

(Question 1 continued)

The box is replaced by a solid sphere of the same mass and radius R . The sphere rolls down the ramp without slipping. The moment of inertia of a sphere is $\frac{2}{5}MR^2$.

- (c) Calculate the linear speed of the sphere at the bottom of the ramp. [3]

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The sphere is replaced by a ring of the same mass and radius.

- (d) Explain, without calculation, why the speed of the ring will be lower than that of the sphere. [1]

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2. An ideal gas is held in a container. Thermal energy is transferred to it by a heater. The heater works at a voltage of 220V and the current in the heater is 2.0A. The gas is heated for 30s at a constant volume.

(a) Calculate the thermal energy transferred to the gas. [1]

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(b) Explain, in terms of the motion of particles, how the increase in pressure arises. [2]

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Before heating, the gas was at a temperature of 293 K and a pressure of 101 kPa. The volume of the container is 0.45 m^3 .

(c) Calculate the increase in temperature. [3]

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The gas is allowed to expand adiabatically to double its original volume. Assume the gas is monatomic.

(d) Determine its final temperature. [2]

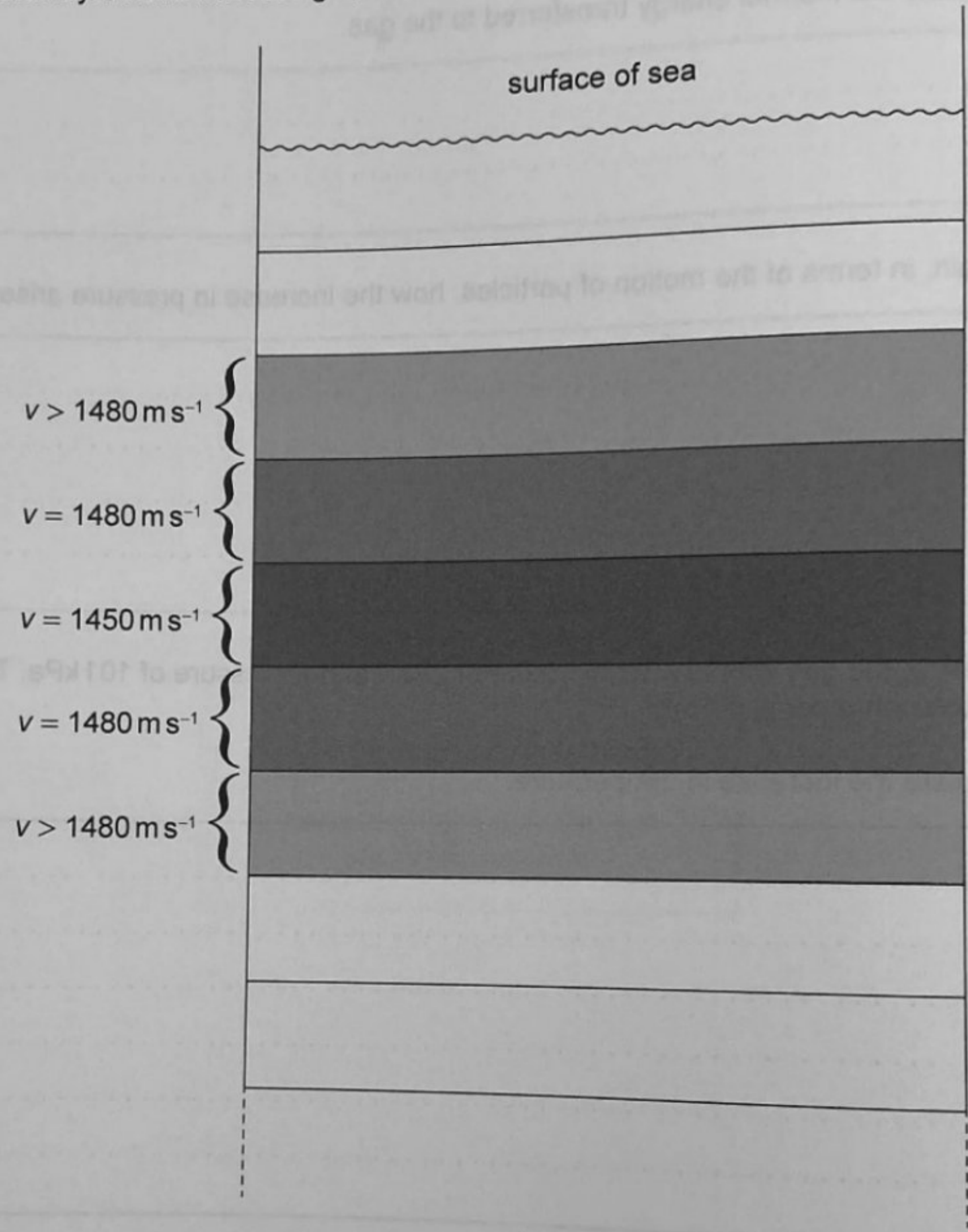
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3. As a result of the variation of temperature and pressure with depth, the speed of sound v in the sea varies so that it reaches a minimum value at a certain depth. This variation can be modelled by layers of constant decreasing speeds of sound up to that depth. Layers above or below that layer have increasing v , as shown in the diagram.

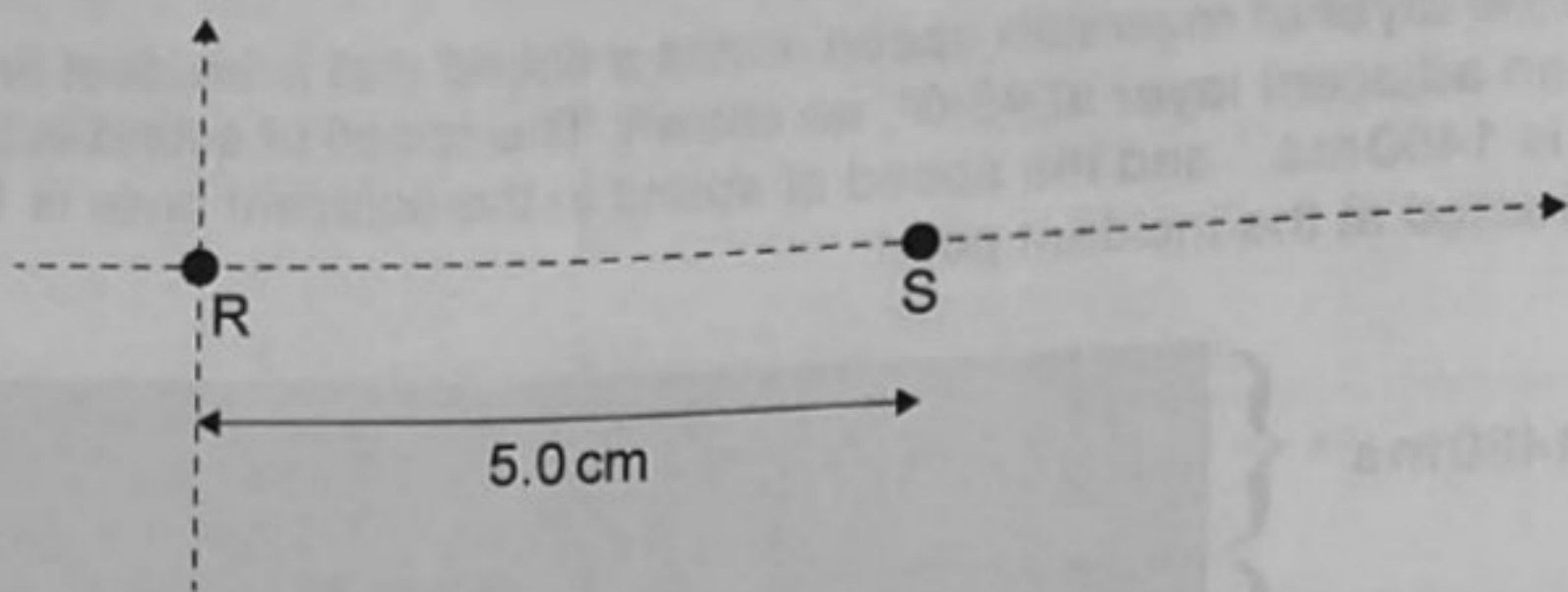


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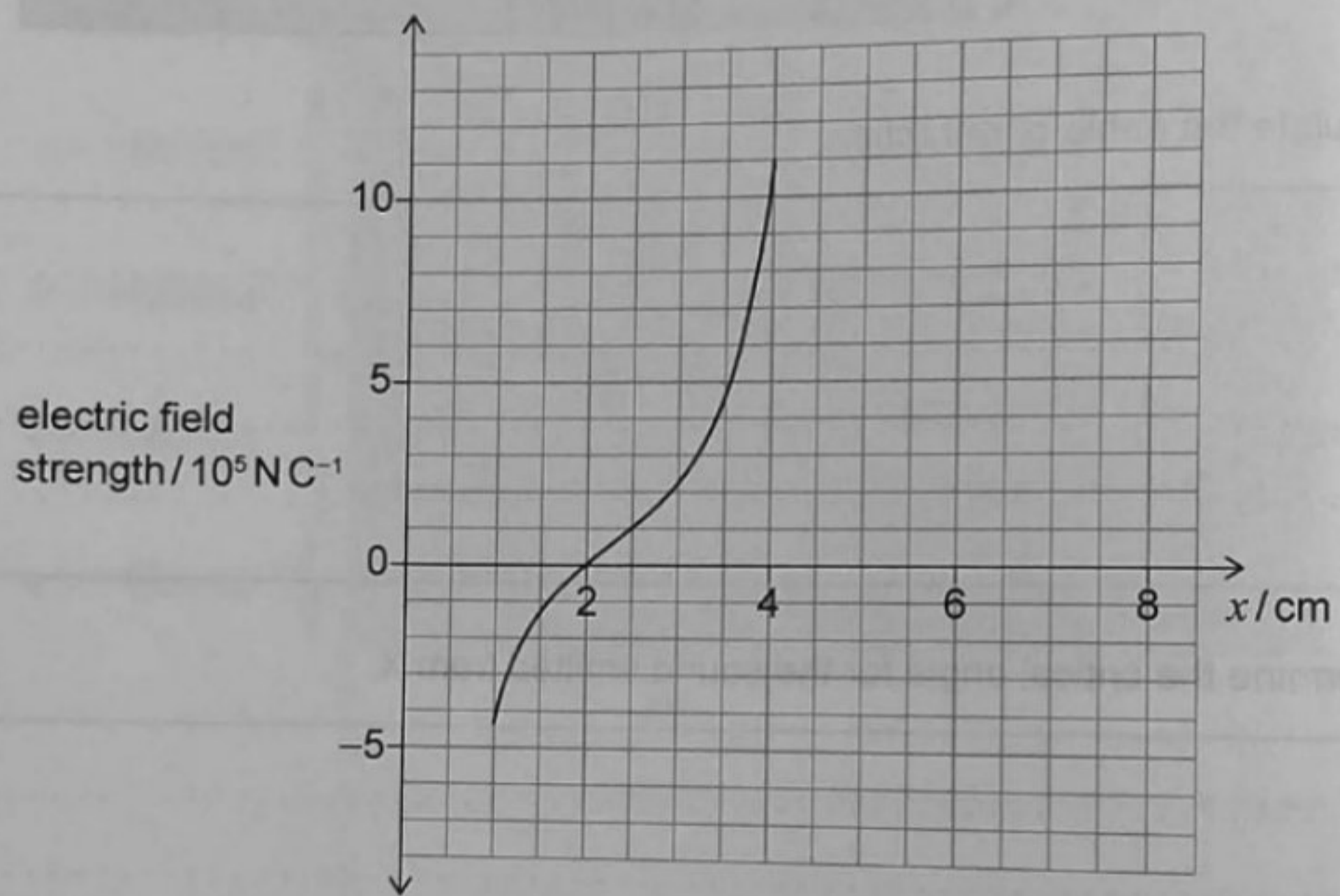
A004

(This question continues on the following page)

4. Two electric point charges, R and S, are 5.0 cm apart.



The graph shows the variation of the resultant electric field strength due to these two charges along the line joining them, for the interval $1.0 \text{ cm} \leq x \leq 4.0 \text{ cm}$, where x is the horizontal position with origin at charge R.



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(a) State the definition of electric field strength at a point.

[2]

A004

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(This question continues on the following page)

(Question 4 continued)

(b) Identify the sign of each charge.

[1]

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(c) Show that the ratio of the magnitudes of the charges is about 2.

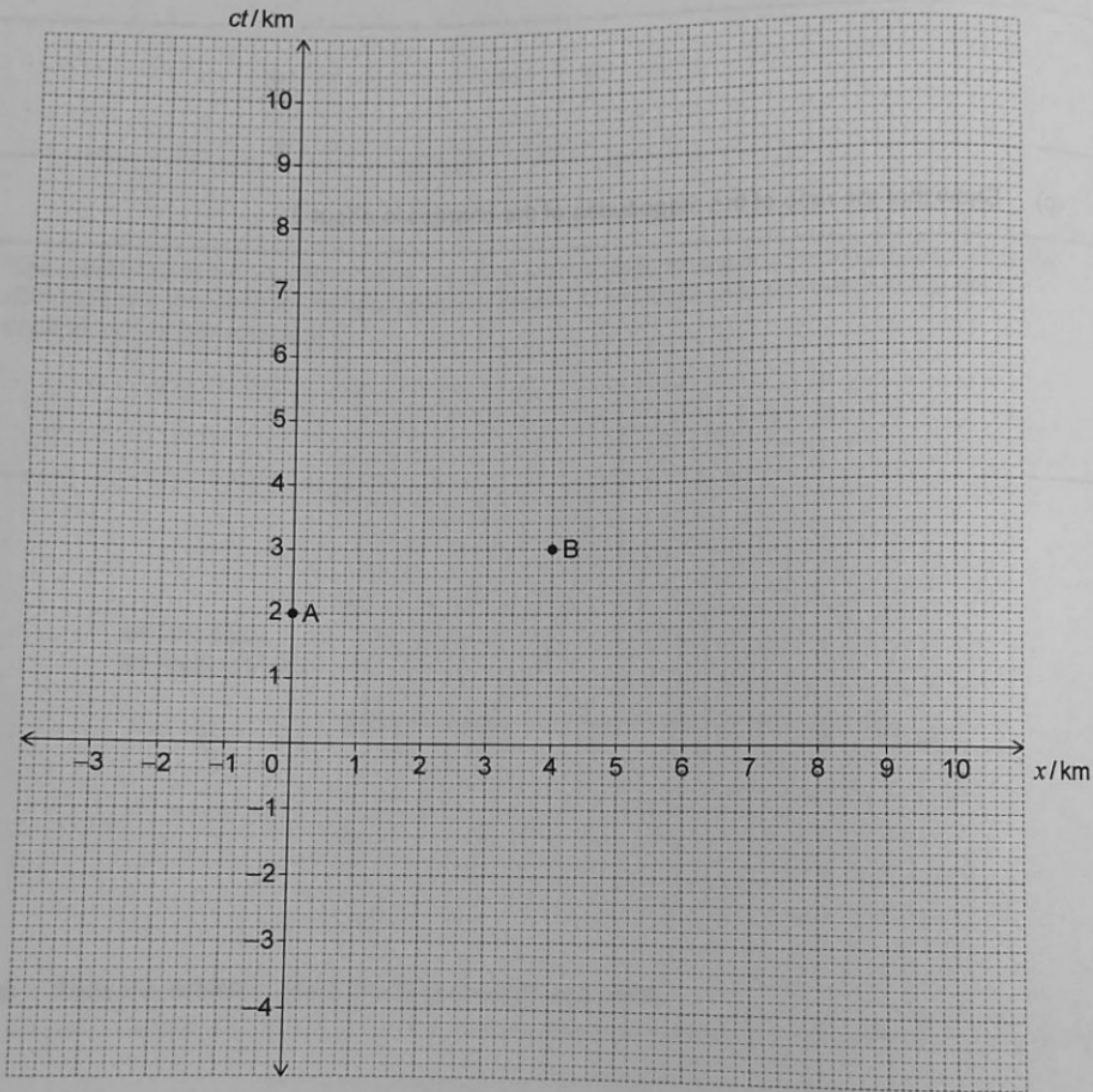
[2]

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5. Events A and B are shown in a space-time diagram drawn for a frame of reference F. Events A and B are 4 km apart, as measured in F.



(a) Calculate the space-time interval between events A and B.

[1]

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(This question continues on the following page)

(Question 5 continued)

An observer O is moving at a speed v away from F. Events A and B are simultaneous for O.

(b) Determine v .

[2]

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(c) Calculate the distance between A and B as measured by O.

[2]

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(d) Explain why 4 km is the proper length between events A and B.

[1]

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A004

(The question continues on the following page)

6. A proton is accelerated from rest through a potential difference $V = 1.2 \text{ kV}$.

(a) Show that the velocity v of the proton is about $5 \times 10^5 \text{ m s}^{-1}$. [2]

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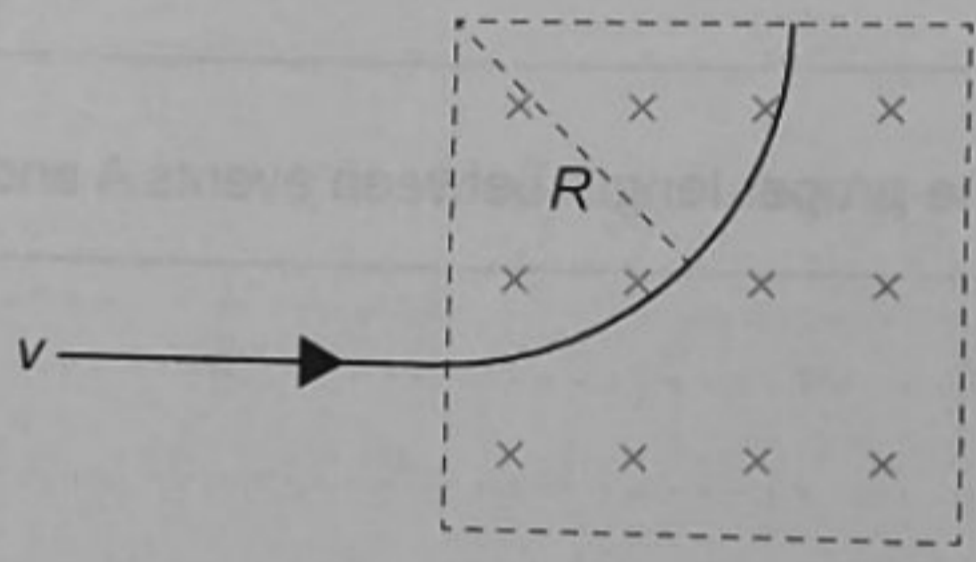
(b) Explain why relativistic effects are negligible. [1]

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The proton enters a region of magnetic field $B = 0.14 \text{ T}$ perpendicular to v and directed into the page so that the proton follows a curved path of radius R , as shown.



(c) Calculate R . [2]

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(Question 6 continued)

When a sample of ionized hydrogen gas is accelerated and enters a region of magnetic field, it shows multiple radii of curvature.

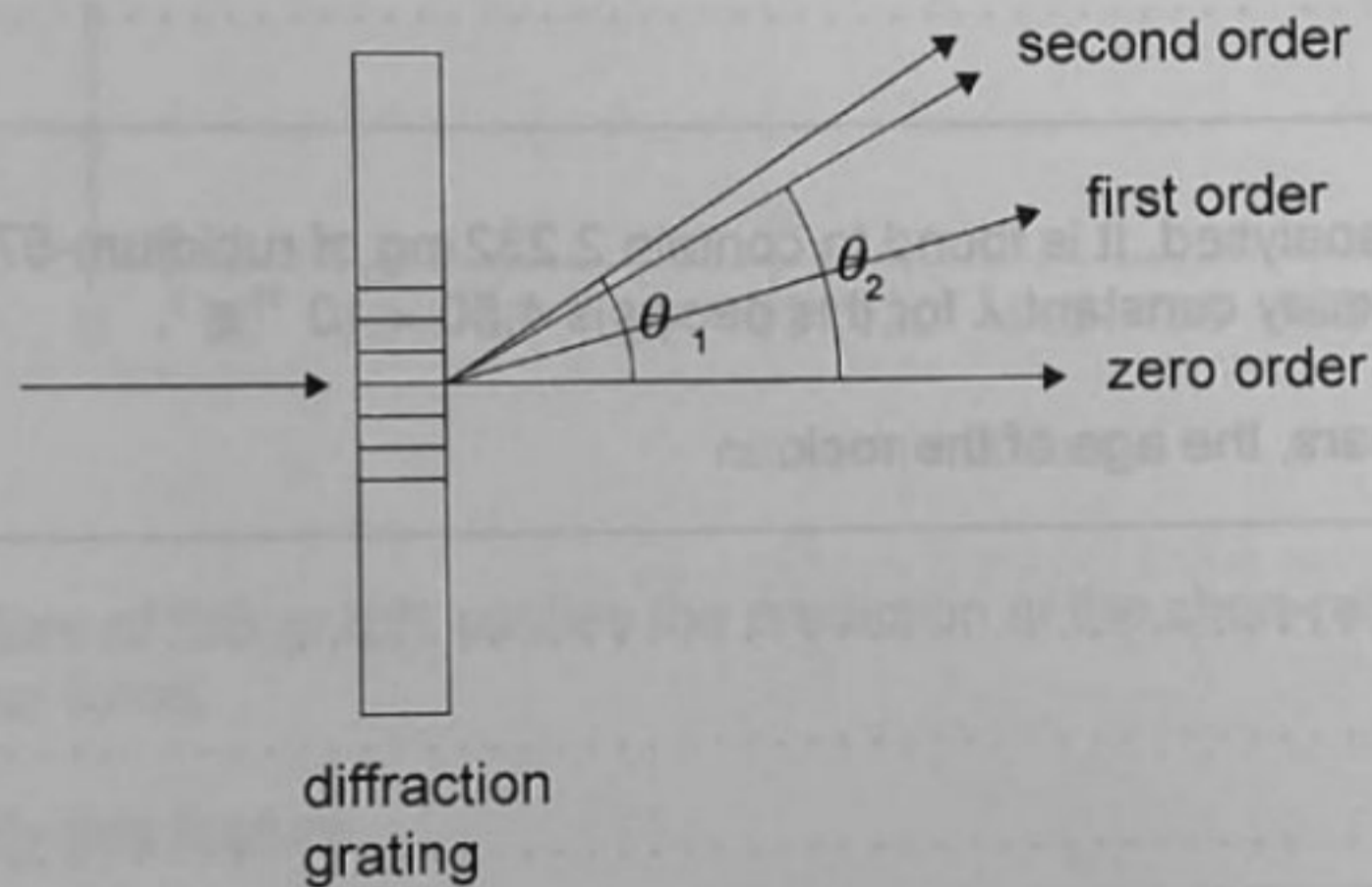
(d) Explain how this accounts for the existence of isotopes.

[1]

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Isotopes produce slightly different wavelengths in their emission spectra.

The emission spectrum for hydrogen is observed using a diffraction grating with $5200 \text{ lines cm}^{-1}$. The same electron transition in two isotopes of hydrogen produces wavelengths of 656.478 nm and 656.296 nm . These lines are observed in the second order where they make an angle of θ_1 and θ_2 , where $\theta_1 > \theta_2$.



(e) Determine θ_1 .

[2]

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A004

7. The radioactive decay of rubidium $^{87}_{37}\text{Rb}$ into strontium $^{87}_{38}\text{Sr}$ is used to date rocks. The rocks do not contain strontium when they are formed.

(a) Identify the type of decay.

[1]

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(b) Explain why the energy spectrum of this type of decay led scientists to postulate the existence of the neutrino.

[2]

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A sample of a rock is analysed. It is found to contain 2.232 mg of rubidium-87 and 0.028 mg of strontium-87. The decay constant λ for this decay is $4.50 \times 10^{-19} \text{ s}^{-1}$.

(c) Determine, in years, the age of the rock.

[3]

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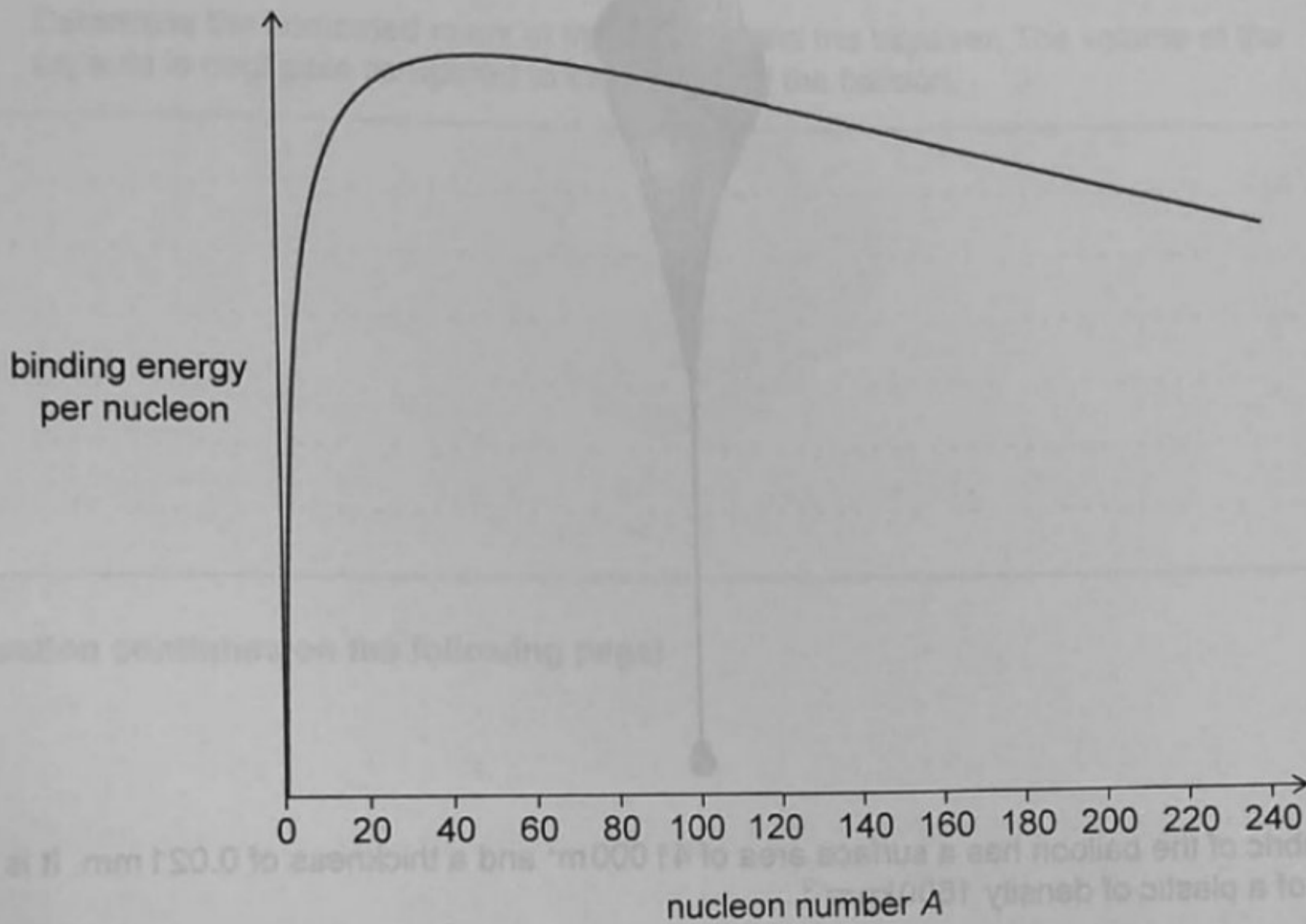
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(Question 7 continued)

- (d) The graph shows the variation of the binding energy per nucleon, with the nucleon number, for the elements in the periodic table.



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- (i) A feature of this graph justifies the prediction of the short-range of the strong nuclear force.

Identify this feature.

[1]

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- (ii) The mass of $^{87}_{37}\text{Rb}$ is $86.91u$. Calculate, in MeV, the binding energy per nucleon of Rb-87.

[2]

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A004

8. Scientists are planning a skydive jump from a height of 39 km above the surface of the Earth. To reach that altitude, a skydiver is to be lifted in a capsule attached to a helium-filled balloon.



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The fabric of the balloon has a surface area of $41\,000\text{ m}^2$ and a thickness of 0.021 mm . It is made of a plastic of density 1600 kg m^{-3} .

- (a) Show that the mass of the balloon is about 1400 kg. [1]

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A004

The balloon is held stationary and helium gas is pumped into it at a nearly atmospheric pressure of $P = 102\text{ kPa}$. The balloon is inflated up to a volume of 3700 m^3 . The ambient temperature is 15°C . The molar mass of helium is 4.0 g mol^{-1} .

- (b) Show that the mass of helium added is about 600 kg. [2]

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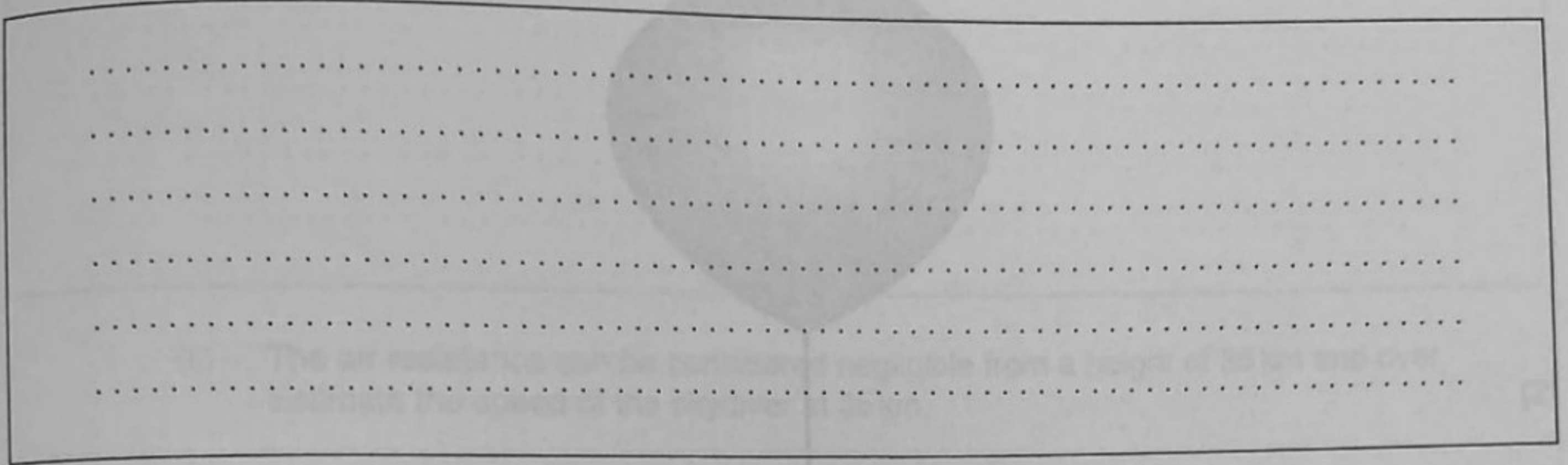
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(Question 8 continued)

The balloon is released, lifting the capsule and skydiver into the air. The balloon accelerates upwards at 2.2 m s^{-2} . The density of air at 15°C is 1.2 kg m^{-3} .

- (c) Determine the combined mass of the capsule and the skydiver. The volume of the capsule is negligible compared to the volume of the balloon. [3]



(This question continues on the following page)

(Question 8 continued)

The balloon stops rising at a height of 39 km, where the external pressure and temperature are 0.35 kPa and -30°C respectively. A heater operates at 0.12 kW to maintain the interior of the capsule at a constant temperature of 15°C .



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- (d) (i) Suggest why the conduction losses from the capsule to the surroundings can be considered negligible at 39 km. [1]

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- (ii) The capsule has a surface area of 14 m^2 . Estimate the emissivity of the capsule. Do not consider any thermal radiation input to the capsule. [2]

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(Question 8 continued)

The skydiver jumps from the capsule when it reaches a height of 39 km.

- (e) (i) The radius of the Earth is 6400 km. Show that g is about 9.7 ms^{-2} at a height of 39 km.

[2]

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- (ii) The air resistance can be considered negligible from a height of 35 km and over. Estimate the speed of the skydiver at 35 km.

[2]

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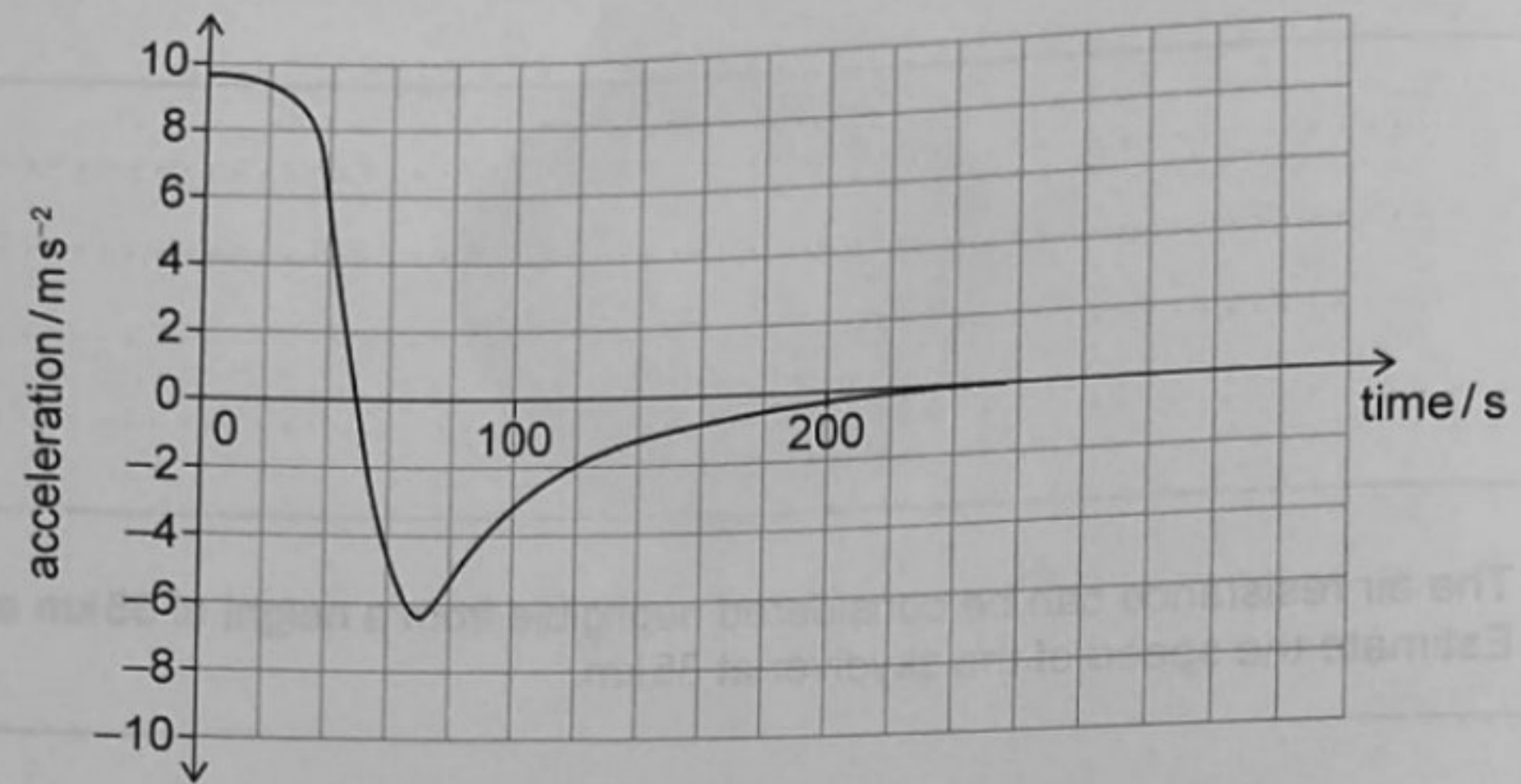
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(Question 8 continued)

The graph shows the variation with time of the acceleration of the skydiver, from the start of the dive to the opening of the parachute 260 s later, for a real jump performed in 2012.



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The graph shows two areas, one above and one below the time axis.

(f) (i) Identify what the areas represent. [2]

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(ii) Explain how the areas compare. [1]

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(This question continues on the following page)

(Question 8 continued)

- (g) The skydiver opens their parachute 260 seconds after jumping. Describe the subsequent motion of the skydiver.

[2]

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The real jump was tracked using thermal-imaging cameras which operate using infrared radiation.

- (h) Identify a possible frequency for this radiation.

[2]

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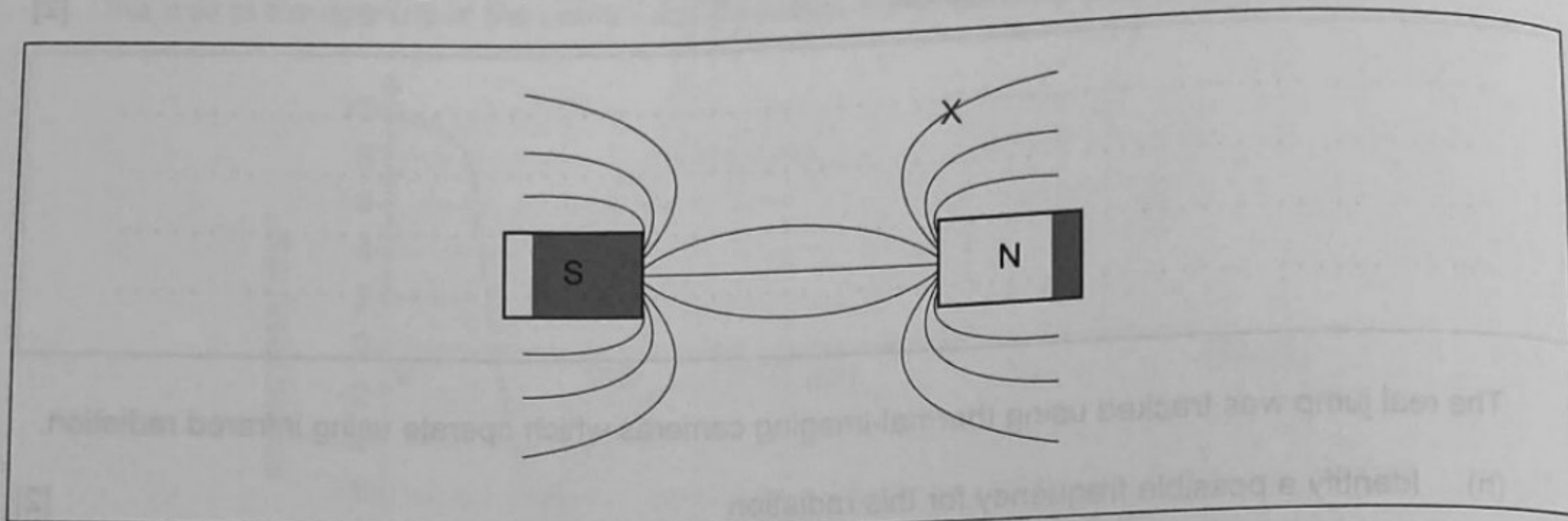
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9. Two bar magnets are aligned with their opposite poles facing each other. The diagram shows the pattern of the magnetic field lines produced by the magnets, without specifying their direction. A small magnet is placed at X. The original magnetic field pattern is negligibly disturbed.

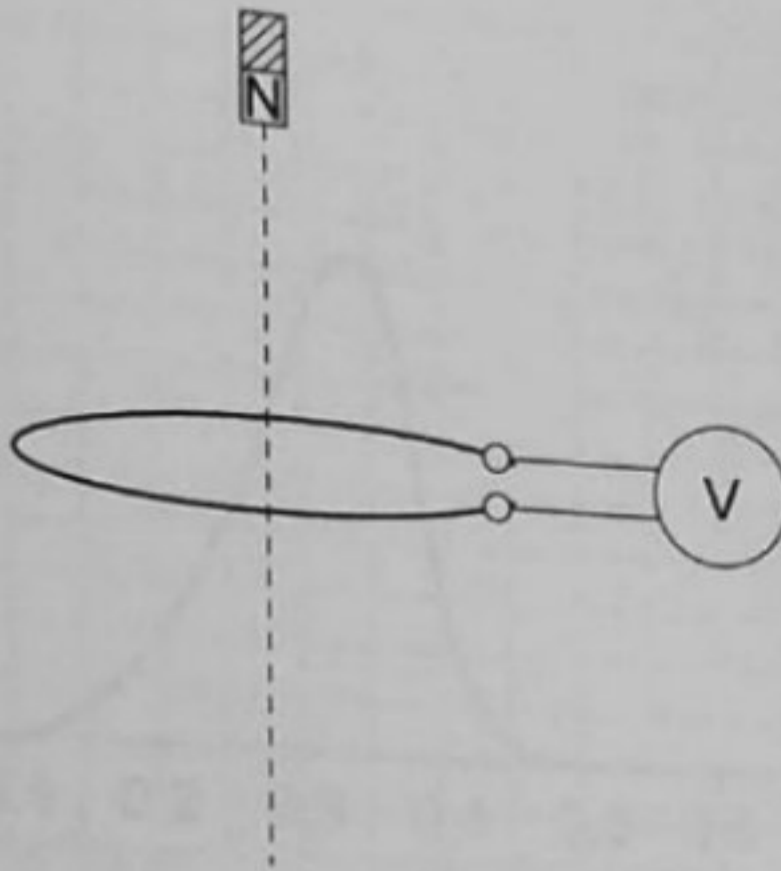


- (a) Draw the small magnet at X, indicating its orientation and polarity. [2]

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(Question 9 continued)

The diagram shows a bar magnet with its north pole pointing down. It is positioned above a conducting loop of wire connected to a voltmeter.



The magnet is dropped and falls through the loop of wire. The magnetic flux through the wire increases and then decreases.

- (b) (i) State the definition of magnetic flux. [1]

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- (ii) Explain, with reference to Faraday's law, the reading of the voltmeter as the magnet approaches the wire. [2]

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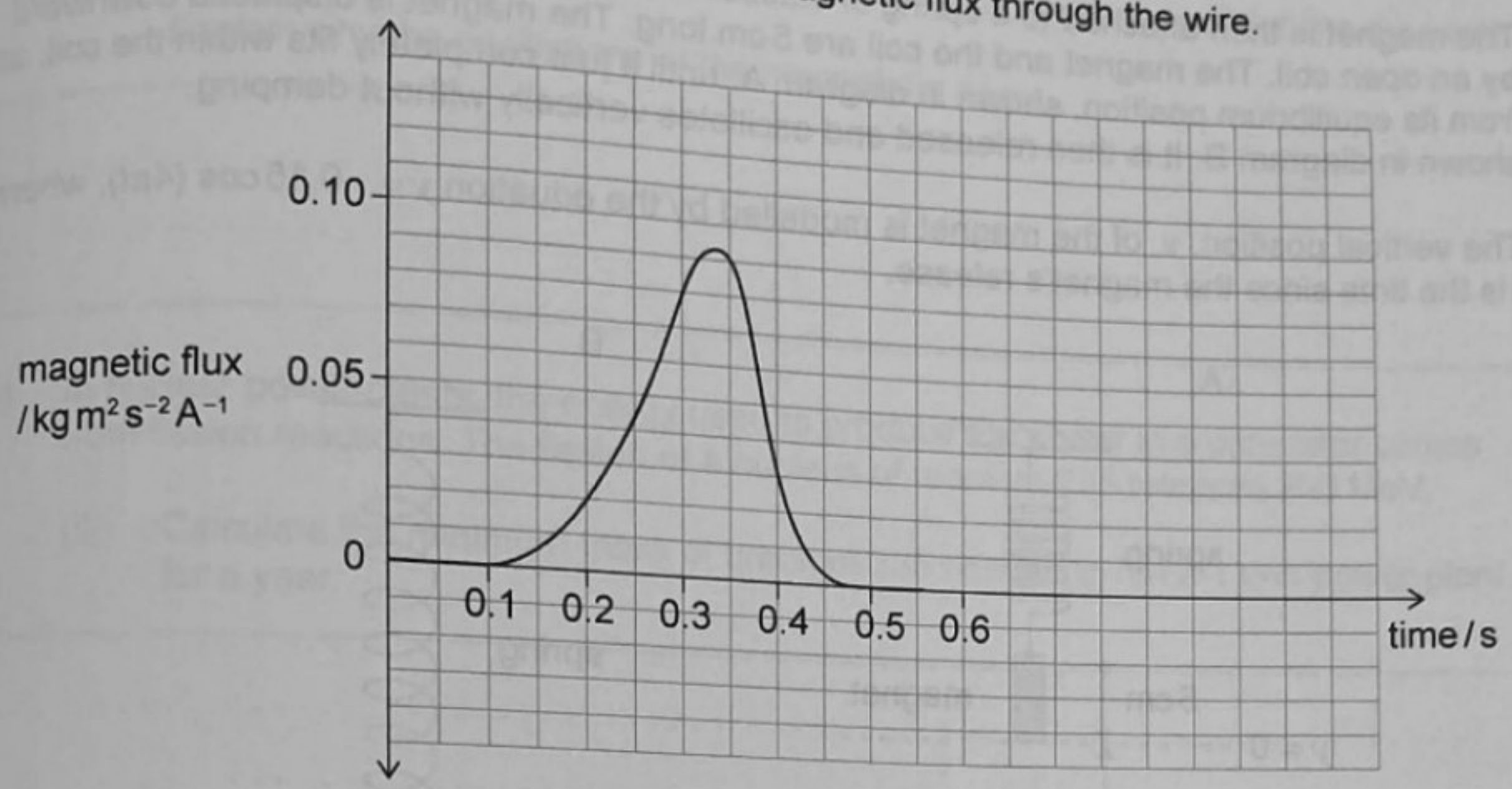
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The graph shows the variation with time of the magnetic flux through the wire.



- (c) (i) Using the graph, determine the maximum value of the emf induced by the fall of the magnet. [3]

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- (ii) State the direction of the current induced in the wire as the magnet enters the loop and as it leaves the loop. [2]

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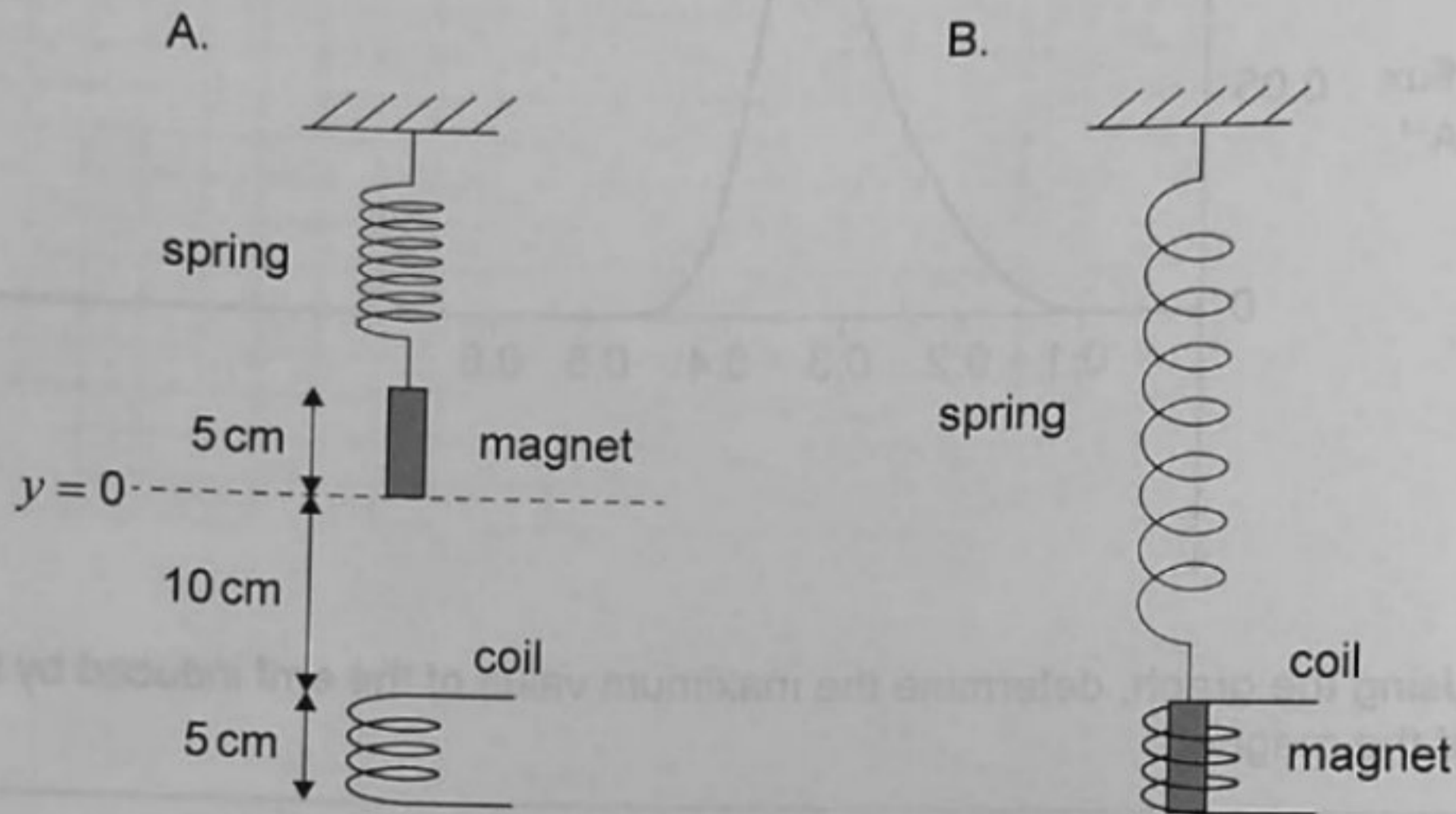
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(Question 9 continued)

The magnet is then attached to a spring of elastic constant $k = 5.0 \text{ N m}^{-1}$. The wire is replaced by an open coil. The magnet and the coil are 5 cm long. The magnet is displaced downward from its equilibrium position, shown in diagram A, until it just completely fits within the coil, as shown in diagram B. It is then released and oscillates vertically without damping.

The vertical position, y , of the magnet is modelled by the equation $y = -0.15 \cos(4\pi t)$, where t is the time since the magnet's release.



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(d) (i) Calculate the speed of the magnet when it is about to enter the coil. [2]

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(ii) Determine the mass of the magnet. [2]

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A004

(Question 9 continued)

(iii) A resistor is connected between the ends of the coil and the oscillations die away.
 Explain why the oscillations of the magnet die away.

[1]

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(e) In nuclear power plants, the energy used to produce the power in a generator comes from fission reactions. The fission of a nucleus of uranium-235 releases 200 MeV.

(i) Calculate the minimum mass of uranium-235 needed to run a 1 GW power plant for a year.

[3]

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(ii) Explain how the energy released from the nucleus is harnessed in a nuclear power plant.

[2]

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A004