L-Università ta' Malta

MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

ADVANCED MATRICULATION LEVEL
2026 SECOND SESSION

SUBJECT:	**Physics**
PAPER NUMBER:	I
DATE:	31st August 2026
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 $g = 9.81$ 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. A smartphone charges by routing electrical current along internal copper traces directly to the battery cell.
   a. A new smartphone battery has an electromotive force of 4.2 V when fully charged. A current of 3 A is supplied.
      i. Explain the difference between e.m.f. and terminal p.d. (2)
      ii. The phone shuts down if its terminal voltage is below 3.5 V. Calculate the maximum internal resistance allowed before the phone shuts down. (2)
   b. The charging system features a Negative Temperature Coefficient (NTC) heat-sensing thermistor as part of a potential divider circuit, and a Positive Temperature Coefficient (PTC) resettable fuse connected in series with the charging cable input.
      i. The table below shows the resistances at 15 °C before charging and at 40 °C after charging for both thermistors. Identify the NTC thermistor and calculate the negative temperature coefficient of resistance. (3)

	R (15 °C)	*R* (40 °C)
Thermistor A	16 kΩ	5 kΩ
Thermistor B	9 kΩ	12 kΩ

      ii. Explain how a PTC thermistor protects the smartphone during charging. (2)
   c. A Light Dependent Resistor (LDR) is used to automatically adjust the screen brightness. State if the resistance of the LDR increases, decreases, or stays the same as the user moves from a dim room to a bright room. (1)

(Total: 10 marks)

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2. a. Define frequency and period in relation to circular motion clearly indicating their units of measure and the relation between them. (1,1,1)
   b. A point starts moving from rest along a circle of radius 40 cm, with constant tangential acceleration $a_t = 10$ cm s^{-2}. What time is needed after the motion begins for the centripetal acceleration of the point to be equal to the tangential acceleration? (3)
   c. A particle of mass $m = 2.0$ kg is attached to a spring of initial length $L = 50$ cm and spring constant $k = 30$ N m^{-1} and is rotated in a horizontal plane with an angular velocity $\omega = 2$ rad s^{-1}. What is the new length of the spring and the tension in the spring? (3,1)

(Total: 10 marks)

3. A spacecraft is equipped with a thruster, where ionized Xenon gas is shot out at extreme speeds to push the spacecraft forward. Figure 1 illustrates the total accumulated charge expelled in the exhaust beam with time. [$e = 1.6 \times 10^{-19}$ C]

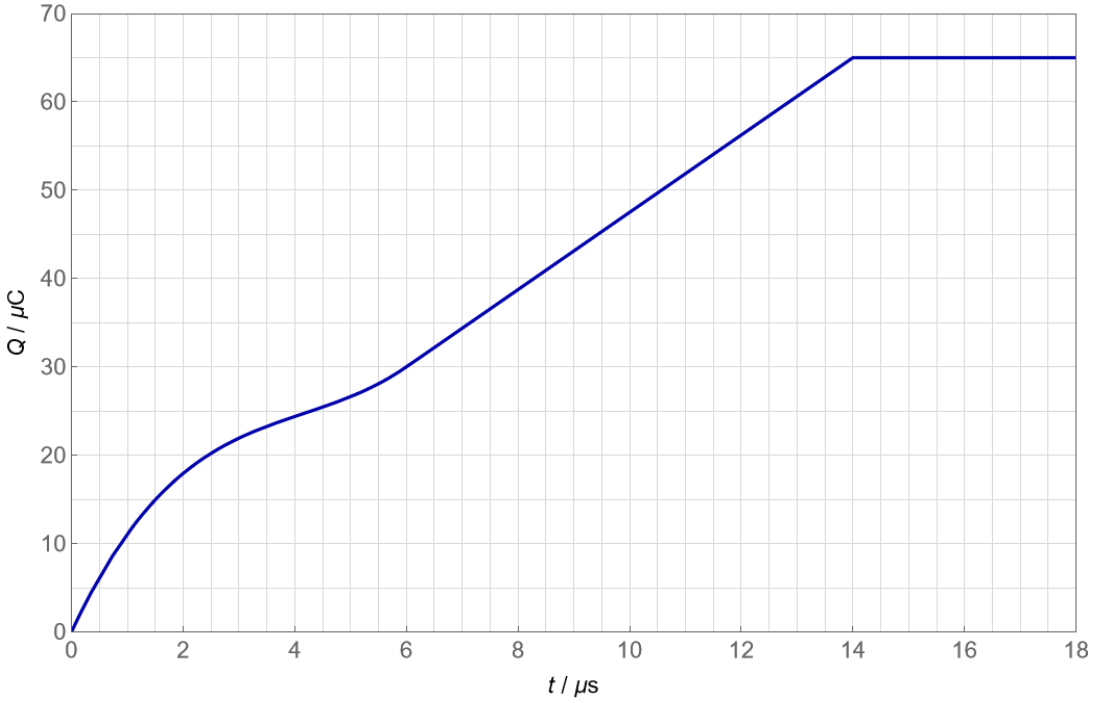

Figure 1

   a. Estimate the instantaneous current at $t = 2.5$ μs. (2)
   b. The thruster fires Xenon ions to the left. The ions carry a positive triple charge. State the direction of the conventional current and explain how it relates to the physical direction of motion of these positive ions. (2)
   c. State and explain the value of the beam current at $t = 16$ μs. (2)
   d. At $t = 2.5$ μs, the beam has a circular cross-section with radius 1 mm. The number density of triple-charged Xenon ions inside the beam volume is 9×10^{17} m^{-3}. Calculate the drift speed of the ions inside the beam. (4)

(Total: 10 marks)

4. The velocity v at which the car turns a flat, unbanked corner is given by

$$v = \sqrt{\mu\, r \left(g + \frac{F_{down}}{m_{car} + m_{driver}}\right)}$$

where μ is the tyre coefficient of friction, r is the corner radius, g is the acceleration due to gravity, F_{down} is the aerodynamic downforce, m_{car} is the mass of the car, and m_{driver} is the mass of the driver.

a. Determine the S.I. unit of the tyre coefficient of friction μ. (3)

b. The race team's data-logging software displays a torque reading of 450 J. Explain why using the unit joule for torque is unsuitable. (2)

c. Figure 2 shows a simple free-body diagram of the race car, where the aerodynamic force is at an angle θ with the horizontal line.

   i. Write equations for the equilibrium of forces in the two perpendicular components. (2)

   ii. A member of the team states that "*the vertical component of the aerodynamic force directly cancels out some of the horizontal drag force*". State whether this statement is correct or incorrect. Explain your answer. (2)

   iii. The term $(s\, F_{friction})$ is added to the equation for the horizontal components obtained in part (ci), to account for the friction $F_{friction}$ over a distance s, for the car to have a constant speed. State why the new equation is incorrect. (1)

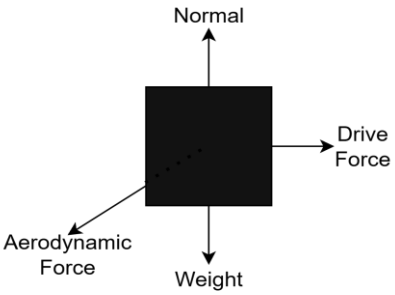

Figure 2

(Total: 10 marks)

5. A new car suspension design features three key components made respectively from steel coil springs, glass fibre composite, and vulcanized rubber.

a. On a single stress-strain graph, sketch the characteristic curves of each material. Clearly label the plot. (3)

b. In reference to the stress-strain graph, explain why glass fibre is suitable for light-weight rigid panels but unsuitable for suspension components that experience heavy impacts. (2)

c. Engineers place rubber pads between car motors and frames to prevent rapid motor vibrations from causing severe structural wear. Explain why rubber is selected over steel. Refer to the area in the stress-strain graph and energy transformation during each vibration cycle. (2)

d. Two identical steel springs, each with a stiffness constant of 42 kN m^{-1}, are used to support the weight of the car's frame.

   i. Calculate the effective stiffness constant of the two springs if they are:
   - connected in series; (1)
   - connected in parallel. (1)

   ii. Explain which arrangement is preferred for supporting heavy loads if the arrangement is compressed by a distance x. (1)

(Total: 10 marks)

Please turn the page.

6. a. Define the terms photon and work function. (1,1)
   b. Light of wavelength 450 nm is incident on a metal surface of work function 2.30 eV. Determine the photon energy. Using Einstein's photoelectric equation, calculate the maximum kinetic energy of the emitted photoelectrons in eV and the stopping potential required to stop them. (1,2,2)
   c. Calculate the de Broglie wavelength associated with a photoelectron emitted with the maximum kinetic energy found in question 6(b). (3)

(Total: 10 marks)

7. a. A greenhouse has a temperature-controlled unit connected to an ideal power supply of 24 V. The circuit consists of two soil-heating mats connected in parallel, each with resistance of $40\ \Omega$. The heating mats are connected in series with a safety switch.
      i. Draw the circuit. Represent the heating mats as resistors. (3)
      ii. Calculate the total current delivered by the power supply to the entire circuit after the switch has been closed. (2)
      iii. At high temperatures, the switch opens up to turn off the heating system. State the value of the following when the circuit is open:
         - Current in the circuit. (1)
         - Potential difference across the parallel heating mats. (1)
         - Potential difference across the open terminals of the switch. (1)
   b. The copper cable delivering power to the mats has a total length of 20 m and a uniform cross-sectional area of 3.5×10^{-6} m^2. Copper resistivity is $1.68 \times 10^{-8}\ \Omega$ m^{-1}.
      i. Define resistivity. (1)
      ii. Calculate the total electrical resistance of this cable. (1)

(Total: 10 marks)

8. An object moves according to the velocity-time graph represented in Figure 3.
   a. Identify the sections (if any) where the object is moving with constant acceleration and where with a variable acceleration. Identify the sections by indicating the respective time intervals and, for the section with constant acceleration, report also its value. (3)
   b. Draw the acceleration-time graph corresponding to Figure 3. Indicate clearly the values and the units of measurement on the axes. (3)

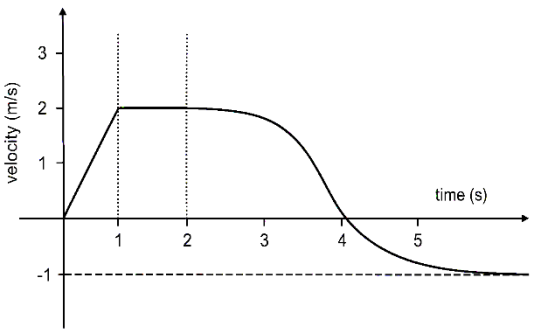

Figure 3

   c. Assume now that the object performing the motion as in Figure 3 for t > 4 s is a sphere freely falling in air. The aerodynamic drag, that is, the resistive force acting on an object falling freely in air, is $F_d = \frac{1}{2}\rho C A v^2$, where ρ=1.3 kg/m³ is the air density, $C = 0.5$ is the drag coefficient for the sphere, and $A = 1.5$ m^2 is the cross-sectional area. Calculate the mass of the falling sphere. You can neglect the air buoyancy, that is, the upward force exerted on the sphere by the air it displaces. (3)
   d. With reference to Figure 3, state the value of the terminal velocity. (1)

(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 wheel of radius $r = 1.2$ m and mass $m = 10$ kg is stationary at the bottom of a step of height $h = 20$ cm and has to be raised over the step by a horizontal force F applied to the centre of gravity (see Figure 4).

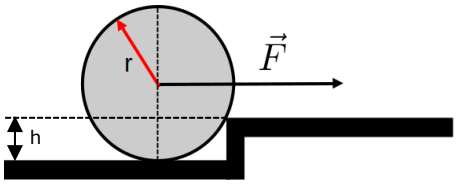

Figure 4

   a. Considering the top of the step as a pivot point, what is the minimum value of F such that the wheel is raised over the step. (4)
   b. Assume now that the force can be applied at any point along the vertical diameter (dotted line in Figure 4).
      i. Along which section of the vertical diameter is it **not** possible to raise the wheel over the step should the force be applied at those points? Justify your answer. (1,1)
      ii. At which point(s) along the vertical diameter would the applied force required to raise the wheel over the step be the lowest? Justify your answer. (1,1)
   c. Assume now that the wheel moves with velocity *v* towards the step from the left. If you aim at modelling the process of the wheel hitting the step and rising over it as a collision, would it be a perfectly elastic or an inelastic collision? Justify your answer. (2)
   d. i. Define moment of inertia of a rigid body. (2)
      ii. The wheel is held vertically with one end on the floor and is then allowed to fall sideways. Calculate the speed of the point on the rim opposite to the point of contact between the wheel and the floor just before it hits the floor, assuming the end on the floor does not slip. Assume that the moment of inertia of the wheel rotating around the point of contact with the floor is $I = 2mr^2$. (3)
      iii. Draw the forces acting on the wheel at an arbitrary position while it is falling, that is, when the wheel is neither in the vertical nor in the horizontal position. (2)
      iv. Explain why the angular acceleration of the wheel increases as it falls. (3)

(Total: 20 marks)

10. a. The diagram in Figure 5 shows a circuit with two batteries, E_1 and E_2, with corresponding internal resistances of r_1 and r_2, along with resistances R_1 and R_2.
      i. State Kirchhoff's laws. (2)
      ii. Derive equations for the left loop and for the right loop. (2)
      iii. Now assume that the batteries are ideal. Derive an equation for the current passing through resistor R_2. (3)
      iv. Hence, write an expression for the power dissipated in resistor R_2. (1)

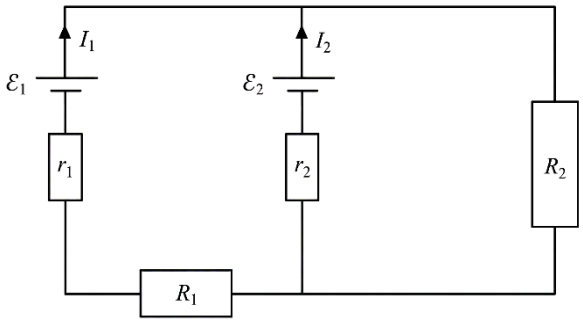

Figure 5

Question continues on the next page.

b. A uniform 1 m potentiometer wire AB with resistance 9 Ω is connected in series with a driver cell $E_{driver} = 4$ V, an internal resistance 1 Ω, and an ideal ammeter. A secondary branch attached at end A contains a test cell of unknown emf E_x and internal resistance 1.5 Ω connected in series with a galvanometer of resistance 40 Ω and a sliding jockey contact P.
   i. State the internal resistance of an ideal ammeter. (1)
   ii. Assume the secondary branch has not yet been connected. Calculate the potential difference across wire AB. (2)
   iii. Explain why connecting a non-ideal voltmeter directly across the test cell fails to measure its true e.m.f. (1)
   iv. Explain how a potentiometer acts as an ideal voltmeter at the null point. (2)
   v. The null point is obtained when slider P is at a length 60 cm from end A. Calculate the unknown e.m.f. E_x. (2)
   vi. The jockey contact P is now placed at 25 cm from B. Calculate the resistance across PB provided that the wire has a uniform area and resistivity remains constant. (1)
   vii. Using the information from part (vi) and assuming the end B has 0 V, show that the potential at A is related to the potential at P by equation $V_A = 4 - \frac{V_p}{2.25}$. (3)

(Total: 20 marks)

11. A CPU chip in a computer contains a silicon transistor channel, a copper interconnect wire, and an n-type silicon region. [$e = 1.6 \times 10^{-19}$ C]
   a. Using simple band theory, compare the energy band structure of copper metal and intrinsic silicon. (2)
   b. Explain how replacing some of the silicon atoms with phosphorus atoms (n-type doping) alters the energy levels. State whether the number of charge carriers increases, decreases, or remains the same. (2)
   c. A CPU logic gate connects a tungsten plug to an n-doped silicon transistor channel where the cross-sectional area of tungsten plug is 5×10^{-15} m^2, tungsten free electron density is 1.2×10^{29} m^{-3}, with signal current of 15 nA.
      i. Calculate the drift velocity of the free electrons inside the tungsten plug. (2)
      ii. Calculate the number of electrons passing through the cross-section of the tungsten per second. (3)
   d. High-performance computations cause the temperature of a region containing both copper interconnect wire and an intrinsic silicon semiconductor to rise from $28\,℃$ to $70\,℃$. Assume the potential difference remains constant across the two individual components.
      i. Explain, on a microscopic level, why the electric current flowing through the copper interconnect wire decreases as the temperature increases. (3)
      ii. Using energy band theory, explain why the electric current flowing through the intrinsic silicon channel increases dramatically over the same temperature range. (3)
   e. Semiconductor devices often rely on a p-n junction, formed by joining a p-type semiconductor to an n-type semiconductor.
      i. State the majority carriers in a p-type semiconductor. (1)
      ii. If the positive terminal of a power supply is connected to the n-type region and the negative terminal to the p-type region, explain how this affects the majority charge carriers in both regions. (2)
      iii. Sketch an energy band diagram for an extrinsic p-type semiconductor at room temperature. Clearly label the diagram. (2)

(Total: 20 marks)

12. Safety engineers are responsible for designing a harness that is attached to suspension cables to perform a high-fall stunt.
    a. The stunt coordinator needs to predict how much a cable of any length will stretch under an applied load without testing every single cable length.
        i. Derive an equation for the stiffness constant k of a uniform cable in terms of original length L, cross-sectional area A, and Young's modulus E. (2)
        ii. State any laws of physics assumed. (1)
    b. The harness is constructed with ductile copper wiring where movement is needed. Define the following critical threshold points on a stress-strain graph of a ductile material:
        i. proportionality limit; (1)
        ii. yield point; (1)
        iii. ultimate tensile strength. (1)
    c. When overloaded, the copper wire undergoes plastic deformation. Explain how plastic behaviour leads to necking in the wire. (1)
    d. New thin copper wires require a quality control test to ensure they have the correct Young's modulus value.
        i. Draw a clearly labelled diagram of the experimental setup to measure the Young's modulus of a thin copper wire. (4)
        ii. Describe the instruments used to measure the original length L, area of wire A, extension ΔL, and applied force F. (2)
    e. During two stunts, two different cables are attached to the main structure, having different dimensions but made of the same aluminium material.

	Cable 1	**Cable 2**
Material	Aluminium	Aluminium
Original Length	2 m	4 m
Radius	1 mm	3 mm
Young's Modulus	6.9×10^{10} Pa	unknown

        i. State the Young's modulus of Cable 2. (1)
        ii. A performer of mass 70 kg drops a vertical distance of 2 m from rest before Cable 1 becomes taut. The cable then stretches by an extension of 0.14 m, and the performer comes to a momentary stop. Calculate the:
            - total potential energy lost by the performer at maximum stretch; (2)
            - elastic potential energy stored in Cable 1 at maximum stretch; (3)
            - amount of energy dissipated to the surroundings during the fall. (1)

(Total: 20 marks)

Please turn the page.

13. A boy of mass $m = 40$ kg, initially at rest, slides down a frictionless ramp of height $h = 5$ m in an amusement park, as shown in Figure 6.
    a. At the end of the ramp there is a flat track where the frictional force between the boy and the track's surface is $F_f = 500$ N.
        i. Calculate the distance, d, the boy travels along the flat track before coming to a complete halt. (3)
        ii. Identify the regions along the path of the boy, from its initial to its final position, where energy transformations occur and state the different forms of energy involved in the transformations for each identified region. (2)

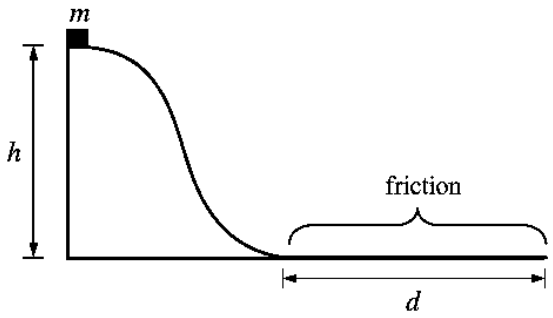

Figure 6

    b. Assume now that, at a distance $a = 2$ m from the bottom of the frictionless ramp, there is fixed one end of a spring of equilibrium length $l_0 = 50$ cm, with the other, free end facing the ramp (see Figure 7).
        i. What is the value of the spring constant *k* such that the boy comes to a halt at a distance of 1.7 m from the bottom of the frictionless ramp? (3)
        ii. After the spring has reached its maximum compression, the boy is pushed again along the flat track. Determine the height the boy moves up the ramp. Hence, evaluate for how many cycles the boy will bounce off the spring before coming to a complete halt. You may assume that the spring returns to, and stays in, its equilibrium position each time immediately after the boy loses contact with the spring. (3,2)
        iii. Define the efficiency of a system and explain why it cannot exceed 1. (2,1)
        iv. With reference to the scenario in question b.(i), what is the efficiency of the system composed of the boy, spring, ramp and flat track? (Consider energy stored in the spring as the useful outcome of the system). (4)

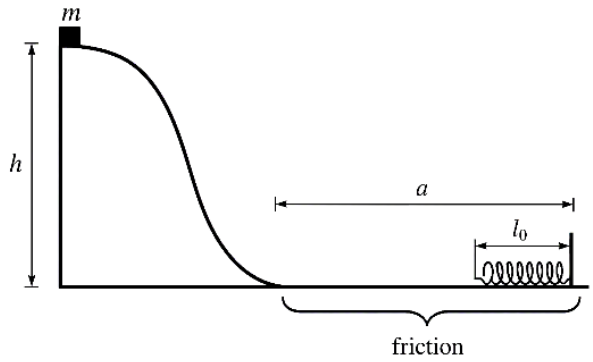

Figure 7

(Total: 20 marks)

14. Cobalt-60 ($^{60}_{27}\text{Co}$, Co-60) is a radioactive isotope that decays into nickel-60 ($^{60}_{28}\text{Ni}$, Ni-60) by β^- emission, with a half-life of 5.27 years.
    a. Define half-life. (2)
    b. Write down the balanced nuclear equation for the β^- decay of Co-60 into Ni-60, including any other particle(s) emitted. (2)
    c. Show that the decay constant λ of Co-60 is 4.17×10^{-9} s^{-1}. (2)
    d. A sealed source contains 0.50 mg of pure Co-60. Calculate the initial number of Co-60 atoms present, and hence the initial activity of the source. (2, 1)
    e. Calculate the number of Co-60 atoms remaining in the source after 10 years. (3)
    f. The atomic masses of Co-60 and Ni-60 are 59.933822 u and 59.930786 u, respectively. Calculate the total energy released in the decay. (3)
    g. The binding energy per nucleon of Ni-60 is 8.78 MeV. Calculate the total binding energy of the Ni-60 nucleus. (1)
    h. Sketch a graph of the activity of the source against time, clearly indicating the half-life. (2)
    i. When using an ionisation chamber to measure the activity of a radon-220 sample, the current recorded also includes a contribution from background radiation. Name at least **TWO** sources of this background radiation, and explain why and how it must be accounted for in the experiment. (2)

(Total: 20 marks)

15. a. Define moment, couple and torque. (3)
    b. State the conditions for static equilibrium of a rigid extended body under the action of a set of coplanar forces. (2)
    c. With reference to Figure 8, identify which panel(s) among 1, 2, 3, and 4, constitute a couple. (2)
    d. A ladder of length $L = 10$ m and mass $M = 12$ kg has its bottom end attached to the ground by a pivot. It makes an angle $\theta = 60°$ with the horizontal, and is held up by a massless stick of length $l = 14$m which is also attached to the ground by a pivot. The ladder and the stick are perpendicular to each other and the system is in static equilibrium, see Figure 9. Assume that the centre of mass of the ladder is at $L/2$.
        i. Find the force that the stick exerts on the ladder. (3)
        ii. Find the magnitude and the direction of the reaction force at the pivot at the bottom of the ladder. (3)
        iii. Draw, stating their names, the forces acting on the ladder. (3)
        iv. Assume now that the stick can safely support a maximum force of 400 N before failing. A person of mass $m = 70$ kg climbs the ladder. Determine the maximum distance the person can climb up the ladder. (4)

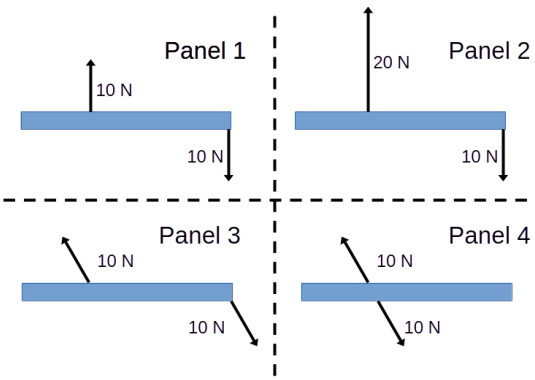

Figure 8

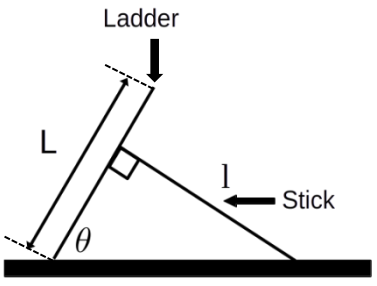

Figure 9

(Total: 20 marks)

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MATRICULATION AND SECONDARY EDUCATION CERTIFICATE
EXAMINATIONS BOARD

ADVANCED MATRICULATION LEVEL
2026 SECOND SESSION

SUBJECT:	**Physics**
PAPER NUMBER:	II
DATE:	1st September 2026
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 $g = 9.81$ 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 pressure-temperature properties of a fixed mass of gas can be investigated by enclosing the gas within a rigid metal container of volume 2.5×10^{-3} m^3. The container is connected to a pressure sensor and placed in a temperature-controlled bath filled with water.

   a. Describe the necessary steps taken to obtain the measurements necessary for the investigation. (2)

   b. State the expected relationship between pressure and temperature for an ideal gas. (1)

   When the gas reaches 20 °C, it produces a pressure of 101 kPa.

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

   d. Calculate the mass of the gas sample if its molar mass is 28 g mol^{-1}. (1)

   To understand the microscopic properties of gases, the motion of smoke particles illuminated by a bright lamp through a microscope was observed.

   e. Describe the observed motion of the smoke particles, also stating the name attributed to this motion. (2)

   f. State any changes to this motion if the smoke's temperature were increased. (1)

   [Molar gas constant $R = 8.31$ J mol^{-1} K^{-1}]

   (Total: 10 marks)

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2. Repeated observations have continuously shown that numerous galaxies in the Universe are receding away from Earth at different speeds, v, relative to their distance measured from Earth, d, as shown in Figure 1.

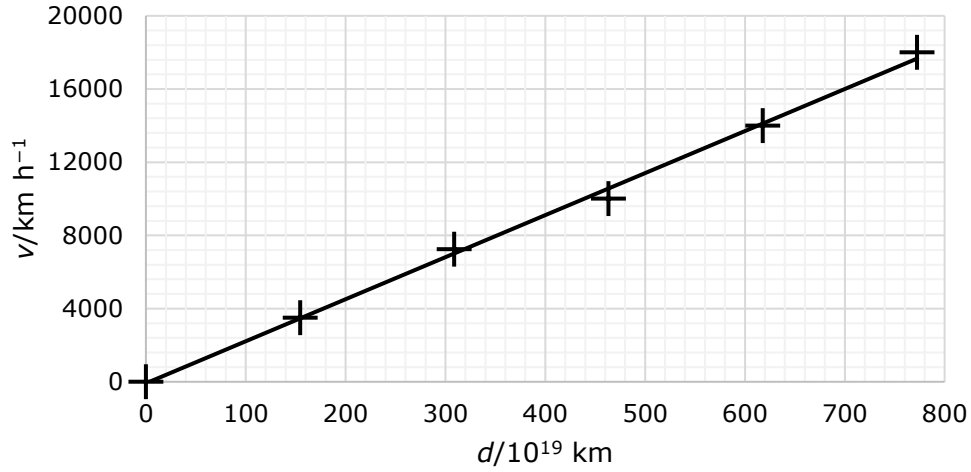

Figure 1

a. Explain the Big Bang model of the Universe. (2)

b. Apart from the recession of galaxies, list **TWO** observations that support the Big Bang model. (2)

c. Calculate the gradient of the graph in Figure 1, and state what it represents. (3)

d. Hence, estimate the age of the Universe in years. (2)

e. Explain why the calculated age is considered an estimate. (1)

(Total: 10 marks)

3. Four charged spheres are fixed at the corners of a square *ABCD* of sides 0.20 m, in a vacuum, as shown in Figure 2. Point *O* is the centre of the square. Each sphere carries the same charge of $+5.0 \times 10^{-9}$ C. For calculation purposes, all spheres are to be considered point charges. Take the permittivity of free space to be $\varepsilon_0 = 8.85 \times 10^{-12}$ F m^{-1}.

a. Define the electric field strength at a point. (1)

b. Consider the point *O* at the centre of the square.

i. Explain why the resultant electric field at *O* is zero. (2)

ii. Calculate the electric potential at *O.* (3)

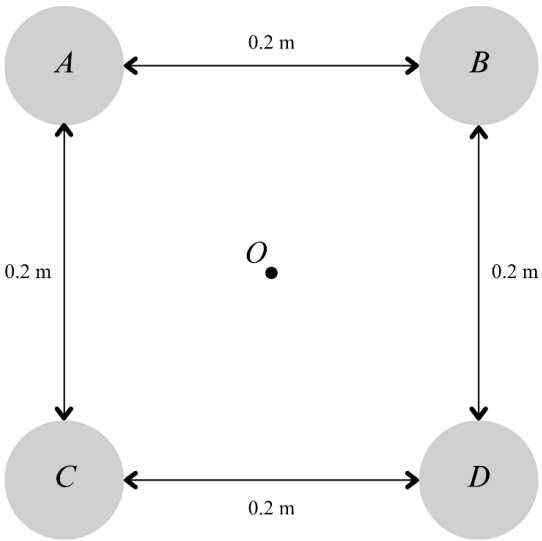

Figure 2

c. The charge at corner *A* is now replaced by a charge of -5.0×10^{-9} C. The charges at the other three corners are unchanged.
   i. Determine the magnitude of the resultant electric field at *O*. (3)
   ii. State the direction of this resultant field. (1)

(Total: 10 marks)

4. A technician builds the capacitor network shown in Figure 3 and connects it across a 12 V d.c. supply. Capacitors C_1 and C_2, each of capacitance 2.0 μF, are connected in series. This series combination is connected in parallel with capacitor C_3, of capacitance 4.0 μF.

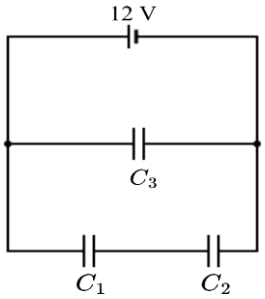

Figure 3

   a. Define the capacitance of a capacitor. (1)

   b. Calculate the total capacitance of the network. (3)

   c. Calculate the total energy stored in the network when connected to the 12 V supply. (2)

   d. The technician decides to check the answer to part (c) experimentally. The charge stored is measured as the potential difference is raised from 0 V to 12 V, and the results are plotted in Figure 4. Use Figure 4 to find by how much the measured value of the energy stored differs from the answer in part (c). (2)

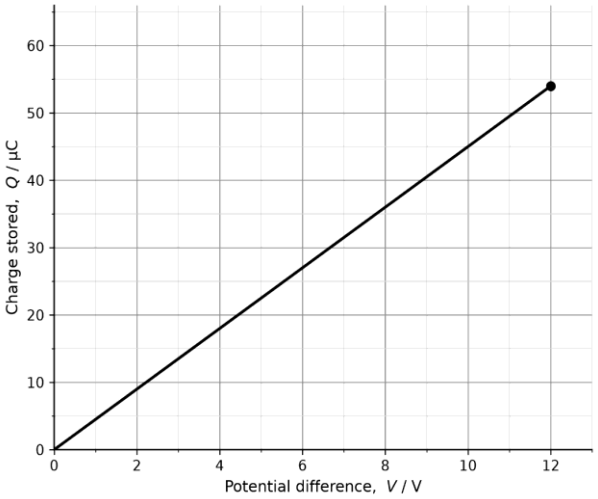

Figure 4

   e. Each capacitor is marked with a maximum operating voltage of 9 V. After the network has been connected to the supply for some time, the technician finds that one of the capacitors has stopped working permanently. Distinguish between operating voltage and breakdown voltage, and discuss which of these is the more likely reason for the permanent damage. (2)

(Total: 10 marks)

Please turn the page.

5. A student uses a bar magnet to investigate electromagnetic induction.

   a. With the aid of a labelled diagram, describe how the student would show that the size of the induced electromotive force depends on the rate of change of magnetic flux through the solenoid. (3)

   b. State what the student would observe when the magnet is held stationary inside the solenoid. Explain why. (2)

   c. In a second experiment, a metal rod rests on two long horizontal parallel rails a distance of l = 0.25 m apart, connected at one end by a resistor of resistance 0.50 Ω. A uniform magnetic field of flux density B = 0.40 T is directed vertically downwards through the plane of the rails. The rod is pulled along the rails at a constant speed of v = 3.0 m s^{-1}, remaining perpendicular to them. Assume that the rod and the rails have negligible resistance.

      i. Starting from Faraday's law, show that the e.m.f. induced across the rod is given by $E = B\,l\,v$. (3)

      ii. Calculate the current through the resistor. (2)

(Total: 10 marks)

6. Heating and cooling systems operate by performing a thermal cycle on an enclosed fixed mass of ideal gas in the presence of hot and cold reservoirs. For a particular system, the gas undergoes the following thermodynamic cycle:

   - AB is an isochoric expansion;
   - BC is an isovolumetric cooling;
   - CD is an isochoric compression;
   - DA is an isovolumetric heating.

   a. Define and distinguish between a heat engine and a heat pump. (2)

   b. Sketch a pressure-volume graph for the above processes, clearly indicating the cycle process. (4)

   c. State whether the process represents a heat engine or a heat pump, giving a reason for your answer. (1)

   d. State the significance of the enclosed graph area based on the answer stated in (c). (1)

   e. During process BC, the change in internal energy is −500 J. Determine the change in heat energy, stating any relevant conventions used. (2)

(Total: 10 marks)

7. An oceanographer lowers a sonar probe beneath their research boat to map the Maltese seabed. The probe sends a note with a frequency of 2.5 kHz into the seawater. The displacement-position graph in Figure 5 shows how far each particle is displaced from its rest position at a given moment in time, plotted against its distance x from the probe. A displacement is taken as positive when a particle has moved away from the probe, and negative when it moves back towards the probe.

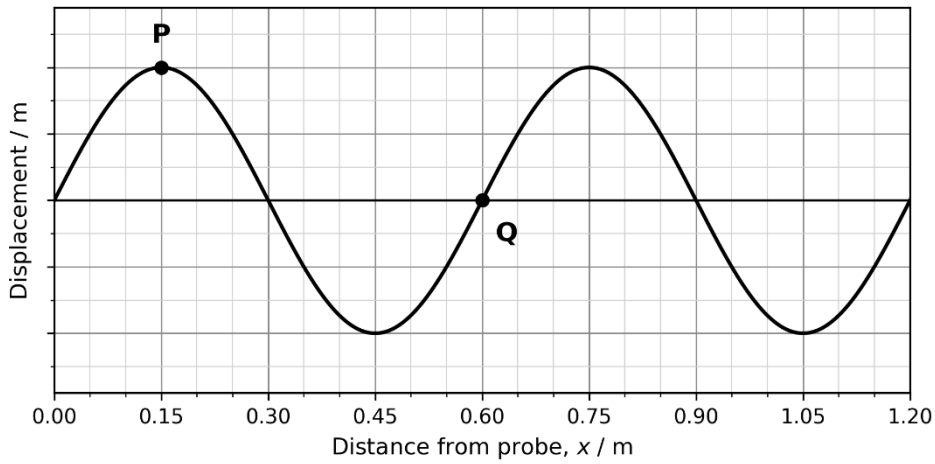

Figure 5

a. Define a longitudinal wave. (1)

b. Find the wavelength of the sound. Hence find the speed of sound in the seawater. (3)

c. Give one value of x at which the water is being compressed, and one value of x at which it is rarefied. Explain each answer by describing how the particles on either side of that position have moved. (2)

d. Copy the axes of Figure 6 and sketch how the pressure of the water varies with x over the same range. Include all labels. (2)

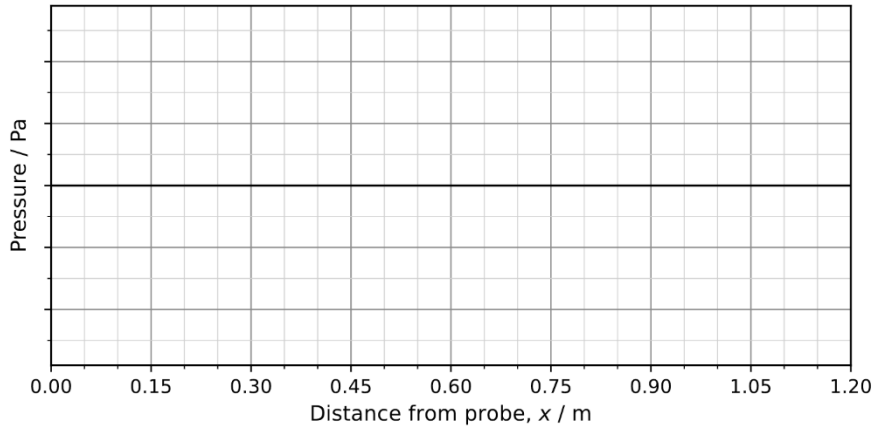

Figure 6

e. Two points, P and Q, are marked on Figure 5. Find the phase difference between the oscillations of the water particles at P and Q. (2)

(Total: 10 marks)

Please turn the page.

8. A small 800 g mass is attached to a horizontal spring of spring constant 50 N m^{-1}. The mass is pulled through a displacement of 0.12 m and released from rest. Assume that frictional forces are negligible.

   a. Calculate:
      i. the elastic potential energy; and (1)
      ii. the kinetic energy when the mass is at a displacement of 0.07 m from the rest position. (2)

   b. On the same set of axes, sketch an energy-displacement graph showing the:
      i. elastic potential energy; (1)
      ii. kinetic energy; (1)
      iii. total energy of the spring-mass system. (1)
      Include any relevant key values.

   c. The mass is now attached to a driver which regulates the applied force in various frequencies. The amplitude of the steady oscillations across various frequencies is represented in Figure 7.

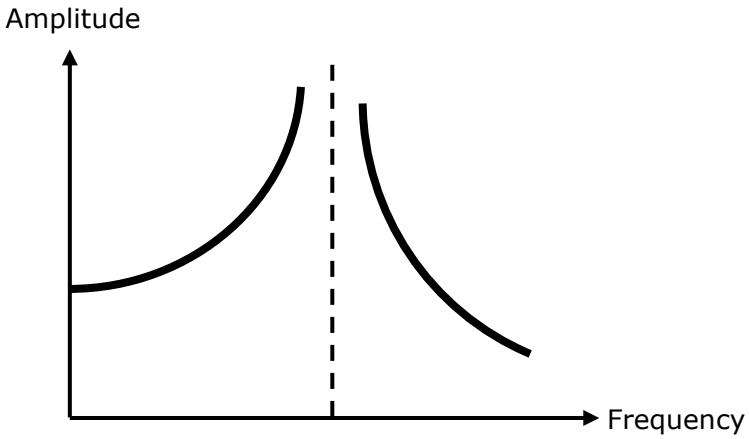

Figure 7

   d. Name the frequency at which the curve is highest, stating the phenomenon causing this to occur. (2)

   e. State and explain the changes to Figure 7 if the system experiences damping. (2)

(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. Two uniform rods, A and B, having the same cross-sectional area, *A*, and of equal length, *L*, are joined in series with each other. Rod A is made of a conducting material of thermal conductivity k_A whereas rod B is made of an insulating material of thermal conductivity k_B. The compound rod is placed a distance from a heater as shown in Figure 8. The end of rod A facing the heater is painted black. After leaving the heater on for a sufficiently long time, the rods reach a steady state with temperatures θ_1 and θ_3 at the end points and θ_2 at the interface.

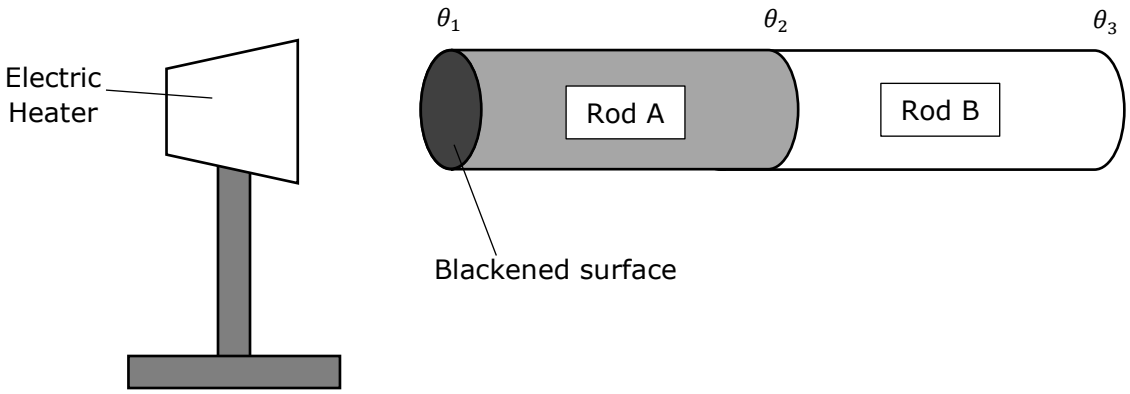

Figure 8

a. Describe the method of heat transfer by which the blackened end is heated. (2)

b. Explain why the blackened end may not be considered as a blackbody. (2)

c. Explain the method of heat transfer present across rod A. (2)

d. Define thermal conductivity. (1)

e. State which rod is expected to have a larger temperature difference across its length. Explain. (3)

f. Show that the interface temperature is $\theta_2 = \frac{k_A\theta_1 + k_B\theta_3}{k_A + k_B}$. (3)

g. Sketch a graph of temperature against distance, taking the blackened end as x = 0. Include any relevant values. (3)

h. The experiment is repeated with the radiator placed further away from rod A. State the effects on the system, stating the relevant law about the emitted heat. (2)

i. Explain, giving reasons, why the calculated temperatures may not agree with the measured temperatures. (2)

(Total: 20 marks)

10. In the search of Earth-like planets, astronomers observe planets orbiting around their native stars in solar systems scattered across various galaxies. By monitoring their orbits, various physical properties such as their masses and orbital period could be determined.

a. State Newton's law of gravitation. (2)

b. Show that the orbital period, T, of a planet is related to its orbital radial distance, r, from its star of mass, M, as $T^2 = \frac{4\pi^2 r^3}{GM}$. (3)

c. A particular planet was observed to take 4.1×10^7 s to complete an orbit found at a distance of 1.8×10^{11} m. Estimate the mass of the star. (2)

Future technology may be able to send mankind to these potentially habitable planets.

d. Define gravitational field strength. (1)

e. A person lands on a planet. State **TWO** factors that can influence their weight apart from their own mass. (2)

f. Distinguish, with reference to their definitions, between inertial and gravitational mass. (2)

Question continues on the next page.

To obtain more observational data, orbiting satellites are launched into space.

g. Sketch the gravitational field lines around the planet. (2)

h. On a separate sketch, draw **TWO** gravitational equipotential surfaces. On your sketch, clearly indicate which equipotential surface has the greater gravitational potential magnitude. (3)

i. Explain why work needs to be done to launch a satellite in space but no work is required to maintain it in a circular orbit around a planet. (3)

[Newton's Gravitational Constant = 6.67×10^{-11} N m^2 kg^{-2}]

(Total: 20 marks)

11. A constant-volume gas thermometer contains a small amount of ideal gas trapped inside a bulb which is connected to a pressure sensor. When the bulb is placed in thermal contact against an object, the corresponding pressure is measured and is used to determine the object's temperature. To calibrate the thermometer, it is placed in a triple-point cell which contains water at its triple-point.

a. Define thermometric property. (1)

b. Explain what is meant by a temperature fixed point. (2)

c. Define what is meant by the triple point of water. (1)

d. State the mathematical relationship between the thermodynamic temperature, T, measured by the thermometer, the pressure, P, of the trapped gas, and the pressure, P_{tp}, of the trapped gas at the triple point. (1)

e. Determine the gas pressure when the thermometer is in thermal equilibrium with an object at 25 °C given that the gas pressure at triple point is 98.6 kPa. (3)

0.35 mol of the gas is later placed in a cylinder fitted with a frictionless movable piston. The gas is heated from 300 K to 360 K without moving the piston. The molar heat capacity at constant volume is 20.8 J mol^{-1} K^{-1}.

f. Define and distinguish between the molar heat capacity at constant volume and at constant pressure. (2)

g. Calculate:
   i. the heat energy supplied to the gas; (2)
   ii. the work done by the gas; (1)
   iii. the change in internal energy of the gas. (2)

The gas is then cooled back to 300 K. It is then reheated back to 360 K while keeping the gas' pressure constant, and allowing the piston to move.

h. State, giving reasons, whether the gas needs to be expanded or compressed in this case. (2)

i. Calculate the heat energy supplied to the gas in this case. (3)

[Molar gas constant R = 8.31 J mol^{-1} K^{-1}]

(Total: 20 marks)

12. A mass spectrometer is used to separate the ions of different isotopes of neon. Singly ionised neon atoms, each of charge +e, are created, and then pass first through a region called the 'velocity selector', in which the uniform and magnetic fields act at right angles to each other and to the motion of the ions. Ions of a particular speed pass straight through into a second region of uniform magnetic field, where they are detected.

[$e = 1.6 \times 10^{-19}$ C]

a. In the velocity selector, the electric field has some strength E and the magnetic field has flux density B_1, and an ion of charge q travels through with speed v.
   i. Write down an expression for the magnitude of the force on the ion due to the magnetic field. (1)
   ii. Explain why an ion passes straight through this region undeflected only if its speed is $v = E/B_1$. (2)
   iii. Calculate the speed of the ions that pass straight through when the electric field strength is $E = 3.0 \times 10^4$ V m^{-1} and the magnetic flux density is $B_1 = 0.15$ T. (1)
   iv. Explain why an ion travelling faster than E/B_1 does not pass into the second region. (2)

b. The ions that pass straight through are now all travelling at the same speed, and enter the second region where the magnetic field is uniform and has a flux density of $B_2 = 0.50$ T. They enter moving horizontally to the right, while B_2 is directed into the plane of the page. Each ion follows a circular arc.
   i. State the direction of the force on an ion as it enters this region, and hence determine whether it curves upwards or downwards. (2)
   ii. Explain why the ion travels at constant speed in this region, even though it is accelerating. (2)
   iii. Show that the radius of the circular path is $r = mv/(qB_2)$. (2)
   iv. A neon-20 ion has a mass of 3.32×10^{-26} kg. Calculate the radius of its path. (2)

c. The uniform magnetic field in the second region is produced by a long solenoid wound around it, with the ions travelling through its hollow centre.
   i. Define the tesla. (1)
   ii. The solenoid has 2000 turns per metre. Calculate the current it must carry to produce a flux density of 0.50 T along its axis. (3)

d. State **TWO** changes that could be made to a solenoid to increase the flux density it produces. (2)

(Total: 20 marks)

13. A farm is powered by a small wind turbine that produces an alternating e.m.f. The turbine stands some distance from the farm and is joined to it by two cables. The output from the turbine is stepped up by a transformer while it is being transmitted through the cables, and is converted to direct voltage once it reaches the farm to charge a bank of batteries.

a. The turbine's alternating output has a peak voltage of 340 V.
   i. Define the root mean square value of an alternating voltage. (1)
   ii. Calculate the root mean square value of the turbine's output. (2)

b. The output is connected to a transformer with 200 turns on its primary coil and 1500 turns on its secondary coil.
   i. Explain how an alternating voltage applied to the primary coil produces an alternating voltage across the secondary coil. (2)
   ii. Calculate the root mean square value of the transformer's output. (2)
   iii. The transformer core is made from laminated soft-iron rather than solid iron. State the purpose of the laminations, and explain how they achieve it. (2)

Question continues on the next page.

c. The two cables have a total resistance of 0.50 Ω. The turbine delivers 3.0 kW of power.
   i. Calculate the power dissipated in the cables when the power is transmitted at an RMS voltage of 240 V. (2)
   ii. Calculate the power dissipated when the same power is instead transmitted at 1800 V. Hence, explain why transformers are used to step up the voltage for the transmission of electricity. (2)

d. At the farm, the alternating supply is passed through a full-wave bridge rectifier, built from p-n junction diodes, to produce the direct voltage that charges the batteries.
   i. Explain how a p-n junction diode allows current to pass through it in one direction only. (2)
   ii. Draw the circuit for a full-wave bridge rectifier connected to a load resistor. Include all labelling and the direction of the diodes. (3)
   iii. A capacitor is then connected in parallel with the load. Explain the effect this has on the output voltage across the load. (2)

(Total: 20 marks)

14. An astronomer uses a refractor telescope with a circular objective of diameter 150 mm to observe the binary star system Albireo, which is a pair of stars orbiting one another, appearing very close together in the sky. The two stars are separated by 6.58×10^{14} m and lie at a distance of 3.64×10^{18} m from Earth. Take the wavelength of the starlight to be 550 nm.

a. State the principle of superposition of waves. (1)

b. Explain why light from a single star passing through the telescope's circular aperture does not converge to a point, and state how the size of the central bright region depends on the aperture diameter and wavelength. (2)

c. To study the effect mentioned in part (b), the astronomer shines a light of wavelength 550 nm through a narrow slit of width 0.12 mm onto a screen in the distance.
   i. Calculate the angle between the centre of the pattern and the first minimum. (2)
   ii. Sketch a graph showing how the intensity of the light on the screen varies with the angle on either side of the centre. Mark all relevant points on the angle axis. (3)

d. Explain what is meant by *resolving power* of an instrument. (1)

e. Calculate the smallest angular separation that this telescope can resolve at the wavelength of 550 nm. (2)

f. Determine whether the astronomer is able to see the binary system as two separate stars. (3)

g. The astronomer directs the starlight into a spectrometer with a diffraction grating having 600 lines per mm.
   i. Calculate the angle at which the second-order maxima for the 550 nm light can be seen. (3)
   ii. Determine the highest order of maxima that can be observed at this wavelength. (3)

(Total: 20 marks)

15. An underwater photographer is taking photos in a perfectly still freshwater lake. With her camera held at a depth of exactly 1.80 m and pointing vertically upwards, she photographs the surface from below. The photograph shows a bright circular patch directly above the camera, through which the sky and the surroundings can be seen. Outside this circle the surface appears dark and reflective. A perpendicular view of this scenario is illustrated in Figure 9.

[Refractive index of lake water=1.33; refractive index of air=1.00]

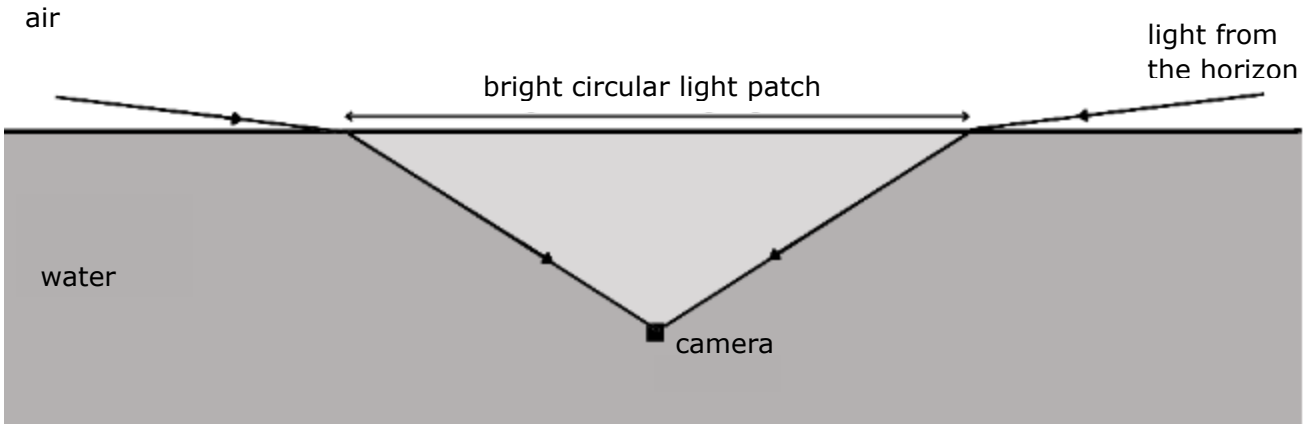

Figure 9

a. State the **TWO** conditions necessary for total internal reflection to occur. (2)

b. Calculate the critical angle for the boundary between the water and the air. (2)

c. A ray of light from a point on the horizon travels through the air and meets the water at an angle of incidence of almost 90°. Determine the angle at which this ray travels through the water after crossing the surface. Take the angle of incidence as if it were 90°. (1)

d. The light from the horizon has a wavelength of 550 nm in air. Calculate its wavelength in the water. (2)

e. Light reaches the water surface from every direction in the sky, starting from directly overhead to the horizon. By considering these two scenarios, and using your answer to part (c), explain, using a diagram, why all the light from the sky that reaches the camera forms a cone. Include all relevant angles and labels. (2)

f. Outside of the bright patch, the surface appears dark and reflective, showing an image of the lake bed. Explain why. (2)

g. Determine the diameter of the bright circular patch at the water surface level. (3)

h. The photographer now dives down to a depth of 3.60 m. State and explain the effect this has on the diameter of the bright patch at the surface. (2)

i. When looked at closely, the rim of the bright patch has a tint of colour. Write down the phenomenon that causes the light to have more than one colour, and state how the refractive index of the lake water depends on the wavelength of the light passing through it. (2)

j. A member of the crew, looking vertically down from a boat through the water sees the camera appear to be closer to the surface than its true depth. Calculate the apparent depth of the camera as seen from the boat. (2)

(Total: 20 marks)

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MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

ADVANCED MATRICULATION LEVEL
2026 SECOND SESSION

SUBJECT:	**Physics**
PAPER NUMBER:	III – *Practical*
DATE:	27th August 2026
TIME:	2 hours 5 minutes

Experiment: The Interrupted Pendulum and Equivalent Compound Pendulum

Apparatus: Stand and clamp, additional clamp, cork top with toothpick, steel nut attached to a string, additional steel nut, metre ruler with an attached pin and a steel disc.

Diagram:

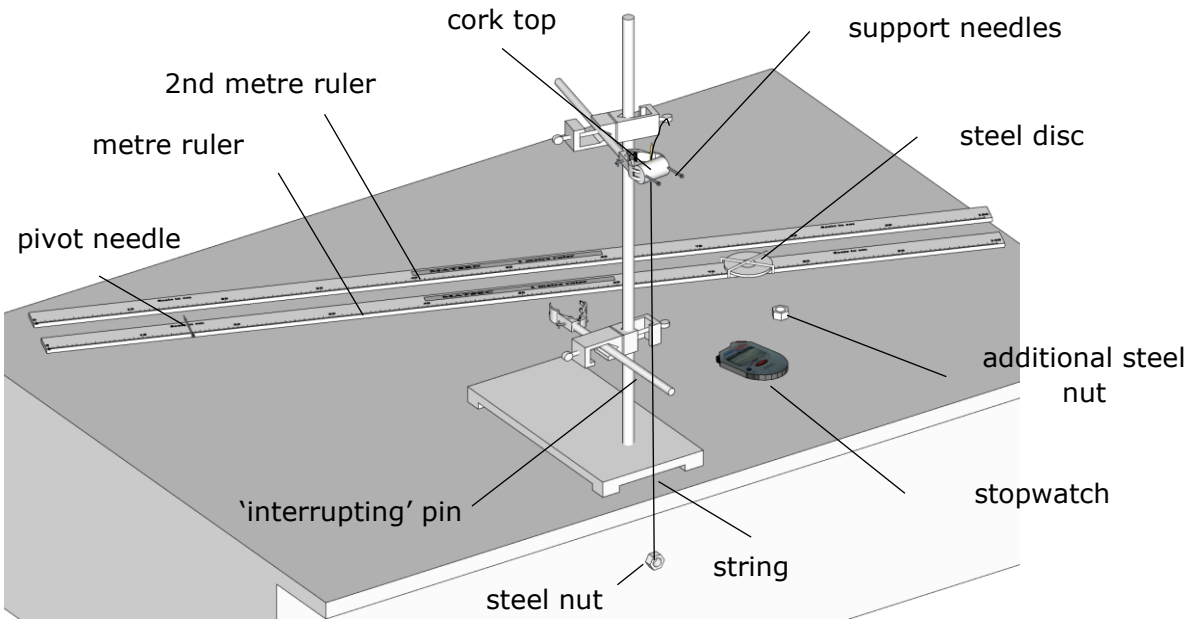

Figure 1: The experimental setup

Method – Part A:

1. The apparatus is set up for you as shown in Figure 1.

2. The string has one end tied to a steel nut, while the other end passes through a hole drilled in the cork top. A toothpick inserted into the hole prevents the string from sliding.

3. You have been provided with an additional nut identical to the one that is tied to the string.

4. Place this additional steel nut on the paper inside the square and draw its outline.

5. Measure the perpendicular distance r in metres from the centre of the steel nut shape to one of its edges.
   r=_____± _____ m. (1)

Please turn the page.

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6. To adjust the length of the pendulum, remove the toothpick, adjust the string to the required length, and then reinsert the toothpick to secure it in position. Refer to the diagrams in Figure 2.

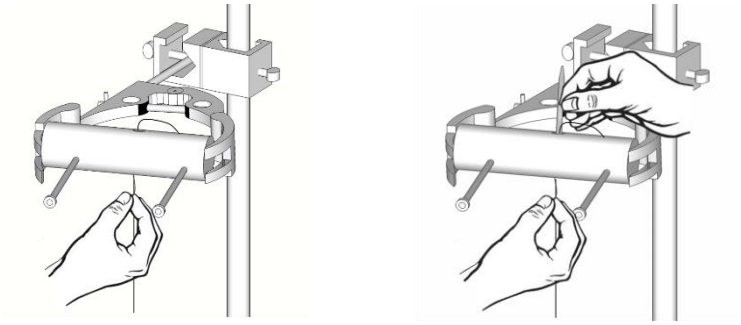

Figure 2

7. Adjust the pendulum so that the length L of the string is approximately $0.70\ \mathrm{m}$. The value of L must remain unchanged throughout this part of the experiment.

8. Position the interrupting pin below the main suspension point, as shown in Figure 3. Ensure that the centre of the pin is vertically below the main suspension axis and that the axis of the pin is perpendicular to the plane of oscillation.

9. The interrupting pin is to be positioned at six different vertical distances D below the main suspension point, with values of D ranging from approximately $12\ \mathrm{cm}$ to $45\ \mathrm{cm}$.

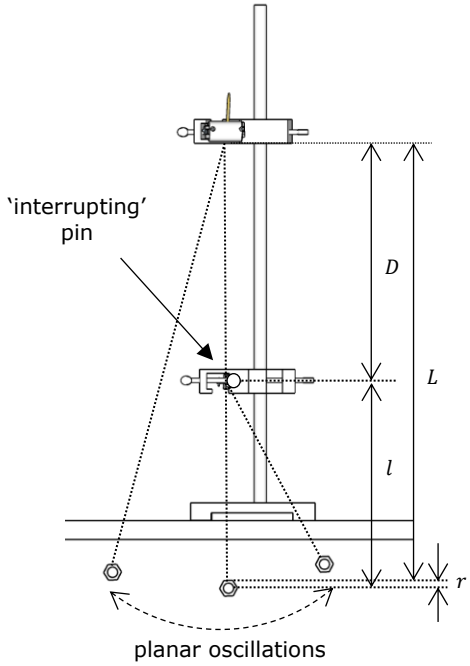

Figure 3

10. For the first position of the interrupting pin, measure the vertical distance D from the main suspension axis to the centre of the pin. Record this value in the first row of Table 1, under the first column D. (1)

11. Displace the steel nut through a small angle on the long, uninterrupted side of the pendulum and release it gently, without applying any additional push. As the pendulum passes through its lowest point, the string should make contact with the interrupting pin, remain taut while the nut moves around the pin, and disengage cleanly from the pin during the return part of the oscillation.

12. Measure the time, T_{A1}, in seconds, taken for 20 complete interrupted oscillations. Record this value in the first row of Table 1, under the second column. (1)

13. Repeat the measurement two more times for the same value of D. Record these readings in the first row of Table 1, under the third and fourth columns, T_{A2} and T_{A3} respectively. (2)

14. Repeat the measurement procedure for five additional positions of the interrupting pin. Record the corresponding value of D and the three measurements of T_{A1}, T_{A2}, T_{A3} in the next five rows of Table 1, under the appropriate columns. (20)

Table 1

D /m	T_{A1} /s	T_{A2} /s	T_{A3} /s	$\overline{T_{A20}}$ /s	$l = (L + r - D)$ /m	$\sqrt{l}$ / $\mathrm{m}^{\frac{1}{2}}$	T_A /s

15. $\overline{T_{A20}}$ is the mean value of the repeated readings taken. Complete Table 1 by working out $\overline{T_{A20}}$, the shortened length l of the pendulum, $\sqrt{l}$ and the periodic time T_A. (4)

16. It is known that the periodic time of such a pendulum whose cycle is interrupted by a pin is given by $T_A = \frac{\pi}{\sqrt{g}}\left(\sqrt{L} + \sqrt{l}\right)$.

17. Plot a graph of the periodic time T_A on the y-axis against $\sqrt{l}$ on the x-axis and draw the best straight line through the plotted points. (8)

18. From the graph, determine a value for the acceleration due to gravity g and state its unit.

_____

_____

_____ (3)

19. Calculate also the value of $k = \frac{4\pi^2}{g}$, which will be used in Part B, using the value of g as determined in step 18.

_____

_____ (1)

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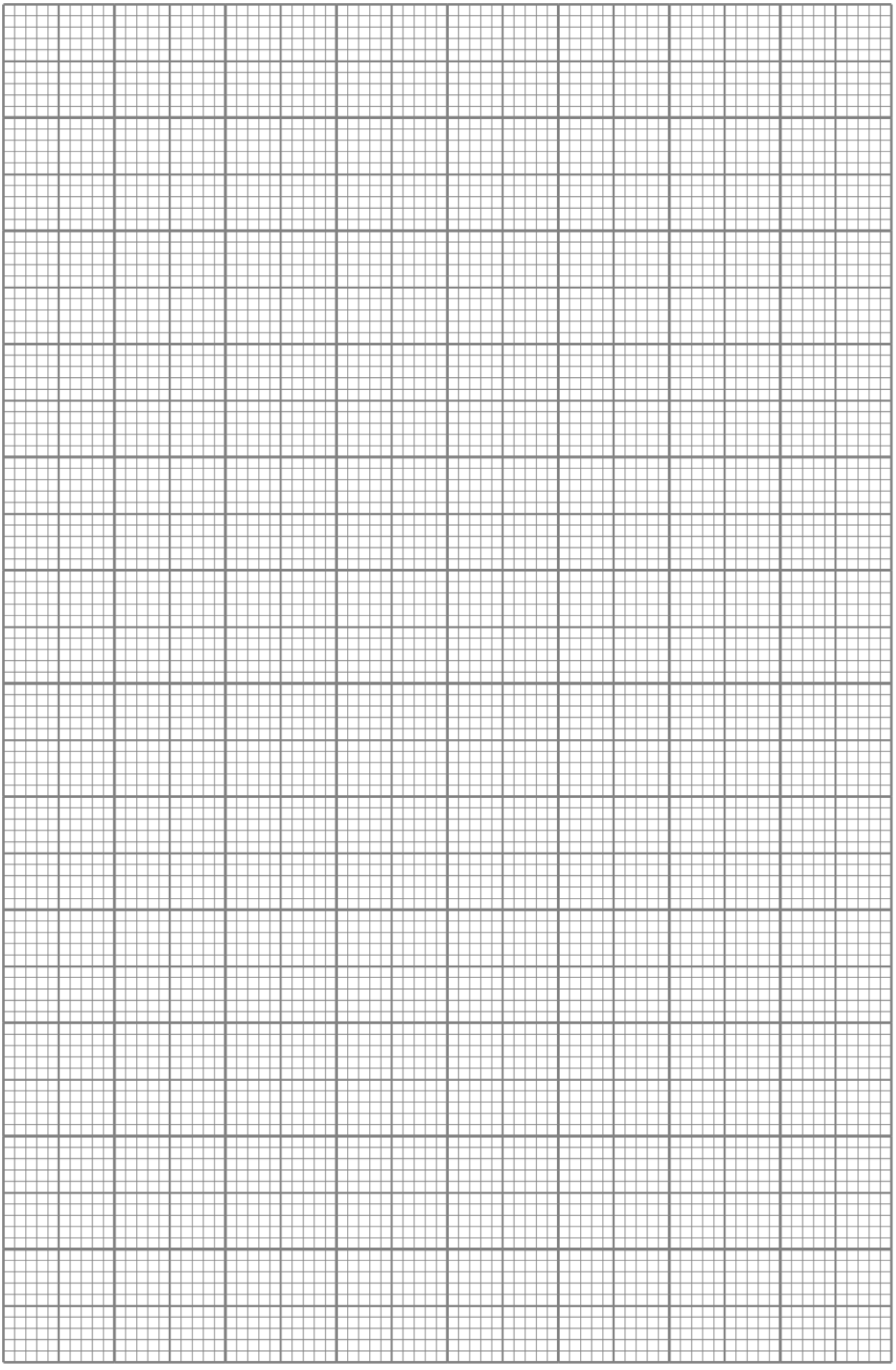


Method – Part B:

20. Carefully move the nut and the hanging portion of the string to one side and secure them so that they do not interfere with this second part of the experiment. Do not remove the string from the cork or the nut from the string. Remove completely from the stand the interrupting pin that was used in the first part of the experiment. Refer to Figure 4.

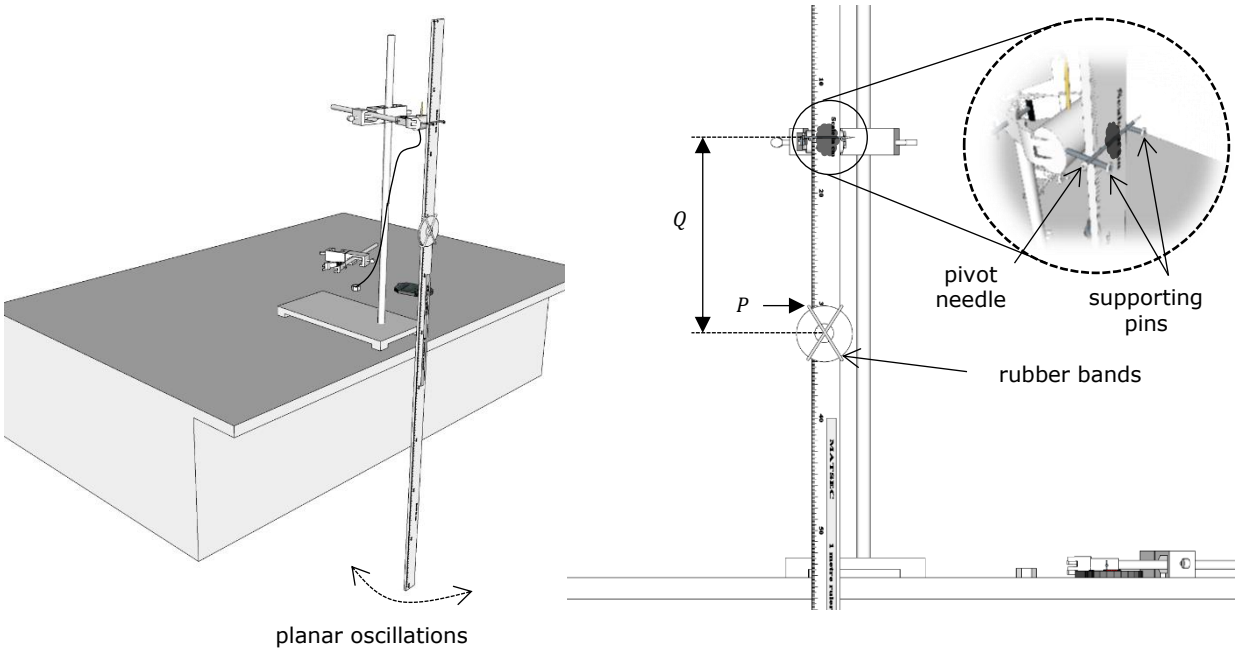


Figure 4

21. In this part of the experiment, you will investigate the oscillations of a compound pendulum about a fixed pivot, but whose centre of mass will be changed by a moveable steel disc along its length.

22. The two pins fixed in the cork act as supports for the pivot pin about which the metre ruler will oscillate.

23. The pivot pin is already fixed to the metre ruler at the $15\ \mathrm{cm}$ mark. This means that the pivot pin is located at a distance $h = 35\ \mathrm{cm} = 0.35\ \mathrm{m}$ away from the midpoint/centre of mass of the metre ruler.

24. A steel disc is already attached to the metre ruler using rubber bands. This steel disc can slide along the length of the metre ruler by lifting the rubber band slightly.

25. Rest the two exposed ends of the pivot needle on the supporting pins. Check that the metre ruler can oscillate freely in a vertical plane without touching the cork or any other part of the apparatus.

Please turn the page.

26. Adjust steel disc so that the top edge of the steel disc is on the $30\ \text{cm}$ mark or the $P = 0.30\ \text{m}$ position. This position is the first out of the six positions through which the steel disc will be moved in this part of the experiment. To slide the steel disc into a new position along the ruler, you may need to remove the metre ruler from its support, slide the steel disc and reposition it on the support.

27. Given that the centre of mass of the steel disc is $2.5\ \text{cm}$ below the top edge of the steel disc, the distance of the centre of mass of the steel disc from the pivot is given by $Q = P - 0.125\ \text{m}$

28. Slightly displace the metre ruler to one side and release it so that it starts oscillating.

29. Measure the time for the metre ruler to perform 20 oscillations and record this in the first row of the column for T_{B1}. (1)

30. Take two more repeated readings of the time it takes the ruler to perform 20 oscillations and record these in the first row under the columns for T_{B2} and T_{B3}. (2)

31. For the next five values of P indicated in Table 2, record the corresponding three measurements of T_{B1}, T_{B2}, T_{B3} under the appropriate columns. (15)

Table 2

P /m	Q /m	T_{B1} /s	T_{B2} /s	T_{B3} /s	$\overline{T_{B20}}$ /s	T_B /s	Q^2 /m^2	Y
0.30								
0.40								
0.50								
0.60								
0.70								
0.80								

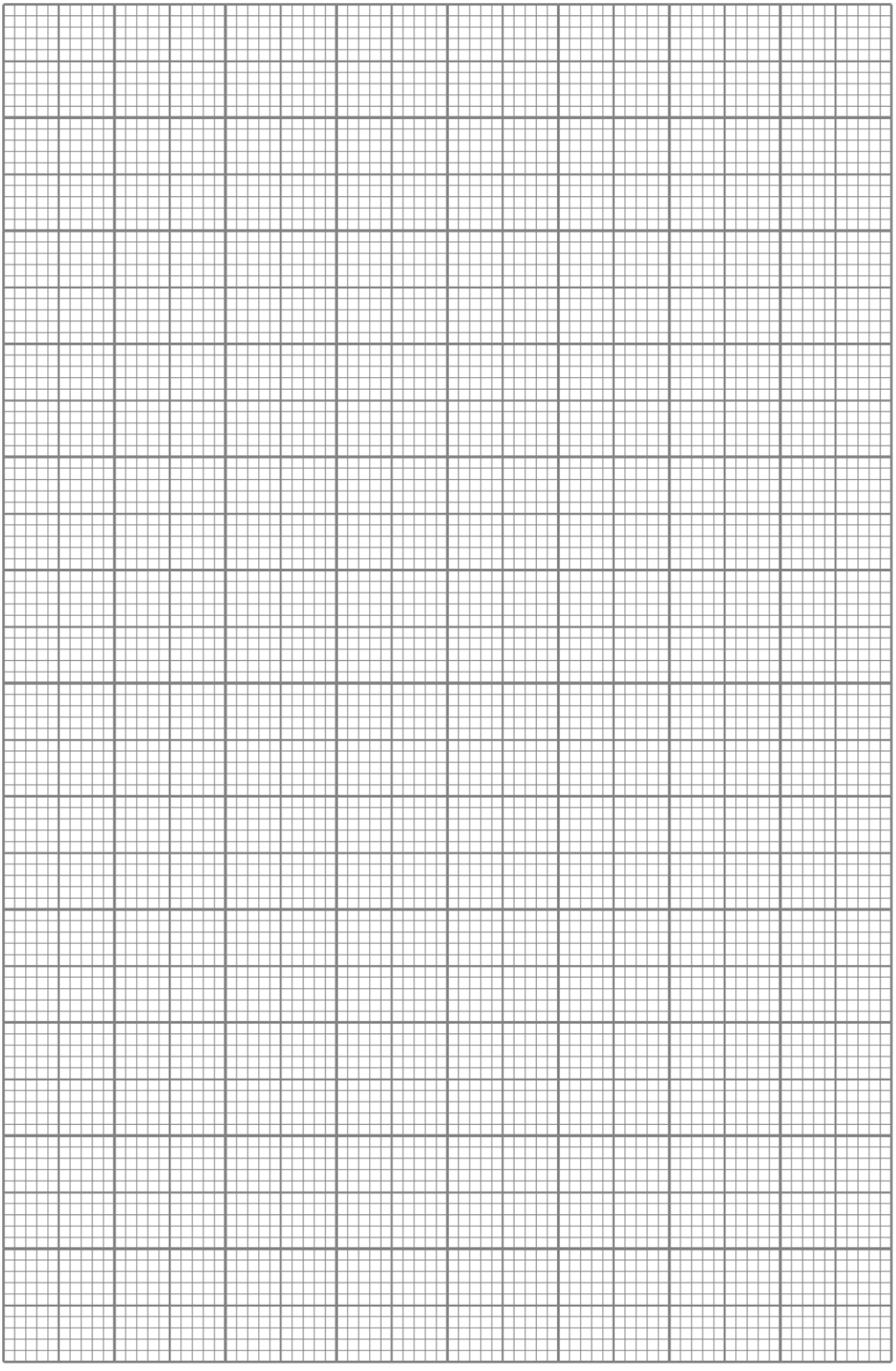
32. $\overline{T_{B20}}$ is the mean value of the repeated readings taken. Complete Table 2 by working out $\overline{T_{B20}}$, the periodic time T_B, Q and Q^2. (4)

33. The values of Y can be calculated through the following expression:

$$Y = \frac{{T_B}^2}{k}(h + 0.44 \times Q)$$

34. Work out the values of Y in Table 2 using the expression in Step 33, the value of k from step 19 and the value of h from step 23. (2)

35. Plot a graph of Y on the y-axis against Q^2 on the x-axis and draw the best straight line through the plotted points. (8)



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36. It is given that $Y = \mu Q^2 + K^2$, where μ is the ratio of the mass of the steel disc to the mass of the metre ruler and K^2 is a constant.

37. Use the gradient of the graph to obtain a value for the mass ratio μ and a value for the constant K.

_____

_____

_____ (5)

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

_____

_____

_____ (2)