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Physics
Higher level
Paper 2

26 April 2024

Zone A morning | **Zone B** morning | **Zone C** morning

Candidate session number

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2 hours 15 minutes

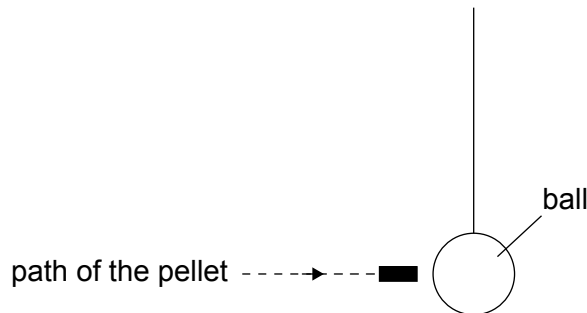
Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Answers must be written within the answer 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 **[90 marks]**.



Answer **all** questions. Answers must be written within the answer boxes provided.

1. A stationary ball is hanging from a light string. A pellet from an air rifle is travelling horizontally and becomes embedded in the ball. The velocity of the pellet when it strikes the ball is 160 ms^{-1} .



The following data are given.

Mass of the ball = 250 g

Mass of the pellet = 2.0 g

- (a) Calculate the speed of the ball and the pellet immediately after the impact. [2]

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- (b) Suggest why the combined kinetic energy of the ball and the pellet after the impact is less than the initial kinetic energy of the pellet. [2]

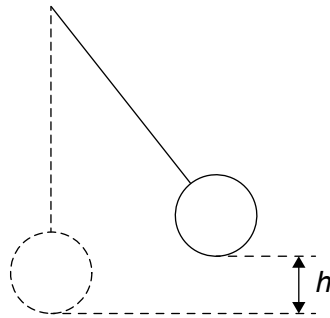
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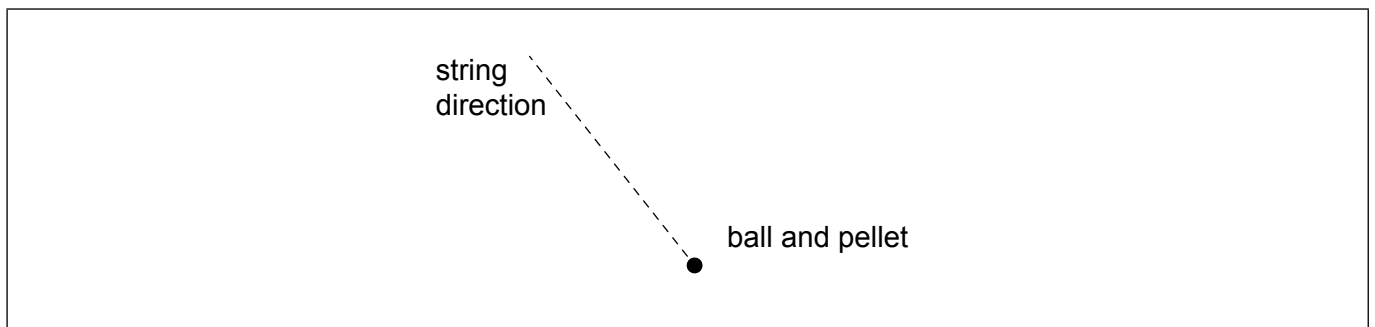


(Question 1 continued)

The ball with the embedded pellet rises to a maximum vertical height h .



(c) Draw and label the free-body diagram for the ball at height h . [2]



(d) Determine h . [2]

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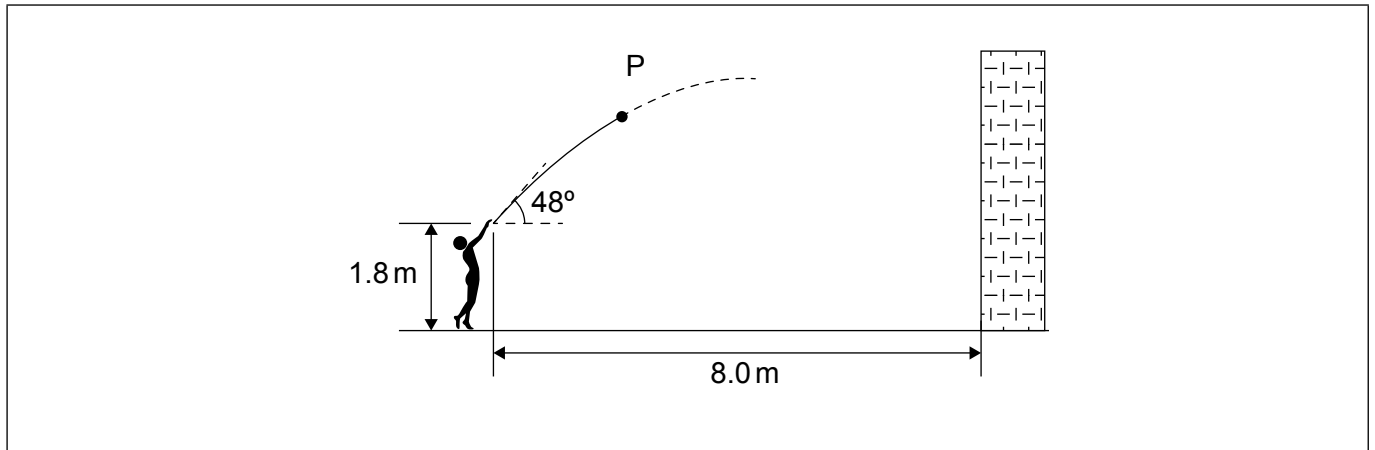
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2. A student throws a ball towards a wall. The ball is released from a point 1.8 m above the ground and 8.0 m from the wall. The initial velocity of the ball makes an angle of 48° with the horizontal. Air resistance is negligible.

The diagram shows the initial path of the ball. P is a point on the path.



- (a) Draw, on the diagram, an arrow to show
- (i) the velocity of the ball at P. Label this arrow v . [1]
 - (ii) the acceleration of the ball at P. Label this arrow a . [1]

The ball takes 1.3 s to reach the wall.

- (b) (i) Show that the initial speed of the ball is about 9 m s^{-1} . [2]

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- (ii) Determine the height above the ground at which the ball hits the wall. [3]

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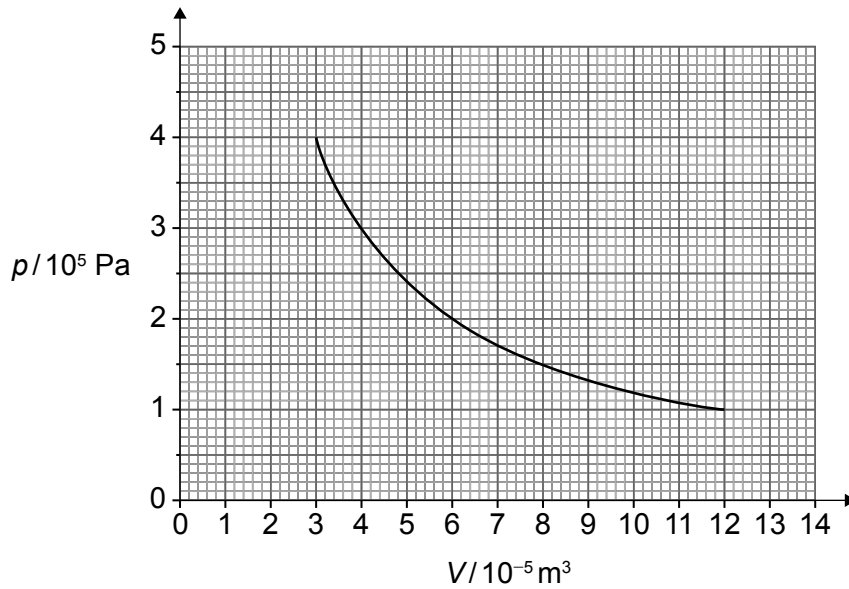
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3. A fixed quantity of 4.5×10^{-3} mol of air is compressed at a constant temperature. The graph shows the variation of pressure p with volume V of the air.



- (a) Suggest whether the air behaves as an ideal gas during this change. [2]

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- (b) Calculate the temperature of the air. [2]

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(Question 3 continued)

- (c) Outline how the kinetic theory of gases relates observable properties of a gas to the motion of the molecules.

[2]

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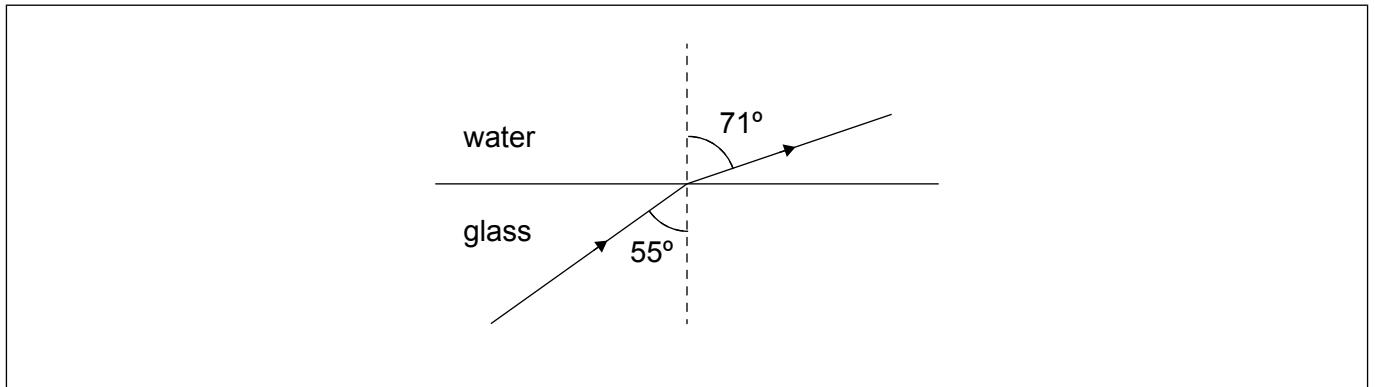
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4. A solid block of glass is covered with water. The diagram shows the path of a monochromatic light ray entering the water from the glass block.



The speed of light in the glass is $2.0 \times 10^8 \text{ ms}^{-1}$.

- (a) Calculate the speed of light in the water. State the answer to an appropriate number of significant figures. [3]

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- (b) Explain the change in the wavelength of the light at the glass–water boundary. [2]

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(Question 4 continued)

The light ray is partly reflected from the glass–water boundary.

- (c) (i) Draw, on the diagram, the path of the reflected ray. [1]
- (ii) Identify the direction of polarization of the reflected ray. [1]

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The water is removed and replaced with air. The refractive index of air is 1.0. The direction of the incident light ray in the glass is unchanged.

- (d) Determine whether light emerges from the glass block into the air. [3]

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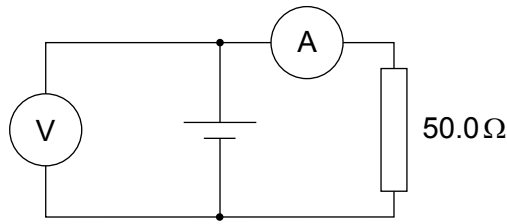
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5. A $50.0\ \Omega$ resistor is connected to a cell of emf $3.00\ \text{V}$. The voltmeter and the ammeter in the circuit are ideal.



- (a) The current in the ammeter is $59.0\ \text{mA}$.

Calculate the internal resistance of the cell.

[2]

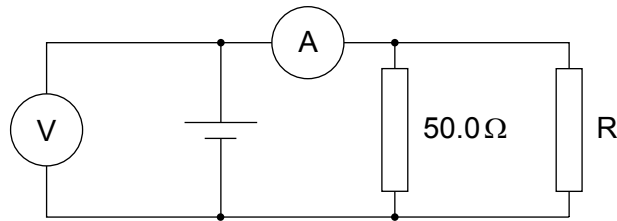
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The circuit is changed by connecting another resistor R in parallel to the $50.0\ \Omega$ resistor.



- (b) Explain the effect of this change on

(i) the reading of the ammeter.

[2]

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(This question continues on the following page)



(Question 5 continued)

(ii) the reading of the voltmeter.

[2]

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R is made of a resistive wire of uniform cross-sectional area $3.1 \times 10^{-8} \text{ m}^2$, resistivity $4.9 \times 10^{-7} \Omega \text{ m}$ and length L . The resistance of R is given by the equation

$$R = kL$$

where k is a constant.

(c) Calculate k . State an appropriate unit for your answer.

[3]

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6. (a) State what is meant by the half-life of a radioactive nuclide. [1]

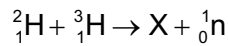
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Tritium, ${}^3_1\text{H}$, is a radioactive isotope of hydrogen. The activity of a sample of tritium decreases to $\frac{A_0}{8}$ after a time of 37.0 years where A_0 is the initial activity.

- (b) Calculate the half-life of tritium. [2]

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Deuterium, ${}^2_1\text{H}$, and tritium undergo nuclear fusion according to:



- (c) Identify nuclide X. [1]

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(Question 6 continued)

The following data are given for binding energies per nucleon.

Nuclide	Binding energy per nucleon/MeV
${}^2_1\text{H}$	1.112
${}^3_1\text{H}$	2.827
X	7.074

(d) (i) Show that the energy released in this reaction is about 18 MeV. [2]

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(ii) Hence, estimate the energy, in J, released as a result of fusion of 1 kg of nuclear fuel according to this reaction. [2]

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(iii) The specific energy of typical fossil fuels is about 10^7 J kg^{-1} .

Outline, with reference to your answer in (d)(ii), the advantage of nuclear fusion over fossil fuels as a source of energy. [1]

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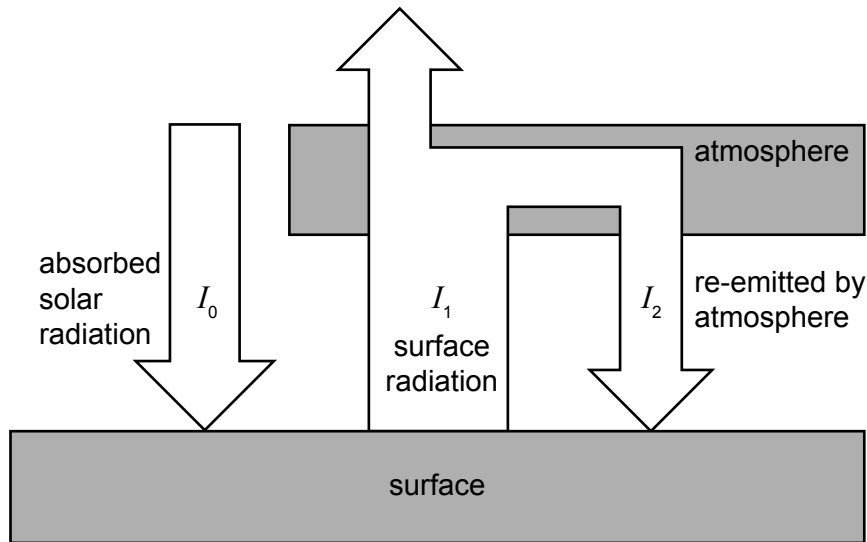
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7. In a simplified model of energy balance of the Earth:

- the surface of the Earth absorbs incoming solar radiation of average global intensity I_0
- the surface emits thermal radiation of average intensity I_1
- some of the radiation emitted by the surface is absorbed by the atmosphere and re-emitted towards the surface. The average intensity of this radiation is I_2 .



(a) Explain the effect of an increase in the concentration of greenhouse gases in the atmosphere on I_2 .

[2]

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The following data are given.

$$I_0 = 240 \text{ W m}^{-2}$$
$$I_2 = 150 \text{ W m}^{-2}$$

(b) Determine the average temperature of the surface of the Earth according to this model.

[2]

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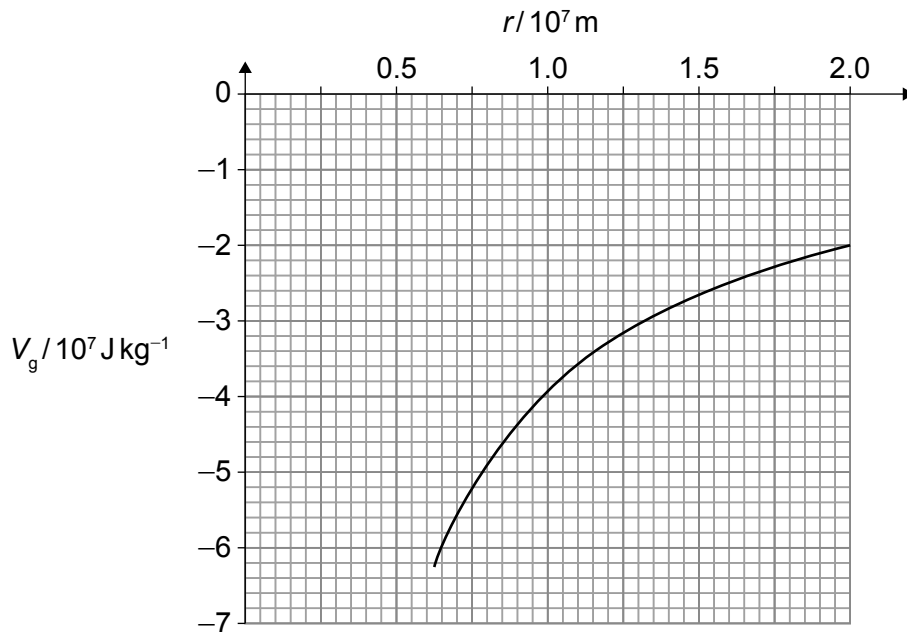
8. At a distance r from the centre of a planet, the gravitational potential due to the planet is V_g and the gravitational field strength is g .

(a) Show that $V_g = -gr$.

[1]

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For the Earth, the variation of V_g with r is shown.



A satellite of mass 750 kg orbits the Earth in a circular orbit of radius $1.0 \times 10^7 \text{ m}$.

(b) Calculate the magnitude of

(i) the gravitational field strength at the orbital radius of the satellite.

[2]

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(This question continues on the following page)



(Question 8 continued)

- (ii) the gravitational force acting on the satellite. [1]

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The satellite is moved to a new circular orbit. The orbital radius of the satellite increases by 2.0 km.

- (c) (i) Outline why the magnitude of the gravitational field strength at the new orbit is approximately the same as at the old orbit. [2]

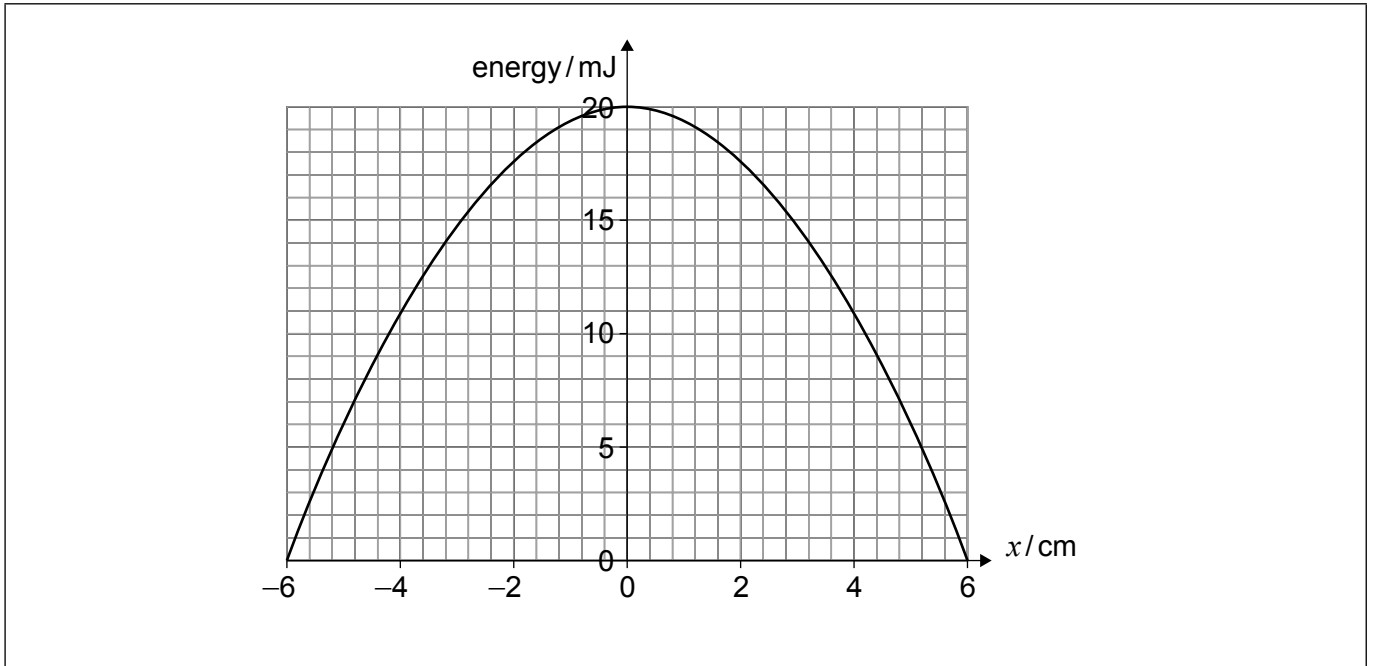
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- (ii) Determine the change in the total orbital energy of the satellite. [3]

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9. An object attached to a spring oscillates with simple harmonic motion in a horizontal plane. The graph shows how the kinetic energy of the object varies with the displacement x .



- (a) State the amplitude of the motion. [1]

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- (b) Draw, on the axes above, the variation with x of the potential energy stored in the spring. [1]

- (c) Explain how many times during **one** oscillation the kinetic energy of the object and the potential energy stored in the spring are equal. [2]

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(Question 9 continued)

(d) The mass of the object is 0.15 kg.

(i) Show that the period of the oscillations is about 0.7 s. [3]

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(ii) Calculate the maximum force exerted on the object by the spring. [2]

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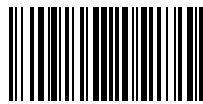
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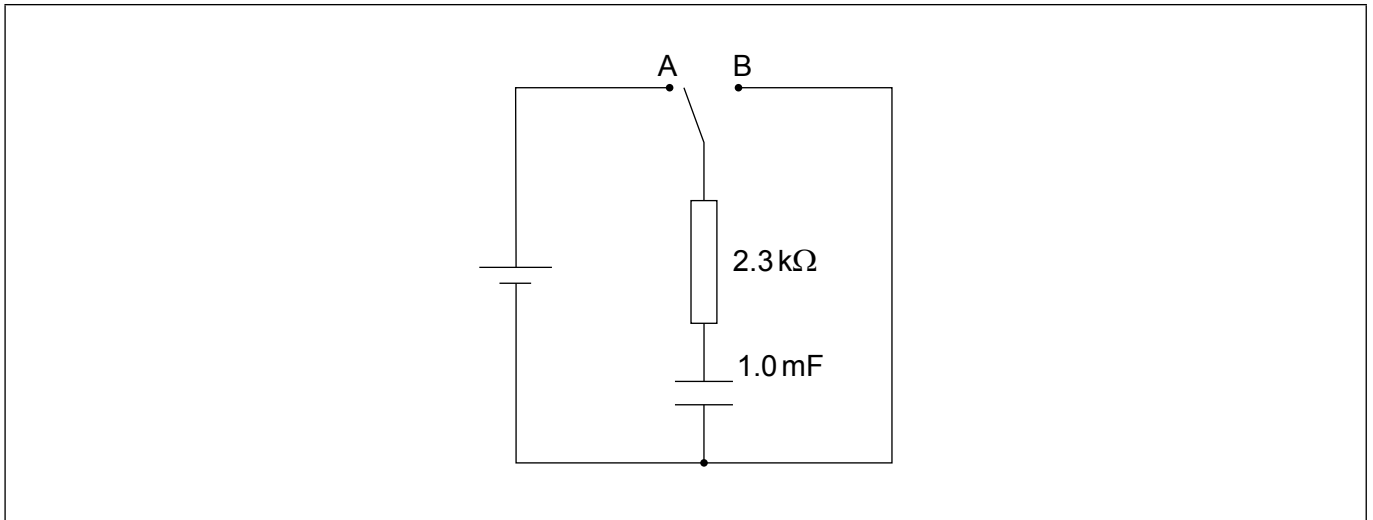


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10. A 1.0 mF capacitor is connected in series to a 2.3 kΩ resistor and a cell of negligible internal resistance.



The capacitor is initially uncharged. At time $t = 0$ the switch is moved to position A. The initial current in the resistor is 3.9 mA.

- (a) (i) Calculate the emf of the cell. [1]

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- (ii) Explain why the current in the resistor decreases with time. [2]

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At time $t = 5.0$ s the switch is moved to position B.

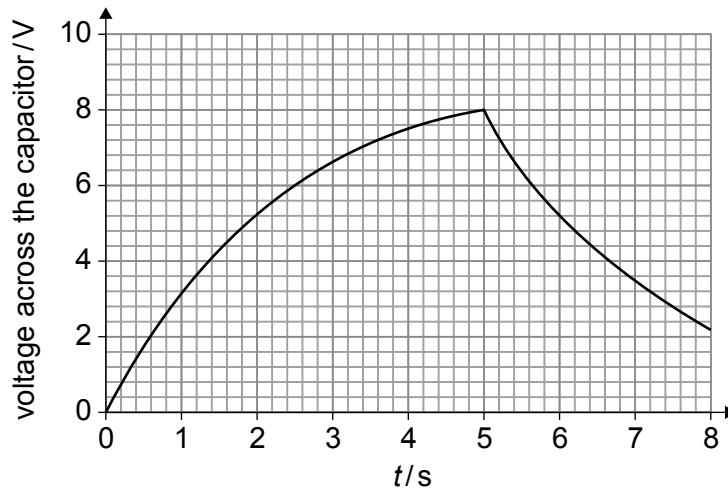
- (b) Draw, on the circuit diagram above, an arrow showing the direction of the conventional current in the resistor for $t > 5.0$ s. [1]

(This question continues on the following page)



(Question 10 continued)

The graph shows how the voltage across the capacitor varies with t .



(c) Estimate the energy dissipated in the resistor between $t = 5.0\text{ s}$ and $t = 8.0\text{ s}$. [3]

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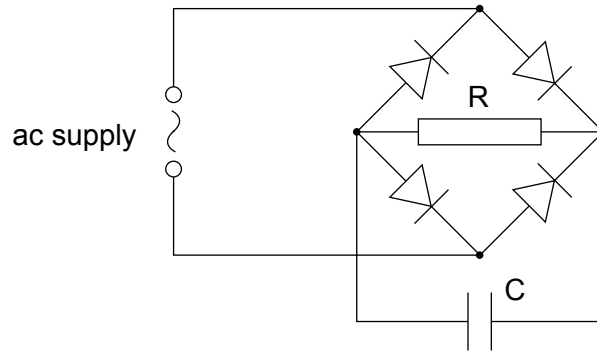
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(Question 10 continued)

- (d) A rectification circuit contains a diode bridge, an alternating current (ac) supply and a load resistor R. A capacitor C is added in parallel with the resistor.



State and explain the effect of the capacitor on the current in R.

[3]

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11. In an experiment to investigate the photoelectric effect, a beam of monochromatic light is incident on a metal surface. When the frequency of light is less than a certain threshold frequency f_0 , no electrons are emitted from the surface.

(a) Outline how this observation supports the photon model of light.

[2]

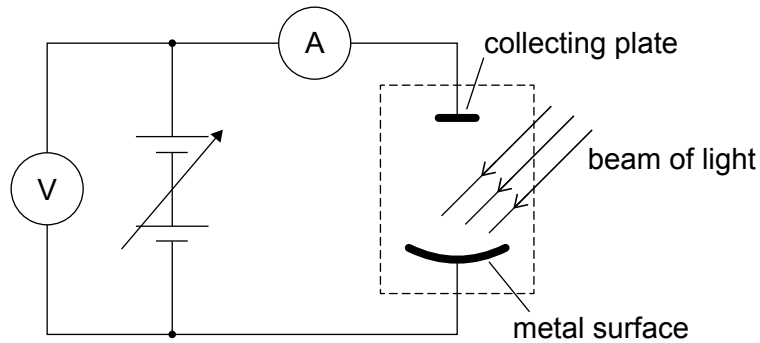
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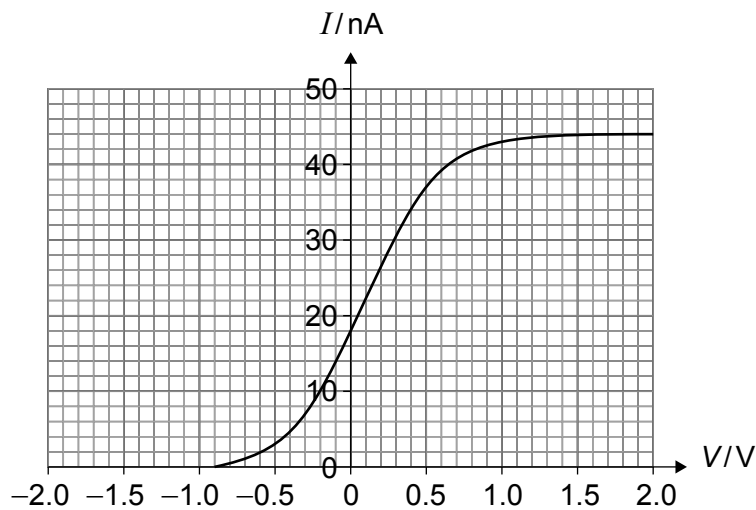
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The collecting plate of the photoelectric cell is at a variable potential V relative to the metal surface.



The graph shows the variation of the current I in the ammeter with V , for light of wavelength 430 nm.



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(Question 11 continued)

(b) Explain why I

(i) is zero for large negative V .

[2]

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(ii) approaches a constant value for large positive V .

[2]

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(c) Calculate, in eV,

(i) the energy of a photon of wavelength 430 nm.

[1]

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(ii) the work function of the metal surface.

[2]

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