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Physics
Higher level
Paper 2

26 April 2024

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

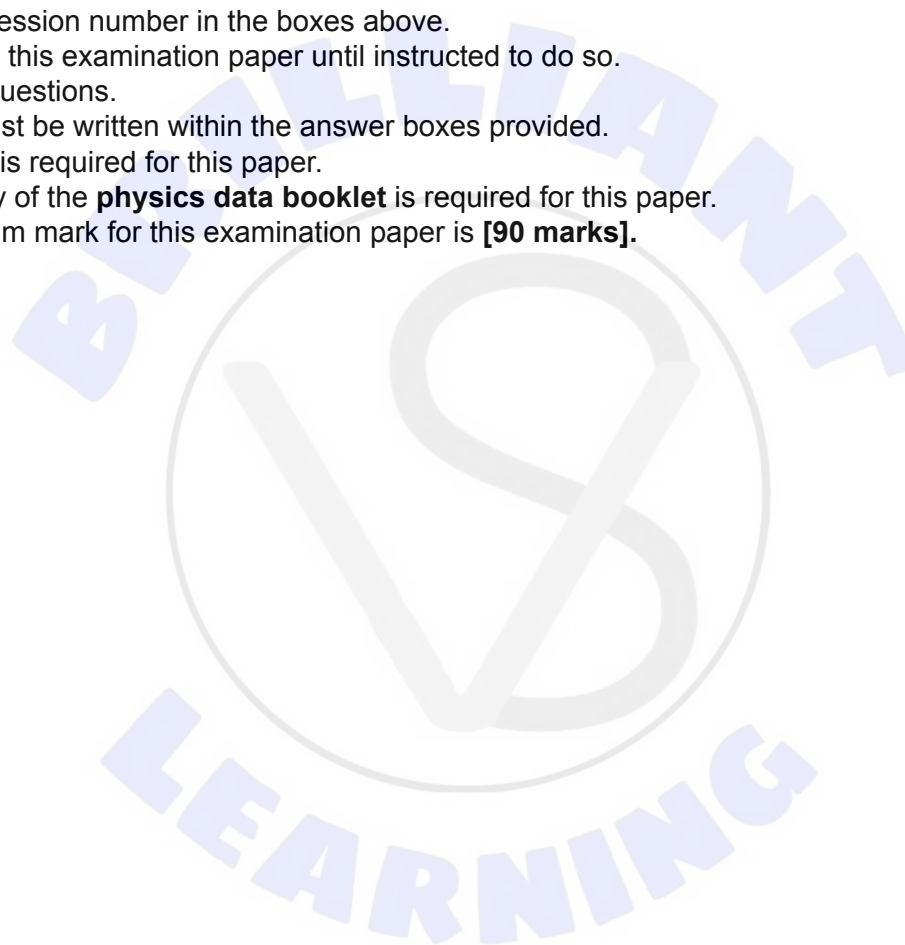
Candidate session number

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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]**.





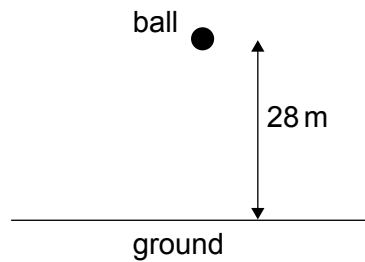
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Answer **all** questions. Answers must be written within the answer boxes provided.

1. A ball of mass 2.7 g is released from rest from a height of 28 m above horizontal ground.



- (a) Show that in the absence of air resistance the ball impacts the ground with a speed of about 23 ms^{-1} . [1]

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- (b) An air resistance force F acts on the ball. F can be modeled by $F = kv^2$ where v is the speed and k is a constant.
- (i) Determine the unit of k in terms of fundamental units. [2]

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- (ii) Describe how the ball reaches terminal speed. [2]

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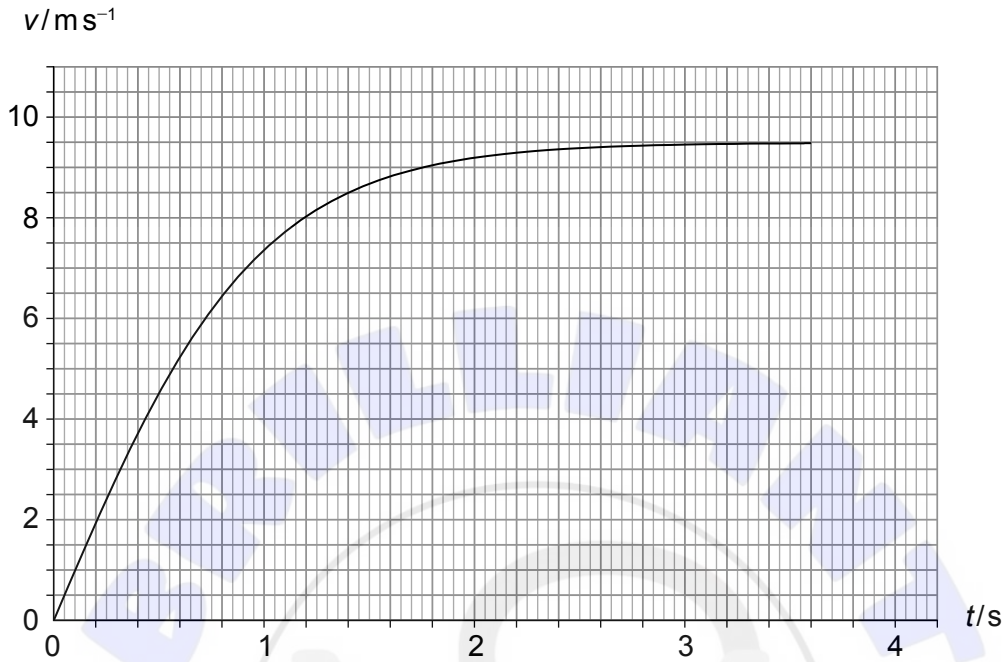
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(Question 1 continued)

- (c) The graph shows the variation with time t of the speed v of the ball from the instant it is released until it impacts the ground.



- (i) State the value of the area under the curve. [1]

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- (ii) Determine k . [2]

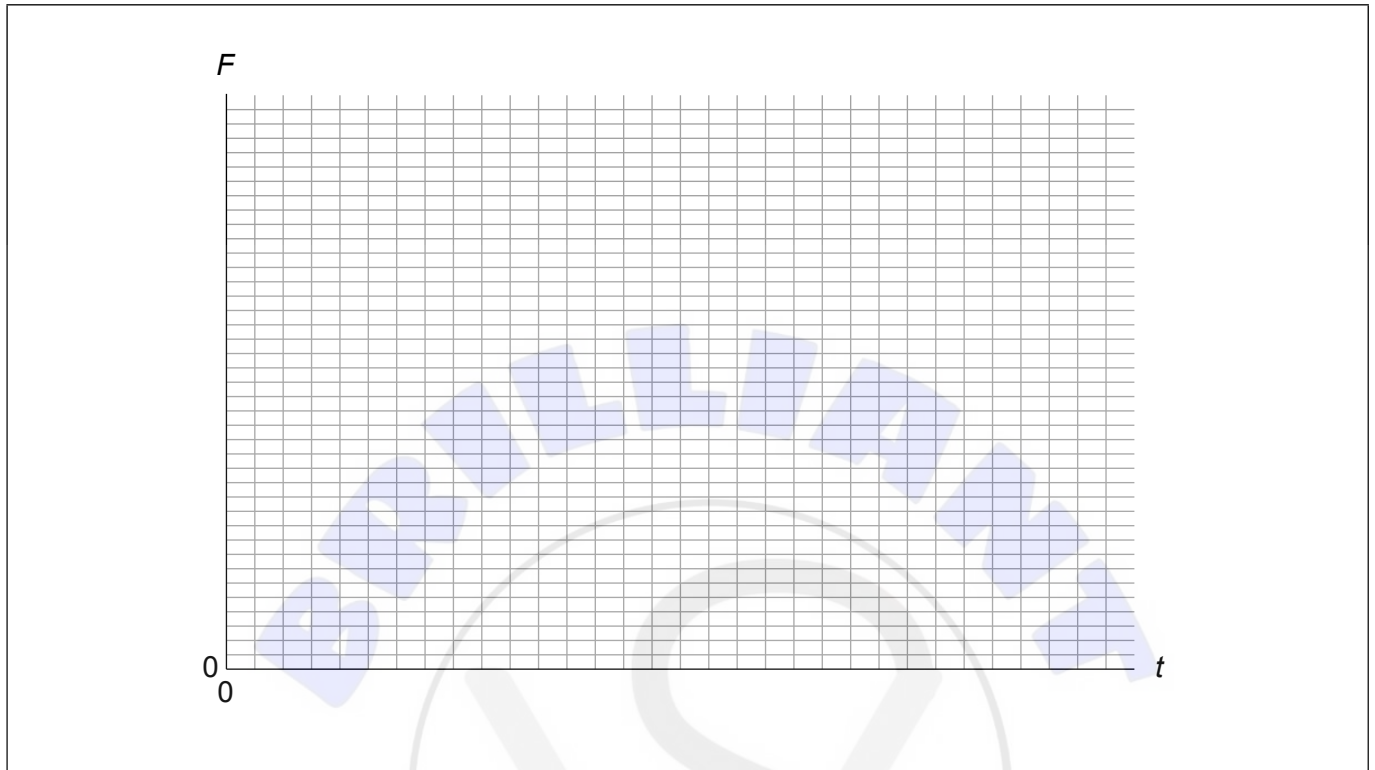
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(Question 1 continued)

- (iii) On the axes below, draw a graph to show the variation of the magnitude of the **resultant** force, F , on the ball with time t . No numbers are required on the axes. [1]



- (iv) Calculate the average power dissipated by the air resistance force. [3]

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- (d) The ball rebounds from the ground with speed 7.8 m s^{-1} . The ball is in contact with the ground for a time T . The average **resultant** force on the ball during this time is 1.1 N .

Determine T . [2]

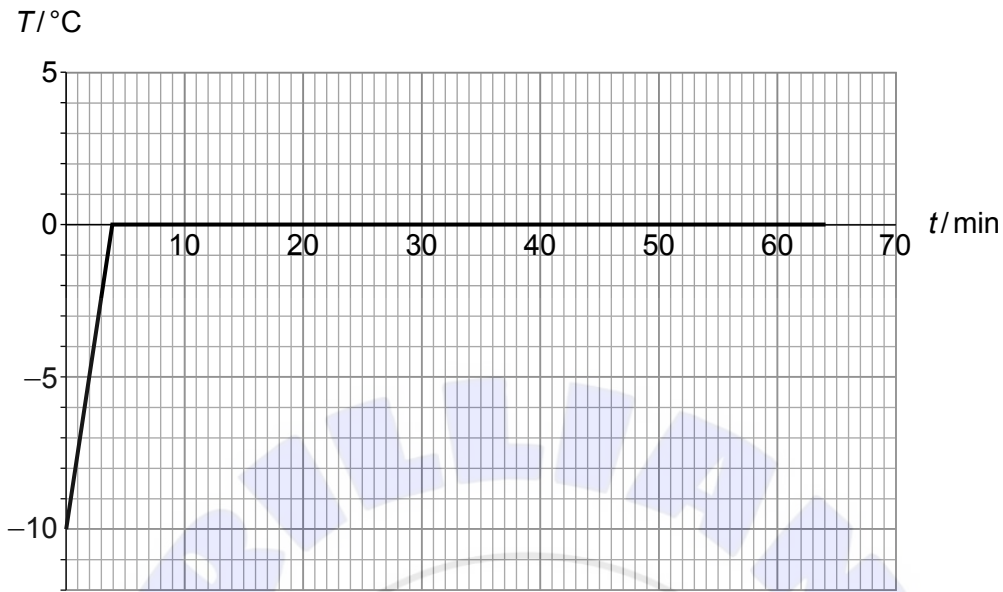
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2. Crushed ice of mass 35 g at temperature -10°C is placed in a warm room. The graph shows the variation of the temperature T of the ice with time t .



The specific heat capacity of ice is $2100\text{ J kg}^{-1}\text{ K}^{-1}$.

- (a) (i) Show that the average rate at which thermal energy is being transferred into the ice is about 3 W. [2]

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- (ii) Estimate the specific latent heat of fusion of ice. [2]

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(This question continues on the following page)



(Question 2 continued)

- (b) Between 4 minutes and 64 minutes solid ice and liquid water coexist at 0 °C. Compare and contrast, during this time, the internal energy of solid ice to that of an equal mass of liquid water. [2]

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3. (a) Outline what is meant by a travelling wave. [2]

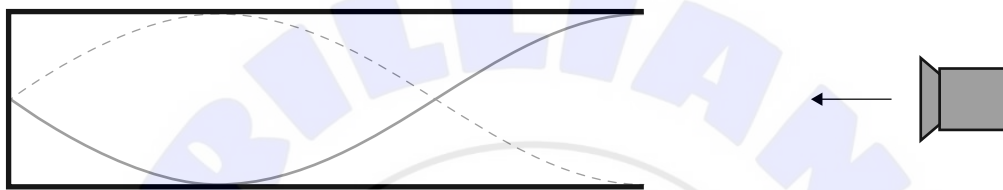
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(b) A loudspeaker emits sound of frequency 210 Hz into a pipe with one open and one closed end. The diagram shows a representation of the standing wave established in the pipe.



The length of the pipe is 1.20 m.

(i) Outline how the standing wave is formed in the pipe. [2]

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(ii) Determine the wavelength of the wave. [1]

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(Question 3 continued)

- (iii) Calculate the speed of sound in the pipe stating the answer to an appropriate number of significant figures. [2]

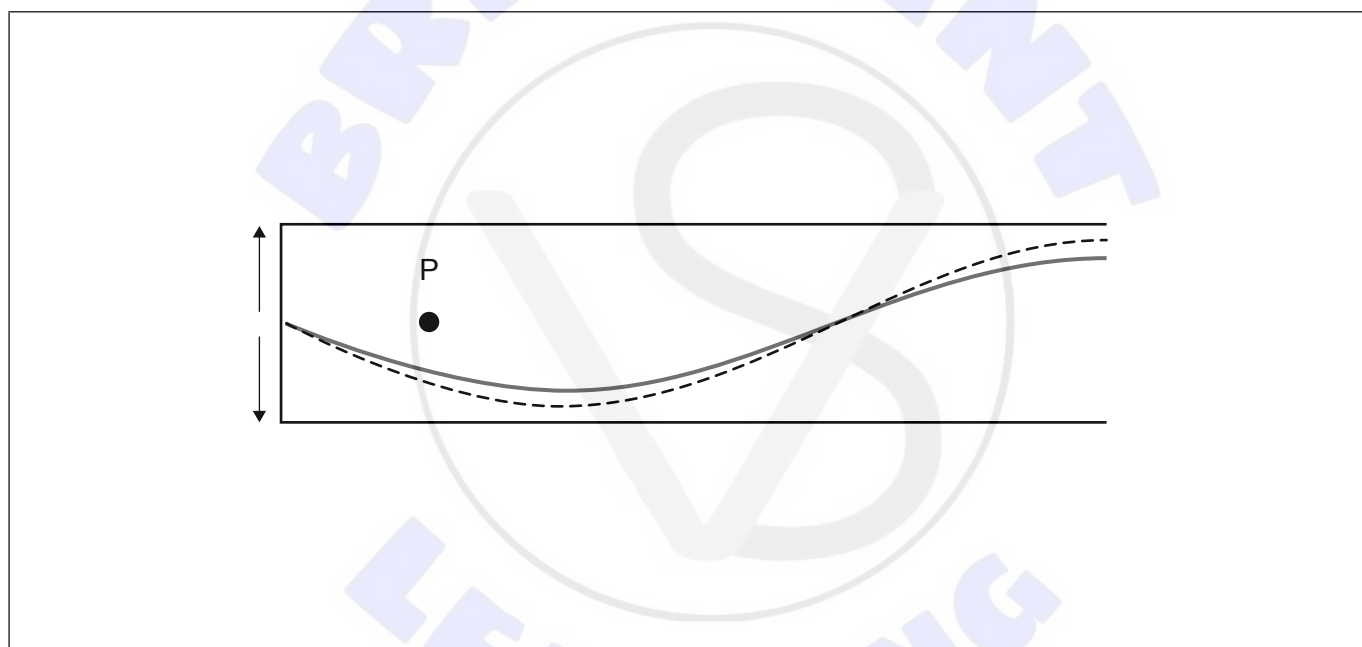
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- (c) The solid line represents the standing wave at time t and the dotted line represents the standing wave at an instant later. The dot is the **equilibrium** position of a particle P in the pipe. The up arrow indicates displacements to the right and the down arrow displacements to the left.



On the diagram, draw

- (i) a dot to indicate the approximate position of P at time t , [1]
- (ii) an arrow to indicate the velocity of P at time t . [1]

(This question continues on page 11)





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(Question 3 continued)

- (d) The amplitude of oscillations of the standing wave in (b) is 4.2 mm. The mass of particle P in (c) is 1.8×10^{-6} kg.

Calculate

- (i) the total energy of P, [2]

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- (ii) the displacement of P, when its kinetic energy is equal to its potential energy. [2]

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- (e) The frequency of sound is reduced to 140 Hz. Explain why a standing wave will not be formed in the pipe. [2]

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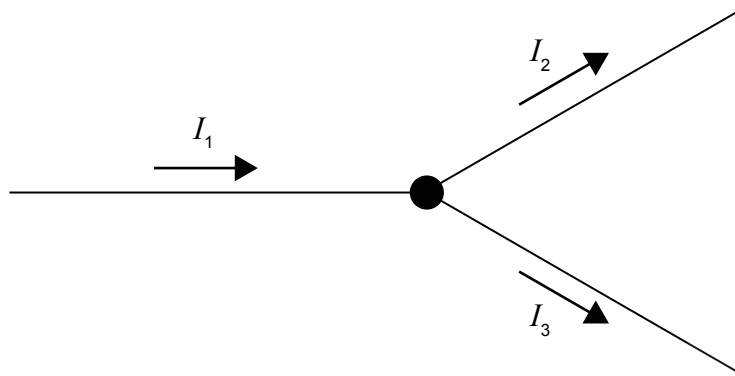
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4. (a) The diagram shows a junction in a circuit.



The currents in the three wires are related by $I_1 = I_2 + I_3$.

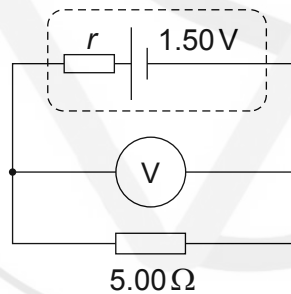
State the fundamental law of Physics from which this relation is derived.

[1]

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- (b) A cell of emf 1.50 V and internal resistance r is connected to a resistor of resistance 5.00Ω and an ideal voltmeter V.



The reading of the voltmeter is 1.20 V.

- (i) Determine the internal resistance r of the cell.

[2]

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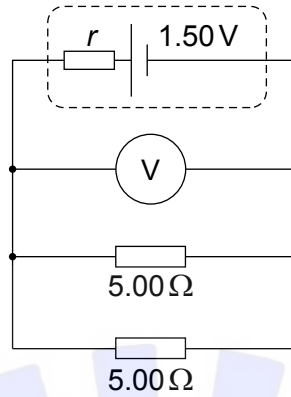
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(Question 4 continued)

(ii) A second $5.00\ \Omega$ resistor is connected in parallel to the first resistor.



State and explain the change, if any, in the voltmeter reading without further calculation.

[2]

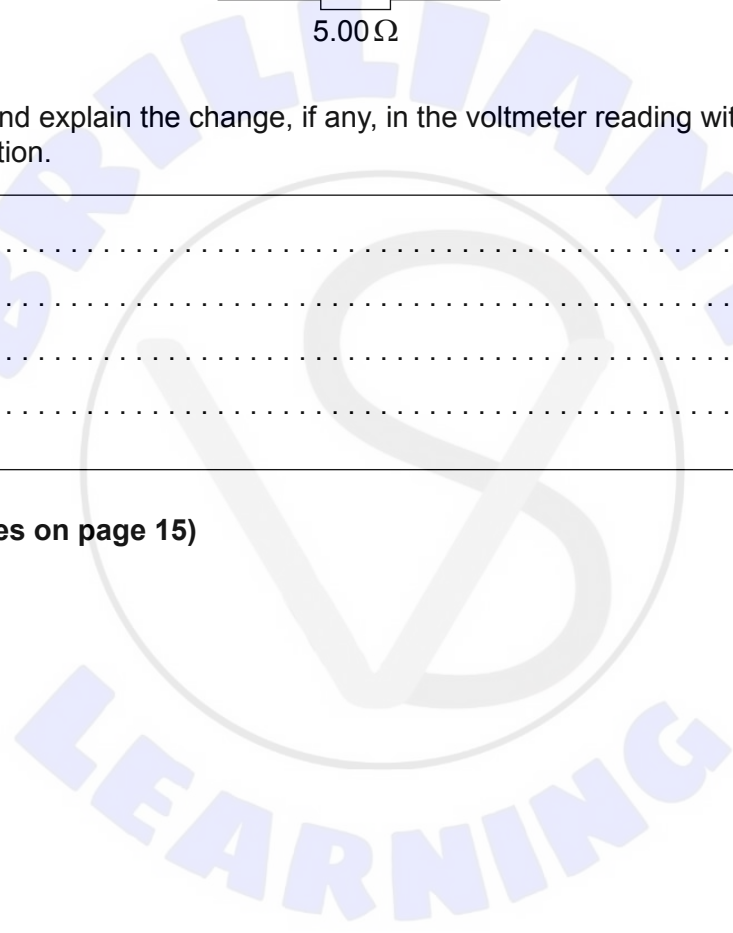
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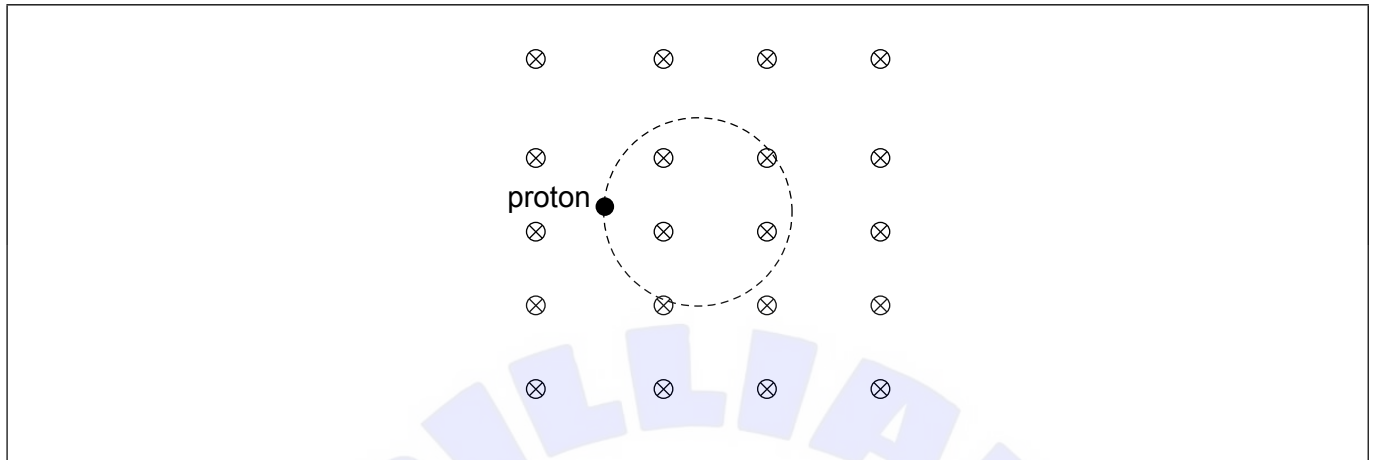
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(Question 4 continued)

- (c) A proton moves on a circular path in a region of uniform magnetic field of magnetic flux density B that is directed into the plane of the page.



- (i) On the diagram, draw an arrow to indicate the velocity of the proton at the position shown. [1]
- (ii) Show that the frequency of revolution of the proton is given by $f = \frac{eB}{2\pi m_p}$. [3]

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- (iii) The magnitude of B is 2.5 T. Calculate the frequency of revolution of the proton. [1]

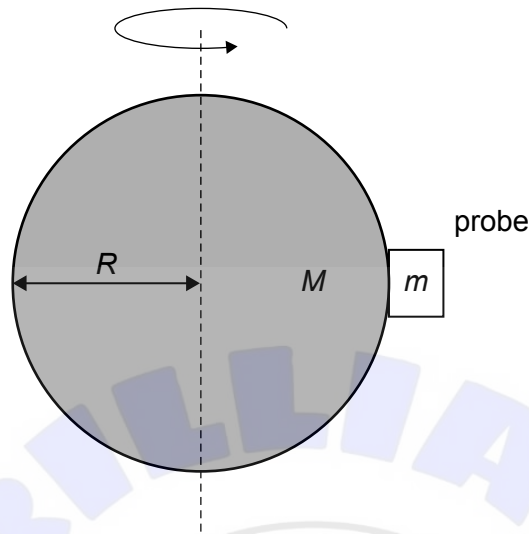
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5. A probe of mass m has landed on the equator of a rotating asteroid of mass M and radius R .

diagram not to scale



The asteroid rotates with angular speed ω .

- (a) By drawing a free-body diagram for the probe, show that the normal force, N , on the probe from the asteroid is given by $N = m\left(\frac{GM}{R^2} - \omega^2 R\right)$. [2]

A large empty rectangular box intended for drawing a free-body diagram for the probe. A faint watermark "BRILLIANT LEARNING" is visible in the background. At the bottom center of the box, there is a small diagram of the probe labeled "probe" and "m".

Two horizontal dotted lines provided for writing the solution to part (a).

(This question continues on the following page)



(Question 5 continued)

- (b) Deduce that the probe will remain on the asteroid surface only if $\omega \leq \sqrt{\frac{GM}{R^3}}$. [1]

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- (c) Another probe orbits the Sun.

- (i) The distance between the probe and the Sun is 4 times the distance between the Earth and the Sun. Show that the intensity of the solar radiation at the surface of the probe is 85 W m^{-2} . [2]

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- (ii) Estimate the equilibrium temperature of the probe assuming it behaves as a black body. [2]

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6. (a) Quarks are elementary particles.

(i) State what is meant by an elementary particle. [1]

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(ii) List the fundamental forces that act on quarks. [1]

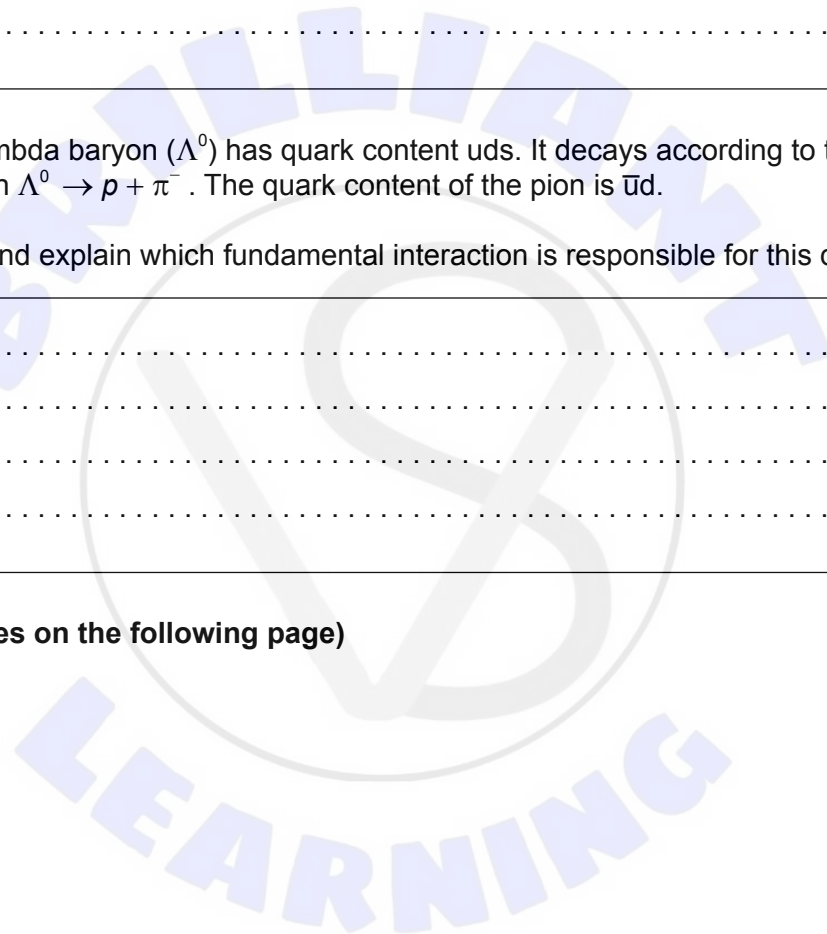
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(iii) The lambda baryon (Λ^0) has quark content uds . It decays according to the reaction $\Lambda^0 \rightarrow p + \pi^-$. The quark content of the pion is $\bar{u}d$.

State and explain which fundamental interaction is responsible for this decay. [2]

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(Question 6 continued)

- (b) (i) By reference to the concept of binding energy, explain why the combined mass of the nucleons of a nucleus is greater than the mass of the nucleus. [2]

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- (ii) The following binding energies per nucleon are available:

Th: 7.645074 MeV
Ra: 7.679917 MeV
He: 7.073915 MeV

Determine the energy released in the decay ${}_{90}^{228}\text{Th} \rightarrow {}_{88}^{224}\text{Ra} + {}_2^4\text{He}$. [2]

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- (iii) It is observed that, sometimes, the alpha decay of thorium is accompanied by gamma ray emission. Suggest an explanation for this observation. [2]

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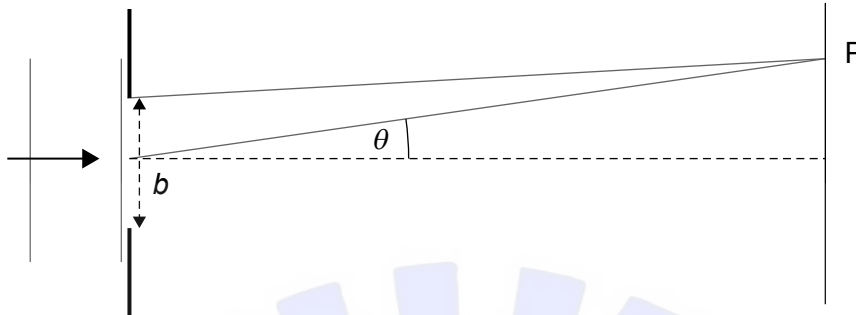
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7. Light of wavelength λ diffracts at a single rectangular slit of opening b . The diagram shows two rays of light leaving the top and middle of the slit. The rays come from the same wavefront. The angle of diffraction is θ . For small angles the approximation $\sin \theta \approx \theta$ may be used.

diagram not to scale



The rays meet at point P on a screen a very large distance from the slit.

- (a) (i) Show that the phase difference between the two rays at P is $\frac{\pi b \theta}{\lambda}$. [2]

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- (ii) The two rays interfere destructively at P to form the first minimum of the single slit diffraction pattern. Explain why $\theta = \frac{\lambda}{b}$. [1]

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(Question 7 continued)

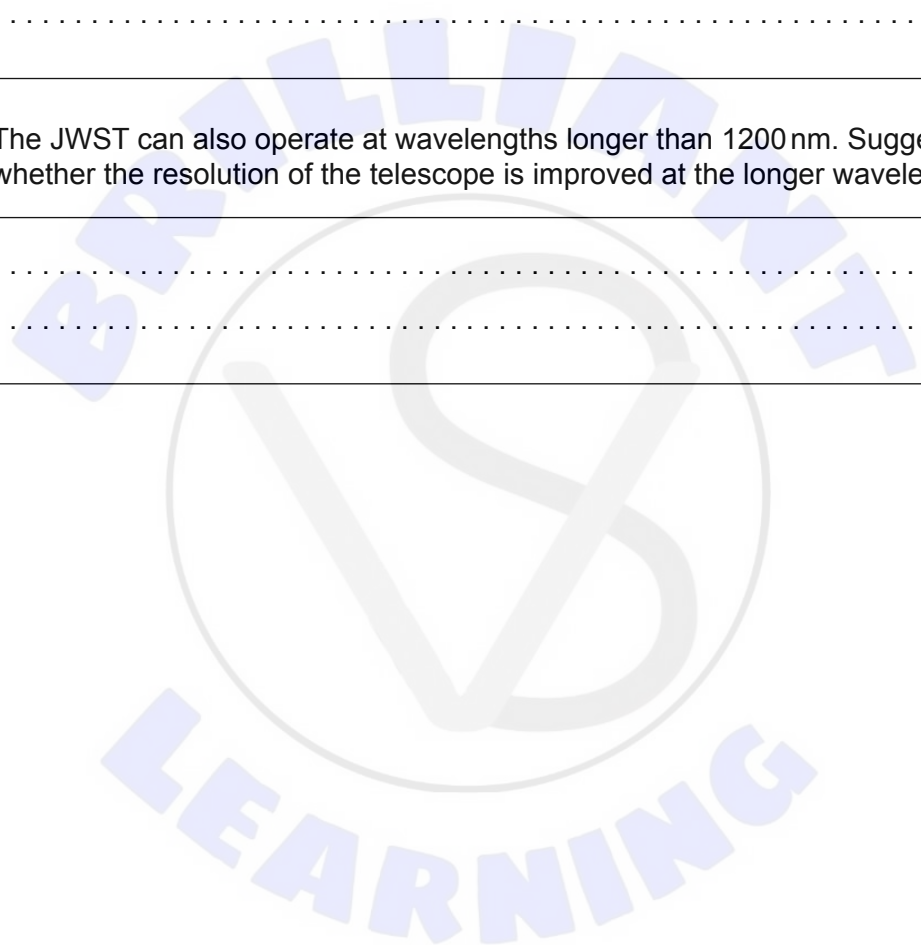
(b) The James Webb Space Telescope (JWST) has an effective diameter of 6.5 m.

(i) Calculate the smallest linear size at a distance of 13.6 billion light years (1.3×10^{26} m) that can be resolved by the JWST when it operates at a wavelength of 1200 nm. [2]

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(ii) The JWST can also operate at wavelengths longer than 1200 nm. Suggest whether the resolution of the telescope is improved at the longer wavelengths. [1]

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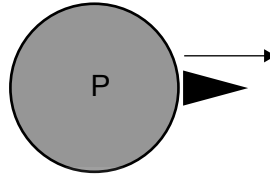
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8. A uniform, spherical planet P has mass M and radius R .

(a) A projectile of mass m is launched with kinetic energy $\frac{2GMm}{3R}$ from the surface of P.

diagram not to scale



Determine whether the projectile will escape the gravitational field of P.

[2]

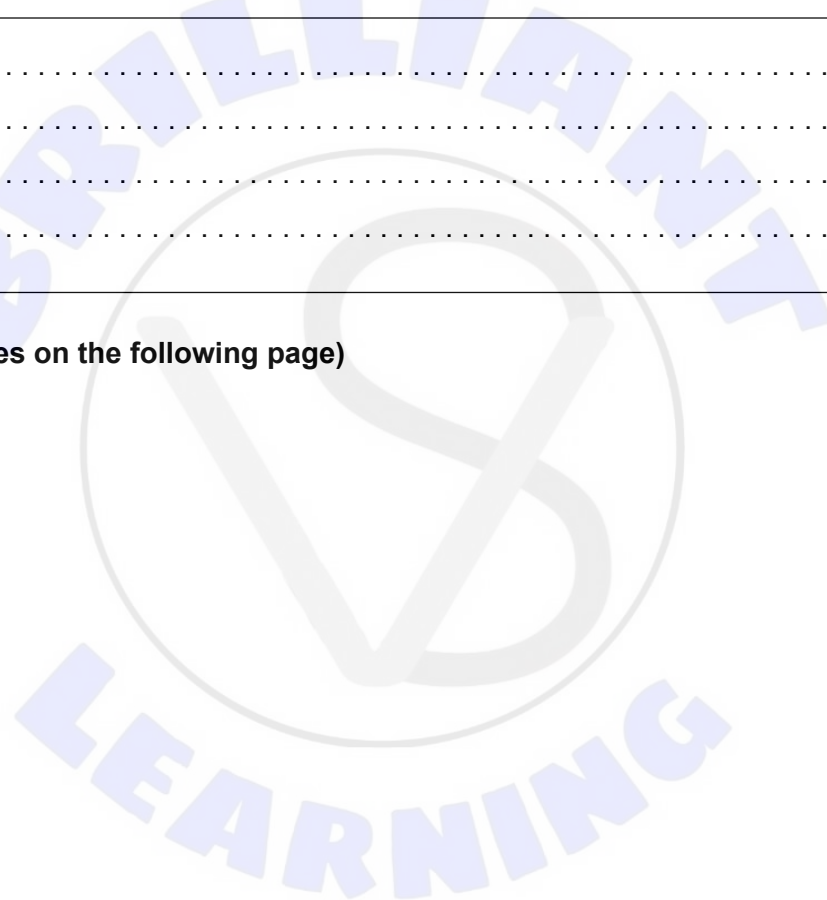
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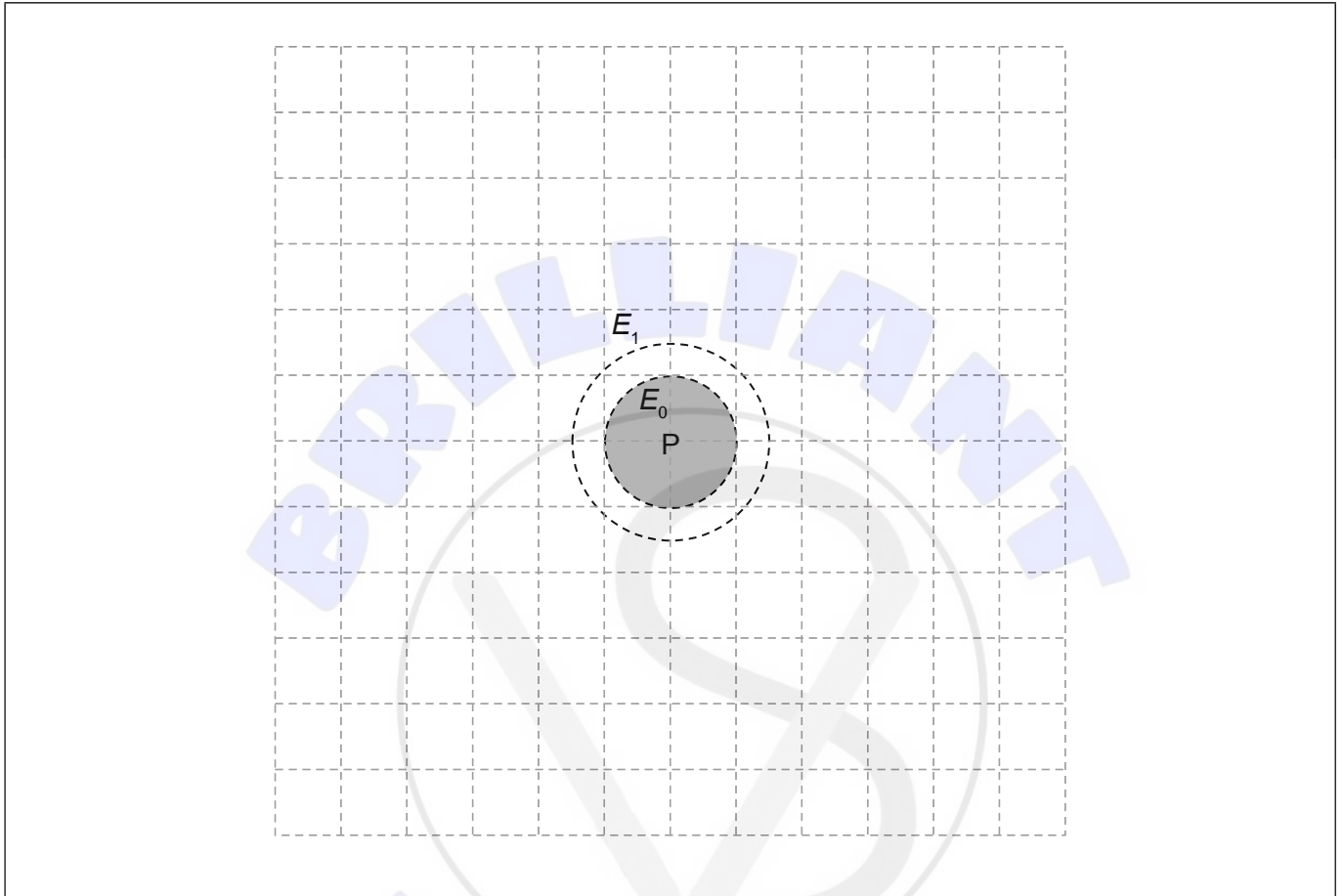
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(Question 8 continued)

- (b) The surface of P is an equipotential surface E_0 . The dotted circle labeled E_1 is an equipotential line at a distance $\frac{3R}{2}$ from the centre of P. The potential difference between E_1 and E_0 is $2.2 \times 10^6 \text{ J kg}^{-1}$.



- (i) The radius R of P is $8.5 \times 10^6 \text{ m}$.

Estimate the magnitude of the gravitational field strength between E_1 and E_0 .

[2]

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(Question 8 continued)

- (ii) E_2 is an equipotential line such that the potential difference between E_2 and E_1 is also $2.2 \times 10^6 \text{ J kg}^{-1}$.

Draw the equipotential line E_2 on the diagram.

[2]

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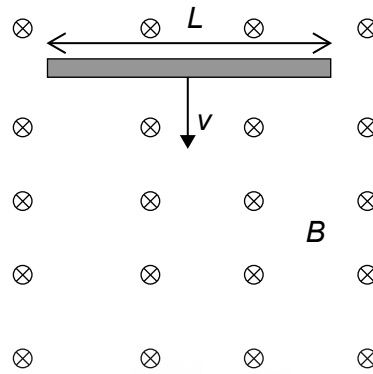


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9. (a) A conducting rod of length L is moved with speed v at right angles to a uniform magnetic field of flux density B . The field is directed into the plane of the page.



- (i) Show, using Faraday's law or otherwise, that the potential difference, V , established between the ends of the rod is $V = vBL$. [3]

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- (ii) Identify the end of the rod that becomes negatively charged. [1]

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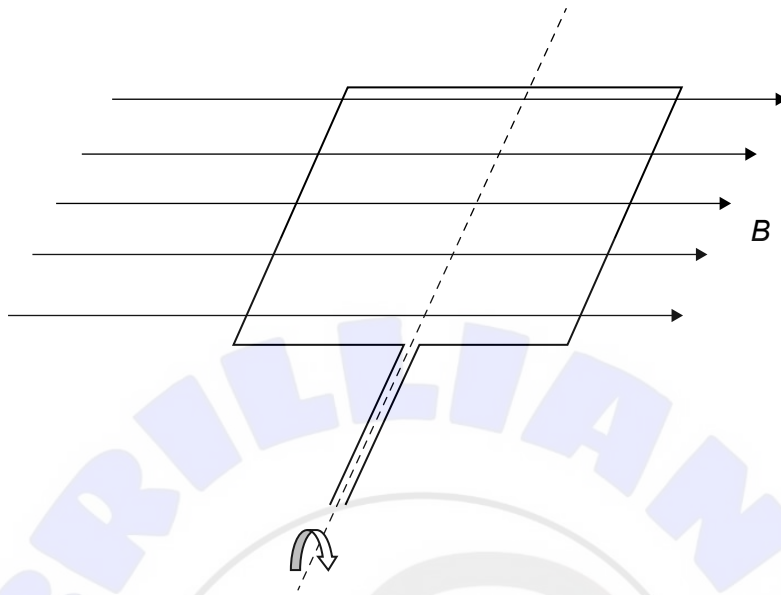
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(Question 9 continued)

- (b) A coil is rotating in a region of magnetic field with angular speed 12.56 rad s^{-1} . At $t = 0$, the field is parallel to the surface of the coil.



- (i) State the magnetic flux linkage through the coil at $t = 0$.

[1]

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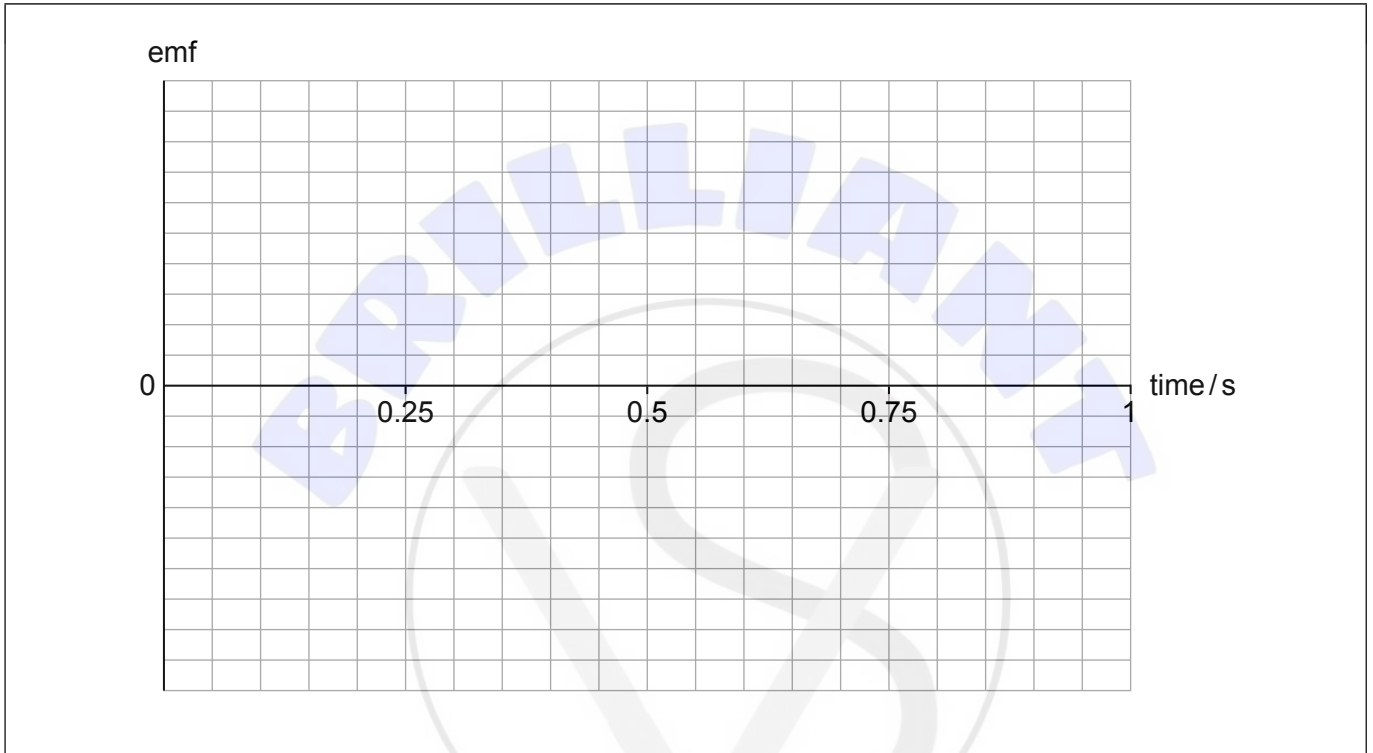
(Question 9 continued)

- (ii) Draw, on the axes, a graph to show the variation with time of the induced emf in the loop. (No numbers are required on the vertical axis.)

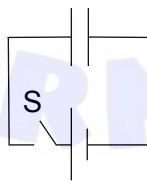
[2]

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- (c) A capacitor is connected to a cell. The switch S is closed and the capacitor becomes fully charged.



A dielectric is then inserted in between the plates of the capacitor. Suggest what, if anything, will happen to the charge on one plate of the capacitor.

[2]

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10. (a) (i) In the Bohr model for the hydrogen atom orbital angular momentum is quantized ($mvr = n\frac{h}{2\pi}$). Outline the effect this has on the electron energy. [1]

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- (ii) For the hydrogen atom, the orbit radius of the electron in the $n = 2$ state is four times larger than the orbit radius in the $n = 1$ state. Determine the ratio $\frac{v_2}{v_1}$ of the electron speed in the $n = 2$ state to the speed in the $n = 1$. [2]

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- (b) Compare and contrast the Bohr prediction for the radius of an electron orbit in hydrogen to that of the description of the electron in terms of a wave function. [2]

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- (c) Determine, using the uncertainty principle, the minimum kinetic energy of a neutron inside a nucleus of radius 3×10^{-15} m. [2]

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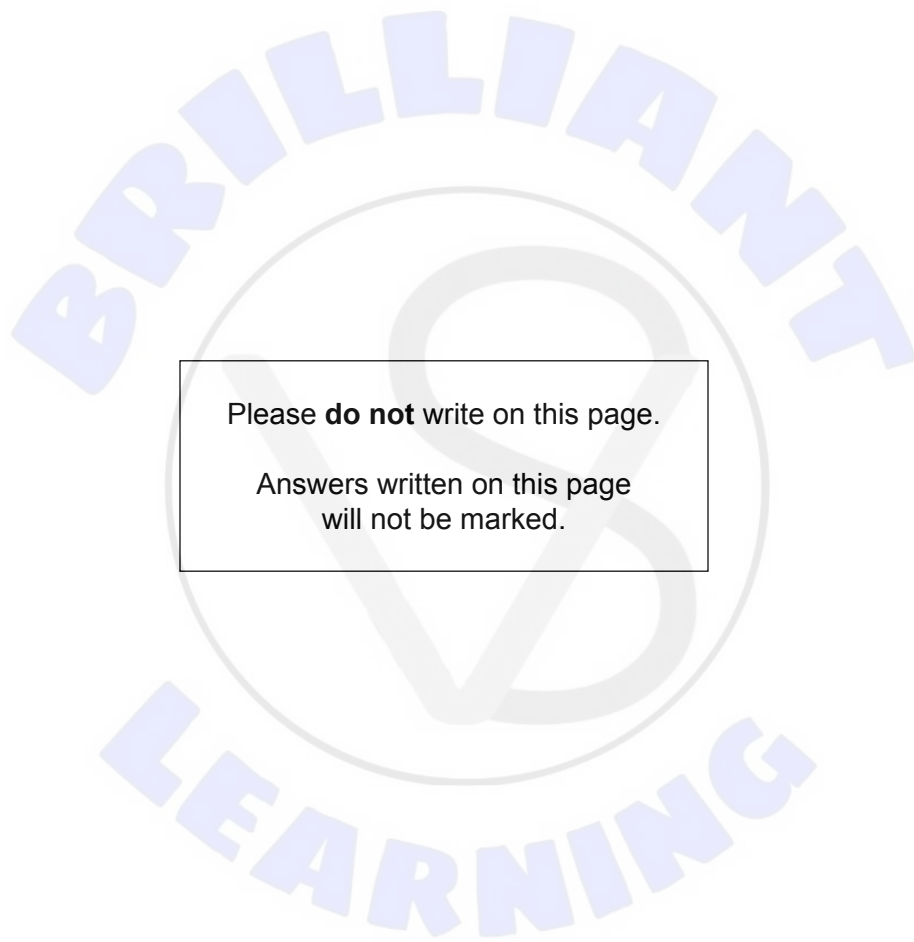




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