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PHYSICS
HIGHER LEVEL
PAPER 2

Candidate session number

0	0							

Wednesday 11 May 2011 (afternoon)

2 hour 15 minutes

Examination code

2	2	1	1	–	6	5	0	8

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 questions.
- Section B: answer two questions.
- Write your answers in the boxes provided.

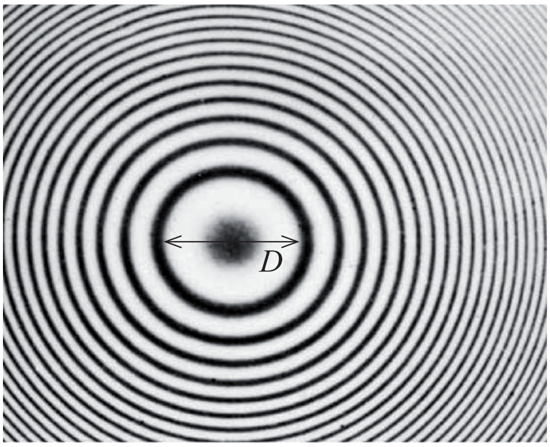
47 pages

SECTION A

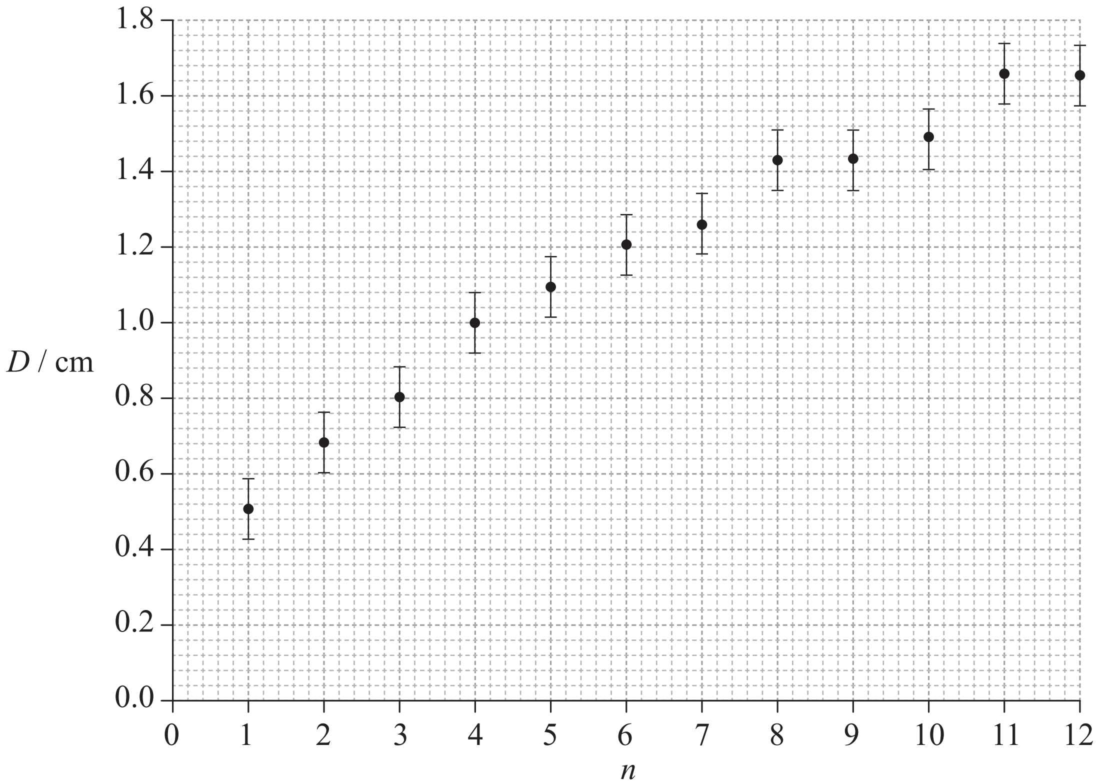
*Answer **all** questions. Write your answers in the boxes provided.*

A1. Data analysis question.

The photograph below shows a magnified image of a dark central disc surrounded by concentric dark rings. These rings were produced as a result of interference of monochromatic light.



The graph below shows how the ring diameter D varies with the ring number n. The innermost ring corresponds to $n=1$. The corresponding diameter is labelled in the photograph. Error bars for the diameter D are shown.



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(Question A1 continued)

(a) State **one** piece of evidence that shows that D is not proportional to n. *[1]*

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(b) On the graph opposite, draw the line of best-fit for the data points. *[2]*

(c) It is suggested that the relationship between D and n is of the form

$$D = cn^p$$

where c and p are constants.

Explain what graph you would plot in order to determine the value of p. *[3]*

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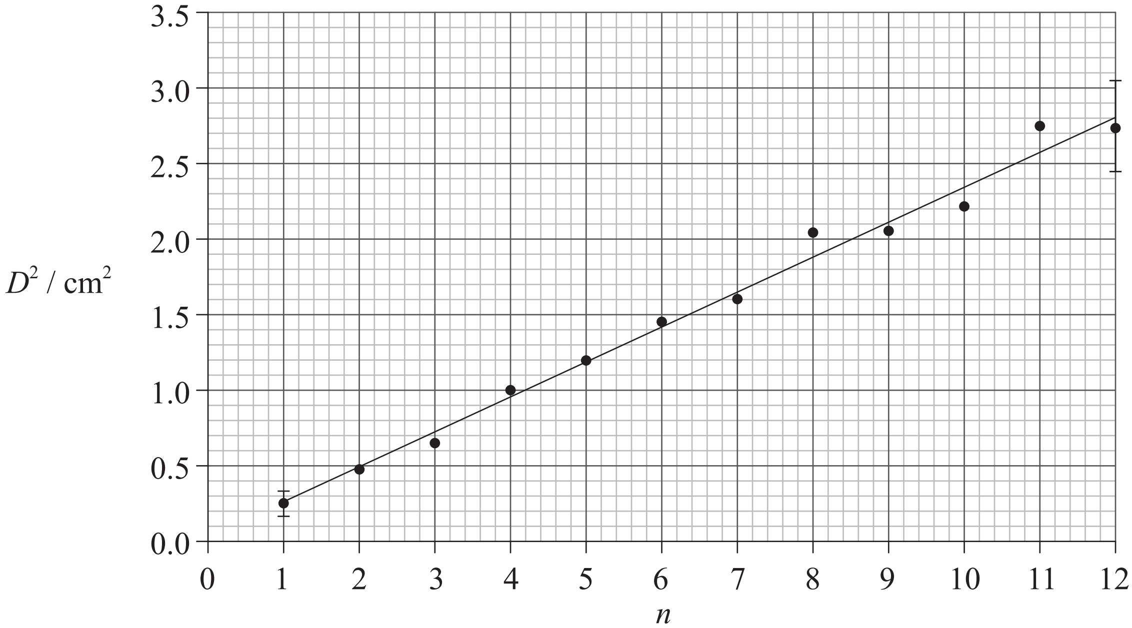
(This question continues on the following page)

(Question A1 continued)

(d) Theory suggests that $p = \frac{1}{2}$ and so $D^2 = kn \left(\text{where } k = c^2\right)$.

A graph of D^2 against n is shown below. Error bars are shown for the first and last data points only.



(i) Using the graph on page 2, calculate the percentage uncertainty in D^2, of the ring $n=7$. *[2]*

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(Question A1 continued)

(ii) Based on the graph opposite, state **one** piece of evidence that supports the relationship $D^2 = kn$. *[1]*

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(iii) Use the graph opposite to determine the value of the constant *k,* as well as its uncertainty. *[4]*

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(iv) State the unit for the constant *k*. *[1]*

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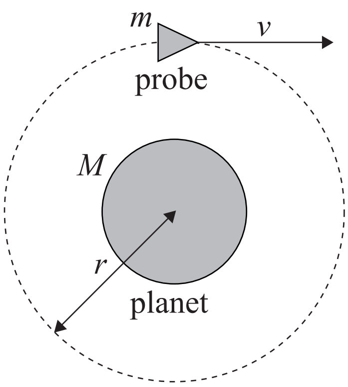
A2. This question is about a probe in orbit.

A probe of mass m is in a circular orbit of radius r around a spherical planet of mass M.



(diagram not to scale)

(a) State why the work done by the gravitational force during one full revolution of the probe is zero. *[1]*

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(b) Deduce for the probe in orbit that its

(i) speed is $v = \sqrt{\frac{GM}{r}}$. *[2]*

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(This question continues on the following page)

(Question A2 continued)

(ii) total energy is $E = -\frac{GMm}{2r}$. *[2]*

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(c) It is now required to place the probe in another circular orbit further away from the planet. To do this, the probe's engines will be fired for a very short time.

State and explain whether the work done on the probe by the engines is positive, negative **or** zero. *[2]*

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A3. This question is about polarization.

(a) State what is meant by polarized light. *[1]*

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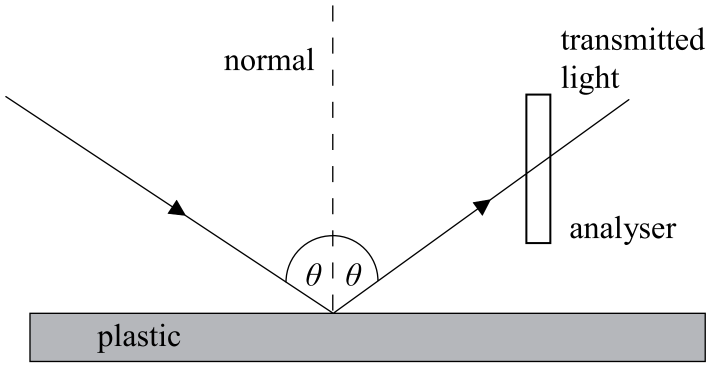
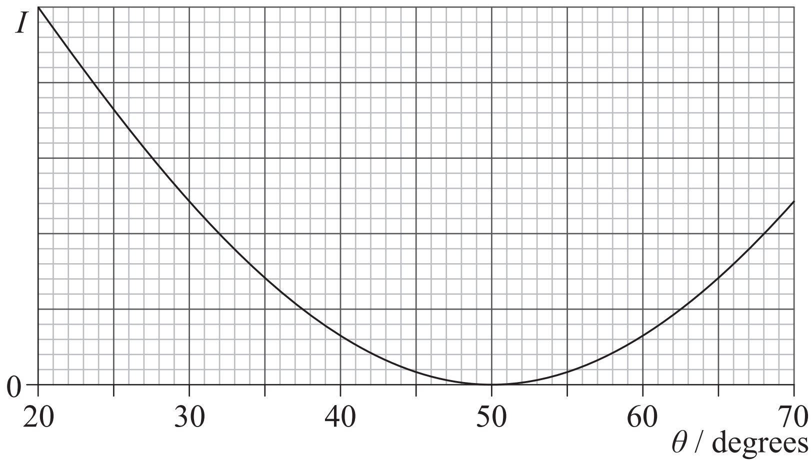
(b) Unpolarized light is incident on the surface of a plastic. The angle of incidence is θ. The reflected light is viewed through an analyser whose transmission axis is vertical.



The variation with θ of the intensity I of the transmitted light is shown in the graph.



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(Question A3 continued)

(i) Explain why there is an angle of incidence, for which the intensity of the transmitted light is zero. *[2]*

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(ii) Calculate the refractive index of the plastic. *[2]*

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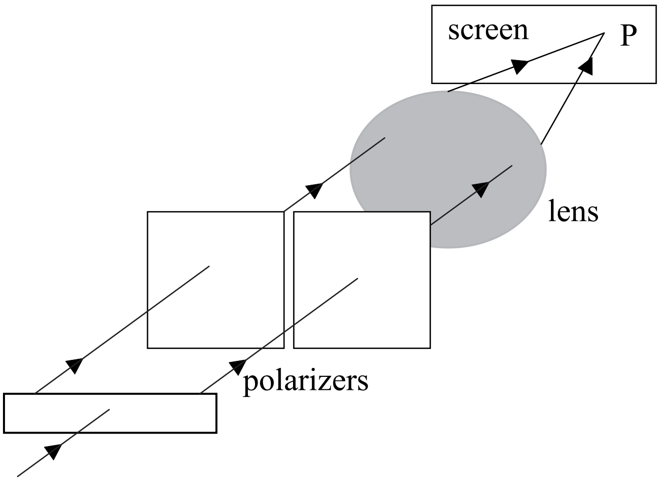
(Question A3 continued)

(c) Unpolarized light from a source is split, so that there is a path difference of half a wavelength between the two beams.



A lens brings the light to focus at point P on a screen. The lens does not introduce any additional path difference.

State and explain whether any light would be observed at P, in the case in which the polarizers have their transmission axes

(i) parallel. *[2]*

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(ii) at right angles to each other. *[2]*

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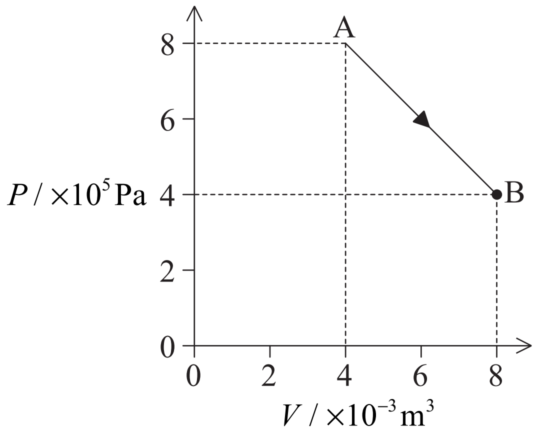
A4. This question is about thermodynamics.

The *P*–*V* diagram shows the expansion of a fixed mass of an ideal gas, from state A to state B.



The temperature of the gas in state A is 400 K.

(a) Calculate the temperature of the gas in state B. *[1]*

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(Question A4 continued)

(b) (i) Calculate the work done by the gas in expanding from state A to state B. *[2]*

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(ii) Determine the amount of thermal energy transferred during the expansion from state A to state B. *[2]*

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(c) The gas is isothermally compressed from state B back to state A.

(i) Using the *P*–*V* diagram axes opposite, draw the variation of pressure with volume for this isothermal compression. *[1]*

(ii) State and explain whether the magnitude of the thermal energy transferred in this case would be less than, equal to **or** greater than the thermal energy transferred in (b)(ii). *[2]*

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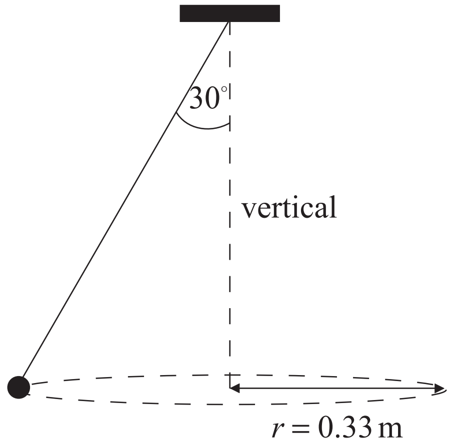
A5. This question is about circular motion.

A ball of mass 0.25 kg is attached to a string and is made to rotate with constant speed v along a horizontal circle of radius $r = 0.33\,\text{m}$. The string is attached to the ceiling and makes an angle of 30° with the vertical.



(a) (i) On the diagram above, draw and label arrows to represent the forces on the ball in the position shown. *[2]*

(ii) State and explain whether the ball is in equilibrium. *[2]*

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(Question A5 continued)

(b) Determine the speed of rotation of the ball. *[3]*

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SECTION B

This section consists of four questions: B1, B2, B3 and B4. Answer ***two*** *questions. Write your answers in the boxes provided.*

B1. This question is in **two** parts. **Part 1** is about charge-coupled devices (CCDs) and photons. **Part 2** is about simple harmonic oscillations.

Part 1 CCDs and photons

(a) State **one** factor that affects the resolution of an image obtained with a CCD. *[1]*

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(b) State **one** advantage of a CCD image, compared to an image on ordinary photographic film. *[1]*

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(This question continues on the following page)

(Question B1, part 1 continued)

(c) Light of intensity $5.3\times10^{-3}\,\mathrm{W\,m^{-2}}$ and frequency $3.9\times10^{14}\,\mathrm{Hz}$ is incident on a pixel of a CCD. The area of the pixel is $4.2\times10^{-12}\,\mathrm{m^2}$ and the quantum efficiency is 80%. The capacitance of the pixel is 14 pF.

(i) Show that the number of photons incident on the pixel of the CCD per second is 8.6×10^4. *[3]*

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(ii) Calculate the charge that accumulates in the pixel during a time of 25 ms. *[2]*

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(iii) Determine the potential difference at the ends of the pixel. *[1]*

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(This question continues on the following page)

(Question B1, part 1 continued)

(iv) Calculate the momentum of one of the incident photons. *[1]*

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(v) Using your answer to (c)(iv), estimate the pressure exerted by the photons in (c)(i) on the pixel of the CCD. *[2]*

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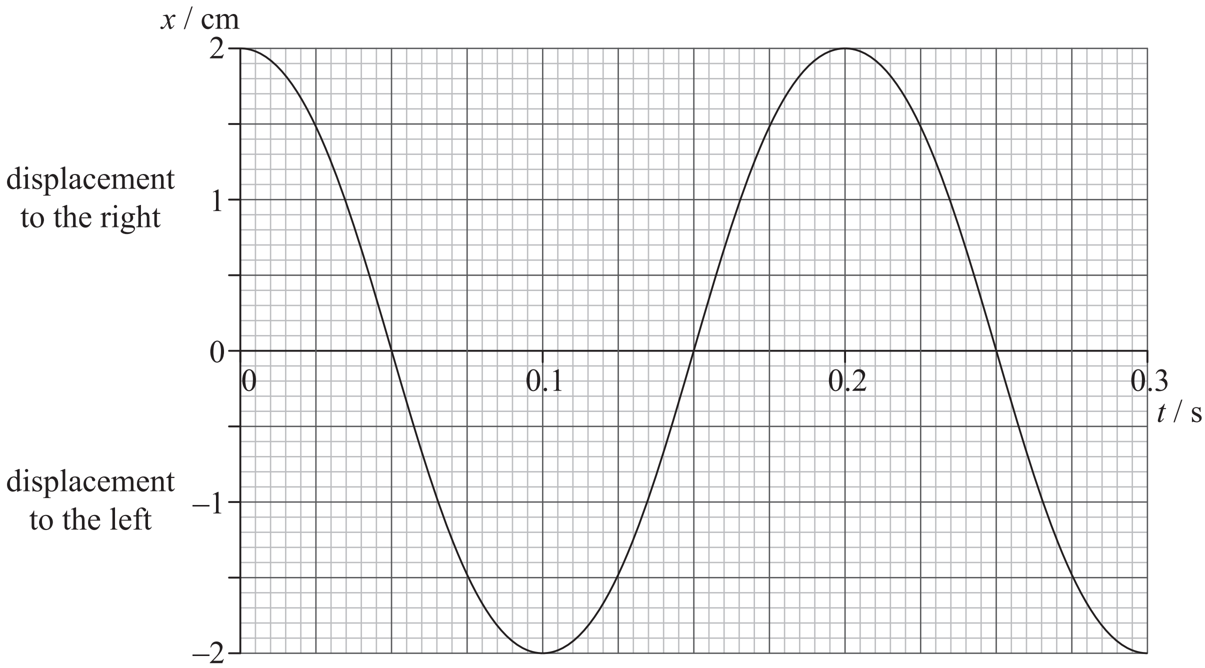
(Question B1 continued)

Part 2 Simple harmonic oscillations

A longitudinal wave travels through a medium from left to right.

Graph 1 shows the variation with time t of the displacement x of a particle P in the medium.

Graph 1



(a) For particle P,

(i) state how graph 1 shows that its oscillations are not damped. *[1]*

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(This question continues on the following page)

(Question B1, part 2 continued)

(ii) calculate the magnitude of its maximum acceleration. *[2]*

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(iii) calculate its speed at $t = 0.12\,\text{s}$. *[2]*

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(iv) state its direction of motion at $t = 0.12\,\text{s}$. *[1]*

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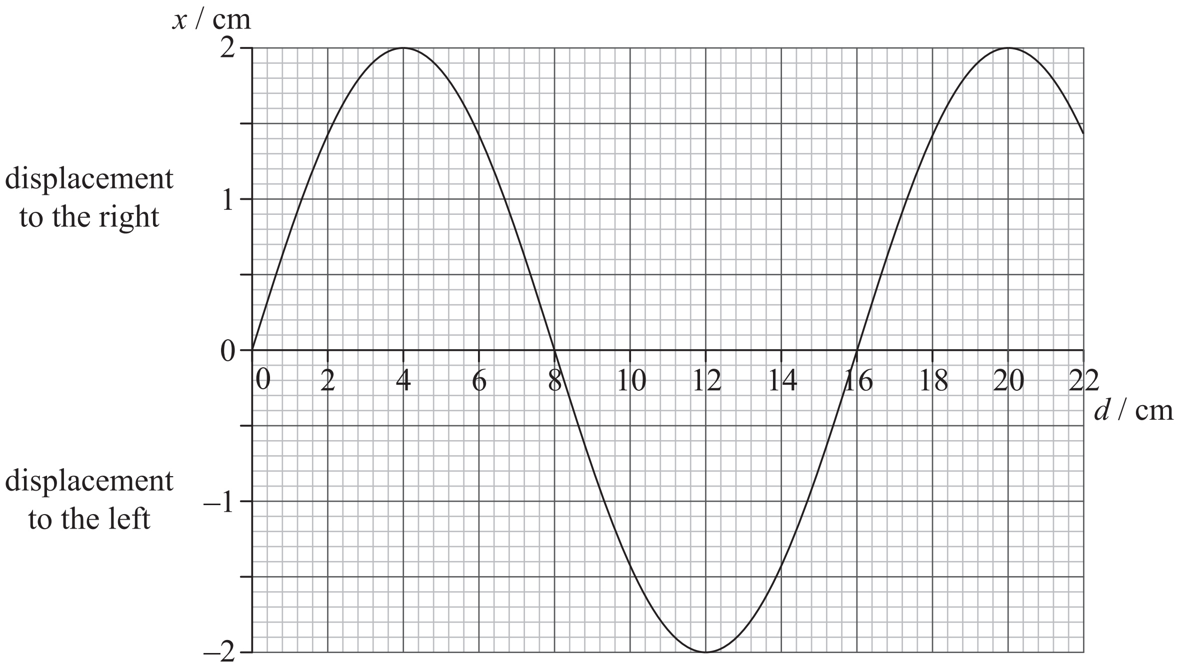
(Question B1, part 2 continued)

(b) Graph 2 shows the variation with position *d* of the displacement *x* of particles in the medium at a particular instant of time.

Graph 2



Determine for the longitudinal wave, using graph 1 and graph 2,

(i) the frequency. *[2]*

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(ii) the speed. *[2]*

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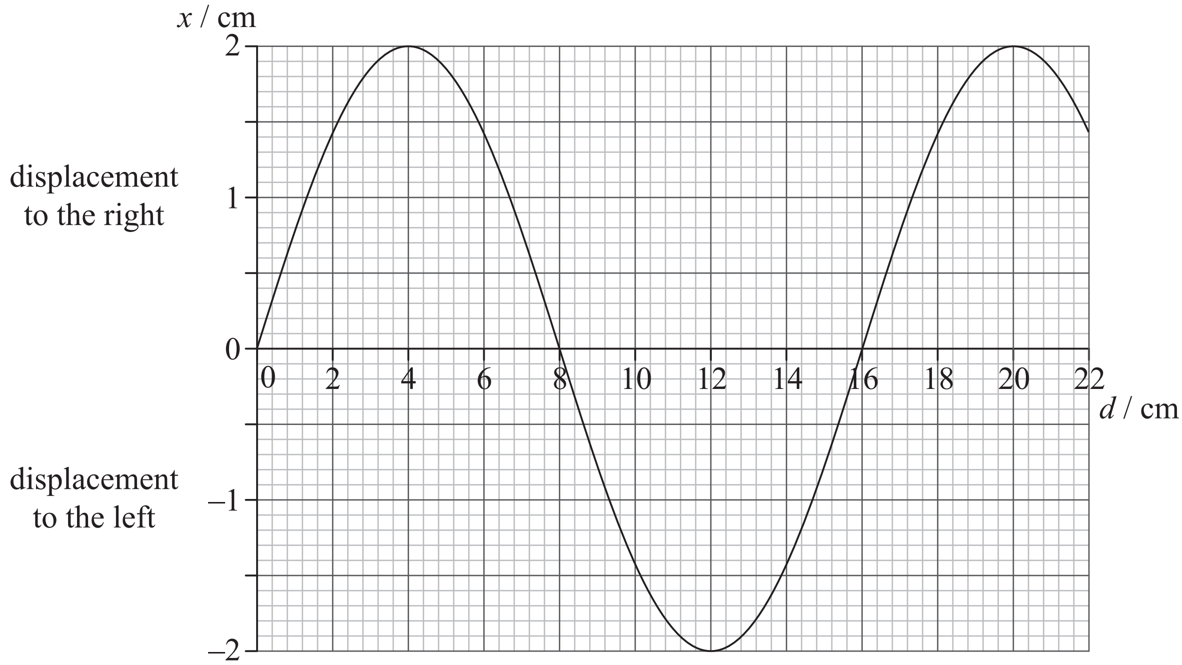
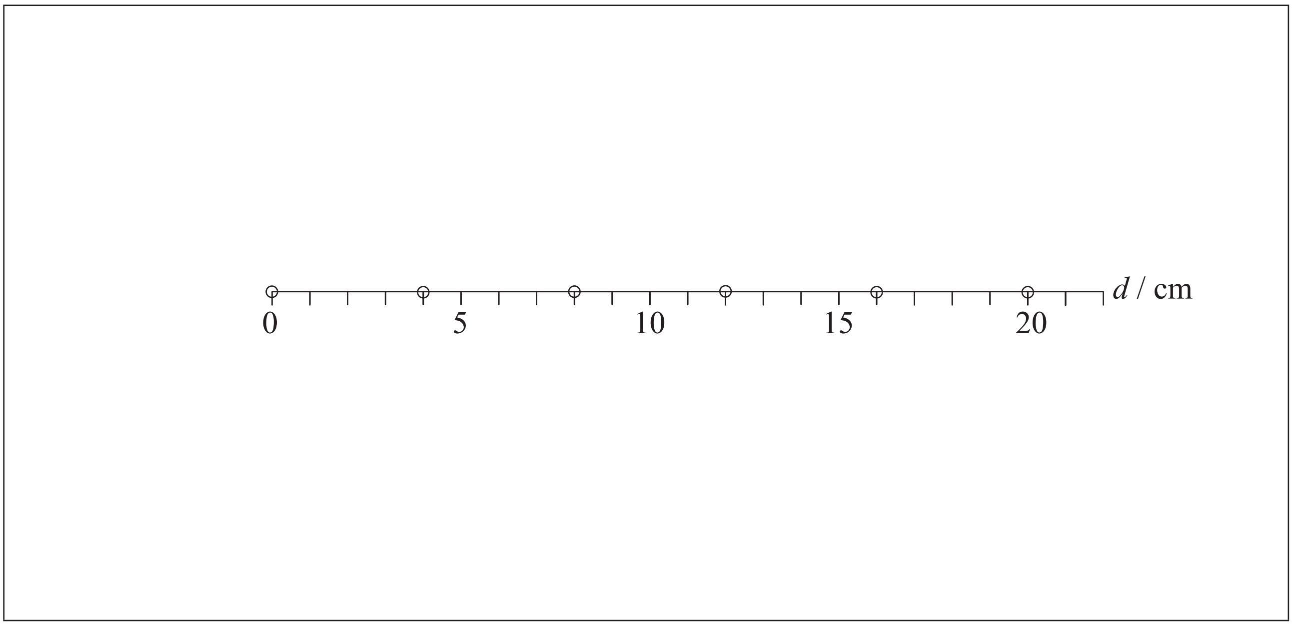
(Question B1, part 2 continued)

Graph 2 – reproduced to assist with answering (c)(i).



(c) The diagram shows the equilibrium positions of six particles in the medium.



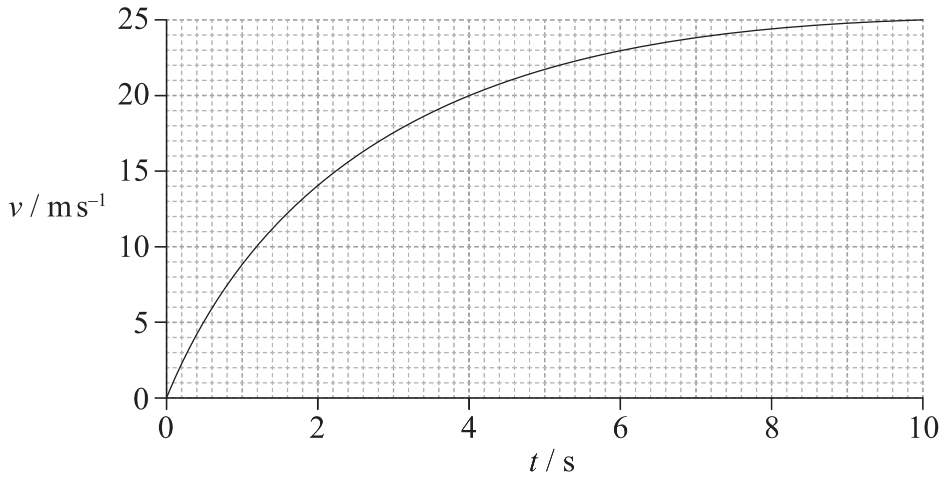
(i) On the diagram above, draw crosses to indicate the positions of these six particles at the instant of time when the displacement is given by graph 2. *[3]*

(ii) On the diagram above, label with the letter C a particle that is at the centre of a compression. *[1]*

B2. This question is in **two** parts. **Part 1** is about mechanics and thermal physics. **Part 2** is about nuclear physics.

Part 1 Mechanics and thermal physics

The graph shows the variation with time t of the speed v of a ball of mass 0.50 kg, that has been released from rest above the Earth's surface.



The force of air resistance is **not** negligible. Assume that the acceleration of free fall is $g = 9.81\,\text{m s}^{-2}$.

(a) State, without any calculations, how the graph could be used to determine the distance fallen. *[1]*

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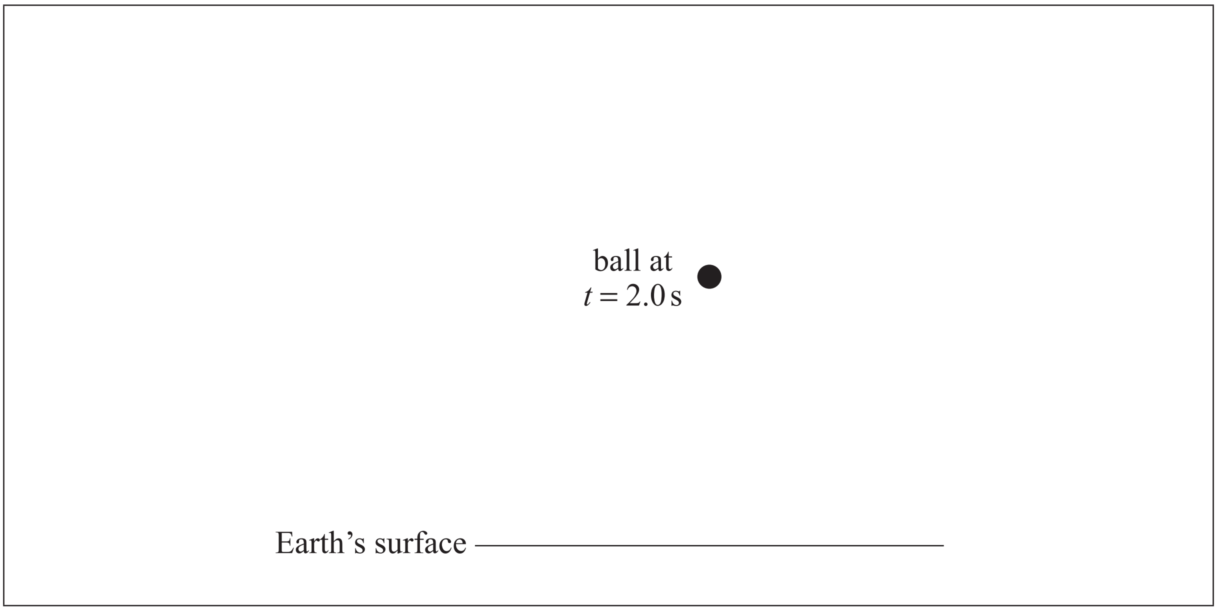
(Question B2, part 1 continued)

(b) (i) In the space below, draw and label arrows to represent the forces on the ball at 2.0 s. *[1]*



(ii) Use the graph opposite to show that the acceleration of the ball at 2.0 s is approximately $4\,\mathrm{m\,s^{-2}}$. *[2]*

(iii) Calculate the magnitude of the force of air resistance on the ball at 2.0 s. *[2]*

(This question continues on the following page)

(Question B2, part 1 continued)

(iv) State and explain whether the air resistance on the ball at $t = 5.0\,\text{s}$ is smaller than, equal to **or** greater than the air resistance at $t = 2.0\,\text{s}$. *[2]*

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(Question B2, part 1 continued)

(c) After 10 s the ball has fallen 190 m.

(i) Show that the sum of the potential and kinetic energies of the ball has decreased by 780 J. *[3]*

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(ii) The specific heat capacity of the ball is $480\,J\,kg^{-1}\,K^{-1}$. Estimate the increase in the temperature of the ball. *[2]*

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(iii) State an assumption made in the estimate in (c)(ii). *[1]*

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will not be marked.

(Question B2 continued)

Part 2	Nuclear physics

(a) (i) Define *binding energy* of a nucleus. *[1]*

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(ii) The mass of a nucleus of plutonium $\left({}^{239}_{94}\text{Pu}\right)$ is 238.990396 u. Deduce that the binding energy per nucleon for plutonium is 7.6 MeV. *[3]*

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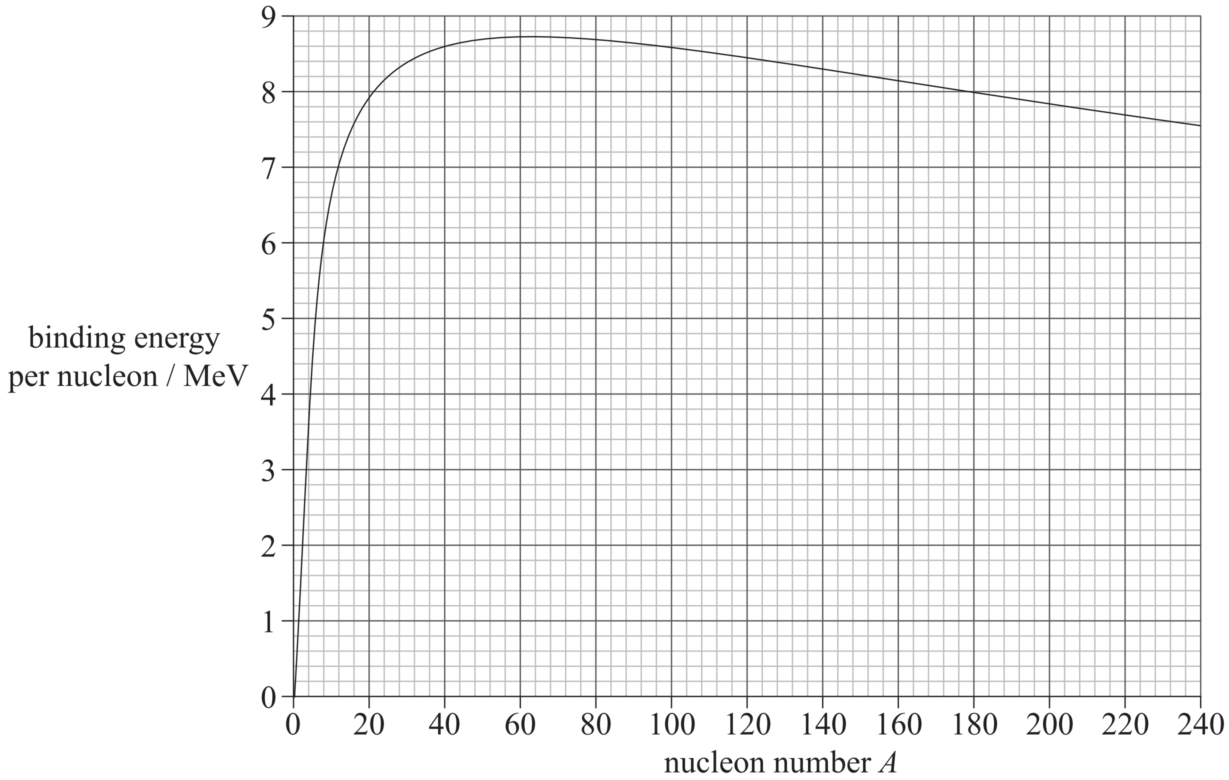
(Question B2, part 2 continued)

(b) The graph shows the variation with nucleon number A of the binding energy per nucleon.



Plutonium $\left({}^{239}_{94}\text{Pu}\right)$ undergoes nuclear fission according to the reaction given below.

$${}^{239}_{94}\text{Pu} + {}^{1}_{0}\text{n} \rightarrow {}^{91}_{38}\text{Sr} + {}^{146}_{56}\text{Ba} + x\,{}^{1}_{0}\text{n}$$

(i) Calculate the number x of neutrons produced. *[1]*

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(Question B2, part 2 continued)

(ii) Use the graph to estimate the energy released in this reaction. *[2]*

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(c) Stable nuclei with a mass number greater than about 20, contain more neutrons than protons. By reference to the properties of the nuclear force and of the electrostatic force, suggest an explanation for this observation. *[4]*

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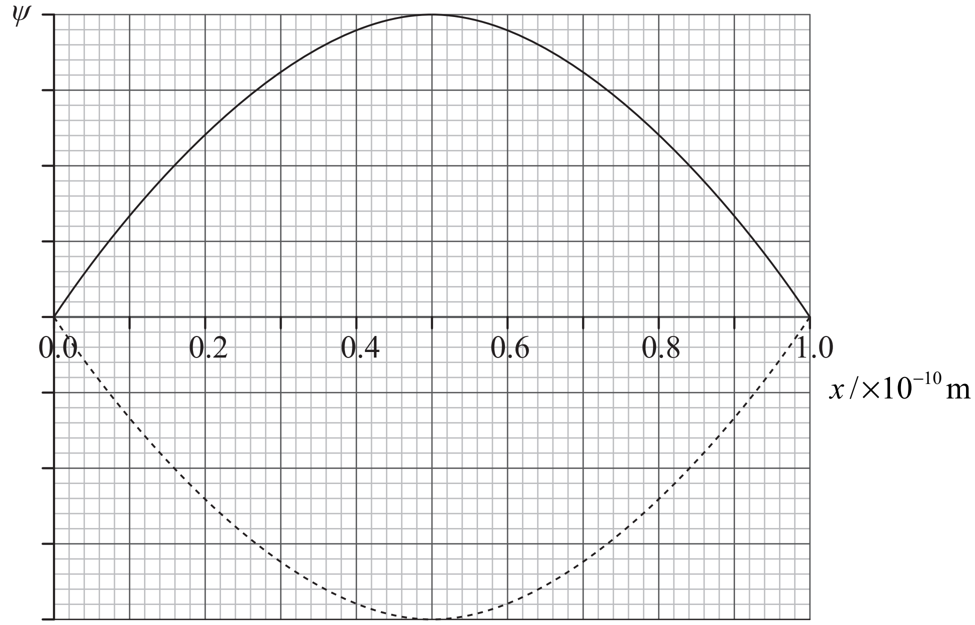
B3. This question is in **two** parts. **Part 1** is about quantum aspects of the electron. **Part 2** is about electric circuits.

Part 1 Quantum aspects of the electron

The wavefunction ψ for an electron confined to move within a "box" of linear size $L = 1.0 \times 10^{-10}\,\text{m}$, is a standing wave as shown.



(a) State what is meant by a wavefunction. *[1]*

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(b) State the position near which this electron is most likely to be found. *[1]*

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(This question continues on the following page)

(Question B3, part 1 continued)

(c) Calculate the momentum of the electron. *[2]*

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(d) The energy, in joules, of the electron in a hydrogen atom, is given by $E = -\frac{2.18\times10^{-18}}{n^2}$ where n is a positive integer. Calculate the wavelength of the photon emitted in a transition from the first excited state of hydrogen to the ground state. *[3]*

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(This question continues on the following page)

(Question B3, part 1 continued)

(e) The electron stays in the first excited state of hydrogen for a time of approximately $\Delta t = 1.0 \times 10^{-10}$ s.

(i) Determine the uncertainty in the energy of the electron in the first excited state. *[2]*

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(ii) Suggest, with reference to your answer to (e)(i), why the photons emitted in transitions from the first excited state of hydrogen to the ground state will, in fact, have a small range of wavelengths. *[2]*

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(Question B3, part 1 continued)

(f) Diagram 1 shows the three lowest energy levels for an electron in the hydrogen atom.

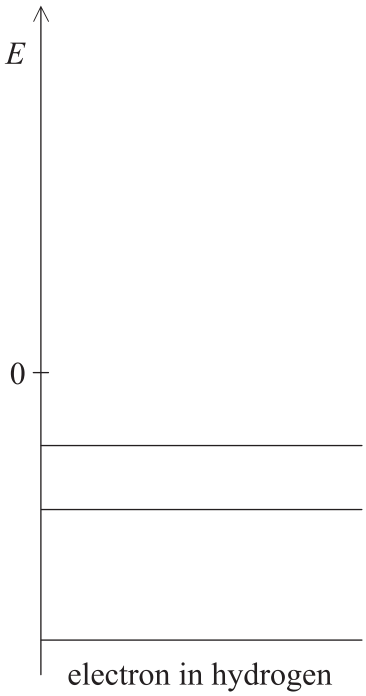

Diagram 1

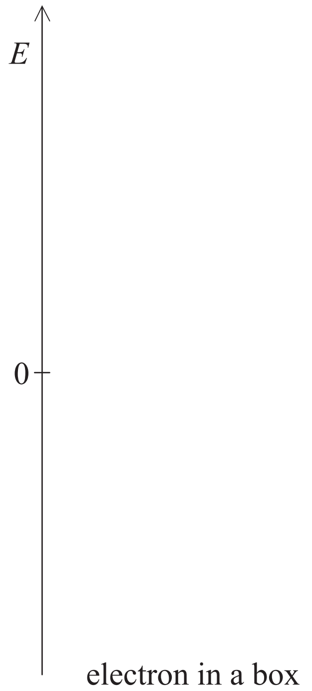

Diagram 2

Using the energy axis on diagram 2, draw the three lowest energy levels for the electron in a box model. You do not have to put any numbers on the vertical axis. *[2]*

(This question continues on the following page)

(Question B3 continued)

Part 2 Electric circuits

(a) Define

(i) *electromotive force* (emf) of a battery. *[1]*

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(ii) *electrical resistance* of a conductor. *[1]*

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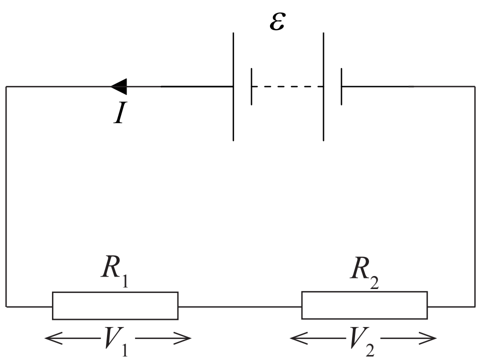
(Question B3, part 2 continued)

(b) A battery of emf ε and negligible internal resistance is connected in series to two resistors. The current in the circuit is I.



(i) State an equation giving the total power delivered by the battery. *[1]*

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(ii) The potential difference across resistor R_1 is V_1 and that across resistor R_2 is V_2. Using the law of the conservation of energy, deduce the equation below. *[2]*

$$\varepsilon = V_1 + V_2$$

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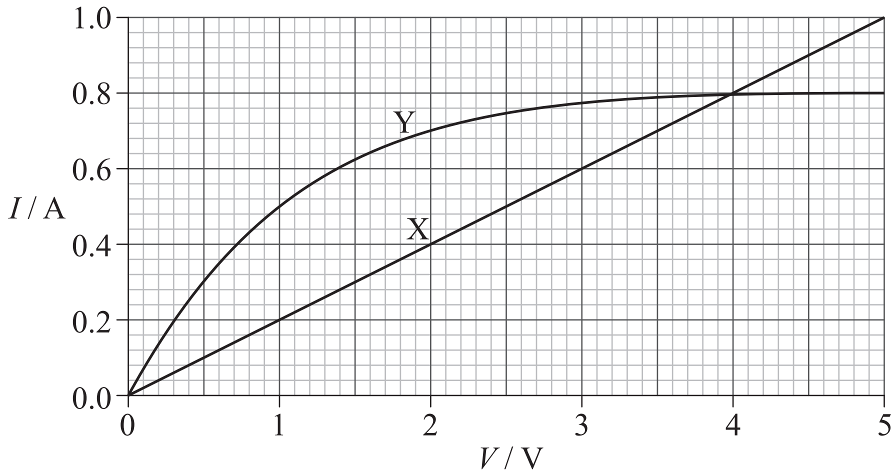
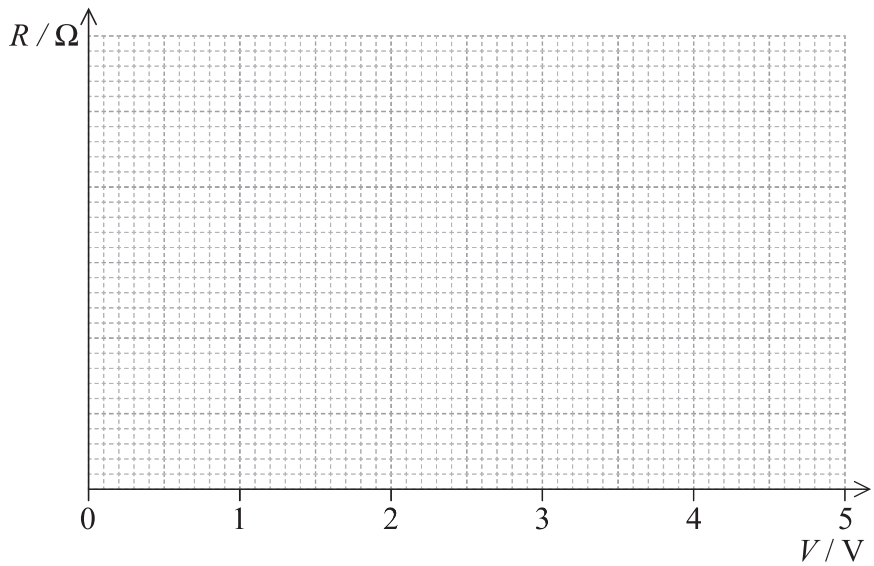
(Question B3, part 2 continued)

(c) The graph shows the *I-V* characteristics of two conductors, X and Y.



On the axes below, sketch graphs to show the variation with potential difference V of the resistance of conductor X (label this graph X) and conductor Y (label this graph Y). You do not need to put any numbers on the vertical axis. *[3]*



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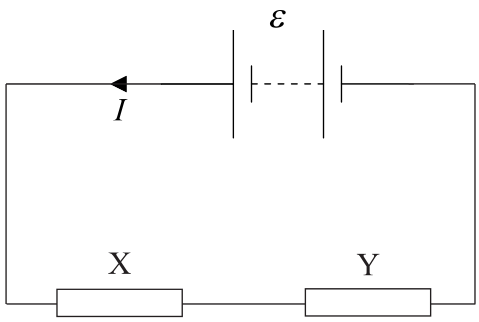
(Question B3, part 2 continued)

(d) The conductors in (c) are connected in series to a battery of emf ε and negligible internal resistance.



The power dissipated in each of the two resistors is the same.

Using the graph given in (c),

(i) determine the emf of the battery. *[2]*

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(ii) calculate the total power dissipated in the circuit. *[2]*

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B4. This question is in **two** parts. **Part 1** is about the energy balance of the Earth. **Part 2** is about motion in a magnetic field and electromagnetic induction.

Part 1 Energy balance of the Earth

(a) The intensity of the Sun's radiation at the position of the Earth is approximately $1400\,W\,m^{-2}$.

Suggest why the average power received per unit area of the Earth is $350\,W\,m^{-2}$. *[2]*

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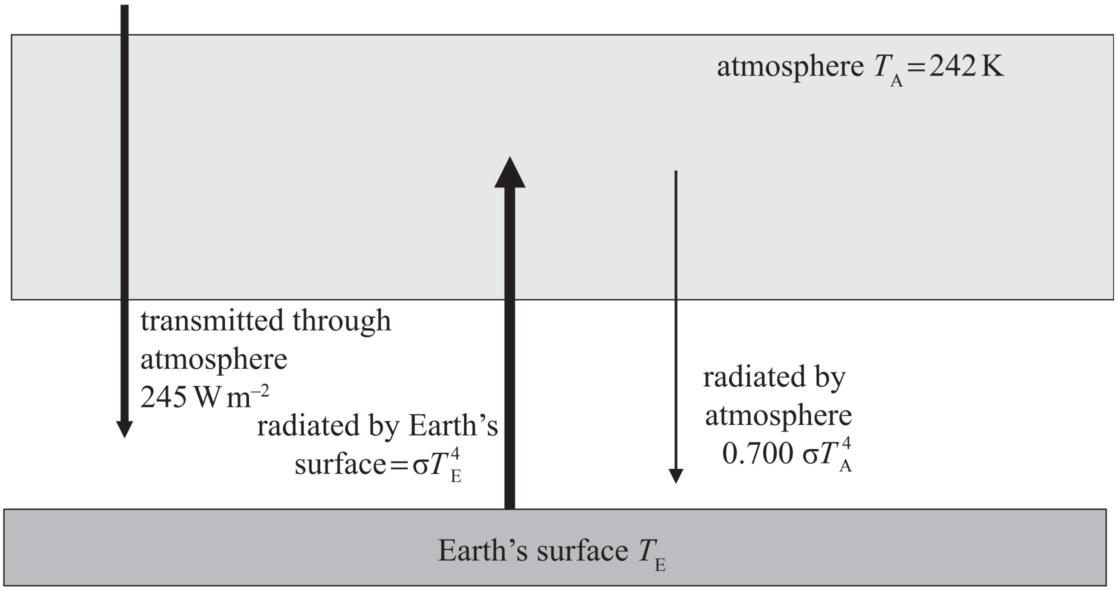
(Question B4, part 1 continued)

(b) The diagram shows a simplified model of the energy balance of the Earth's surface. The diagram shows radiation entering or leaving the Earth's surface only.



The average equilibrium temperature of the Earth's surface is T_E and that of the atmosphere is $T_A = 242\,K$.

(i) Using the data from the diagram, state the emissivity of the atmosphere. *[1]*

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(ii) Show that the intensity of the radiation radiated by the atmosphere towards the Earth's surface is $136\,W\,m^{-2}$. *[1]*

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(This question continues on the following page)

(Question B4, part 1 continued)

(iii) By reference to the energy balance of the Earth's surface, calculate T_E. *[2]*

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(Question B4, part 1 continued)

(c) (i) Outline a mechanism by which part of the radiation radiated by the Earth's surface is absorbed by greenhouse gases in the atmosphere. *[3]*

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(ii) Suggest why the incoming solar radiation is not affected by the mechanism you outlined in (c)(i). *[2]*

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(iii) Carbon dioxide (CO_2) is a greenhouse gas. State **one** source and **one** sink (object that removes CO_2) of this gas. *[2]*

Source: . . . .

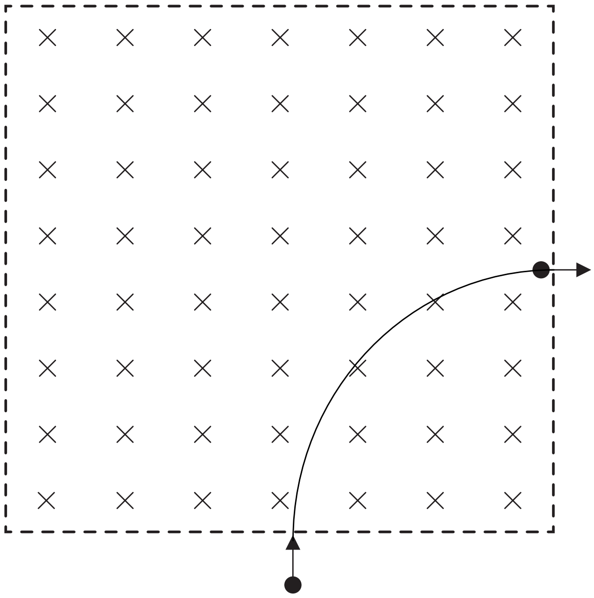
Sink: . . . .

(This question continues on the following page)

(Question B4 continued)

Part 2 Motion in a magnetic field and electromagnetic induction

An electron, that has been accelerated from rest by a potential difference of 250 V, enters a region of magnetic field of strength 0.12 T that is directed into the plane of the page.



(a) The electron's path while in the region of magnetic field is a quarter circle. Show that the

(i) speed of the electron after acceleration is $9.4\times10^{6}\,\text{m s}^{-1}$. *[2]*

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(Question B4, part 2 continued)

(ii) radius of the path is 4.5×10^{-4} m. *[2]*

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(iii) time the electron spends in the region of magnetic field is 7.5×10^{-11} s. *[1]*

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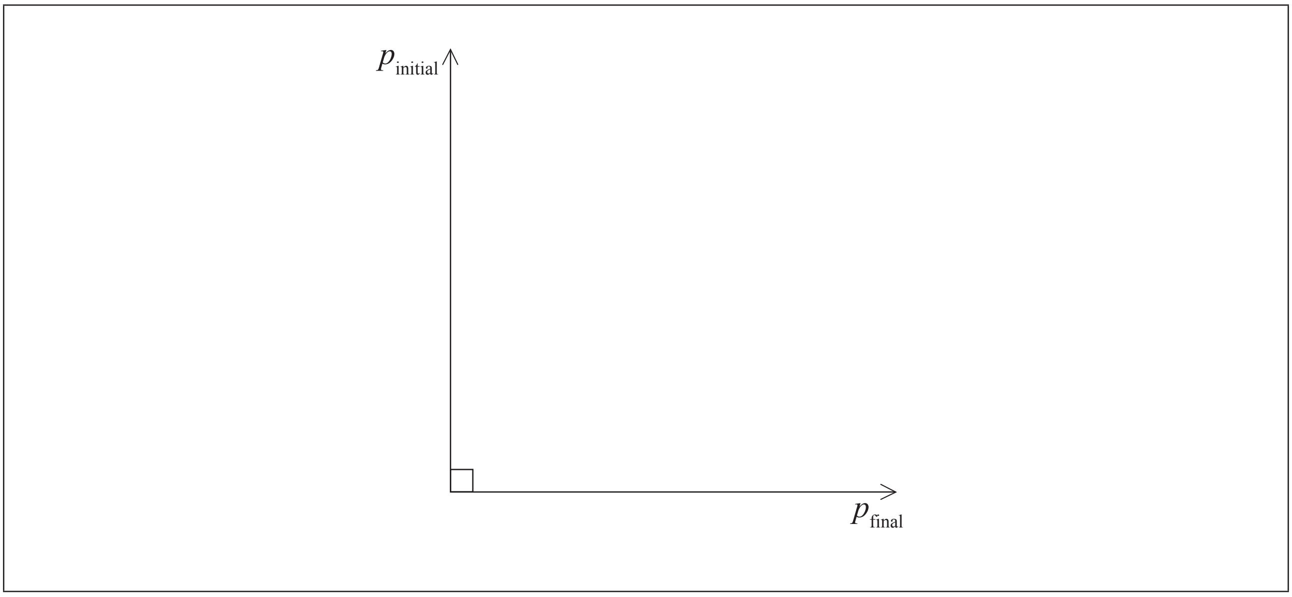
(This question continues on the following page)

(Question B4, part 2 continued)

(b) The diagram below shows the momentum of the electron as it enters and leaves the region of magnetic field. The magnitude of the initial momentum and of the final momentum is 8.6×10^{-24} N s.



(i) On the diagram above, draw an arrow to indicate the vector representing the change in the momentum of the electron. *[1]*

(ii) Show that the magnitude of the change in the momentum of the electron is 1.2×10^{-23} N s. *[1]*

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(iii) Estimate the magnitude of the average force on the electron. *[1]*

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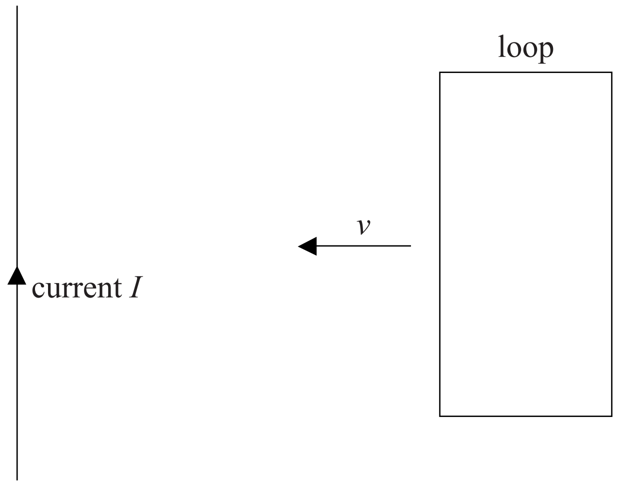
(Question B4, part 2 continued)

(c) A square loop of conducting wire is placed near a straight wire carrying a constant current I. The wire is in the same plane as the loop.



The loop is made to move with constant speed v towards the wire.

(i) Explain, by reference to Faraday's and Lenz's laws of electromagnetic induction, why work must be done on the loop. *[3]*

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(ii) Suggest what becomes of the work done on the loop. *[1]*

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Please **do not** write on this page.

Answers written on this page
will not be marked.