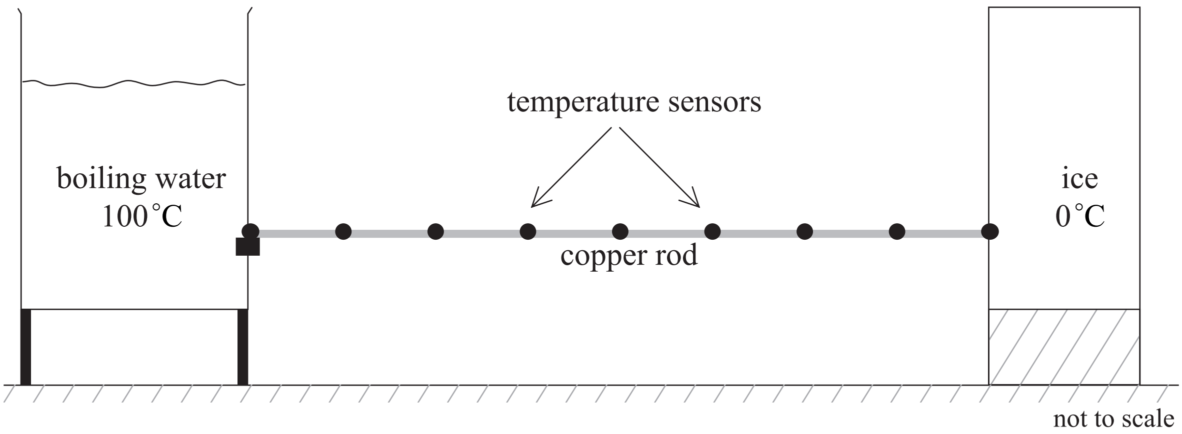
SECTION A

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

A1. This question is about thermal energy transfer through a rod.

A student designed an experiment to investigate the variation of temperature along a copper rod when each end is kept at a different temperature. In the experiment, one end of the rod is placed in a container of boiling water at 100 °C and the other end is placed in contact with a block of ice at 0.0 °C as shown in the diagram.



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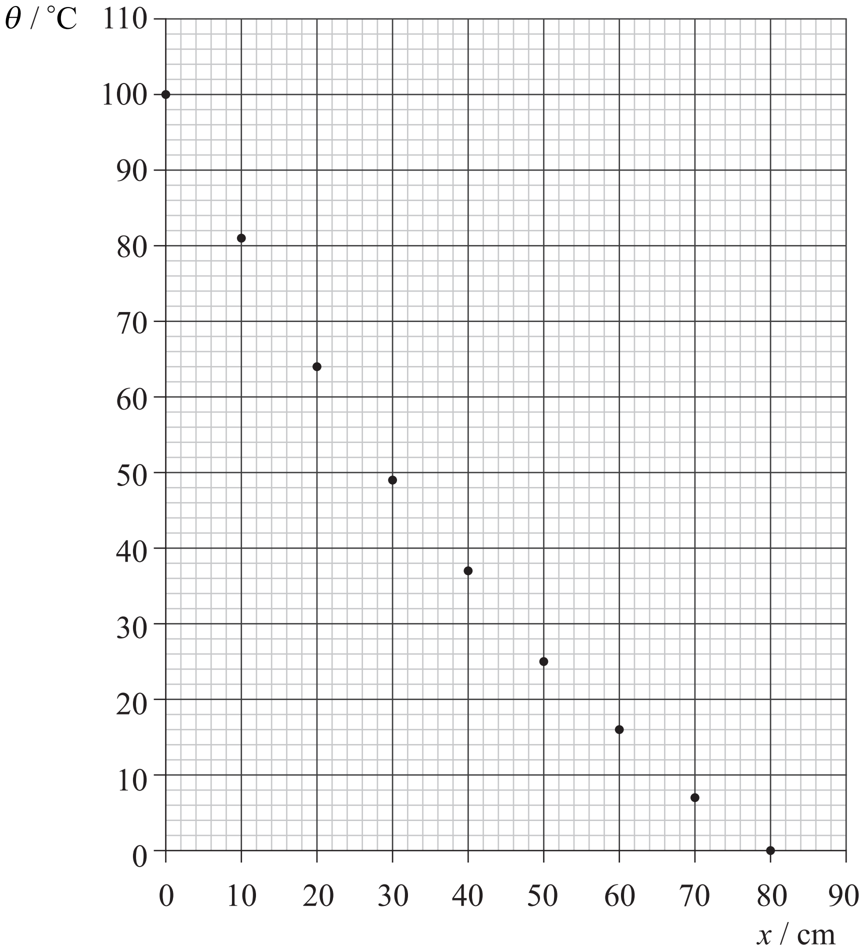
(Question A1 continued)

Temperature sensors are placed at 10 cm intervals along the rod. The final steady state temperature θ of each sensor is recorded, together with the corresponding distance x of each sensor from the hot end of the rod.

The data points are shown plotted on the axes below.



The uncertainty in the measurement of θ is ±2°C. The uncertainty in the measurement of x is negligible.

(a) On the graph above, draw the uncertainty in the data points for $x = 10$ cm, $x = 40$ cm and $x = 70$ cm. *[2]*

(b) On the graph above, draw the line of best-fit for the data. *[1]*

(This question continues on the following page)

(Question A1 continued)

(c) Explain, by reference to the uncertainties you have indicated, the shape of the line you have drawn. *[2]*

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(d) (i) Use your graph to estimate the temperature of the rod at $x = 55$ cm. *[1]*

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(ii) Determine the magnitude of the gradient of the line (the temperature gradient) at $x = 50$ cm. *[3]*

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(e) The rate of transfer of thermal energy R through the cross-sectional area of the rod is proportional to the temperature gradient $\frac{\Delta\theta}{\Delta x}$ along the rod. At $x = 10$ cm, $R = 43$ W and the magnitude of the temperature gradient is $\frac{\Delta\theta}{\Delta x} = 1.81\,^{\circ}\text{C cm}^{-1}$. At $x = 50$ cm the value of R is 25 W.

Use these data and your answer to d(ii) to suggest whether the rate R of thermal energy transfer is in fact proportional to the temperature gradient. *[3]*

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(This question continues on the following page)

(Question A1 continued)

(f) It is suggested that the variation with x of the temperature θ is of the form

$$\theta = \theta_0 e^{-kx}$$

where θ_0 and k are constants.

State how the value of k may be determined from a suitable graph. *[2]*

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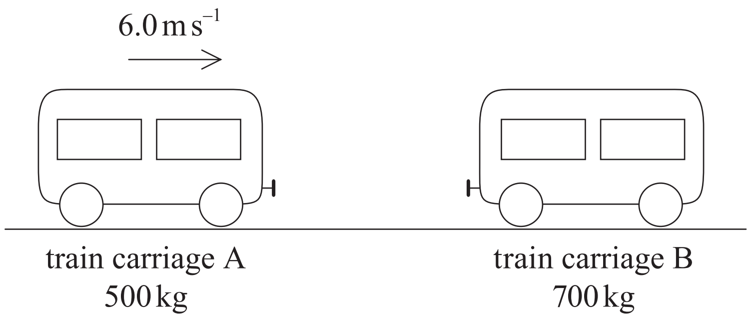
A2. This question is about energy and momentum.

A train carriage A of mass 500 kg is moving horizontally at $6.0\,m\,s^{-1}$. It collides with another train carriage B of mass 700 kg that is initially at rest, as shown in the diagram below.



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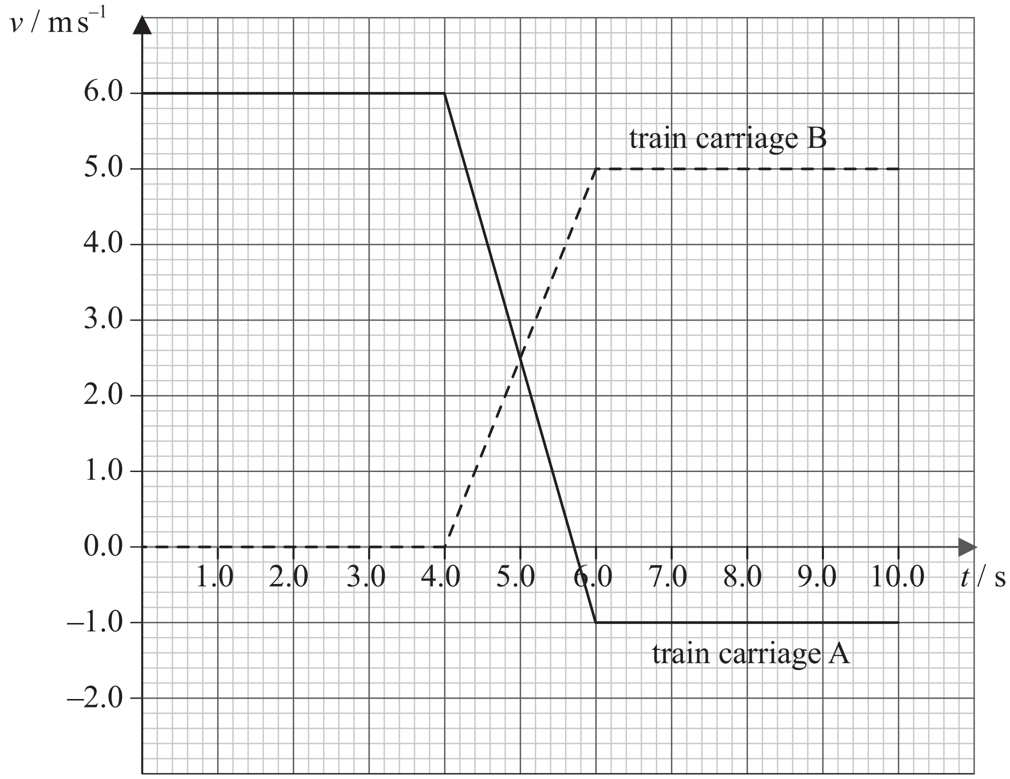
(Question A2 continued)

The graph below shows the variation with time t of the velocities of the two train carriages before, during and after the collision.



(a) Use the graph to deduce that

(i) the total momentum of the system is conserved in the collision. *[2]*

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(ii) the collision is elastic. *[2]*

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(b) Calculate the magnitude of the average force experienced by train carriage B. *[3]*

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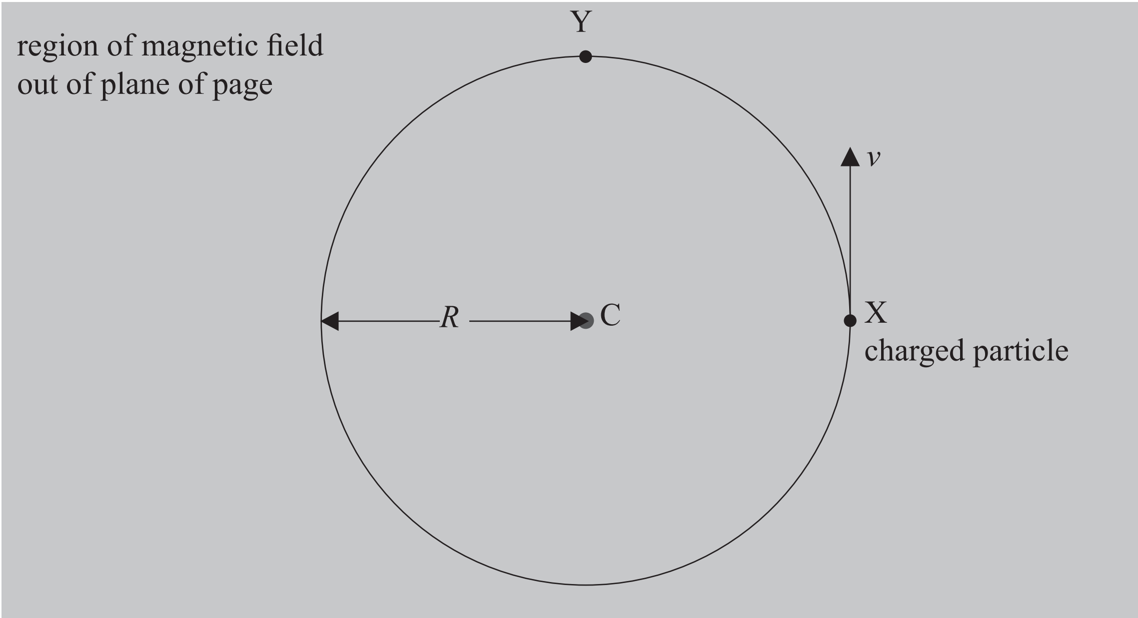
A3. This question is about motion of a charged particle in a magnetic field.

A charged particle is projected from point X with speed v at right angles to a uniform magnetic field. The magnetic field is directed out of the plane of the page. The particle moves along a circle of radius R and centre C as shown in the diagram below.



(a) On the diagram above, draw arrows to represent the magnetic force on the particle at position X and at position Y. *[1]*

(b) State and explain whether

(i) the charge is positive **or** negative. *[1]*

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(ii) work is done by the magnetic force. *[2]*

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(c) A second identical charged particle is projected at position X with a speed $\frac{v}{2}$ in a direction opposite to that of the first particle. On the diagram above, draw the path followed by this particle. *[2]*

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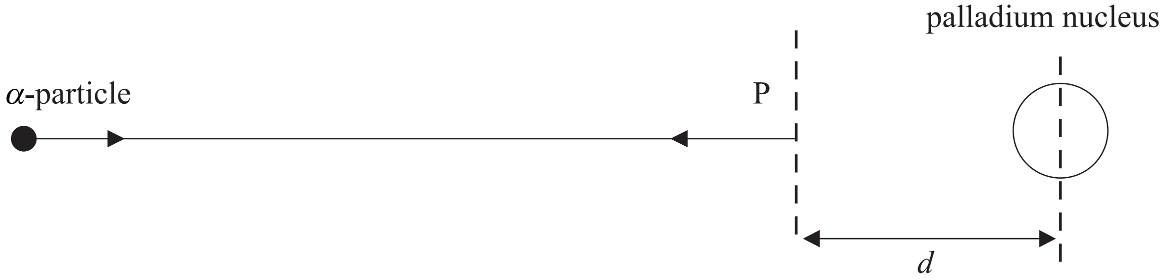
A4. This question is about calculating the distance of closest approach of an α-particle to a nucleus.

An α-particle approaches a nucleus of palladium. The initial kinetic energy of the α-particle is 3.8 MeV. The particle is brought to rest at point P, a distance *d* from the centre of the palladium nucleus. It then moves back along the path from which it came as shown in the diagram below.



(a) Calculate the value, in joules, of the electric potential energy of the α-particle at point P. Explain your working. *[2]*

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(b) The atomic (proton) number of palladium is 46. Calculate the distance *d*. *[3]*

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(c) Gold has an atomic (proton) number of 79.

Explain whether the distance of closest approach of this α-particle to a gold nucleus would be greater **or** smaller than your answer in (b). *[1]*

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(This question continues on the following page)

(Question A4 continued)

(d) The radius R of a nucleus of mass (nucleon) number A is given by

$$R = 1.2 \times 10^{-15} A^{\frac{1}{3}} \text{ m}.$$

(i) State in terms of the unified atomic mass unit u, the approximate mass of a nucleus of mass number A. *[1]*

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(ii) The volume of a sphere of radius R is given by $V = \frac{4\pi R^3}{3}$. Deduce that the density of all nuclei is approximately $2 \times 10^{17}\,\text{kg}\,\text{m}^{-3}$. *[1]*

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SECTION B

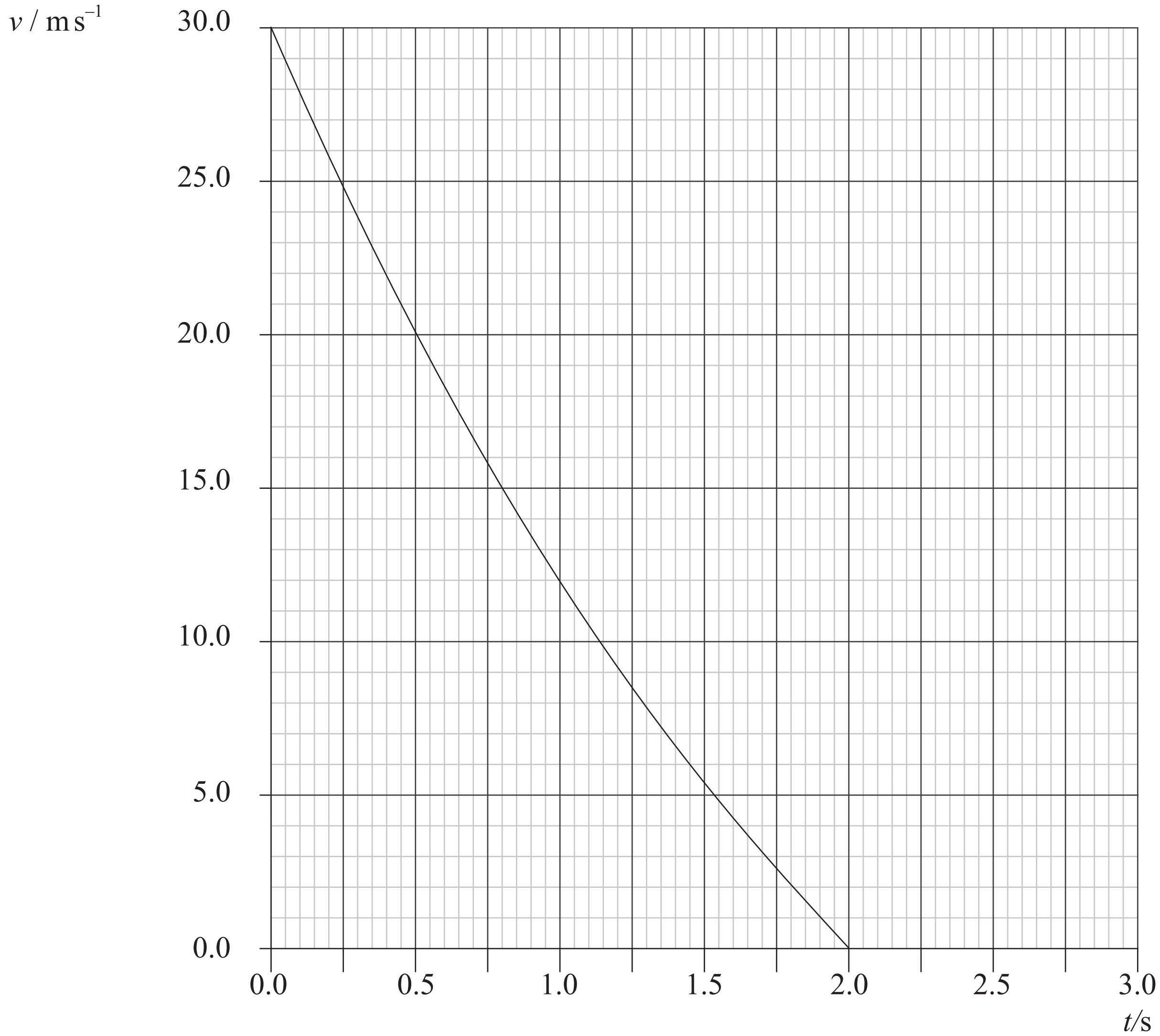
This section consists of four questions: B1, B2, B3 and B4. Answer ***two*** *questions.*

B1. This question is in **two** parts. **Part 1** is about the motion of a ball in the presence of air resistance. **Part 2** is about the emission of electrons from a surface.

Part 1 Motion of a ball

A ball of mass 0.25 kg is projected vertically upwards from the ground with an initial velocity of 30 m s^{-1}. The acceleration of free fall is 10 m s^{-2}, but air resistance **cannot** be neglected.

The graph below shows the variation with time t of the velocity v of this ball for the upward part of the motion.



(This question continues on the following page)

(Question B1, part 1 continued)

(a) State what the area under the graph represents. *[1]*

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(b) Estimate the maximum height reached by the ball. *[1]*

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(c) Determine, for the ball at $t = 1.0\,\text{s}$,

(i) the acceleration. *[3]*

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(ii) the magnitude of the force of air resistance. *[2]*

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(d) Use the graph to explain, without any further calculations, that the force of air resistance is decreasing in magnitude as the ball moves upward. *[2]*

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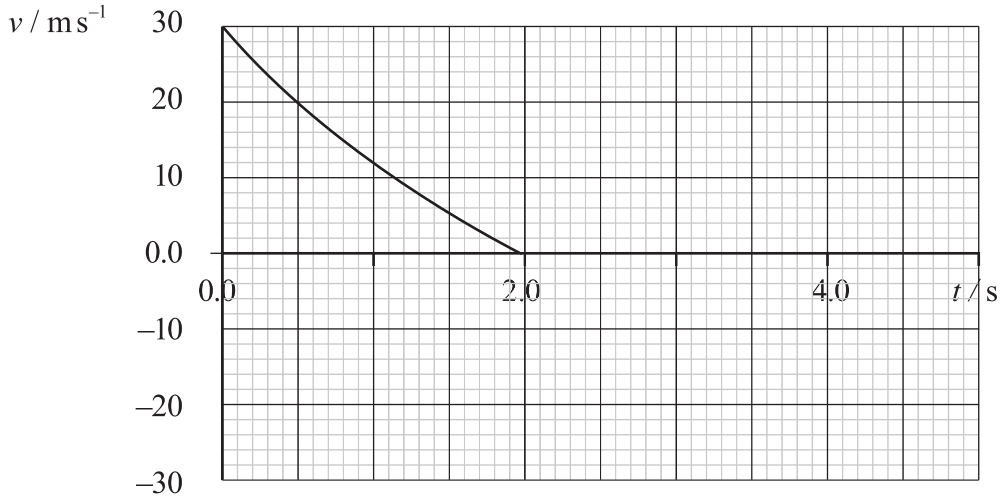
(This question continues on the following page)

(Question B1, part 1 continued)

(e) The diagram below is a sketch graph of the upward motion of the ball.

Draw a line to indicate the downward motion of the ball. The line should indicate the motion from the maximum height of the ball until just before it hits the ground. *[2]*



(f) State and explain, by reference to energy transformations, whether the speed with which the ball hits the ground is equal to $30\,m\,s^{-1}$. *[2]*

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(g) Use your answer in (f) to state and explain whether the ball takes 2.0 s to move from its maximum height to the ground. *[2]*

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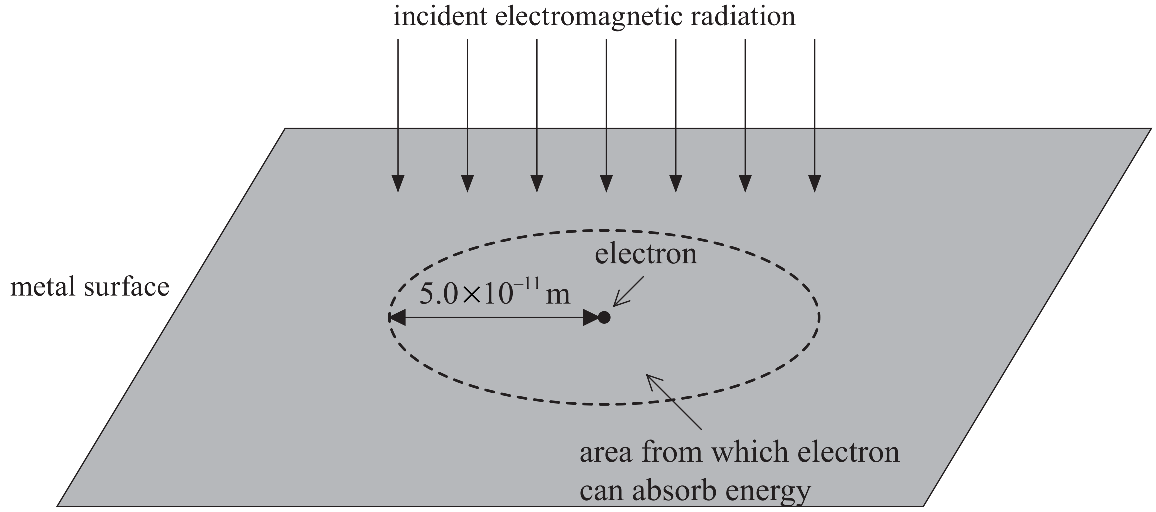
(Question B1, continued)

Part 2 Emission of electrons

The diagram below shows an electron on the surface of a metal. Electromagnetic radiation is incident normally on the surface.



According to a model based on the electromagnetic theory of light, the electron absorbs all the energy that is incident on the surface within a distance of 5.0×10^{-11} m from the electron. The intensity of light incident on the surface is $1.6\,\mathrm{W\,m^{-2}}$. The energy required to remove an electron from the surface is 1.8 eV.

(a) Calculate, on the basis of this model, that the time taken for the electron to gain sufficient energy to leave the surface is 23 s. (The area of a circle of radius R is πR^2.) *[4]*

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(b) Experimental observation indicates that electrons are emitted from the surface in less than 10^{-9} s. Explain how this observation is consistent with the particle theory of light. *[2]*

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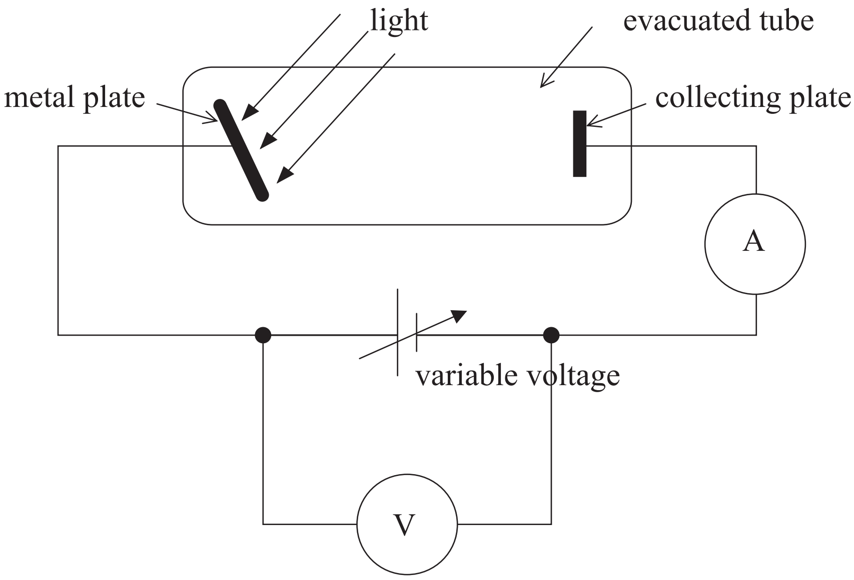
(Question B1, part 2 continued)

(c) The diagram below illustrates an apparatus used to investigate the photoelectric effect.



(i) Describe how, using this apparatus, the maximum kinetic energy of the emitted electrons may be determined for incident light of frequency f. *[2]*

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(This question continues on the following page)

(Question B1, part 2 continued)

(ii) On the axes provided below draw a sketch graph to show the variation with frequency f of the maximum kinetic energy E_K of the emitted electrons. (Numerical values are not required.) *[2]*

(iii) State and explain what is represented by the gradient (slope) of the graph. *[2]*

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(d) The incident light has intensity $1.6\,\text{W}\,\text{m}^{-2}$, wavelength 520 nm and 5.0 % of the incident photons cause the ejection of electrons from the surface. Determine the number of electrons ejected from $1.0\,\text{m}^2$ of the surface per second. *[3]*

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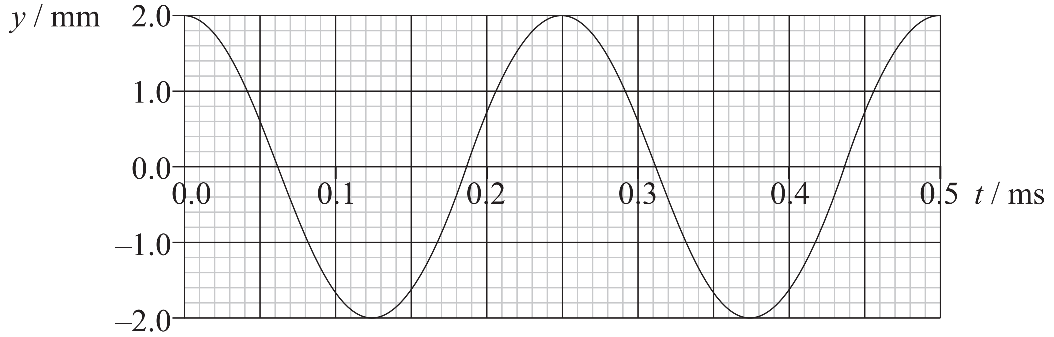
B2. This question is in **two** parts. **Part 1** is about waves on a string and interference. **Part 2** is about electromagnetic induction.

Part 1 Waves on a string

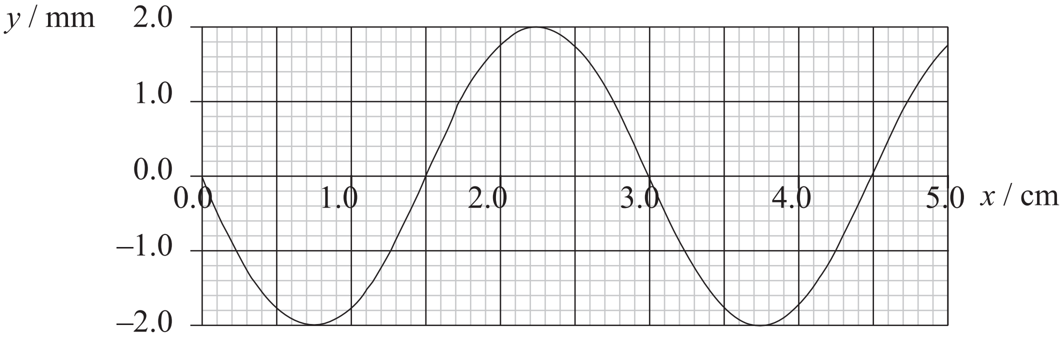
A travelling wave is created on a string. The graph below shows the variation with time t of the displacement y of a particular point on the string.

Graph 1



The variation with distance x of the displacement y of the string at $t=0$ is shown below.

Graph 2



(a) Use information from the graphs to calculate, for this wave,

(i) the wavelength. *[1]*

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(ii) the frequency. *[2]*

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(iii) the speed of the wave. *[1]*

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(This question continues on the following page)

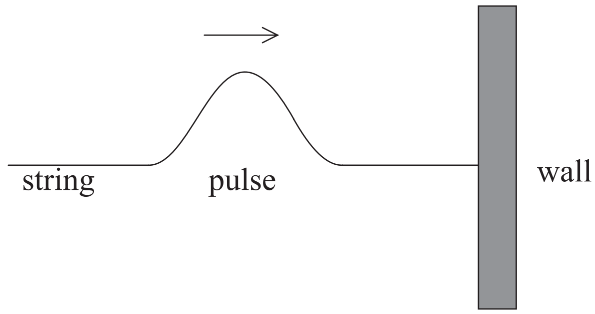
(Question B2, part 1 continued)

(b) The wave is moving from left to right and has period T.

(i) On **graph 1**, draw a labelled line to indicate the amplitude of the wave. *[1]*

(ii) On **graph 2**, draw the displacement of the string at $t = \frac{T}{4}$. *[2]*

(c) One end of the string is attached to a wall. A student creates a single pulse in the string that travels to the right as shown in the diagram below.



(i) In the space below, draw a diagram to show the shape and size of the pulse after it has been reflected from the wall. *[2]*

(ii) By reference to Newton's third law, explain the nature of the reflected pulse that you have drawn in (c)(i) above. *[2]*

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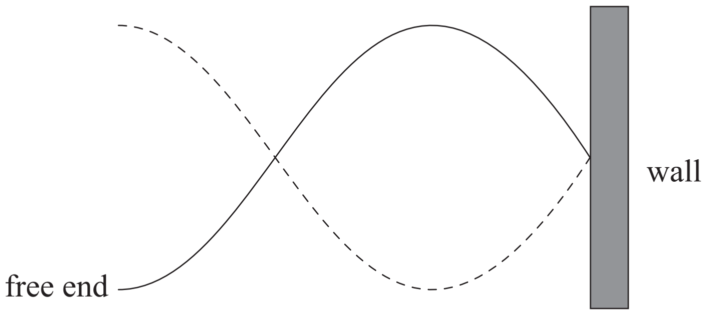
(Question B2, part 1 continued)

(d) The free end of the string in (c) is now made to oscillate with frequency f such that a standing wave is established on the string. The diagram below illustrates the standing wave.



(i) Explain, by reference to the principle of superposition, the formation of a standing wave. *[3]*

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(ii) The length of the string is 3.0 m. Using your answer for the speed of the wave in (a)(iii) calculate the frequency f. *[2]*

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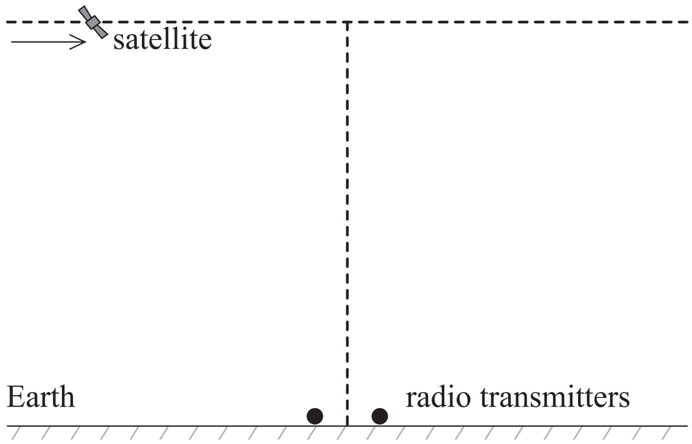
(Question B2, part 1 continued)

(e) A satellite orbits the Earth at a fixed height above the equator. Two coherent radio transmitters on the equator emit radio waves of equal amplitude as illustrated in the diagram below.



The signal that the satellite receives varies in intensity.

(i) State what is meant by *coherent sources*. *[1]*

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(ii) Suggest why the signal received by the satellite varies in intensity. *[2]*

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(iii) The transmitters have a separation of 160 m and emit waves of wavelength 1.2 m. The signal received by the satellite varies in intensity with a frequency of 3.0 Hz as it flies overhead. The speed of the satellite is 7.7 km s^{-1}.

Calculate the height of the satellite above the Earth's surface. *[3]*

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(This question continues on the following page)

(Question B2 continued)

Part 2 Electromagnetic induction

(a) State Faraday's law of electromagnetic induction. *[1]*

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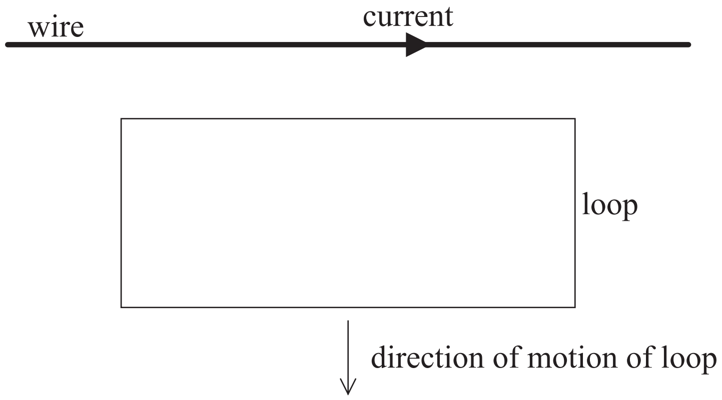
(b) A long straight wire carries a constant current. A rectangular loop of conducting wire is placed near the wire such that the wire is on the plane of the loop. The loop is then moved at constant speed **away** from the wire as shown in the diagram below.



(i) Explain why an e.m.f. is induced in the loop. *[2]*

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(ii) On the diagram above, draw an arrow to indicate the direction of the current induced in the loop. Explain your answer. *[2]*

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(iii) Energy is dissipated in the wire of the loop. Explain how the movement of the loop gives rise to energy dissipation. *[3]*

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B3. This question is in **two** parts. **Part 1** is about electrical conduction and **Part 2** is about thermodynamics.

Part 1 Electrical conduction

In a copper wire the number of conduction electrons is equal to the number of copper atoms in the wire.

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

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(b) (i) The density of copper is $8.93 \times 10^3\ \text{kg m}^{-3}$ and its molar mass is 64 g. Deduce that the number of moles of copper in a volume of $1.0\ \text{m}^3$ is 1.4×10^5. *[2]*

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(ii) Estimate the number of conduction electrons in $1.0\ \text{m}^3$ of copper. *[1]*

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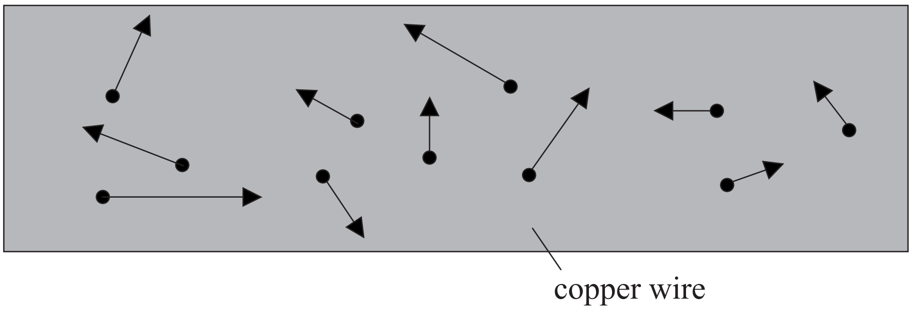
(c) The diagram below shows some of the conduction electrons in a copper wire. The arrows represent the random velocities of some of the electrons.



Explain, by reference to the motion of the electrons, why there is no current in the wire. *[2]*

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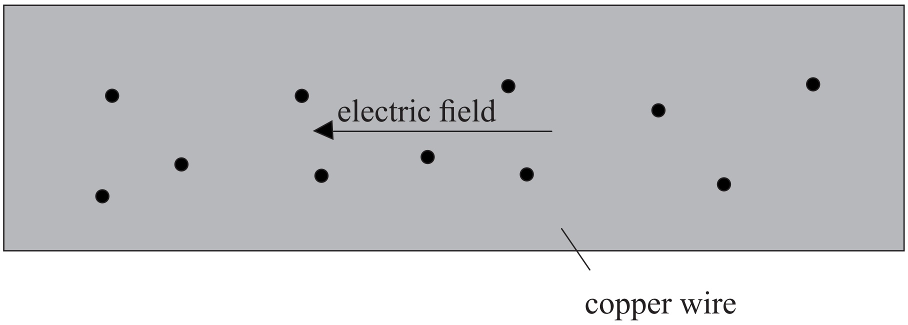
(Question B3, part 1 continued)

(d) An electric field is established inside the copper wire directed as shown in the diagram below. The dots represent electrons. The random velocities of the electrons are not shown.

On the diagram below, draw an arrow to indicate the direction of the drift velocity of the electrons. *[1]*



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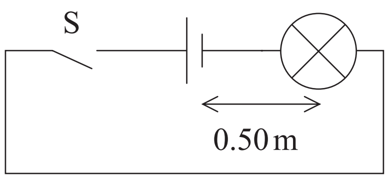
(Question B3, part 1 continued)

(e) A typical value for the electron drift velocity in a copper wire is $10^{-3}\,m\,s^{-1}$. In the circuit below, the length of the copper wire joining the negative terminal of the battery to the lamp is 0.50 m.



(i) The switch S is closed. Calculate the time it would take for an electron to move from the negative terminal of the battery to the lamp. *[1]*

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(ii) The lamp lights in a time much less than that calculated in (e)(i). Explain this observation. *[2]*

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(iii) Discuss, in terms of the movement of the electrons, the energy transformations taking place in the filament of the lamp. *[4]*

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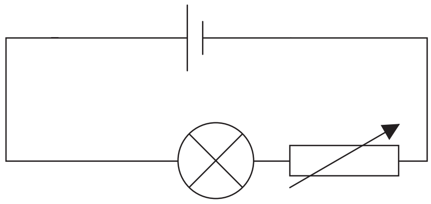
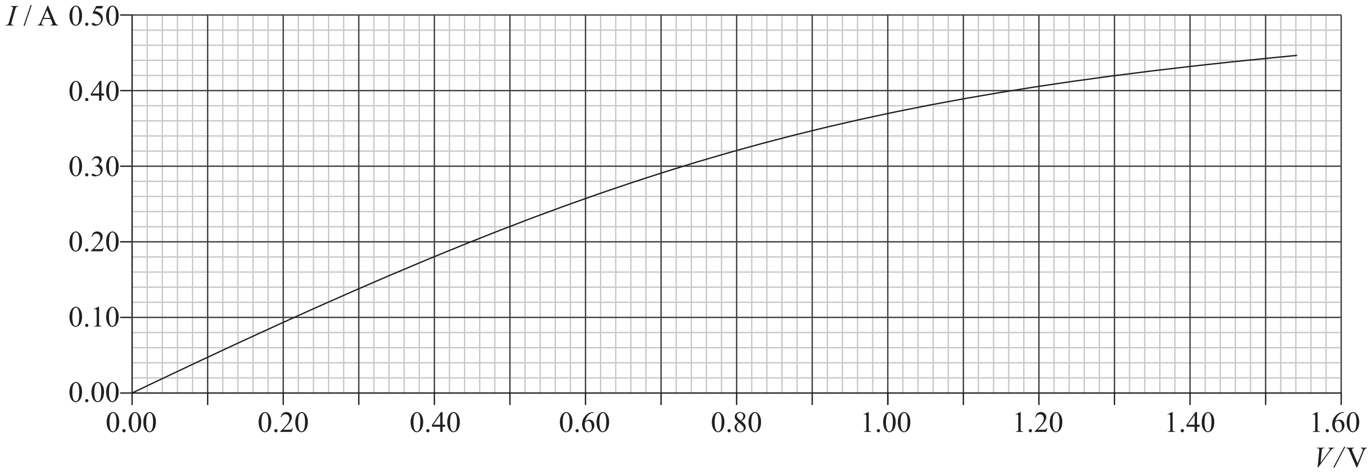
(Question B3, part 1 continued)

(f) The diagram below shows part of a circuit that may be used to determine the current - potential difference (*I*-*V*) characteristics of a lamp.



An ammeter and a voltmeter are required. On the diagram above, draw symbols to show the correct positions of the ammeter and the voltmeter. *[2]*

(g) The *I*-*V* characteristics for one lamp are shown below.



(i) State a range of values of the current *I* for which the lamp may be considered to show ohmic behaviour. *[1]*

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(ii) The potential difference across the lamp is 0.80 V. Calculate the resistance of the lamp at this potential difference. *[2]*

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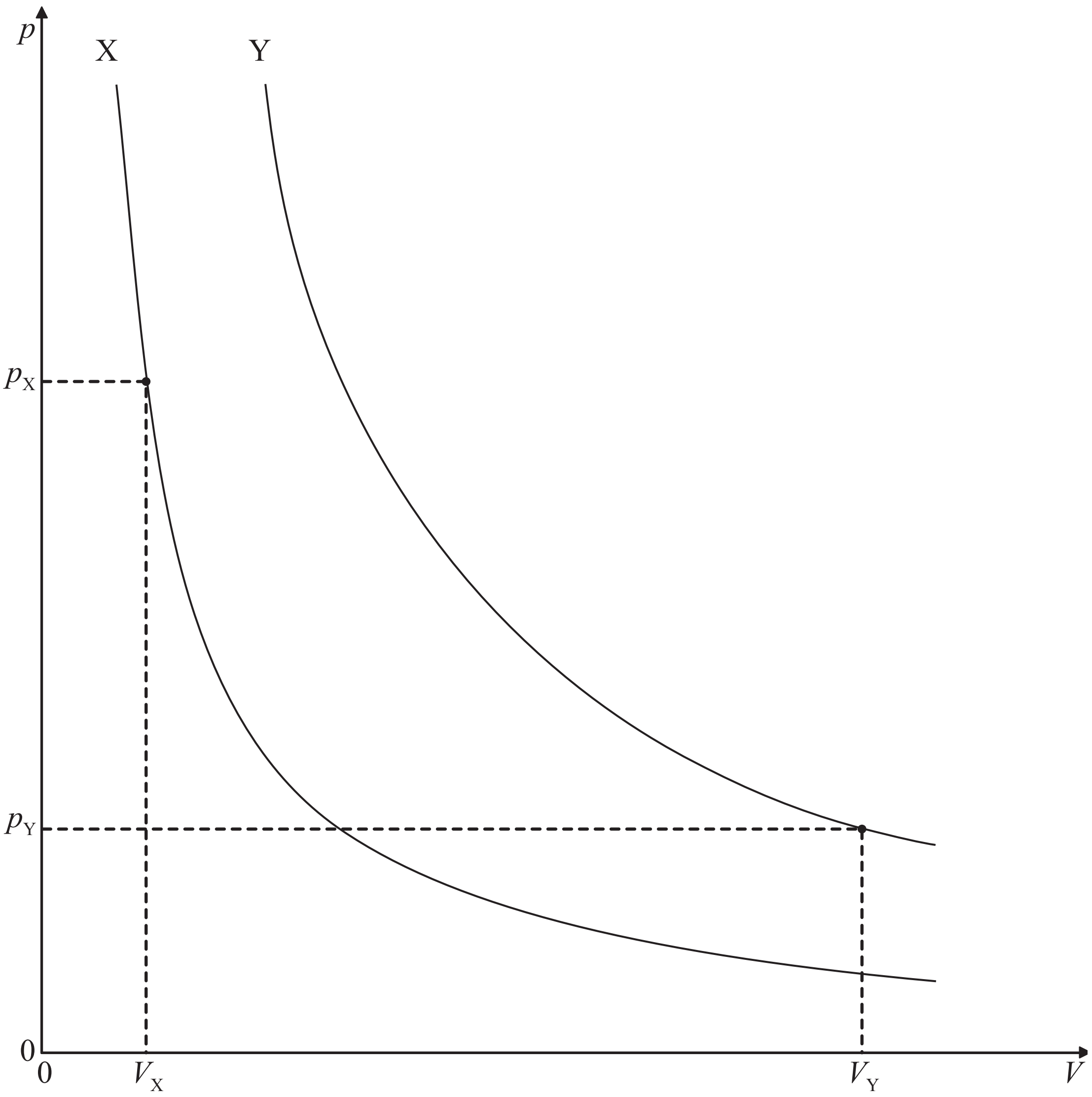
(This question continues on the following page)

(Question B3 continued)

Part 2 Thermodynamics

The graph below shows the variation with volume V of the pressure p for two isothermal changes of two ideal gases X and Y. The gases have the same number of moles. The dots indicate two particular states of the gases, (p_X, V_X) and (p_Y, V_Y).



(a) State what is meant by an *isothermal change*. *[1]*

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(This question continues on the following page)

(Question B3, part 2 continued)

(b) Explain whether gas X in the state (p_X,V_X) is at a higher **or** lower temperature than gas Y in the state (p_Y,V_Y). *[2]*

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(c) Gas Y is compressed adiabatically from state (p_Y,V_Y) until it reaches the pressure p_X.

(i) Explain whether the temperature of gas Y will increase, decrease **or** stay the same during this process. *[3]*

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(ii) On the graph opposite, draw a line to represent this adiabatic compression of gas Y. *[3]*

(d) On the graph opposite, shade the area that represents the work done when gas X is compressed isothermally from volume V_Y to volume V_X. *[2]*

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B4. This question is in **two** parts. **Part 1** is about using plutonium as a power source. **Part 2** is about the orbital motion of a satellite.

Part 1 Plutonium as a power source

The alpha decay of plutonium-238 is to be used as a power source. Plutonium-238 $\left({}^{238}_{94}\text{Pu}\right)$ decays by emission of an α-particle to form an isotope of uranium (U).

(a) Write down the nuclear equation for this decay. *[2]*

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(b) The nuclear masses of the isotopes and the α-particle in this decay are

Plutonium	237.9979539 u
Uranium	233.9904441 u
α-particle	4.0015050 u.

(i) Deduce that the energy released in this reaction is 8.9×10^{-13} J. *[3]*

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(ii) The plutonium nucleus is at rest before the decay. Explain why most of the energy in (b)(i) is kinetic energy of the α-particle. *[2]*

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(This question continues on the following page)

(Question B4, part 1 continued)

(c) The half-life of plutonium is 88 years.

(i) Explain why over a period of six months the activity of a sample of plutonium-238 may be considered to be constant. *[2]*

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(ii) The activity of the sample of plutonium-238 is 4.1×10^{13} Bq. Calculate the rate at which energy is released. *[2]*

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(iii) The mass of the sample of plutonium-238 in (c)(ii) is 65 g. Using your answer to (c)(ii) calculate the rate at which the temperature of the plutonium sample is increasing. Assume that no energy is lost from the sample. (The specific heat capacity of plutonium is $150\,\text{J kg}^{-1}\,\text{K}^{-1}$.) *[2]*

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(This question continues on the following page)

(Question B4, part 1 continued)

(d) As the temperature of the sample in (c) rises the plutonium will eventually melt. Describe and explain, in terms of atomic behaviour, the processes of

(i) the temperature rise of plutonium. *[3]*

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(ii) the phase change of plutonium. *[3]*

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(This question continues on the following page)

(Question B4, continued)

Part 2 Motion of a satellite

(a) Define *gravitational potential*. *[2]*

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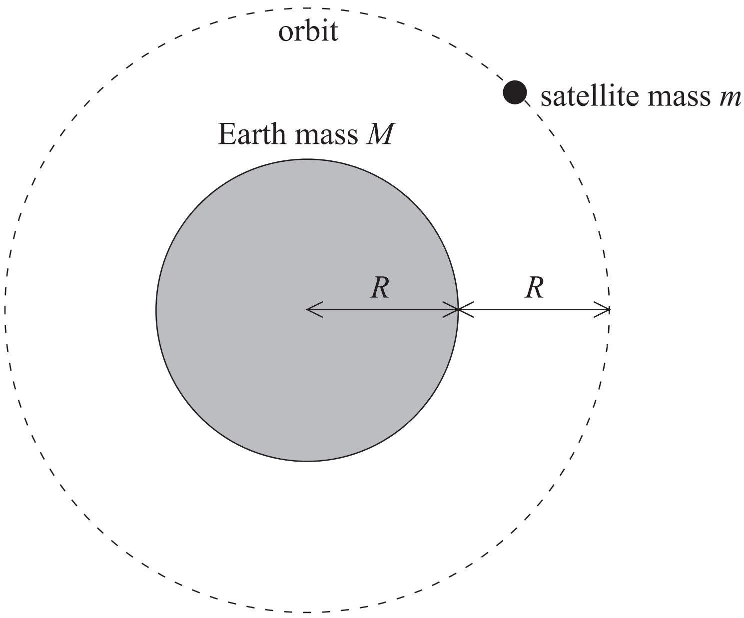
(b) A satellite of mass m is in a circular orbit around the Earth at height R from the Earth's surface. The mass of the Earth may be considered to be a point mass concentrated at the Earth's centre. The Earth has mass M and radius R.



(i) Deduce that the kinetic energy E_K of the satellite when in orbit of height R is

$$E_K = \frac{GMm}{4R}.$$ *[3]*

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(This question continues on the following page)

(Question B4, Part 2 continued)

(ii) The kinetic energy of the satellite in this orbit is 1.5×10^{10} J. Calculate the **total energy** of the satellite. *[3]*

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(iii) Explain how your answer to (b)(ii) indicates that the satellite will not escape the Earth's gravitational field and state the minimum amount of energy that must be provided to this satellite so that it does escape. *[3]*

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