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PHYSICS
HIGHER LEVEL
PAPER 2

Candidate session number

Thursday 6 November 2014 (morning)

2 hours 15 minutes

Examination code

8	8	1	4	–	6	5	0	2

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.
- A calculator is required for this paper.
- A clean copy of the ***Physics*** *Data Booklet* is required for this paper.
- The maximum mark for this examination paper is *[95 marks]*.

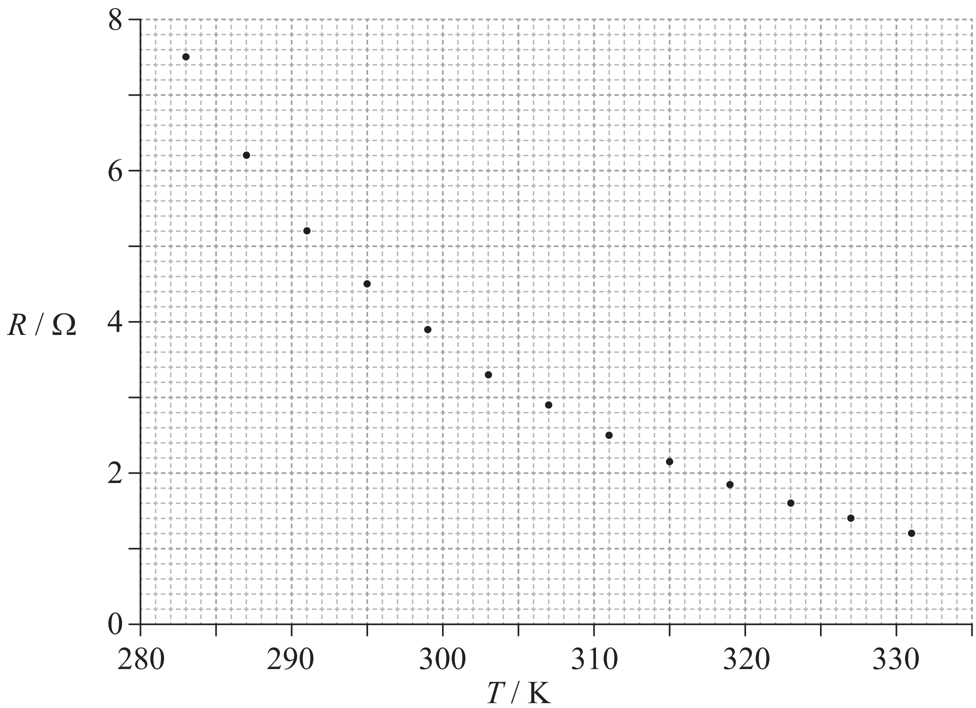
35 pages

SECTION A

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

1. Data analysis question.

A student sets up a circuit to study the variation of resistance R of a negative temperature coefficient (NTC) thermistor with temperature T. The data are shown plotted on the graph.



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

(This question continues on the following page)

(Question 1 continued)

(b) (i) Calculate the gradient of the graph when $T = 291\,\text{K}$. *[3]*

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(ii) State the unit for your answer to (b)(i). *[1]*

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(c) The uncertainty in the resistance value is 5%. The uncertainty in the temperature is negligible. On the graph, draw error bars for the data point at $T = 283\,\text{K}$ and for the data point at $T = 319\,\text{K}$. *[2]*

(This question continues on the following page)

(Question 1 continued)

(d) The electric current through the thermistor for $T = 283\,\text{K}$ is 0.78 mA. The uncertainty in the electric current is 0.01 mA.

(i) Calculate the power dissipated by the thermistor at $T = 283\text{K}$. *[1]*

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(ii) Determine the uncertainty in the power dissipated by the thermistor at $T = 283\,\text{K}$. *[3]*

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2. This question is about melting ice.

A container of negligible mass, isolated from its surroundings, contains 0.150 kg of ice at a temperature of –18.7 °C. An electric heater supplies energy at a rate of 125 W.

(a) After a time interval of 45.0 s all of the ice has reached a temperature of 0 °C without any melting. Calculate the specific heat capacity of ice. *[2]*

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(b) The following data are available.

Specific heat capacity of water $= 4200\,\text{J kg}^{-1}\,\text{K}^{-1}$
Specific latent heat of fusion of ice $= 3.30 \times 10^{5}\,\text{J kg}^{-1}$

Determine the final temperature of the water when the heater supplies energy for a further 600 s. *[3]*

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3. This question is about nuclear reactions.

(a) A reaction that takes place in the core of a particular nuclear reactor is as shown.

$$^{235}_{92}\text{U} + \text{X} \rightarrow {}^{144}_{56}\text{Ba} + {}^{89}_{36}\text{Kr} + 3\text{X}$$

(i) State the nature of X. *[1]*

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(ii) State **one** form of energy that is instantaneously released in the reaction. *[1]*

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(b) In the nuclear reactor, 9.5×10^{19} fissions take place every second. Each fission gives rise to 200 MeV of energy that is available for conversion to electrical energy. The overall efficiency of the nuclear power station is 32 %.

(i) Determine the mass of U-235 that undergoes fission in the reactor every day. *[3]*

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(Question 3 continued)

(ii) Calculate the power output of the nuclear power station. *[2]*

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(c) In addition to the U-235, the nuclear reactor contains graphite that acts as a moderator. Explain the function of the moderator. *[3]*

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(d) Outline how energy released in the nuclear reactor is transformed to electrical energy. *[3]*

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4. This question is about the energy of an orbiting satellite.

A space shuttle of mass *m* is launched in the direction of the Earth's South Pole.

(a) The kinetic energy E_K given to the shuttle at its launch is given by the expression

$$E_K = \frac{7GMm}{8R_E}$$

where G is the gravitational constant, M is mass of the Earth and R_E is the radius of the Earth. Deduce that the shuttle cannot escape the gravitational field of the Earth. *[2]*

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(Question 4 continued)

(b) (i) The shuttle enters a circular orbit of radius R around the Earth.

Show that the total energy of the shuttle in its orbit is given by $-\frac{GMm}{2R}$. Air resistance is negligible. *[3]*

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(ii) Using the expression for E_K in (a) and your answer to (b)(i), determine R in terms of R_E. *[3]*

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(c) In practice, the total energy of the shuttle decreases as it collides with air molecules in the upper atmosphere. Outline what happens to the speed of shuttle when this occurs. *[2]*

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5. This question is about a charge-coupled device (CCD).

Monochromatic light of wavelength 550 nm is incident on one pixel in a CCD for an exposure time of 0.03 s. The intensity of the light falling on the pixel is $20\,\text{mW m}^{-2}$ and the area of the pixel is $3.5\times10^{-10}\,\text{m}^2$.

(a) Show that about 6×10^5 photons are incident on the pixel during the exposure. *[3]*

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(b) The quantum efficiency of the pixel is 75 % and it has a capacitance of 60 pF. Calculate the change in potential difference across the pixel. *[3]*

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SECTION B

*This section consists of four questions: 6, 7, 8 and 9. Answer **two** questions. Write your answers in the boxes provided.*

6. This question is in **two** parts. **Part 1** is about energy resources. **Part 2** is about transformers.

Part 1 Energy resources

(a) The Sun is a renewable energy source whereas a fossil fuel is a non-renewable energy source. Outline the difference between renewable and non-renewable energy sources. *[2]*

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(b) With reference to the energy transformations and the operation of the devices, distinguish between a photovoltaic cell and a solar heating panel. *[2]*

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(Question 6, part 1 continued)

(c) A photovoltaic panel is made up of a collection (array) of photovoltaic cells. The panel has a total area of $1.3\,m^2$ and is mounted on the roof of a house. The maximum intensity of solar radiation at the location of the panel is $750\,W\,m^{-2}$. The panel produces a power output of $210\,W$ when the solar radiation is at its maximum intensity.

(i) Determine the efficiency of the photovoltaic panel. *[2]*

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(ii) State **two** reasons why the intensity of solar radiation at the location of the panel is not constant. *[2]*

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(Question 6, part 1 continued)

(d) The owner of the house chooses between photovoltaic panels and solar heating panels to provide 4.2 kW of power to heat water. The solar heating panels have an efficiency of 70 %. The maximum intensity of solar radiation at the location remains at 750 W m^{-2}.

(i) Calculate the minimum area of solar heating panel required to provide this power. *[2]*

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(ii) Comment on whether it is better to use a solar heating panel rather than an array of photovoltaic panels for the house. Do not consider the installation cost of the panels in your answer. *[2]*

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(e) The use of solar energy is a way by which nations can fulfil their obligations under the Kyoto Protocol. Identify **one** aim of the Kyoto Protocol and outline the steps a nation might take to meet its commitments under the protocol. *[3]*

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(Question 6 continued)

Part 2 Transformers

Modern televisions (TVs) can be left in "standby" mode so that they are available for immediate use. The internal circuits are powered at low voltage using a step-down transformer connected to the mains power supply. To prevent the TV from using any energy, the transformer must be disconnected from the mains supply.

(f) Outline the features of an ideal step-down transformer. *[2]*

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(g) Real transformers are subject to energy loss. State and explain how **two** causes of these energy losses may be reduced by suitable features in these transformers. *[4]*

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(Question 6, part 2 continued)

(h) When in "standby" mode, a TV transformer supplies a current of 0.45 A at 9.0 V to the internal circuits.

(i) Calculate the power consumed by the internal circuits when the TV is in "standby" mode. *[1]*

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(ii) The efficiency of the transformer is 0.95. Determine the current supplied by the 230 V mains supply. *[2]*

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(iii) The TV is on "standby" for 75 % of the time. Calculate the energy wasted in one year by not switching off the TV. *[1]*

$$1\,\text{year} = 3.2 \times 10^{7}\,\text{s}$$

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7. This question is about the motion of a ship and observing objects from it.

(a) Outline the meaning of work. *[2]*

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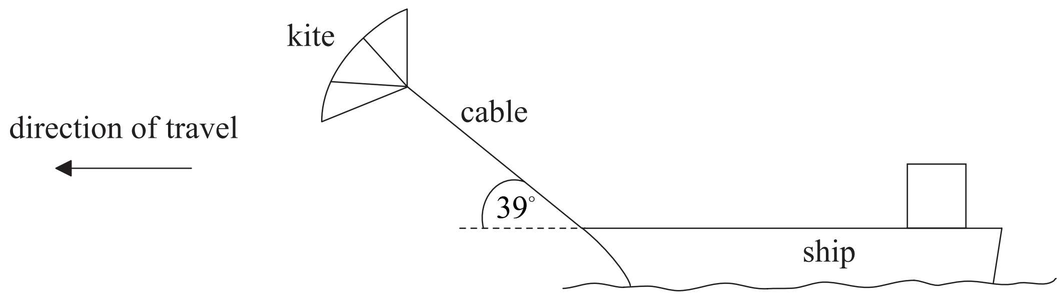
(b) Some cargo ships use kites working together with the ship's engines to move the vessel.



The tension in the cable that connects the kite to the ship is 250 kN. The kite is pulling the ship at an angle of 39° to the horizontal. The ship travels at a steady speed of 8.5 m s^{-1} when the ship's engines operate with a power output of 2.7 MW.

(i) Calculate the work done on the ship by the kite when the ship travels a distance of 1.0 km. *[2]*

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(Question 7 continued)

(ii) Show that, when the ship is travelling at a speed of $8.5\,m\,s^{-1}$, the kite provides about 40% of the total power required by the ship. *[4]*

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(c) The kite is taken down and no longer produces a force on the ship. The resistive force F that opposes the motion of the ship is related to the speed v of the ship by

$$F = kv^2$$

where k is a constant.

Show that, if the power output of the engines remains at 2.7 MW, the speed of the ship will decrease to about $7\,m\,s^{-1}$. Assume that k is independent of whether the kite is in use or not. *[3]*

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(This question continues on the following page)

(Question 7 continued)

(d) The ship's engines are switched off and the ship comes to rest from a speed of $7\,m\,s^{-1}$ in a time of 650 s.

(i) Estimate the distance that the ship takes to stop. Assume that the acceleration is uniform. *[2]*

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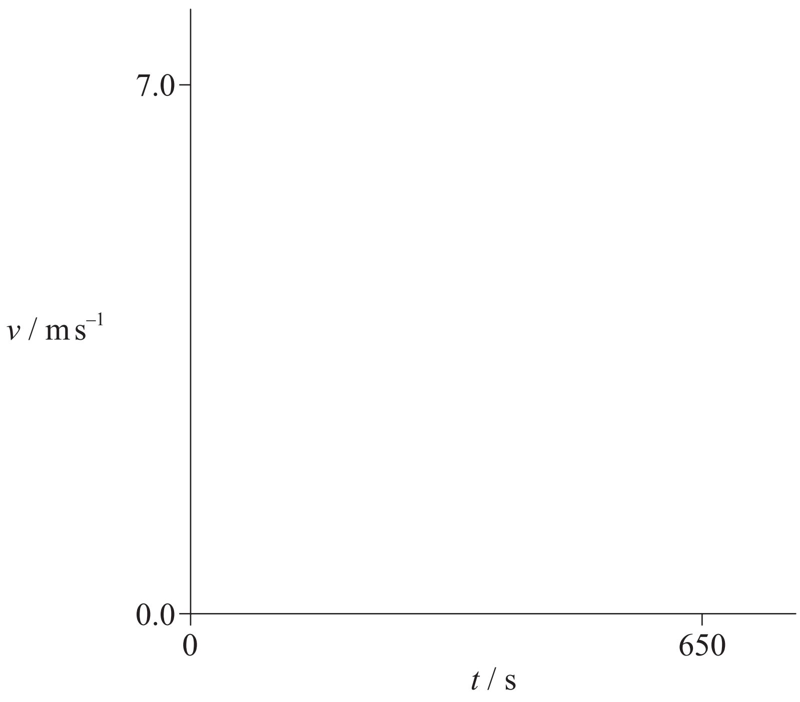
(ii) It is unlikely that the acceleration of the ship will be uniform given that the resistive force acting on the ship depends on the speed of the ship. Using the axes, sketch a graph to show how the speed v varies with time t after the ship's engines are switched off. *[2]*



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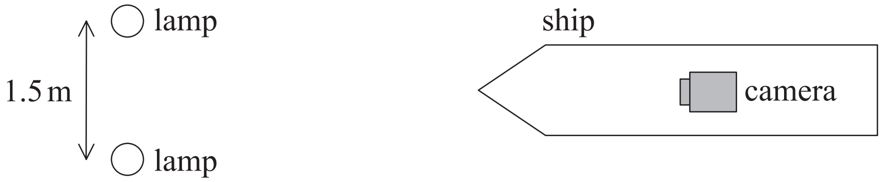
(Question 7 continued)

(e) A security camera on the ship captures an image of two green lamps on the shore. The lamps emit light of wavelength 520 nm.



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The camera has a circular aperture of diameter 6.2 mm. The lamps are separated by 1.5 m. Determine the maximum distance between the camera and the lamps at which the images of the lamps can be distinguished. *[3]*

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(This question continues on the following page)

(Question 7 continued)

(f) The sailors on the ship wear polarized sunglasses when observing the sea from the ship. Unpolarized light from the Sun is incident on the sea.

(i) Describe the polarization of the sunlight that is reflected from the sea. *[2]*

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(ii) A ray of light is incident on the sea at the Brewster angle. Calculate the angle to the horizontal at which this ray is reflected from the sea. The refractive index of sea water is 1.3. *[2]*

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(iii) Outline how polarized sunglasses help to reduce glare from the sea. *[3]*

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8. This question is in **two** parts. **Part 1** is about internal resistance of a cell. **Part 2** is about expansion of a gas.

Part 1 Internal resistance of a cell

(a) Define *electromotive force (emf)*. *[1]*

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(b) Outline, with reference to charge carriers, what is meant by the internal resistance of a cell. *[3]*

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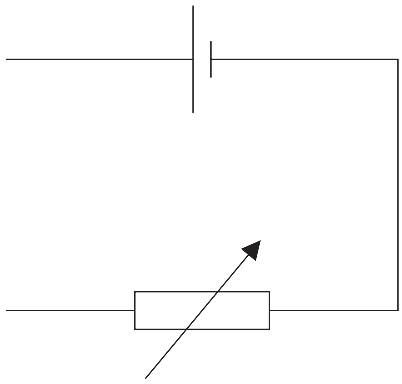
(This question continues on the following page)

(Question 8, part 1 continued)

(c) A circuit is used to determine the internal resistance and emf of a cell. It consists of the cell, a variable resistor, an ideal ammeter and an ideal voltmeter. The diagram shows part of the circuit with the ammeter and voltmeter missing.



The variable resistor is set to 1.5 Ω. When the cell converts 7.2 mJ of energy, 5.8 mC of charge moves completely around the circuit. The potential difference across the variable resistor is 0.55 V.

(i) Draw on the diagram the positions of the ammeter and voltmeter. *[1]*

(ii) Show that the emf of the cell is 1.25 V. *[1]*

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(This question continues on the following page)

(Question 8, part 1 continued)

(iii) Determine the internal resistance of the cell. *[2]*

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(iv) Calculate the energy dissipated per second in the variable resistor. *[2]*

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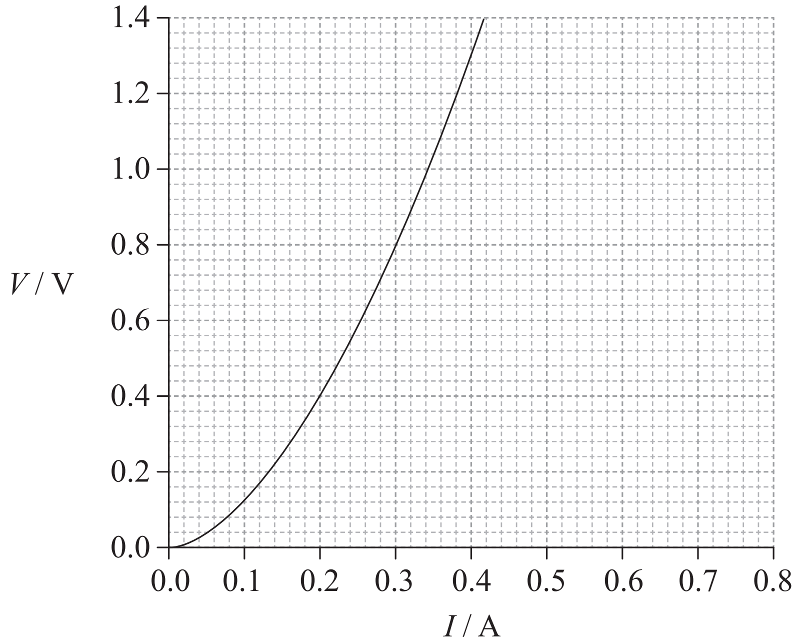
(Question 8, part 1 continued)

(d) The graph shows the voltage–current (V–I) characteristics of a non-ohmic conductor.



The variable resistor in the circuit in (c) is replaced by this non-ohmic conductor.

(i) On the graph, sketch the variation of V with I for the cell. *[2]*

(ii) Using the graph, determine the current in the circuit. *[3]*

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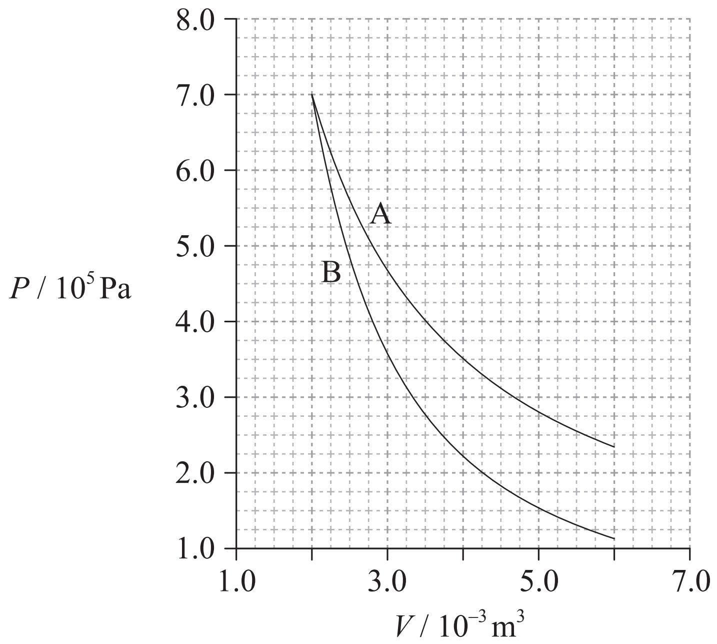
(Question 8, continued from page 26)

Part 2 Expansion of a gas

(e) The graph shows how the pressure P of a fixed mass of gas varies with volume V. The lines show the state of the gas sample during adiabatic expansion and during isothermal expansion.



State and explain whether line A **or** line B represents an adiabatic expansion. *[2]*

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(Question 8, part 2 continued)

(f) Determine the work done during the change represented by line A. *[4]*

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(g) Outline, with reference to the first law of thermodynamics, the direction of change in temperature during the adiabatic expansion. *[4]*

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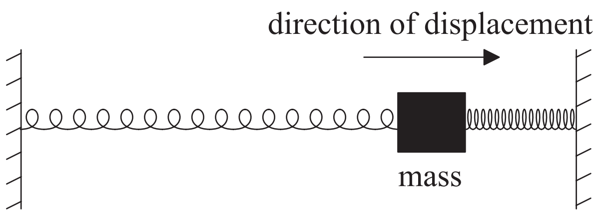
9. This question is in **two** parts. **Part 1** is about the oscillation of a mass. **Part 2** is about the photoelectric effect.

Part 1 Oscillation of a mass

A mass of 0.80 kg rests on a frictionless surface and is connected to two identical springs both of which are fixed at their other ends. A force of 0.030 N is required to extend or compress each spring by 1.0 mm. When the mass is at rest in the centre of the arrangement, the springs are not extended.

(a) The mass is displaced to the right by 60 mm and released.



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(i) Determine the acceleration of the mass at the moment of release. *[3]*

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(ii) Outline why the mass subsequently performs simple harmonic motion (SHM). *[2]*

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(This question continues on the following page)

(Question 9, part 1 continued)

(iii) Calculate the period of oscillation of the mass. *[2]*

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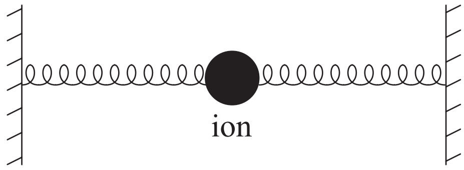
(Question 9, part 1 continued)

(b) The motion of an ion in a crystal lattice can be modelled using the mass–spring arrangement. The inter-atomic forces may be modelled as forces due to springs as in the arrangement shown.



The frequency of vibration of a particular ion is 7×10^{12} Hz and the mass of the ion is 5×10^{-26} kg. The amplitude of vibration of the ion is 1×10^{-11} m.

(i) Estimate the maximum kinetic energy of the ion. *[2]*

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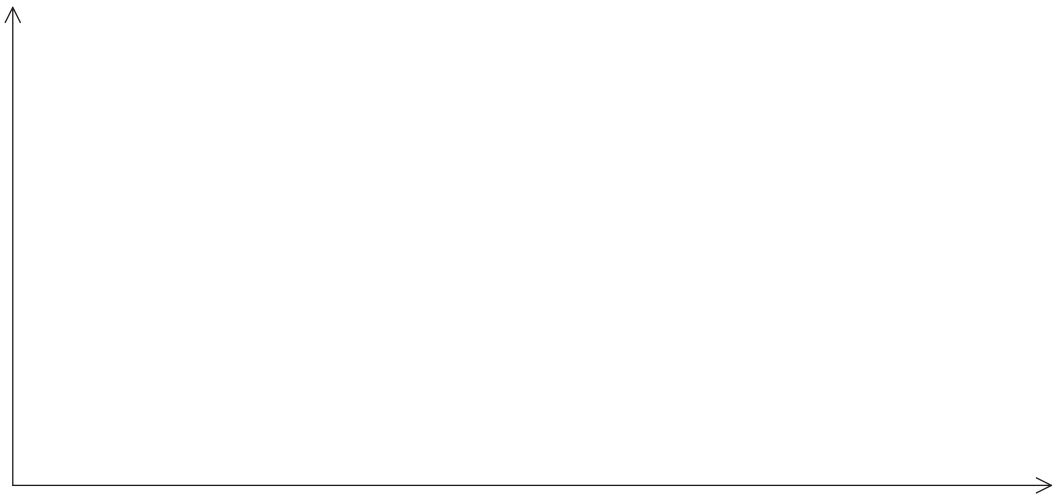
(ii) On the axes, draw a graph to show the variation with time of the kinetic energy of mass and the elastic potential energy stored in the springs. You should add appropriate values to the axes, showing the variation over one period. *[3]*



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(Question 9, part 1 continued)

(c) (i) Calculate the wavelength of an infrared wave with a frequency equal to that of the model in (b). *[1]*

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(ii) Explain how the model in (b) predicts how the lattice will absorb a certain wavelength of electromagnetic infrared radiation. *[2]*

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(Question 9 continued)

Part 2 Photoelectric effect

A student carries out a photoelectric experiment in which radiation is incident on a metal surface in a vacuum.

(d) Explain why photoelectrons are not emitted from the metal surface unless the frequency of incident light exceeds a minimum value. *[2]*

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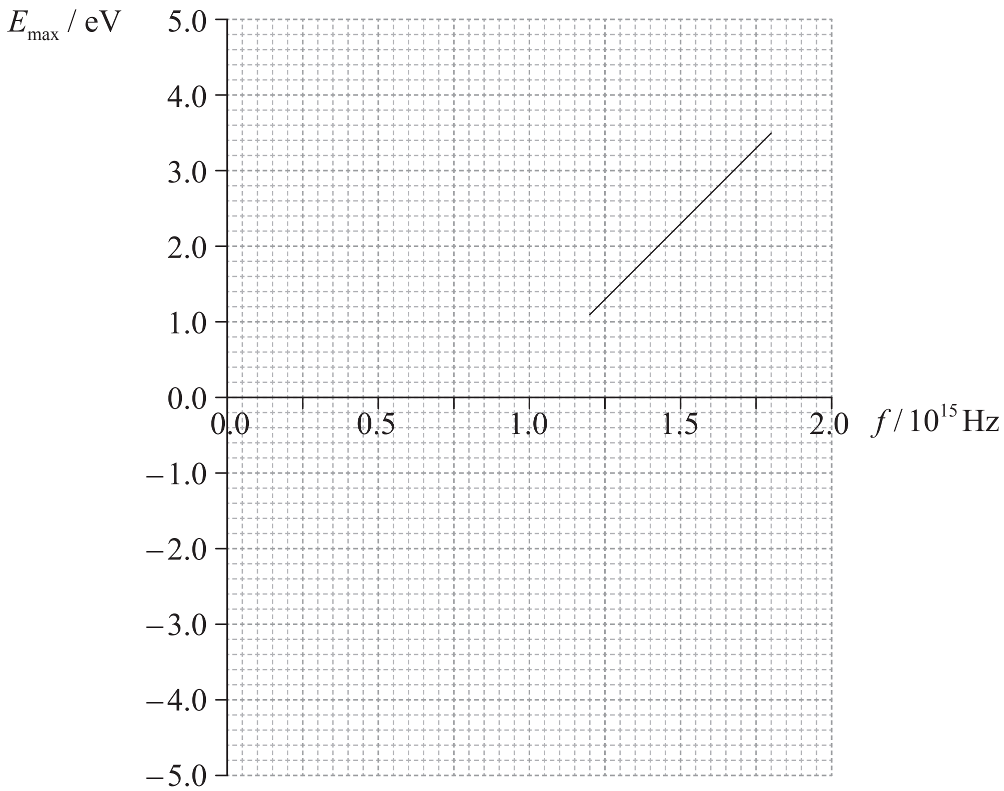
(e) A graph of the results of the experiment show how the maximum kinetic energy E_{max} of the emitted photoelectrons varies with the frequency f of the incident radiation.



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(Question 9, part 2 continued)

Use the graph to

(i) identify the minimum value of the frequency f_0 for photoelectrons to be emitted. *[1]*

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(ii) determine the Planck constant. *[3]*

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(iii) calculate the work function, in eV, for the metal surface. *[2]*

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(f) The student repeats the experiment with a different metal surface that has a smaller value for the work function. On the graph in (e), draw a line to show how E_{max} varies with f. *[2]*

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