Diploma Programme
Programme du diplôme
Programa del Diploma

Physics
Higher level
Paper 2

Tuesday 30 October 2018 (afternoon)

2 hours 15 minutes

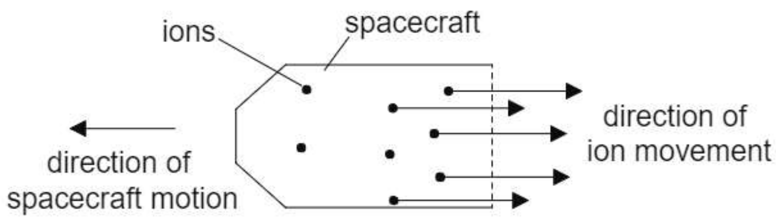
Candidate session number

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 **[95 marks]**.

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

1. Ion-thrust engines can power spacecraft. In this type of engine, ions are created in a chamber and expelled from the spacecraft. The spacecraft is in outer space when the propulsion system is turned on. The spacecraft starts from rest.



The mass of ions ejected each second is 6.6×10^{-6} kg and the speed of each ion is $5.2 \times 10^{4}\ \mathrm{m\,s^{-1}}$. The initial total mass of the spacecraft and its fuel is 740 kg. Assume that the ions travel away from the spacecraft parallel to its direction of motion.

(a) Determine the initial acceleration of the spacecraft. [2]

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(Question 1 continued)

(b) An initial mass of 60 kg of fuel is in the spacecraft for a journey to a planet. Half of the fuel will be required to slow down the spacecraft before arrival at the destination planet.

(i) Estimate the maximum speed of the spacecraft. [2]

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(ii) Outline why the answer to (b)(i) is an estimate. [1]

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(iii) Outline why scientists sometimes use estimates in making calculations. [1]

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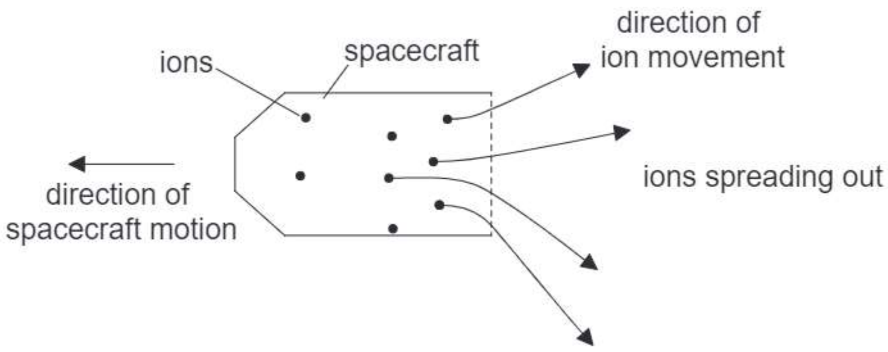
will not be marked.

(Question 1 continued from page 3)

(c) In practice, the ions leave the spacecraft at a range of angles as shown.



(i) Outline why the ions are likely to spread out. [2]

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(ii) Explain what effect, if any, this spreading of the ions has on the acceleration of the spacecraft. [2]

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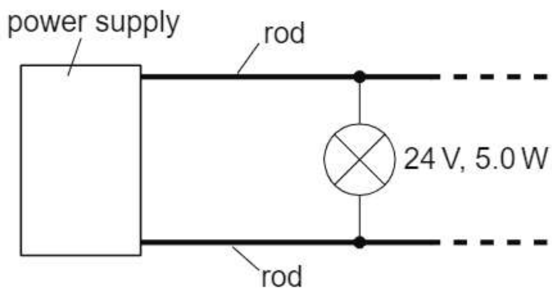
2. A lighting system consists of two long metal rods with a potential difference maintained between them. Identical lamps can be connected between the rods as required.



The following data are available for the lamps when at their working temperature.

Lamp specifications	24 V, 5.0 W
Power supply root mean square (rms) emf	24 V
Power supply maximum rms current	8.0 A
Length of each rod	12.5 m
Resistivity of rod metal	$7.2 \times 10^{-7}\ \Omega\,\text{m}$

(a) Each rod is to have a resistance no greater than $0.10\ \Omega$. Calculate, in m, the minimum radius of each rod. Give your answer to an appropriate number of significant figures. [3]

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(b) Calculate the maximum number of lamps that can be connected between the rods. Neglect the resistance of the rods. [2]

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(Question 2 continued)

(c) One advantage of this system is that if one lamp fails then the other lamps in the circuit remain lit. Outline **one** other electrical advantage of this system compared to one in which the lamps are connected in series. [1]

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(d) A step-down transformer is used to transfer energy to the two rods. The primary coil of this transformer is connected to an alternating mains supply that has an emf of root mean square (rms) magnitude 240 V. The transformer is 95 % efficient.

(i) Outline how eddy currents reduce transformer efficiency. [2]

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(ii) Determine the peak current in the primary coil when operating with the maximum number of lamps. [4]

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3. (a) Define *impulse*. [1]

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(b) A chicken's egg of mass 58 g is dropped onto grass from a height of 1.1 m. Assume that air resistance is negligible and that the egg does not bounce or break.

(i) Show that the kinetic energy of the egg just before impact is about 0.6 J. [1]

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(ii) The egg comes to rest in a time of 55 ms. Determine the magnitude of the average decelerating force that the ground exerts on the egg. [4]

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(Question 3 continued)

(iii) Explain why the egg is likely to break when dropped onto concrete from the same height. [2]

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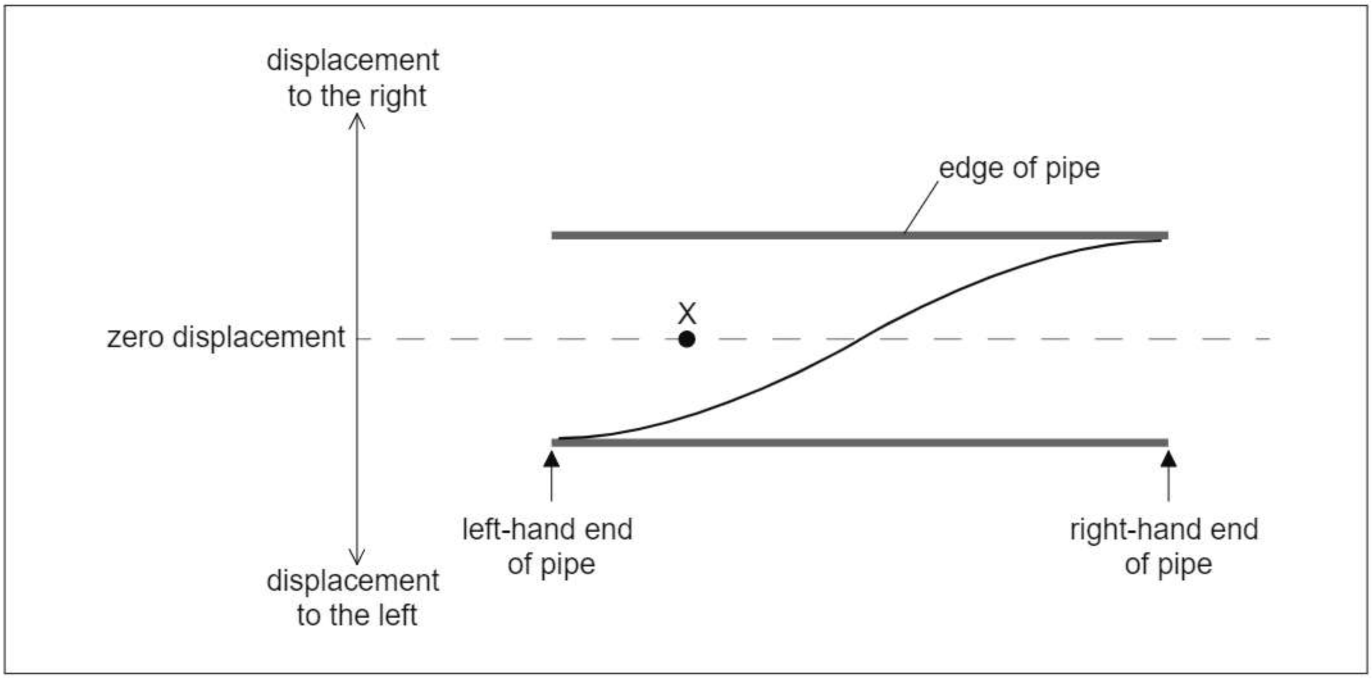
4. A pipe is open at both ends. A first-harmonic standing wave is set up in the pipe. The diagram shows the variation of displacement of air molecules in the pipe with distance along the pipe at time $t = 0$. The frequency of the first harmonic is f.



(a) (i) Sketch, on the diagram, the variation of displacement of the air molecules with distance along the pipe when $t = \dfrac{3}{4f}$. [1]

(ii) An air molecule is situated at point X in the pipe at $t = 0$. Describe the motion of this air molecule during one complete cycle of the standing wave beginning from $t = 0$. [2]

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(Question 4 continued)

(b) The speed of sound c for longitudinal waves in air is given by

$$c = \sqrt{\frac{K}{\rho}}$$

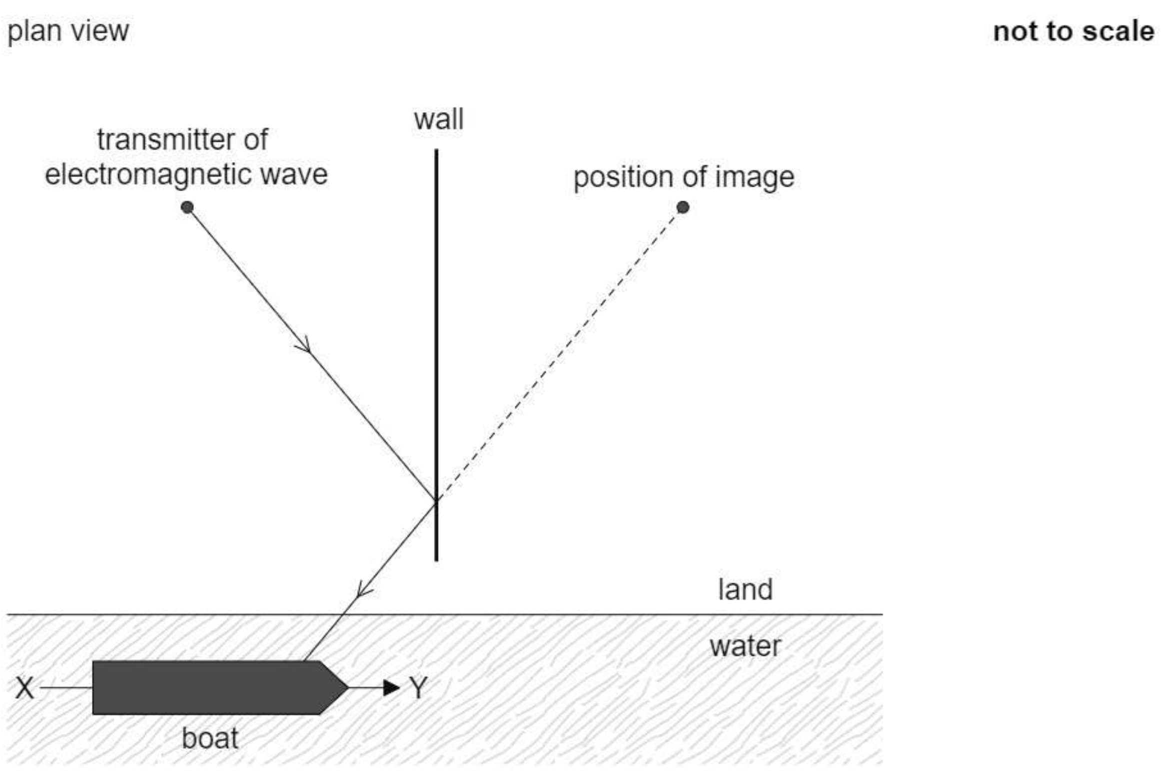
where ρ is the density of the air and K is a constant.

A student measures f to be 120 Hz when the length of the pipe is 1.4 m. The density of the air in the pipe is 1.3 kg m^{-3}. Determine the value of K for air. State your answer with the appropriate fundamental (SI) unit. [4]

(This question continues on the following page)

(Question 4 continued)

(c) A transmitter of electromagnetic waves is next to a long straight vertical wall that acts as a plane mirror to the waves. An observer on a boat detects the waves both directly and as an image from the other side of the wall. The diagram shows one ray from the transmitter reflected at the wall and the position of the image.



(i) Demonstrate, using a second ray, that the image appears to come from the position indicated. [1]

(ii) Outline why the observer detects a series of increases and decreases in the intensity of the received signal as the boat moves along the line XY. [2]

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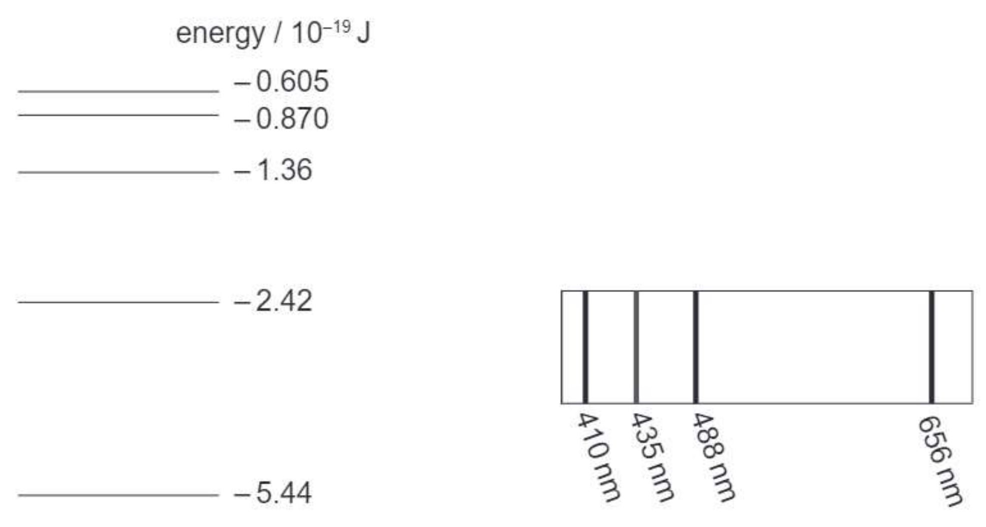
5. (a) The diagram shows the position of the principal lines in the visible spectrum of atomic hydrogen and some of the corresponding energy levels of the hydrogen atom.



(i) Determine the energy of a photon of blue light (435nm) emitted in the hydrogen spectrum. [3]

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(ii) Identify, with an arrow labelled B on the diagram, the transition in the hydrogen spectrum that gives rise to the photon with the energy in (a)(i). [1]

(iii) Explain your answer to (a)(ii). [2]

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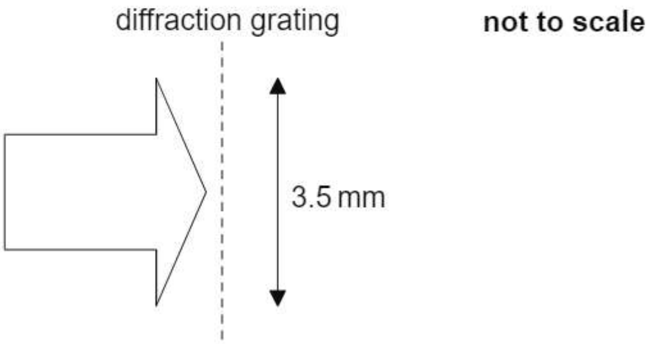
(Question 5 continued)

(b) A low-pressure hydrogen discharge lamp contains a small amount of deuterium gas in addition to the hydrogen gas. The deuterium spectrum contains a red line with a wavelength very close to that of the hydrogen red line. The wavelengths for the principal lines in the visible spectra of deuterium and hydrogen are given in the table.

	Hydrogen wavelength / nm	**Deuterium wavelength / nm**
Red line	656.288	656.107
Violet line	410.180	410.048

Light from the discharge lamp is normally incident on a diffraction grating.



(i) The light illuminates a width of 3.5 mm of the grating. The deuterium and hydrogen red lines can just be resolved in the second-order spectrum of the diffraction grating. Show that the grating spacing of the diffraction grating is about 2×10^{-6} m. [2]

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(Question 5 continued)

(ii) Calculate the angle between the first-order line of the red light in the hydrogen spectrum and the second-order line of the violet light in the hydrogen spectrum. [3]

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(iii) The light source is changed so that white light is incident on the diffraction grating. Outline the appearance of the diffraction pattern formed with white light. [3]

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6. (a) (i) State how the density of a nucleus varies with the number of nucleons in the nucleus. [1]

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(ii) Show that the nuclear radius of phosphorus-31 $\left({}^{31}_{15}P\right)$ is about 4 fm. [1]

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(b) ${}^{32}_{15}P$ is formed when a nucleus of deuterium $\left({}^{2}_{1}H\right)$ collides with a nucleus of ${}^{31}_{15}P$. The radius of a deuterium nucleus is 1.5 fm.

(i) State the maximum distance between the centres of the nuclei for which the production of ${}^{32}_{15}P$ is likely to occur. [1]

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(ii) Determine, in J, the minimum initial kinetic energy that the deuterium nucleus must have in order to produce ${}^{32}_{15}P$. Assume that the phosphorus nucleus is stationary throughout the interaction and that only electrostatic forces act. [2]

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(Question 6 continued)

(c) $^{32}_{15}P$ undergoes beta-minus (β^-) decay. Explain why the energy gained by the emitted beta particles in this decay is not the same for every beta particle. [2]

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(d) (i) State what is meant by decay constant. [2]

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(ii) In a fresh pure sample of $^{32}_{15}P$ the activity of the sample is 24 Bq. After one week the activity has become 17 Bq. Calculate, in s^{-1}, the decay constant of $^{32}_{15}P$. [3]

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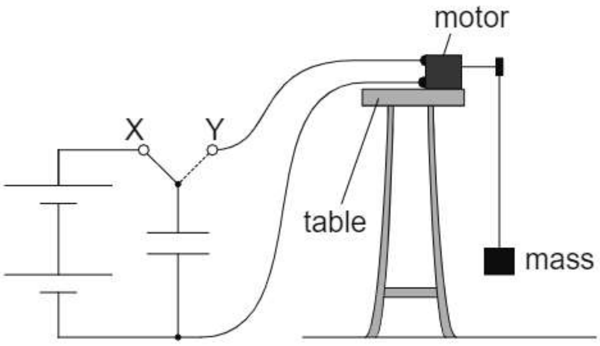
7. A small electric motor is used with a 12 mF capacitor and a battery in a school experiment.



When the switch is connected to X, the capacitor is charged using the battery. When the switch is connected to Y, the capacitor fully discharges through the electric motor that raises a small mass.

(a) The battery has an emf of 7.5 V. Determine the charge that flows through the motor when the mass is raised. [1]

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(b) The motor can transfer one-third of the electrical energy stored in the capacitor into gravitational potential energy of the mass. Determine the maximum height through which a mass of 45 g can be raised. [2]

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(Question 7 continued)

(c) An additional identical capacitor is connected in series with the first capacitor and the charging and discharging processes are repeated. Comment on the effect this change has on the height and time taken to raise the 45 g mass. [3]

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8. There is a proposal to place a satellite in orbit around planet Mars.

(a) (i) Outline what is meant by gravitational field strength at a point. [2]

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(ii) Newton's law of gravitation applies to point masses. Suggest why the law can be applied to a satellite orbiting Mars. [2]

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(Question 8 continued)

(b) The satellite is to have an orbital time T equal to the length of a day on Mars. It can be shown that

$$T^2 = kR^3$$

where R is the orbital radius of the satellite and k is a constant.

(i) Mars has a mass of 6.4×10^{23} kg. Show that, for Mars, k is about $9 \times 10^{-13}\ \text{s}^2\ \text{m}^{-3}$. [3]

(ii) The time taken for Mars to revolve on its axis is 8.9×10^4 s. Calculate, in m s^{-1}, the orbital speed of the satellite. [2]

(This question continues on the following page)

(Question 8 continued)

(c) The ratio $\frac{\text{distance of Mars from the Sun}}{\text{distance of Earth from the Sun}} = 1.5$.

(i) Show that the intensity of solar radiation at the orbit of Mars is about $600\ \text{W m}^{-2}$. [2]

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(ii) Determine, in K, the mean surface temperature of Mars. Assume that Mars acts as a black body. [2]

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(iii) The atmosphere of Mars is composed mainly of carbon dioxide and has a pressure less than 1 % of that on Earth. Outline why the mean temperature of Earth is strongly affected by gases in its atmosphere but that of Mars is not. [3]

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9. Liquid oxygen at its boiling point is stored in an insulated tank. Gaseous oxygen is produced from the tank when required using an electrical heater placed in the liquid.

The following data are available.

Mass of 1.0 mol of oxygen = 32 g
Specific latent heat of vaporization of oxygen = 2.1×10^5 J kg^{-1}

(a) Distinguish between the internal energy of the oxygen at the boiling point when it is in its liquid phase and when it is in its gas phase. [2]

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(b) An oxygen flow rate of 0.25 mol s^{-1} is needed.

(i) Calculate, in kW, the heater power required. [2]

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(ii) Calculate the volume of the oxygen produced in one second when it is allowed to expand to a pressure of 0.11 MPa and to reach a temperature of –13 °C. [2]

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(Question 9 continued)

(c) State **one** assumption of the kinetic model of an ideal gas that does not apply to oxygen. [1]

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