L-Università ta' Malta

MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

ADVANCED MATRICULATION LEVEL
2025 FIRST SESSION

SUBJECT:	**Physics**
PAPER NUMBER:	I
DATE:	17th May 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 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. An object that is travelling within a fluid is subjected to a drag force F_D which is given by the equation $F_D = \frac{1}{2} C_D \rho v^2 A$, where C_D is the drag coefficient, ρ is the density of the fluid, v is the speed of the object and A is the contact surface area of the object.

   Determine the base units of C_D. (4)

   b. A plane is flying towards a destination located directly East. During its flight, the plane was subjected to a constant wind blowing at a velocity of 50 ms^{-1} to the North East. Due to this wind, the plane needs to adjust its direction to maintain a constant Eastward velocity.

      i. Sketch a diagram illustrating the wind's and the plane's velocity vectors. Include any known information. (2)

      ii. By resolving vectors, determine the necessary speed and angle that the plane must maintain such that the plane travels at a speed of 150 ms^{-1} due East. (4)

(Total: 10 marks)

2. A vehicle uses a suspension system that is composed of two springs made of the same material, and having the same unstretched length, arranged in parallel with each other to be able to absorb shocks from uneven road surfaces. The springs have spring constants k_1 = 1800 N m^{-1} and k_2 = 2200 N m^{-1}. At a certain instant, the suspension system experiences an external force of F = 2400 N.

   a. State Hooke's law. (1)

   b. If the system were to be replaced by a single spring of effective spring constant, k, determine its value. (3)

   c. Hence, calculate the total deformation experienced by the suspension system. (2)

   d. Discuss, giving reasons, the effectiveness of the suspension system in smoothening the ride when a car is being driven over uneven surfaces if:

      i. more springs were to be attached in parallel; (2)

      ii. the two springs were to be attached in series. (2)

(Total: 10 marks)

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3. Consider the circuit shown in Figure 1. Assume that the cells are ideal.

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

   b. By identifying circuit loops and writing the relevant equations, determine the direction and magnitude of the current flowing through **each** resistor. (6)

   (Total: 10 marks)

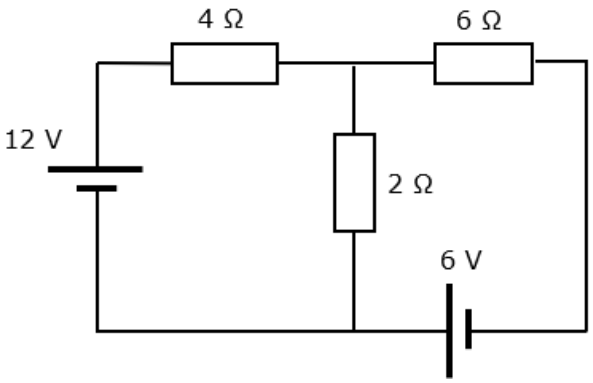

Figure 1

4. Consider the circuit shown in Figure 2. The battery of emf ε has an internal resistance, r, which is determined by recording the current flowing through the circuit for various resistances using the variable resistor. Figure 3 shows a graph of inverse current, I^{-1}, against the variable resistance, R.

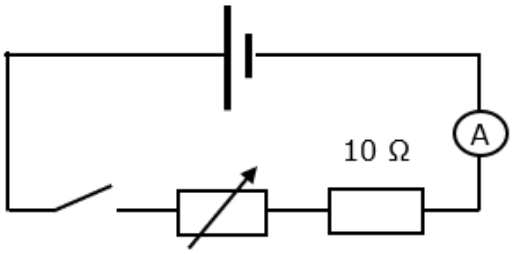

Figure 2

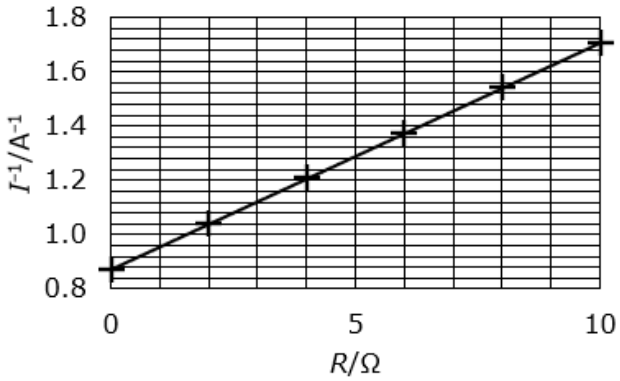

Figure 3

   a. Define electromotive force (emf) and potential difference, clearly outlining the difference between the two terms. (2)

   b. Show that the current and the resistances of the circuit are related via the equation

$$\frac{1}{I} = \frac{R}{\varepsilon} + \frac{10+r}{\varepsilon} \quad (3)$$

   c. Hence, use the given data to determine the emf and internal resistance of the battery. (5)

   (Total: 10 marks)

5. An alpha particle with kinetic energy 5.30 MeV is directed towards the nucleus of a $^{14}_{6}\mathrm{C}$ atom.

   a. Describe the nuclear composition of an alpha particle. (1)

   b. What is the distance of the closest approach of the alpha particle to the $^{14}_{6}\mathrm{C}$ nucleus if the atom remains stationary? (3)

   c. What is the radius of the $^{14}_{6}\mathrm{C}$ nucleus, given that the radius of a single nucleon is 1.25 fm?(2)

   Carbon-14, $^{14}_{6}\mathrm{C}$, decays into nitrogen-14, $^{14}_{7}\mathrm{N}$.

   d. Which physical process is responsible for this radioactive decay? Write down its corresponding nuclear equation. (2)

   e. The half-life of $^{14}_{6}\mathrm{C}$ is 5,370 years. If a sample initially contains 10^3 nuclei of $^{14}_{6}\mathrm{C}$, how long does it take to contain 125 nuclei of $^{14}_{6}\mathrm{C}$? (2)

   (Total: 10 marks)

6. a. Communication satellites are typically placed in a geostationary orbit. They appear stationary relative to a specific point on Earth because their orbital period matches the Earth's rotation period. Assume the mass of the Earth to be 5.97×10^{24} kg.
   i. What is the distance from the centre of the Earth of a communication satellite in a geostationary orbit? (3)
   ii. Hence, what is the tangential speed of the satellite? (2)
   iii. If the satellite is moved to a higher orbit than that of the geostationary one, will its orbital period increase, decrease or remain the same? Give a reason for your answer. (1)

   b. A road has a circular shape of radius r = 210 m, and there is no friction between the wheels of the car and the road.
   i. Explain why the banking of the circular road is necessary for the car to complete the curve. (1)
   ii. Derive the banking angle if the car were to move along the curve with a constant speed of 45 ms^{-1}. (3)

(Total: 10 marks)

7. a. A sphere rolls up a ramp without slipping, with an initial speed of 10.0 ms^{-1}. The moment of inertia of a sphere of radius R and mass M rotating around its centre is $2/5\ MR^2$.
   i. State whether any friction is acting between the sphere and the ramp. Give a reason for your answer. (1)
   ii. State whether the angular momentum of the sphere about its centre is conserved while it rolls up the inclined plane. Justify your answer. (1)
   iii. Show that the maximum height reached by the rolling sphere is independent of the size of the sphere. Determine this height, assuming the initial position to be at height zero. (4)

   b. A solid disk is rotating around its central axis. The disk starts from rest and accelerates uniformly to an angular speed of 20 rad s^{-1} in 10 s.
   i. Find the angular acceleration of the disk. (1)
   ii. Calculate the total angular displacement (in radians) of the disk during this time. (1)
   iii. Given that the rotational kinetic energy of the disk when it reaches its final angular speed is 50 J, determine the moment of inertia of the disk. (2)

(Total: 10 marks)

8. A crate of mass 80 kg is pushed up a slope for a distance of 10.0 m to a height of 4.00 m at a steady, constant speed using a constant applied force of 400 N parallel to the slope. The motion takes 15.0 s.

   a. Calculate the work done by gravity. (2)

   b. Calculate the total work done by the applied force. (2)

   c. State whether there is friction between the crate and the slope. Justify your answer. (2)

   d. How much work is done by friction? (2)

   e. Define efficiency, and calculate it for this process of pushing up the crate along the slope. (2)

(Total: 10 marks)

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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. An agency is constructing a satellite which is required to withstand the harsh conditions of space, including launch forces and temperature variations. To construct a suitable satellite, its frame is required to be very stiff to prevent undesirable deformations. A set of materials were tested using thin long wires.

   a. Describe an experiment that the agency can conduct to determine the Young's modulus of such materials. Your experiment should include:
      i. a well-labelled diagram; (3)
      ii. the method used, including the required measurements. (2)

   After sufficient testing, the agency determines the best two materials, X and Y. Their stress-strain graphs are shown in Figure 4.

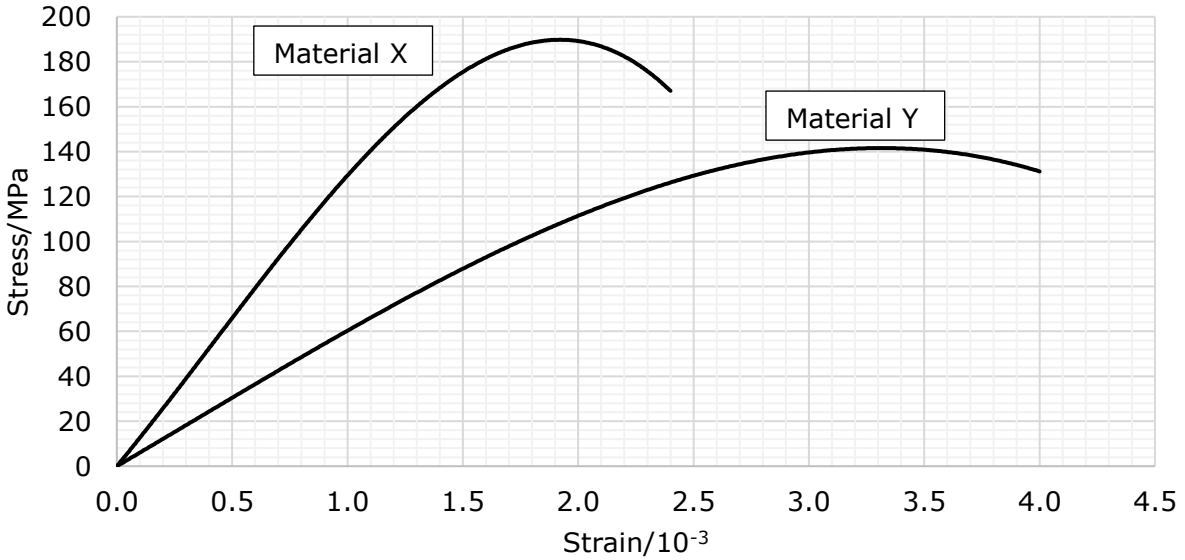

Figure 4

   b. Define proportionality limit and elastic limit of a material. (2)

   c. Use the given graphs to determine the Young's modulus of each material. (5)

   d. Define ultimate tensile strength, and hence identify which material experiences a larger ultimate tensile strength. (2)

   e. Which material is more suited for the satellite? Explain. (2)

   During launch, the satellite and its frame experience an acceleration of 25 m s^{-2}. The total mass of the system is 450 kg and the total surface area of the frame subjected to stress is 1.5 m^2.

   f. Calculate the stress experienced by the frame. (2)

   g. Hence, determine the strain of the frame for the material chosen in part (e). (2)

(Total: 20 marks)

10. a. Define the temperature coefficient of resistance of an electrical component. (2)

    b. Describe a simple experiment that can be used to determine the temperature coefficient of resistance of a resistive component. Your description must include:
    i. a well-labelled diagram; (3)
    ii. the method used, including the measurements that are required. (2)

    c. Describe how the resistance of a fixed metallic resistor varies with temperature. (1)

    The cooling system of a computer CPU is composed of a circuit with a negative temperature coefficient thermistor connected in series with a fixed resistor, connected to a power supply. The thermistor is used to monitor the temperature of the CPU. The circuit controls the speed of a fan that cools the system based on the measured temperature. This is done by measuring the voltage with a voltmeter connected in parallel with the thermistor.

    d. Draw a setup of the cooling circuit (excluding the fan). (3)

    e. Explain how the total resistance of the circuit changes as the temperature of the CPU increases. (2)

    f. Hence, referring to changes in voltage across the thermistor, explain how a variation in the CPU's temperature adjusts the speed of the fan. (2)

    g. Sketch the IV-characteristic graph for an NTC thermistor. (2)

    h. Would the cooling system operate correctly if a positive temperature coefficient thermistor were to be used instead? Explain. (3)

(Total: 20 marks)

11. Figure 5 represents a circuit composed of switches and resistors connected with a 9 V cell. Initially, both switches are open. The switches are then opened and closed at different time intervals to produce a plot of the total charge, Q, through the circuit against time, t, shown in Figure 6.

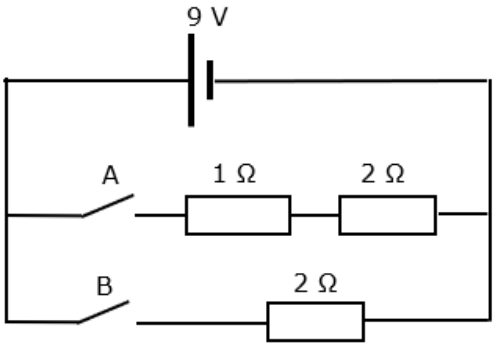

Figure 5

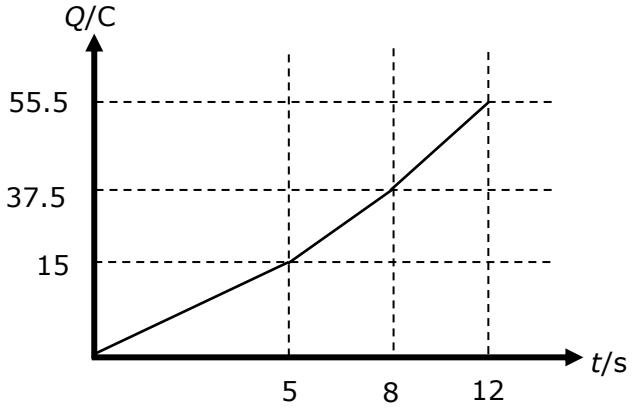

Figure 6

    a. Identify the location where:
    i. an ammeter needs to be placed to measure the current flowing through the whole circuit; (1)
    ii. a voltmeter needs to be placed to measure the p.d. across the 1 Ω resistor. (1)

    b. Explain what charge carriers are. (1)

    c. Define electric current. (1)

Question continues on the next page.

d. Use the graph to determine the current flowing during each time interval. (4)

e. Hence, or otherwise, identify the state of the two switches (whether it was open or closed) for each time interval. (8)

f. Sketch a labelled current-time graph across the whole duration of operation. (3)

g. Explain how the current-time graph can be used to obtain the amount of charge that has flowed through each period. (1)

(Total: 20 marks)

12. Silicon, which has four valence electrons, is a semiconductor that has various uses in industry, either in its pure form or doped to form a p-type or an n-type semiconductor.

a. Distinguish between intrinsic and extrinsic semiconductors. (1)

b. Use the equation $I = nAve$ to describe the conductivity of intrinsic and extrinsic semiconductors. (2)

c. Sketch a diagram of the crystal structure of pure silicon in its solid state. (2)

d. Use band theory to explain why pure silicon is a poor electrical conductor at room temperature. (2)

e. The silicon crystalline structure is now doped with boron which has three valence electrons.
   i. In terms of charge carriers, compare the differences between p-type and n-type semiconductors. (2)
   ii. Explain whether this doping produces a p-type or an n-type semiconductor. Use a diagram to support your reasoning. (3)
   iii. Sketch a labelled band diagram and use it to explain how electrical conduction takes place in this doped semiconductor. In your description, identify the majority and minority charge carriers. (5)
   iv. Explain how temperature influences the conduction of this doped semiconductor. (3)

(Total: 20 marks)

13. a. Particle 1 of mass m_1 = 0.30 kg moves to the right along the x-axis on a frictionless floor with a speed of 2.0 ms^{-1}. Particle 1 undergoes an elastic collision with particle 2, initially at rest, of mass m_2 = 0.40 kg.
   i. Which physical quantities are conserved in an elastic collision? (2)
   ii. Write down the equations for the conservation of these physical quantities in terms of masses and velocities of particles 1 and 2. (2)
   iii. By expressing the velocities of the two particles right after the collision in terms of the velocities just before the collision, or otherwise, determine the velocities of the two particles right after the collision. *[Hint: You may wish to use the result, which holds for any two quantities a and b, that $a^2 - b^2 = (a - b)(a + b)$.]* (6)

b. In Figure 7, two blocks are connected over a pulley. The mass of block A is 10 kg, and the magnitude of the frictional force between A and the incline is 17 N. The angle θ of the incline is 30°. Block A slides down the incline at constant speed. Assume that the connecting inextensible rope has negligible mass.

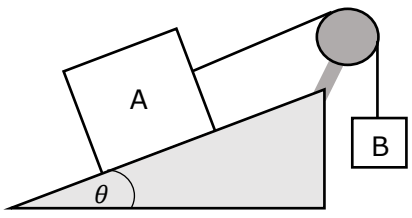

Figure 7

   i. Draw the free body diagram of the forces acting on block A and on block B. (3)
   ii. Determine the mass of block B. (4)

iii. Assume now that there is no friction between block A and the incline. What is the relation between the masses of the blocks A and B and the angle θ such that block A moves up the incline? (3)

(Total: 20 marks)

14. a. In Figure 8, one end of a uniform beam of length L and mass m = 10.0 kg is hinged to a wall while the other end is supported by a wire that makes an angle θ = 30.0° with both the wall and the beam. (Useful formula: $\sin 2\theta = 2 \sin\theta \cos\theta$)

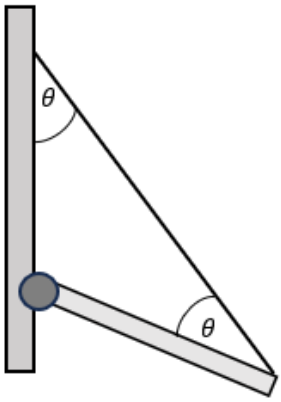

Figure 8

i. Define the terms equilibrium and centre of mass. (2)

ii. Determine the tension in the wire. (2)

iii. If the length of the wire is shortened by half, without changing the points where the wire is fixed to the wall and the beam, does its tension increase, decrease or stay constant? Justify your answer. (2)

iv. Determine the horizontal and the vertical components of the force of the hinge on the beam for the situation depicted in Figure 8. (2)

v. Determine the magnitude of the reaction force of the hinge on the beam, and the angle α, the force makes with the wall, counting the angle anticlockwise from an axis directed outwards from the wall. Draw the reaction force at the hinge clearly indicating the angle α, and its vertical and horizontal components. (3)

vi. Suppose now that the wire breaks. Show that the angular acceleration of the beam is $\alpha = Lmg \sin 2\theta \,/2I$, where I is the moment of the inertia about the hinge. Hence, does the angular acceleration of the beam rotating around the hinge increase, decrease or stay constant between the initial position and when it hits the wall? Justify your answer. (2)

b. A uniform L-shaped bar, free to move in any direction, has three forces applied as depicted in Figure 9. The magnitudes of the forces are F_1 = 30 N, F_2 = 10 N, and F_3 = 5.0 N. The distances in the figure are a = 2.0 m, b = 3.0 m, and c = 1.0 m. The thickness of the bar can be neglected in your calculations.

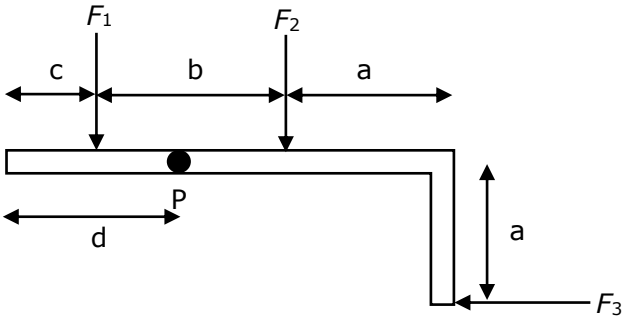

Figure 9

i. Find the vertical and horizontal force components that need to be applied to point P, indicated by a dot in Figure 9, such that the bar is in equilibrium. (2)

ii. For this equilibrium, find the distance d of point P from the end of the bar by taking the moment of the forces about point P. (3)

iii. Suppose now that the same force found in part (b)(i) is applied instead at the point $d/2$. Will the bar rotate, translate, or both? Justify your answer, specifying the direction of the rotation and/or translation with respect to Figure 9. (2)

(Total: 20 marks)

Please turn the page.

15. a. $^{6}_{2}\mathrm{He}$ is an isotope of helium.

i. How many neutrons does this atom have? (1)

ii. Describe the Rutherford model of the atom and explain why this model of an atom is unstable. (2)

iii. Given the four energy levels, $E_0 = -24.7$ eV, $E_1 = -4.15$ eV, $E_2 = -2.18$ eV, and $E_3 = -1.05$ eV, what is the longest and the shortest wavelength of the electromagnetic radiation that may be emitted by the atom? (3)

iv. If one irradiates the helium gas with electromagnetic radiation within the whole range of wavelengths comprised by the minimum and maximum value found in part (a)(iii), state how many absorption lines are observed. (1)

v. Explain why the four energy levels in part (a)(iii) are assigned negative values. (1)

After shining light of a lower wavelength than the minimum value obtained in part (a)(iii), an electron is found to be emitted with an energy E = +2.7 eV.

vi. What is the name of the physical process that occurred? State the name given to this positive energy. (2)

b. Consider a beam of electrons with kinetic energy of 120 eV incident on a crystal.

i. Determine the de Broglie wavelength of the electrons. (3)

ii. Sketch a labelled experimental setup and explain how it shows that electrons may behave as waves. (2)

Consider that the crystal is equivalent to a diffraction grating with grating spacing $d = 4.00 \times 10^{-10}$ m.

iii. Is the kinetic energy of the electrons sufficient to display the diffraction pattern in this experimental setup? Justify your answer. (2)

iv. How many peaks is it possible to observe in the electron diffraction pattern? (3)

(Total: 20 marks)

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ADVANCED MATRICULATION LEVEL
2025 FIRST SESSION

SUBJECT:	**Physics**
PAPER NUMBER:	II
DATE:	17th May 2025
TIME:	4:00 p.m. to 7:05 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. Satellites are used for GPS navigation, weather forecasting for Earth and space exploration.
[Earth has a mass $m_E = 6 \times 10^{24}$ kg, radius $r_E = 6378$ km]

   a. Define gravitational potential and gravitational potential energy. (2)

   b. A satellite X of mass $m_X = 500$ kg is designed to monitor Earth's atmospheric changes to study climate patterns. The satellite is placed at low Earth orbit at an altitude of 400 km. Calculate the potential difference between the satellite launched from Earth's surface and its low Earth orbit position. (4)

   c. Another satellite Y of mass m_Y is launched from Earth's surface.
      i. Define escape velocity. (1)
      ii. Derive an expression for the escape velocity in terms of m_E and r_E. (2)
      iii. Calculate the escape velocity of the satellite Y in $\mathrm{km\ s^{-1}}$. (1)

(Total: 10 marks)

2. a. A barista would like to prepare iced coffee. Initially, 300 g of coffee is poured into a ceramic mug with mass of 150 g and left to settle until the system reaches thermal equilibrium at a temperature of $83.23\ ℃$. 100 g of ice cubes at temperature of $-5\ ℃$ are later added. Assume no heat losses to the surroundings. Assume specific heat capacity of coffee is equivalent to that of water.
[Latent heat of ice $= 3.4 \times 10^5$ J kg^{-1}; Specific heat capacity of ice $= 2108$ J kg^{-1} K^{-1};
Specific heat capacity of water $= 4200$ J kg^{-1} K^{-1};
Specific heat capacity of ceramic $= 900$ J kg^{-1} K^{-1}]
      i. Define latent heat of fusion. (1)
      ii. State the zeroth law of thermodynamics. (1)
      iii. Calculate the final temperature of the system after the ice is added and all of the ice melts. (6)

   b. During an experiment the thermometric property X is measured at an unknown temperature to be 450. In addition, $X_0 = 10$ at $0\ ℃$ and $X_{100} = 675$ at $100\ ℃$ are measured.
      i. Calculate the temperature of the substance. (1)
      ii. What is the relationship between thermometric property X and temperature? (1)

(Total: 10 marks)

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3. a. Draw the magnetic field of the Earth and explain the difference between the geographic poles and magnetic poles. (2)

   b. The intensity of Earth's magnetic field, *B*, in Valletta is 0.4 μT. A vertically hung metal spring with 100 turns and a radius, *r*, of 10 cm is in the presence of Earth's magnetic field as shown in Figure 1.

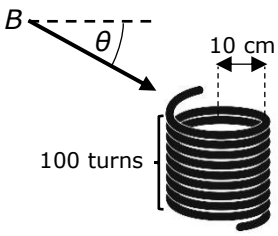

Figure 1

      i. Calculate θ if the total flux linkage between the spring and the Earth's magnetic field is 109.5 nWb. (4)
      ii. How would one expect the flux linkage to change if the spring was hung at the North pole (Arctic), rather than in Valletta? Explain your answer. (2)
      iii. When a current of 0.02 A passes through the spring, a magnetic field of 0.1 mT is generated at the centre of the spring. Calculate the length of the spring. (Assume that the spring is suspended in air). (2)

(Total: 10 marks)

4. a. Explain the term self-induction and identify the associated conservation law. (3)

   b. A 9 V cell is connected in series with a switch, a 3 Ω resistor, and a 0.1 H inductor. When the switch is closed, the current in the circuit increases from 0 to 0.2 A. After that, it keeps on increasing but eventually becomes constant.
      i. For the instant when the current is 0.2 A, calculate the potential difference across the resistor, and across the inductor. (2)
      ii. Assuming the initial rate of change of current from 0 to 0.2 A is constant, use your result from part b (i) to estimate this initial rate of change of current. (2)
      iii. If the resistance of the inductance is negligible, calculate the magnitude of the current when this reaches a constant value. (2)
      iv. Explain the role of the inductor at this stage. (1)

(Total: 10 marks)

5. a. An alternating current, I, in Amps varies with time, *t*, in seconds according to the equation $I = 3\sin(30t)$. The mean power dissipated in a resistive load is 44 W. Calculate the resistance of the load. (3)

   b. i. Define alternating current rectification. Mention the semiconductor component used to achieve this and very briefly explain how this achieves rectification. (2)
      ii. Draw the circuit for a full-wave bridge rectifier. (3)
      iii. Explain how capacitors can be included within such a rectification circuit to smooth the output. (2)

(Total: 10 marks)

6. Diamond cutters use concepts in optics to design cuts that maximise the brilliance of the gemstone.

   a. A diamond cutter measures the angle of incidence of light as it enters the diamond from air to be at $35°$. Light is refracted inside the diamond at an angle of $13.7°$. Find the refractive index of the diamond n_d. (2)

   b. Calculate the critical angle for light going from the diamond to air. (2)

   c. If the light inside the diamond strikes the diamond's surface at an angle of $25°$ to the normal, will the light undergo total internal reflection? Give a reason for your answer by referring to **all** conditions for total internal reflection. (2)

d. Imperfections in the diamond may lead to a different refractive index. Suppose light strikes the diamond's surface at an angle of incidence equal to the critical angle obtained in part (b). Should the modified refractive index be higher or lower than n_d to ensure total internal reflection occurs under the conditions described in part (c)? Give a reason for your answer. (2)

e. The diamond cutter notices rainbow-like colours as light exits the diamond.
   i. State what this phenomenon is called. (1)
   ii. Red wavelengths experience a lower refractive index than blue wavelengths. Give a reason why. (1)

(Total: 10 marks)

7. a. Hubble's law states that the farther a galaxy is from Earth, the faster it appears to be moving away. In other words, it relates the relative velocity to the distance.
   i. Sketch a velocity-distance graph representing Hubble's law. Clearly mark **all** axes and indicate notable quantities. (2)
   ii. The Whirlpool Galaxy, at a distance 2.3×10^7 light years from Earth, is observed to have a relative velocity of 463 km s^{-1}. Estimate the age of the Universe. (3)

   b. The Andromeda Galaxy emits a wavelength of 600 nm and it is observed to move towards an observer in the Milky Way at a relative velocity of 110 km s^{-1}.
   i. Name the phenomenon observed when an observer and source are moving towards each other. (1)
   ii. Use the equation $f = f_0\left(1 - \frac{v}{c}\right)$ to calculate the wavelength observed by the observer in the Milky Way. (4)

(Total: 10 marks)

8. A spectrophotometer is an instrument used to measure the intensity of light as a beam passes through a sample solution. The instrument is equipped with a device that produces a monochromatic wavelength. Single slit diffraction is used to calibrate for different wavelengths.

   a. Sketch an intensity-angular distance plot to illustrate the pattern from a rectangular aperture. Mark the bright and dark fringes. (2)

   b. Describe the behaviour of the angular distance between the normal and the first minimum when:
   i. slit width a is increased; (1)
   ii. wavelength λ is shorter; (1)
   iii. the rectangular aperture is replaced with a circular one and the diameter d is equal to slit width a. (1)

   Double slit calibrations are performed to study interference-based measurements.

   c. Monochromatic light is directed through two slits separated by 0.25 mm. The interference pattern is noted on the screen 1.5 m away. The distance between the first and fifth bright fringe is measured to be 12 mm.
   i. Calculate the wavelength of the source. (3)
   ii. A transparent film is placed between one of the slits and the screen. Describe the resulting effect on the fringe pattern. (1)
   iii. The light source is moved slightly away from the two slits. Describe the resulting effect on the fringe pattern. (1)

(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. Gas is placed in an enclosed cylinder with cross-sectional area of $9 \times 10^{-3}\ \mathrm{m}^2$. It is equipped with a moveable piston which moves outwards as the gas expands. The gas is supplied with 400 J of heat energy, causing the piston to move slowly 25 cm outwards. The external pressure remains $1.02 \times 10^5\ \mathrm{Pa}$ throughout the process.
   i. State the mathematical formula for the first law of thermodynamics. Define **all** quantities used. (2)
   ii. State the thermodynamic process this system represents. (1)
   iii. Obtain the change in internal energy due to the gas pushing the piston. (4)

   b. The Carnot cycle for a 0.3 mol ideal gas is given by the PV-diagram shown in Figure 2. It represents a heat engine with an adiabatic index of 1.4. The pressure at point A is $9.5 \times 10^5\ \mathrm{Pa}$ and drops to point B along an isotherm to temperature $T_1 = 243\ ℃$ such that the volume doubles. BC is an adiabatic expansion while during CD the system compresses along an isotherm at $T_2 = 20\ ℃$.

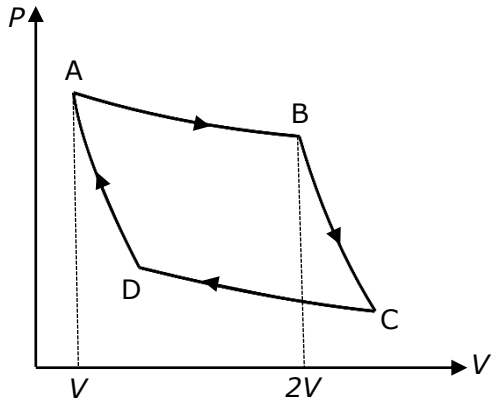

Figure 2

   i. Find the pressure and volume at points A, B, and C. (9)
   ii. State the second law of thermodynamics as applied to a heat engine. (2)
   iii. State and compute the maximum theoretical efficiency of this cycle. (2)

(Total: 20 marks)

10. A toddler of mass 9 kg is placed on a swing. The swing is slightly pulled back from its rest position to simulate simple harmonic motion. In the case of no energy losses, the displacement-time graph is shown in Figure 3.

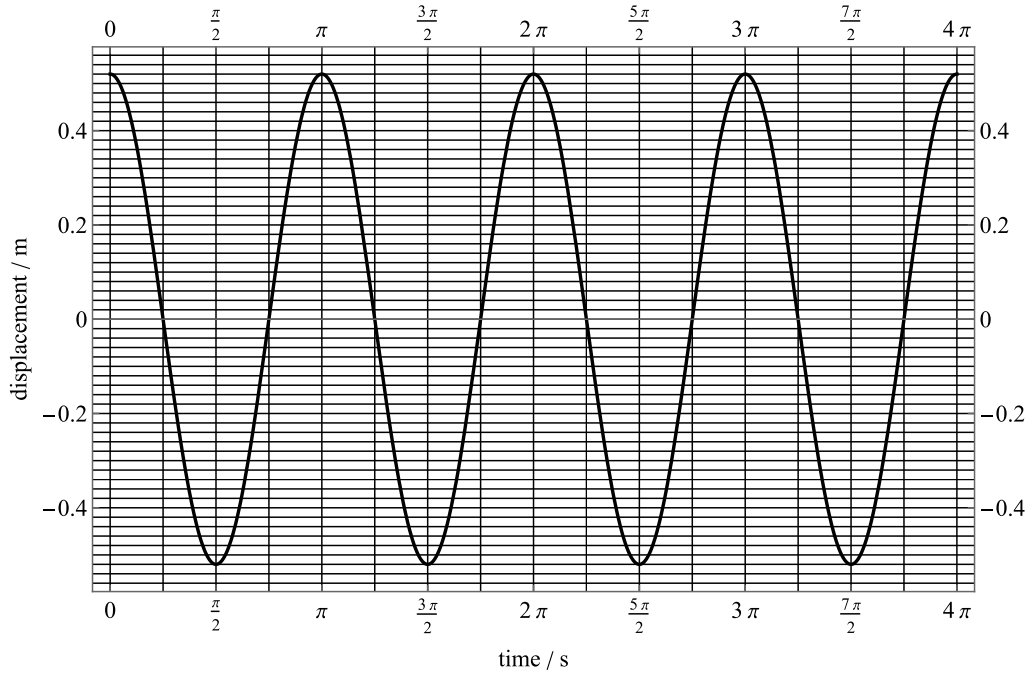

Figure 3

a. State **TWO** conditions necessary for simple harmonic motion. (2)

b. Use the graph to calculate the following quantities:
   i. angular frequency; (2)
   ii. maximum velocity; (2)
   iii. maximum acceleration. (2)

c. Write the mathematical representation of the graph in Figure 3 where y is the displacement and t is the time. (2)

d. The total energy of the toddler-swing is $7.785\,\text{J}$. Find the mass of the swing. (4)

e. Determine the displacement from the equilibrium position at which the potential energy of the toddler-swing system is equal to its kinetic energy. (3)

f. Air resistance results in energy losses and oscillations become damped. Sketch displacement-time graphs to show the behaviour of:
   i. lightly damped oscillations; (1)
   ii. heavily damped oscillations; (1)
   iii. critically damped oscillations. (1)

(Total: 20 marks)

11. a. Heat can be transferred in different modes, one of which is convection.
   i. Identify **THREE** methods of heat transfer other than convection. (3)
   ii. Briefly describe heat transfer via convection. (3)

b. A rod is made of two separate rods of different metals joined together as shown in Figure 4. The joint rod is heated at one end and raised to a temperature of 400 K. The joint rod is perfectly insulated along its length. When equilibrium conditions are reached, the other end of the rod is at a temperature of 320 K. Rod 2 has twice the thermal conductivity of Rod 1.

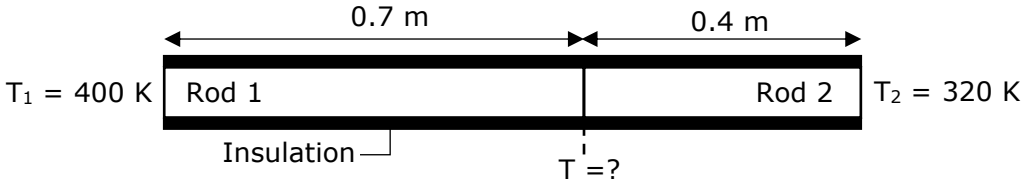

Figure 4

   i. Explain **each** term in the equation for thermal conduction. (4)
   ii. What is meant by: equilibrium conditions are reached? (2)
   iii. Find the temperature T, where Rod 1 and Rod 2 meet. (5)
   iv. Why is it important that equilibrium conditions are reached? (2)
   v. In order to determine T without perfect insulation, what extra information is required? (1)

(Total: 20 marks)

Please turn the page.

12. a. Sketch the electric field between two particles of the same charge. (2)

b. State Coulomb's law of electrostatics. (2)

c. A small positive charge $+q$ is moved a distance d from one conducting plate to another against a uniform electric field E.

i. Show that the work done W in moving the charge against the field is given by: (1)

$$W = Eqd$$

ii. If the potential difference between the conducting plates is V, show that the electric field is given by: (3)

$$E = \frac{V}{d}$$

d. The voltage between the anode plate and the cathode plate inside an electron gun is 2000 V. A charged sphere is moved towards the electron gun along a line perpendicular to the direction in which electrons leave the gun, as shown in Figure 5. When the centre of the sphere is about 0.3 m from the gun, the path of the electron beam is an arc of a circle.

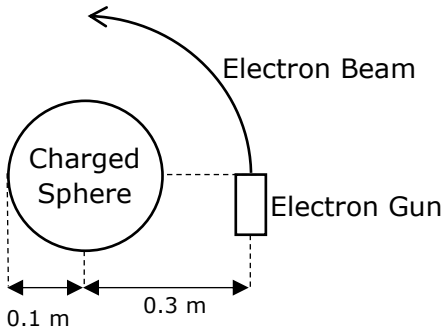

Figure 5

i. State whether the sphere is positively or negatively charged. Explain. (2)

ii. Show that the centripetal force on each electron is about 2.13×10^{-15} N. (5)

iii. Calculate the electric field strength at the surface of the sphere. (5)

(Total: 20 marks)

13. a. Draw a diagram of a single circuit that can be used to study both the charging and the discharging of a capacitor. (3)

b. Describe qualitatively the construction of an electrolytic capacitor. (4)

c. A 1 μF capacitor is charged through a 150 Ω resistor using a 12 V power supply.

i. Define and calculate the time constant. (3)

ii. Sketch a graph of the voltage across the resistor against time whilst the capacitor is being charged. Clearly indicate the time constant and the associated voltage. (3)

iii. Find the time taken for the fully charged capacitor to discharge to a point where the energy stored inside it is 0.03 mJ. (4)

iv. After how much time is the capacitor considered to be fully discharged? (1)

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

(Total: 20 marks)

14. a. Figure 6 shows a typical structure of an electric motor.

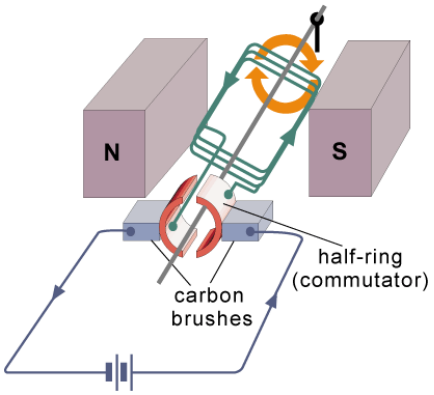

Figure 6

i. Briefly explain how an electric motor works and identify the force that drives this device. (2)

ii. Identify the energy changes that take place in the motor. (1)

iii. Explain the function of the half-ring commutator and carbon brushes. (3)

iv. A motor draws the largest amount of current the instant it is turned on, just before it starts moving. Explain this statement and identify the phenomenon responsible for this behaviour. (4)

b. A transformer has a voltage of V_p = 240 V and a current of I_p = 0.1 A in its primary coil. The voltage in the secondary coil is V_s = 6V.

i. The primary coil has 1000 turns. Assuming that it is an ideal transformer, calculate the number of turns in the secondary coil. (2)

ii. If the transformer is 80% efficient, calculate the current in the secondary coil. (2)

iii. Mention and explain **TWO** ways how transformer efficiency may be increased. (4)

iv. Briefly explain how and why transformers are employed in the transmission of electricity from the generating stations to the consumers. (2)

(Total: 20 marks)

15. A company manufactures inflatable weather balloons, typically used for atmospheric research. They are filled with helium gas such that their behaviour changes with varying temperature conditions. Consider a sealed container of volume $2.5\ \text{m}^3$ filled with helium gas at room temperature $24\ ^\circ\text{C}$ under pressure of $1.108 \times 10^5\ \text{Pa}$.

a. Helium gas is assumed to behave ideally.

i. Write the ideal gas equation in terms of the number of moles. (1)

ii. Plot a graph of $\frac{PV}{T}$ against P for one mole of an ideal gas. Indicate notable quantities. (2)

iii. Determine the number of moles of helium present in the container. (2)

iv. Given the density of helium is $\rho = 0.166\ \text{kg m}^{-3}$, calculate the molar mass. (2)

b. The kinetic theory equation $P = \frac{1}{3}\rho < c^2 >$ holds for all ideal gases in containers irrespective of shape, where P is pressure, ρ is density of gas and $< c^2 >$ is the mean square speed of the particles.

i. List **TWO** assumptions made for the above equation to hold. (2)

ii. Derive $< c^2 > = \frac{3RT}{M}$, where M is the molar mass. (3)

iii. Calculate the root mean square speed of the helium atoms in the sealed container. (2)

iv. Derive an equation and calculate the mean translational kinetic energy of one mole of gas. (3)

c. The balloon material cannot exceed a pressure of $2.3 \times 10^5\ \text{Pa}$. During the testing phase, the helium gas remains in a fixed volume container so that the relationship between pressure and temperature can be observed.

i. State the relationship between pressure and temperature for an ideal gas at constant volume. (1)

ii. Calculate the maximum temperature achievable in testing conditions. (2)

(Total: 20 marks)

L-Università ta' Malta

MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

ADVANCED MATRICULATION LEVEL
2025 FIRST SESSION

SUBJECT:	**Physics**
PAPER NUMBER:	III - Practical
DATE:	3rd June 2025
TIME:	2 hours 5 minutes

Experiment: Properties of Lenses

Apparatus: Filament lamp, convex lens, concave lens, lens holders, screen, 30 cm ruler and a metre ruler

Diagram:

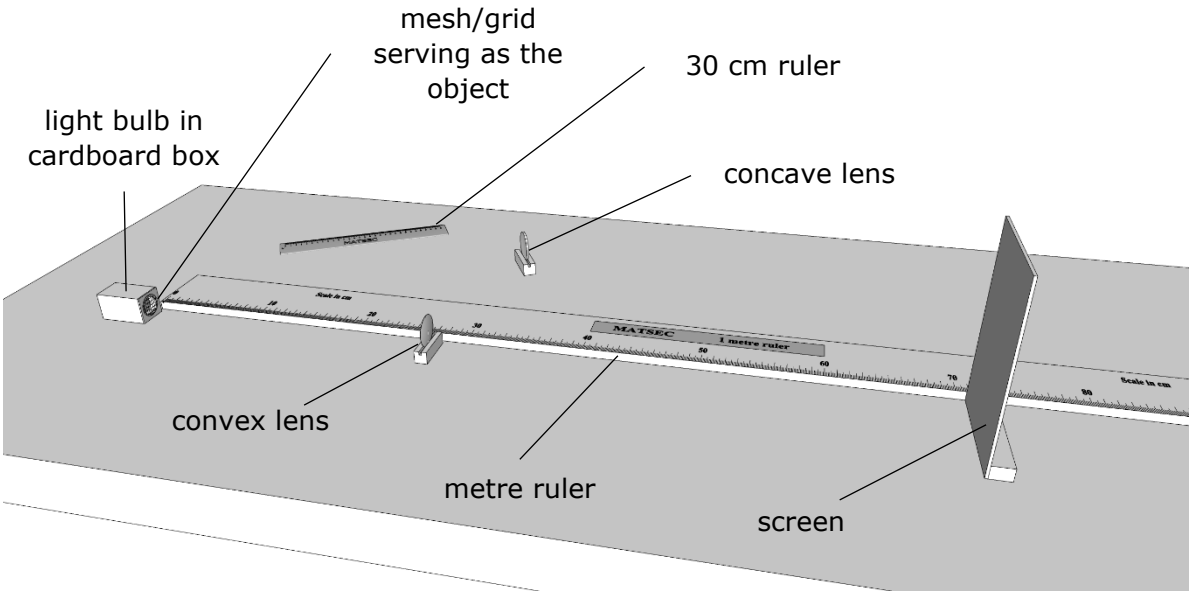

Figure 1 The experimental setup

Method – Part A:

1. Set up the optical system in the order shown in Figure 1. Place only the convex lens between the object and the screen, with the light bulb at the 0 cm mark.

2. Move the screen such that the distance between the screen and the object is about 70 cm.

3. With the convex lens placed closer to the object than the screen, find a position such that a real sharp image of the mesh is formed on the screen.

4. List **TWO** other properties of the image formed on the screen.

_____

_____ (2)

Please turn the page.

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5. When the distance between the object and the screen is fixed, a convex lens can be moved to two distinct locations along the optical axis where it forms a sharp, real image. State the thin-lens formula and use it to show why these two distinct lens positions are possible.

_____

_____ (3)

6. It is known that for a lens of fixed focal length there is a smallest possible separation between the object and the screen, below which, a real, sharply focused image cannot be formed. Devise and describe an experiment to investigate and measure this minimum distance, clearly outlining your procedure and calculations. Then, using the fact that this distance equals four times the lens's focal length, provide a first approximation of the focal length.

_____

_____

_____

_____

_____

_____

_____ (6)

7. If m is the magnification of the converging lens in this setup, make use of the thin lens equation to show that $\frac{f(1+m)}{um} = 1$, where f is the focal length of the convex lens and u is the object distance.

_____

_____

_____ (5)

8. Use the $30\ \text{cm}$ ruler to measure the horizontal width w_{obj} of ten grid squares from the mesh attached to the front of the light bulb box.

_____

_____ (1)

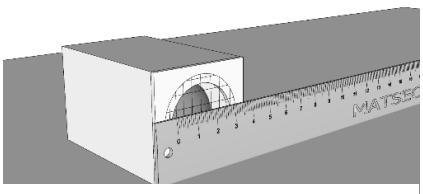


Figure 2

9. Take **SIX** values of the object distance u (the separation between the mesh and the centre of the base of the lens holder) varying between $21\,\text{cm}$ to $31\,\text{cm}$, and for each setting, use the $30\,\text{cm}$ ruler to measure the horizontal width w_{img} of ten grid squares in the focussed image on the screen. Record these measurements in Table 1. (12)

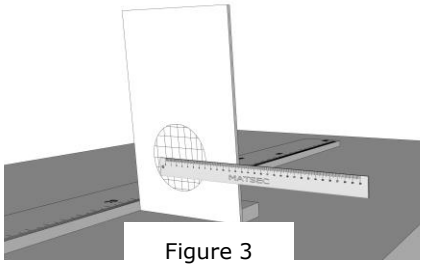


Figure 3

Table 1

u /cm	w_{img} /cm	$m = \frac{w_{img}}{w_{obj}}$	$\frac{1}{m}$

10. Using the value of w_{obj} obtained in Step 8, complete Table 1 by working out m and $\frac{1}{m}$. (6)

11. Plot a graph of $\frac{1}{m}$ on the y-axis against u on the x-axis and draw the best straight-line graph through the plotted points. (8)

12. The magnification m, the object distance u and the focal length f of the lens are related by the equation provided in Step 7. Express this equation in straight line form to represent the graph plotted.

_____

_____

_____ (4)

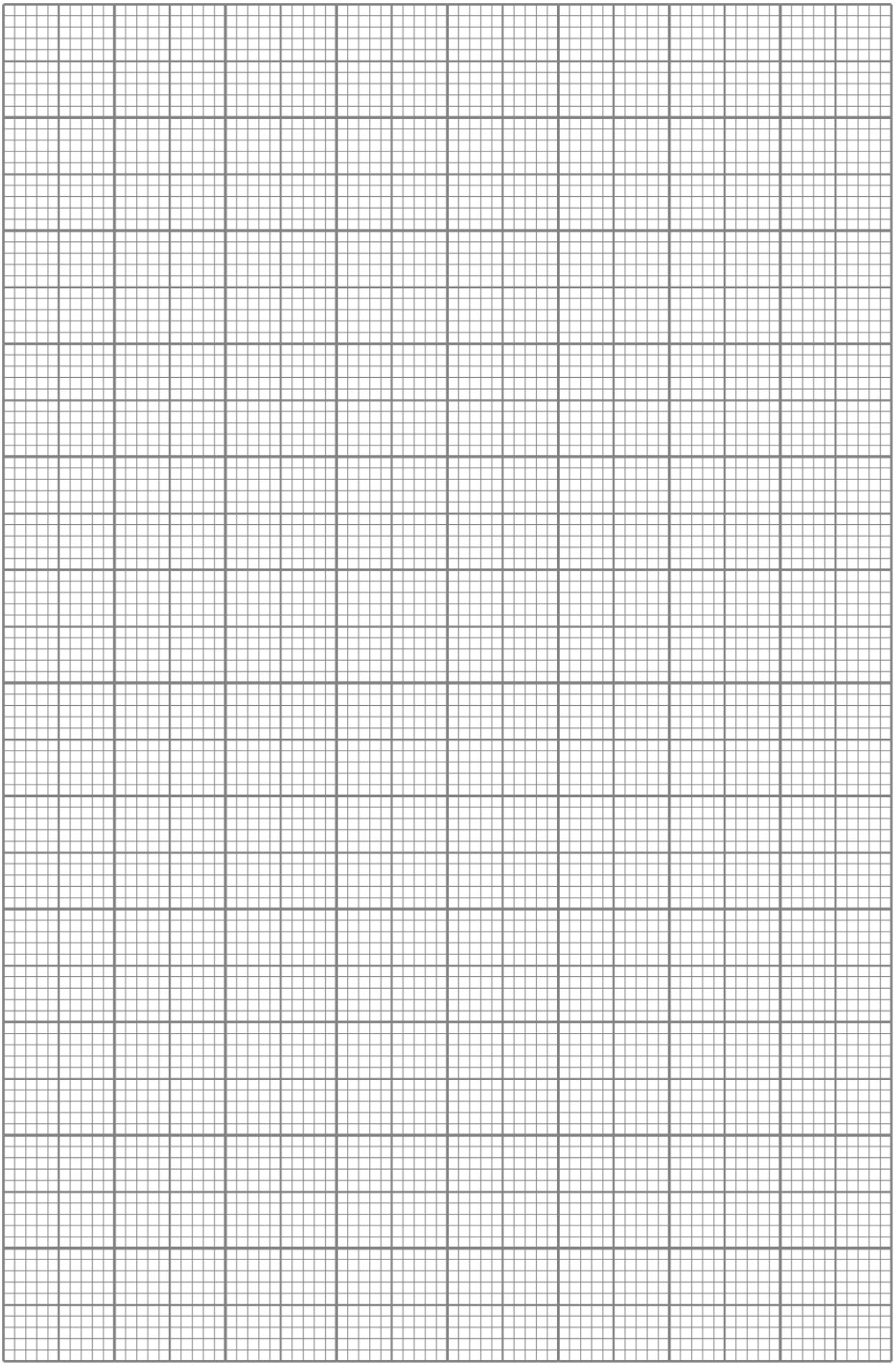
13. Use the graph to determine the focal length f of the converging lens.

_____

_____

_____ (4)

Question continues on the next page.



Method – Part B:

14. In this stage of the experiment, you will measure the combined (effective) focal length of a convex–concave lens pair aligned on the optical axis and then use that result to calculate the focal length of the concave lens. In the setup, the image formed by the convex lens acts as a virtual object for the concave lens, enabling the concave lens to cast a real image onto the screen.

15. Position the convex lens at $U = 50\,\text{cm}$ from the object along the optical axis. **The position of the convex lens will remain fixed for the rest of the experiment.**

16. Adjust the position of the screen until the image comes into sharp focus, as shown in Figure 4.

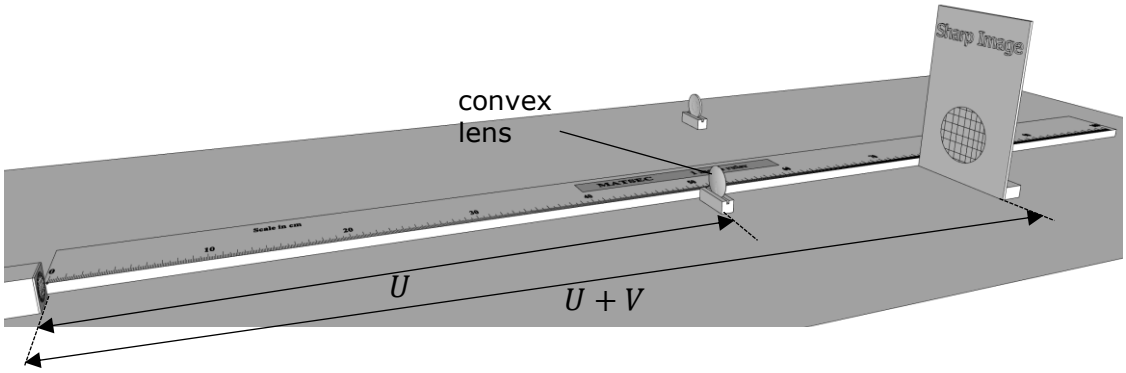


Figure 4

17. Insert the concave lens between the convex lens and the screen.

18. Set the separation P between the convex lens and the concave lens to $11.0\,\text{cm}$, the first P value listed in Table 2. The image on the screen should now appear blurred (see Figure 5).

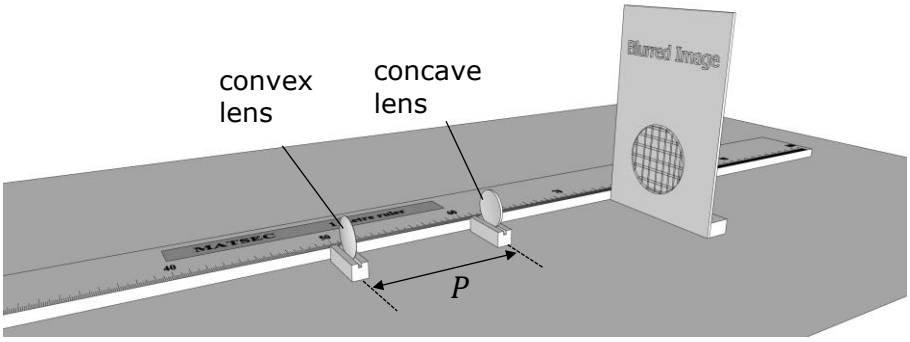


Figure 5

19. Slide the screen away from the lenses and object to restore a sharp and clear image (see Figure 6). When a sharp and clear image is obtained, record the distance between the object and the screen in the column for $U + V$ in Table 2. (1)

Question continues on the next page.

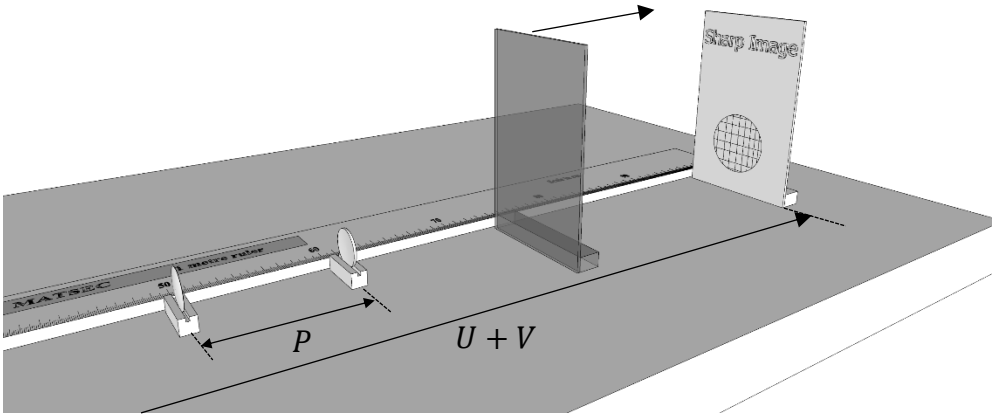


Figure 6

20. Move the concave lens such that its separation distance P from the convex lens is the next one indicated in Table 2. The image should now again appear blurred.

21. Slide the screen towards the object until the image is sharp again and record the value for the distance between the object and the screen in the column for $U + V$. (1)

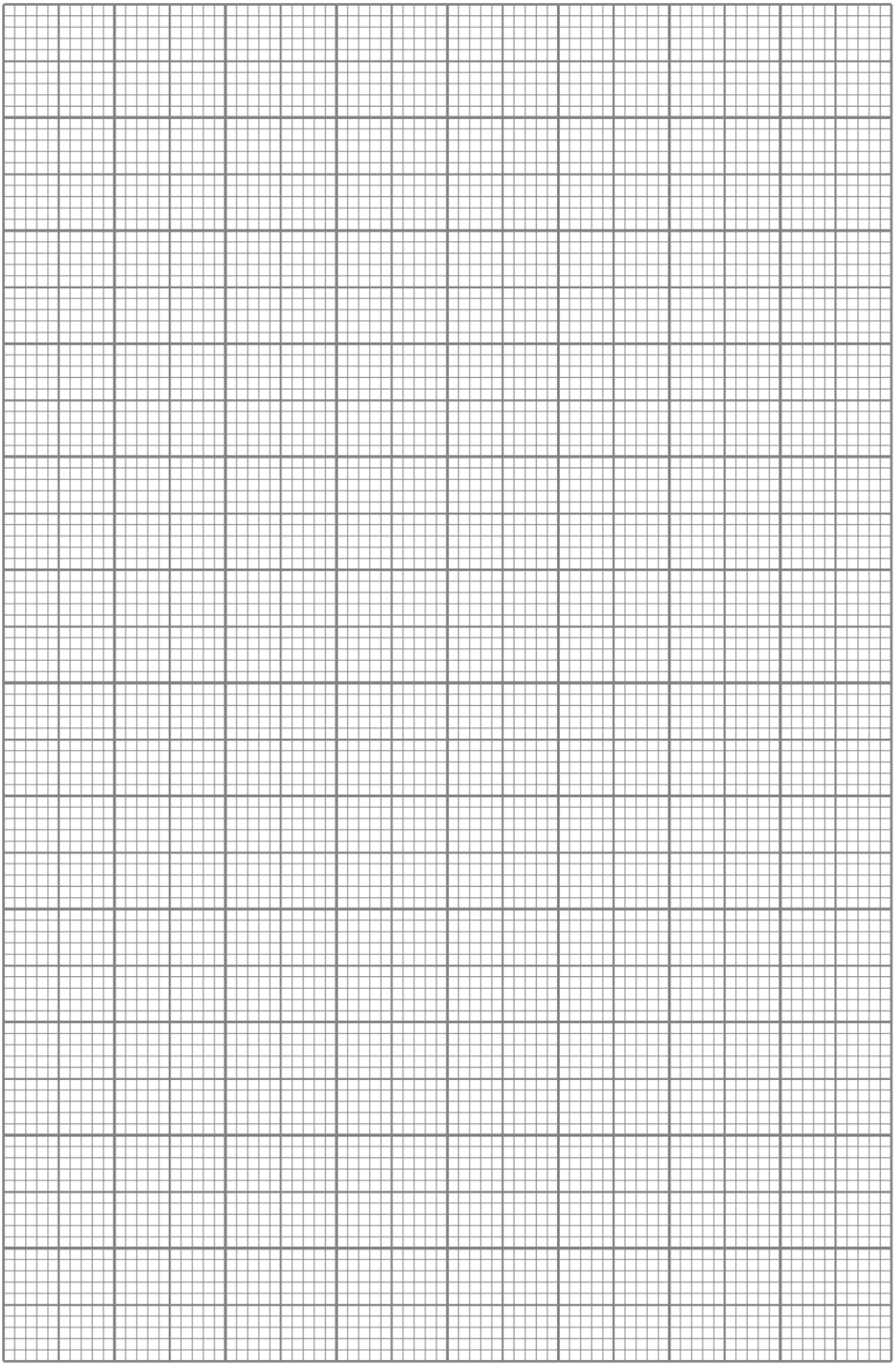
22. Repeat steps 20 and 21, each time recording the distance between the object and the screen in the column for $U + V$ in Table 2. (4)

23. The combined (effective) focal length F_{eff} of the convex-concave lens setup can be calculated using the equation $F_{eff} = \frac{UV}{U+V}$.

Table 2

U /cm	P /cm	$U + V$/cm	V /cm	F_{eff} /cm	$\frac{1}{F_{eff}}$ /cm^{-1}
50.0	11.0				
50.0	12.0				
50.0	13.0				
50.0	14.0				
50.0	15.0				
50.0	16.0				

24. Complete Table 2 by working out the missing values for V, F_{eff} and $\frac{1}{F_{eff}}$. (9)



25. The effective focal length of the combined convex-concave lens setup depends on the separation P between the two lenses by the equation:

$$\frac{1}{F_{eff}} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{P}{f_1 f_2}$$

where f_1 is the focal length of the convex lens and f_2 is the focal length of the concave lens.

26. Plot a graph of $\frac{1}{F_{eff}}$ on the y-axis against P on the x-axis. The graph is a straight line with a positive gradient. (8)

27. Use the graph and the value of the focal length of the convex lens obtained in Part A to obtain a value for the focal length f_2 of the concave lens.

_____

_____

_____

_____

_____ (4)

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

_____

_____

_____ (2)