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Diploma Programme
Programme du diplôme
Programa del Diploma

Physics
Higher level
Paper 2

Wednesday 28 October 2020 (afternoon)

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]**.

25 pages

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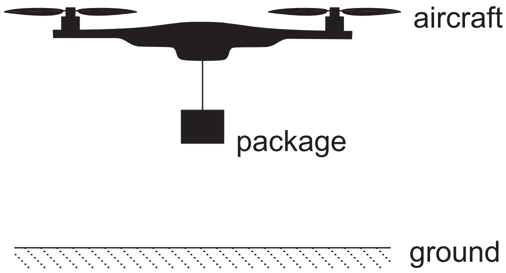
Answer **all** questions. Answers must be written within the answer boxes provided.

1. A company delivers packages to customers using a small unmanned aircraft. Rotating horizontal blades exert a force on the surrounding air. The air above the aircraft is initially stationary.



The air is propelled vertically downwards with speed *v*. The aircraft hovers motionless above the ground. A package is suspended from the aircraft on a string. The mass of the aircraft is 0.95 kg and the combined mass of the package and string is 0.45 kg. The mass of air pushed downwards by the blades in one second is 1.7 kg.

(a) (i) State the value of the resultant force on the aircraft when hovering. [1]

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(ii) Outline, by reference to Newton's third law, how the upward lift force on the aircraft is achieved. [2]

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(iii) Determine *v*. State your answer to an appropriate number of significant figures. [3]

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(Question 1 continued)

(iv) Calculate the power transferred to the air by the aircraft. [2]

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(b) The package and string are now released and fall to the ground. The lift force on the aircraft remains unchanged. Calculate the initial acceleration of the aircraft. [2]

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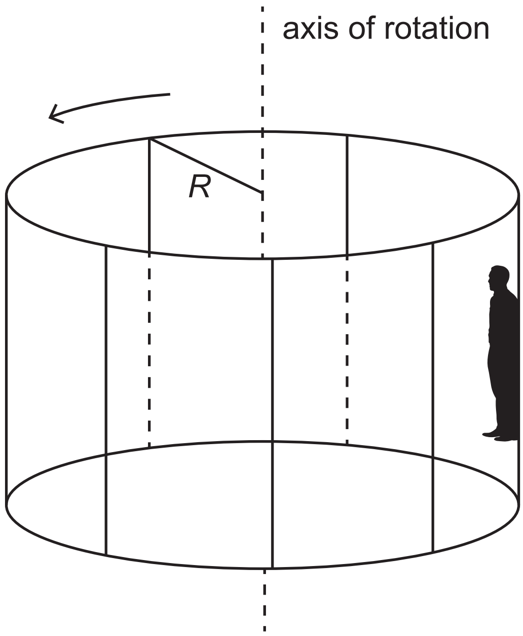
2. The Rotor is an amusement park ride that can be modelled as a vertical cylinder of inner radius R rotating about its axis. When the cylinder rotates sufficiently fast, the floor drops out and the passengers stay motionless against the inner surface of the cylinder. The diagram shows a person taking the Rotor ride. The floor of the Rotor has been lowered away from the person.



(a) Draw and label the free-body diagram for the person. [2]

(This question continues on the following page)

(Question 2 continued)

(b) The person must not slide down the wall. Show that the minimum angular velocity ω of the cylinder for this situation is

$$\omega = \sqrt{\frac{g}{\mu R}}$$

where μ is the coefficient of static friction between the person and the cylinder. [2]

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(c) The coefficient of static friction between the person and the cylinder is 0.40. The radius of the cylinder is 3.5 m. The cylinder makes 28 revolutions per minute. Deduce whether the person will slide down the inner surface of the cylinder. [3]

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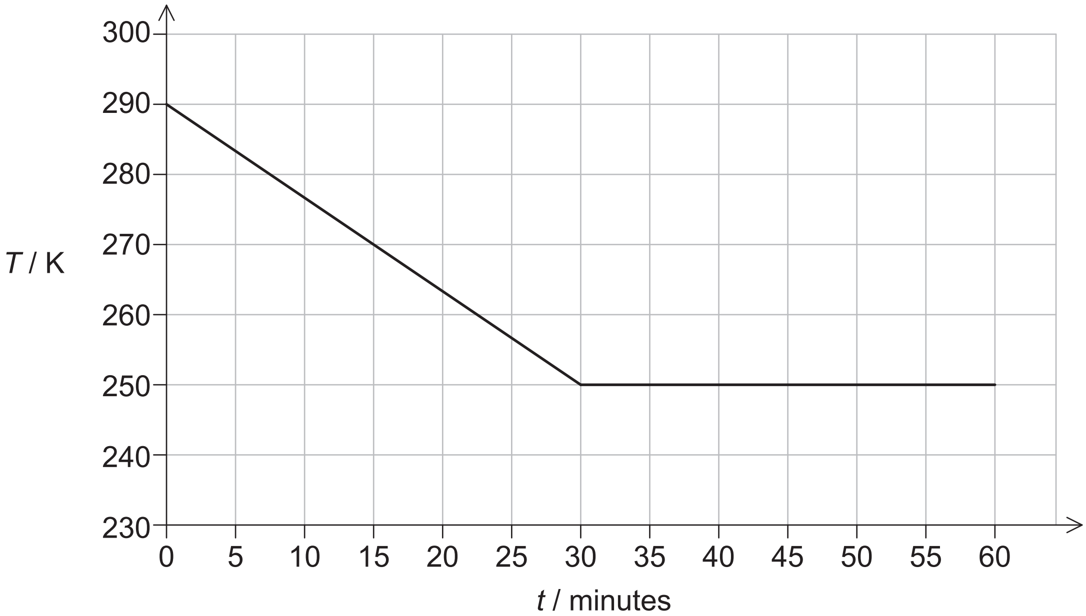
3. A sample of vegetable oil, initially in the liquid state, is placed in a freezer that transfers thermal energy from the sample at a constant rate. The graph shows how temperature T of the sample varies with time t.



The following data are available.

Mass of the sample = 0.32 kg
Specific latent heat of fusion of the oil = 130 kJ kg^{-1}
Rate of thermal energy transfer = 15 W

(a) (i) Calculate the thermal energy transferred from the sample during the first 30 minutes. [1]

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(ii) Estimate the specific heat capacity of the oil in its liquid phase. State an appropriate unit for your answer. [2]

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(Question 3 continued)

(b) The sample begins to freeze during the thermal energy transfer. Explain, in terms of the molecular model of matter, why the temperature of the sample remains constant during freezing. [3]

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(c) Calculate the mass of the oil that remains unfrozen after 60 minutes. [2]

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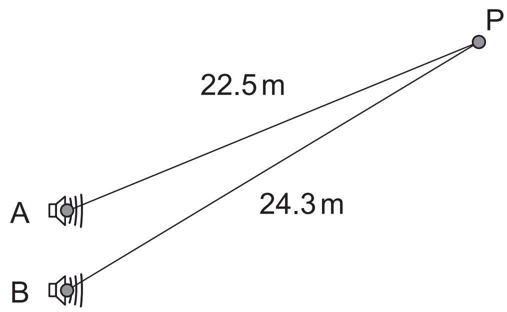
4. Two loudspeakers, A and B, are driven in phase and with the same amplitude at a frequency of 850 Hz. Point P is located 22.5 m from A and 24.3 m from B. The speed of sound is 340 m s^{-1}.



(a) Deduce that a minimum intensity of sound is heard at P. [4]

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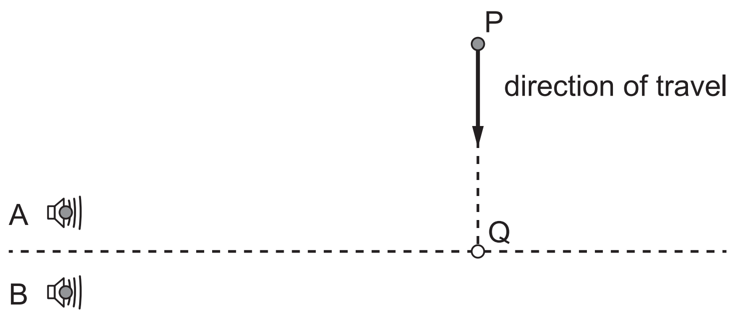
(Question 4 continued)

(b) A microphone moves along the line from P to Q. PQ is normal to the line midway between the loudspeakers.



The intensity of sound is detected by the microphone. Predict the variation of detected intensity as the microphone moves from P to Q. [2]

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(c) When both loudspeakers are operating, the intensity of sound recorded at Q is I_0. Loudspeaker B is now disconnected. Loudspeaker A continues to emit sound with unchanged amplitude and frequency. The intensity of sound recorded at Q changes to I_A.

Estimate $\frac{I_A}{I_0}$. [2]

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(Question 4 continued)

(d) In another experiment, loudspeaker A is stationary and emits sound with a frequency of 850 Hz. The microphone is moving directly away from the loudspeaker with a constant speed *v*. The frequency of sound recorded by the microphone is 845 Hz.

(i) Explain why the frequency recorded by the microphone is lower than the frequency emitted by the loudspeaker. [2]

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(ii) Calculate *v*. [2]

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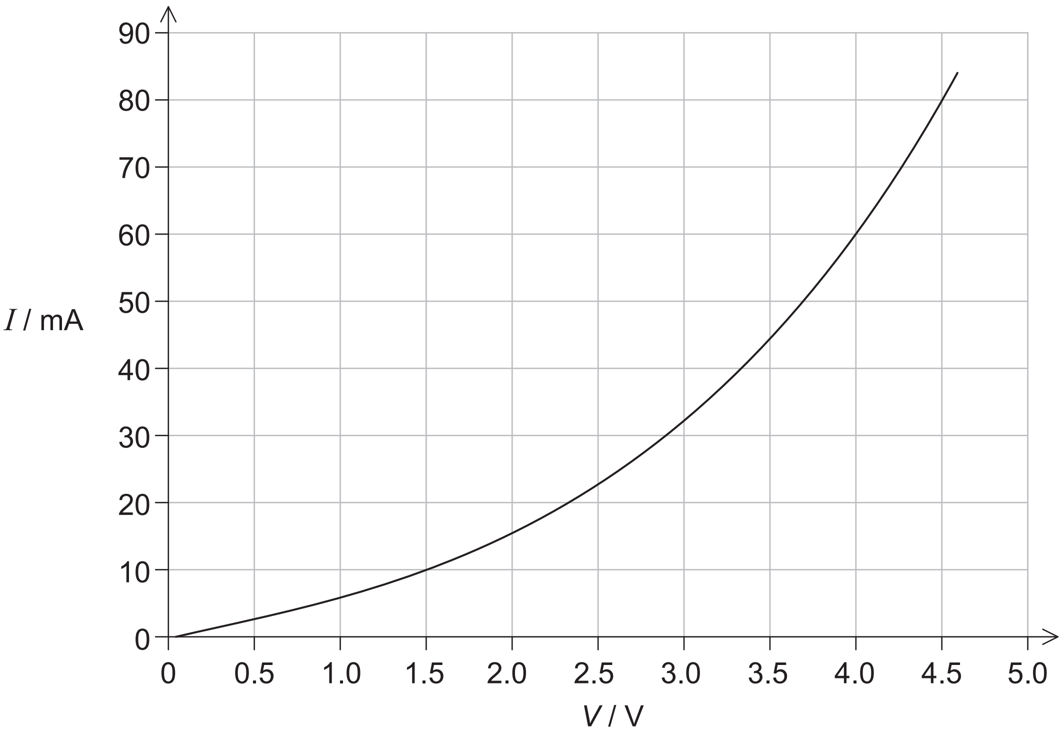
5. The graph shows how current I varies with potential difference V across a component X.



(a) Outline why component X is considered non-ohmic. [1]

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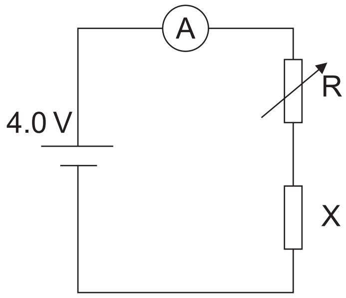
(Question 5 continued)

(b) Component X and a cell of negligible internal resistance are placed in a circuit. A variable resistor R is connected in series with component X. The ammeter reads 20 mA.



(i) Determine the resistance of the variable resistor. [3]

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(ii) Calculate the power dissipated in the circuit. [1]

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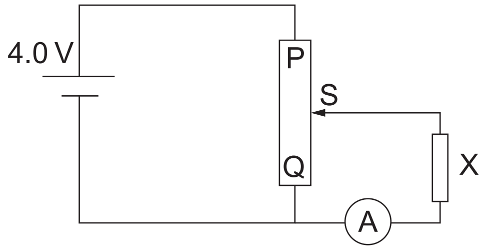
(Question 5 continued)

(c) Component X and the cell are now placed in a potential divider circuit.



(i) State the range of current that the ammeter can measure as the slider S of the potential divider is moved from Q to P. [1]

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(ii) Slider S of the potential divider is positioned so that the ammeter reads 20 mA. Explain, without further calculation, any difference in the power transferred by the potential divider arrangement over the arrangement in (b). [3]

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6. (a) One possible fission reaction of uranium-235 (U-235) is

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2^{1}_{0}n$$

The following data are available.

Mass of one atom of U-235 = 235 u
Binding energy per nucleon for U-235 = 7.59 MeV
Binding energy per nucleon for Xe-140 = 8.29 MeV
Binding energy per nucleon for Sr-94 = 8.59 MeV

(i) State what is meant by binding energy of a nucleus. [1]

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(ii) Outline why quantities such as atomic mass and nuclear binding energy are often expressed in non-SI units. [1]

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(iii) Show that the energy released in the reaction is about 180 MeV. [1]

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(b) A nuclear power station uses U-235 as fuel. Assume that every fission reaction of U-235 gives rise to 180 MeV of energy.

(i) Estimate, in $J\,kg^{-1}$, the specific energy of U-235. [2]

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(Question 6 continued)

(ii) The power station has a useful power output of 1.2 GW and an efficiency of 36 %. Determine the mass of U-235 that undergoes fission in one day. [2]

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(iii) The specific energy of fossil fuel is typically 30 $MJ\,kg^{-1}$. Suggest, with reference to your answer to (b)(i), **one** advantage of U-235 compared with fossil fuels in a power station. [1]

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(c) A sample of waste produced by the reactor contains 1.0 kg of strontium-94 (Sr-94). Sr-94 is radioactive and undergoes beta-minus (β^-) decay into a daughter nuclide X. The reaction for this decay is

$$^{94}_{38}\mathrm{Sr} \rightarrow \mathrm{X} + \bar{\nu}_e + e.$$

(i) Write down the proton number of nuclide X. [1]

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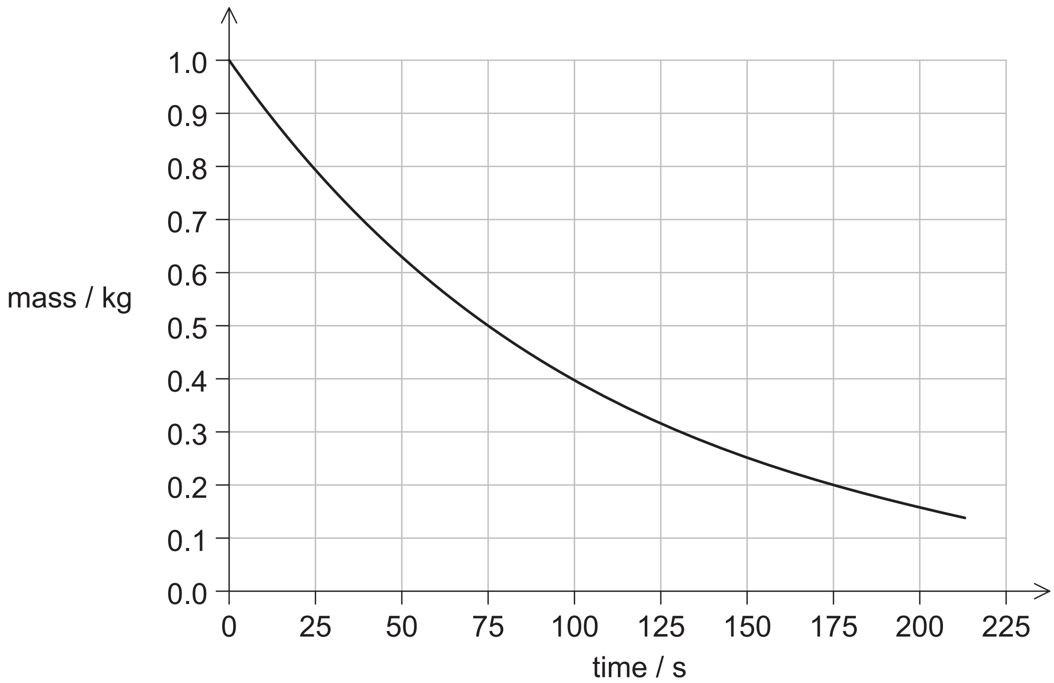
(Question 6 continued)

The graph shows the variation with time of the mass of Sr-94 remaining in the sample.



(ii) State the half-life of Sr-94. [1]

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(iii) Calculate the mass of Sr-94 remaining in the sample after 10 minutes. [2]

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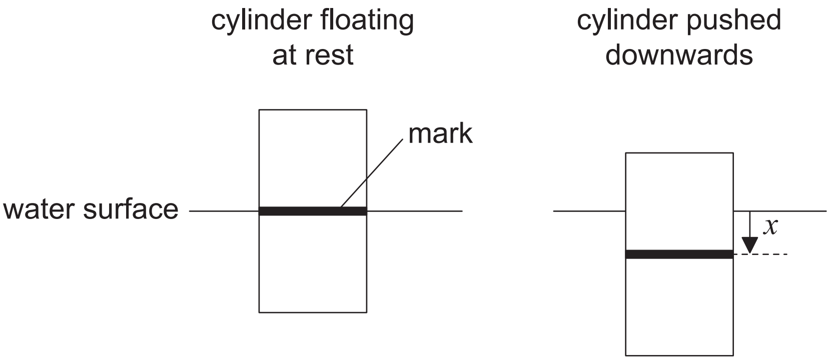
7. A vertical solid cylinder of uniform cross-sectional area A floats in water. The cylinder is partially submerged. When the cylinder floats at rest, a mark is aligned with the water surface. The cylinder is pushed vertically downwards so that the mark is a distance x below the water surface.



At time $t = 0$ the cylinder is released. The resultant vertical force F on the cylinder is related to the displacement x of the mark by

$$F = -\rho A g x$$

where ρ is the density of water.

(a) Outline why the cylinder performs simple harmonic motion when released. [1]

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(b) The mass of the cylinder is 118 kg and the cross-sectional area of the cylinder is $2.29 \times 10^{-1}\,\text{m}^2$. The density of water is $1.03 \times 10^{3}\,\text{kg}\,\text{m}^{-3}$. Show that the angular frequency of oscillation of the cylinder is about $4.4\ \text{rad s}^{-1}$. [2]

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(Question 7 continued)

(c) The cylinder was initially pushed down a distance $x = 0.250\,\text{m}$.

(i) Determine the maximum kinetic energy E_{kmax} of the cylinder. [2]

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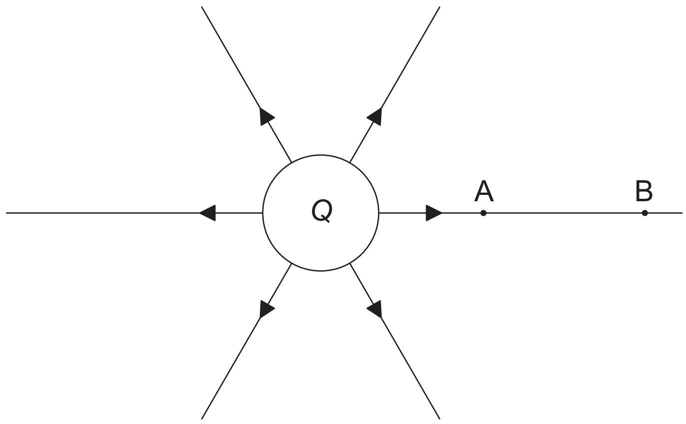
(ii) Draw, on the axes, the graph to show how the kinetic energy of the cylinder varies with time during **one** period of oscillation T. [2]

8. The diagram shows the electric field lines of a positively charged conducting sphere of radius R and charge Q.



Points A and B are located on the same field line.

(a) Explain why the electric potential decreases from A to B. [2]

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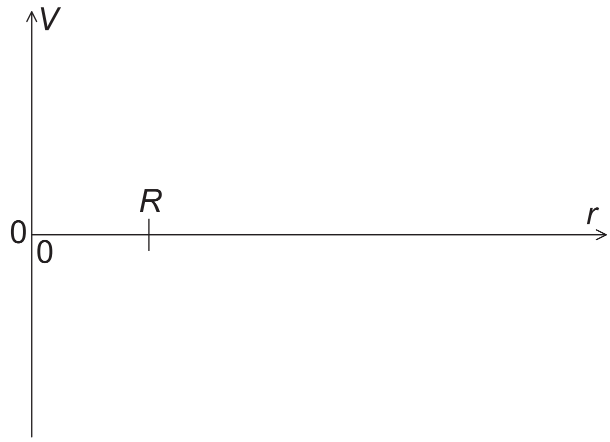
(b) Draw, on the axes, the variation of electric potential V with distance r from the centre of the sphere. [2]



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(Question 8 continued)

(c) A proton is placed at A and released from rest. The magnitude of the work done by the electric field in moving the proton from A to B is 1.7×10^{-16} J. Point A is at a distance of 5.0×10^{-2} m from the centre of the sphere. Point B is at a distance of 1.0×10^{-1} m from the centre of the sphere.

(i) Calculate the electric potential difference between points A and B. [1]

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(ii) Determine the charge Q of the sphere. [2]

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(d) The concept of potential is also used in the context of gravitational fields. Suggest why scientists developed a common terminology to describe different types of fields. [1]

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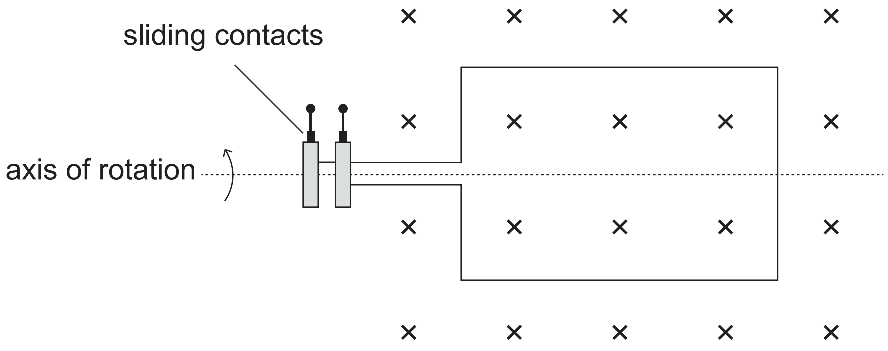
9. The diagram shows an alternating current generator with a rectangular coil rotating at a constant frequency in a uniform magnetic field.



(a) Explain, by reference to Faraday's law of induction, how an electromotive force (emf) is induced in the coil. [3]

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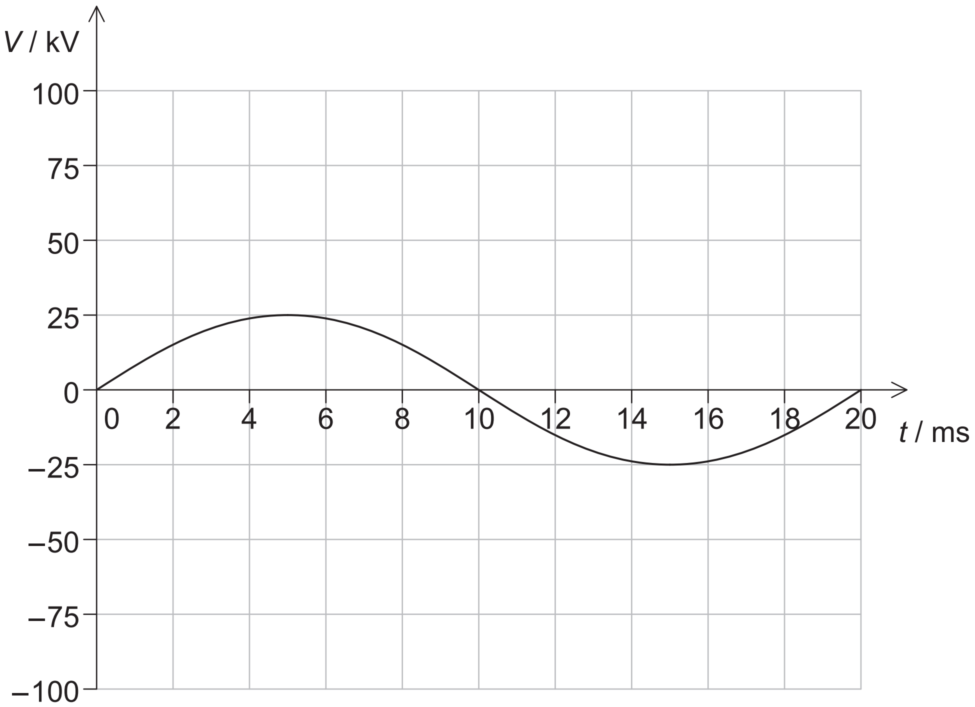
(Question 9 continued)

(b) The graph shows how the generator output voltage V varies with time t.



Electrical power produced by the generator is delivered to a consumer some distance away.

(i) The average power output of the generator is 8.5×10^5 W. Calculate the root mean square (rms) value of the generator output current. [2]

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(Question 9 continued)

(ii) The voltage output from the generator is stepped up before transmission to the consumer. Estimate the factor by which voltage has to be stepped up in order to reduce power loss in the transmission line by a factor of 2.5×10^2. [1]

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(iii) The frequency of the generator is doubled with no other changes being made. Draw, on the axes, the variation with time of the voltage output of the generator. [2]

10. The de Broglie wavelength λ of a particle accelerated close to the speed of light is approximately

$$\lambda \approx \frac{hc}{E}$$

where E is the energy of the particle.
A beam of electrons of energy 4.2×10^{8} eV is produced in an accelerator.

(a) Show that the wavelength of an electron in the beam is about 3×10^{-15} m. [1]

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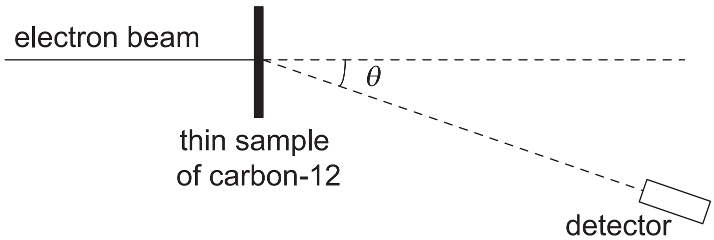
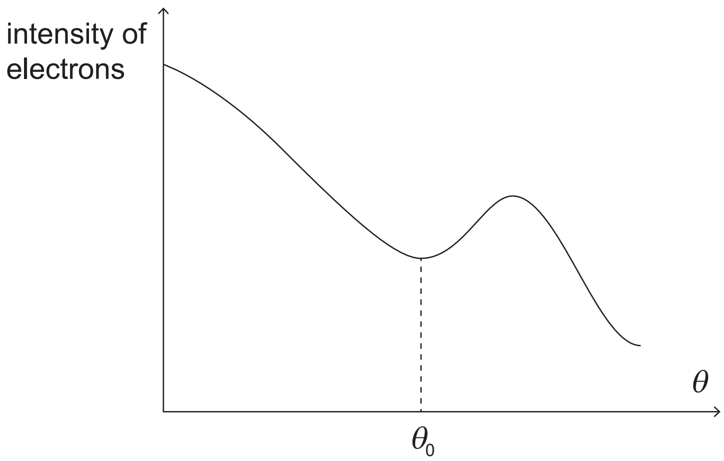
(b) The electron beam is used to study the nuclear radius of carbon-12. The beam is directed from the left at a thin sample of carbon-12. A detector is placed at an angle θ relative to the direction of the incident beam.



The graph shows the variation of the intensity of electrons with θ. There is a minimum of intensity for $\theta = \theta_0$.



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(Question 10 continued)

(i) Discuss how the results of the experiment provide evidence for matter waves. [2]

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(ii) The accepted value of the diameter of the carbon-12 nucleus is 4.94×10^{-15} m. Estimate the angle θ_0 at which the minimum of the intensity is formed. [2]

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(iii) Outline why electrons with energy of approximately 10^7 eV would be unsuitable for the investigation of nuclear radii. [2]

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(c) Experiments with many nuclides suggest that the radius of a nucleus is proportional to $A^{\frac{1}{3}}$, where A is the number of nucleons in the nucleus. Show that the density of a nucleus remains approximately the same for all nuclei. [2]

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