Diploma Programme
Programme du diplôme
Programa del Diploma

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]**.

31 pages

2225 – 6721
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Answer **all** questions. Answers must be written within the answer boxes provided.

1. A box of mass 1.2 kg is lying at rest on a surface. The coefficient of static friction between the box and the surface is 0.36 and the coefficient of dynamic friction between the box and the surface is 0.28.

(a) Outline why the coefficients of friction have no units. [1]

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(b) Show that the minimum force needed to accelerate the box is about 4 N. [2]

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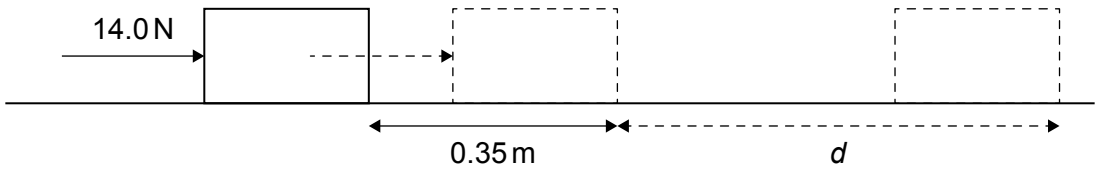
A force of 14.0 N acts on the box for 0.35 m as shown. The force is then removed and the box continues to move. The box comes to rest after a further displacement *d*.

diagram not to scale



(c) Determine *d*. [3]

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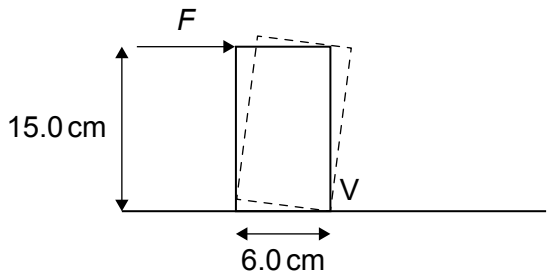
(Question 1 continued)

The box is now standing up. The height of the box is 15.0 cm and its base is 6.0 cm. A person pushes the box with an increasing force *F* at the top until the box tips about the corner V without sliding, as shown.

diagram not to scale



(d) (i) Determine *F*. [2]

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(ii) Outline why the box does not slide. [1]

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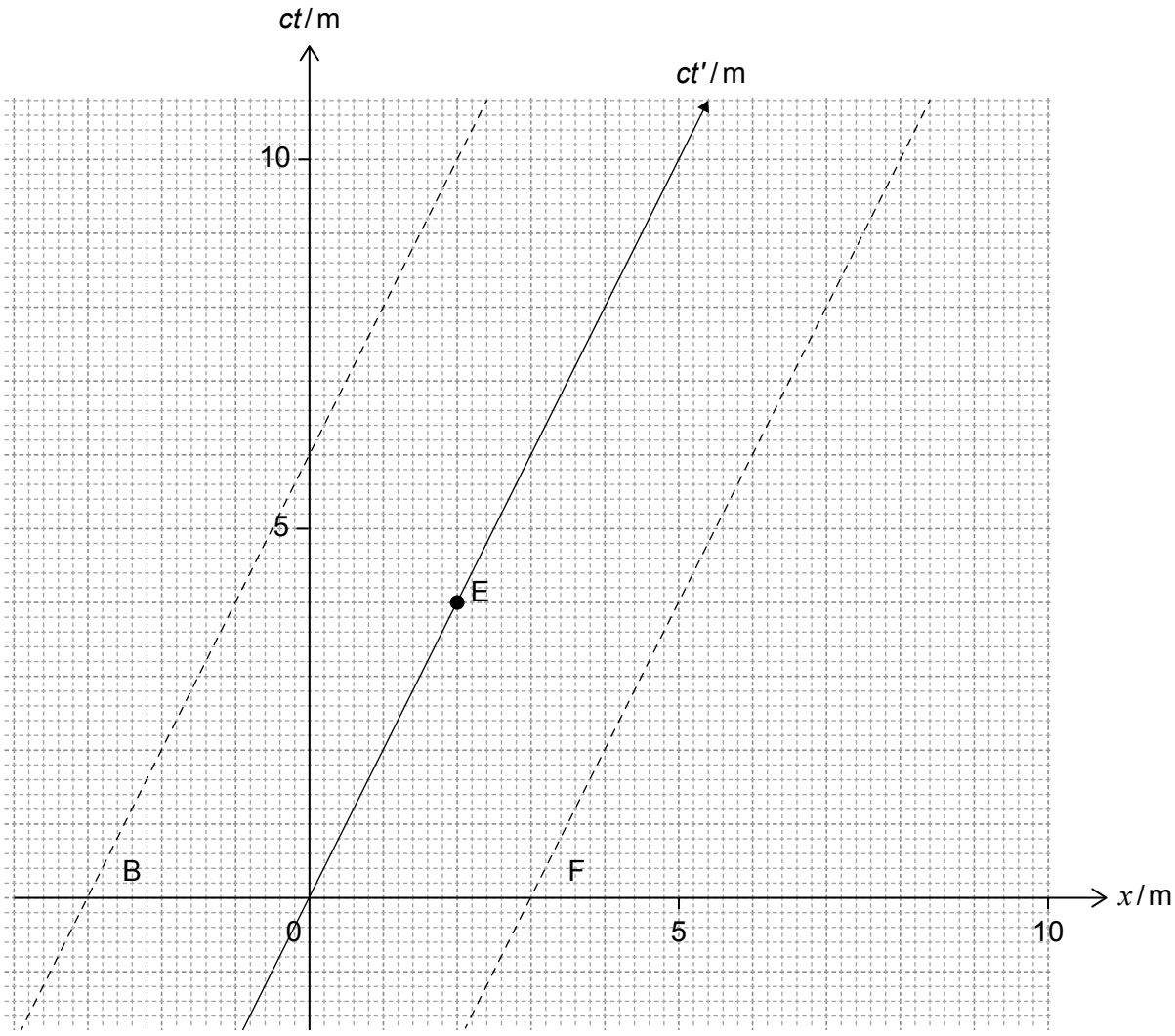
2. The spacetime diagram shows the x, *ct* axes for an observer on the ground. The *ct′* axis for a passenger on a train moving relative to the observer and world lines for the back (B) and front (F) of the moving train are also shown. The observer on the ground and the passenger are opposite each other at the origin of the spacetime diagram.

The train is travelling at 0.5*c*.



Event E is the lighting of a match by the passenger in the train, with coordinates $x = 2$ m and $ct = 4$ m. The light from the match reaches two mirrors at the back and front of the train.

(a) Draw, on the graph, the x' axis for the passenger on the train. [1]

(b) Draw, on the graph, the path of the light emitted from the match to show the events where the light strikes both mirrors. Label the events T_B and T_F. [1]

(This question continues on the following page)

(Question 2 continued)

(c) Explain, with reference to T_B and T_F, which person concludes that the light reached both mirrors simultaneously. [2]

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(d) State the length of the train for the observer on the ground. [1]

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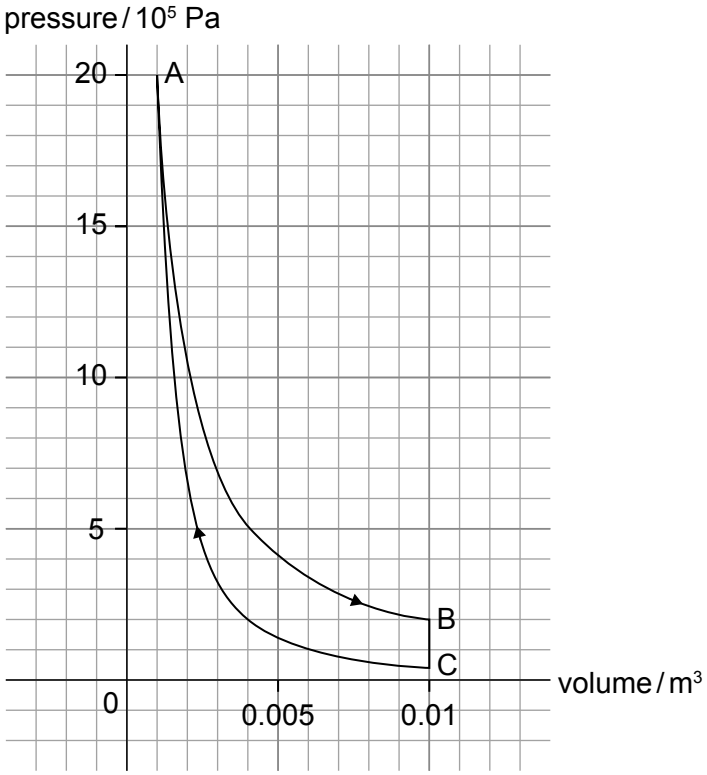
3. The pressure–volume diagram shows a 3-stage cyclic process of 0.20 moles of an ideal gas in a closed container. A–B is an isothermal process. C–A is an adiabatic process.



The following data are available:

$$\text{Pressure at A} = 2.0 \times 10^6\,\text{Pa}$$
$$\text{Volume at A} = 1.0 \times 10^{-3}\,\text{m}^3$$
$$\text{Pressure at B} = 2.0 \times 10^5\,\text{Pa}$$
$$\text{Volume at B} = 1.0 \times 10^{-2}\,\text{m}^3$$

(a) Show that the temperature at C is about 260 K. [2]

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(Question 3 continued)

(b) Determine the work done by the gas in C–A. [2]

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(c) Outline why this cycle can be used for a heat engine. [1]

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4. (a) Identify **two** differences between sound waves in air and light waves. [2]

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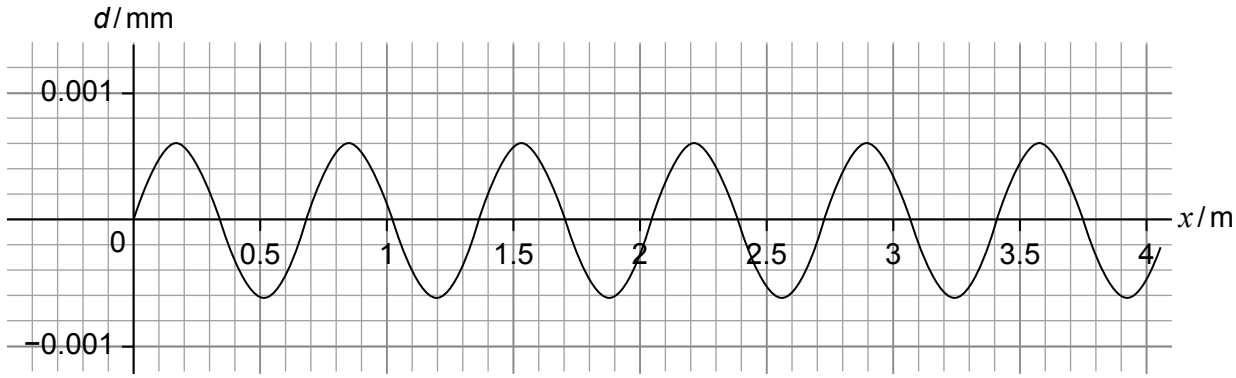
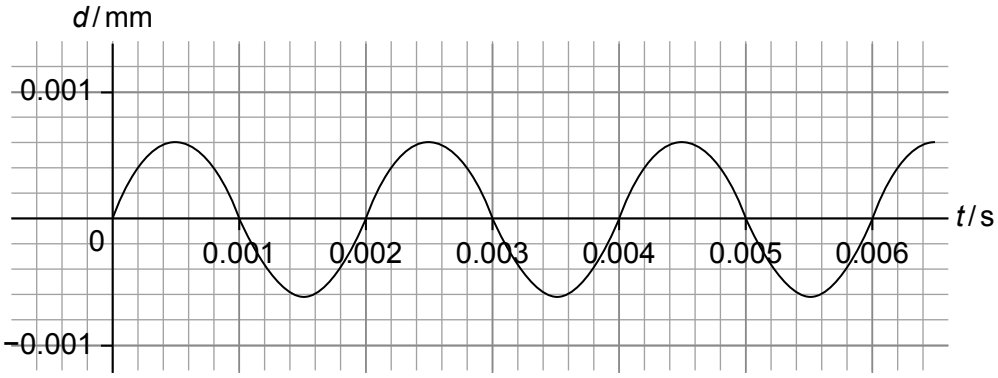
Graph 1 shows the variation of particle displacement *d* with position x for a travelling sound wave.

Graph 1



Graph 2 shows the variation of particle displacement *d* with time *t* for the same travelling sound wave.

Graph 2



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(Question 4 continued)

(b) (i) State the wavelength and the period of the sound wave. [2]

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(ii) Calculate the speed of the sound wave. [1]

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(Question 4 continued)

The Doppler effect applies to both sound and light waves.

(c) (i) Explain the Doppler effect. [2]

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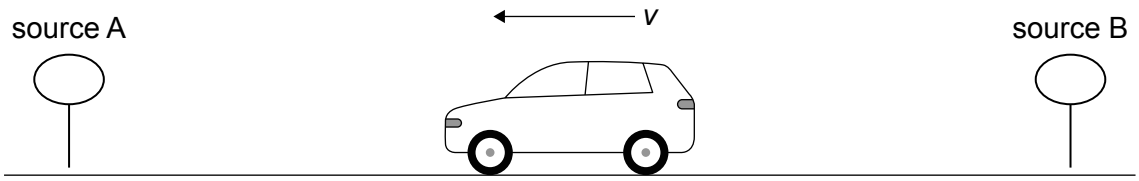
(ii) A car is moving at constant velocity v between two sources of sound as shown in the diagram. The sources emit sound at 440 Hz and at 540 Hz. The driver hears both sounds at the same frequency. The speed of sound is $340\,\mathrm{m\,s^{-1}}$.

diagram not to scale



Determine v. [2]

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(Question 4 continued)

(iii) The spectrum of light received from a galaxy shows a peak at a wavelength of 659.0 nm. The peak corresponds to an atomic transition in the hydrogen atom that emits a wavelength of 656.1 nm when observed in a laboratory on Earth.

Calculate the velocity of the galaxy with respect to Earth. [2]

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5. (a) A stationary isotope of $_{88}$Ra (Radium) decays into Rn (Radon) and an alpha particle.

(i) Identify the proton number of Rn. [1]

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The following data are available:

Atomic mass of Ra = 226.02540 u
Atomic mass of Rn = 222.01757 u
Mass of α = 4.00260 u

(ii) Show that the energy released in this decay is about 5 MeV. [2]

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(iii) Show that about 98 % of the energy released is carried by the alpha particle. [2]

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(Question 5 continued)

(b) In an experiment performed by Geiger, Marsden and Rutherford to investigate the atomic structure, alpha particles were directed into a thin metal foil.

(i) Describe two observations of this experiment. [2]

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(ii) Outline how the experiment was interpreted. [2]

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(iii) In this experiment, $^{197}_{79}Au$ (gold) foil was used.

Calculate the distance of closest approach for alpha particles of 4.8 MeV in head-on scattering. [3]

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(Question 5 continued)

(iv) Calculate $\dfrac{\text{radius of } {}^{197}_{79}\text{Au nucleus}}{\text{radius of } {}^{27}_{13}\text{Al}\left(\text{aluminium}\right) \text{ nucleus}}$. [2]

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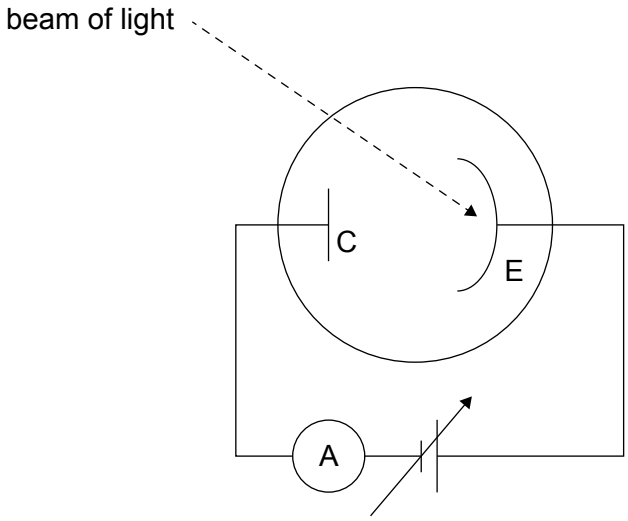
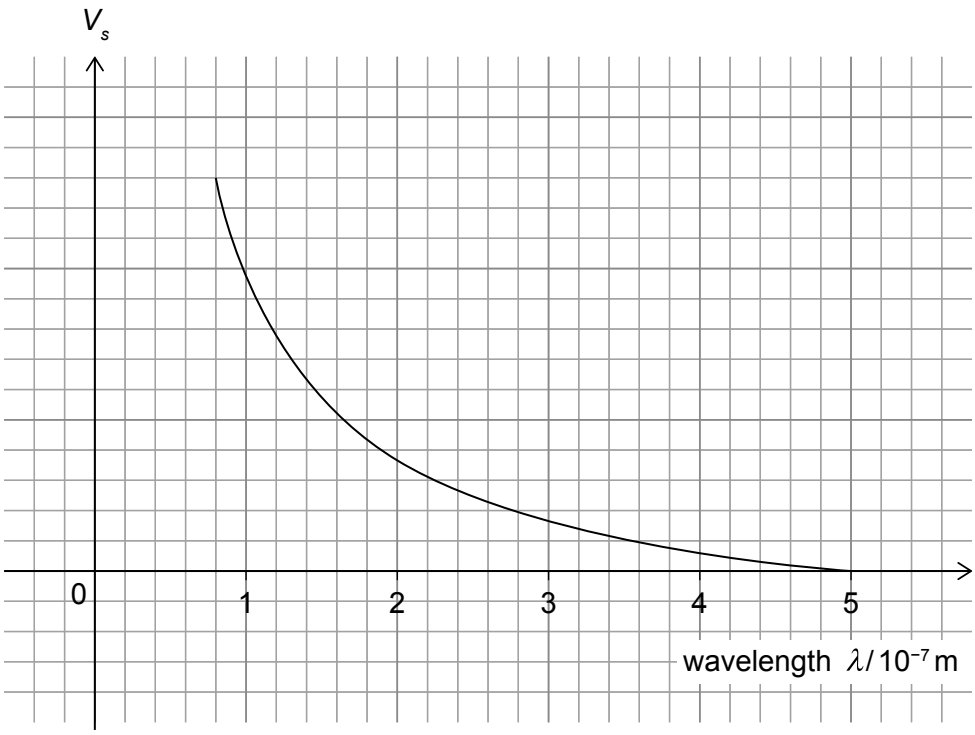
6. An electric circuit is used to investigate the photoelectric effect.

A beam of light from a laser of variable wavelength λ and constant intensity I is used to illuminate a curved metallic electrode E. Another electrode, C, is near E. Both electrodes are in vacuum. For each λ tuned in the laser, the voltage across CE is raised. The minimum voltage V_s that shows no current in the ammeter is recorded.

diagram not to scale



The graph shows the variation of V_s with λ.



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(Question 6 continued)

(a) Show that the work function of the metal used in C is about 2.5 eV. [2]

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(b) Calculate V_s when λ is 4.0×10^{-7} m. [2]

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The laser is now replaced by a monochromatic laser of red light and variable intensity.

Although the intensity of the laser is increased significantly, no current is read in the ammeter.

(c) Explain how this observation is consistent with the particle nature of light. [2]

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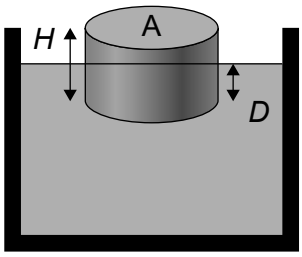
7. A cylindrical cork of height *H* and cross-sectional area A is floating stationary in water. Its depth below the water surface is *D*.

diagram not to scale



(a) (i) Draw and label the forces acting on the cork. [1]

(ii) Show that

$$\frac{D}{H} = \frac{\rho_c}{\rho_w}$$

where ρ_c is the density of the cork and ρ_w is the density of water. [2]

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(This question continues on the following page)

(Question 7 continued)

The cork is displaced downward by a force. It is then released and it oscillates.

(b) Outline why the cork undergoes simple harmonic motion. [2]

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(Question 7 continued)

(c) (i) Explain why the density of most substances in a solid state is larger than its density in a liquid state. [2]

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Water shows an anomaly with respect to what is stated in (c)(i).

Graph 1 shows the variation with temperature of the density of water between –100 °C and 100 °C. **Graph 2** shows the same graph enlarged for the range 0 to 10 °C.

(ii) Identify the temperature at which water has its maximum density. [1]

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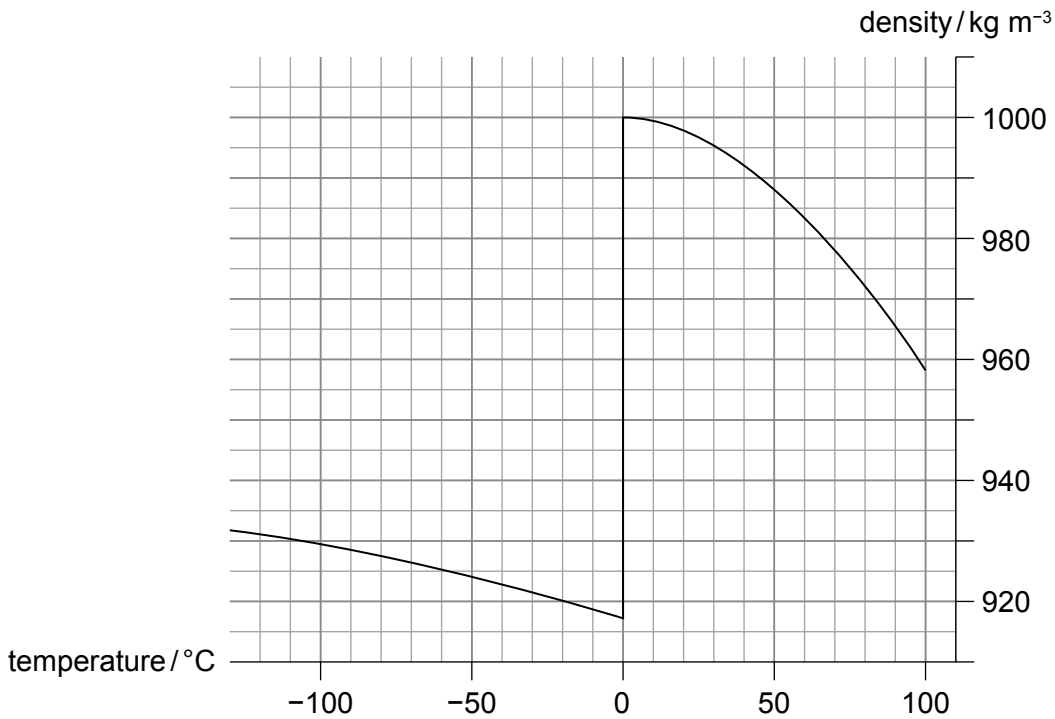
Graph 1



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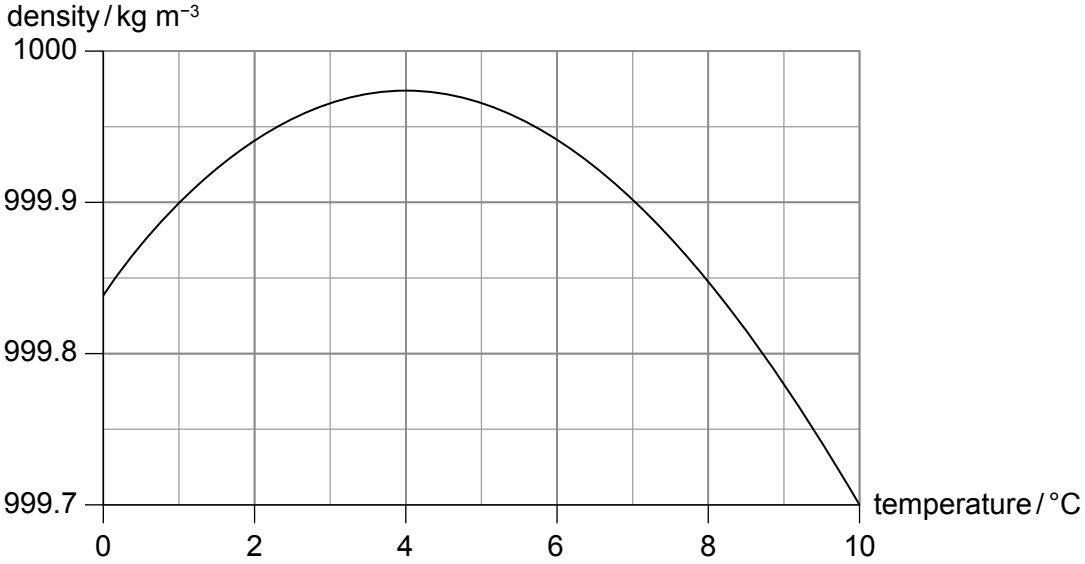
(Question 7 continued)

Graph 2



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(Question 7 continued)

(d) An icebreaking ship is designed to withstand a collision with an iceberg, a large partially submerged body of ice freely floating in water. The designers model the shape of the iceberg as a cylinder with an approximate cross-sectional area of $4200\,m^2$ and height above sea level of 32 m.

The following data are available:

$$\rho_{ice} = 920\,kg\,m^{-3}$$
$$\rho_{seawater} = 1030\,kg\,m^{-3}$$

(i) Show that the mass of the iceberg is about 1.2×10^9 kg. [2]

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The designers assume that the mass of the ship is about $\frac{1}{40}$ the mass of the iceberg and is moving at $12\,m\,s^{-1}$ when it collides with the iceberg. They stick together after the collision.

(ii) Calculate the speed of the ship after the collision. [2]

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(This question continues on the following page)

(Question 7 continued)

Ice in a still lake will usually form in a single layer on the surface.

(e) On a winter day, the surface of a lake is frozen. The temperature of the air above the lake is –6.0 °C. The layer of ice frozen on the surface of the lake has a thickness of 1.9 cm.

(i) The thermal conductivity of ice is $2.3\,\mathrm{W\,m^{-1}\,K^{-1}}$. Calculate the rate per unit area at which thermal energy leaves the lake by conduction through the ice layer. [2]

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(ii) The depth of water below the ice is 22 m and its average initial temperature is 2.0 °C. Estimate the minimum thermal energy per unit area that must be removed to freeze all the water in the lake. [3]

The following data are available:

Specific heat capacity of water $= 4.2 \times 10^3\,\mathrm{J\,kg^{-1}\,K^{-1}}$

Latent heat of fusion of water $= 3.3 \times 10^5\,\mathrm{J\,kg^{-1}}$

$\rho_{\mathrm{water}} = 1000\,\mathrm{kg\,m^{-3}}$

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(Question 7 continued)

Layers of ice on lakes do not grow thicker than a small percentage of the lake's depth even when the exterior temperature remains constant below the freezing point for some time.

(iii) Explain how the rate calculated in (e)(i) changes as the layer of ice grows thicker. [1]

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(iv) Discuss why the anomaly in the value of the density of water supports life in water on Earth. [2]

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8. A rod, R, lies perpendicular to a uniform magnetic field *B* of strength 0.50 T directed into the plane of the page. R is connected to a circuit and the electric current I_R is 2.0 A.

(a) (i) Calculate the magnitude of the force per unit length on R. [2]

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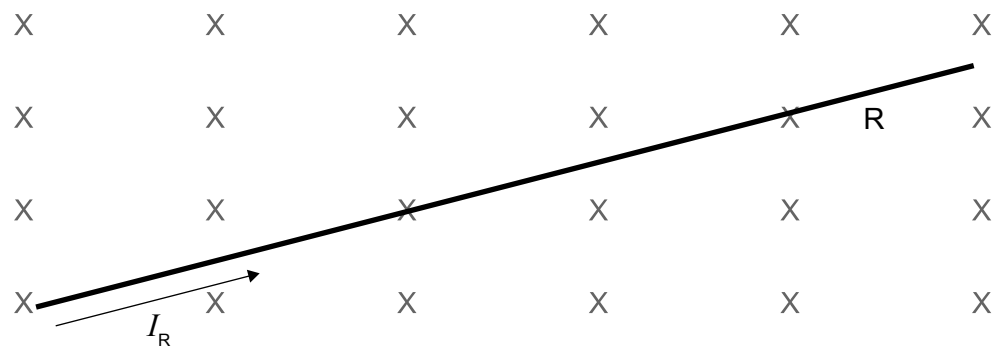
(ii) Identify on the diagram the direction of the force on R. [1]



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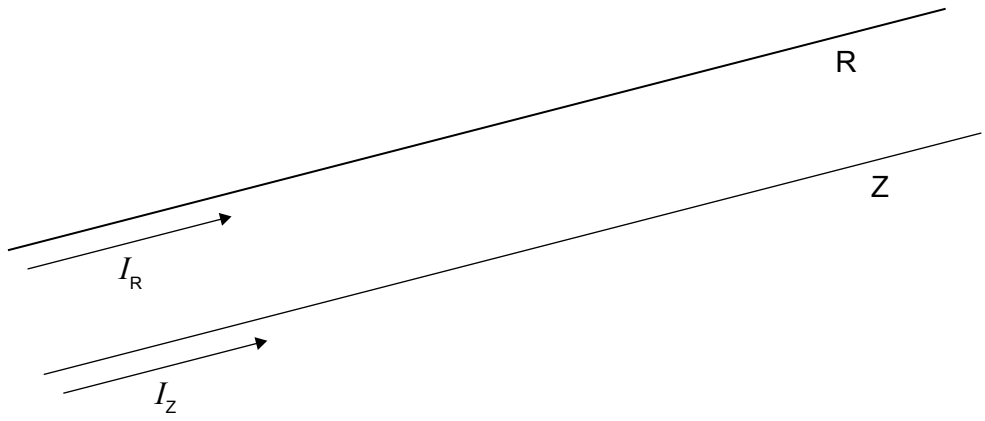
(Question 8 continued)

(b) *B* is removed and a wire Z, carrying a current I_Z, is placed parallel to R.



(i) Show that the magnetic field strength B_R due to R at a point on Z is

$$B_R = \frac{\mu_0}{2\pi}\frac{I_R}{r}$$

where *r* is the distance between R and Z. [2]

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(ii) Derive the units of μ_0 in SI fundamental units. [1]

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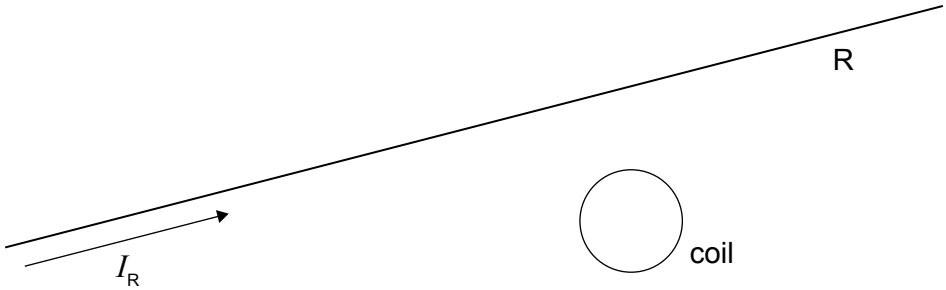
(This question continues on the following page)

(Question 8 continued)

(c) A small coil of wire of radius 2.0 cm and 20 turns is now located with its centre 10.0 cm from R. The current in R is kept constant at 2.0 A.

diagram not to scale



(i) Explain why there is no current induced in the coil. [2]

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(ii) The current in R increases at a constant rate from 2.0 A to 10.0 A in 0.5 seconds.

Calculate the emf induced in the coil. [3]

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(Question 8 continued)

(iii) Deduce the direction of the current induced in (c)(ii). [2]

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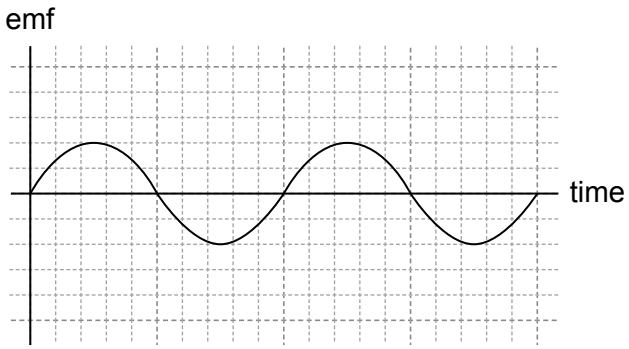
(Question 8 continued)

(d) The coil is made to rotate such that an emf is induced. The graph shows the variation with time of the emf induced in the coil.



The frequency of rotation is doubled. Draw on the graph the variation with time of the new emf induced. [2]

(This question continues on the following page)

(Question 8 continued)

(e) An electron is moving at constant velocity $v = 9.0 \times 10^5\,\mathrm{m\,s^{-1}}$ parallel to a rod T, at a perpendicular distance *d*. T is connected to a cell via a switch. When the switch is closed the electron's path curves with initial radius *r*. The magnetic field strength at the position of the electron at *d* is $4.0 \times 10^{-6}\,\mathrm{T}$.

(i) Calculate the initial radius of the electron's path. [3]

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(ii) Explain the subsequent change in the radius of the electron's path. [2]

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