L-Università ta' Malta

MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

ADVANCED MATRICULATION LEVEL
2025 SECOND SESSION

SUBJECT:	**Physics**
PAPER NUMBER:	I
DATE:	29th August 2025
TIME:	9:00 a.m. to 12:05 p.m.

A list of useful formulae and equations is provided. Take the acceleration due to gravity $g = 9.81\ \mathrm{m\ s^{-2}}$ unless otherwise stated.

SECTION A
Attempt all EIGHT questions in this section. This section carries 50% of the total marks for this paper.

1. The cavitation number, Ca, is used to predict the formation of vapour bubbles in a liquid. It is defined as $\mathrm{Ca} = \frac{p - p_v}{\frac{1}{2}\rho v^2}$ where p and p_v represent pressures, ρ the fluid's density, and v the fluid's velocity.

   a. State **TWO** requirements for an equation relating physical quantities to be physically correct. (2)

   b. Write the units of pressure in terms of base units. (2)

   c. Determine the units of the cavitation number, Ca. (2)

   d. Classify the quantities appearing in the definition of the cavitation number as scalar or vector. (2)

   e. Calculate the cavitation number for a fluid of density 13.6 g cm^{-3}, velocity of 5 ms^{-1}, pressure p of 40 kPa and p_v of 10 kPa. (2)

   (Total: 10 marks)

2. a. Sketch a stress-strain graph of a ductile material. (2)

   b. On your graph, clearly mark the:
   (i) proportionality limit with a P; (1)
   (ii) ultimate tensile strength with a T. (1)

   c. Explain 'necking' and how it arises. (2)

   d. Explain why a ductile material experiences necking and mark on the sketched graph the region where necking occurs. (2)

   e. Explain how a stress-strain graph can be used to determine the Young's modulus of a material. (2)

   (Total: 10 marks)

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3. Figure 1 represents a circuit with switches (initially open) and resistors connected with a 6 V cell. The state of the switches was changed as follows:

- 0-3 s: A closed, B open;
- 3-7 s: A open, B closed;
- 7-9 s: A closed, B open;
- After 9s: A and B open.

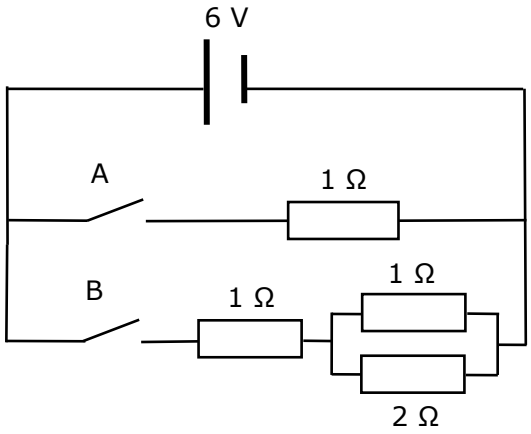

Figure 1

a. Suggest a position where the ammeter needs to be connected to measure the current flowing through the whole circuit. (1)

b. Calculate the current flowing through the circuit during each time interval. (5)

c. Sketch a current-time graph during the first 9 s interval including relevant values. (3)

d. Explain how the current-time graph can be used to determine the total amount of charge that has passed throughout the whole duration. (1)

(Total: 10 marks)

4. Figure 2 represents a circuit containing a cell having an internal resistance. When a voltmeter is connected across the contact points AG, it reads 9 V.

a. Explain the difference between emf and potential difference (p.d.). (2)

b. Define terminal p.d. (1)

c. Explain what can be concluded about the value of the cell's emf compared to the terminal p.d. (2)

d. Determine the value of the p.d. across the following contact points:
   i. AB; (1)
   ii. BC; (3)
   iii. BF. (1)

(Total: 10 marks)

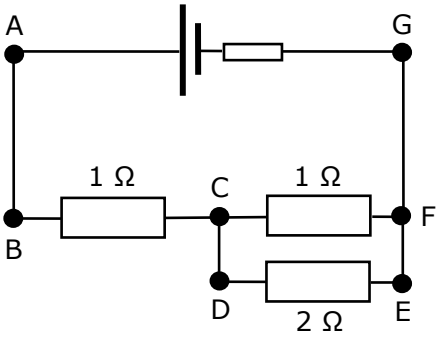

Figure 2

5. The most abundant isotope of oxygen, chemical symbol O, accounting for more than 99% of naturally occurring oxygen, has 8 protons and 8 neutrons.

a. Represent this isotope with its corresponding nuclear symbol (or isotopic notation). (1)

b. Knowing that the typical distance between protons in a nucleus is 1.00×10^{-15} m, calculate the Coulomb repulsive force inside a nucleus. (2)

c. Compare the range and the magnitude of the strong nuclear force with those of the electrostatic force. (1)

d. Evaluate the mass defect, *m*, in kg, and the nuclear binding energy per nucleon, *BEN*, in eV for the oxygen nucleus in question, knowing that its mass is 15.995 u. (2,2)

e. By referring to the appropriate stability curve, explain why the isotope of oxygen with 16 neutrons is unstable. (2)

(Total: 10 marks)

6. A bead of mass m = 1.2 kg is threaded onto a circular wire ring of radius r = 2.3 m and is held vertically on a table as shown in Figure 3. The bead is initially at rest at the highest point of the ring and then it is slightly displaced with initial zero velocity. Assume that the bead slides on the ring without friction.

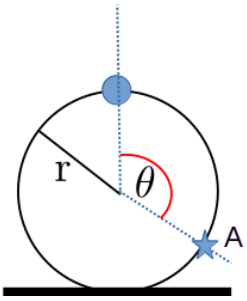

Figure 3

   a. Draw the free-body diagram of the forces acting on the particle at position A, clearly indicating the names of the drawn forces. (1)

   b. Show that the square of the speed of the bead along the ring is given by $v^2 = 2gr(1 - \cos\theta)$. (2)

   c. Calculate the tangential and the angular velocity of the particle at point A, where θ = 120°. (1,1)

   d. Calculate the centripetal and the angular acceleration at point A. (1,1)

   e. Determine the angle, counting clockwise from the vertical dotted line as in the figure, at which the reaction force from the wire ring on the bead becomes zero. (3)

(Total: 10 marks)

7. A uniform, frictionless disk of radius R = 3 m is rotating on a horizontal plane with angular velocity 100 rad/s as in Figure 4. A person of mass m = 80.0 kg stands at distance r = 1.50 m from the centre of the disk at position A. The person then moves to the border of the disk in position B. The moment of inertia of the system disk+person is I_A = 75 kg m^2 and I_B = 615 kg m^2, when the person is at position A and B, respectively.

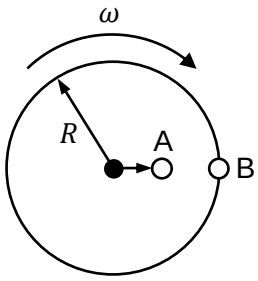

Figure 4

   a. Calculate the angular momentum and the rotational kinetic energy of the system at position A and B. (2,2)

   b. Calculate how much work the person did in moving from position A to position B. (1)

   c. Calculate the change in kinetic energy of the person between position A and B. (2)

   d. Explain why the work done by the person in moving from A to B is not equal to the person's change of kinetic energy. (2)

   e. Assume now that brakes are applied to the system and it comes to a halt in time t = 8 s. Calculate the power of the work done by the brakes on the system. (1)

(Total: 10 marks)

8. Three boxes of weight, F_1 = 10 N, F_2 = 50 N, and F_3 = 20 N, are suspended by massless strings from a uniform rod of weight F_r = 30 N, as depicted in Figure 5. The system is pivoted at point O through a vertical stick and is free to rotate in the xy-plane. The values of the distances are a = 20 cm and c = 50 cm. The system is in static equilibrium. You may assume that the centre of mass of the rod alone is to the right of the pivot point O.

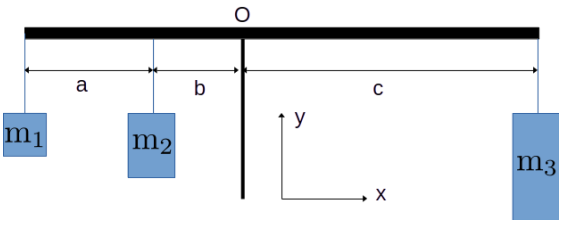

Figure 5

   a. State **TWO** conditions for the system to be in equilibrium. (1,1)

   b. Find the distance b such that the system is in equilibrium. (4)

Question continues on the next page.

c. Calculate the reaction force of the vertical stick on the rod at point O. (1)

d. Assume now that all the masses are removed from the rod. Find the angular acceleration of the rod rotating in the xy-plane when it is in the horizontal position. Assume the moment of inertia of the rod rotating around point O is $I = \frac{1}{12} m_r L^2 + m_r d^2$, where m_r is the mass of the rod, L its length, and d the distance between the pivot point O and the centre of gravity of the rod. (3)

(Total: 10 marks)

SECTION B

Attempt any FOUR questions from this section. Each question carries 20 marks. This section carries 50% of the total marks for this paper.

9. A student wishes to investigate the elastic properties of a rubber band.

   a. Describe an experiment that the student needs to carry out to investigate the force-extension properties of the rubber band for both loading and unloading. The experiment should include:
      i. a well-labelled diagram of the apparatus used; (3)
      ii. the method used, including the required measurements; (2)
      iii. a sketch of the obtained force-extension graph, indicating both loading and unloading properties on the same sketch. (2)

   b. State Hooke's law and hence state whether the rubber band obeys such law. (2)

   c. Explain what the area under the force-extension graph obtained signifies. (1)

   d. The rubber band experiences a particular property between loading and unloading.
      i. State what this property is called and explain its physical significance. (2)
      ii. Explain a practical situation where this phenomenon is used. (2)

   The student then decides to investigate the behaviour of two springs of equal length connected in parallel to a 50 N weight. The spring constants are 200 N m^{-1} and 300 N m^{-1} respectively.

   e. Determine the extension of **each** spring. (4)

   f. Calculate the elastic energy stored in each spring when they are fully stretched. (2)

(Total: 20 marks)

10. LDRs are devices whose resistance changes depending on the light falling on them. The circuit in Figure 6 contains a power supply of emf ϵ, a resistor of resistance R, an LDR of resistance R_{LDR} and a filament lamp of resistance R_B.

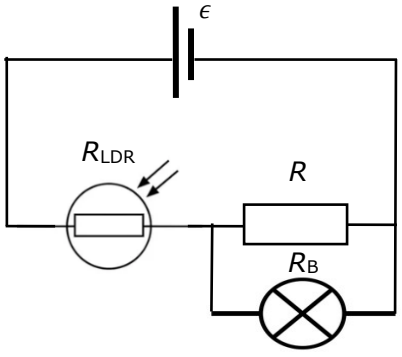

Figure 6

   a. Sketch the IV characteristic graph of a filament lamp. (2)

   b. Explain in detail the shape of the IV graph in (a) by making clear reference to changes in temperature and resistance of the filament lamp. (4)

   c. Describe how the resistance of an LDR changes under the effects of light. (1)

   d. State, giving reasons, whether the filament lamp and the LDR obey Ohm's law. (2)

e. Show that the voltage across the filament lamp obeys the equation $V = \epsilon \times \frac{R_t}{R_{LDR}+R_t}$ where $R_t = \frac{R\,R_B}{R+R_B}$. (4)

f. Hence, or otherwise, explain how the brightness of the filament lamp changes throughout the day for the given circuit. (2)

g. Suggest a location where the voltmeter should be connected to measure the voltage across the filament lamp. (1)

h. If the voltmeter was not ideal, would this affect the brightness of the filament lamp? Explain. (3)

i. The fixed resistor is replaced with a variable resistor. Suggest **ONE** use for this change in the setup. (1)

(Total: 20 marks)

11. Figure 7 represents a potentiometer circuit which is used to determine the unknown emf, ϵ_2 , having internal resistance R_2. The wire BF is 1 m long and has a resistance R. When the jockey is at point C, no current flows through the galvanometer. The distance is measured in centimetres.

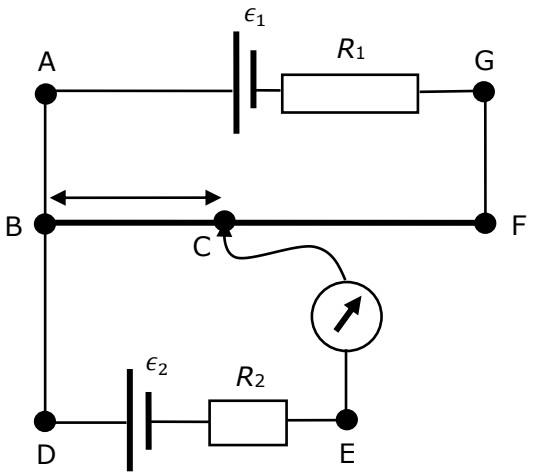

Figure 7

a. State Kirchhoff's laws and their associated conservation laws. (4)

b. Use Kirchhoff's laws, in the case when the jockey is at C, to construct an equation for the loops:
   i. BDEC; (1)
   ii. ABCFG. (2)

c. Show that the unknown emf is $\epsilon_2 = \frac{x}{100} \times \frac{\epsilon_1 R}{R_1+R}$. (3)

d. Hence, explain why a potentiometer is an ideal voltmeter. (2)

e. Derive expressions for the electrical power generated by the cell ϵ_1 and across the resistor R_1. (2,2)

f. State what property should the unknown emf have for the potentiometer setup to work. (1)

g. Explain, giving reasons, how the length of the wire BF should be modified to more accurately determine the unknown emf. (2)

h. Explain how the setup can be modified such that only the position of the jockey is sufficient to determine the unknown emf. (1)

(Total: 20 marks)

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12. Two wires made of different materials A and B are connected as shown in Figure 8. Material A has a conductivity of $5.8 \times 10^7\ \Omega^{-1}\ m^{-1}$, length 1 m, and charge carrier density $8.5 \times 10^{28}\ m^{-3}$. Material B has a conductivity of $2.1\ \Omega^{-1}\ m^{-1}$, length 2 m, and charge carrier density $2.4 \times 10^{19}\ m^{-3}$. Both wires have the same cross-sectional area.

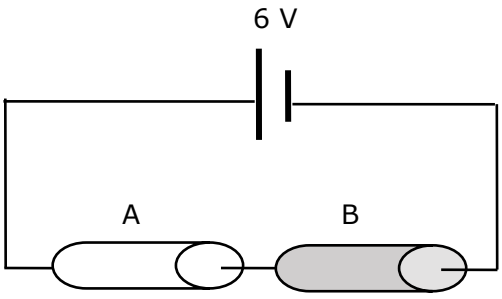

Figure 8

a. Define the resistivity and conductivity of a material. (2)

b. Show that the drift velocity of a material under a potential difference, *V,* satisfies the equation $v = \frac{\sigma V}{neL}$ where *L* is the length of the wire, *n* is the charge carrier density and σ is the conductivity. (5)

c. By considering the current flowing through the circuit, show that the drift velocities are related via the equation $v_A = 2.8 \times 10^{-10} v_B$. (4)

d. Given that the electronic charge is 1.6×10^{-19} C, use the result obtained in (b) to show that $v_B = 1.6\ m\ s^{-1}$. (5)

The investigation of drift velocity was carried out for another material C, which is an intrinsic semiconductor. This was then doped to produce a p-type semiconductor.

e. Sketch a labelled band level diagram for the p-type semiconductor. (2)

f. Hence, compare the drift velocity of the doped p-type semiconductor with that of the intrinsic semiconductor for a fixed current. (2)

(Total: 20 marks)

13. A student wishes to perform an experiment demonstrating the photoelectric effect.

a. Sketch the experimental apparatus and list its main components. (1,3)

b. State **THREE** main properties of photoelectric emission. (3)

c. Explain why the wave theory of light is unable to predict **each** of the main properties listed in (b). (3)

d. A clean surface of sodium (Na) is illuminated with monochromatic light of wavelength 300 nm. The work function of sodium is 2.28 eV.
   i. Calculate the energy of an incident photon in electron volts (eV). (2)
   ii. Calculate the maximum kinetic energy (in eV) of the emitted electrons. (2)
   iii. Determine the threshold wavelength (in nanometres) for light so that the photoelectric effect occurs for sodium. (2)
   iv. Sketch a plot of the measured photocurrent, I, as a function of the applied potential, *V*, between the cathode and the anode. On the graph, write down explicitly the value of the stopping potential in Volt when the wavelength of the incident light is 300 nm.(2)
   v. Suppose now that you increase the intensity of the incident light, keeping its frequency constant. On the same graph, sketch the resulting curve, clearly labelling the two curves for distinguishing them. (2)

(Total: 20 marks)

14. A block of mass m = 5.00 kg is compressing a spring by d = 50.0 cm (Point A in Figure 9). The spring constant is k = 200 kN/m. At time t = 0 s, the spring is released and the block climbs a plane, inclined by θ= 30.0° with respect to the horizontal. The frictional force between the block and the surface of the inclined plane is 5.00 N. You may assume that the block loses contact with the spring when the spring is at its equilibrium position (Point B); that before the block loses contact with the spring, that is, between points A and B, there is no friction; and that the spring does not oscillate after it has released the block.

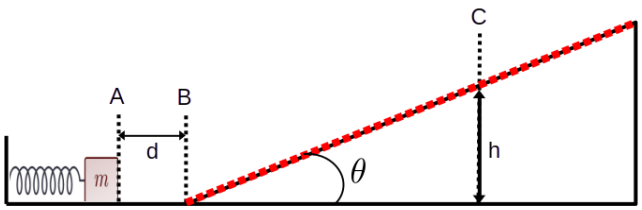

Figure 9

a. Calculate the speed of the block at point B. (2)

b. Determine the time it takes for the block to reach the maximum height (point C). (3)

c. Determine the maximum height h, with respect to the horizontal, the block climbs along the inclined plane. (3)

d. Draw the position along the inclined plane, i.e. along the direction BC, of the block as a function of time, the velocity of the block along the inclined plane as a function of time, and the acceleration of the block along the inclined plane as a function of time. Report also on the axes the numerical values found in (a)-(c). (1,1,1)

e. Calculate the work done on the block by the gravitational force and by the frictional force between the point B (where the block loses contact with the spring) and the point C (where it reaches the maximum height). (1,1)

f. State the principle of conservation of mechanical energy and specify whether it holds between the points A and B and between the points B and C. (1,1)

g. Assuming now that, after reaching the maximum height, the block slides back towards the spring.
   i. Calculate the speed with which the block hits the spring (which is at its equilibrium position, point B). (2)
   ii. Calculate the rate at which the frictional force does work on the block from point C to point B, i.e., when the block is sliding back. (3)

(Total: 20 marks)

Please turn the page.

15. A ball of mass m = 2.0 kg is attached to one end of a massless string of length L = 3.5 m. A person starts to whirl the rope and the ball experiences a constant angular acceleration of 7.0 rad s^{-2} for t=3.0 s. Then the ball performs a uniform circular motion whose trajectory is a circle parallel to the ground, as shown in Figure 10. The angle of the axis of the cone with its generatrix (the line joining the apex with the circle at the cone's base) is denoted by θ.

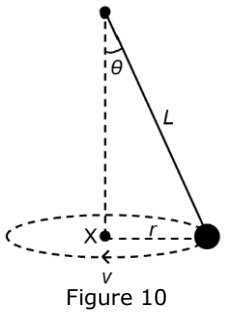

Figure 10

a. Calculate the angular velocity after 3 s. (2)

b. Calculate the angular distance the ball has travelled in 3 s. (2)

c. Assume now that the ball performs uniform circular motion with the angular velocity found in part (a).
   i. Draw the free-body diagrams of all forces acting on the ball. Label clearly all acting forces as well as all relevant angles. (3)
   ii. Calculate the value of the tension of the rope, the value of the angle θ and the components of the tension along the horizontal plane and the vertical direction. (2,2,2)
   iii. If the rope were shortened by half of its length L, keeping constant the tensions and the angle found in (c)(ii), what would be the effect on the angular velocity? Justify your answer. (3)

d. Assume now that the rope, with its initial length of 3.5 m can withstand a maximum tension of 4000.0 N before it breaks and releases the ball.
   i. Calculate the maximum linear speed at which the ball can rotate. (2)
   ii. Describe the motion of the ball after the rope breaks. Justify your answer. (1)
   iii. Calculate the component of the ball's velocity parallel to the ground at the moment the ball hits the ground. (1)

(Total: 20 marks)

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SECTION A
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1. [Earth has mass $m_E = 5.98 \times 10^{24}$ kg and radius $r_E = 6378$ km.]

   a. State Newton's law of gravitation in words. (1)

   b. Define the gravitational field strength at a point in terms of gravitational force. (1)

   c. Using the definitions in (1a) and (1b), calculate the value of *g* on the Earth's surface given that the gravitational constant $G = 6.67 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$. (3)

   d. Sketch a graph showing how the gravitational field strength varies with distance away from Earth's surface. Clearly label the graph, including notable quantities. (3)

   e. State **TWO** factors that result in the variation of gravitational field strength over the Earth's surface. (2)

   (Total: 10 marks)

2. a. Describe the ways in which the following properties differ between a progressive wave and a standing wave:
      i. amplitude; (1)
      ii. phase; (1)
      iii. energy propagation. (1)

   b. Sketch a diagram of a standing wave, clearly marking a node and an antinode. (2)

   c. A cello string of length 80 cm and mass 1.7 g is attached at the pegbox (at the top) and at the tailpiece (at the bottom), such that the vibrating length is 68 cm and the rest is wrapped around the pegbox. The string experiences 109 N of tension.
      i. Calculate the mass per unit length. (1)
      ii. Calculate the fundamental frequency. (2)
      iii. A cellist would like to achieve a lower frequency to tune the string to D. Without varying the other quantities, should the tension increase or decrease? Give a reason for your answer. (2)

   (Total: 10 marks)

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3. a. Draw the magnetic field (indicating the direction of current and B-field in each case) of:
   i. a long straight current-carrying conductor; (2)
   ii. a current-carrying solenoid. (2)

   b. Describe **THREE** ways in which the magnetic field strength of a solenoid can be increased. (3)

   c. Determine the number of turns per unit length needed for a hollow solenoid to produce a magnetic field at its centre that is equal in magnitude to the field generated by a long, straight conductor carrying the same current, measured at a perpendicular distance of 0.015 cm from the wire in free space. (3)

(Total: 10 marks)

4. a. State Faraday's and Lenz's laws of electromagnetic induction. (4)

   b. Consider a straight conductor of length l, moving in a uniform magnetic field B, at a velocity v. Derive an equation for the emf induced across the conductor. The quantities B, l and v are to be taken perpendicular to each other. (3)

   c. A rod of length 3 m moves with a velocity of 5 m s^{-1} within a uniform magnetic field directed into the plane of the paper, as shown in Figure 1.
      i. Given that the induced emf in the rod is E = 0.02 V, calculate the magnitude of the magnetic field strength.(2)
      ii. Explain how rotating the rod by angle θ within the plane of the paper affects the induced emf, assuming velocity remains perpendicular to the rod. (1)

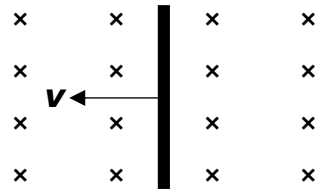

Figure 1

(Total: 10 marks)

5. An alternating voltage source with a peak voltage of 12 V and a frequency of 300 Hz is connected to a pure inductor. The root mean square current observed in the circuit is 0.2 A.
   i. Explain the term 'root mean square current'. (2)
   ii. Assuming there are no resistors in the circuit, calculate its inductance. (4)
   iii. If the inductor is replaced with a capacitor, what value of capacitance would be required to produce the same rms current in the circuit? (2)
   iv. Briefly explain how current flows in the circuit when an AC supply is connected to a capacitor. (2)

(Total: 10 marks)

6. A student is having a difficult time reading a vernier scale. The lab demonstrator has supplied the student with a thin converging lens marked with a focal length of 15 cm. The lens is placed 10 cm from the vernier scale.

   a. Sketch a ray diagram illustrating how an image is formed. Mark the lens, object, image, principal focus, and principal axis. (4)

   b. Calculate the position of the image from the lens. (3)

   c. Calculate the magnification of the image. (2)

   d. State **THREE** characteristics of the image formed. (1)

(Total: 10 marks)

7. The Big Bang cosmological model describes the origin and the evolution of the Universe. [$1\ \text{Mpc} = 3.086 \times 10^{19}\ \text{km}$]

   a. Hubble's law provides strong evidence for the Big Bang theory.
      i. Explain the Big bang model. (2)
      ii. State Hubble's law and write an equation describing the law. (2)

   b. List **TWO** other observations that provide evidence for the Big Bang model. (2)

   c. Using Figure 2, estimate the age of the Universe. (3)

   d. Local measurements of the Hubble constant tend to give higher values. If the Hubble constant increases, would the estimated age of the Universe be greater, smaller, or unchanged? (1)

(Total: 10 marks)

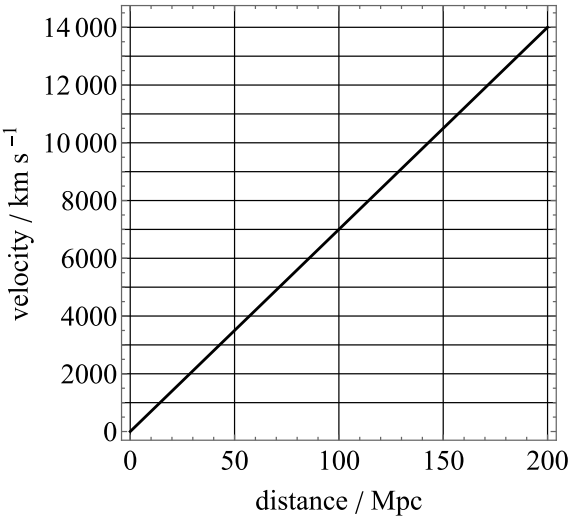

Figure 2

8. a. A container filled with an unknown liquid is measured to have a total mass of 225 g. To determine what liquid it is, a student decides to obtain the value for the latent heat of vaporization of the liquid. The liquid, initially at 23°C, is supplied with an electric heater to reach a boiling point of 78.4°C. After reaching this point, the heater is left on for 20 g of liquid to vaporize.
      i. For the entire process to occur, it took a total energy of $Q_{\text{Total}} = 43{,}672\ \text{J}$. The container has a mass of 25 g on its own, and energy transfer to the container is negligible. Determine the latent heat of vaporization in terms of the specific heat capacity *c.* (5)
      ii. Determine which of the following liquids corresponds to the unknown liquid in the container. (1)

Liquid	**Latent Heat of Vaporization *L*** (kJ kg^{-1})	**Specific Heat Capacity *c*** $(\text{kJ kg}^{-1}\ \text{K}^{-1})$
Isopropanol	667	2.7
Ethanol	854	2.4
Acetonitrile	538	2.2

   b. 12.04×10^{23} molecules of a diatomic ideal gas sample have a molar heat capacity at constant volume given by $C_V = \frac{5}{2} R$, where $R = 8.314\ \text{J mol}^{-1}\ \text{K}^{-1}$. [Avogadro's number = $6.02 \times 10^{23}\ \text{mol}^{-1}$.]
      i. Calculate the molar heat capacity at constant pressure. (2)
      ii. Determine the heat required to raise the temperature of the gas sample by 20 K at constant pressure. (2)

(Total: 10 marks)

Please turn the page.

SECTION B

Attempt any FOUR questions from this section. Each question carries 20 marks. This section carries 50% of the total marks for this paper.

9. a. An ideal gas is placed in the cylinder of an engine, and it undergoes a series of changes in temperature, pressure, and volume. Figure 3 shows an example of such a cycle. Curves BC and DA are isothermal processes.

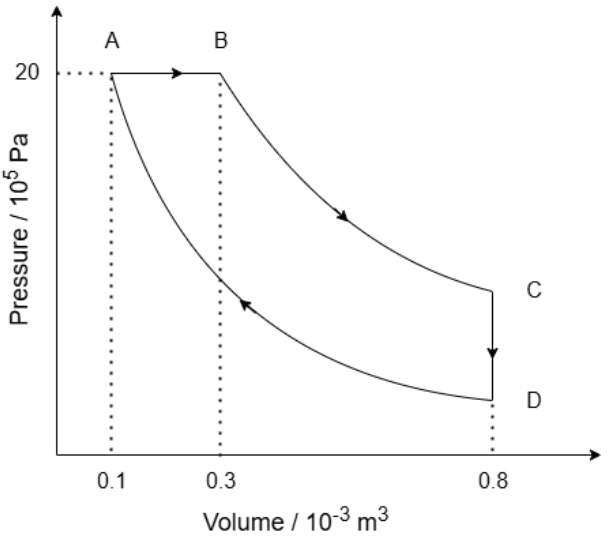

Figure 3

i. The temperature at A is noted to be 283 K. Calculate the temperature at B and state the law used. (3)

ii. Calculate the pressure at C and state the law used. (3)

iii. Calculate the pressure at D and state the law used. (3)

b. The kinetic theory of gases states that the pressure P can be related to the gas density ρ and the mean square speed of molecules $\langle c^2 \rangle$ by the equation

$$P = \frac{1}{3}\rho\langle c^2 \rangle.$$

State **TWO** assumptions made in deriving the above equation. (2)

c. Helium gas can be considered to behave as an ideal gas at $8\,℃$. It is placed within a cubic container of sides $12\,\text{cm}$ and experiences a pressure of $1.85 \times 10^6\,\text{Pa}$. $[R = 8.314\,\text{J mol}^{-1}\,\text{K}^{-1}, k_B = 1.38 \times 10^{-23}]$

i. Determine the number of moles present in the gas. (3)

ii. Calculate $\langle c^2 \rangle$ if the gas has a molar mass of $4\,\text{g mol}^{-1}$. (2)

iii. Derive the equation for the average kinetic theory:

$$\langle E_{\text{k,per mole}} \rangle = \frac{3}{2}RT \quad (2)$$

iv. Find the average kinetic energy for one molecule of this gas. (2)

(Total: 20 marks)

10. A simplified version of a grandfather clock is made up of a rod with negligible mass and a bob at its end, acting as a simple pendulum swinging through small angles. The regular swing breaks time into equal chunks, hence making it reliable to keep time.

a. Explain why the motion of the pendulum can be said to be simple harmonic motion. (2)

b. The maximum angular displacement is $5°$. Every 20 full oscillations correspond to 36 s. Calculate the following quantities:

i. periodic time; (1)

ii. angular frequency; (1)

iii. length of the pendulum; (2)

iv. maximum velocity; (2)

v. maximum acceleration. (2)

Hint: Arc length $s = l\theta$ where θ is in radians.

c. Sketch the following graphs separately, detailing one complete cycle starting from maximum displacement. Mark notable values.
   i. Displacement-time graph. (2)
   ii. Velocity-time graph. (2)

d. Two identical pendulum clocks are placed next to each other. While identical, Pendulum A leads Pendulum B and they are out of phase.
   i. Define the term phase lead in this context. (1)
   ii. Write two equations for the displacement of the two pendula in terms of these quantities: A, ω, t, ϕ. (2)
   iii. One of the pendula reaches its maximum displacement 0.15 s after the other. Calculate the phase difference in radians using the values found in part (b). (1)

e. Timekeeping can become inaccurate during seasonal temperature changes. Explain why, and how it impacts the periodic time. (2)

(Total: 20 marks)

11. a. Identify the main mode of heat transfer involved in each of the following situations:
   i. The handle of a metal spoon in hot coffee heats up, even though the handle is not in contact with the liquid; (1)
   ii. Experiencing a chill after getting out of the water; (1)
   iii. The formation of a sea breeze. (1)

b. The Sun is often modelled as a blackbody.
   i. Define the term 'blackbody'. (2)
   ii. Describe, with the aid of a labelled diagram, how a blackbody can be approximated in practice. (4)
   iii. On the same set of axes, sketch graphs showing the variation of blackbody radiation intensity with wavelength for two temperatures, T_1 and T_2, where $T_2 > T_1$. (4)
   iv. State what the area under each curve represents. (1)

c. A point source emits electromagnetic radiation uniformly in all directions with a total power output of 120 W.
   i. State the inverse square law as it applies to radiation intensity. (2)
   ii. Calculate the intensity of the radiation at a distance of 3.0 m from the source. (2)
   iii. At what distance from the source would the intensity be reduced to 5.0 W m^{-2}? (2)

(Total: 20 marks)

12. a. Sketch the electric field between two particles of opposite charge. On a separate diagram, illustrate at least two equipotential surfaces around one of the charges, and another where the net electric potential is zero. (5)

b. Explain qualitatively what is meant by 'permittivity of free space'. Define the relative permittivity (dielectric constant). Identify the symbols used for each term. (4)

c. A particle with charge $+2.0 \times 10^{-6}$ C and mass 4.0×10^{-6} kg enters a uniform electric field of strength 3.0×10^{4} N C^{-1}. The particle is accelerated by the field in the same direction as its velocity. If the particle's initial velocity of 5.0 m s^{-1} is parallel to the electric field lines, calculate:
   i. its acceleration; (2)
   ii. its velocity after 0.01 s. (2)

Question continues on the next page.

d. If instead, the particle's initial velocity of 5.0 m s^{-1} is perpendicular to the electric field lines, find:
   i. the magnitude of its velocity after 0.01 s; (4)
   ii. the angle its velocity makes with its initial direction after 0.01 s. (1)

e. List **ONE** similarity and **ONE** difference between gravitational and electric fields. (2)

(Total: 20 marks)

13. a. Give a qualitative definition of the capacitance of a capacitor. (2)

b. Sketch a well labelled diagram of a charged parallel plate capacitor. (3)

c. A capacitor is connected in series with a 100 Ω resistor and charged using a DC power supply. After a time equal to three time constants, the voltage across the capacitor is found to be 8.6 V.
   i. Determine the voltage supplied by the power source. (4)
   ii. Draw a graph showing how the current through the resistor varies with time. Determine and label the maximum current. On the graph, mark the time constant and the current value at that instant. (4)
   iii. Given that the energy stored in the capacitor after three time constants is 0.05 mJ, calculate the time constant of the circuit. (3)
   iv. Explain how the capacitance and the energy stored in the capacitor can be obtained from a graph of charge versus voltage. (2)

d. Derive an expression for the total capacitance of two capacitors connected in parallel. (2)

(Total: 20 marks)

14. a. Describe a simple experimental setup using a solenoid and a magnet to explore how a changing magnetic flux induces an electromotive force in a circuit. Explain the expected qualitative observations in accordance with Faraday's and Lenz's laws, and comment on how the number of turns in the solenoid influences the outcome. Include a clearly labelled diagram to illustrate the arrangement. (7)

b. Sketch a structure of a simple generator and briefly explain how it works. (4)

c. A coil of inductance L = 0.4 H and resistance R = 6 Ω is connected in series with a 12 V DC power supply.
   i. Sketch a graph showing how the current in the circuit changes with time after the switch is closed. (2)
   ii. Briefly explain the shape of the graph. (2)
   iii. After the current reaches its maximum steady-state value, the switch is suddenly opened. Explain why the back e.m.f. generated at that moment may be significantly larger than the original supply voltage. (2)
   iv. Calculate the rate of change of current at the instant when the current in the circuit is 1 A. (3)

(Total: 20 marks)

15. a. The first law of thermodynamics describes the conservation of energy within a system during a thermodynamic process.
    i. Write an equation to describe the first law of thermodynamics. (1)
    ii. Define each term in the first law of thermodynamics. State the physical meaning of these terms when they are positive. (3)
    iii. Write an equation for the first law of thermodynamics for the following situations:
        I. Heating a pot filled with water with the lid on, and kept below boiling point. (2)
        II. A filament lamp after being switched on for a few minutes and thermal equilibrium is reached. (2)
    iv. Using the first law of thermodynamics and the ideal gas law, obtain the relationship between the heat capacity at constant pressure C_P to the heat capacity at constant volume C_V:

$$C_P - C_V = R \quad (4)$$

b. A bicycle pump is used to inflate a flat tyre. As the piston is pushed down, the air inside the pump's cylinder compresses rapidly. Because this compression happens quickly, there is insufficient time for heat to be transferred between the air inside the cylinder and the surrounding environment. Assume ideal gases throughout.
    i. Give a reason why this process can be assumed to be adiabatic. (1)
    ii. The air in the pump cylinder has an initial volume of $450\ \text{cm}^3$, pressure of $1.2 \times 10^5\ \text{Pa}$. The air is compressed to a volume of $300\ \text{cm}^3$. Given the adiabatic constant is 1.4, calculate the final pressure. (2)
    iii. The initial temperature in part (b)(ii) is 290 K. Determine the final temperature. (2)
    iv. Instead of air, a monatomic gas is used, such that the adiabatic constant is $\frac{5}{3}$. Calculate the final volume required to obtain the same pressure as that obtained in part (b)(i). (3)

(Total: 20 marks)

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MATRICULATION AND SECONDARY EDUCATION CERTIFICATE
EXAMINATIONS BOARD

ADVANCED MATRICULATION LEVEL
2025 SECOND SESSION

SUBJECT:	**Physics**
PAPER NUMBER:	III – *Practical*
DATE:	28th August 2025
TIME:	2 hours 5 minutes

Experiment: Determining the thermal conductivity of boiling tube glass.

Apparatus: Stand and clamp, spirit lamp, two glass beakers, boiling tube, thermistor, multi-meter, liquid-in-glass thermometer and stopwatch.

Health and Safety:

- This experiment involves an open flame (spirit lamp) and warm to very hot/boiling water. For this reason, particular attention is required to carry out the procedure safely.
- Keep hair, sleeves and paper well away from the flame. Do not knock or tip the spirit lamp. In the rare event of a fire, inform the invigilator immediately.
- Failure to follow these instructions may incur harm, damage to the apparatus and loss of time.

Diagram:

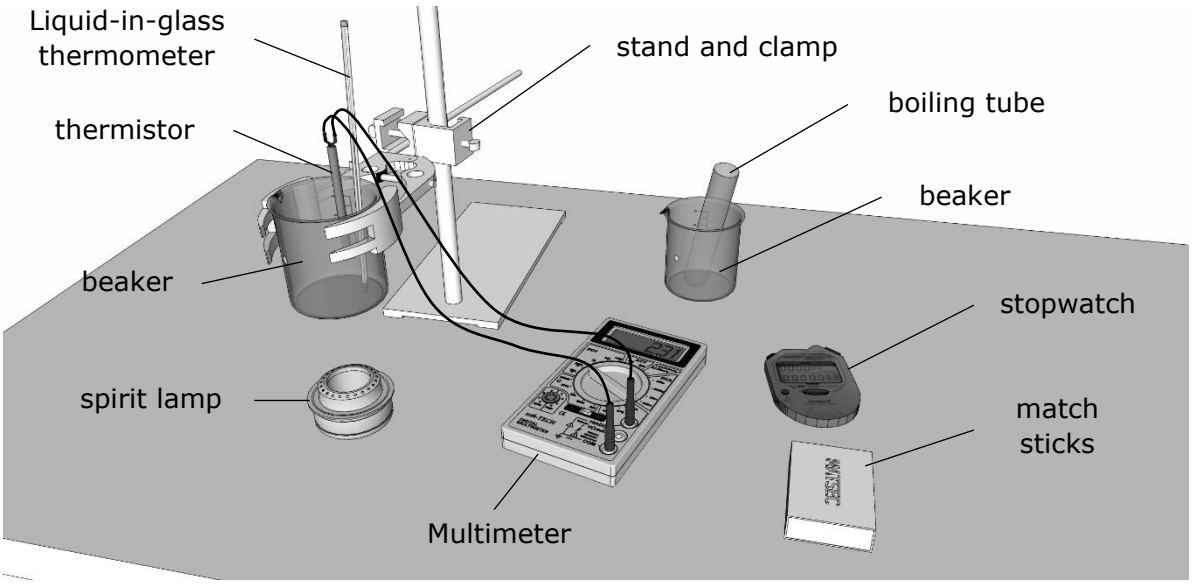

Figure 1 The experimental setup

Method – Part A:

1. The apparatus is set up for you. Make sure that you have all the apparatus that is shown in the diagram (actual setup may vary from the one shown) of Figure 1.

2. This stage of the experiment involves calibrating a thermistor, enabling it to be used as a thermometer in the following part.

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3. The thermistor provided is a *negative temperature coefficient* thermistor. Explain what is meant by *negative temperature coefficient thermistor.*

_____

_____ (2)

4. A beaker containing about 150 ml of water is already clamped to the stand above the spirit lamp. Check that it is held securely but avoid tightening the clamp unnecessarily, as this may cause the beaker to break.

5. Place both the liquid-in-glass thermometer and the thermistor into the beaker of water, ensuring that the thermistor does **not** touch the bottom.

6. Connect the thermistor leads to the multimeter: one lead to the common socket and the other to the resistance-measuring socket.

7. The thermistor has a resistance $R_0 = 10\ \text{k}\Omega\ (10{,}000\ \Omega)$ at a temperature $T_0 = 298.15\ \text{K}$. Use this information to set the multimeter to measure resistance in the correct range.

8. Record the initial water temperature θ_i in the beaker and the corresponding thermistor resistance R_i in the first row of Table 1 below. (2)

9. With assistance from a technician, or by using the provided matchsticks, light the spirit lamp, and then start the stopwatch. You will begin taking readings of the resistance R when the temperature on the liquid-in-glass thermometer θ reaches the values indicated in Table 1. Ensure that the water is continuously stirred throughout.

10. Record in Table 1 the resistance of the thermistor, R, when the thermometer reads the values indicated in the column for θ. Also record the total heating time Δt when the water reaches $65\ ^\circ\text{C}$. Turn off the spirit lamp when ready. (6)

Table 1

$\theta\ /^\circ\text{C}$	$T\ /\text{K}$	$\frac{1}{T}\ /\text{K}^{-1}$	$R\ /\Omega$	$\ln R$
40°C				
45°C				
50°C				
55°C				
60°C				
65°C				

11. The time Δt in seconds taken by the water to reach 65°C is $\Delta t =$ _____s. (1)

12. Complete Table 1 by working out the absolute temperature T, $\frac{1}{T}$ and $\ln R$. Note that $T = \theta + 273.15\ \text{K}$. (9)

13. The relationship between the resistance R and the absolute temperature T is given by:

$$R = R_0 e^{-\beta\left(\frac{1}{T_0}-\frac{1}{T}\right)}$$

where β is a constant and R_0 is the resistance of the thermistor at temperature T_0 (refer to Part 7).

14. Rearrange the equation in part (13) to show that $\ln R = \frac{\beta}{T} + K$, where $K = \ln R_0 - \frac{\beta}{T_0}$.

_____

_____ (3)

15. Plot a graph of $\ln R$ against $\frac{1}{T}$. (8)

16. Using the graph, determine the value of the constants β and K.

_____

_____

_____ (5)

17. The power P of the spirit lamp can also be estimated using $P = (C_{water} + C_{beaker}) \times \frac{\Delta\theta}{\Delta t}$, where C_{water} is the heat capacity of water, C_{beaker} is the heat capacity of the beaker and $\Delta\theta$ is the rise in temperature in time Δt. Use the data below, the value of θ_i recorded in part 8 and the value of Δt recorded in part 11 to determine an estimate of the power of the spirit lamp.

Mass of Beaker	$0.0417\ \text{kg}$
Specific Heat Capacity of Beaker	$753\ \text{J kg}^{-1}\text{K}^{-1}$
Volume of Water in Beaker	$150\ \text{ml}$
Density of Water	$1000\ \text{kg m}^{-3}$
Specific Heat Capacity of Water	$4184\ \text{J kg}^{-1}\text{K}^{-1}$
Rise in temperature $\Delta\theta$	$65 - \theta_i$

_____

_____

_____

_____ (4)

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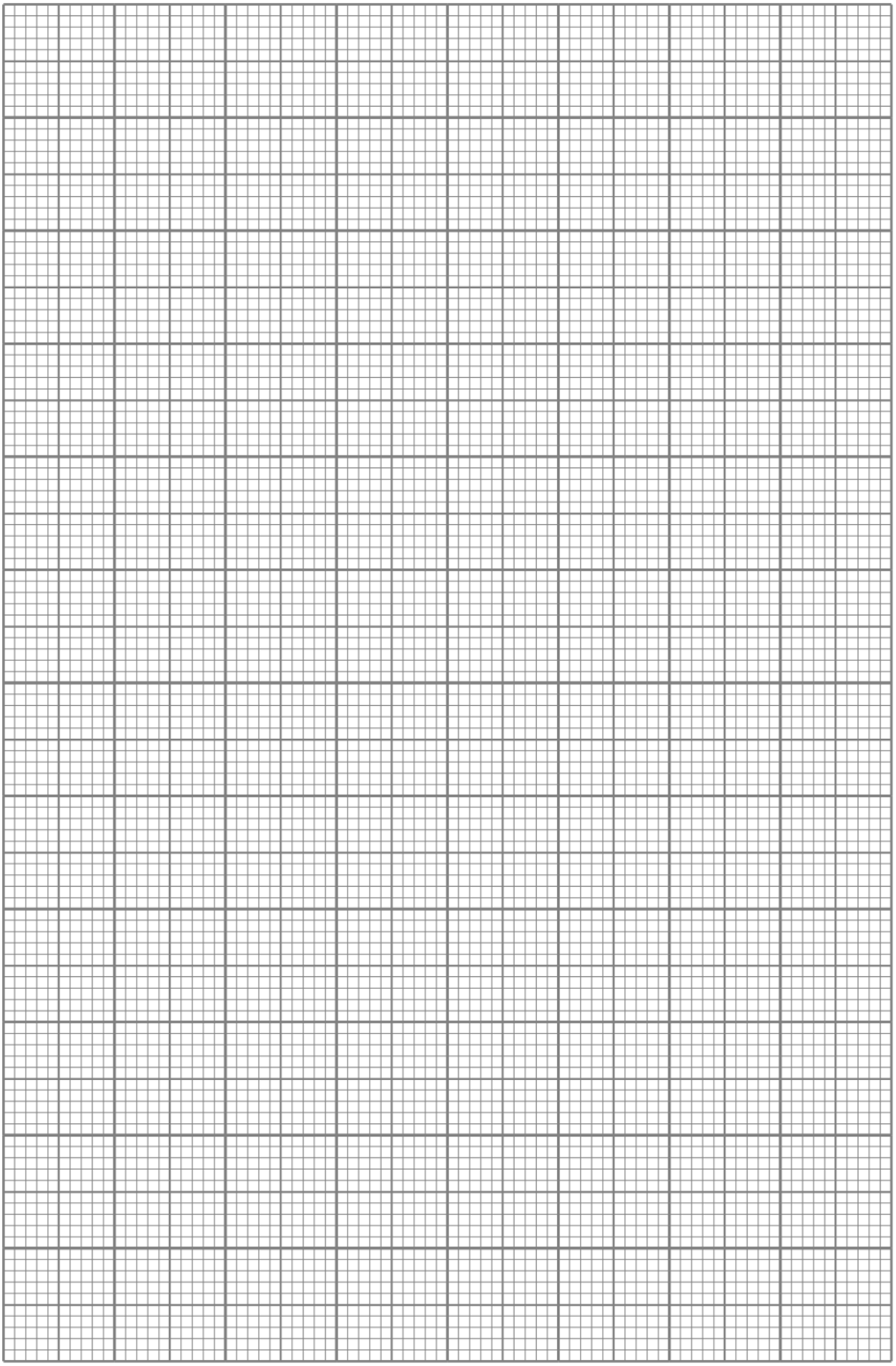


Method – Part B:

18. In this stage of the experiment, the thermistor will measure the temperature of the water inside the boiling tube, while the liquid-in-glass thermometer will measure the temperature of the hot water in the beaker. By analysing how these two temperatures vary with time, the thermal conductivity of the Pyrex glass of the boiling tube can be determined.

19. First, remove the thermistor from the beaker and let it cool for a while. The liquid-in-glass thermometer is to remain inside the beaker.

20. Next, place the thermistor in the boiling tube that is partially filled with water at room temperature.

21. Observe the temperature of the water inside the beaker. If it is below $65\,°\text{C}$, relight the spirit lamp and continue heating until the temperature reaches at least $65\,°\text{C}$. Turn off the spirit lamp when this is achieved.

22. Stir the water in the beaker and record the initial temperature θ_i of the hot water inside the beaker. Record also the resistance of the thermistor R_i. Enter both readings in the row corresponding to $t = 0\,\text{s}$ of Table 2. (2)

23. Now place the boiling tube (with the thermistor inside) into the beaker with hot water and start the stopwatch. Every 30 seconds for a total duration of 3 minutes, record the resistance R from the multimeter and the temperature θ from the liquid-in-glass thermometer in the corresponding rows of Table 2. Ensure that the water in the beaker is stirred before each reading. (12)

Table 2

Time, t /s	R/Ω	$\theta/°\text{C}$
0		
30		
60		
90		
120		
150		
180		

24. Use the relationship $T = \frac{\beta}{\ln(R) - K}$, and the values of β and K obtained in part 16, to calculate the temperature T (in kelvin) from each measured resistance R of the thermistor. Record these values in the T_{in} column of Table 3. (2)

Please turn the page.

25. Convert the thermometer readings θ (in °C) from the liquid-in-glass thermometer into kelvin and record the results in the T_{out} column of Table 3. (2)

Table 3

Time, t /s	T_{in}/K	T_{out}/K	$\Delta T = T_{out} - T_{in}$ /K	$\ln(\Delta T)$
0				
30				
60				
90				
120				
150				
180				

26. Complete Table 3 by working out the missing values for ΔT and $\ln(\Delta T)$. (4)

27. It is given that the difference between the inside and outside temperatures of the boiling tube is related to the conductivity, k, of the Pyrex glass by the expression:

$$\ln(\Delta T) = \mathrm{P} - \lambda t$$

where λ is defined as

$$\lambda = \frac{kA}{m_{bt} c_{water} d}$$

In this expression:

- k is the thermal conductivity of the glass,
- A is the surface area of the immersed portion of the boiling tube,
- m_{bt} is the mass of the water inside the boiling tube,
- c_{water} is the specific heat capacity of water, and
- d is the thickness of the glass wall.

Here, P is a constant that depends on the initial temperature conditions.

28. Plot a graph of $\ln(\Delta T)$ on the y-axis against t/s on the x-axis. (8)

29. Use the graph to determine a value for the constant λ and state its unit.

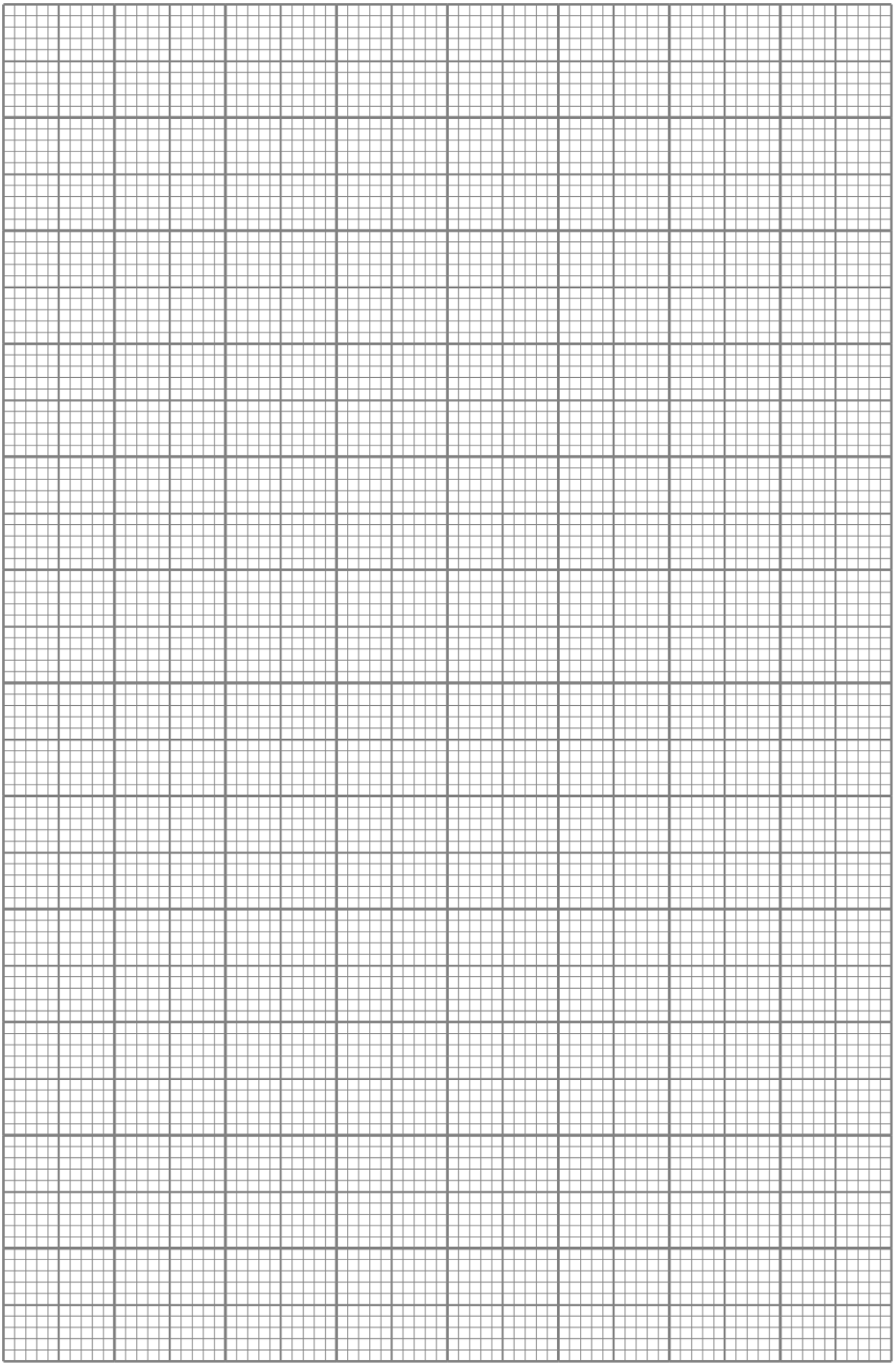
_____

_____

_____

_____

_____ (4)



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30. The volume of water inside the boiling tube is $30\ ml$ and the surface area of the boiling tube that is in contact with the water inside the beaker is $0.0035\ m^2$. Use the value of the specific heat capacity of water provided in part A and the fact that the thickness of glass is $0.00125\ m$ to determine the conductivity k of the glass.

_____

_____

_____

_____

_____ (4)

31. State **ONE** possible source of error and **ONE** corresponding precaution that could be taken to improve the setup or the procedure.

_____

_____

_____ (2)