B3 continued)

(f) A long solenoid is connected in series with a battery and a switch S. Several loops of wire are wrapped around the solenoid close to its midpoint as shown below.





The ends of the wire are connected to a high resistance voltmeter V that has a centre zero scale (as shown in the inset diagram).

Describe, and explain, the deflection on the voltmeter when

(i) the switch S is closed. *[4]*

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Explanation: . . . .

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(Question B3 continued)

(ii) the switch S is re-opened a short time after being closed. *[4]*

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Explanation: . . . .

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B4. This question is about nuclear energy and radioactive decay.

(a) A neutron collides with a nucleus of uranium-235 and the following reaction takes place.

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{96}_{37}\text{Rb} + ^{138}_{55}\text{Cs} + 2\,^{1}_{0}\text{n}$$

Using the data below, calculate the energy, in MeV, that is released in the reaction. *[4]*

mass of $^{235}_{92}\text{U} = 235.0439\,u$

mass of $^{96}_{37}\text{Rb} = 95.9342\,u$

mass of $^{138}_{55}\text{Cs} = 137.9112\,u$

mass of $^{1}_{0}\text{n} = 1.0087\,u$

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(b) The reaction in (a) is more likely to take place if the colliding neutron has an energy of about 0.1 eV. In certain types of nuclear reactors in which this reaction might take place, the neutrons produced have their energy reduced by collisions with nuclei of graphite (^{12}C). The law of conservation of momentum can be used to estimate the number of collisions required to reduce the energy of the neutrons to 0.1 eV.

State the law of conservation of momentum. *[2]*

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(c) A neutron has a kinetic energy of 2.00 MeV. Deduce that the speed of the neutron is $1.95 \times 10^{7}\,\text{m s}^{-1}$. *[2]*

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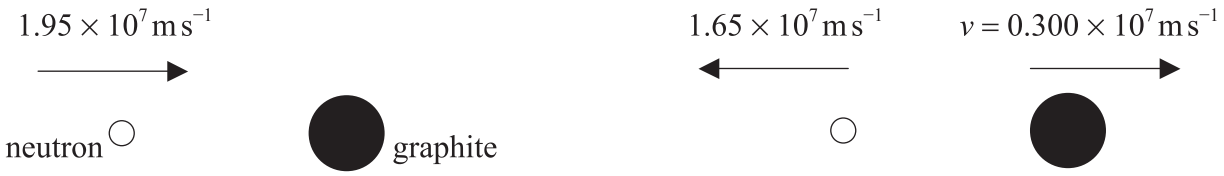
(Question B4 continued)

(d) You may assume that the mass of a nucleus of graphite is twelve times the mass of a neutron. In a certain collision between a neutron and a stationary graphite nucleus, the neutron of kinetic energy 2.00 MeV, rebounds from the graphite nucleus in a direction along a line joining the centres of the nucleus and neutron.



before collision after collision

The rebound speed of the neutron is $1.65 \times 10^7\,\mathrm{m\,s^{-1}}$.

(i) Deduce that the speed v of the graphite nucleus after collision is $0.300 \times 10^7\,\mathrm{m\,s^{-1}}$. *[3]*

(ii) Using your answer in (i), deduce whether the collision is elastic or inelastic. *[3]*

(iii) Use your answer to (ii) to deduce that each time a neutron collides in this manner with a graphite nucleus it loses about 30 % of its kinetic energy. *[2]*

(This question continues on the following page)

(Question B4 continued)

(iv) Explain briefly, why quite a lot of collisions are necessary to reduce the energy of the neutron to 0.1 eV. *[2]*

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(e) Determine the de Broglie wavelength associated with a neutron that has a kinetic energy of 2.00 MeV. *[4]*

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(f) The nucleus of ${}^{138}_{55}\mathrm{Cs}$ produced in the fission reaction

$$ {}^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{96}_{37}\mathrm{Rb} + {}^{138}_{55}\mathrm{Cs} + 2\,{}^{1}_{0}\mathrm{n} $$

is radioactive. It undergoes β^- decay to a nucleus of barium (Ba).

(i) Write down the equation for the decay of ${}^{138}_{55}\mathrm{Cs}$. *[2]*

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(ii) State the name of the force and the name of exchange particle involved in β^- decay. *[2]*

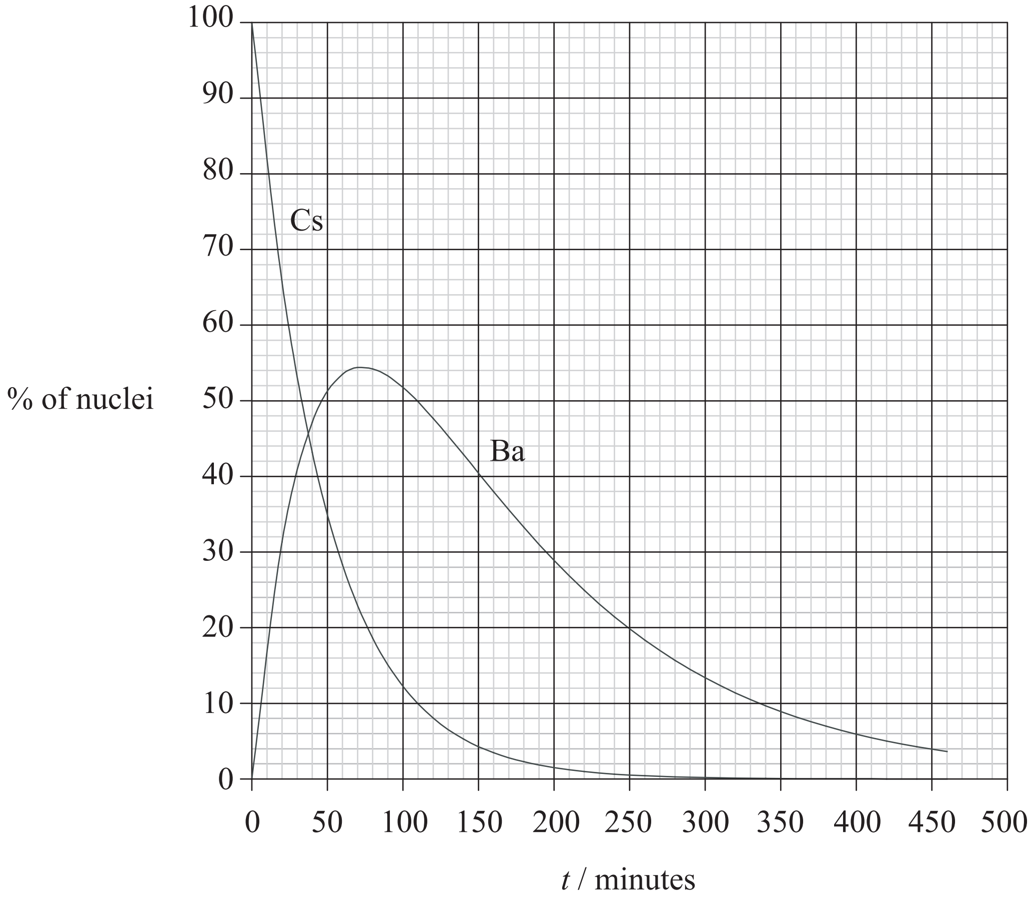
Force: . . . .

Exchange particle: . . . .

(This question continues on the following page)

(Question B4 continued)

(g) The graph below shows the variation with time t of the percentage of nuclei of caesium-138 and the percentage of nuclei of the isotope of barium formed from the decay of a pure sample of caesium-138.



Use the graph, explaining your working, to estimate the half-life of

(i) caesium-138. *[1]*

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(ii) the isotope of barium. *[3]*

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