MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

ADVANCED MATRICULATION LEVEL
2024 SECOND SESSION

SUBJECT:	**Physics**
PAPER NUMBER:	I
DATE:	29th August 2024
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 electric field, E, between the ends of an electrode satisfies the equation $E = \frac{\rho I}{\pi r^2}$, where I is the current, ρ is the resistivity of the electrode, and r is the electrode's radius.

   a. Define scalar and vector quantities. (2)

   b. Classify the quantities in the given equation as being scalars or vectors. (2)

   c. Obtain the base units describing the electric field, and use the given equation to obtain the base units for the resistivity. (4)

   An experimenter later used the electrodes to measure the voltage across two points in a material. They suggest that the voltage, V, satisfies the relation $V = \frac{\rho I}{r_2 - r_1}$ for some radii r_1 and r_2. However, the experimental data do not match with the suggested relation despite it being homogeneous.

   d. State **TWO** possible reasons for this observation. (2)

(Total: 10 marks)

2. A child is swinging a small spherical bob attached to an inextensible string in an anticlockwise motion in a vertical circle of radius r as shown in Figure 1.

   a. Sketch a copy of Figure 1 and draw the directions of acceleration and velocity when the bob is at point A. (2)

   b. By deriving suitable equations, determine the position where the string is most likely to break. (4)

   c. Explain what happens to the likelihood of breaking if:
      i. the radius is increased while keeping the angular speed fixed; (2)
      ii. the frequency of rotation is increased. (2)

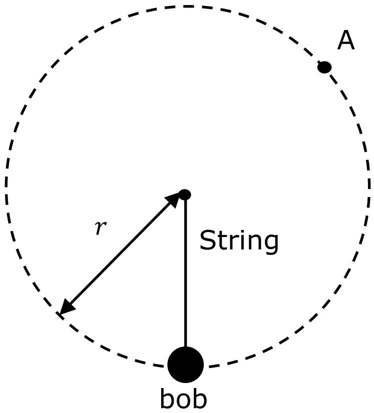

Figure 1

(Total: 10 marks)

Please turn the page.

3. A rocket ejects its burnt fuel at a constant relative velocity of 3.0 km s^{-1} to create thrust.

   a. Use Newton's second law to derive an expression for the thrust forces generated by mass ejection at a constant velocity. Explain all symbols used. (2)

   b. Calculate how much fuel needs to be ejected per second to create a thrust of 3.0×10^5 N. (2)

   c. Calculate the time for which the rocket can generate this thrust if it contains 8 tonnes of fuel. (2)

   d. Given that the entire rocket weighs 10 tonnes, calculate the initial acceleration with which the rocket leaves the ground pointing straight up. (4)

(Total: 10 marks)

4. In a vacuum tube, electrons can be emitted from a filament held at the potential $V = 0$ and accelerated toward an anode with a pinhole at a potential V_0. The electrons are then sent through a double slit with separation $d = 6.20\ \mu\text{m}$ and exhibit wave-like behaviour on a screen at a distance of $D = 1.00\ \text{m}$.

   a. Calculate the potential V_0 required to produce electrons with de Broglie wavelength 30×10^{-12} m. (3)

   b. Calculate the time of flight of the electrons from the double slit to the screen. (2)

   c. Calculate the expected separation of the fringes assuming the electrons act identically to monochromatic visible light. (2)

   d. Heisenberg's uncertainty relation can be used to estimate the uncertainty in velocity of an electron passing the double slit. The uncertainty of the position of the electron at the double slit can be taken as the slit distance and the resulting uncertainty in velocity $\Delta v_x = 117\ \text{m s}^{-1}$.
      i. Calculate the distance ΔX an electron can travel in the lateral direction with velocity Δv_x during the time of flight calculated in part b. (1)
      ii. Compare this uncertainty, ΔX, of the lateral position of electrons at the screen with the separation of the fringes. (1)

   e. Given that interference fringes can be observed, explain how the student can convince themselves that what they are observing are indeed electrons. (1)

(Total: 10 marks)

5. A uniform solid beam which is 8 m long, has a mass of 20 kg and is fixed in a horizontal position. It is hinged to a vertical wall at point H and supported by a cable which is held taut, being attached to the other end of the beam and fixed to the vertical wall, at point B. The cable makes an angle of 53° with the horizontal. A man weighing 600 N stands on the beam, 2 m away from the wall (see Figure 2).

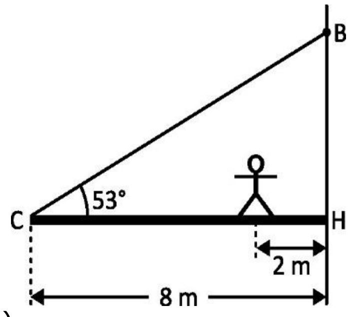

Figure 2

   a. Draw a free body diagram showing forces acting on the beam. (3)

   b. Find the tension in the cable. (2)

   c. Find the magnitude and direction of the force exerted by the wall on the beam at point H. (5)

(Total: 10 marks)

6. Figure 3 shows the stress-strain graphs for two rods made from materials X and Y.

   a. Define stress, stating its units, if any. (2)

   b. Define strain, stating its units, if any. (2)

   c. During an experiment, a student is using another rod, Z, which is made from a different material. This material is stiffer than material X and has a lower ultimate stress than material Y. On a sketch of Figure 3, add a stress-strain graph to show the behaviour of rod Z. (2)

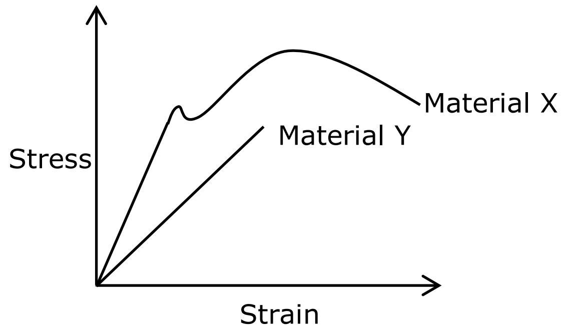

Figure 3

   d. The student is asked to decide about which one of the materials, X or Y, would be the better one to use to make the body of a car. It is well known that car bodies are designed to deform in a crash, thus minimising the energy transferred to the passengers. Compare the properties of materials X and Y, stating **TWO** specific reasons that explain which one of the materials will be the more suitable for this purpose. (4)

(Total: 10 marks)

7. A small spherical rain drop, of diameter 1 mm, falls through air. After some time, it moves with *terminal velocity*.

   a. Draw a diagram that shows the forces acting on the rain drop as it falls through the air. Clearly label the forces, including the direction in which they act. (3)

   b. State **THREE** factors upon which the drag experienced by the rain drop depends. (1)

   c. If the velocity of the rain drop increases, does this have any effect on the drag acting on the rain drop? Explain your answer. (1)

   d. Explain what is *'terminal velocity'*. (1)

   e. Briefly describe the motion of the rain drop after it starts falling through the air. Your answer must include the following words: velocity, force/s, weight of the drop, terminal velocity, acceleration. (2)

   f. Sketch a velocity versus time graph to show how the velocity of the rain drop changes with time. Carefully label the x and y axes, also indicating where the drop experiences a terminal velocity. (2)

(Total: 10 marks)

8. a. State Kirchhoff's second law. (2)

   b. A student is supplied with two cells of emf 5 V and 9 V respectively. Each cell has an internal resistance. A 6 Ω resistor is also supplied. The student connects these electrical components, as shown in Figure 4.

      i. Find the current flowing through the 6 Ω resistor. (4)

      ii. Calculate the p.d. developed across the 6 Ω resistor. (2)

      iii. Find the power dissipated by the 6 Ω resistor. (2)

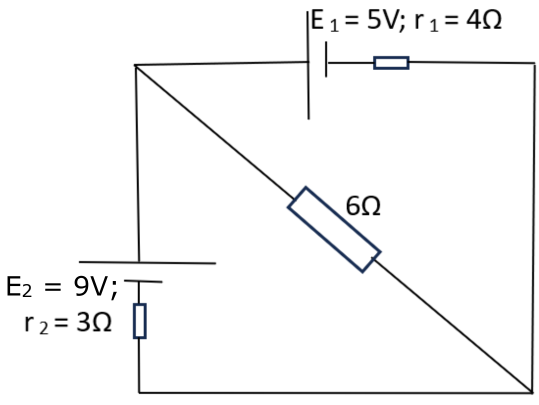

Figure 4

(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. An engineer is testing the elasticity of various materials in order to determine the ideal set of wires to lift a heavy weight.

   a. Describe in detail an experiment to measure the Young's modulus of a wire of a certain material. Your explanation must include:
      i. a labelled diagram of the required setup; (3)
      ii. the procedure to conduct the experiment including all relevant measurements; (2)
      iii. **TWO** precautions to conduct the experiment correctly. (2)

   b. One of the materials tested was a 1.5 m long copper wire having a radius of 2 mm. The data obtained is shown in Figure 5.

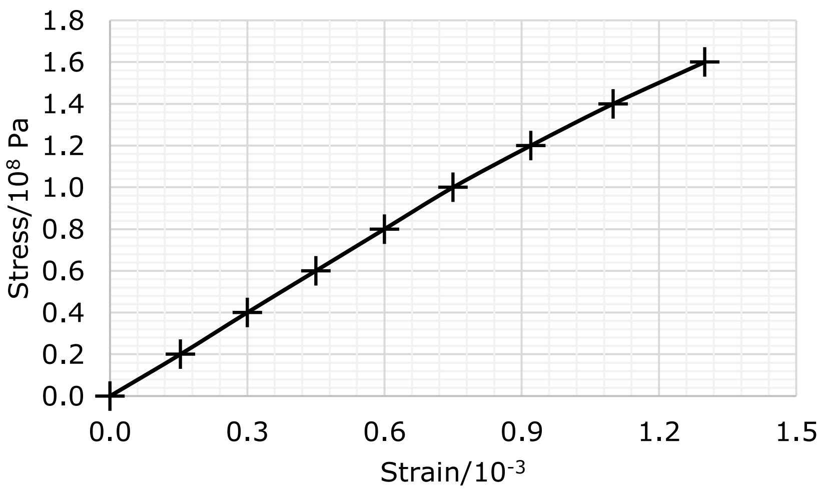

Figure 5

      i. State the significance of the gradient of the graph and obtain its value. (3)
      ii. Hence, calculate the effective spring constant of the copper wire. (3)
      iii. State the significance of the area under the graph. (1)

The engineer eventually decides to use a pair of wires, one made of steel and the other of iron, having equal cross-sectional areas, and connects them in series. The length of the steel wire is double that of the iron wire. Assume that the mass of each wire is negligible.

   c. Show that the extensions of the steel wire and of the iron wire are related to the Young's moduli of the wire via the equation $\frac{\Delta l_s}{\Delta l_i} = \frac{2Y_i}{Y_s}$. (4)

   d. The engineer later tests two steel and iron wires having identical lengths. They test the setup in two configurations: the first having the wires connected in series; the second by connecting them in parallel with each other. Discuss any observed differences between the two configurations. (2)

(Total: 20 marks)

10. Expert snooker players have to be aware where the cue ball is struck as it completely alters its resulting motion and behaviour. In particular, a stick can hit a cue ball initially at rest with some force F at a specific position that ensures that the cue ball moves in a purely rolling motion without slipping. The situation is illustrated in Figure 6.

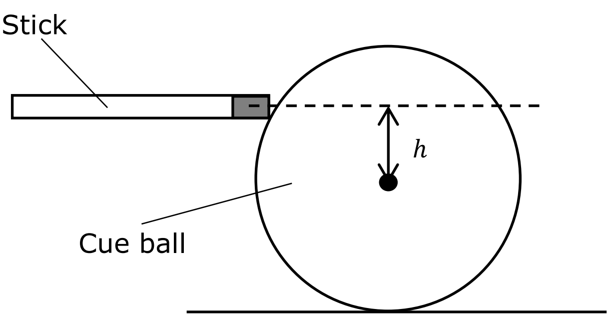

Figure 6

   a. State the principle of conservation of angular momentum and explain why the angular momentum of the ball is **not** conserved in this case. (2)

   b. Write down an expression for the torque, τ, about the centre of the cue ball due to the force exerted by the stick and show that $\tau = \frac{mvh}{t}$, where t is the duration of impact and v is the linear velocity after impact. (3)

   c. Obtain an alternative expression for the torque in terms of the moment of inertia and hence show that $h = \frac{2}{5}R$, where R is the radius of the cue ball, given that the moment of inertia of a sphere of mass M and radius r is $\frac{2}{5}Mr^2$.(4)

   A standard snooker stick has a mass of 450 g whereas the cue ball has a mass of 165 g and radius 30 mm. The snooker player strikes the cue ball, initially at rest, at a speed of 6 m s^{-1} which causes the stick to recoil at a speed of 1.5 m s^{-1} and the cue ball to move. Assume that the momentum caused by the snooker player's arm is neglected.

   d. Calculate the speed of the cue ball. (4)

   e. Deduce whether the collision is elastic. (7)

(Total: 20 marks)

11. A 100 kg stuntperson is hired to film for a drop down from a building. Being aware of the danger of this scene, the stuntperson takes time to prepare for the shoot.

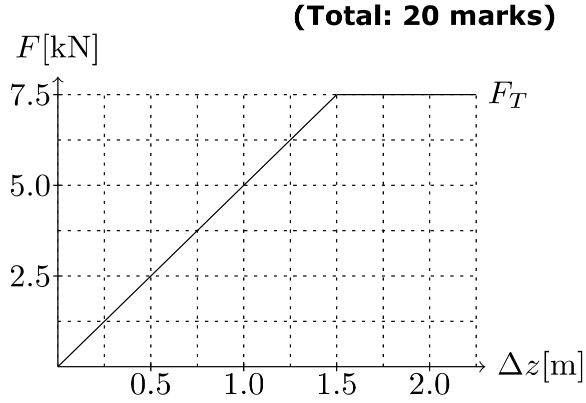

Figure 7

   a. The stuntperson starts practicing by jumping off a ledge onto a trampoline. To get to the ledge, the stuntperson needs to go up a height of 7.0 m from the ground. The trampoline is suspended 5.0 m below the ledge. The trampoline's elasticity follows the force-displacement curve shown in Figure 7.
      i. Calculate the work done by the stuntperson in climbing to the ledge. (2)
      ii. Alternatively, the stuntperson can take a 700 kg elevator powered by a 10 kW motor. Calculate the efficiency of the elevator carrying the stuntperson assuming that travelling to the top takes 10 s. (4)

   b. The safety weight allowance for a person jumping from the ledge onto the trampoline dictates that the extension of the trampoline must not exceed the end of the linear (proportional) relationship of the force-displacement curve. The stuntperson would like to try the jump in a 20 kg costume. Use the graph to calculate the maximum allowable elastic energy that can be stored in the trampoline. Hence:
      i. determine the maximum allowable mass that a jumper can have; (5)
      ii. judge whether this jump is permitted. (1)

Question continues on the next page.

iii. calculate the total extension of the trampoline during this jump, and hence the height above ground at which he would come to a stop. (3)

c. On the day of the movie shoot, the stuntperson needs to jump off a building 15 m above the ground with their costume. The fall is damped by a pile of empty cardboard boxes stacked to a height of 5 m. The stuntperson sinks 4 m into the boxes before stopping.

i. The film crew captures the fall and the director states: "Wow, that was at least 50 km/h on impact". Verify the statement with a computation. (3)

ii. Find the mean force with which the cardboard boxes stop the stuntperson. (2)

(Total: 20 marks)

12.

a. In various calculations dealing with electrical circuits, students are asked to assume that ammeters and voltmeters are ideal. What is the assumed resistance of an ideal ammeter and an ideal voltmeter? Give a reason for **each** answer. (2)

b. With reference to the electric circuit in Figure 8, find the value of the resistance R. (6)

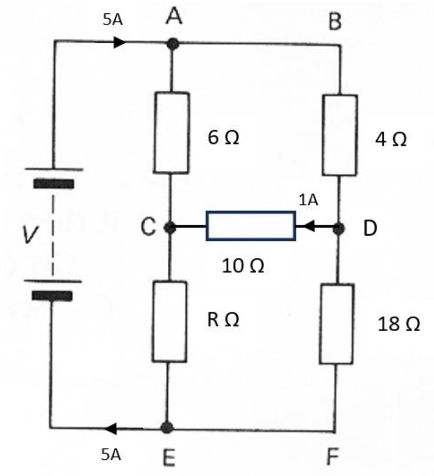

Figure 8

c. Now, the circuit components are changed. The 10 Ω resistance between C and D is replaced by a galvanometer having an internal resistance of 60 Ω. The other resistances and the cell are also changed, as shown in Figure 9.

i. Referring to points C and D, explain what it means, in terms of p.d. and current, when the galvanometer reads zero. (2)

ii. Calculate the value of R_1 when the galvanometer reading is zero. (3)

iii. Calculate the effective value of the resistance of the circuit, when R_1 has the value calculated in part (c)(ii). (2)

iv. Calculate the current in each resistor of this circuit given that $V_1 = 9$ V. (3)

v. The galvanometer is now replaced by one having twice the internal resistance. The same resistances are used in the circuit as before. What would be the effective resistance of the circuit now? Explain. (2)

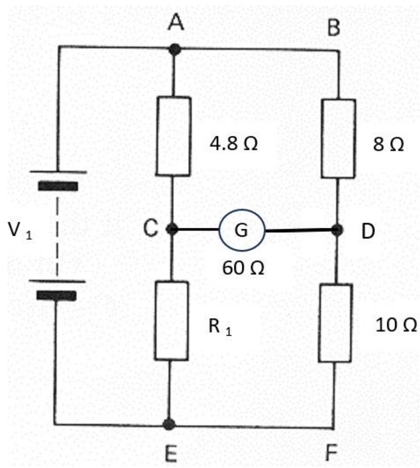

Figure 9

(Total: 20 marks)

13. In nuclear power plants, during the fission of ^{235}U, one of the resulting nuclei is ^{85}Kr which decays further via β^--decay into $^{85}_{37}$Rb. It remains in the core elements but is regularly emitted into the atmosphere through reprocessing. As natural sources of ^{85}Kr are negligible, it is a good indicator for global nuclear reprocessing efforts.

a. Give a description of the process during a β^--decay. (2)

b. Describe the energy spectrum of the β^--decay particles and what can be predicted from it.(3)

c. Write down the nuclear equation to represent the β^--decay of ^{85}Kr. (1)

d. The mass of the ^{85}Kr nucleus is 84.912527 u and that of $^{85}_{37}$Rb is 84.911790 u. Calculate the energy released during the process, giving your answer in MeV. (2)

e. The ^{85}Kr nucleus can decay with a 0.4% probability into an excited state of $^{85}_{37}\mathrm{Rb}$ that later decays into its ground state by emission of a γ-photon. Calculate the resulting frequency of the photon if the energy difference is 0.51 MeV. (2)

f. During the production of paper, the thickness is checked by passing it in between a ^{85}Kr sample and a detector. The background radiation signal is 19 min^{-1} and the experimental calibration data is illustrated in Table 1.

Table 1

Thickness in mm	0.00	0.10	0.20	0.30	0.40	0.50
Count rate in min^{-1}	211	167	133	107	86	71

i. State the equation defining the radiation absorption observed in the detector and deduce the absorption coefficient from the obtained data. (3)

ii. Define the term half-value thickness and derive its dependence on the absorption coefficient. Calculate its value using the data. (3)

iii. Determine the count rate required to produce paper of thickness 0.13 mm. (2)

iv. This measuring process is explained to a customer. However, they are concerned about the paper being subjected to additional radioactive radiation. Explain how no such concerns exist. (2)

(Total: 20 marks)

14.

a. Define moment of a force. (1)

b. A painter rests a uniform ladder of mass 6 kg against a rough wall and exerts a horizontal force *F* of 20 N at the bottom end of the ladder, to hold it in equilibrium (see Figure 10). End A rests on a frictionless horizontal surface.

i. Copy the diagram and on it show **all** forces acting on the ladder. (3)

ii. Calculate the magnitude and direction of the reaction force at point B. (4)

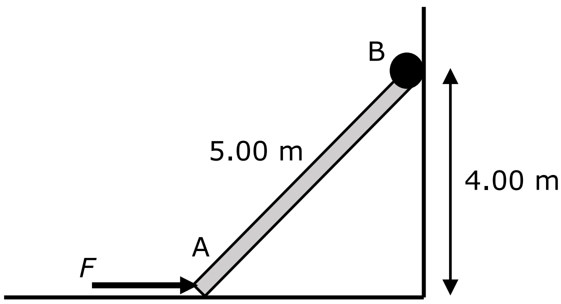

Figure 10

c. Figure 11 shows a vehicle which is travelling fast on a horizontal surface, going round a curved path of radius 91.5 m. The distance between the wheels is *d* = 1.52 m. The centre of gravity of the car is at a height *h* = 0.94 m above the ground. The diagram shows the vehicle at the point when one of the tyres just about lifts off the ground, but the vehicle does not overturn nor does it slip sideways.

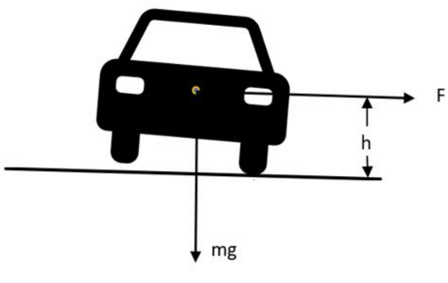

Figure 11

i. Briefly explain what is a couple. (2)

ii. Define the term *torque*. (2)

iii. Sketch a copy of Figure 11, and include the forces acting on the wheel shown touching the ground, explaining why these forces result. (2)

iv. By taking moments about a point, write down an equation that applies for the vehicle when the wheel on the left in Figure 9 is about to lift off the ground. (3)

v. Hence find the maximum velocity of the vehicle before it overturns. (3)

(Total: 20 marks)

Please turn the page.

15.

a.

i. Distinguish between the electromotive force (emf) of a cell and the potential difference (p.d.) across a resistor. (2)

ii. When starting a car, the current from the car battery is approximately 100 A. Suggest why the internal resistance of the battery should be as low as possible. (2)

b. The graph in Figure 12 shows the variation of current with potential difference for an electrical component X.

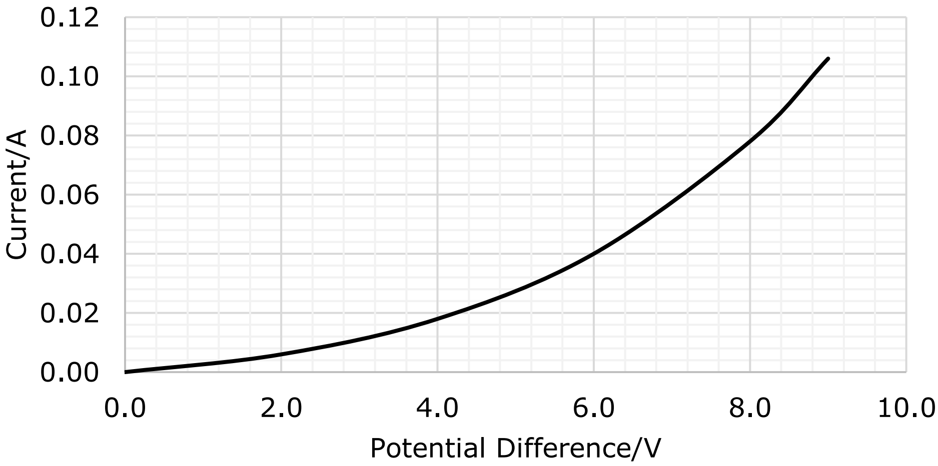

Figure 12

i. Determine the resistance of X when a potential difference of 6.0 V is applied. (2)

ii. Describe qualitatively how the resistance of X varies with applied potential difference, explaining your answer. (2)

c. Component X is connected into the circuit as shown in Figure 13. The battery has an emf of 9.0 V and negligible internal resistance. R is a fixed resistor of resistance 75 Ω.

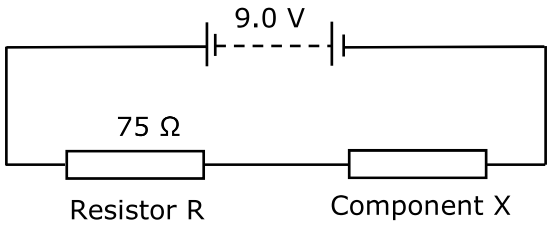

Figure 13

i. Calculate the current in resistor R when the p.d. across it is 4.5 V. (2)

ii. Copy the graph from part (b) and on it show how the current in R varies with p.d. across R. (2)

iii. Describe in detail how from the graphs of I versus V for X and R, one can find the current in the given circuit. (4)

iv. The fixed resistor, R, is now changed so that the new current in the circuit becomes 0.060 A. Determine the new value of the resistance of R. (4)

(Total: 20 marks)

MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

ADVANCED MATRICULATION LEVEL
2024 SECOND SESSION

SUBJECT:	**Physics**
PAPER NUMBER:	II
DATE:	30th August 2024
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 private space exploration company GalaxY plans two missions to explore the universe from their base situated on Earth.

[Gravitational Constant = 6.67×10^{-11} m^3 kg^{-1} s^{-2};
Earth's radius = 6370 km; Earth's mass = 6×10^{24} kg]

a. Their first mission is to send material to a space station using the Lizard spacecraft. The space station is orbiting at a height of 400 km.

i. Which force is holding the space station in its orbit? (1)

ii. In order for the Lizard to dock on to the space station, it needs to be at the same orbital height as the station. Derive an expression for the final velocity that Lizard needs to attain. (2)

iii. Define the term geostationary orbit and derive an expression for the radius Lizard would need to move in for such an orbit. (2)

b. Their second mission is to send an exploration team leaving from the space station to set up a colony on Mars with the spaceship sWallow6.

i. Define the term escape velocity. (1)

ii. Calculate the escape velocity from the space station. (4)

(Total: 10 marks)

2. An insulated beaker contains 200 cm^3 of water at a temperature of 75 °C. To cool down the water, a 10 g block of ice is added to it. After some time, the water cools down and reaches thermal equilibrium at some temperature, T.

[Density of Water = 1 g cm^{-3}; Latent Heat of Ice = 3.36×10^5 J kg^{-1},
Specific Heat Capacity of Water = 4200 J kg^{-1} $°C^{-1}$]

a. State what is meant by the term 'thermal equilibrium'. (2)

b. Determine the final equilibrium temperature, T, of the water. (6)

c. List **TWO** errors that could influence the value of the temperature calculated in (b). (2)

(Total: 10 marks)

Please turn the page.

3. As skyscrapers are built to taller heights, they are subject to wind gusts of larger speeds which can set the building in motion. The Empire State Building is estimated to have a mass of 365,000 tonnes and winds can cause a displacement x of its centre of mass. The centre of mass can be modelled to be held in place by restoring forces from the foundation that are proportional to its displacement satisfying $F = -kx$ with spring constant $k = 3.6\ \mathrm{GN\,m^{-1}}$.

   a. Use Newton's laws to derive an expression for the acceleration of the centre of mass and state the resulting motion that the building can exhibit. (2)

   b. Compute the periodic time T of the centre of mass. (2)

   c. Wind gusts occur at periodic times of between 10 s to 100 s while earthquakes can shake the ground with periods ranging from 0.05 s to 5 s. Identify whether a wind gust or an earthquake of equal force is able to cause a more dangerous shaking of the Empire State Building. What is the name of the physical effect? (2)

   d. In places with severe earthquakes, damage to the building can be avoided by a "mass tuned damper". It consists of a suspended pendulum with the same periodic time as the building installed in its top.
      i. Describe the motion that the pendulum will undergo as an earthquake displaces the building. (1)
      ii. State how the phases of both motions are related. (1)

   e. Describe the motion of the building if it were to behave as a critically damped system. (2)

(Total: 10 marks)

4. The equipotential lines 1) to 5) of an electric field in the vicinity of a plate capacitor illustrated in Figure 1 have been measured experimentally. The experimenter's notes show that the electric potential *V* at the points A and B were recorded as 6 V and 15 V respectively, whereas the potential at the negatively charged plate has been set at 0 V.

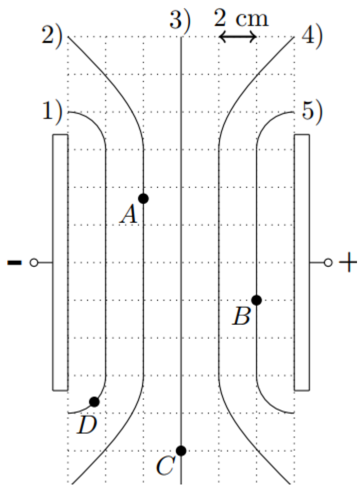

Figure 1

   a. Copy Figure 1 and on it draw the lines of force at points A, B, C, and D of the electric field. (4)

   b. State the values of the potential at the points C and D as well as the voltage V_0 across the capacitor. (2)

   c. Let x denote the distance of a point from the negatively charged plate within the homogeneous part of the electric field.
      i. Sketch the plot of the electric potential against the distance x for the plate capacitor, clearly marking any notable values. (3)
      ii. Use the plot to compute the value of the electric field strength between the plates. (1)

(Total: 10 marks)

5. Astronomers make use of absorption spectra originating from stellar bodies to determine their composition and their estimated distance from Earth. In Figure 2, the absorption spectrum of a star from a faraway galaxy is compared with the absorption spectrum of the Sun.

[Hubble's Constant = 2.2×10^{-18} s^{-1}]

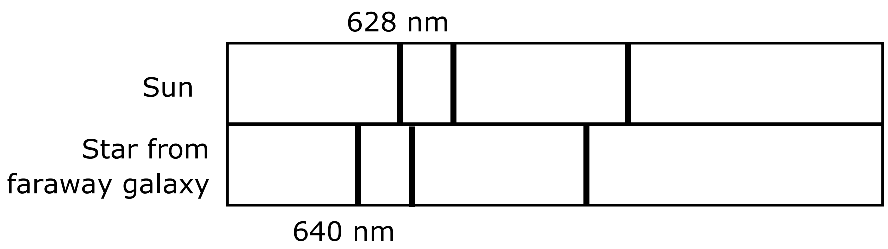

Figure 2

a. Provide a brief description of the Big Bang theory. (1)

b. Name the phenomenon observed by the astronomer and explain how this phenomenon supports the Big Bang theory. (3)

c. Calculate the recessional velocity of the star. (4)

d. Hence, estimate the distance of the star from Earth. (2)

(Total: 10 marks)

6.

a. One mole of an ideal gas is enclosed in a container having a moveable piston that allows the gas to expand or compress. Initially, the gas has a pressure of 95 kPa at a temperature of 300 K. The gas is then heated keeping the piston at a fixed position to a temperature of 350 K. Then, the gas is allowed to expand at constant temperature until its volume is twice the initial volume.

   i. Determine the final pressure of the gas, naming the relevant gas laws used to derive the result. (5)

   ii. Explain whether the final pressure value would change from that calculated in (a)(i) if two moles of gas were enclosed in the container at the same P-T-V conditions. (1)

b. Figure 3 illustrates the *PV/T* against *P* relationship for one mole of oxygen at some fixed temperature.

   i. State the significance of the *y*-intercept. (1)

   ii. Explain how the graph illustrates that oxygen does **not** behave as an ideal gas. (1)

   iii. State **TWO** conditions that are required for oxygen gas to behave as an ideal gas. (2)

(Total: 10 marks)

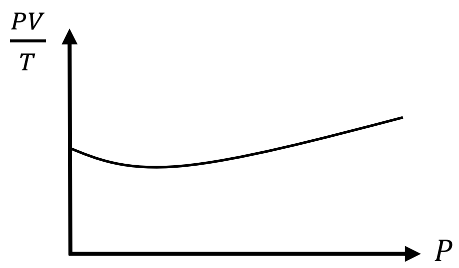

Figure 3

Please turn the page.

7. The remote control for an air conditioner is not working despite having working batteries. To identify the fault, an inspection of the remote control's components is conducted.

   a. The top of the remote which is used to point towards the air conditioner contains a p-n junction diode that emits infrared light when the different charge carriers recombine. Explain the behaviour of the charge carriers at a p-n junction when a power source is connected, and how this may lead to infra-red light emission. (4)

   b. After opening the case, it is observed that the board is missing a "330 mH" component. A multimeter that can measure rms voltage and current is used to check its connectivity.
      i. Identify the missing electronic component. (1)
      ii. Define the term root mean square current. (1)
      iii. If the component were connected to an AC power source delivering $V_{rms} = 10\text{ V}$ at $f = 50$ Hz, what is the expected root mean square current to be measured on the multimeter connected in series? (2)

   c. Further inspection of the circuit board revealed the need for a capacitor having the same reactance at 50 Hz as that of the 330 mH component. Compute the capacitance of the capacitor required with the aforementioned properties. (2)

(Total: 10 marks)

8. A student wishes to determine the focal length, *f*, of a thin converging lens using a screen, a cut-out window with cross-wires, and a metre ruler. The student measures the heights of the object and produced image of the window to determine the linear magnification, *m*, and the object distance, *u*, between the window and the lens.

   a. Starting from the lens equation $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, where *v* represents the image distance from the lens, show that the equation can be rewritten as $\frac{1}{m} = \frac{u}{f} - 1$. (2)

   b. Sketch a suitable straight-line graph involving the two experimental variables. Clearly mark any relevant values. (3)

   c. State how the gradient of the graph can be used to determine the focal length of the lens. (1)

   d. If the lens has a focal length of 7.5 cm and the produced image has a linear magnification of 3, determine the image distance from the lens. (4)

(Total: 10 marks)

SECTION B

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

9. A student decided to investigate the production of sound notes using a 0.65 m long piece of wire in the setup shown in Figure 4. The wire was clamped at both ends, with one of the ends having a slotted mass hanger attached to vary the tension of the wire.

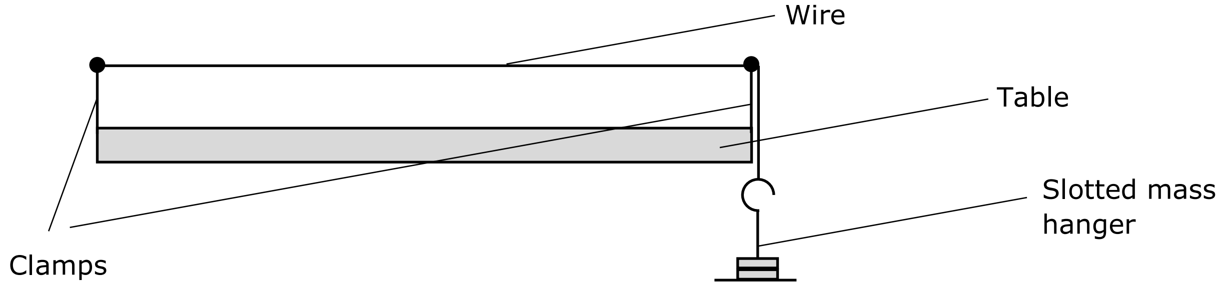

Figure 4

After adding some masses and keeping the tension fixed, the student investigated the pitch of the sound note produced using a set of tuning forks of known frequencies and observing the vibrations of the wire. The observations are tabulated in Table 1. When the wire was hit with the 196 Hz tuning fork, the wire produced vibrations as illustrated in Figure 5.

Table 1

Tuning Fork Frequency/Hz	Observation
196	Large vibrations
294	Very small vibrations
392	Notable vibrations

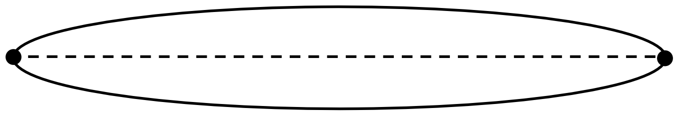

Figure 5

a. Describe how the induced vibrations produce a stationary wave along the wire. (2)

b. Explain in detail the observations made by the student for each tuning fork frequency. Your answer should include reference to relevant physical phenomena. (6)

c. Define the terms 'node' and 'antinode'. (2)

d. Copy Figure 5 and mark the positions of the nodes and antinodes. (2)

e. The variation of the displacement, y, as a function of time, t, at some point along the string can be described according to the equation $y = (1.5\ \text{cm})\cos(1231.5t)$. Determine the:
   i. maximum displacement at this point; (1)
   ii. wavelength of the stationary wave; (2)
   iii. speed of the wave; (2)
   iv. distance of this point as measured from the left clamp if the maximum displacement at this point is the amplitude of the stationary wave. (1)

f. The student wishes to produce a higher pitched note without changing the material of the wire. State **TWO** other ways how this could be achieved. (2)

(Total: 20 marks)

Please turn the page.

10.

a. Describe a simple experiment used to investigate the relationship between the current flowing through a solenoid having a fixed number of turns, and the produced magnetic field. Your description should include:

i. a labelled diagram of the apparatus used; (3)

ii. a description of the procedure; (2)

iii. a precaution when measuring the magnetic field. (1)

b. Figure 6 illustrates a magnet being inserted into a single turn coil which is connected to a galvanometer.

i. State Faraday's law. (2)

ii. State the direction of the current as viewed from the left side of the diagram. Explain the reasoning for the chosen direction stating any relevant laws used. (3)

iii. Explain what happens to the reading of the galvanometer once the magnet is left at rest in the centre of the coil. (1)

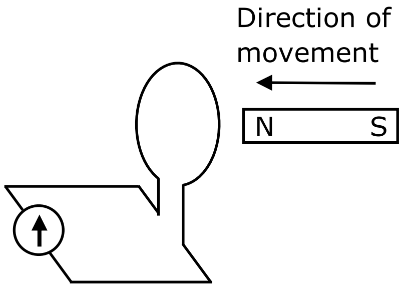

Figure 6

c. Figure 7 represents a small solenoid of length L_2 having N_2 turns of radius r_2 placed at the centre of a much longer coil of length L_1 having N_1 turns of radius r_1. The smaller coil is connected to a galvanometer whereas the longer coil is connected to an a.c. supply.

i. Show that the mutual inductance, M, of the system is $M = \frac{\mu_0 N_2 N_1 \pi r_2^2}{L_1}$. (6)

ii. The aforementioned setup is used in wireless phone charging systems, where the base of the charger contains a long solenoid while mobile phones have a smaller coil. Explain why the phone would **not** charge if the charger is connected to a d.c. supply. (2)

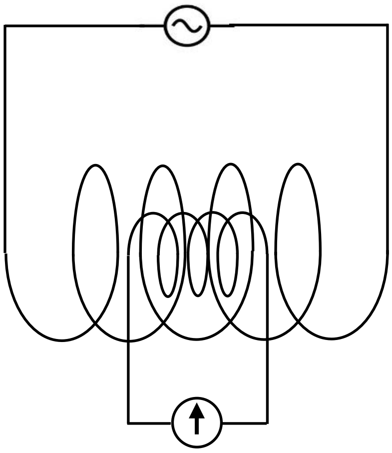
Figure 7

(Total: 20 marks)

11.

a. An electric kettle is used to boil water to prepare tea.

i. Name **THREE** heat transfer mechanisms that occur within the kettle while boiling water. (3)

ii. Give a physical explanation for **each** process and locate where each process takes place in the kettle. (3)

b. An aluminium pot with a circular base of thickness 2 cm and radius 0.1 m is being heated on an electric stove. Assume that the cylindrical side walls isolate the water from the environment and are thin enough to be negligible for heat conduction. The aluminium possesses a thermal conductivity of 239 W m^{-1} K^{-1}.

i. Given that the structure has established steady state conditions, state the equation that governs heat transfer through the base of the pot. (1)

ii. Calculate the temperature at the top of the base of the pot for a rate of heat transfer of 3 kW given that the bottom of the base is at a temperature of 105 °C. (3)

iii. Sketch a graph of the temperature variation against position within the base of the pot. Clearly indicate significant values. (2)

iv. Judge whether the stove is able to provide enough power to boil water in this pot without a lid. (1)

c. The pot in the previous question is now sealed with an aluminium lid such that the metal container approximately constitutes a black body.
   i. Describe the defining properties of a black body. (1)
   ii. Making use of a diagram, describe a better way to create a black body in practice. (2)
   iii. Sketch a plot of the intensity of the radiation emitted by the metal container against wavelength for temperatures $T_0 = 400\ \mathrm{K}$, $T_1 = 1000\ \mathrm{K}$, and $T_2 = 4000\ \mathrm{K}$. Explain what does the area under the graph signify. (4)

(Total: 20 marks)

12. Figure 8 illustrates the setup of a mass spectrometer, an apparatus used to determine the mass-to-charge ratio of ions.

The source, S, emits ions which are accelerated through an electric field using two oppositely charged plates at a potential difference *V*. Then, the ions enter a velocity selector to only allow ions of a specific velocity to enter the chamber. The chamber contains a uniform magnetic field perpendicular to the ion's velocity, which deflects the ions onto a detector.

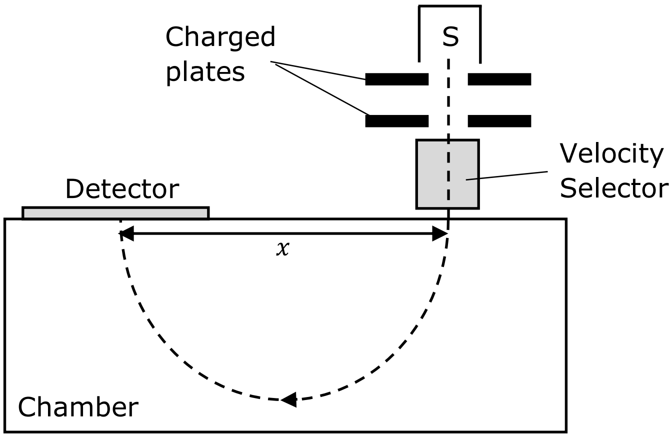

Figure 8

By varying the magnetic flux density, *B*, inside the chamber, various distances, x, could be measured that help determine the mass-to-charge ratio of an ion.

a. Define magnetic flux density. (1)

b. State the direction of the magnetic field needed in the chamber if negatively charged ions are emitted by the source. (1)

c. Derive an equation for the speed of the ion, *v*, with which it enters the velocity selector in terms of the p.d., *V*, of the plates. (3)

d. Explain how crossed perpendicular electric and magnetic fields in the velocity selector ensure that only ions of a specific speed, and hence a specific charge-to-mass ratio, pass through. (4)

e. Derive a relation between the magnetic flux density and the ion's speed when the ion is in the chamber. (2)

f. Show that the mass-to-charge ratio obeys the equation $\frac{m}{q} = \frac{B^2x^2}{8V}$. (4)

g. Sketch a suitable straight-line graph relating the dependence of the magnetic flux density with the distance x for a fixed p.d. Hence, state how the mass-to-charge ratio could be determined from the graph. (3)

h. Explain what happens to the trajectory of the ion if the magnetic field in the chamber is set at an angle to the velocity of the ion. (2)

(Total: 20 marks)

Please turn the page.

13. A student wishes to investigate the properties of a bulb emitting monochromatic red light using a spectrometer and a diffraction grating.

   a. Describe in detail an experiment that the student could conduct in order to measure the wavelength of the monochromatic light source. Your description should include:
      i. a diagram; (3)
      ii. the procedure entailing the measurements taken; (3)
      iii. the plotted graph and calculations necessary to obtain the wavelength. (3)

   b. Explain what happens to the observed spectrum if the student:
      i. uses a diffraction grating with a larger number of slits per metre; (2)
      ii. replaces the bulb with one emitting monochromatic blue light. (2)

   The student then replaces the bulb with one that emits white light.

   c. Once the light passes through the diffraction grating, a rainbow spectrum is observed. The student claims that the phenomenon is identical to that observed when using a prism. State whether the student is correct, providing **THREE** reasons to support your answer. (3)

   d. The student then places a second diffraction grating behind the first such that the slits are perpendicular to each other. Describe what the student observes in this case, providing an explanation for this observation. (4)

(Total: 20 marks)

14. Thunderstorms tend to form in cumulonimbus clouds and can accumulate considerable electric charge over large areas. Consider a cloud with an area A = 9.5 km^2 that accumulates a charge of Q = 90 C, constituting a plate capacitor with the ground.

   a. Name **TWO** conditions that need to be met to have a homogeneous electric field between the ground and the cloud. (1)

   b. Show that the electric field strength of the homogeneous field is given by $E = \frac{1}{\varepsilon_0} \times \frac{Q}{A}$ and compute its value. (5)

   Now consider the effect of a lightning rod fixed on a building. In Figure 9, the electric potential, φ, at various altitudes between the ground and the cloud is presented in the presence of a conducting lightning rod.

   c. Using the result from b., determine the values of the potential along each equipotential line assuming that the potential of the ground and surface of the rod is $\varphi = 0$. (3)

   d. Copy the diagram and draw lines of force from the black dots on the cloud towards the surface of the rod. (3)

   e. Explain why the electric field strength at the tip of the rod is larger than it would be at the same height without the rod. (1)

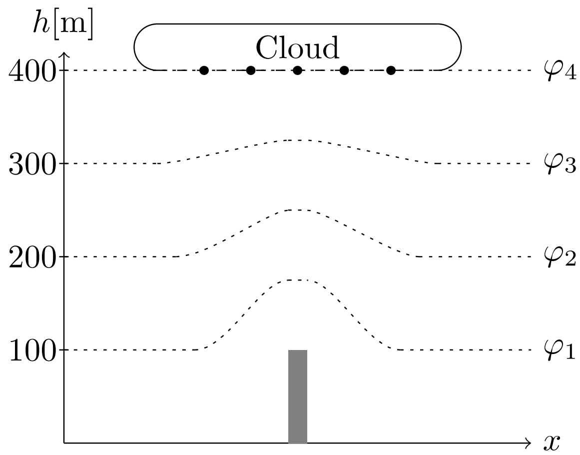

Figure 9

   f. Lightning can start to occur for electric field values of $E = 1.2\ \text{kV mm}^{-1}$.
      i. Calculate the electric field strength at the ground. (1)
      ii. Calculate the electric field strength at the tip of the conducting rod. (1)
      iii. Determine whether lightning can form from **both** the ground and the conducting rod. (1)

g. The cloud eventually discharges with a time constant of $T = 20\ \mu s$. Calculate the effective resistance for this process to occur. (3)

h. The cloud can be considered completely discharged after 5 time constants. Calculate the mean current of the lightning during this time. (1)

(Total: 20 marks)

15. The Carnot cycle is an idealised thermodynamic cycle whose pV-diagram is depicted for an ideal gas of adiabatic index $\gamma = \frac{5}{3}$ by the solid lines in Figure 10. A system has a hot bath at $T_H = 400\ \mathrm{K}$ and a cold bath at $T_C = 300\ \mathrm{K}$ undergoing the four steps of the Carnot cycle in the following order:
    i. Isothermal compression;
    ii. Adiabatic compression;
    iii. Isothermal expansion;
    iv. Adiabatic expansion.

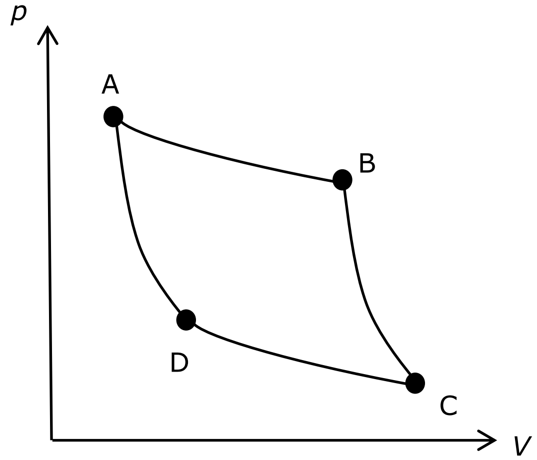

Figure 10

a. State the first law of thermodynamics, defining all appearing quantities and the meaning of **each** quantity when positive. (4)

b. Identify each of the path-segments appearing in the Carnot diagram with the steps given above. For each step, explain your answer and write down the relevant p-V equation. (4)

c. Indicate for each step in the Carnot cycle whether the change of each thermodynamical quantity appearing in the first law of thermodynamics is smaller than zero, larger than zero, or equal to zero. (4)

d. Define the terms heat engine and heat pump. (2)

e. Explain if the system shown is operating as a heat engine or a heat pump. (1)

f. Identify a series of four steps that must be taken to make the system operate as the opposite machine. (1)

g. State and compute the maximum efficiency of this system as a heat engine. (2)

h. List **TWO** factors that limit the practical efficiency of heat engines. (2)

(Total: 20 marks)

MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

L-Università ta' Malta

ADVANCED MATRICULATION LEVEL
2024 SECOND SESSION

SUBJECT:	**Physics**
PAPER NUMBER:	III – *Practical*
DATE:	28th August 2024
TIME:	2 hours 5 minutes

Experiment: Investigating the charging of a capacitor.

Apparatus: 9V battery, circuit board with two resistors and two sockets, a chain of nine resistors, a set of five standalone electrolytic capacitors, a multimeter and a stopwatch

Diagram:

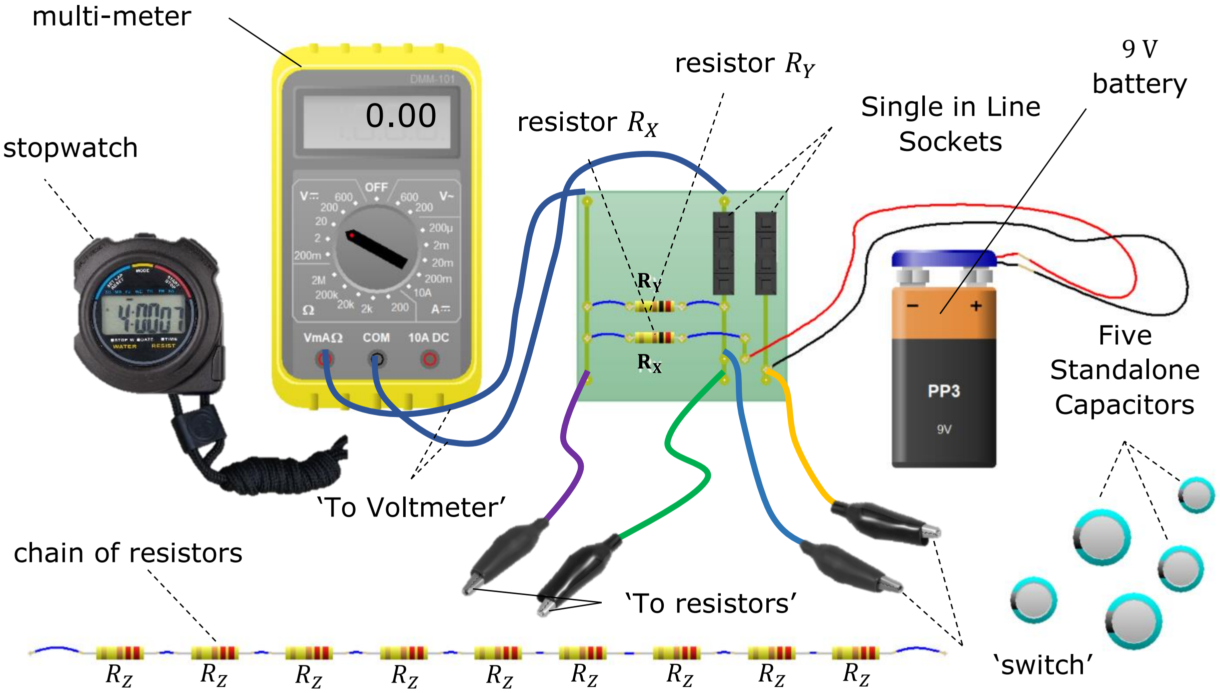

Figure 1: The experimental setup

Method – Part A:

1. The circuit board includes two resistors R_X and R_Y and two sets of four-in-line sockets. A chain of identical resistors R_Z and five (5) standalone electrolytic capacitors are also provided.

2. The 9 V battery is already connected to the battery clip. If it is not, kindly ask for assistance as connecting it the wrong way round may damage the circuit.

3. Three pairs of wires are soldered to the circuit, labelled as 'Switch', 'To Voltmeter', and 'To Resistors'.

4. In this part of the experiment, you will determine the value of the resistance, R_Y, which is one of the resistors on the circuit board. You will also obtain your own value for the battery terminal voltage V_0.

Please turn the page.

5. Connect together the crocodile clips labelled 'switch' and maintain this connection throughout the first part of this experiment.

6. State whether resistors R_Z are connected in series or in parallel.

____ (1)

7. Connect the red crocodile clip of the set labelled 'to resistors' to one end of the chain of resistors and the black crocodile clip (of the same set) to the wire joining the first and second resistor. Set the multi-meter to read DC voltage up to $20\ \mathrm{V}$ to show a voltage reading.

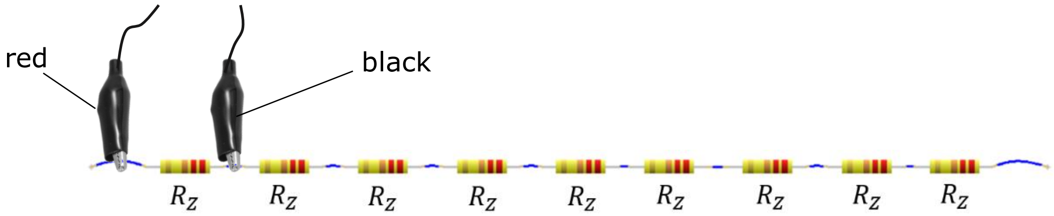

Figure 2

8. Record the voltage V_Y on the voltmeter in the row for $n = 1$ in Table 1, where n stands for the number of resistors connected between the two crocodile clips. (1)

9. Disconnect the black crocodile clip and connect it to the wire joining the second and third resistor. The red crocodile clip should be left connected to the end of the chain of resistors.

10. Record the voltage in Table 1 in the row for $n = 2$. Repeat this procedure for all the resistors in the set. For $n = 9$, you should end up with the red crocodile clip connected to one end and the black crocodile clip connected to the other end of the chain. (8)

Table 1

n	V_Y/V	$\frac{1}{n}$	$\frac{1}{V_Y}\ /\mathrm{V}^{-1}$
1			
2			
3			
4			
5			
6			
7			
8			
9			

Please turn the page.

11. Complete Table 1 by working out $\frac{1}{n}$ and $\frac{1}{V_Y}$ to three decimal places. (9)

12. For this particular circuit, it is known that the relation between the number of resistors and the voltage V_Y on resistor R_Y is given by

$$\frac{1}{V_Y} = \left(\frac{R_Y}{V_0 R_Z}\right)\left(\frac{1}{n}\right) + \frac{2}{V_0}$$

where V_0 is the terminal voltage of the battery and R_Z is the resistance of each resistor in the chain of resistors.

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

14. Use the graph to determine the value of V_0. The value of V_0 should be close to the battery voltage.

____

____

____

____ (3)

15. Each of resistors R_Z has a value of $22000\ \Omega$. Use the graph to determine the value of R_Y. Express R_Y in $\mathrm{k}\Omega$.

____

____

____

____ (4)

Method – Part B:

16. In this part of the experiment, another value for the resistance R_Y will be determined.

17. Disconnect the crocodile clips labelled 'to resistors' from the chain of resistors and place them on the bench ensuring that these do not touch each other.

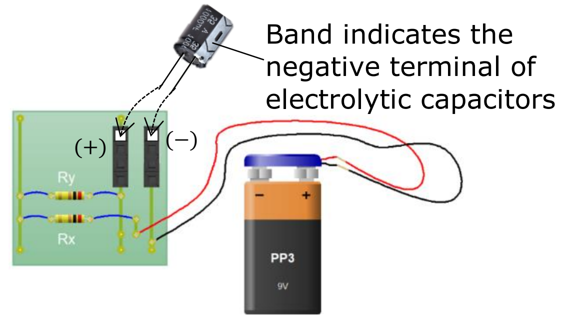

Figure 3

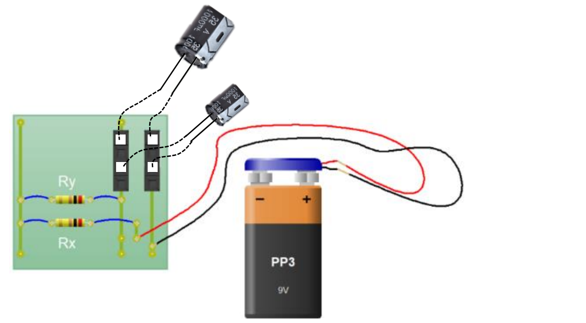

Figure 4

18. Select the 1000 μF capacitor from the five standalone capacitors you have available. Referring to Figure 3, insert the negative pin of the electrolytic capacitor in the socket on the right hand side of the board and the positive terminal in the socket on the left hand side.

19. Add a second capacitor, the 680 μF, to the same sockets and in the same way described in step 18. Setup should now look as shown in Figure 4.

20. These two capacitors are now connected in parallel. Calculate the total capacitance in μF of the system.

____ (1)

21. When the two crocodile clips labelled 'switch' are connected together they short circuit and discharge the capacitors. When they are disconnected from each other they let the capacitors start charging through the series resistors R_X and R_Y. Connect the two crocodile clips labelled 'switch' together.

22. Disconnect the two crocodile clips labelled 'switch' and observe what happens to the voltage read by the multimeter. Briefly explain these observations.

____

____

____

____ (2)

Please turn the page.

23. Let V_C be the voltage on the capacitor (or combination of capacitors) during charging. This voltage changes according to the equation $V_C = V_0\left(1 - e^{-\frac{t}{RC}}\right)$, where R is the total resistance in the circuit. If the value of R_X is equal to R_Y, show that after a period of time equivalent to RC, the voltage V_Y on the resistor R_Y is equal to $\frac{V_0}{2e}$.

____

____

____

____

____ (4)

24. You will record the time it takes the voltage V_Y on the resistor R_Y (as displayed on the multi-meter) to reach the value of $\frac{V_0}{2e}$. Use the value of V_0 obtained in step 14 to calculate $\frac{V_0}{2e}$.

____ (1)

25. Reconnect the crocodile clips labelled 'switch' such that the reading on the voltmeter settles.

26. Disconnect the two crocodile clips labelled 'switch' and at the same instant start the stopwatch. Stop the stopwatch as soon as the value of the voltage V_Y on the voltmeter reaches the value $\frac{V_0}{2e}$ calculated in step 24. Record this time in the first row of Table 2 and in the first column for T_1. (1)

27. Repeat another two times to have three repeated readings and record these repeated readings in the columns for T_2 and T_3. (2)

28. Repeat steps 25, 26 and 27 for the total capacitance values indicated in the column C of Table 2. A combination of capacitors may be needed to make up the capacitance C. (15)

Table 2

C	C_{true}	T_1/s	T_2/s	T_3/s	$\bar{T}$/s
1680 μF	2520 μF				
1220 μF	1830 μF				
1000 μF	1500 μF				
680 μF	1020 μF				
470 μF	705 μF				
330 μF	495 μF				

29. Complete Table 2 by working out the average value for the time $\bar{T}$. (6)

DO NOT WRITE ABOVE THIS LINE

Please turn the page.

30. The capacitance of large electrolytic capacitors is highly variable. They are designed such that the tolerance errors are on the high side because it is easier to handle more capacitance rather than less. The column C_{true} of Table 2 shows the approximate true value of the capacitance.

31. Calculate the positive tolerance in percentage of the $470\ \mu\text{F}$ capacitor used in this experiment.

____ (1)

32. The relationship between the time taken for the voltage on the resistor R_Y to reduce to $\frac{V_0}{2e}$ and the true capacitance is given by $T = 2R_Y C_{true}$.

33. Plot a graph of $\bar{T}$ in s on the y-axis against C_{true} in μF on the x-axis. (8)

34. Use the graph to determine a second value for R_Y and state its value in $\text{k}\Omega$.

____

____

____ (3)

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

____

____

____ (2)