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Physics
Higher level
Paper 2

26 October 2023

Zone A afternoon | **Zone B** afternoon | **Zone C** afternoon

Candidate session number

2 hours 15 minutes

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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 space probe of mass 95 kg is designed to land on the surface of an asteroid. The gravitational field strength g of the asteroid at its surface is $2.7 \times 10^{-3} \text{ ms}^{-2}$.

(a) The radius r of the asteroid is 230 km. Calculate the mass of the asteroid.

[2]

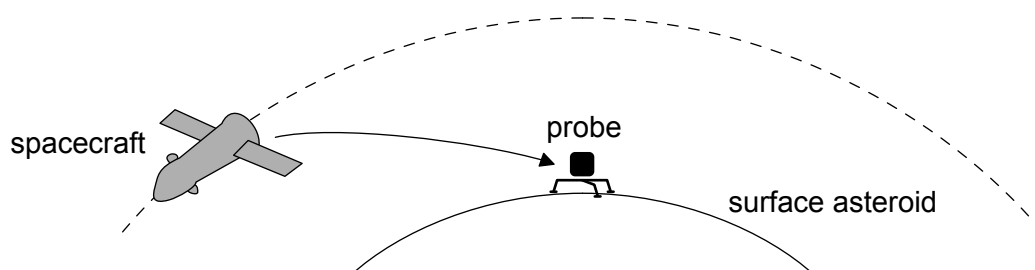
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(b) The probe is carried to the asteroid on board a spacecraft.



Calculate the weight of the probe when close to the surface of the asteroid.

[1]

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(This question continues on the following page)



(Question 1 continued)

- (c) (i) As the probe approaches the surface of the asteroid, a rocket engine is fired to slow its descent. Explain how the engine changes the speed of the probe. [3]

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- (ii) A constant force of 12.0 N is exerted by the rocket engine. Determine the time for which the rocket must fire to reduce the speed of the probe from 0.64 m s^{-1} to zero. State your answer to an appropriate number of significant figures. [4]

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(Question 1 continued)

- (d) (i) Show that the escape speed v_{esc} of the asteroid is given by

$$v_{\text{esc}} = \sqrt{2gr} . \quad [1]$$

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- (ii) Calculate the escape speed of the asteroid.

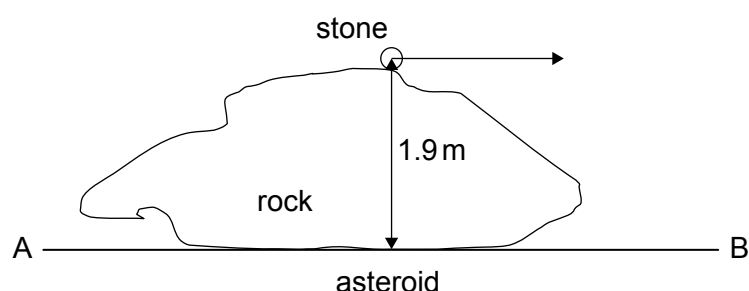
[1]

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- (e) As the probe lands, a small stone resting on a rock on the asteroid's surface is projected horizontally from the top of the rock. The horizontal speed of the stone is 34 ms^{-1} from a height of 1.9 m above the surface of the asteroid.

diagram not to scale



Estimate the horizontal distance from the stone's point of projection along the line AB at which the stone lands. Ignore the curvature of the asteroid.

[2]

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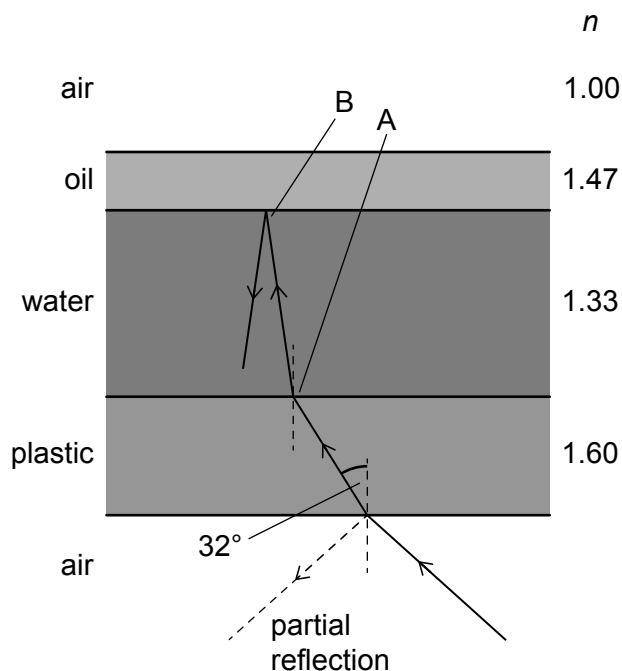
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2. Monochromatic light enters the base of a plastic beaker that contains water with an oil layer floating on it. A student draws a diagram to show the directions the light takes as it passes through the layers. The student's diagram has one **error** at position A and one **error** at position B. The refractive indices of the materials are shown on the diagram.

diagram not to scale



The light is refracted at an angle of 32° when it enters the plastic layer as shown.

(This question continues on the following page)



(Question 2 continued)

(a) Identify, with a reason, the **error** in the student's diagram for

(i) light crossing the plastic–water interface (position A). [2]

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(ii) light at the water–oil interface (position B). [2]

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(b) Calculate the angle of incidence at the air–plastic interface. [2]

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(This question continues on the following page)



(Question 2 continued)

- (c) Calculate the critical angle for the plastic–water interface.

[2]

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- (d) The student hypothesizes that the partially-reflected ray of light from the bottom surface of the plastic is polarized.

- (i) Outline what is meant by polarization.

[1]

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- (ii) Explain how the hypothesis can be tested experimentally.

[2]

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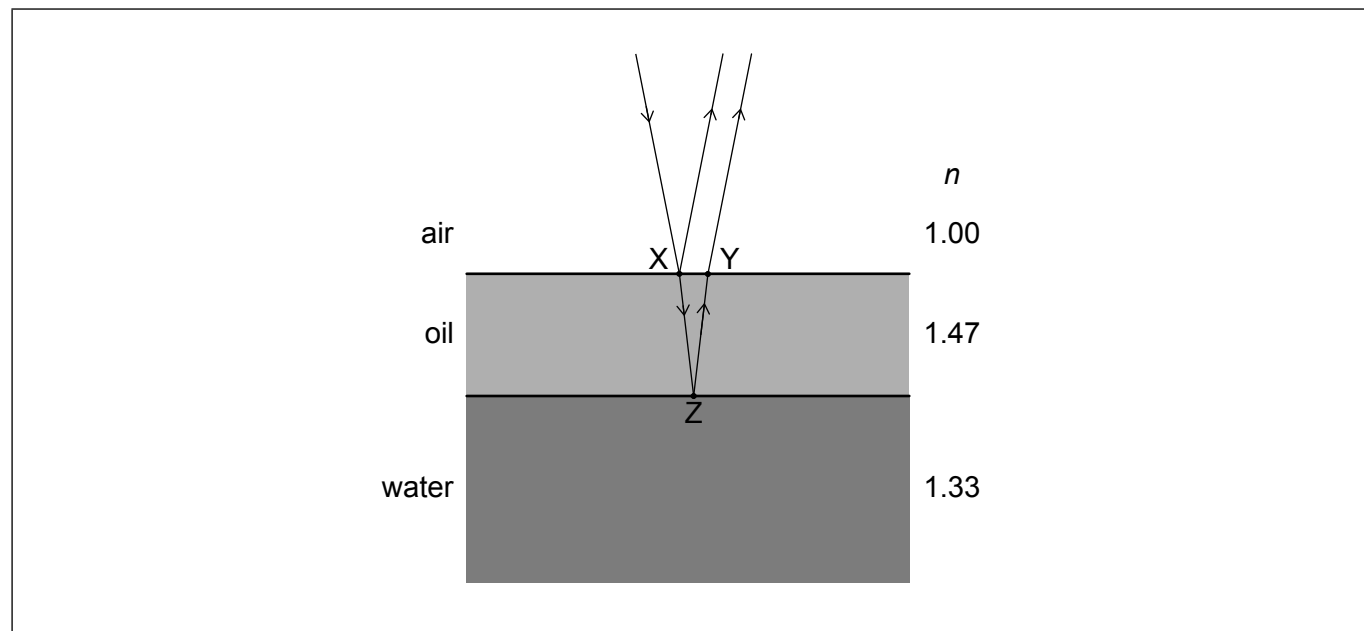
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(Question 2 continued)

- (e) Monochromatic light of wavelength $6.3 \times 10^{-7} \text{ m}$ in air is incident from above at a normal to the oil layer. Rays on the diagram are shown at near-normal incidence for clarity. Three positions X, Y and Z are shown on the diagram.



- (i) Identify, with a reason, a position at which there is a phase change of 180° . [1]

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- (ii) Determine the minimum thickness of the oil layer for which light is **not** reflected. State your answer to an appropriate number of significant figures. [3]

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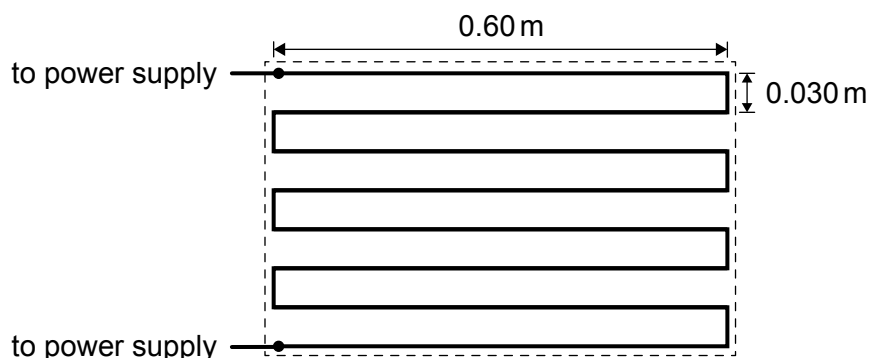
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3. An engineer designs an electric heater to melt ice from the rear window of a car. The heater consists of a single thin metal wire made from a high-resistance alloy. The horizontal parts of the wire are 0.60 m long and are separated by a vertical distance of 0.030 m. The heater is designed for a 12 V supply and for an output power of 150 W.

diagram not to scale



- (a) (i) Calculate the resistance of the heater when it is at its working temperature. [1]

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- (ii) The resistivity of the high-resistance alloy is $1.5 \times 10^{-6} \Omega \text{ m}$. Calculate the radius of the wire. [3]

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(This question continues on the following page)



(Question 3 continued)

- (b) The heater is used to clear a layer of ice from the window over an area indicated by the dotted line on the diagram. The water that has melted immediately flows away from the heater. Determine the minimum time required to melt the ice. [3]

Thickness of ice layer = 0.50 mm
Initial temperature of ice = 0 °C
Density of ice = 900 kg m⁻³
Specific latent heat of fusion of ice = 0.336 MJ kg⁻¹

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- (c) The battery of the car was almost discharged before turning on the heater. Discuss how this is likely to affect your answer to (b). [2]

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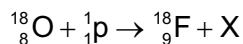
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- (d) Outline **two** reasons why it is important for scientists to research effective solutions for energy storage using battery technology. [2]

1.
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2.
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4. Fluorine-18 ($^{18}_9\text{F}$) can be created when a proton travelling at high speed interacts with an oxygen-18 ($^{18}_8\text{O}$) nucleus. The following gives the nuclear equation for this process.



- (a) (i) Identify X.

[1]

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- (ii) Explain why the proton must be travelling at high speed for this process to occur.

[3]

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- (b) Fluorine-18 is a positron emitter; it is injected into a patient during a medical procedure. The initial activity required for the procedure is 1.5 GBq. The patient is unsafe to others until this activity has decreased.

$$\text{Decay constant of fluorine-18} = 1.1 \times 10^{-4} \text{ s}^{-1}$$

Calculate the time taken for the activity to decrease from its initial value to 1.2 MBq. Assume that none of the fluorine leaves the body of the patient during this time.

[2]

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(This question continues on the following page)



(Question 4 continued)

(c) A positron can also be produced through the process of pair production.

(i) State the relationship between particles emitted in pair production. [1]

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(ii) Identify the other particle produced during the pair production. [1]

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(iii) Suggest why pair production can only occur when a single photon is close to a nucleus. [2]

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(iv) Suggest what is likely to happen to the positron after its production. [1]

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5. The table shows some of the energy levels for a hydrogen atom.

	Level	Energy / eV
Ionized state	$n = \infty$	0
Excited states	$n = 3$	–1.51
	$n = 2$	–3.40
Ground state	$n = 1$	–13.6

- (a) Distinguish between an atom in an excited state and an atom in an ionized state.

[1]

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- (b) Explain how electromagnetic radiation is emitted from a hydrogen atom in an excited state.

[2]

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(Question 5 continued)

- (c) When radiation of wavelength $6.6 \times 10^{-7} \text{ m}$ is incident on cold hydrogen gas some of it is absorbed by the gas.

- (i) State the region of the electromagnetic spectrum of this radiation. [1]

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- (ii) Determine the initial and final states of the hydrogen atom that are involved in this absorption. [3]

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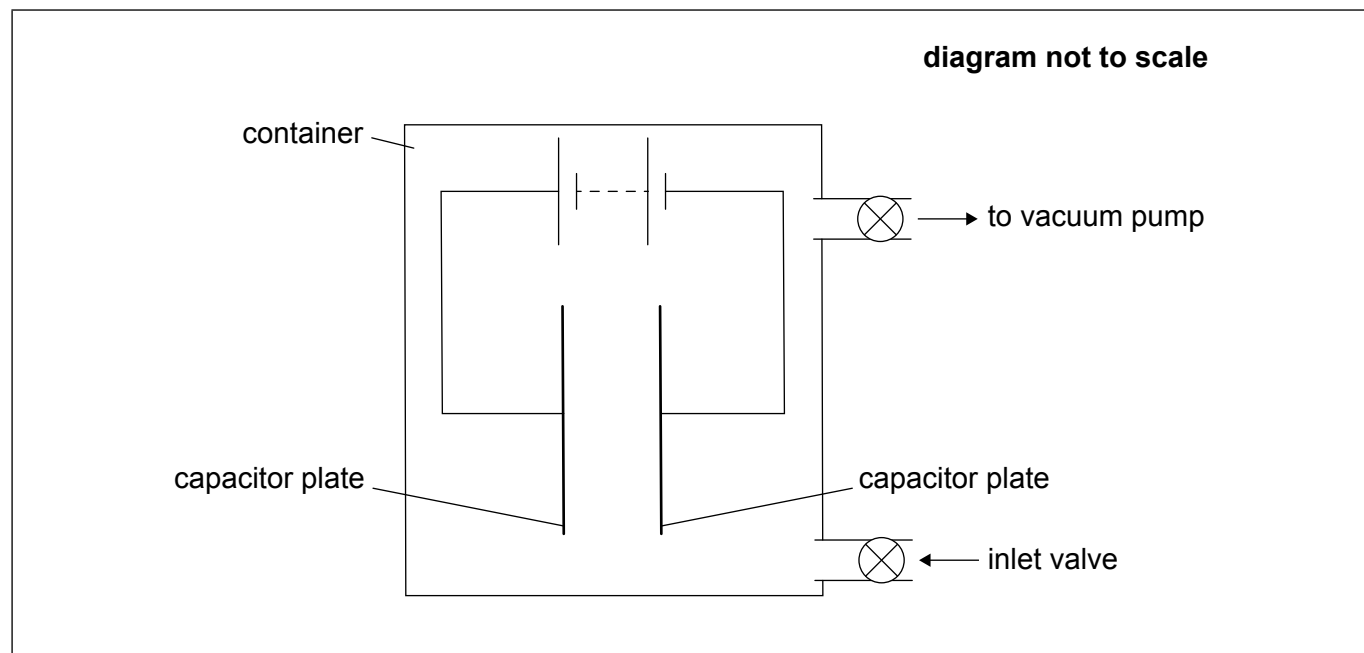


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6. A capacitor consists of two square metal plates, arranged parallel to each other and connected across a power supply that has an internal resistance. The capacitor is in a container that can be either evacuated with a vacuum pump or filled with a gas.



- (a) The container is evacuated so that there is no air between the plates. The plates are initially uncharged and the power supply is switched on.
- (i) Draw, on the diagram, the arrangement of electric field lines between the plates. [2]
- (ii) The capacitor has a capacitance of 75 pF. The separation of the plates is 3.2 mm. Determine the length of one side of a plate. [2]

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- (iii) The emf of the power supply is 16 kV. Calculate the maximum charge stored on the capacitor. [1]

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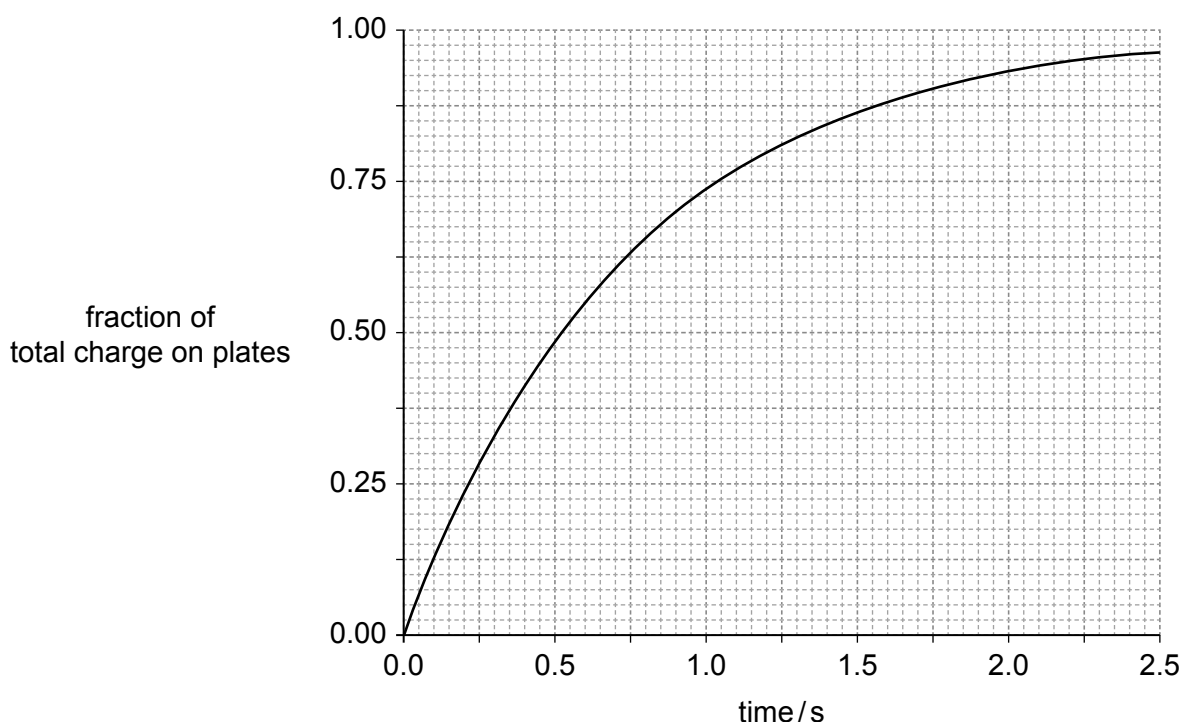
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(Question 6 continued)

- (b) The graph shows the variation with time of the fraction of the total charge on the plates after the power supply is switched on with no air in the container.



The container is now opened to the atmosphere so that there is air between the plates. This air is observed to conduct and discharge the capacitor when the potential difference between the plates exceeds 9.0 kV. Assume that the capacitance of the capacitor is unchanged when air is present.

- (i) Calculate the minimum electric field strength between the plates at which the capacitor will discharge.

[1]

(This question continues on the following page)



(Question 6 continued)

- (ii) Determine, using the graph, the time taken for the air to become conducting for the first time. [2]

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- (c) The air is replaced by a gas that has a larger relative permittivity than that of air. This gas also conducts when the potential difference between the plates exceeds 9.0 kV. Explain how the time in (b)(ii) changes when the air is replaced by the gas. [2]

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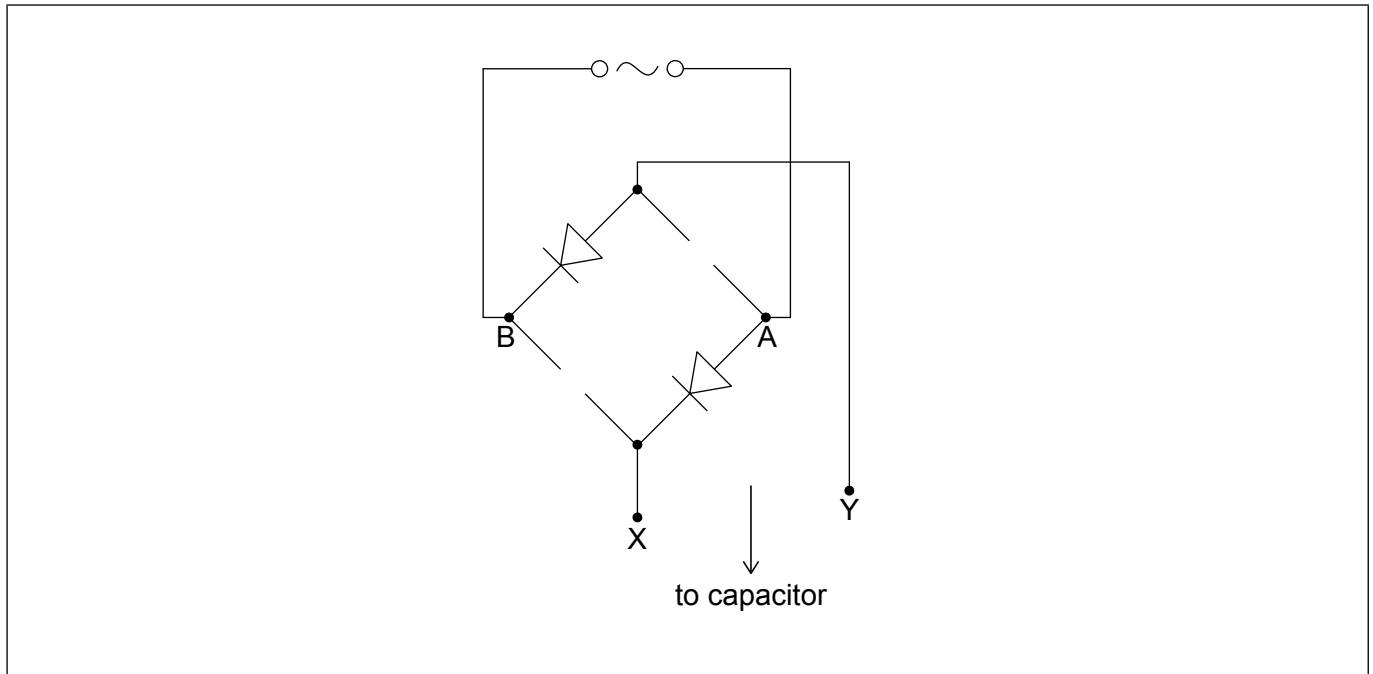
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(Question 6 continued)

- (d) The direct current (dc) power supply is to be replaced by an alternating current (ac) power supply and a full-wave rectifier. An incomplete diagram of the rectifier and power supply is shown.



- (i) Draw, on the diagram, the remainder of the diode bridge. [1]
- (ii) Outline, with reference to points A and B in the arrangement, why charge can only flow in one direction through the output terminals XY of the rectifier. [3]

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7. Ceres is a dwarf planet in the asteroid belt. The following data are available.

Mean distance of Ceres from the Sun = $4.4 \times 10^{11} \text{ m}$

Mean power output of the Sun = $3.8 \times 10^{26} \text{ W}$

- (a) (i) Determine the mean temperature of Ceres assuming that it acts as a black-body radiator.

[3]

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- (ii) Ceres has a solid rocky core covered with solid ice. The mean temperature is higher than your answer in (a)(i) because radioactive nuclei in the centre of Ceres are decaying. Outline how the energy from the radioactive decay reaches the surface.

[2]

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(This question continues on the following page)



(Question 7 continued)

- (b) At low temperatures such as the mean temperature of Ceres, water undergoes a phase change directly from solid to gas.

- (i) Compare the molecular conditions of the solid phase and the gas phase at the same temperature. [3]

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- (ii) The maximum surface temperature of Ceres is -38°C . Observations show that significant quantities of water vapour are released from the surface of Ceres every second when the temperature is at this maximum. Calculate the mean kinetic energy of a molecule of water vapour at this temperature. [1]

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- (iii) The following data are available.

$$\text{Radius of Ceres} = 4.7 \times 10^5 \text{ m}$$

$$\text{Mass of Ceres} = 9.0 \times 10^{20} \text{ kg}$$

Show that the gravitational potential at the surface of Ceres is about -10^5 J kg^{-1} . [1]

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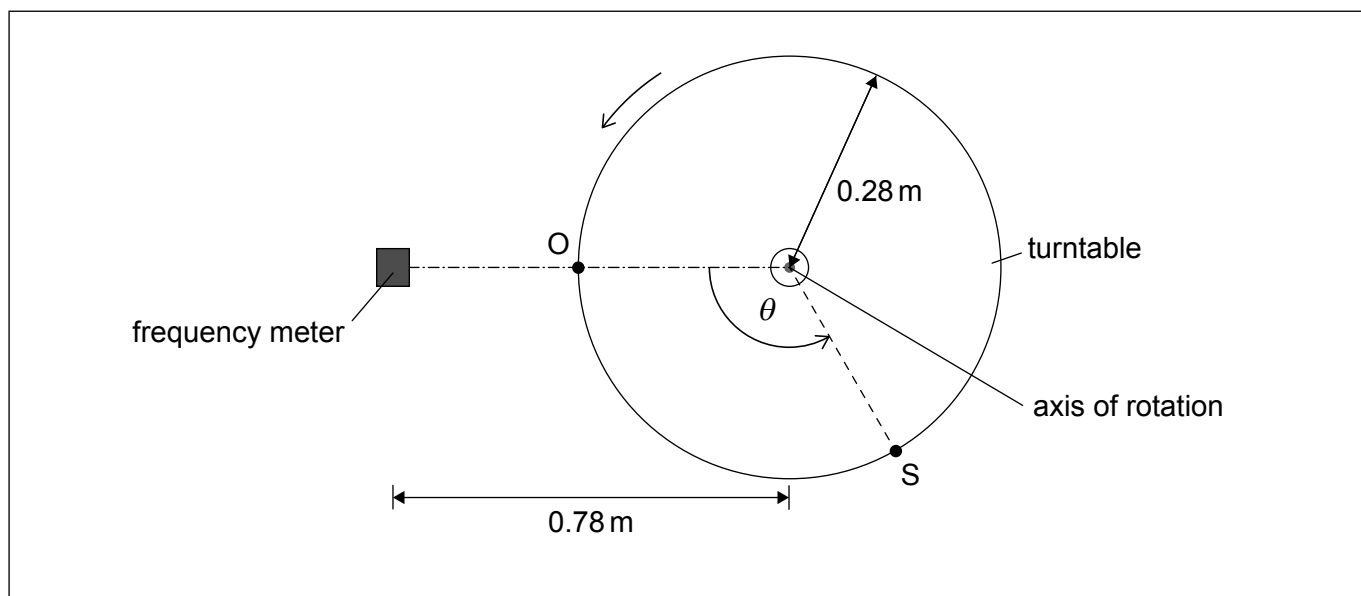
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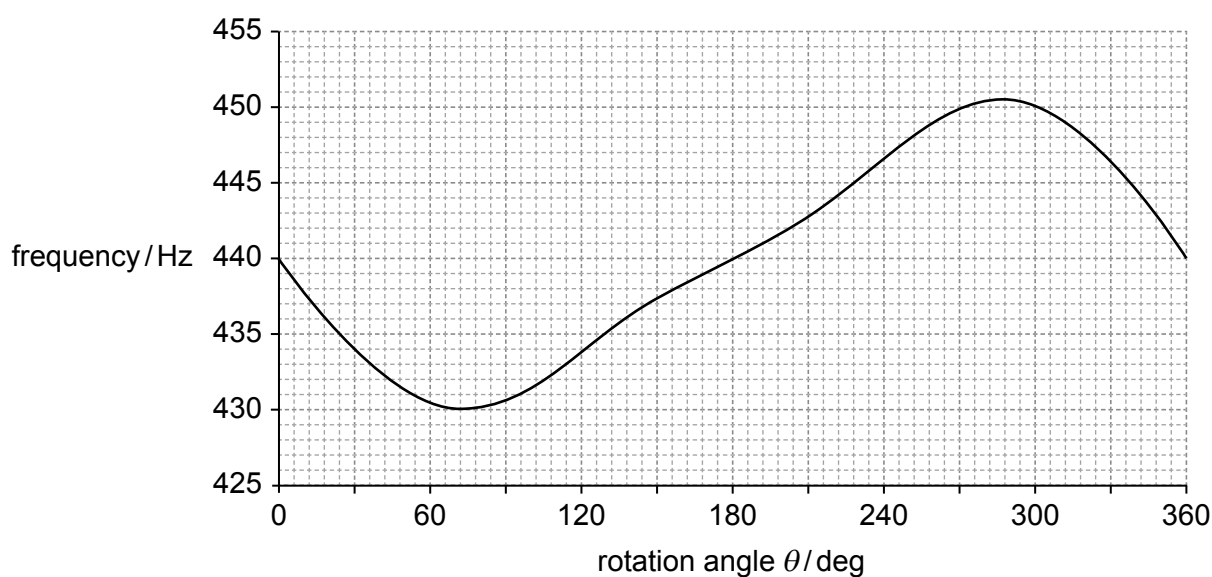
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8. The **diagram** shows a point source of sound S on the edge of a horizontal turntable that rotates about a vertical axis. The sound is detected using a small stationary frequency meter placed 0.78 m from the axis of the turntable. The turntable has a radius of 0.28 m. The linear speed of S is much less than the speed of sound.



The **graph** shows the variation of the detected frequency with rotation angle θ for one revolution of the turntable.



(This question continues on the following page)



(Question 8 continued)

- (a) (i) Identify, on the **diagram**, the position of S for which the detected frequency is at a maximum. Label this position A. [1]
- (ii) Outline why this maximum frequency shift does not occur when $\theta = 90^\circ$ or when $\theta = 270^\circ$. [2]

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- (b) Determine the angular speed of the turntable. The speed of sound is 330 m s^{-1} . State an appropriate unit for your answer. [5]

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