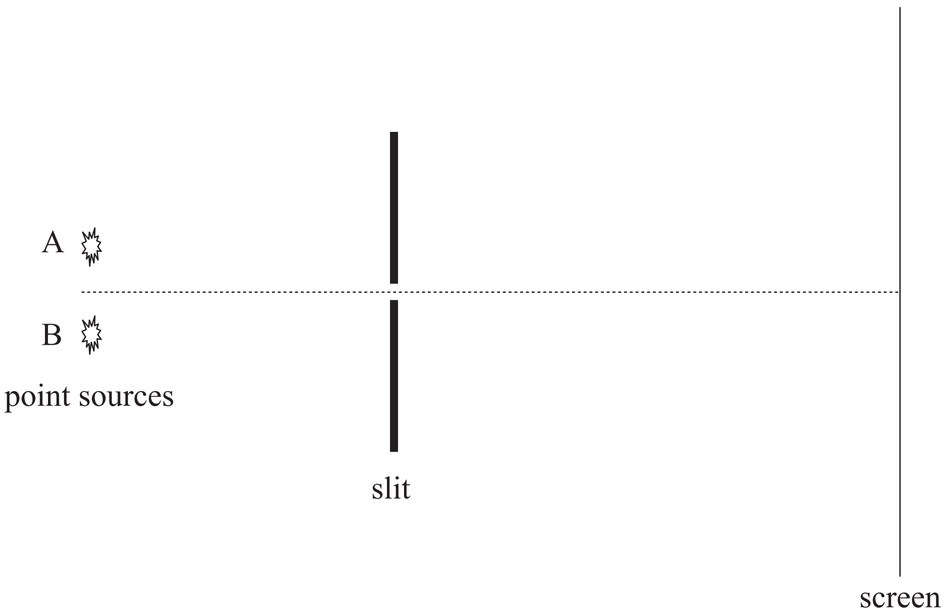
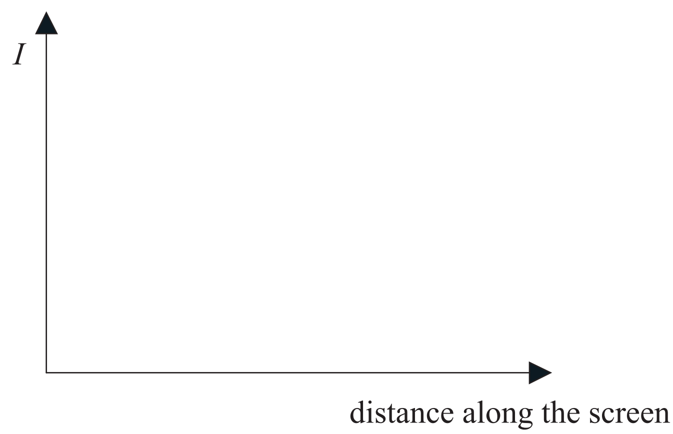
A2. This question is about optical resolution.

The two point sources shown in the diagram below (not to scale) emit light of the same frequency. The light is incident on a rectangular narrow slit and, after passing through the slit, is brought to a focus on the screen.



(a) Point source B is covered. Using the axes below, sketch a graph to show how the intensity *I* of the light from point source A varies with distance along the screen. Label the curve you have drawn A. *[2]*



(b) Point source B is now uncovered. The images of A and B on the screen are just resolved. Using the axes above, sketch a graph to show how the intensity *I* of the light from point source B varies with distance along the screen. Label this curve B. *[1]*

(This question continues on the following page)

(Question A2 continued)

(c) The bright star Sirius A is accompanied by a much fainter star, Sirius B. The mean distance of the stars from Earth is 8.1×10^{16} m. Under ideal atmospheric conditions, a telescope with an objective lens of diameter 25 cm can just resolve the stars as two separate images.

Assuming that the average wavelength emitted by the stars is 500 nm, estimate the apparent, linear separation of the two stars. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

A3. This question is about polarization and liquid crystals.

(a) A liquid crystal has the property of being able to rotate the plane of polarization of light. Explain what is meant by the expression "able to rotate the plane of polarization of light". *[2]*

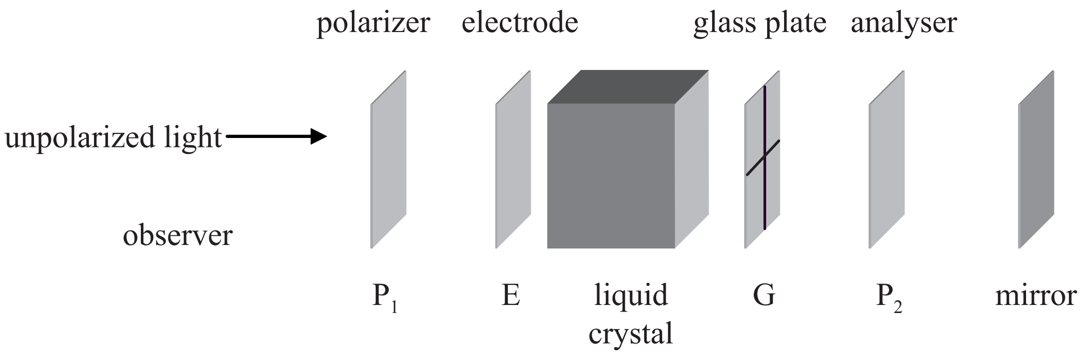
. . . .

. . . .

. . . .

. . . .

(b) The diagram below is a representation of a liquid crystal display.



P_1 is a polarizer and P_2 is an analyser. The transmission axis of P_2 is at right angles to that of P_1. E is an electrode. G is a glass plate upon which a shaped electrode is etched. Unpolarized light is incident on P_1.

(i) State, and explain, what the observer would see if the liquid crystal were not present. *[2]*

. . . .

. . . .

. . . .

. . . .

(ii) Outline how the application of a potential difference between E and the electrode etched on G enables the observer to see the shape of the electrode. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

A4. This question is about an ideal gas.

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

$$P \propto T \, .$$

State the relation between the

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

. . . .

. . . .

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

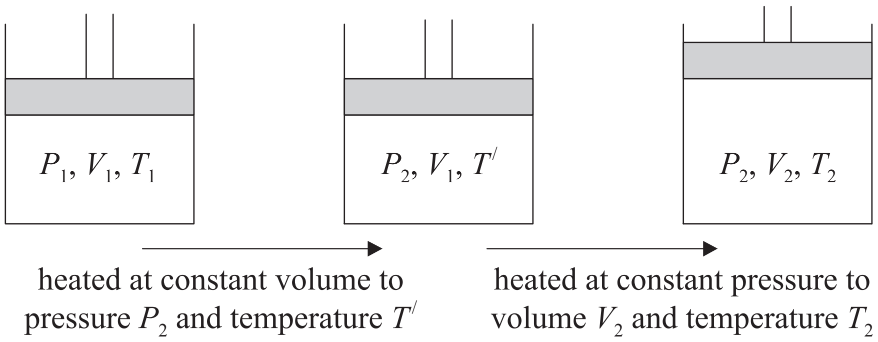
. . . .

. . . .

(This question continues on the following page)

(Question A4 continued)

(b) The ideal gas is held in a cylinder by a moveable piston. The pressure of the gas is P_1, its volume is V_1 and its kelvin temperature is T_1. The pressure, volume and temperature are changed to P_2, V_2 and T_2 respectively. The change is brought about as illustrated below.



State the relation between

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

. . . .

. . . .

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

. . . .

. . . .

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

$$PV=KT,$$

where K is a constant. *[4]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

A6. This question is about gravitational fields.

(a) Define *gravitational field strength*. *[2]*

. . . .

. . . .

. . . .

(b) The gravitational field strength at the surface of Jupiter is $25\,\text{N kg}^{-1}$ and the radius of Jupiter is $7.1 \times 10^{7}\,\text{m}$.

(i) Derive an expression for the gravitational field strength at the surface of a planet in terms of its mass M, its radius R and the gravitational constant G. *[2]*

. . . .

. . . .

. . . .

. . . .

(ii) Use your expression in (b)(i) above to estimate the mass of Jupiter. *[2]*

. . . .

. . . .

. . . .

. . . .

(Question B1 continued)

Part 2 Charge coupled device (CCD)

(a) A digital camera is used to take a photograph of a plant. The CCD in the camera has 1.6×10^{7} square pixels. Each pixel has an area of $2.3\times10^{-10}\,m^2$. A particular leaf of the plant has an area of $2.5\times10^{-2}\,m^2$. The image of the leaf formed on the CCD is $1.0\times10^{-3}\,m^2$. Two indentations on the leaf are separated by 0.50 mm. Deduce that it is unlikely that the images of the two indentations will be resolved. *[4]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(b) Light is incident on the image collection area for a time of 100 ms. The number of photons incident on one pixel is 5.5×10^{4}. Each pixel has a quantum efficiency of 80 % and a capacitance 40 pF.

(i) State what is meant by quantum efficiency. *[1]*

. . . .

. . . .

(ii) Estimate the change in potential difference across each pixel. *[4]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question B1, part 2 continued)

(c) Outline how the variation in potential difference across individual pixels enables a black and white image to be produced by a digital camera. *[2]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

B2. This question is in **two** parts. **Part 1** is about nuclear power production. **Part 2** is about electromagnetic induction.

Part 1 Nuclear power production

(a) With reference to the concept of fuel enrichment in a nuclear reactor explain,

(i) the advantage of enriching the uranium used in a nuclear reactor. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

(ii) from an international point of view, a possible risk to which fuel enrichment could lead. *[2]*

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question B2, part 1 continued)

(b) A particular nuclear reactor uses uranium-235 as its fuel source. When a nucleus of uranium-235 absorbs a neutron, the following reaction can take place.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{144}_{54}Xe + ^{90}_{38}Sr + 2\,^{1}_{0}n$$

The following data are available.

$$\text{rest mass of } ^{235}_{92}U = 2.1895\times10^{5}\,\text{MeV c}^{-2}$$
$$\text{rest mass of } ^{144}_{54}Xe = 1.3408\times10^{5}\,\text{MeV c}^{-2}$$
$$\text{rest mass of } ^{90}_{38}Sr = 8.3749\times10^{4}\,\text{MeV c}^{-2}$$
$$\text{rest mass of } ^{1}_{0}n = 939.56\,\text{MeV c}^{-2}$$

(i) Show that the energy released in the reaction is approximately 180 MeV. *[1]*

. . . .

. . . .

(ii) State the form in which the energy appears. *[1]*

. . . .

(c) The energy released by one atom of carbon-12 during combustion is approximately 4 eV.

(i) Using the answer to (b)(i), estimate the ratio *[3]*

$$\frac{\text{energy density of uranium-235}}{\text{energy density of carbon-12}}.$$

. . . .

. . . .

. . . .

. . . .

. . . .

(ii) Suggest, with reference to your answer in (c)(i), **one** advantage of uranium-235 compared with fossil fuels. *[1]*

. . . .

. . . .

(This question continues on the following page)

(Question B2, part 1 continued)

(d) A sample of waste produced by the reactor contains 1.0 kg of strontium 90 (Sr-90). Sr-90 has a half-life of 9.1×10^{8} s.

For the strontium in the sample,

(i) show that its initial activity of is 5.1×10^{15} Bq. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

(ii) calculate its activity after a period of 70 years. (1 yr $= 3.2 \times 10^{7}$ s) *[3]*

. . . .

. . . .

. . . .

. . . .

(e) Based on your answers to (d), comment on a problem associated with using uranium-235 as an energy source. *[3]*

. . . .

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question B2 continued)

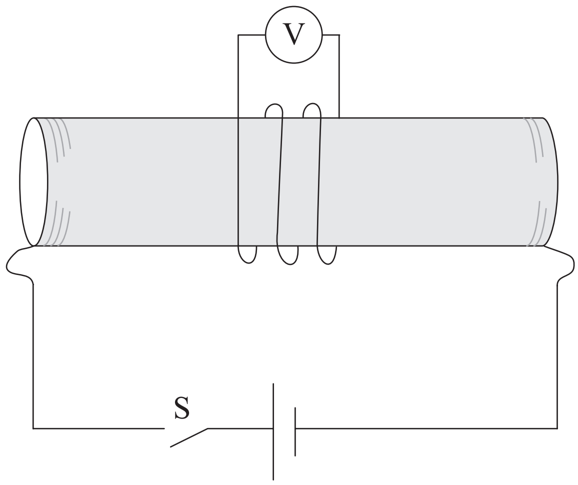
Part 2 Electromagnetic induction

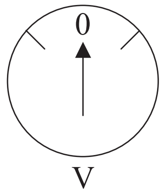
(a) State Lenz's law. *[1]*

. . . .

. . . .

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





The ends of the wire are connected to a high resistance voltmeter V that has a centre zero scale (as shown in the inset diagram). The switch S is closed and it is observed that the needle on V moves to the right and then drops back to zero.

Describe and explain, the deflection on the voltmeter when the switch S is re-opened. *[4]*

Description: . . . .

. . . .

. . . .

. . . .

Explanation: . . . .

. . . .

. . . .

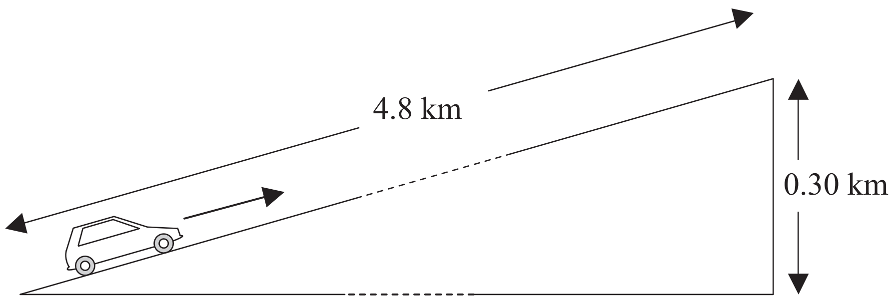
. . . .

. . . .

B3. This question is in **two** parts. **Part 1** is about mechanical power. **Part 2** is about gravitational potential.

Part 1 Mechanical power

(a) A car drives up a straight incline that is 4.8 km long. The total height of the incline is 0.30 km.



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

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

. . . .

. . . .

. . . .

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

. . . .

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

. . . .

. . . .

. . . .

. . . .

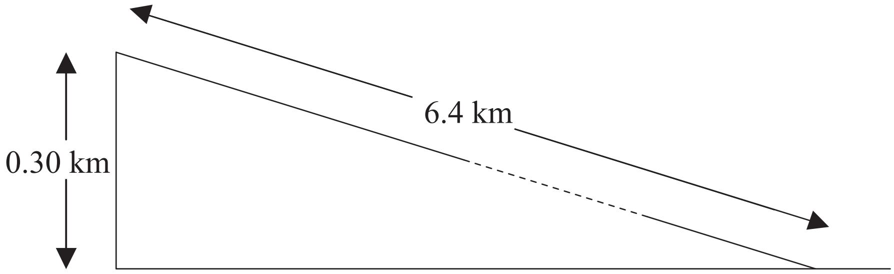
. . . .

. . . .

(This question continues on the following page)

(Question B3, part 1 continued)

(b) From the top of the incline, the road continues downwards in a straight line. At the point where the road starts to go downwards, the driver of the car in (a), stops the car to look at the view. In continuing his journey, the driver decides to save fuel. He switches off the engine and allows the car to move freely down the hill. The car descends a height of 0.30 km in a distance of 6.4 km before levelling out.



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

Estimate

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

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

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

. . . .

. . . .

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

. . . .

(This question continues on the following page)

(Question B3 continued)

Part 2 Gravitational potential

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

. . . .

. . . .

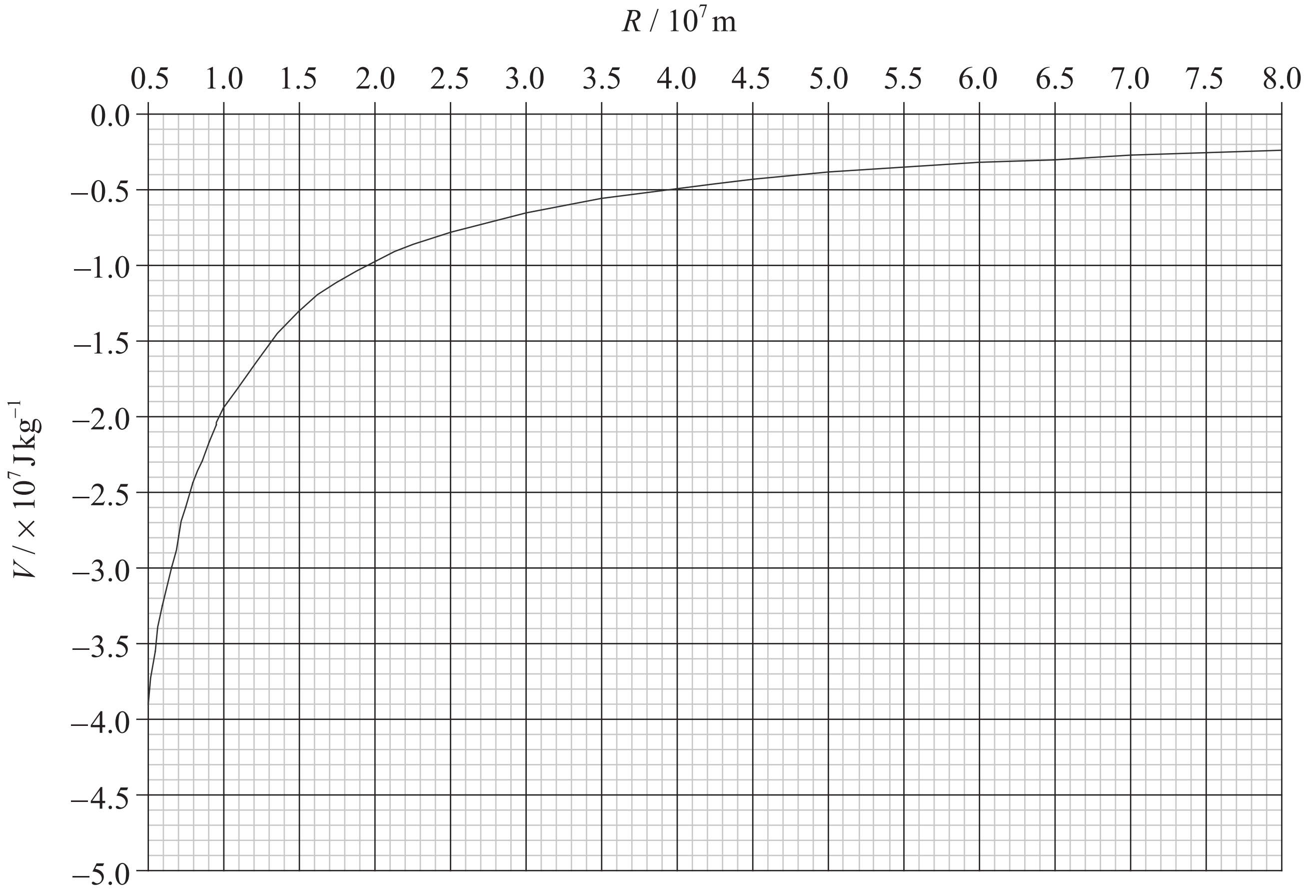
. . . .

. . . .

(This question continues on the following page)

(Question B3, part 2 continued)

(b) The graph below shows the variation with distance R from the centre of a planet of the gravitational potential V. The radius R_0 of the planet $= 5.0\times10^6$ m. Values of V are not shown for $R<R_0$.



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

. . . .

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question B3, part 2 continued)

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

. . . .

. . . .

. . . .

. . . .

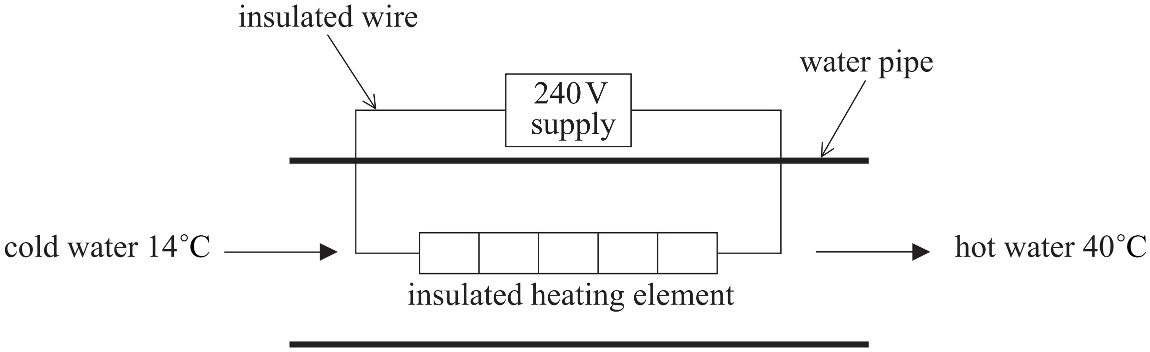
. . . .

. . . .

B4. This question is in **two** parts. **Part 1** is about heating water for a domestic shower. **Part 2** is about the photoelectric effect.

Part 1 Domestic shower

(a) The diagram below shows part of the heating circuit of a domestic shower.



Cold water enters the shower unit and flows over an insulated heating element. The heating element is rated at 7.2 kW, 240 V. The water enters at a temperature of 14 °C and leaves at a temperature of 40 °C. The specific heat capacity of water is $4.2 \times 10^3\,\text{J kg}^{-1}\,\text{K}^{-1}$.

(i) Define *specific heat capacity*. *[1]*

. . . .

. . . .

. . . .

(ii) Estimate the flow rate of the water. *[4]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question B4, part 1 continued)

(iii) Suggest **two** reasons why your answer to (a)(ii) is only an estimate. *[2]*

1. . . . .

. . . .

2. . . . .

. . . .

(iv) Calculate the current in the heating element when the element is operating at 7.2 kW. *[2]*

. . . .

. . . .

. . . .

(v) Explain why, when the shower unit is switched on, the initial current in the heating element is greater than the current calculated in (a)(iv). *[2]*

. . . .

. . . .

. . . .

(This question continues on page 29)

(Question B4, part 1 continued)

(b) In some countries, shower units are operated from a 110 V supply. A heating element operating with a 240 V supply has resistance R_{240} and an element operating from a 110 V supply has resistance R_{110}.

Show that for heating elements to have identical power outputs

$$\frac{R_{110}}{R_{240}} = 0.21.$$

[3]

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

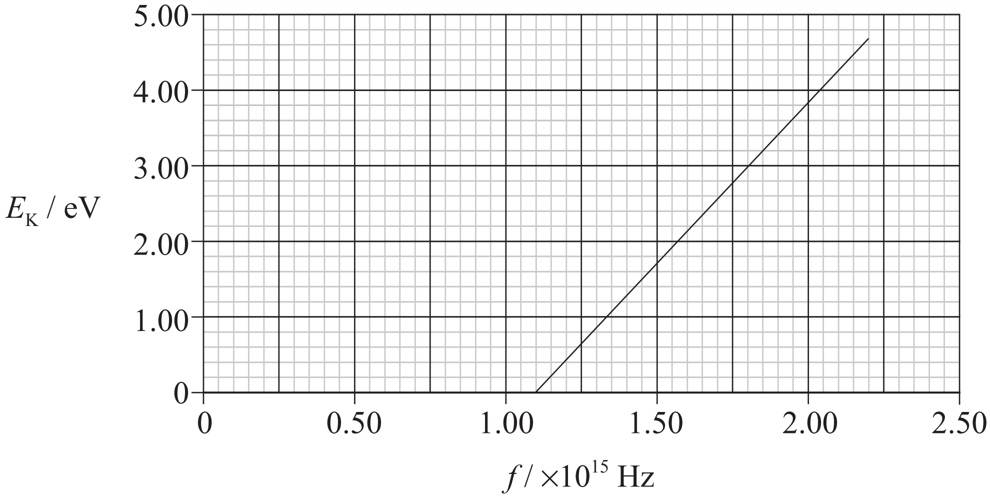
. . . .

(This question continues on the following page)

(Question B4 continued)

Part 2 Photoelectric effect

A metal is placed in a vacuum and light of frequency f is incident on its surface. As a result, electrons are emitted from the surface. The graph below shows the variation with frequency f of the maximum kinetic energy E_K of the emitted electrons.



(a) The graph above shows that there is a threshold frequency of the incident light below which no electrons are emitted from the surface. With reference to the Planck constant and the photoelectric work function, explain how Einstein's photoelectric theory accounts for this threshold frequency. *[4]*

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question B4, part 2 continued)

(b) Use the graph in (a) to calculate the

(i) threshold frequency. *[1]*

. . . .

(ii) Planck constant. *[4]*

. . . .

. . . .

. . . .

. . . .

. . . .

(iii) work function of the metal. *[2]*

. . . .

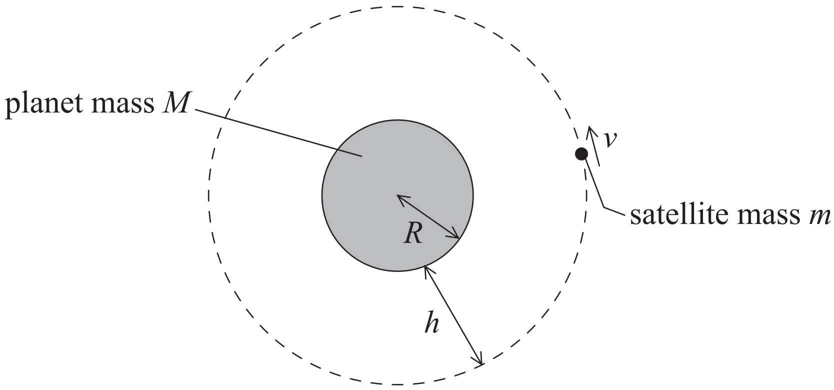
. . . .

. . . .

B4. This question is in **two** parts. **Part 1** is about gravitation and **Part 2** is about linear and circular motion.

Part 1 Gravitation

A spherical planet has radius R and mass M. A satellite of mass m orbits the planet with constant linear speed v at a height h above the planet's surface, as shown below (not to scale).



(a) Outline why

(i) although the satellite is moving at constant speed, it is not in equilibrium. *[2]*

. . . .

. . . .

. . . .

. . . .

(ii) an object in the satellite appears to be weightless. *[3]*

. . . .

. . . .

. . . .

(This question continues on the following page)

(Question B4, part 1 continued)

(b) For the satellite in its orbit,

(i) state an expression, in terms of M, m, R and h, for its potential energy. *[1]*

. . . .

. . . .

(ii) derive an expression, using the same terms as in (b)(i), for its kinetic energy. *[3]*

. . . .

. . . .

. . . .

. . . .

(c) The total energy of the satellite is reduced. Use your expressions in (b) to outline what change, if any, occurs in the radius of the orbit and the speed of the satellite. *[4]*

. . . .

. . . .

. . . .

. . . .

. . . .

(d) The force of friction between the satellite and the atmospheric air increases as the speed of the satellite increases. By reference to your answer in (c), suggest why small satellites will "burn up" as they re-enter the Earth's atmosphere. *[4]*

. . . .

. . . .

. . . .

. . . .

. . . .

(This question continues on the following page)