Physics
Higher level
Paper 2

30 April 2025

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

Candidate session number

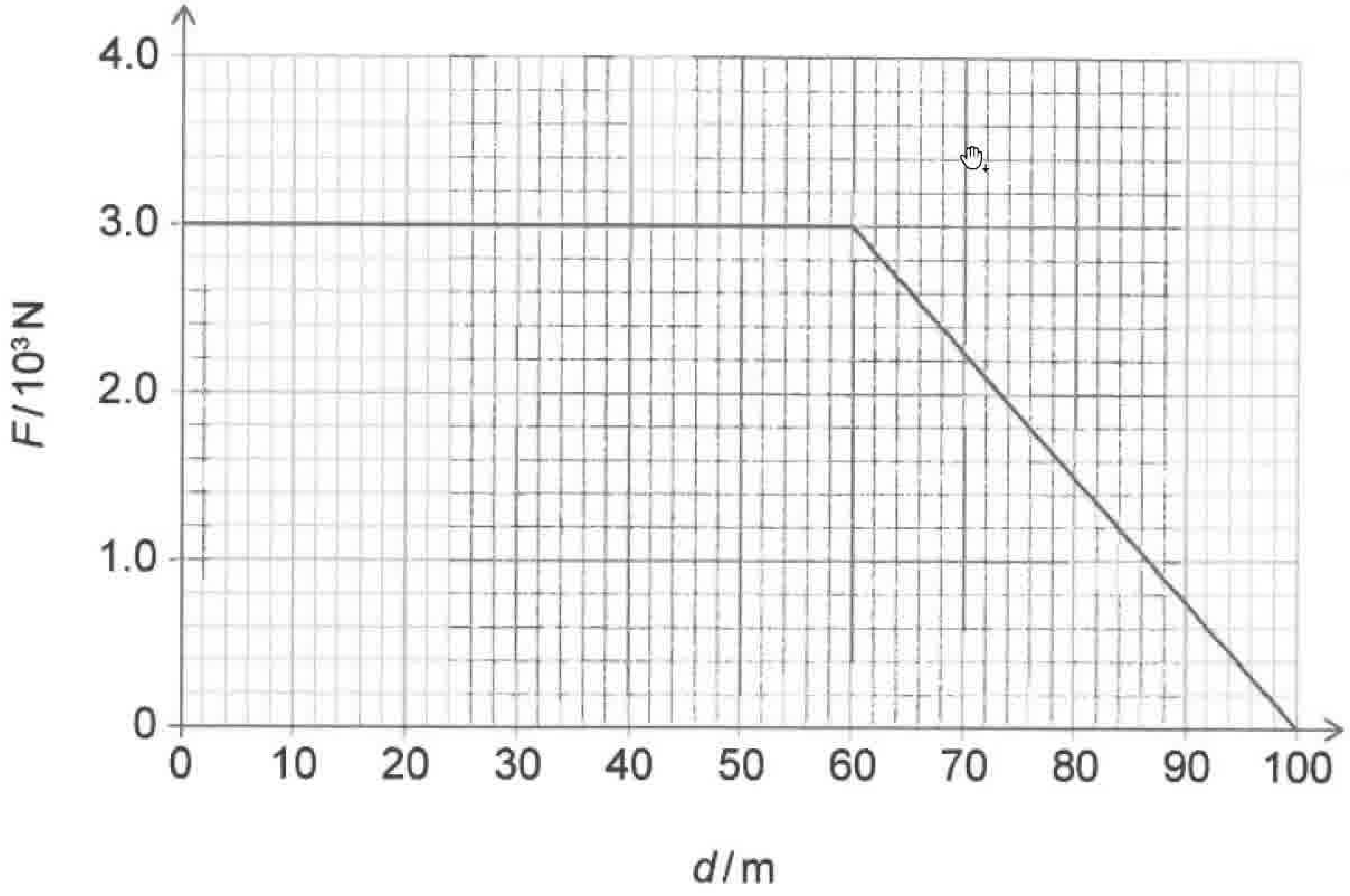
2 hours 30 minutes

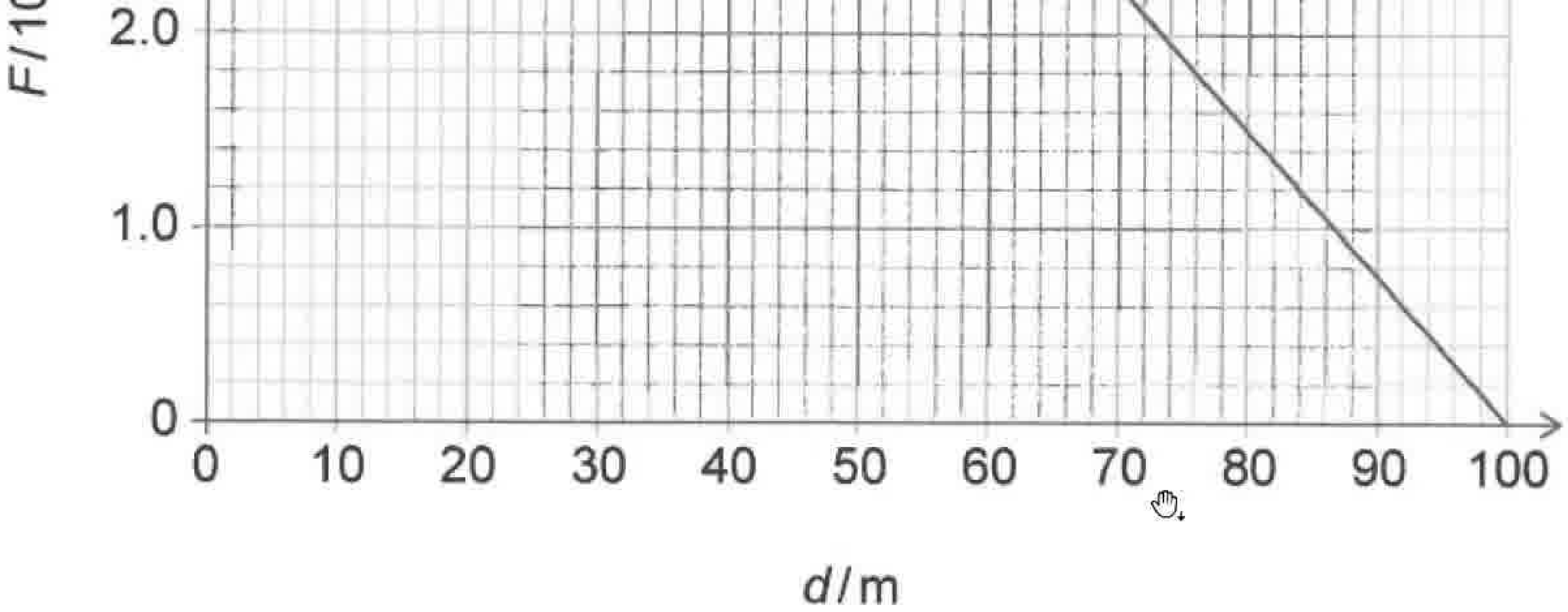
Instructions to candidates

- 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]**.

1. (a) A car of mass 1600 kg accelerates from rest.

The graph shows how the resultant force F acting in the direction of motion of the car varies with the distance d travelled by the car.





(i) State what is represented by the area under the graph. [1]

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(ii) Calculate the final speed of the car. [2]

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A different car travels on a horizontal road at a constant speed of $45\,m\,s^{-1}$. The engine of the car develops a power of 140 kW. The resistive force F_d acting on the car is given by

$$F_d = cv^2$$

where v is the speed of the car and c is a constant.

(b) Determine c. State the fundamental SI unit for your answer. [3]

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2. Venus is a planet in the Solar System. The following data are given:

Orbital period of Venus = 225 days
Orbital period of Earth = 365 days

(a) Calculate the ratio $\dfrac{\text{orbital radius of Venus}}{\text{orbital radius of Earth}}$. [2]

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(b) Explain how observations of the motion of the planets allow scientists to determine the mass of the Sun. [2]

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(c) The difference between the maximum and minimum Earth–Sun distances is 5.0×10^{9} m. The difference in gravitational potential due to the Sun between these positions is $3.0 \times 10^{7}\ \mathrm{J\,kg^{-1}}$.

Estimate the average gravitational field strength due to the Sun at the position of Earth. [2]

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3. (a) Rutherford modelled the scattering of alpha particles by a nucleus of gold. However, when the initial alpha particle energy is greater than a certain value E_0, the fraction of alpha particles scattered at angles close to 180° does not follow Rutherford's model.

Outline

(i) why this deviation from the model occurs, and [1]

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(ii) how E_0 can be used to estimate the nuclear radius of gold. [2]

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Gold-198 (Au-198) is a radioactive nuclide of gold. Au-198 decays into stable mercury-198 (Hg-198) with an emission of a beta particle followed by one or two gamma photons.

The half-life of Au-198 is 2.69 days.

(b) (i) Calculate, in s^{-1}, the decay constant of Au-198. [1]

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(ii) A sample contains 5.0 mg of pure Au-198. Determine the mass of Hg-198 present in the sample after one week. [2]

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(Question 3 continued)

Gamma photons of the following frequencies are emitted in the decay of Au-198:

Frequency / 10^{20} Hz
1.00
1.63
2.63

(c) Explain how this observation provides evidence that nuclear energy levels are discrete. [2]

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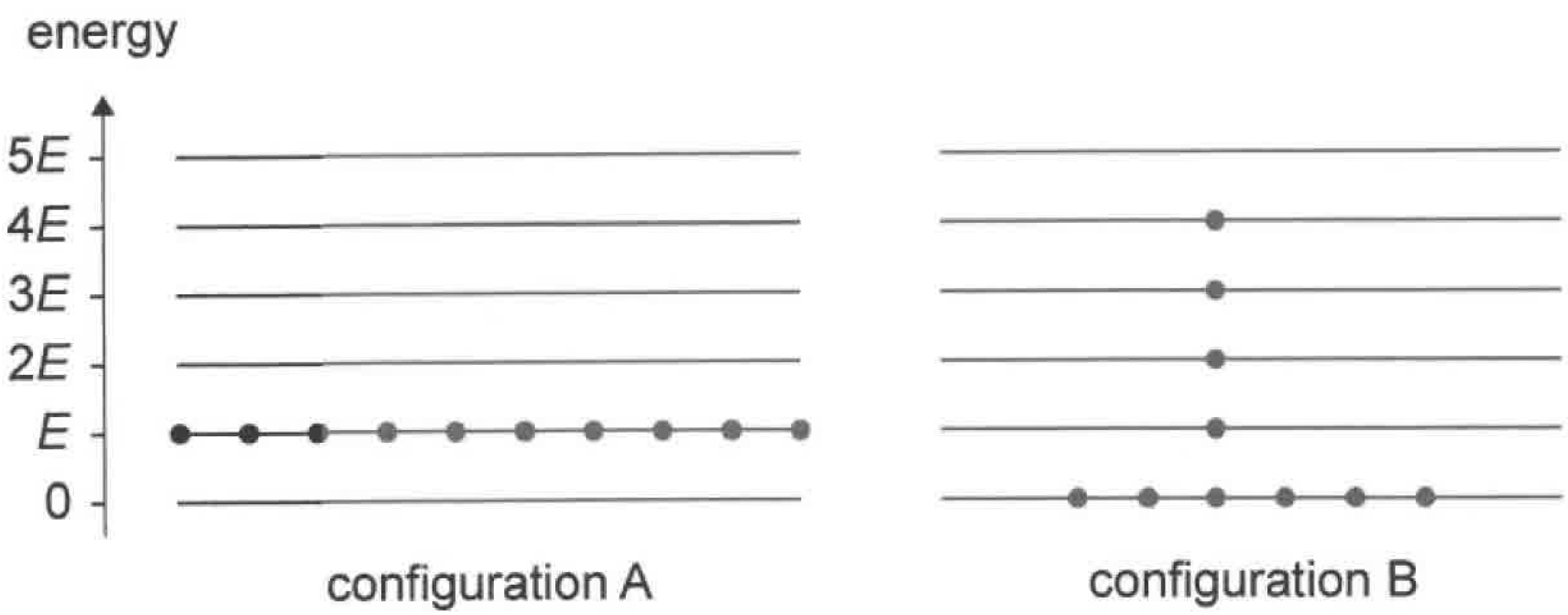
4. A system consists of ten distinguishable particles which can exchange energy in integer multiples of a constant value E. The total energy of the system is $10E$.

The diagram shows two possible energy configurations of the system. In configuration A, all particles have the same energy E. In configuration B, the particles have a range of energies from 0 to $4E$.



When the energy of any particle in the system changes, a new microstate of the system is formed.

(a) Outline which of the two configurations has a greater number of microstates. [2]

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The system of ten particles is isolated. Two processes are considered for the overall evolution of the system.

Process 1: the system is initially in configuration A and evolves to configuration B

Process 2: the system is initially in configuration B and evolves to configuration A

(b) Explain why process 1 is more likely to occur. [3]

5. A sound detector moves along a line connecting it to a stationary loudspeaker. The loudspeaker emits a sound of frequency 1700 Hz. The speed of sound in air is 340 $m\,s^{-1}$. The detected frequency of the sound is 1600 Hz.

(a) (i) State the direction of motion of the detector. [1

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(ii) Calculate the speed of the detector. [2

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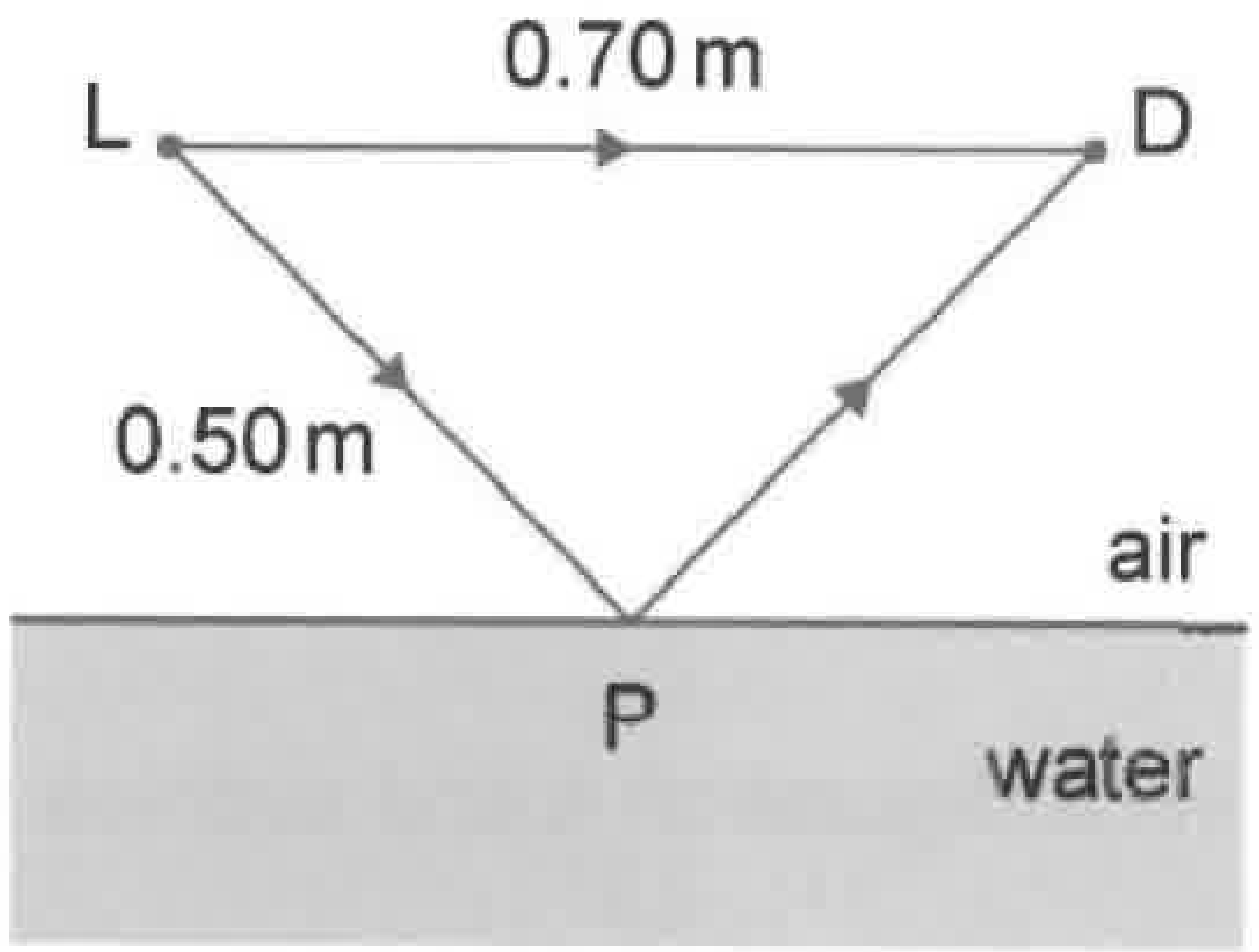
The loudspeaker and the detector are now stationary and above a surface of water. The loudspeaker is at point L and the detector is at point D. L and D are at the same height above the surface of the water. The sound reaches D by two routes: along the direct path LD and the reflection-path LPD.

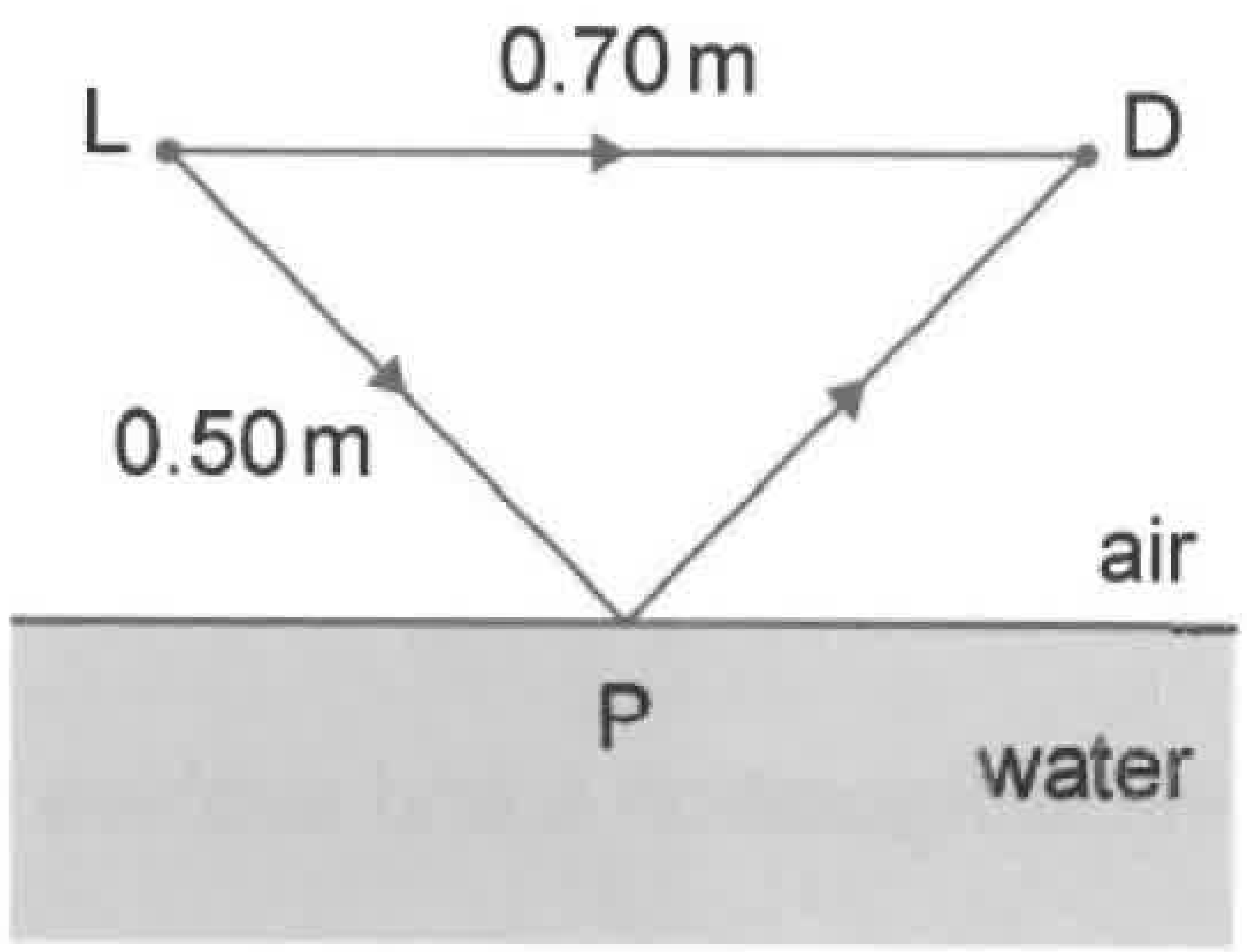


The following data are given:

Frequency of the sound wave $= 1700\,\text{Hz}$

Speed of sound in air $= 340\,\text{m}\,\text{s}^{-1}$

Speed of sound in water $= 1500\,\text{m}\,\text{s}^{-1}$



The following data are given:

Frequency of the sound wave $= 1700\,\text{Hz}$

Speed of sound in air $= 340\,\text{m s}^{-1}$

Speed of sound in water $= 1500\,\text{m s}^{-1}$

Distance LD $= 0.70\,\text{m}$

Distance LP $= 0.50\,\text{m}$

(b) (i) Calculate the wavelength of the sound wave in air. [1]

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(ii) Outline why sound from L undergoes destructive interference at D. [2]

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(c) Predict whether the sound wave can enter the water at P. [3]

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6. An electron is accelerated from rest by an electric potential difference V. The electron reaches a speed of $9.4 \times 10^{6}\,m\,s^{-1}$.

(a) Calculate V. [2]

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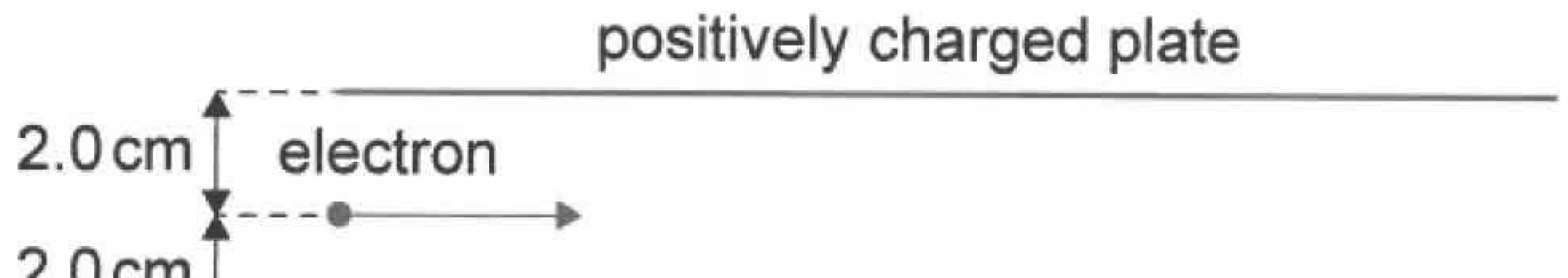
The electron now enters a region of a uniform electric field between two parallel charged plates. The electron is initially halfway between the plates and its initial velocity is parallel to the plates.



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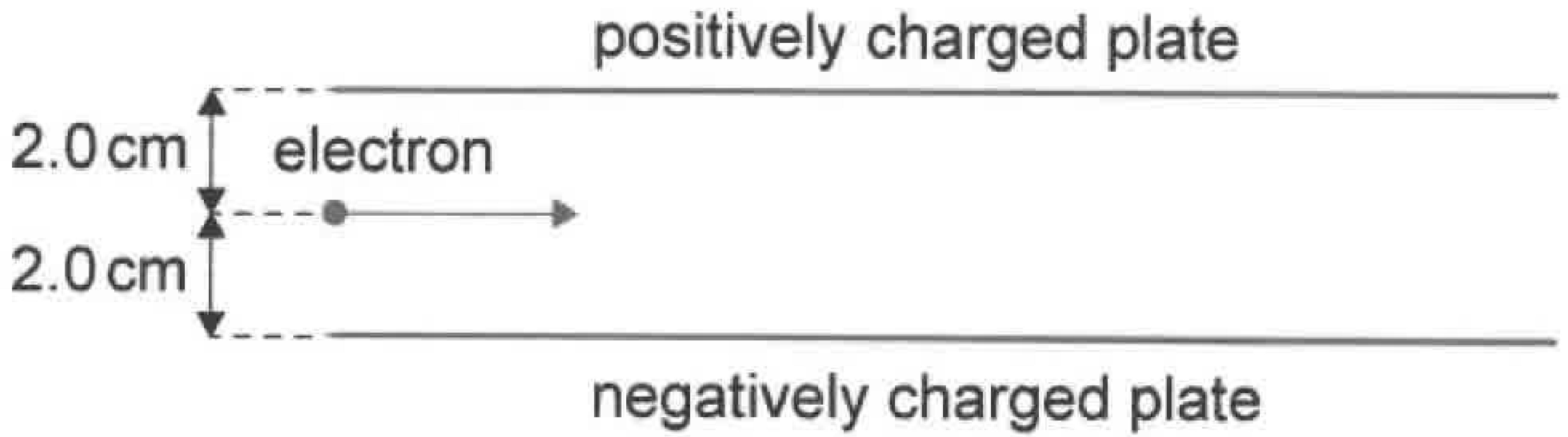

The following data are given:

Initial speed of the electron $= 9.4 \times 10^6\,\mathrm{m\,s^{-1}}$

Potential difference between the plates $= 30\,\mathrm{V}$

Distance between the plates $= 4.0\,\mathrm{cm}$

(b) (i) State the direction of the acceleration of the electron. [1]

Initial speed of the electron $= 9.4 \times 10^{6}\,m\,s^{-1}$

Potential difference between the plates $= 30\,V$

Distance between the plates $= 4.0\,cm$

(b) (i) State the direction of the acceleration of the electron. [1]

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(ii) Show that the magnitude of the acceleration of the electron is about $10^{14}\,m\,s^{-2}$. [2]

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(Question 6 continued)

(c) The electron collides with one of the plates. Determine the distance the electron travels parallel to the plates. [3]

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In another experiment, a uniform magnetic field directed into the plane of the diagram is established between the charged plates. The initial velocity of the electron, the distance between the plates and their electric potential difference remain unchanged.

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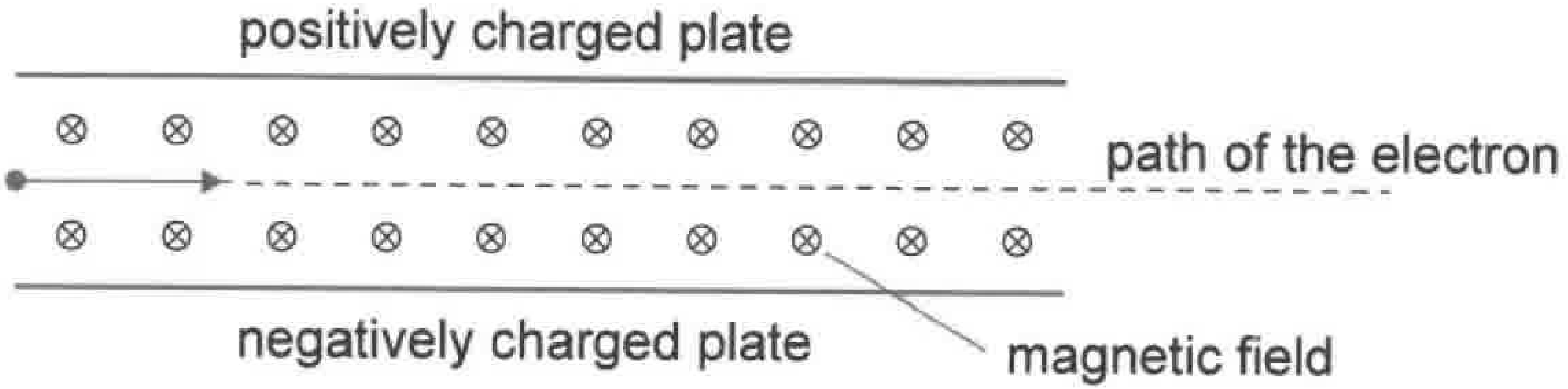

The electron passes undeflected through the region of the electric and magnetic fields.

(d) Calculate the magnetic field strength. [2]

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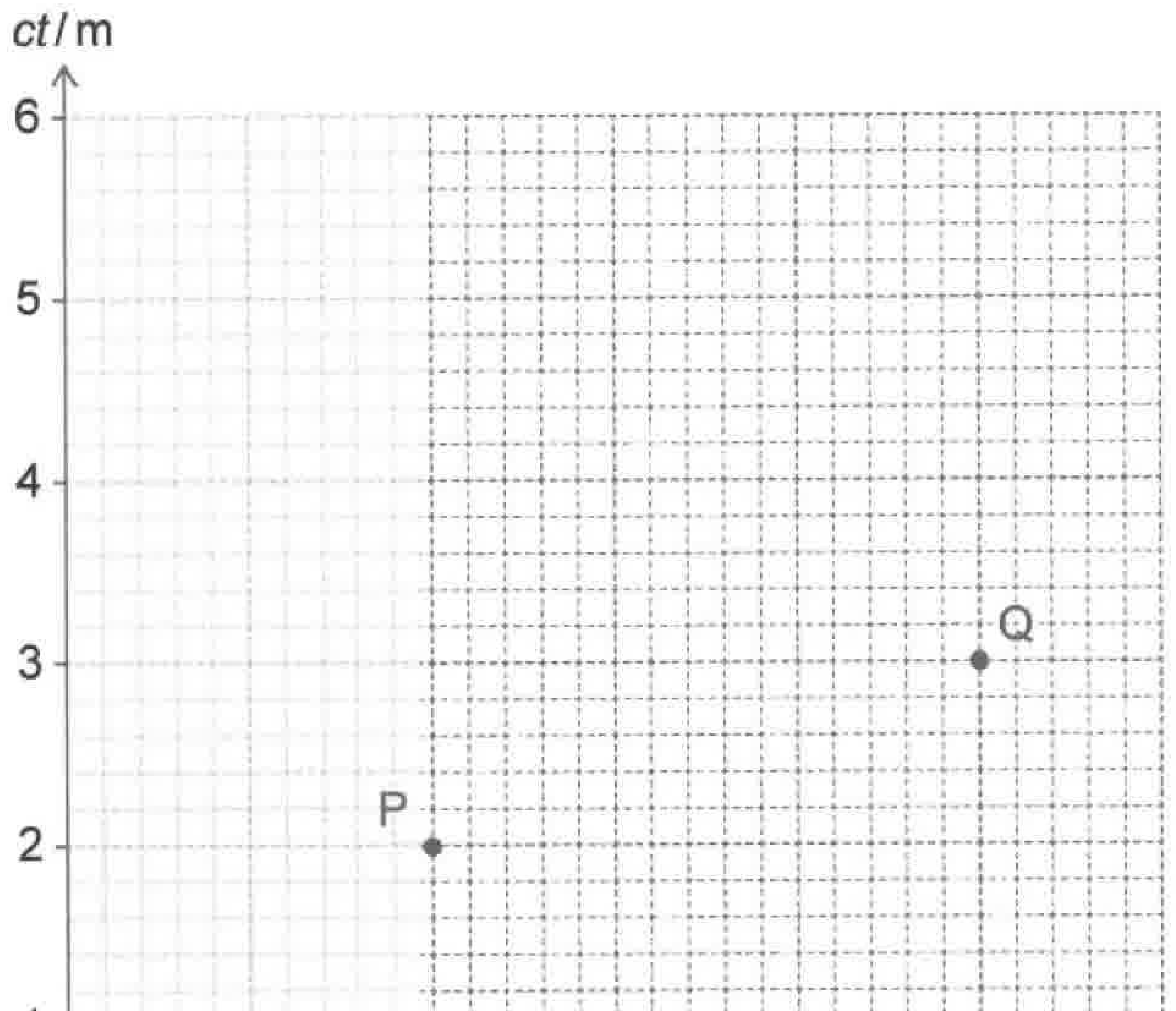
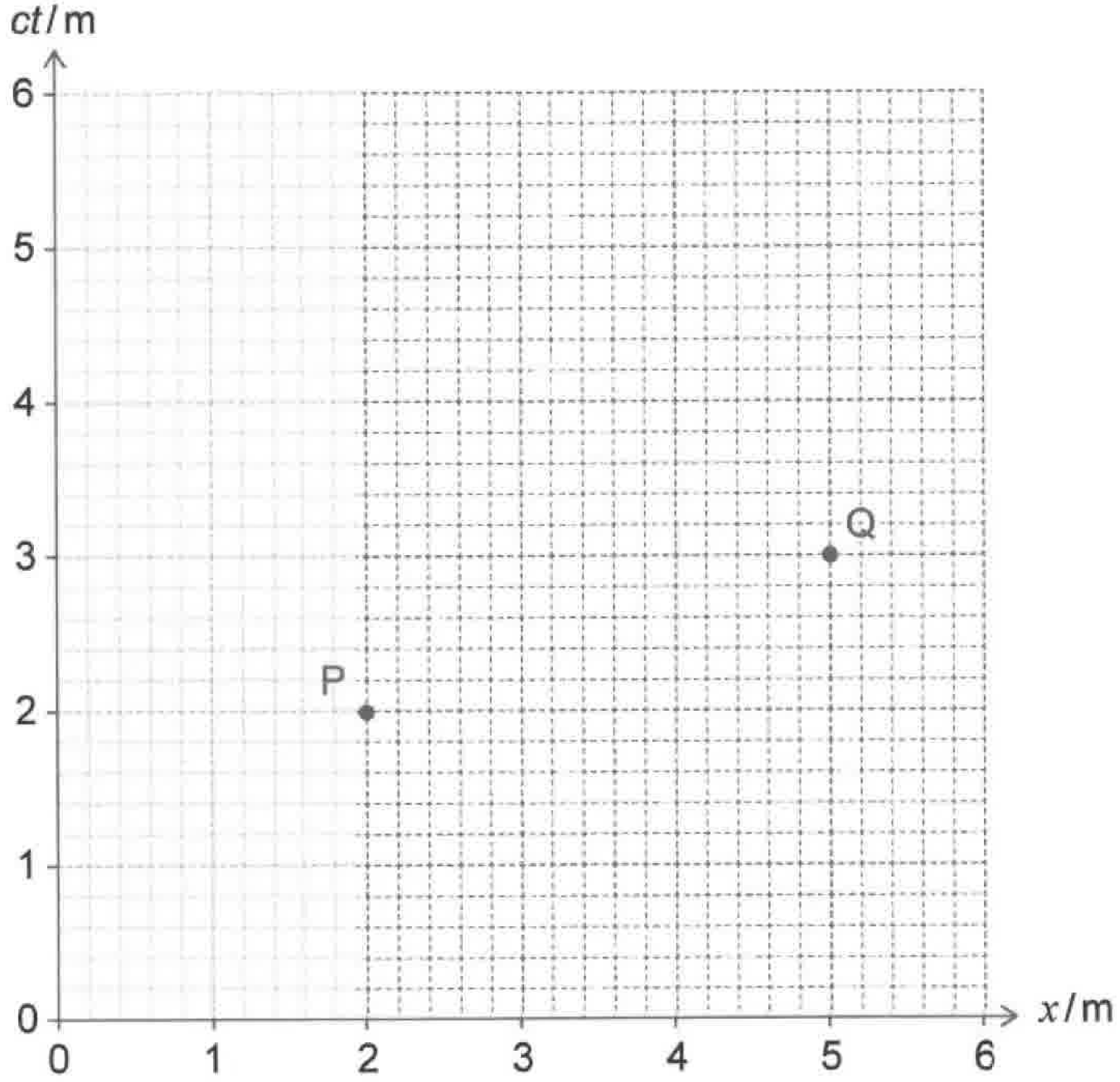
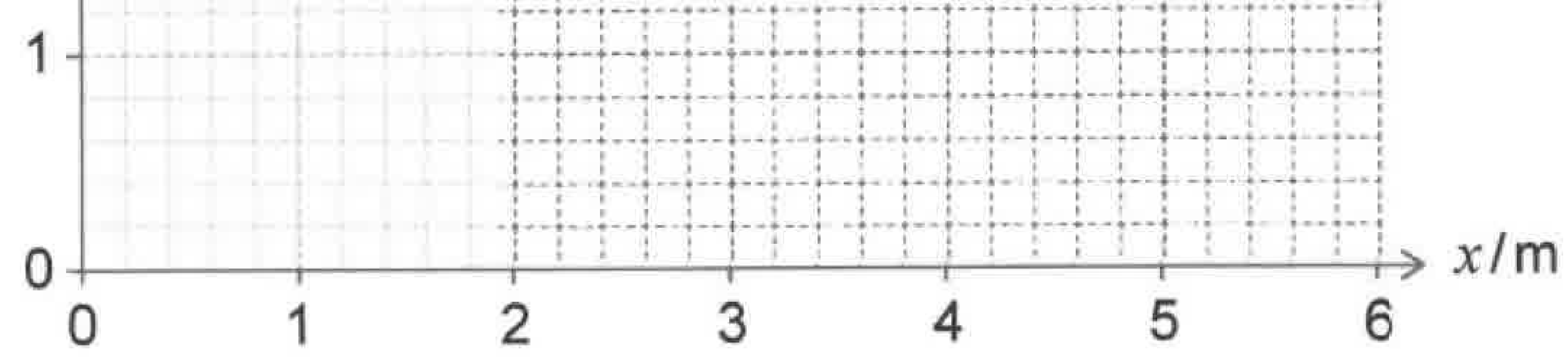
7. The space–time diagram shows the coordinate axes (x, ct) of an inertial reference frame S. Two events, P and Q, are plotted.




ct / m
x / m
P
Q
0
1
2
3
4
5
6



(a) (i) Calculate the space–time interval $(\Delta s)^2$ between P and Q. [2]

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(ii) $(\Delta s)^2$ is an invariant quantity. Outline what is meant by an invariant quantity. [1]

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(Question 7 continued)

Events P and Q occur simultaneously in an inertial reference frame S'. The clocks of S and S' are synchronized at $x = x' = 0$.

(b) (i) Sketch, on the diagram, the coordinate axes (x', ct') of S'. [2]

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(ii) Determine the speed of S' relative to S. [1]

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8. (a) State what is meant by the solar constant. [1]

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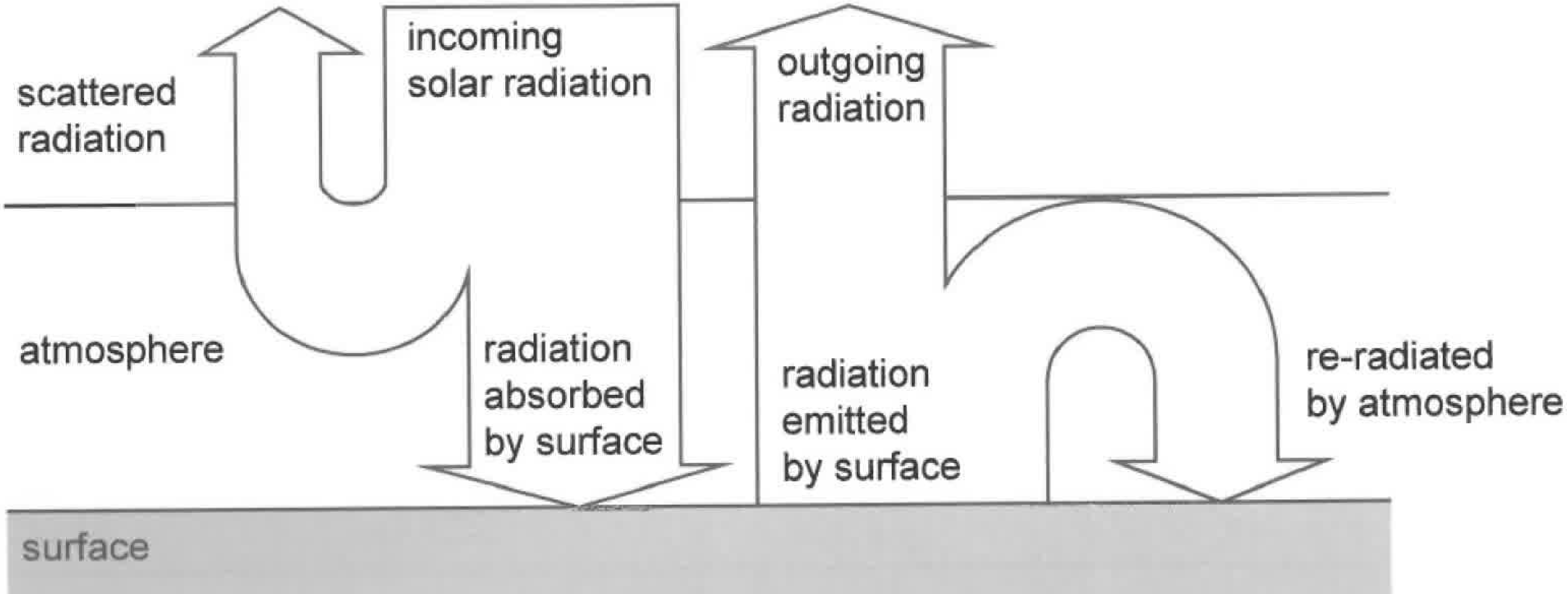
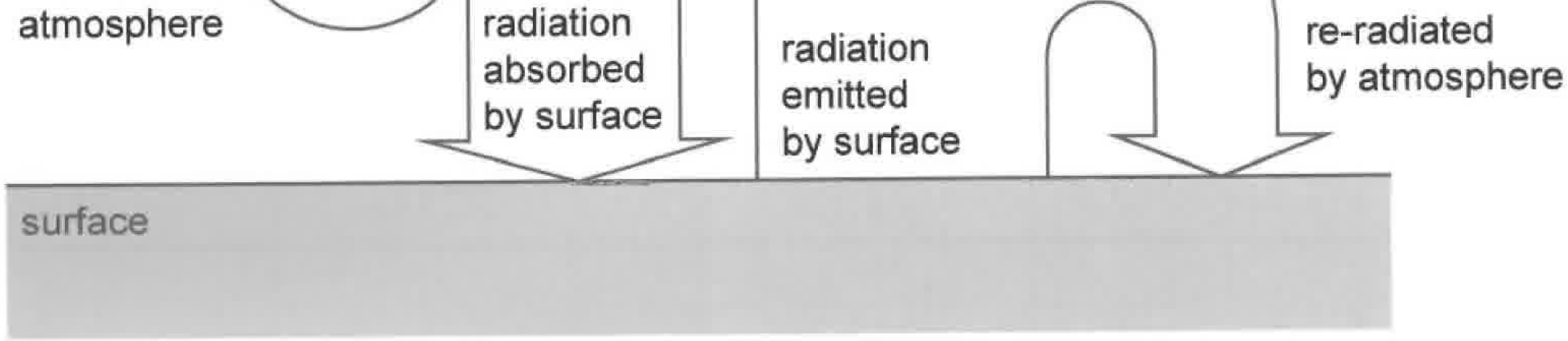
The diagram shows a simplified energy-balance model for the Earth surface–atmosphere system.





The following data are given:

Average albedo of Earth $= 0.30$

Average global temperature of the surface $= 288\,K$

Average Earth–Sun distance $= 1.5 \times 10^{11}\,m$

(b) (i) Outline the physical mechanism by which some of the radiation emitted by the surface is absorbed by greenhouse gases in the atmosphere and re-radiated towards the surface. [2]

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(Question 8 continued)

(ii) Show that the average global intensity of radiation absorbed by the surface is about 240 $W m^{-2}$. [2]

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(iii) Determine the average intensity re-radiated by the atmosphere towards the surface. Assume that the emissivity of the surface is 0.90. [3]

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(c) Show, with reference to the solar constant, that the total power radiated by the Sun is about 4×10^{26} W. [2]

(d) The primary energy source of the Sun is the proton–proton (p–p) chain of fusion reactions. Four protons and two electrons produce a helium nucleus together with neutrinos and gamma photons. The overall reaction is:

$$4\,{}^{1}_{1}\mathrm{p} + 2\,{}^{0}_{-1}\mathrm{e} \rightarrow {}^{4}_{2}\mathrm{He} + 2\,{}^{0}_{0}\nu_{e} + 4\gamma$$

(i) The mass of the helium nucleus is 4.001506 u. Calculate, in MeV, the energy released in the reaction. [2]

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(ii) Outline the role of fusion reactions in maintaining a stable radius of the Sun. [2]

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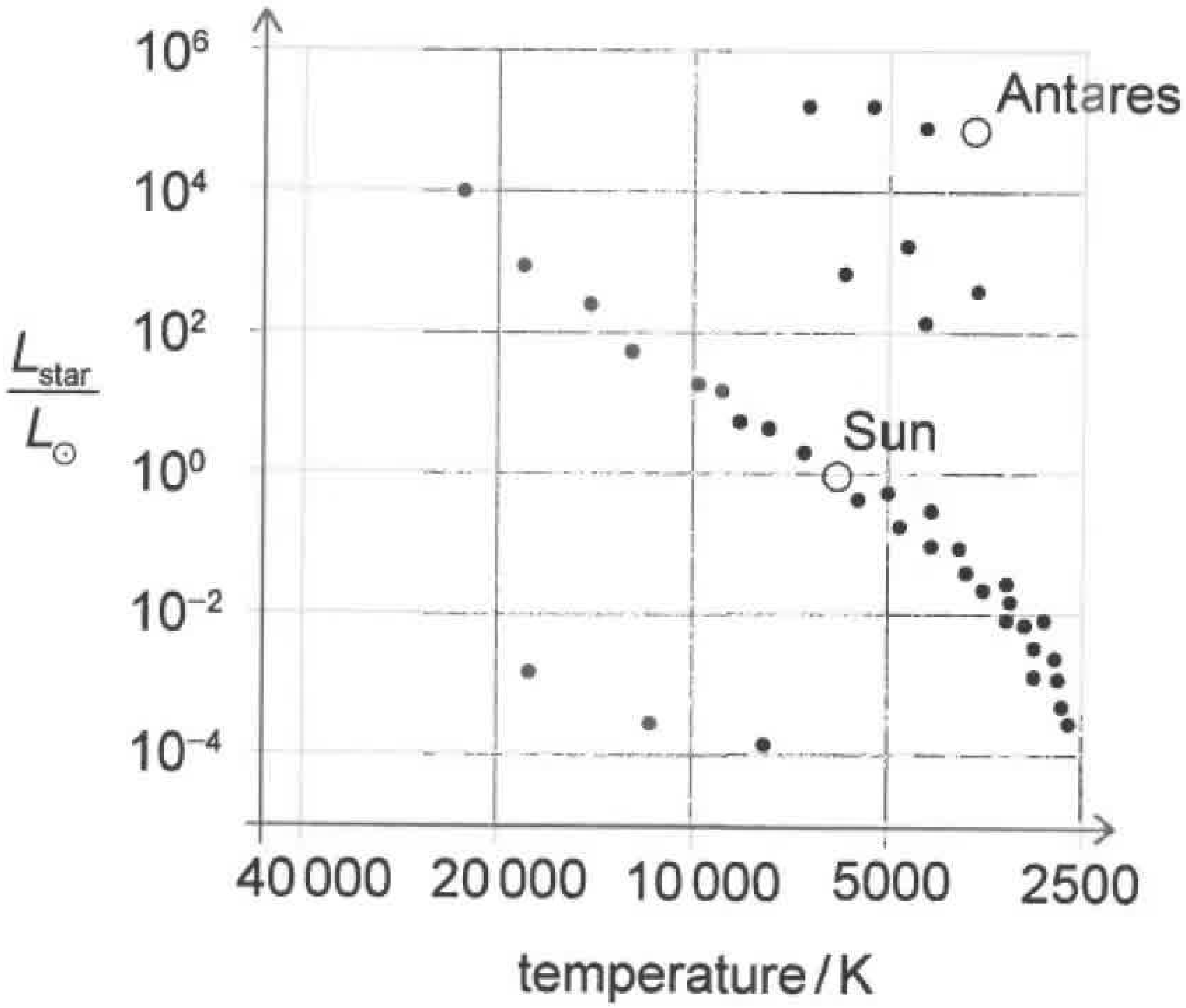
(iii) Outline how the presence of helium in the Sun can be confirmed empirically. [2]

(e) The positions of the Sun and the star Antares are shown in the Hertzsprung-Russell (HR) diagram.



(i) State the star type of Antares. [1]

(ii) Discuss how nuclear fusion processes in Antares are different from those in the Sun. [3]

9. A bar magnet of mass 0.12 kg is suspended from a vertical spring of spring constant $7.4\,\mathrm{N\,m^{-1}}$. The mass of the spring is negligible.

(a) For the magnet in the equilibrium position, calculate the elastic potential energy stored in the spring. [2]

The magnet–spring system performs simple harmonic motion in the vertical direction. The spring remains stretched all the time. The diagram shows how the elastic potential energy E_p stored in the spring varies with time t during **one** period of oscillation.

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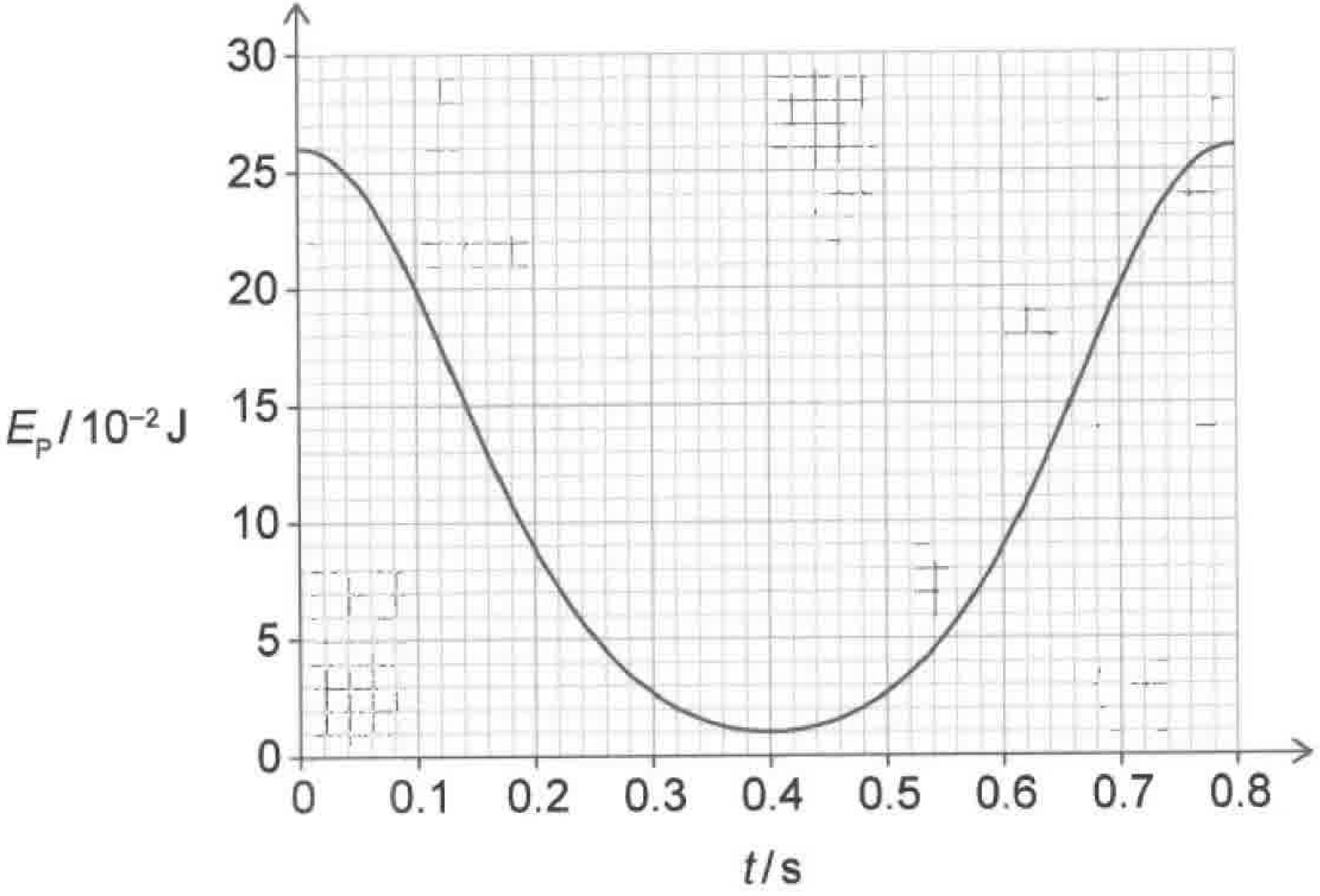

(Question 9 continued)

(b) (i) State and explain the direction of motion of the magnet at $t = 0.2$ s. [2]

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(ii) Describe the energy transfers that take place between $t = 0.2$ s and $t = 0.4$ s. [2]

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(Question 9 continued)

(c) (i) Show that the amplitude of the oscillation of the magnet is about 0.1 m. [3]

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(ii) Calculate the maximum speed of the magnet. [2]

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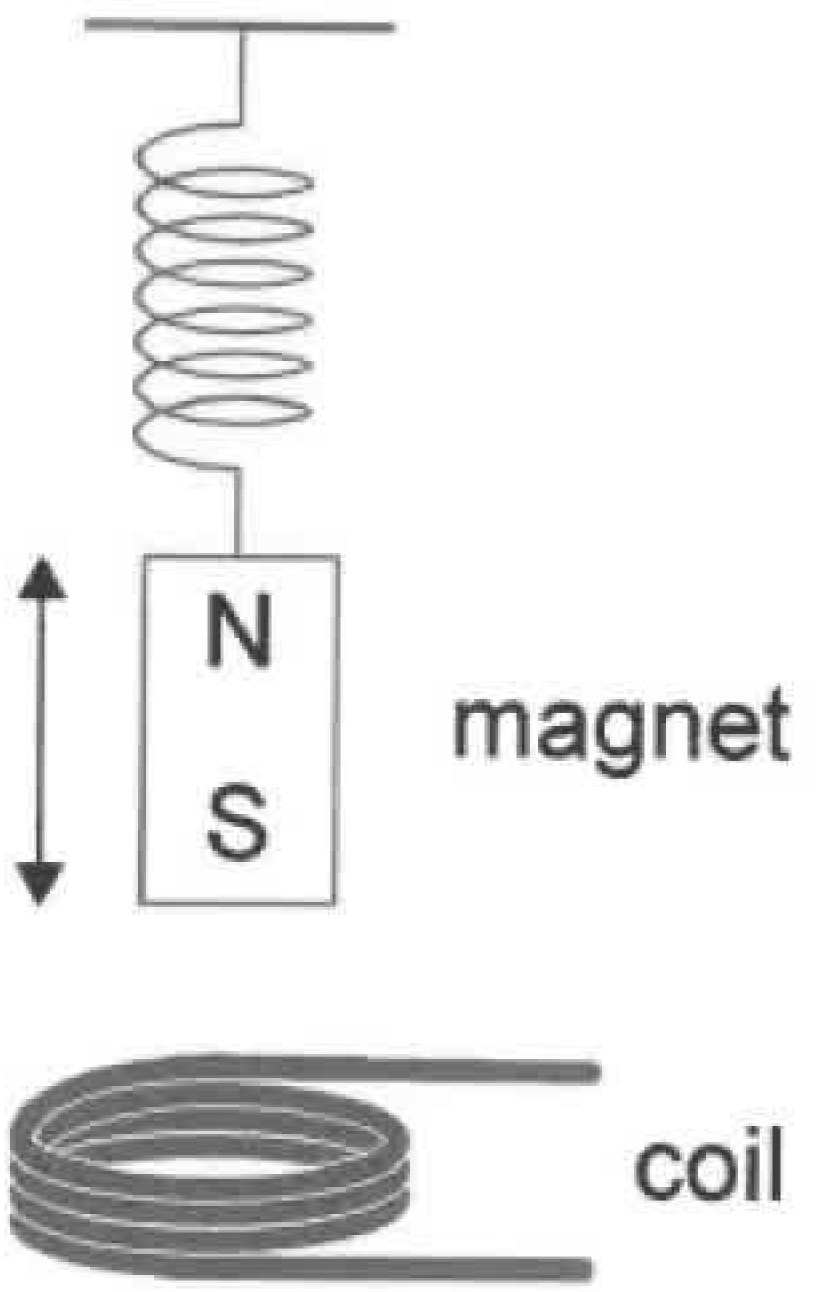
(iii) Determine the kinetic energy of the magnet at $t = 0.15$ s. [2]

A stationary horizontal coil is placed directly below the oscillating magnet.



(d) (i) Discuss **two** factors that affect the magnitude of the emf induced in the coil. In your answer, you should explain:

- how an induced emf can arise in the coil, and
- how each factor affects the magnitude of the emf. [4]

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(ii) A resistor is now connected across the coil. The amplitude of oscillation of the magnet rapidly decreases.

Explain this phenomenon. [3]

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