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PHYSICS
HIGHER LEVEL
PAPER 2

Candidate session number

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Wednesday 11 May 2011 (afternoon)

2 hours 15 minutes

Examination code

2	2	1	1	–	6	5	1	4

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.

0136

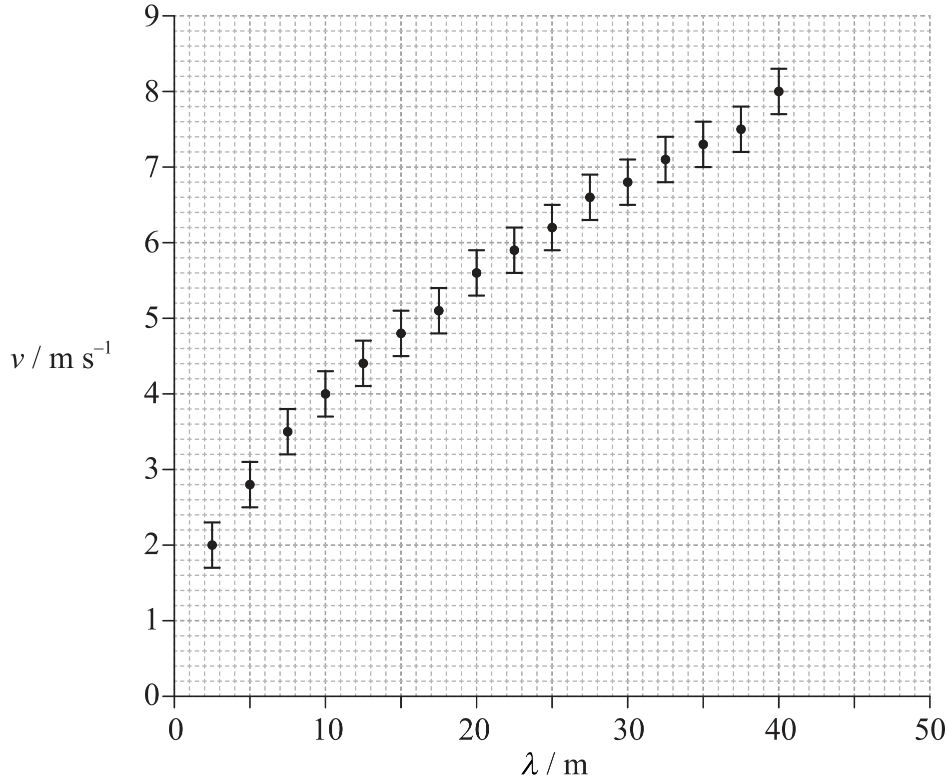
36 pages

SECTION A

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

A1. Data analysis question.

The speed v of waves on the surface of deep water depends only on the wavelength λ of the waves. The data gathered from a particular region of the Atlantic Ocean are plotted below.



The uncertainty in the speed v is $\pm 0.30\,\text{m s}^{-1}$ and the uncertainty in λ is too small to be shown on the diagram.

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

(This question continues on the following page)

(Question A1 continued)

(b) State, with reference to the line you have drawn in (a),

(i) why v is not directly proportional to λ. *[1]*

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(ii) the value of v for $\lambda = 39\,\text{m}$. *[1]*

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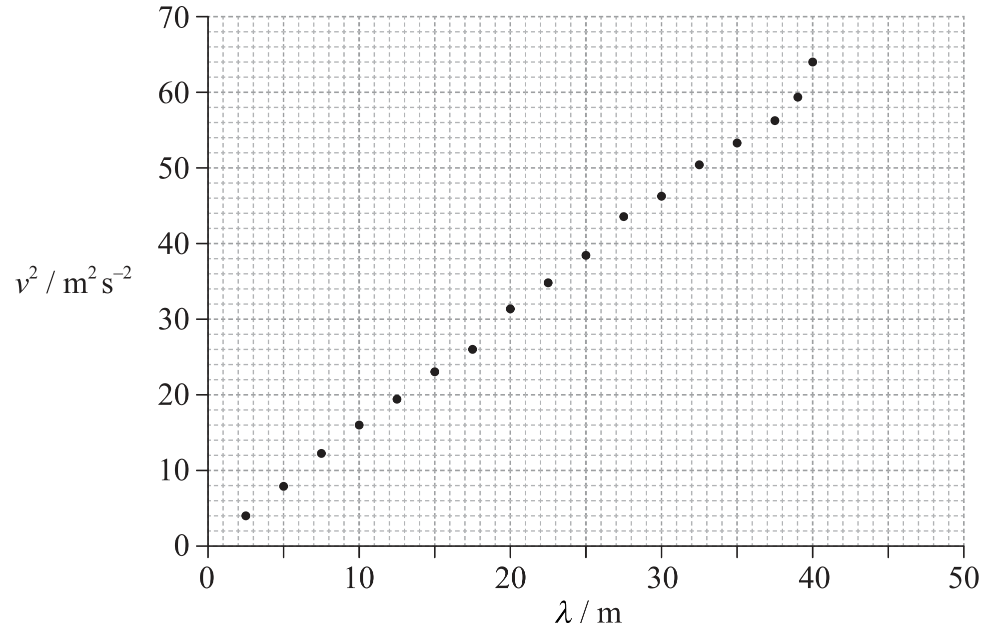
(Question A1 continued)

(c) It is suggested that the relationship between v and λ is of the form

$$v = a\sqrt{\lambda}$$

where a is a constant. To test the validity of this hypothesis, values of v^2 against λ are plotted below.



(i) Use your answer to (b)(ii) to show that the absolute uncertainty in v^2 for a wavelength of 39 m is $\pm 5\,m^2\,s^{-2}$. *[3]*

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(ii) The absolute uncertainty in v^2 for a wavelength of 2.5 m is $\pm 1\,m^2\,s^{-2}$. Using this value and the value in (c)(i), construct error bars for v^2 at the data points for $\lambda = 2.5$ m and 39 m. *[1]*

(This question continues on the following page)

(Question A1 continued)

(iii) State why the plotted data in (c)(ii) suggest that it is likely that v is proportional to $\sqrt{\lambda}$. *[1]*

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(iv) Use the graph opposite to determine the constant a. *[3]*

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(v) Theory shows that $a = \sqrt{\frac{k}{2\pi}}$. Determine a value for k. *[1]*

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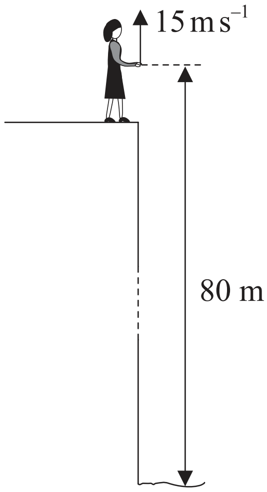
A2. This question is about kinematics.

Lucy stands on the edge of a vertical cliff and throws a stone vertically upwards.



The stone leaves her hand with a speed of $15\,\text{m}\,\text{s}^{-1}$ at the instant her hand is 80 m above the surface of the sea. Air resistance is negligible and the acceleration of free fall is $10\,\text{m}\,\text{s}^{-2}$.

(a) Calculate the maximum height reached by the stone as measured from the point where it is thrown. *[2]*

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(b) Determine the time for the stone to reach the surface of the sea after leaving Lucy's hand. *[3]*

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A3. This question is about internal energy and thermal energy (heat).

(a) Distinguish between internal energy and thermal energy. *[3]*

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(Question A3 continued)

(b) A piece of iron is placed in a kiln until it reaches the temperature θ of the kiln. The iron is then quickly transferred to water held in a thermally insulated container. The water is stirred until it reaches a steady temperature. The following data are available.

Thermal capacity of the piece of iron	$= 60\,\mathrm{J\,K^{-1}}$
Thermal capacity of the water	$= 2.0 \times 10^{3}\,\mathrm{J\,K^{-1}}$
Initial temperature of the water	$= 16\,^{\circ}\mathrm{C}$
Final temperature of the water	$= 45\,^{\circ}\mathrm{C}$

The thermal capacity of the container and insulation is negligible.

(i) State an expression, in terms of θ and the above data, for the energy transfer of the iron in cooling from the temperature of the kiln to the final temperature of the water. *[1]*

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(ii) Calculate the increase in internal energy of the water as the iron cools in the water. *[1]*

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(iii) Use your answers to (b)(i) and (b)(ii) to determine θ. *[2]*

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A4. This question is about the unified atomic mass unit and a nuclear reaction.

(a) Define the term *unified atomic mass unit*. *[1]*

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(b) The mass of a nucleus of rutherfordium-254 is 254.1001 u. Calculate the mass in GeV c^{-2}. *[1]*

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(Question A4 continued)

(c) In 1919, Rutherford produced the first artificial nuclear transmutation by bombarding nitrogen with α-particles. The reaction is represented by the following equation.

$$\alpha + {}^{14}_{7}\text{N} \rightarrow {}^{17}_{8}\text{O} + \mathbf{X}$$

(i) Identify **X**. *[1]*

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(ii) The following data are available for the reaction.

Rest mass of α	$= 3.7428\ \text{GeV c}^{-2}$
Rest mass of ${}^{14}_{7}\text{N}$	$= 13.0942\ \text{GeV c}^{-2}$
Rest mass of ${}^{17}_{8}\text{O} + \mathbf{X}$	$= 16.8383\ \text{GeV c}^{-2}$

The initial kinetic energy of the α-particle is 7.68 MeV. Determine the sum of the kinetic energies of the oxygen nucleus and **X**. (Assume that the nitrogen nucleus is stationary.) *[3]*

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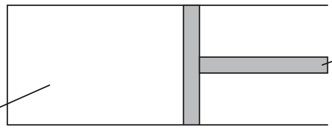
A5. This question is about changes of state of a gas.

(a) A cylinder fitted with a piston contains 0.23 mol of helium gas.



The following data are available for the helium with the piston in the position shown.

Volume $= 5.2 \times 10^{-3}\, m^3$
Pressure $= 1.0 \times 10^{5}\, Pa$
Temperature $= 290\, K$

(i) Use the data to calculate a value for the universal gas constant. *[2]*

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(ii) State the assumption made in the calculation in (a)(i). *[1]*

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(Question A5 continued)

(b) The gas is now compressed isothermally by the piston so that the volume of the gas is reduced. Explain why the compression must be carried out slowly. *[2]*

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(c) After the compression, the gas is now allowed to expand adiabatically to its original volume. Use the first law of thermodynamics to explain whether the final temperature will be less than, equal to or greater than 290 K. *[4]*

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A6. This question is about the emf induced in a coil.

(a) Define *magnetic flux*. *[2]*

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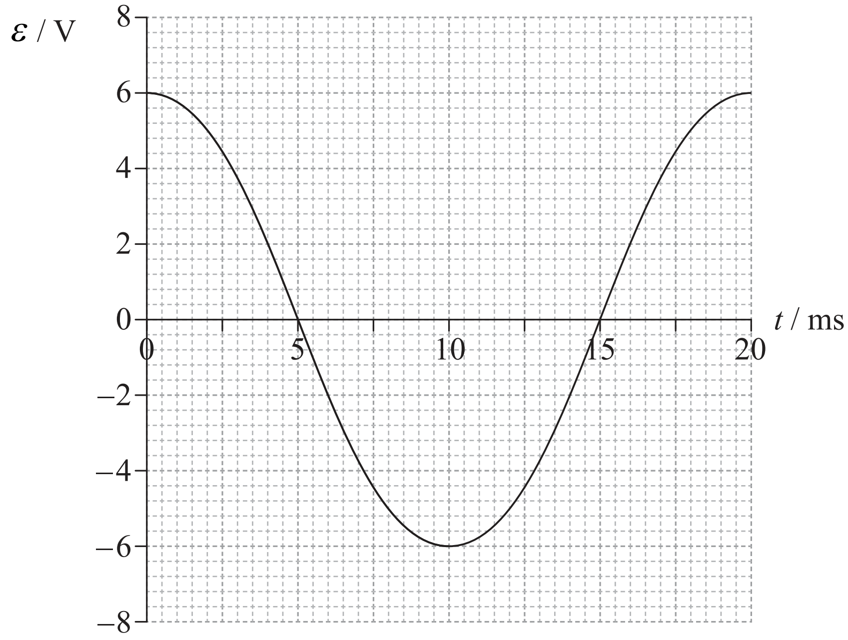
(This question continues on the following page)

(Question A6 continued)

(b) A coil is rotated at constant speed in a region of uniform magnetic field.

The graph shows the variation with time t of the emf ε induced in the coil for one cycle of rotation.



(i) On the graph label, with the letter T, a time at which the flux linkage in the coil is a maximum. *[1]*

(ii) Use the graph to determine the rate of change of flux at $t = 4.0\,\text{ms}$. Explain your answer. *[2]*

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(iii) Calculate the root mean square value of the induced emf. *[1]*

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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 electric charge and resistance. **Part 2** is about orbital motion.

Part 1 Electric charge and resistance

(a) A plastic rod XY is held at end X. The end Y is rubbed with a piece of cloth and, as a result, the end Y becomes electrically charged.

The procedure is now repeated using a copper rod and it is found that the copper rod remains electrically neutral. Explain these observations in terms of the properties of conductors and insulators. *[5]*

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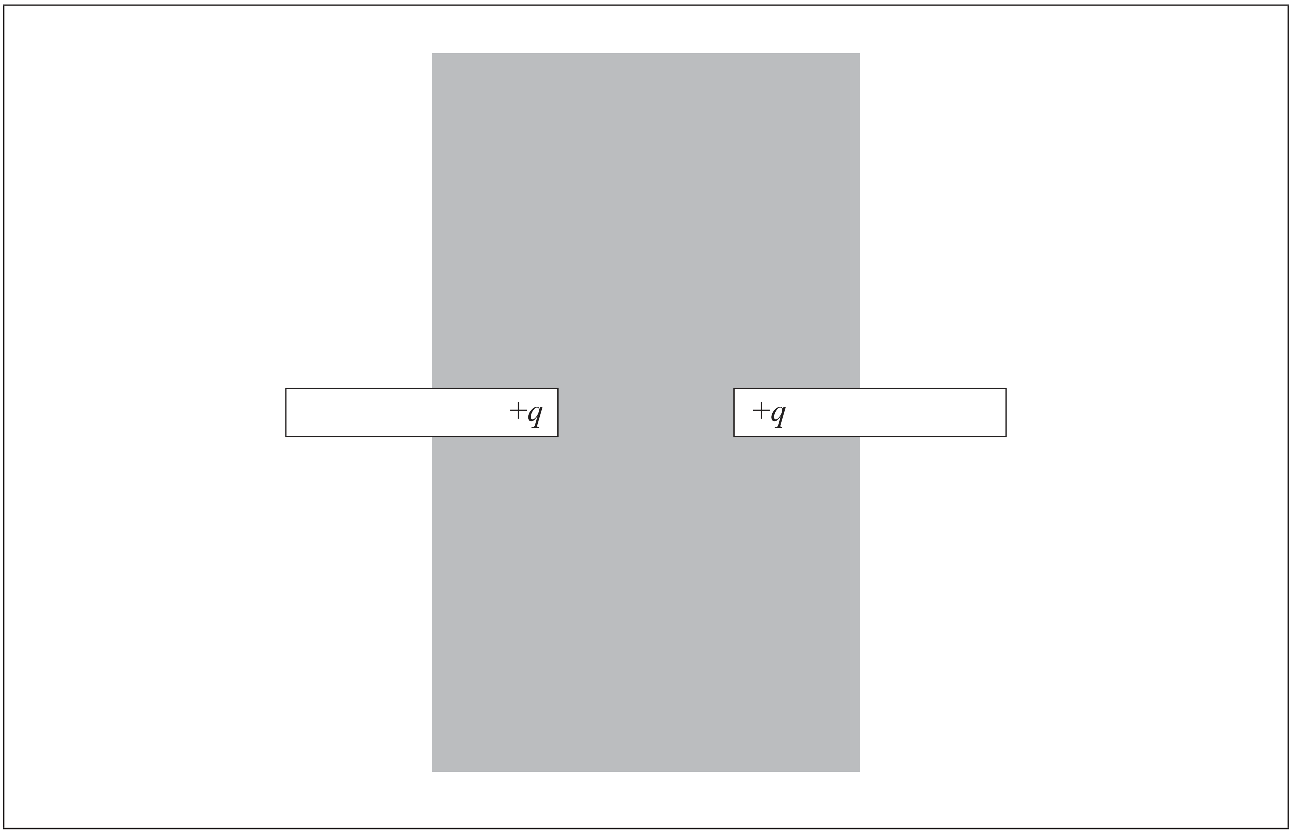
(Question B1, part 1 continued)

(b) Two plastic rods each have a positive charge $+q$ situated at one end. The rods are arranged as shown.



Assume that the charge at the end of each rod behaves as a point charge. Draw, in the shaded area on the diagram

(i) the electric field pattern due to the two charges. *[2]*

(ii) a line to represent an equipotential surface. Label the line with the letter V. *[1]*

(This question continues on the following page)

(Question B1, part 1 continued)

(c) A resistor of resistance 1.5 Ω is made from copper wire of radius 0.18 mm. The resistivity of copper is $1.7\times10^{-8}\,\Omega\,m$. Determine the length of copper wire used to make the resistor. *[2]*

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(d) The manufacturer of the resistor in (c) guarantees that the resistance is within 10 % of 1.5 Ω, provided that the power dissipation in the resistor does not exceed 1.0 W.

(i) Suggest why the resistance of the resistor might be greater than 1.65 Ω if the power dissipation in the resistor is greater than 1.0 W. *[2]*

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(ii) Show that, for a power dissipation of 1.0 W, the current in a resistor of resistance 1.5 Ω is 0.82 A. *[1]*

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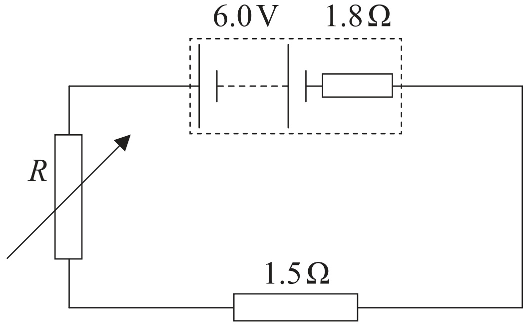
(This question continues on the following page)

(Question B1, part 1 continued)

(iii) The 1.5 Ω resistor is connected in series with a variable resistor and battery of emf 6.0 V and internal resistance 1.8 Ω.



Estimate the resistance R of the variable resistor that will limit the current to 0.82 A. *[3]*

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(Question B1 continued)

Part 2 Orbital motion

(a) A satellite, of mass m, is in orbit about Earth at a distance r from the centre of Earth. Deduce that the kinetic energy E_K of the satellite is equal to half the magnitude of the potential energy E_P of the satellite. *[3]*

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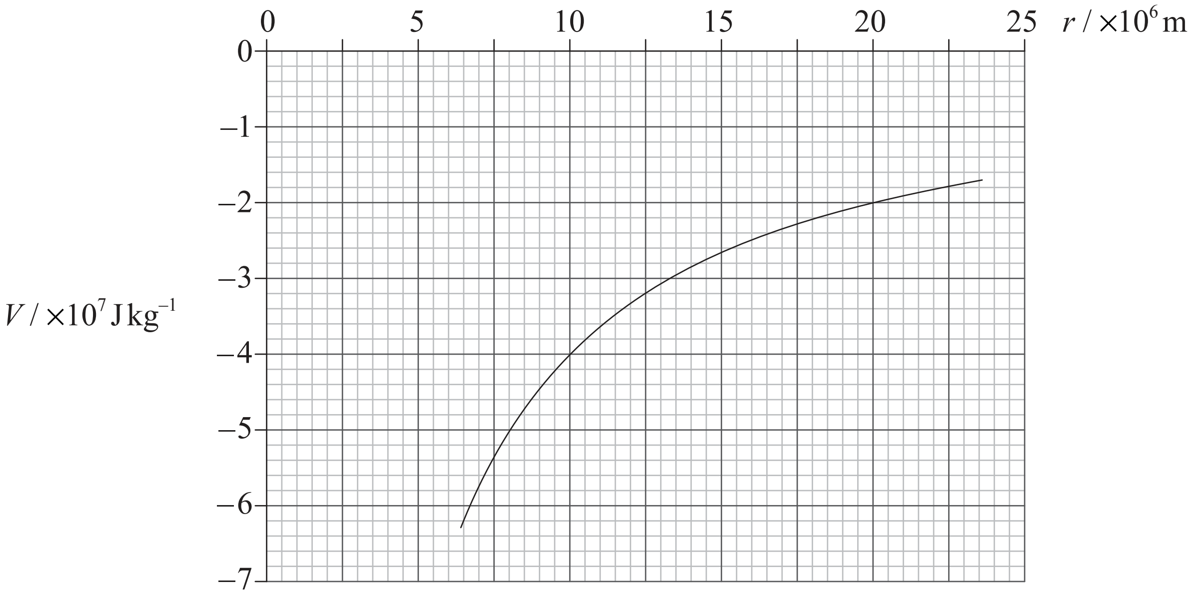
(Question B1, part 2 continued)

(b) The graph shows the variation with distance r of the Earth's gravitational potential V. Values of V for $r < R$, where R is the radius of Earth, are not shown.



The satellite in (a) has a mass of 8.2×10^2 kg and it is in orbit at a distance of 1.0×10^7 m from the centre of Earth. Using data from the graph and your answer to (a), calculate for the satellite

(i) its total energy. *[2]*

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(Question B1, part 2 continued)

(ii) its orbital speed. *[2]*

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(iii) the energy it must gain to move to an orbit a distance 2.0×10^{7} m from the centre of the Earth. *[2]*

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B2. This question is in **two** parts. **Part 1** is about power production and global warming. **Part 2** is about a charge-coupled device (CCD).

Part 1 Power production and global warming

(a) In any cyclical process designed to continuously convert thermal energy to work, some energy is always degraded. Explain what is meant by degraded energy. *[2]*

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(b) A nuclear power station uses uranium-235 (U-235) as fuel. Outline the

(i) processes and energy changes that occur through which thermal energy is produced. *[4]*

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(Question B2, part 1 continued)

(ii) role of the heat exchanger of the reactor and the turbine in the generation of electrical energy. *[3]*

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(c) Identify **one** process in the power station where energy is degraded. *[1]*

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(d) The maximum power output of the Drax coal-fired power station in the UK is 4.0 GW. Determine the minimum mass of pure U-235 that would be required by a nuclear power station to provide the same maximum annual energy output as the Drax power station. *[2]*

Energy density of U-235 $= 82\ \text{TJ kg}^{-1}$
1 year $= 3.2 \times 10^{7}\ \text{s}$

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(This question continues on the following page)

(Question B2, part 1 continued)

(e) It has been suggested that the production of greenhouse gases by coal-fired power stations has increased global warming. One piece of evidence to support this suggestion is the increase in sea-level due to an increase in temperature of the oceans. Over the past 100 years it is suggested that sea-levels have risen by 6.4×10^{-2} m due to volume expansion.

Using the following data, determine the average rise in temperature in the top levels of the oceans in the last 100 years. *[3]*

Mean depth of oceans that is affected by global warming $=4.0\times10^{2}$ m
Coefficient of volume expansion of sea water $=5.1\times10^{-5}$ K^{-1}

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(Question B2 continued)

Part 2 Charge-coupled device (CCD)

(a) State **two** advantages of storing information in a digital form rather than an analogue form. *[2]*

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(b) A CCD is effectively a silicon chip that is divided into small areas called pixels. Each pixel is provided with electrodes. Outline how light incident on a pixel produces a change in potential difference across the pixel. *[3]*

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(Question B2, part 2 continued)

(c) Light of frequency 7.2×10^{14} Hz and intensity $1.6\,\mathrm{mW\,m^{-2}}$ is incident on a pixel for a time of 18 ms. The area of the pixel is $2.0\times10^{-10}\,\mathrm{m^2}$ and its capacitance is 12 pF. The resulting change in potential difference across the pixel is $10\,\mu\mathrm{V}$.

(i) Deduce that the number of photons incident on the pixel is 1.2×10^{4}. *[2]*

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(ii) Determine the quantum efficiency of the pixel. *[3]*

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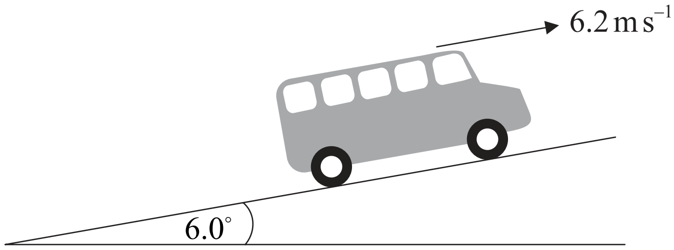
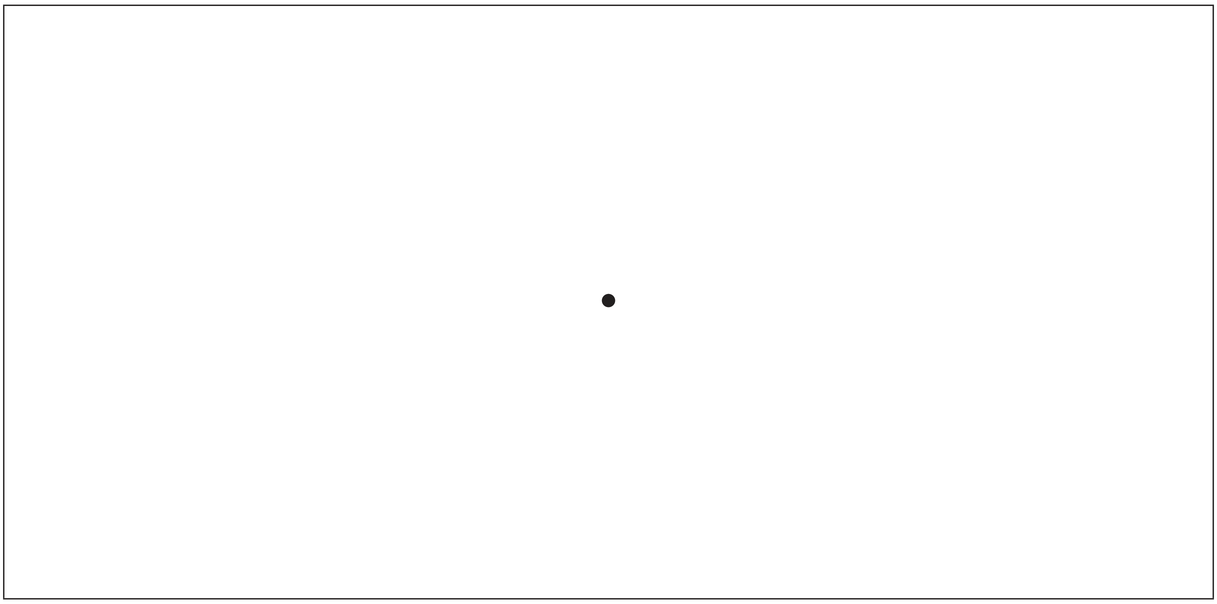
B3. This question is in **two** parts. **Part 1** is about power and efficiency. **Part 2** is about the photoelectric effect and de Broglie wavelength.

Part 1 Power and efficiency

A bus is travelling at a constant speed of $6.2\,\text{m s}^{-1}$ along a section of road that is inclined at an angle of 6.0° to the horizontal.



(a) (i) The bus is represented by the black dot shown below. Draw a labelled sketch to represent the forces acting on the bus. *[4]*



(ii) State the value of the rate of change of momentum of the bus. *[1]*

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(Question B3, part 1 continued)

(b) The total output power of the engine of the bus is 70 kW and the efficiency of the engine is 35 %. Calculate the input power to the engine. *[2]*

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(c) The mass of the bus is 8.5×10^{3} kg. Determine the rate of increase of gravitational potential energy of the bus. *[3]*

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(d) Using your answer to (c) and the data in (b), estimate the magnitude of the resistive forces acting on the bus. *[3]*

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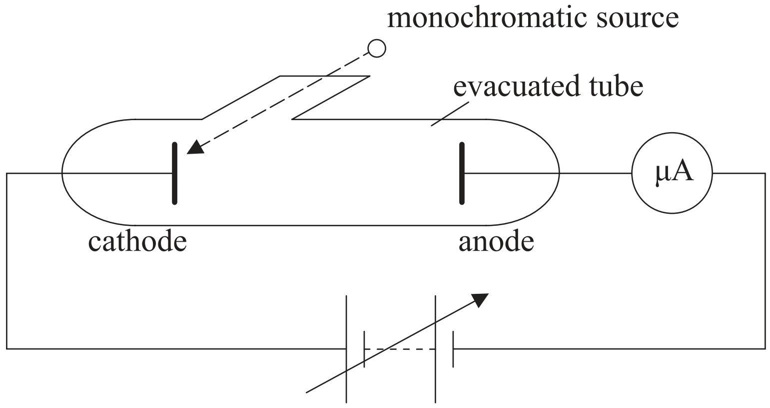
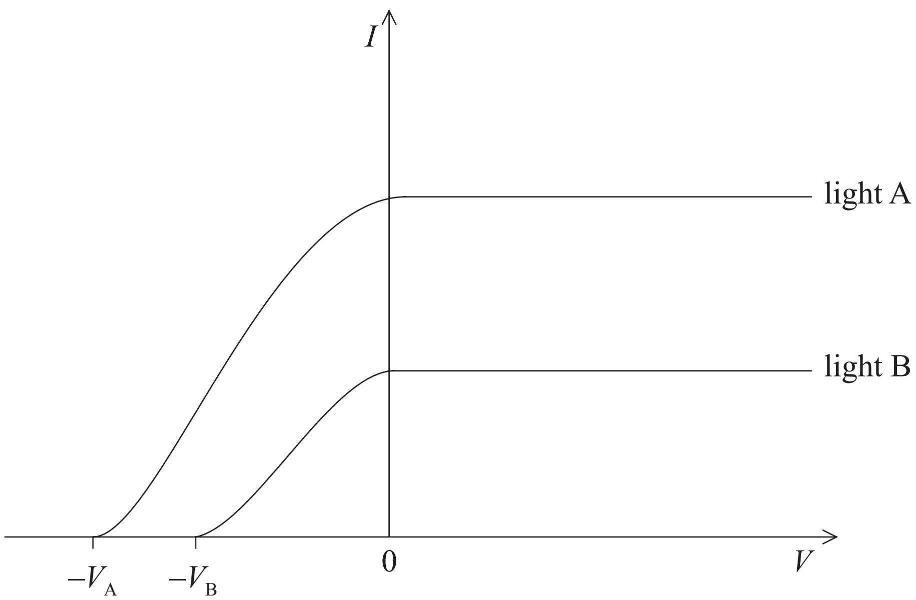
(Question B3 continued)

Part 2 Photoelectric effect and de Broglie wavelength

The diagram is a representation of apparatus used to study the photoelectric effect.



Light from the monochromatic source is incident on a cathode placed in an evacuated tube. A variable voltage supply is connected between anode and cathode and the photoelectric current is registered by the microammeter. The sketch graph shows how the photoelectric current I varies with the potential difference V between anode and cathode for two sources of light, A and B, of different frequencies and intensities.



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(Question B3, part 2 continued)

(a) Explain with reference to the Einstein model, which graph, A or B, corresponds to the light with the greater frequency. *[4]*

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(b) The frequency of the light that produces graph A is 8.8×10^{14} Hz. The magnitude of V_A is 1.6 V.

(i) State the value of the maximum energy, in eV, of the electrons emitted from the cathode. *[1]*

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(ii) Determine the work function, in eV, of the surface of the cathode. *[2]*

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(This question continues on the following page)

(Question B3, part 2 continued)

(c) The frequency of the incident light is increased but the intensity remains constant. Explain why this increase in frequency results in a change to the maximum photoelectric current (saturation current). *[3]*

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(d) The electrons emitted from the photo-cathode have an associated de Broglie wavelength. Describe what is meant by the de Broglie wavelength. *[2]*

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B4. This question is about simple harmonic motion (SHM), wave motion and polarization.

(a) By reference to simple harmonic motion, state what is meant by amplitude. *[1]*

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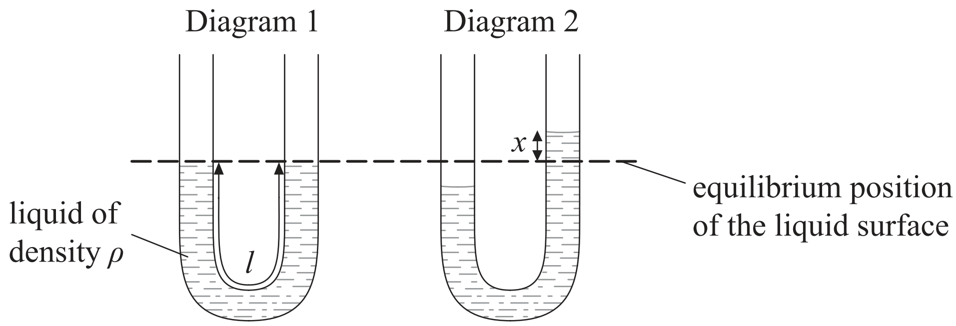
(b) A liquid is contained in a U-tube.



The pressure on the liquid in one side of the tube is increased so that the liquid is displaced as shown in diagram 2. When the pressure is suddenly released the liquid oscillates. The damping of the oscillations is small.

(i) Describe what is meant by damping. *[2]*

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(Question B4 continued)

(ii) The displacement of the liquid surface from its equilibrium position is x. The acceleration a of the liquid in the tube is given by the expression

$$a = -\frac{2g}{l}x$$

where g is the acceleration of free fall and l is the total length of the liquid column. Explain, with reference to the motion of the liquid, the significance of the minus sign. *[2]*

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(iii) The total length of the liquid column in the tube is 0.32 m. Determine the period of oscillation. *[3]*

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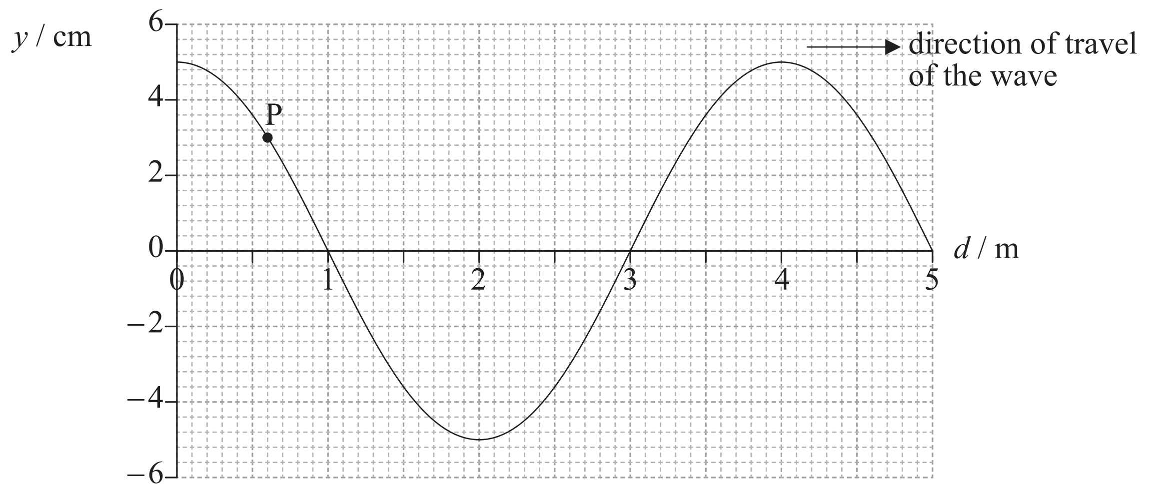
(Question B4 continued)

(c) A wave is travelling along a string. The string can be modelled as a single line of particles and each particle executes simple harmonic motion. The period of oscillation of the particles is 0.80 s.

The graph shows the displacement y of part of the string at time $t=0$. The distance along the string is d.



(i) On the graph, draw an arrow to show the direction of motion of particle P at the point marked on the string. *[1]*

(ii) Determine the magnitude of the velocity of particle P. *[4]*

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(Question B4 continued)

(iii) Show that the speed of the wave is $5.0\,m\,s^{-1}$. *[3]*

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(iv) On the graph opposite, label with the letter X the position of particle P at $t = 0.40\,s$. *[1]*

(d) The string in (c) is fixed at both ends and is made to vibrate in a vertical plane in its first harmonic.

(i) Describe how the standing wave in the string gives rise to the first harmonic. *[3]*

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(ii) Outline how a travelling wave in a string can be used to describe the nature of polarized light. *[3]*

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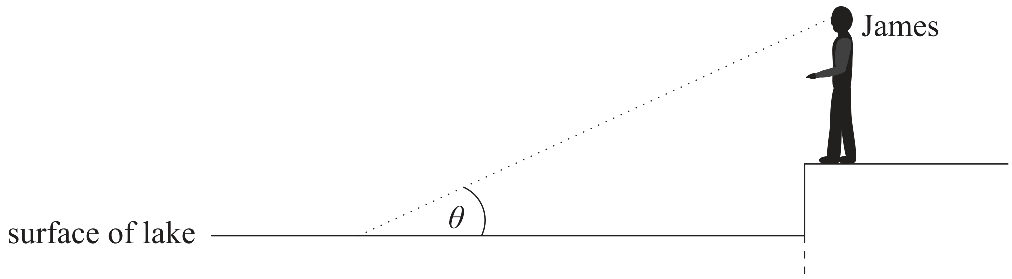
(Question B4 continued)

(e) James is wearing polarized sunglasses and views the sunlight reflected from the smooth surface of a lake.



The angle θ is the angle between the surface of the lake and James's line of sight. Calculate the value of θ at which the reflected sunlight from the surface is minimized. The refractive index of the water is 1.3. *[2]*

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