Diploma Programme
Programme du diplôme
Programa del Diploma

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Physics
Higher level
Paper 2

30 April 2025

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

Candidate session number

2 hours 30 minutes

Instructions to candidates

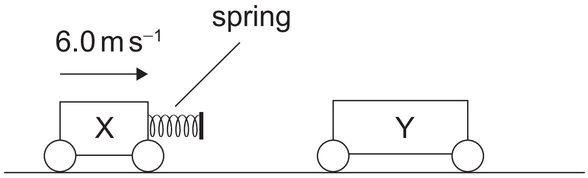
- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **physics data booklet** is required for this paper.
- The maximum mark for this examination paper is **[90 marks]**.

24 pages

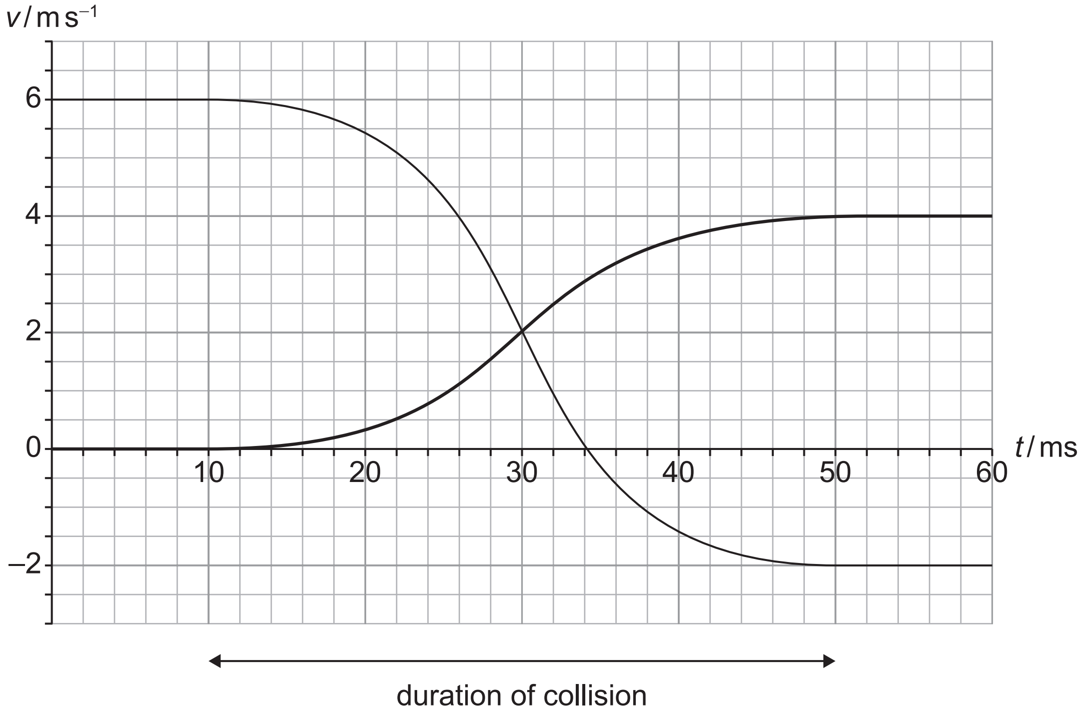
2225 – 6715

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

1. A cart X of mass 3.0 kg moving at 6.0 m s^{-1} collides with a stationary cart Y of mass 6.0 kg. A spring is attached to X as shown.



The graph shows the velocities of X and Y before, during and after the collision.



The collision lasted for 40 ms.

(a) Show that the collision is elastic. [2]

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(Question 1 continued)

(b) Determine

(i) the magnitude of the average force exerted on Y, [2]

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(ii) the average power delivered to Y, [2]

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(iii) the elastic energy stored in the spring at $t = 30\,\text{ms}$. [2]

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2. (a) Describe the mechanism of heat transfer by conduction. [2]

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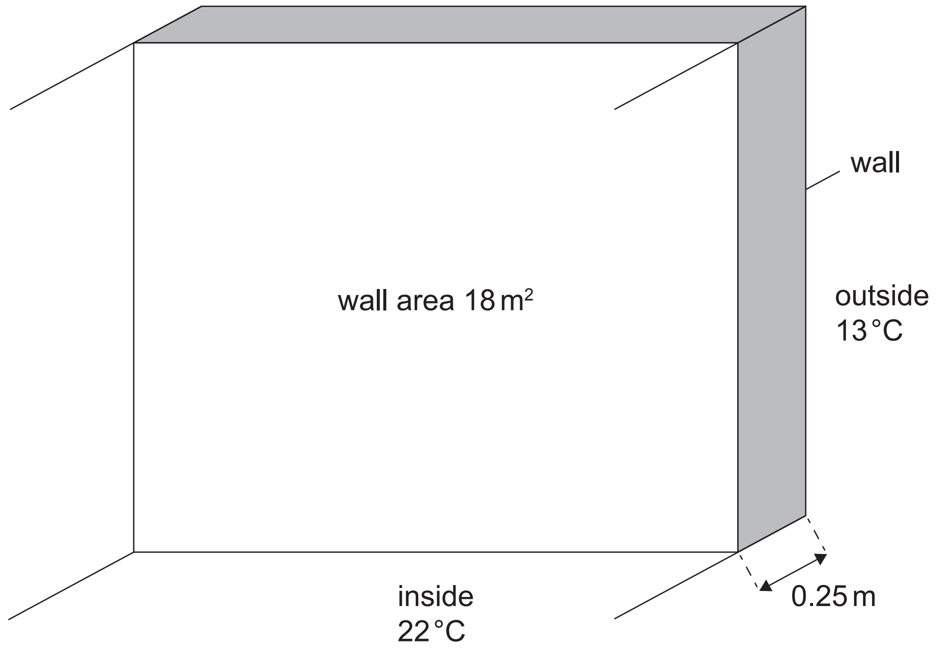

The following data are available:

$$\text{Thickness of wall} = 0.25\,\text{m}$$
$$\text{Area of wall} = 18\,\text{m}^2$$
$$\text{Thermal conductivity of wall} = 1.3\,\text{W m}^{-1}\,\text{K}^{-1}$$
$$\text{Constant room temperature} = 22\,°\text{C}$$
$$\text{Constant outside temperature} = 13\,°\text{C}$$

(This question continues on the following page)

(Question 2 continued)

(b) Estimate the rate at which thermal energy leaves the room through the wall giving the answer with an appropriate unit. [2]

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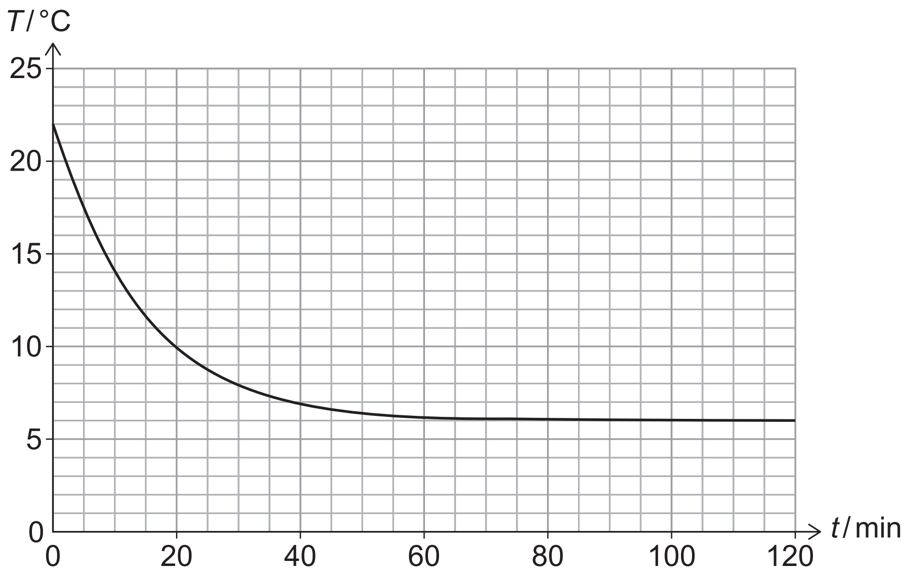
(This question continues on the following page)

(Question 2 continued)

(c) At night the outside temperature falls below 13 °C. The heater is turned off at time $t = 0$. The graph shows the variation with time t of the temperature T of the room.



(i) Outline why the magnitude of the gradient of the graph decreases. [1]

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(ii) The pressure and volume of the air in the room remain constant but the number of molecules has increased. Determine the percentage increase in the number of molecules of air in the room between $t = 0$ and $t = 120$ min. [3]

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(Question 2 continued)

(d) Discuss how the second law of thermodynamics applies to the situation of the room cooling down. [2]

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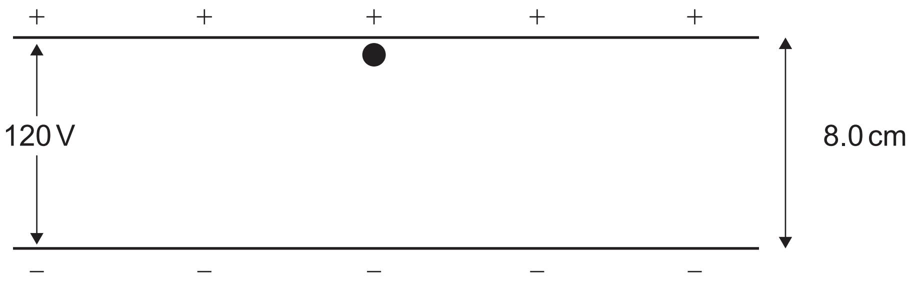
3. Two oppositely charged parallel plates are a distance 8.0 cm apart. The potential difference between the plates is 120 V. An alpha particle is placed on the positively charged plate and released from rest. Gravity is ignored.



(a) Calculate the electric field between the plates. [1]

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(b) (i) Show that the acceleration of the alpha particle is about $7 \times 10^{10}\,\text{m s}^{-2}$. [2]

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(ii) Calculate the time taken for the alpha particle to reach the negative plate. [2]

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(iii) State, in eV, the kinetic energy of the alpha particle when it arrives at the negative plate. [1]

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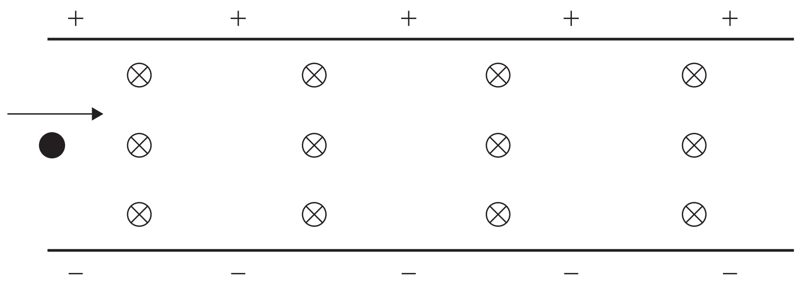
(Question 3 continued)

(c) A magnetic field directed into the plane of the page is now established between the plates. An alpha particle enters the region between the plates with a horizontal speed of $5.0 \times 10^5\,\mathrm{m\,s^{-1}}$. The particle is not deflected.



Calculate the magnitude of the magnetic field. [2]

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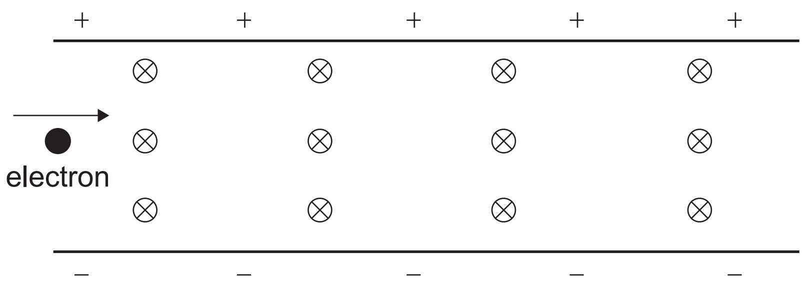
(d) The alpha particle in (c) is replaced by an electron. The electron enters the region between the plates with the same velocity as the alpha particle.

Draw, on the diagram, the path of the electron. [1]



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4. Two sources of light produce an interference pattern on a screen.

(a) Explain why the two sources need to be coherent for the interference pattern to be observed. [2]

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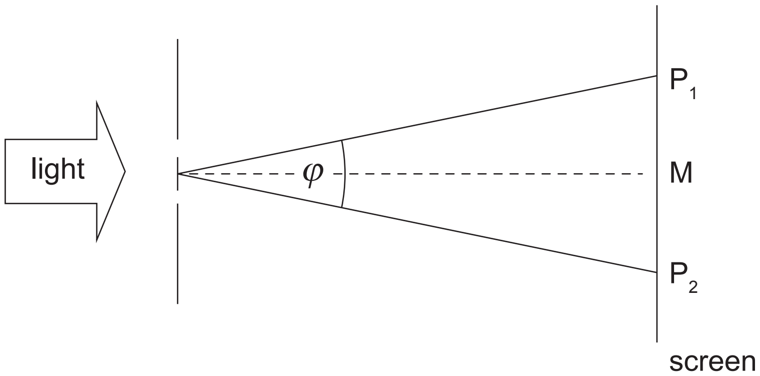
(b) Light of wavelength 720 nm is incident on two narrow slits that are separated by 0.12 mm. An interference pattern is observed on a screen. P_1 and P_2 are the points of destructive interference closest to the central maximum M.



(i) Calculate, in radians, the angular separation φ of P_1 and P_2. [2]

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(ii) Suggest how energy conservation is consistent with the fact that the energy at P_1 and P_2 is zero. [1]

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(This question continues on the following page)

(Question 4 continued)

A beam of light containing all wavelengths in the range [550 nm, 650 nm] is incident normally on a diffraction grating. The grating has 580 lines per mm. A diffraction pattern is observed on a screen as shown.

(c) Outline why the interference at M is constructive. [1]

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(d) Determine the largest order of the diffraction pattern in which all the wavelengths in the incident beam are present. [3]

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5. (a) Outline why Compton scattering offers better evidence for the particle nature of light than the photoelectric effect. [2]

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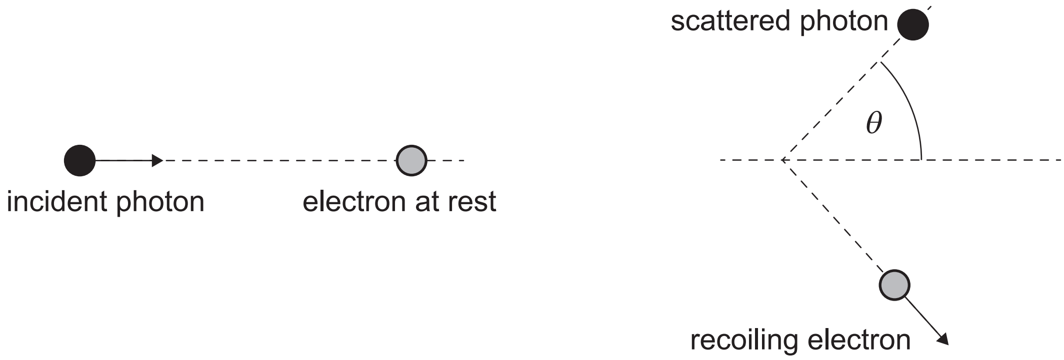
A photon of wavelength 6.40×10^{-12} m and energy 0.194 MeV is incident on an electron at rest. The photon scatters at an angle θ with wavelength 7.47×10^{-12} m. The electron recoils.



(b) Outline why the wavelength of the scattered photon is longer than that of the incident photon. [2]

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(c) (i) Show that the energy of the scattered photon is about 0.17 MeV. [1]

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(Question 5 continued)

(ii) Calculate the kinetic energy of the recoiling electron. [1]

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(iii) For an electron, $\frac{h}{m_e c} = 2.43 \times 10^{-12}$ m. Determine θ. [2]

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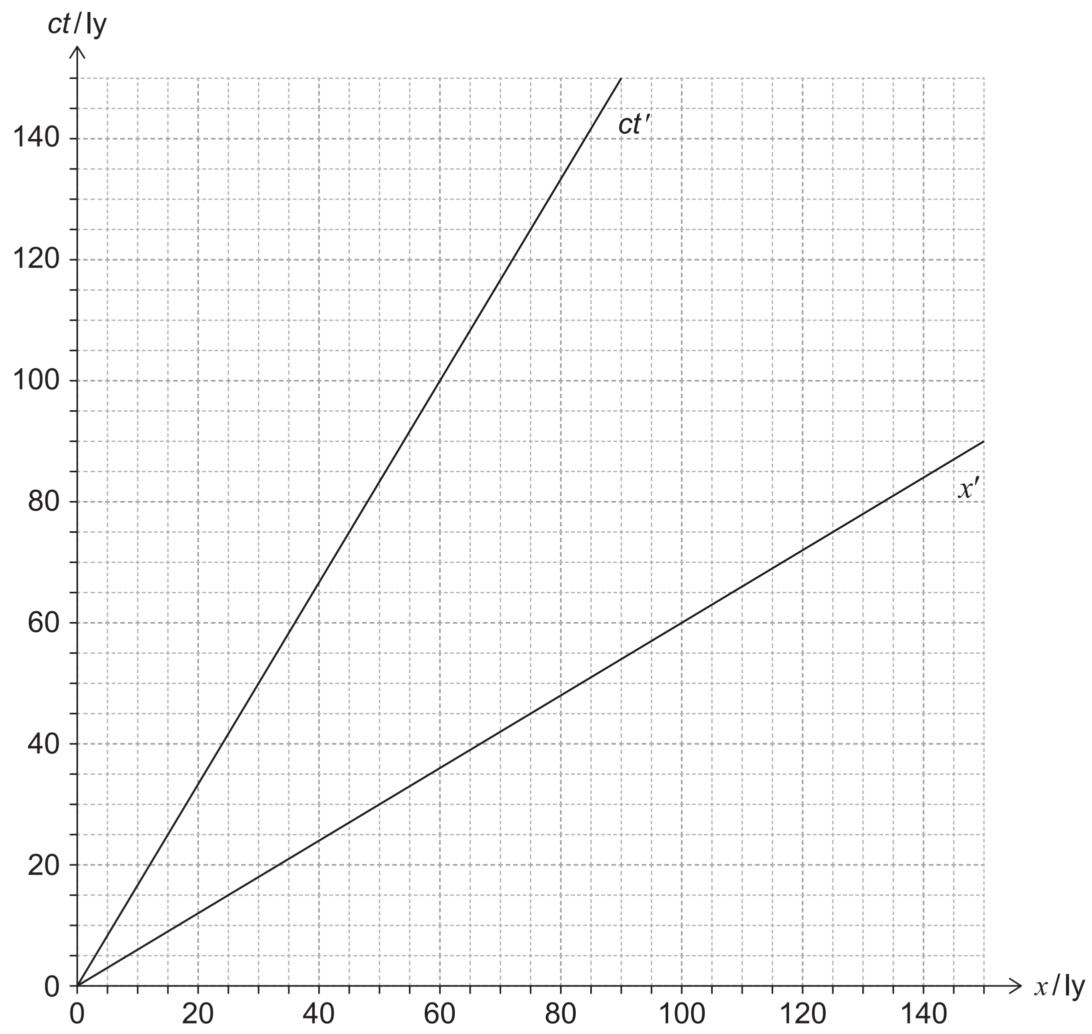
6. Spacecraft S leaves Earth with speed 0.60c on the way to a planet P. As measured by Earth, P is at a distance of 30 ly from Earth. The diagram shows the spacetime axes of Earth (x, ct) and of S (x', ct').



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(Question 6 continued)

(a) S arrives at P after 50 years according to Earth. Calculate the time at which S arrives at P according to S clocks. [2]

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(b) When S arrives at P, S sends a radio signal back to Earth.

(i) Draw, on the spacetime diagram, the world line of the signal from when it is emitted until it is received on Earth. [1]

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(ii) Determine, using the spacetime diagram or otherwise, the time of travel of the signal according to S. [3]

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7. The following data are available for the Sun when it entered the main sequence.

$$\text{Mass} = 2.0 \times 10^{30}\,\text{kg}$$
$$\text{Radius} = 7.0 \times 10^{8}\,\text{m}$$
$$\text{Surface temperature} = 5800\,\text{K}$$
$$\text{Core temperature} = 1.5 \times 10^{7}\,\text{K}$$
$$\text{Core density} = 1.6 \times 10^{5}\,\text{kg m}^{-3}$$

(a) (i) State and explain which of the above features make nuclear fusion in the Sun possible. [3]

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(ii) Outline how the Sun maintains its equilibrium state. [2]

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(This question continues on the following page)

(Question 7 continued)

(b) The following sequence of nuclear fusion reactions takes place in the Sun.

$$\text{Stage 1: } {}^{1}_{1}\text{H} + {}^{1}_{1}\text{H} \rightarrow {}^{2}_{1}\text{H} + {}^{0}_{1}\text{e}^{+} + {}^{0}_{0}\nu$$
$$\text{Stage 2: } {}^{1}_{1}\text{H} + {}^{2}_{1}\text{H} \rightarrow {}^{3}_{2}\text{He} + {}^{0}_{0}\gamma$$
$$\text{Stage 3: } {}^{3}_{2}\text{He} + {}^{3}_{2}\text{He} \rightarrow {}^{4}_{2}\text{He} + 2 \times {}^{1}_{1}\text{H}$$

The nuclear mass of ${}^{1}_{1}\text{H}$ is 1.007276 u and that of ${}^{2}_{1}\text{H}$ is 2.013550 u. Estimate the energy released in stage 1 of these reactions. [2]

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(Question 7 continued)

(c) The Sun will leave the main sequence when it has converted 10 % of its hydrogen mass into helium. The **total** energy released in the reactions in (b) is 4.3×10^{-12} J. The current luminosity of the Sun is 3.8×10^{26} W. When the Sun entered the main sequence its hydrogen mass was 1.5×10^{30} kg.

(i) Show that the Sun will stay on the main sequence for about 8×10^{9} years. [3]

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(ii) State **one** assumption that was made in getting the answer to (c)(i). [1]

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(iii) Estimate the total mass lost by the Sun in this time. [2]

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(d) The surface temperature of the Sun is 5800 K. Determine the peak wavelength in the Sun's spectrum. [2]

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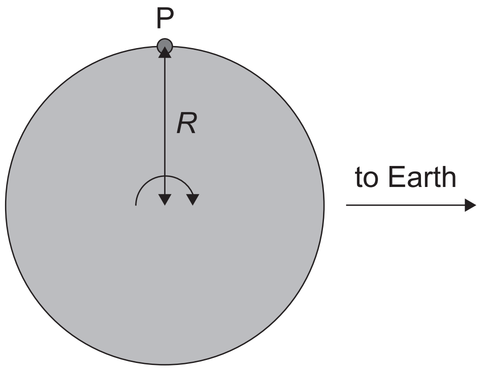
(Question 7 continued)

(e) The Sun rotates about its axis. P is a point on the Sun's equator.



A particular spectral line of hydrogen from a laboratory source has wavelength 656.2797 nm. The same spectral line emitted from P has wavelength 656.2753 nm when measured on Earth.

(i) Explain this observation. [2]

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(ii) Calculate the period of revolution of the Sun. [3]

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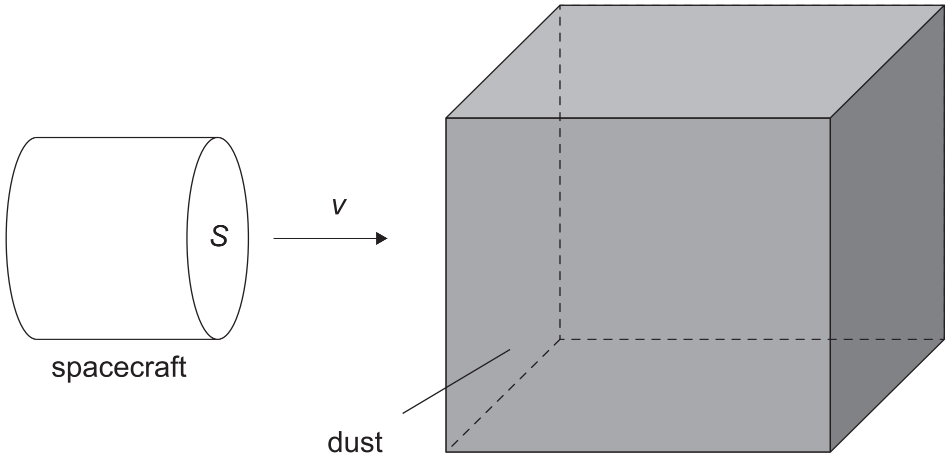
8. (a) A cylindrical spacecraft of cross-sectional area S moves with velocity v. The spacecraft enters a region of dust of density ρ. All the dust that comes into contact with the forward cross-sectional area of the spacecraft sticks to the spacecraft increasing its mass.



(i) Show that in time Δt the mass of the spacecraft will increase by an amount $\rho S v \Delta t$. [1]

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(ii) Deduce that the spacecraft will experience a drag force $\rho S v^2$ opposite to its velocity. [2]

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(Question 8 continued)

(b) A satellite of mass m is in a circular orbit of radius r around Earth. Earth has mass M.

(i) Show that the total energy of the satellite is given by $E_T = -\frac{GMm}{2r}$. [2]

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(ii) The satellite experiences a drag force due to the atmosphere of Earth. With reference to the results in (a) and (b)(i), state and explain the likely fate of this satellite. [4]

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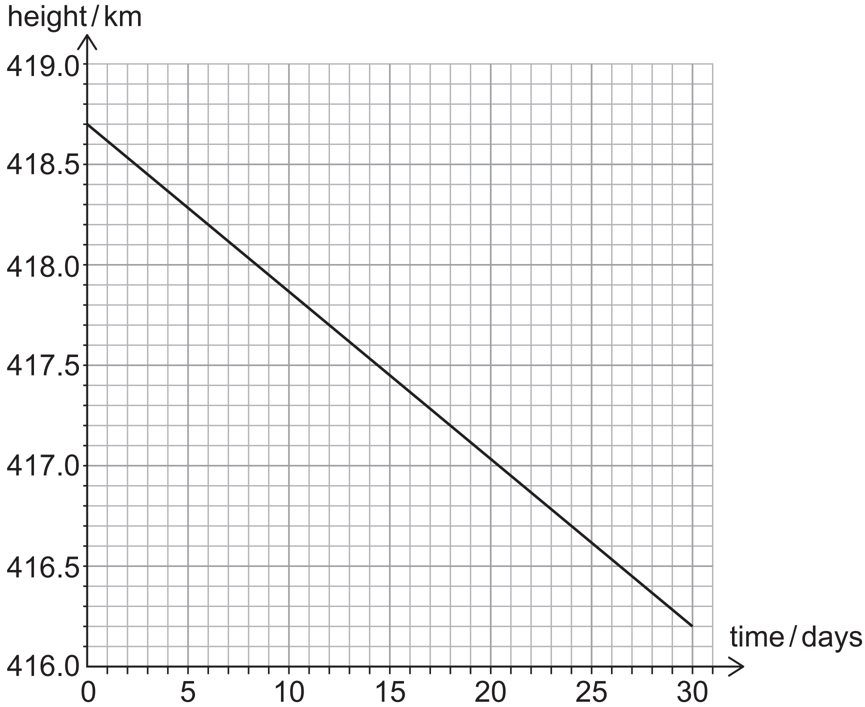
(Question 8 continued)

(c) The graph shows the variation with time of the height of the International Space Station (ISS) during a 30-day period.



The following data are available:

Mass of Earth $= 5.98 \times 10^{24}$ kg
Mass of the ISS $= 4.20 \times 10^{5}$ kg
Radius of the Earth $= 6.38 \times 10^{6}$ m

For the 30-day period indicated in the graph the loss of total energy of the ISS is 4.5×10^{9} J.

(i) Calculate the average rate at which the energy of the ISS is being dissipated. [2]

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(This question continues on the following page)

(Question 8 continued)

(ii) Show, using the average height during the 30-day period, that the speed of the ISS is about $8 \times 10^3\,m\,s^{-1}$. [2]

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(iii) Estimate the increase in the temperature of the ISS assuming all the lost energy went into thermal energy of the ISS. Take the specific heat capacity of the ISS to be $500\,J\,kg^{-1}\,K^{-1}$. [2]

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(iv) Estimate, using the answers to (c)(i) and (c)(ii), the average drag force that acted on the ISS. [3]

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(This question continues on the following page)

(Question 8 continued)

(d) At the end of the 30-day period, rockets are fired to bring the ISS back to its initial height. The energy density of liquid hydrogen rocket fuel is $8.5 \times 10^3\ \text{MJ m}^{-3}$.

Estimate the volume of fuel needed. [2]

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