Diploma Programme
Programme du diplôme
Programa del Diploma

Physics
Higher level
Paper 2

26 April 2024

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

Candidate session number

2 hours 15 minutes

Instructions to candidates

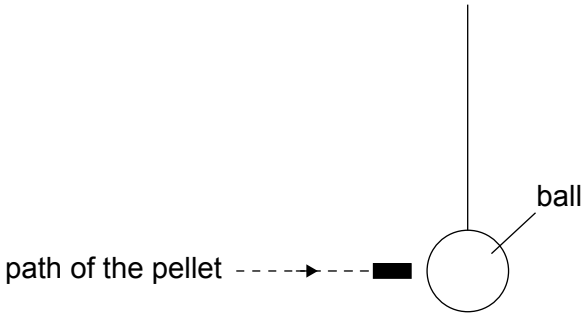
- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **physics data booklet** is required for this paper.
- The maximum mark for this examination paper is **[90 marks]**.

2224 – 6702

25 pages

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 $160\,m\,s^{-1}$.



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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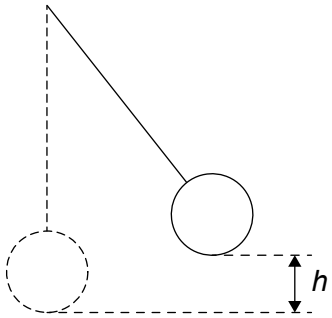
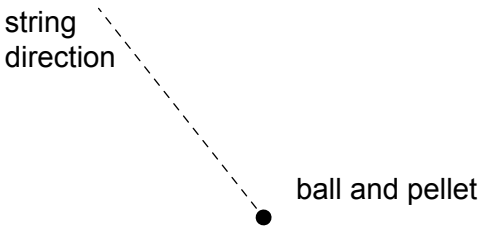
(Question 1 continued)

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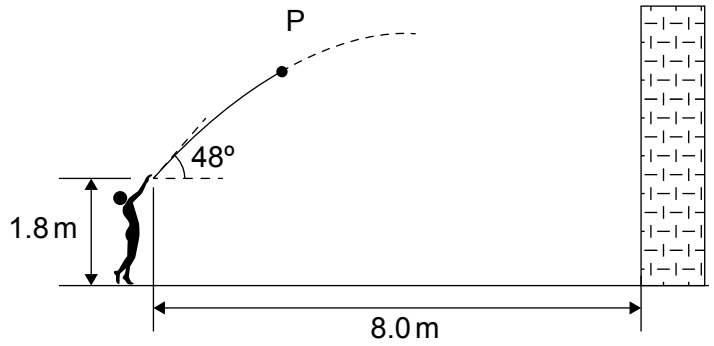
2. A student throws a ball towards a wall. The ball is released from a point 1.8 m above the ground and 8.0 m from the wall. The initial velocity of the ball makes an angle of 48° with the horizontal. Air resistance is negligible.

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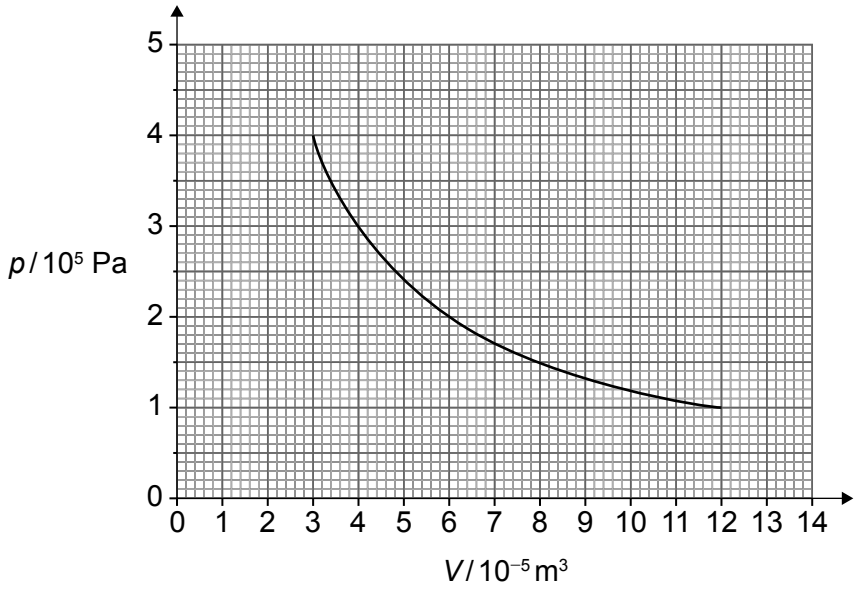
3. A fixed quantity of 4.5×10^{-3} mol of air is compressed at a constant temperature. The graph shows the variation of pressure p with volume V of the air.



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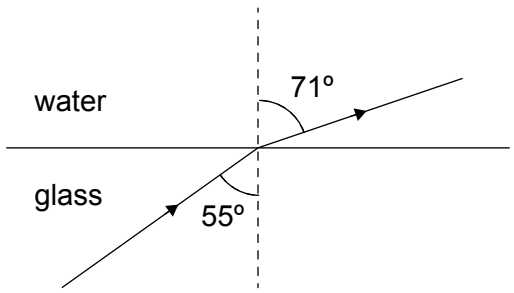
4. A solid block of glass is covered with water. The diagram shows the path of a monochromatic light ray entering the water from the glass block.



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

(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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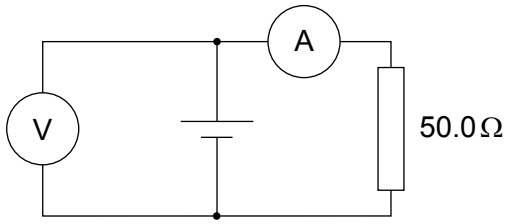
5. A 50.0 Ω resistor is connected to a cell of emf 3.00 V. The voltmeter and the ammeter in the circuit are ideal.



(a) The current in the ammeter is 59.0 mA.

Calculate the internal resistance of the cell. [2]

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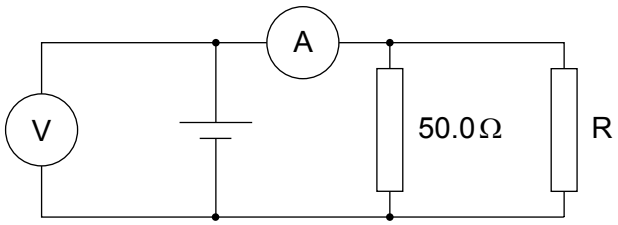
The circuit is changed by connecting another resistor R in parallel to the 50.0 Ω resistor.



(b) Explain the effect of this change on

(i) the reading of the ammeter. [2]

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(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 $3.1 \times 10^{-8}\,m^2$, resistivity $4.9 \times 10^{-7}\,\Omega m$ 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, ${}^{3}_{1}\mathrm{H}$, 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, ${}^{2}_{1}\mathrm{H}$, and tritium undergo nuclear fusion according to:

$$ {}^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \rightarrow \mathrm{X} + {}^{1}_{0}\mathrm{n} $$

(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
$^{2}_{1}H$	1.112
$^{3}_{1}H$	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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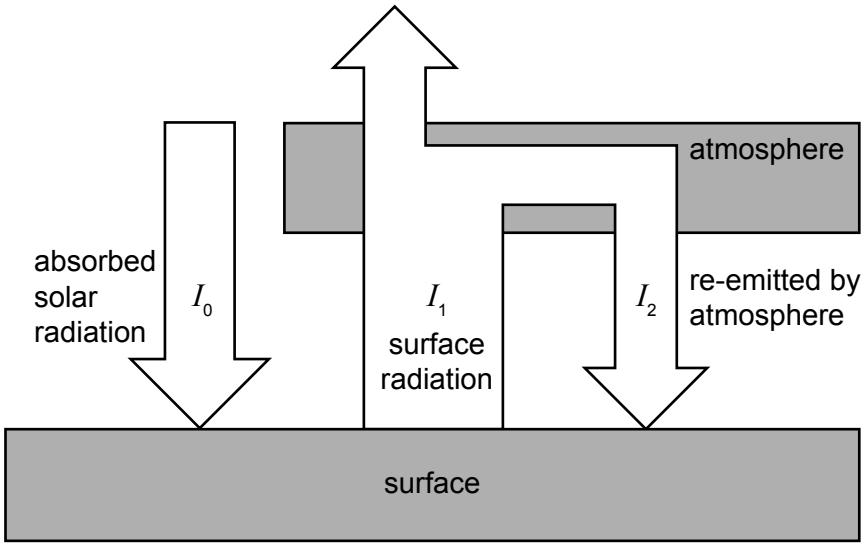
7. In a simplified model of energy balance of the Earth:

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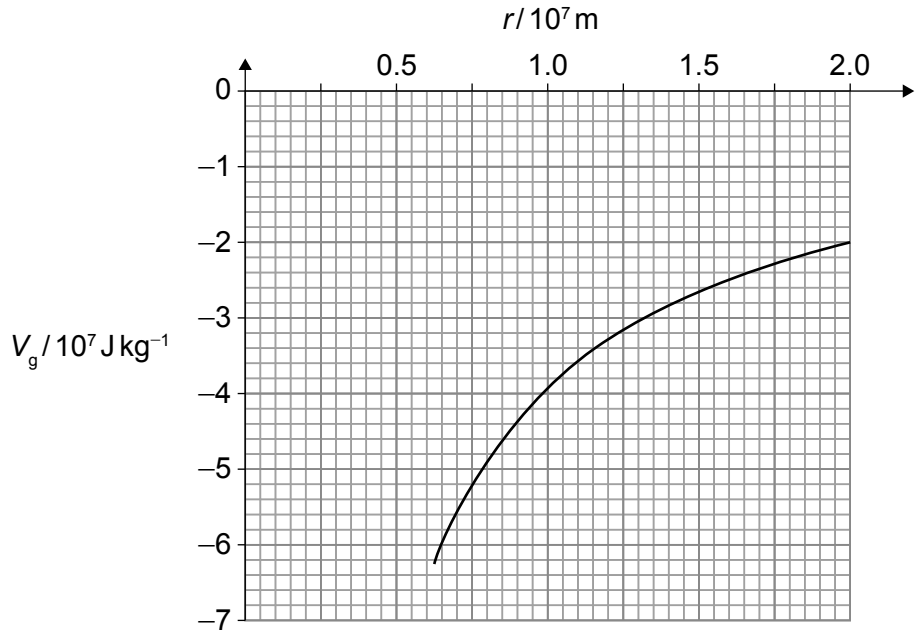
For the Earth, the variation of V_g with r is shown.



A satellite of mass 750 kg orbits the Earth in a circular orbit of radius 1.0×10^7 m.

(b) Calculate the magnitude of

(i) the gravitational field strength at the orbital radius of the satellite. [2]

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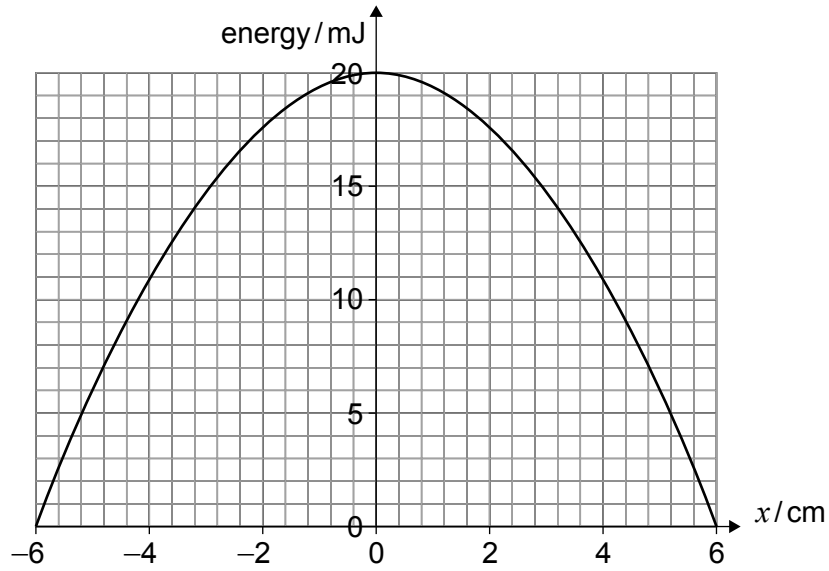
9. An object attached to a spring oscillates with simple harmonic motion in a horizontal plane. The graph shows how the kinetic energy of the object varies with the displacement x.



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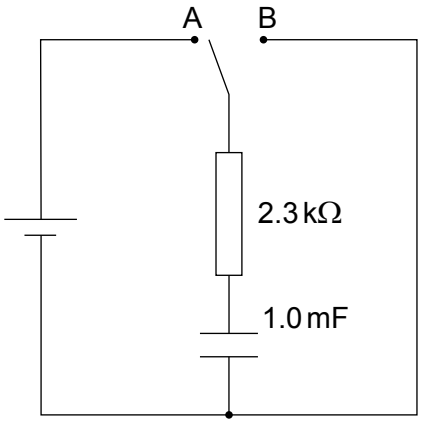
10. A 1.0 mF capacitor is connected in series to a 2.3 kΩ resistor and a cell of negligible internal resistance.



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]

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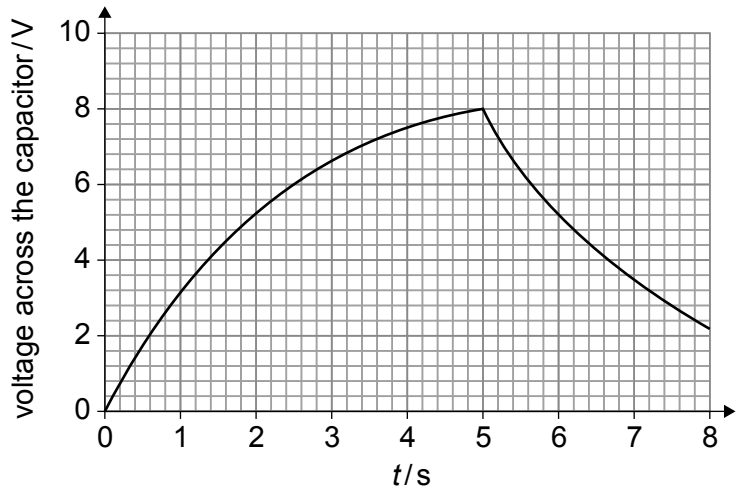
(Question 10 continued)

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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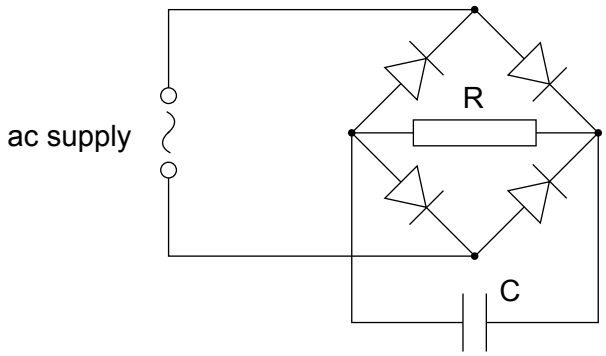
(Question 10 continued)

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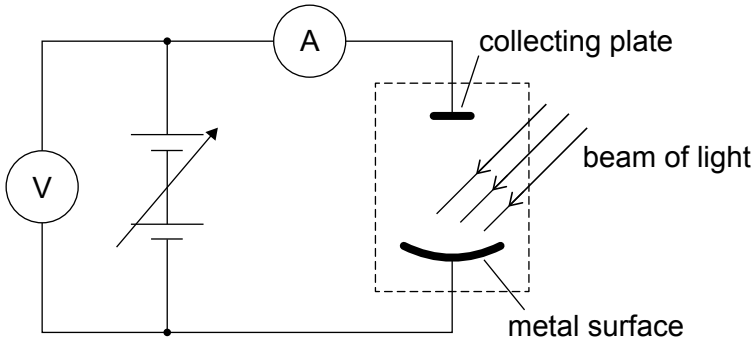
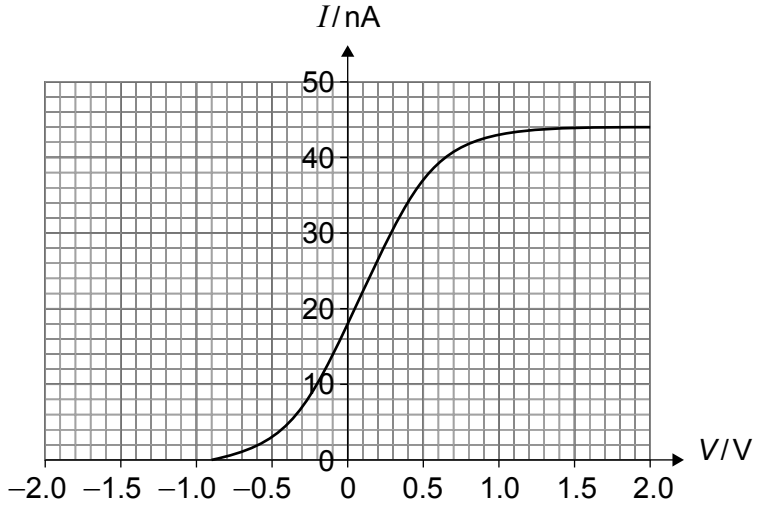
The collecting plate of the photoelectric cell is at a variable potential *V* relative to the metal surface.



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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