MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

L-Università ta' Malta

ADVANCED MATRICULATION LEVEL
2024 FIRST SESSION

SUBJECT:	**Physics**
PAPER NUMBER:	I
DATE:	18th May 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. Describe the difference between base units and derived units and provide **ONE** example for **each** type of unit. (2)

b. i. The force per unit length between 2 parallel current-carrying straight conductors, each of length l, separated by a distance r, is given by:

$$\frac{F}{l} = \frac{\mu_0\, I_1\; I_2}{2\,\pi\, r}$$

where μ_0 is the magnetic permeability, I_1 is the current flowing through wire 1 and I_2 is the current flowing through wire 2. Derive the base units of magnetic permeability μ_0. (3)

ii. Explain what you understand by a homogeneous equation and indicate how an equation can be homogeneous but **not** physically correct, using the same equation. (2)

c. A wire is used to hang a picture frame such that the position of the nail is equidistant to the two upper corners of the picture frame. The total angle between the two halves of the wire is 2θ.

i. Explain how the tension in each half of the wire changes, if a shorter or a longer wire is used. (2)

ii. Suggest whether a shorter or a longer wire should be used to minimize the tension. (1)

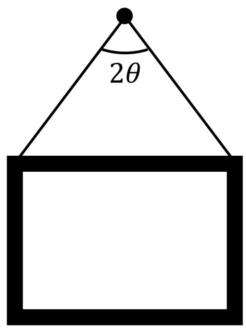

Figure 1

(Total: 10 marks)

2. a. Derive the equation for the acceleration, $a = \frac{u^2}{R}$, of a particle moving in a circular path of radius R with uniform speed u. The derivation should include a diagram. (5)

b. By referring to the equation $a = \frac{u^2}{R}$, explain why a person driving a car should slow down when approaching a curve. (2)

Please turn the page.

c. A small body of mass m is placed on a rotating platform at a distance *r* from its centre. The maximum frictional force between the body and the rotating platform, such that the body does not slip is $\frac{mg}{2}$. Find an expression for the maximum angular velocity of the body in terms of *g* and *r*. (2)

d. Calculate the maximum angular velocity, given that the distance *r* is 4 m. (1)

(Total: 10 marks)

3. a. A solid cylinder with a mass of 7 kg and radius 0.3 m rolls without slipping down a slope of length 5.0 m from a height of 0.05 m. The total time taken for the cylinder to roll down the total length of the slope is 15 s.

i. Calculate the final velocity of the cylinder. (2)
ii. Calculate the moment of inertia of the cylinder. (3)
iii. Find the acceleration of the rolling cylinder. (1)

b. A disk rotates about a thin vertical axle of negligible diameter at an angular speed of 10 rad s^{-1}, and a ring is gently dropped on the axle of the disk. The masses of the disk and ring are 25 kg and 10 kg respectively and the radii of the disk and ring 20 cm and 5 cm. Calculate the new angular speed of the system, stating the principle used. The moment of inertia of a disk is given by $I = \frac{1}{2}MR^2$ and the moment of inertia of a ring is given by $I = MR^2$. (4)

(Total: 10 marks)

4. Figure 2 shows a simple potentiometer circuit.

a. Explain why the potentiometer is usually referred to as an ideal voltmeter for measuring the electromotive force (emf) of a cell. (2)

b. With reference to the circuit diagram, if the emf of cell *X* is not known, explain how the circuit could be modified to improve the accuracy of the measurement of this emf. (2)

c. In Figure 2, AB is a uniform wire, 1.0 m long, having a resistance of 2.0 Ω. The driver cell has an emf of 4 V and can be assumed to have negligible internal resistance. *R* has a value of 2.4 Ω. The length of AC for zero galvanometer deflection is 82.5 cm. Calculate the emf of cell *X*. (3)

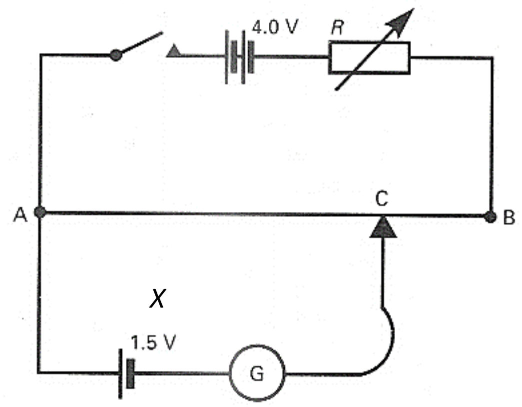

Figure 2

d. Now, the value of *R* is changed to 1.0 Ω, and cell *X* and the galvanometer are replaced by a voltmeter of resistance 20 Ω. Calculate the reading on the voltmeter, if the contact C is put at the centre of the wire AB. (3)

(Total: 10 marks)

5. a. Define resistance. (2)

b. Figure 3 (i) shows the variation of current with voltage for a thermistor.

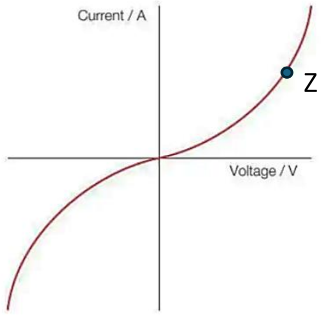

Figure 3 (i)

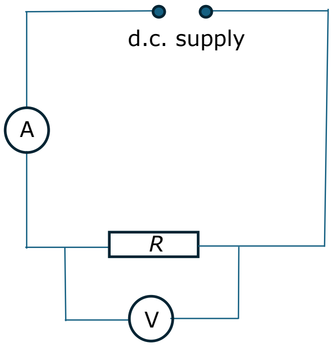

Figure 3 (ii)

Explain how the resistance of the thermistor at point Z can be found from the graph. Include a sketch to help your explanation. (2)

c. Describe a simple experiment to find a value for the internal resistance (r) of a cell, using the circuit suggested in Figure 3 (ii). Your description must include the readings that should be taken, the equation to be used and a sketch of the graph to be plotted. Also, state how r would be calculated. (4)

d. The circuit in Figure 3 (ii) is used by a student to find the value of a resistance R. The ammeter and voltmeter are not ideal and R has a similar value to the resistance of the voltmeter. Explain, providing reasons, whether this is the best circuit connection that the student could use under the circumstances. (2)

(Total: 10 marks)

6. A ball is thrown vertically upwards at 10 ms^{-1} and then caught at the same height from where it was released. The ball first decelerates until it reaches the maximum height and then accelerates downwards.

a. Sketch the displacement versus time graph for the ball. (2)

b. Sketch the corresponding velocity versus time graph for the ball, indicating the velocity at the maximum height reached by the ball. (2)

c. Sketch the acceleration versus time graph for this projectile motion. (2)

d. Calculate the total time of flight. (2)

e. Calculate the maximum height reached by the ball. (2)

(Total: 10 marks)

7. a. State Hooke's Law. (1)

b. A student is testing the extension resulting from loading wires made from different materials. He starts by loading a metal wire, adding loads until the wire is stretched beyond the yield point.

i. Sketch a graph of Force versus Extension for the wire. On your sketch, clearly indicate the proportionality limit, the elastic limit and the ranges on the graph which show elastic deformation and plastic deformation respectively. (2)

ii. Use the graph drawn in part (i) to diagrammatically show what happens to the extension of the wire, as the student unloads it, indicating whether the wire will suffer a permanent extension or not. (2)

Question continues on the next page.

iii. With reference to the sketch drawn in (i), explain how the student can calculate the work done on the wire to extend it to the proportionality limit. Quote the equation that the student will use in this calculation. (2)

iv. The student now works with a rubber strip and obtains a force versus extension graph as shown in Figure 4. Estimate the work done in stretching the strip to point Q. Explain how this estimate was worked out. (3)

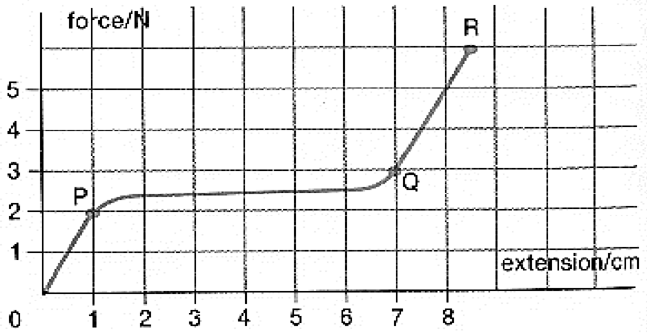

Figure 4

(Total: 10 marks)

8. Carbon-14 is a radioactive isotope used to determine the age of carbon-based materials up to 62,000 years old. The half-life of Carbon-14 is approximately 5730 years. The initial number of radioactive nuclei present in a sample is 25,000.

   a. Define half-life of a radioactive isotope and derive the relation between the decay constant, λ and half-life. (3)

   b. Determine the decay constant of Carbon-14. (1)

   c. Calculate the percentage of nuclei left after 17,190 years. (2)

   d. Calculate the number of half-lives required for the sample to have less than 500 nuclei. (2)

   e. List **THREE** causes for the uncertainty involved in the age of a sample obtained using carbon dating. (2)

(Total: 10 marks)

SECTION B

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

9. a. Explain the term moment of inertia of a rigid body. (2)

   b. An orbiting satellite is fitted with two sensors of mass 7 kg attached to the ends of the extendable and retractable telescopic booms of the satellite, as shown in Figure 5. The mass of the booms is negligible and the length of the booms when they are fully extended is 3.3 m from the axis of rotation. The moment of inertia of the satellite body, excluding the sensors, is 250 kg m^2.

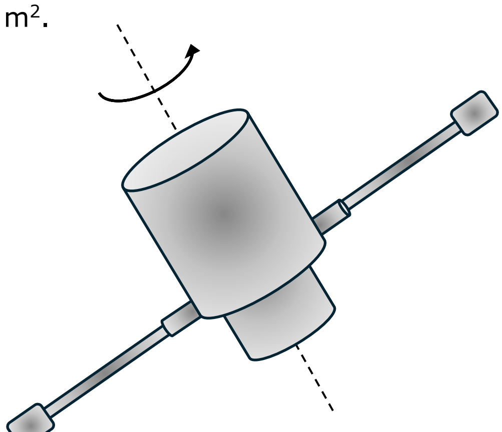
Figure 5

i. Calculate the moment of inertia of the combined system and state the assumption used to calculate the moment of inertia of the sensors. (3)

ii. Calculate the total angular momentum and kinetic energy of the system when the angular speed is 0.3 rad s^{-1}. (2,2)

iii. Explain what happens to the satellite's angular velocity when the satellite's telescopic booms are slowly retracted. (3)

c. A 0.5 kg point mass is moving horizontally at 15 m s^{-1} and collides with the lower end of a 1.7 m long stationary rod which is hanging vertically about a pivot at its upper end. The mass of the rod is 4.5 kg. After the collision, the motion of the point mass undergoes a change in speed and angle to the horizontal, and the rod swings freely, reaching a maximum angle of 90° to the vertical. The point mass does not stick to the rod. The kinetic energy of the system is conserved. The moment of inertia of the rod about the pivot is $I_{rod} = \frac{ml^2}{3}$. The collision preserves kinetic energy, but linear momentum of the rod mass system is not conserved.

i. Calculate the angular velocity of the rod after collision. (2)

ii. Calculate the speed of the point mass after collision using the principle of conservation of kinetic energy. (2)

iii. Calculate the angular momentum of the point mass about the pivot before collision. (1)

iv. Determine the angle to the horizontal made by the point mass after collision. (3)

(Total: 20 marks)

10. a. State the conditions for static equilibrium of a rigid body under the action of a set of coplanar forces. (2)

b. Figure 6 shows the open bonnet of a car. The bonnet is held open at an angle of 45° to the horizontal by a vertical force V applied at the upper end of the bonnet, as shown in the diagram. The bonnet is 0.90 m long and has a mass of 2.5 kg acting at the centre of gravity G, which is 0.35 m away from the hinge, H.

i. Copy the diagram and label **all** forces acting on the bonnet. (3)

ii. Calculate the value of the force V. (3)

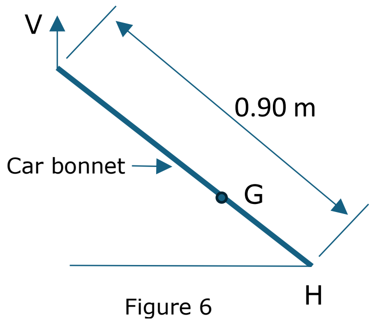

Figure 6

c. Pole vaulting, also known as pole jumping, is typically classified as one of the four major jumping events in athletics, alongside the high jump, long jump and triple jump. In pole vaulting, an athlete uses a long and flexible pole to help in jumping over a bar (see Figure 7).

Figure 7

Figure 8 shows a vaulting pole XZ being steadily held in equilibrium by an athlete. The pole makes an angle of 40° to the horizontal.

The athlete exerts forces D and U on the pole with their right and left hand, respectively. D is applied perpendicular to the pole at point X, while U is applied at point Y, making an angle θ with the vertical.
The uniform pole has a weight of 31 N.

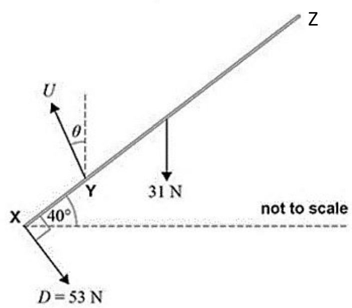

Figure 8

i. Calculate the values for θ and the force U exerted by the athlete's left hand on the pole at Y. (6)

Question continues on the next page.

ii. The athlete now moves the pole to a horizontal position and keeps it stationary in this position. The athlete's right hand is at X, where the athlete applies a force S vertically downwards (see Figure 9).

The athlete uses their left hand to apply a force V at Y.

Figure 9

Write an equation expressing V in terms of S, explaining your answer. (2)

d. Is the moment of the weight of the pole about the point X in this situation, the same, smaller or larger than in the previous situation shown in Figure 8 above? Explain your answer. (4)

(Total: 20 marks)

11\. a. State Newton's Laws of motion. (3)

b. Explain how the Newton is defined from these laws. (2)

c. Figure 10 shows a painter in a crate of weight 250 N which hangs alongside a building. When the painter who weighs 1000 N pulls on the rope, the force they exert on the floor of the crate is 450 N. The crate accelerates upwards, with a tension T being created in the rope.

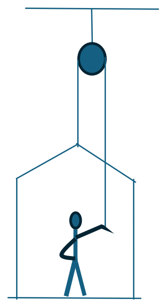

Figure 10

i. Use the given data to draw a free body diagram showing the forces acting on the painter. (2)

ii. Similarly, draw a free body diagram showing the forces acting on the crate. (2)

iii. Write down **TWO** equations relating T to the acceleration of the system. Use these equations to calculate the acceleration. (4)

d. Figure 11 shows the displacement-time graph for a high-speed lift over a 60-second period.

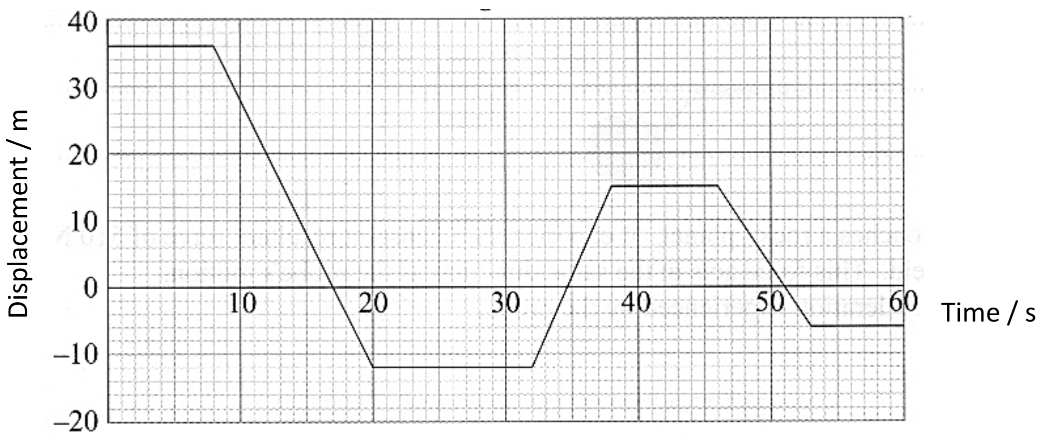

Figure 11

i. Calculate the average velocity of the lift over this period of time. (2)

ii. Calculate the average speed of the lift over this period. (2)

iii. With reference to Figure 11, sketch the corresponding velocity-time graph of the lift. Show the necessary calculations and indicate the relevant values of the velocities on your sketch. (3)

(Total: 20 marks)

12. a. A wheel nut falls straight down from a helicopter which is descending vertically at a constant speed of 4 m s^{-1}. The wheel nut strikes the ground 6 s later.

i. Assuming zero air resistance on the nut, calculate the distance dropped by the nut. (2)

ii. Sketch a displacement versus time graph for the wheel nut, indicating known values of the displacement and the time of flight. Explain the shape of the graph. (3)

b. An air rifle fires pellets with a mass of 0.6 g to a target which is 100 m away. The air rifle delivers an impulse of 0.15 Ns to a pellet. Assume that the air resistance is zero.

i. Define impulse. (1)

ii. Find the pellet's velocity immediately after it has been fired. (2)

iii. The target stands with its centre at 1.4 m above the ground. The target is circular and has a diameter of 1.2 m. Determine whether the pellet can hit the target, assuming the pellet is fired horizontally from a height 1.4 m above the ground. (5)

iv. Another pellet is fired from the same height as before, with the same initial speed. The pellet is now fired at an angle θ to the horizontal. The pellet hits the centre of the target. Show that:

$$\sin(\theta)\cos(\theta) = 0.0078$$ (7)

(Total: 20 marks)

13. a. An electronic tablet is dropped and the glass screen shatters upon impact whilst the aluminium enclosure remains undamaged. Explain why this happens with reference to the material properties. (4)

b. Railway tracks are made from steel due to its flexibility and ability to expand. Thus, rails expand during warm weather and are required to be laid and pre-strained. A steel rail with a cross-sectional area of 7.7×10^{-3} m^2 is laid at a temperature of 8 °C using a pre-strain of 3.0×10^{-4}. (Take the Young's modulus of steel to be 200 GPa.)

i. Calculate the stored elastic strain energy in a rail of length 72 m under these conditions. (6)

ii. Explain whether the highest observed temperature should be used to calculate the pre-strain required. (3)

c. i. A steel wire and a brass wire of equal length and cross-sectional area are clamped together to a horizontal plane (Figure 12). A load M of 15 N is attached to the clamped wires. Derive the relation $\frac{E_b}{E_s} = \frac{F_b}{F_s}$ between Young's moduli and the forces of the steel and brass wires and state the assumption used. (3)

ii. Find the total energy stored in the brass wire, given that the cross-sectional area is 1.35×10^{-6} m^2 and the original length of the wire is 1.3 m. (Take the Young's modulus of brass to be 100 GPa and the Young's modulus of steel to be 200 GPa.) (4)

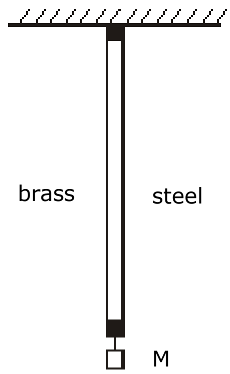

Figure 12

(Total: 20 marks)

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14. a. Identify which graph from the ones shown below in Figure 13 shows how the power dissipated from a fixed resistor changes with current. (1)
Give a reason for your choice. (2)

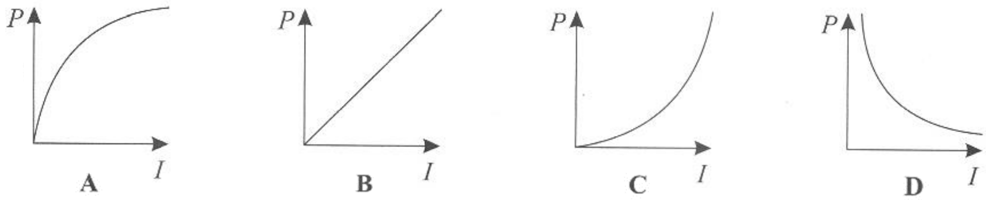

Figure 13

b. i. Figure 14 shows the use of a thermistor in a temperature-sensing circuit. The cell has negligible internal resistance and supplies energy to the circuit at 2.4 J s^{-1}. Calculate the p.d. across the variable resistor when this has a resistance of 9 Ω and when the resistance of the thermistor is 6 Ω. (6)

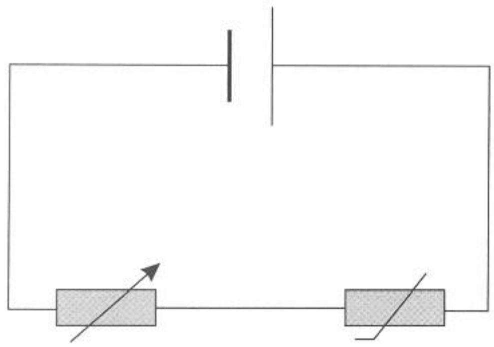

Figure 14

ii. A filament lamp is now added to the circuit to create a temperature-sensing circuit for a freezer. When the temperature falls below a certain level, the filament lamp in the circuit lights up.

- Copy the circuit diagram and on it include the position of the filament lamp. (1)
- Explain how the circuit will operate for the lamp to light up. (2)
- If another cell, with negligible internal resistance, were to be added in series with the first cell, will there be any effect on the p. d. across the thermistor that will change the behaviour of the lamp as the temperature varies? Explain your answer. (6)
- State and explain how the brightness of the filament lamp would be different if the cells had an internal resistance that was **not** negligible. (2)

(Total: 20 marks)

15. a. i. Define the term mass defect. (2)
ii. Calculate the binding energy for $^{56}_{26}Fe$ atom in MeV. The rest masses of $^{56}_{26}Fe$, a proton and a neutron are 55.9349 u, 1.0073 u and 1.0087 u respectively. (4)

b. The photoelectric effect consists of the emission of free electrons from metal surfaces when exposed to electromagnetic waves.
i. Define the threshold frequency. (2)
ii. The work function for tungsten metal is 4.52 eV. Determine the cutoff wavelength λ_c for tungsten. (3)
iii. Determine the maximum kinetic energy of the electrons when radiation of wavelength 198 nm is used. (3)
iv. Calculate the stopping voltage. (2)

c. i. Explain the terms nuclear fusion and nuclear fission, giving **ONE** example of where each may occur. (2)
ii. Discuss how the nuclear binding energy curve explains why fission and fusion occur.(2)

(Total: 20 marks)

MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

ADVANCED MATRICULATION LEVEL
2024 FIRST SESSION

SUBJECT:	**Physics**
PAPER NUMBER:	II
DATE:	18th May 2024
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. Three satellites, A, B and C, are orbiting a planet of radius 5000 km as shown in Figure 1. Satellites A and B are found at the same orbital radius whereas satellite C is found at a higher altitude orbit. The gravitational field strength at the surface of the planet is 6 N kg^{-1}.

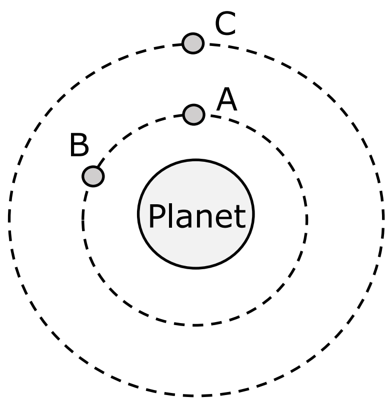

Figure 1

   a. Copy Figure 1 and sketch the gravitational field lines due to the planet. (2)

   b. Sketch a graph of the gravitational field strength, g, of the planet against the radial distance away, r, from the planet. On your graph, clearly mark any notable values on the two axes. (3)

   c. Satellite A is twice as heavy as satellite B. Compare, giving reasons, the orbital period of each satellite. (3)

   d. Are satellites A and C in the same equipotential surface? Give **ONE** reason for your answer. (2)

(Total: 10 marks)

2. The circuit shown in Figure **2** is governed by the equation

$$\varepsilon - L\frac{\mathrm{d}I}{\mathrm{d}t} = IR$$

where I represents the current flowing through the circuit.

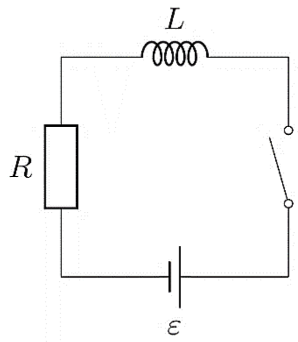

Figure 2

   a. State the significance of the term $-L\frac{\mathrm{d}I}{\mathrm{d}t}$, and the corresponding laws of physics associated with this term. (2)

   b. The switch is now closed. Explain how the current across the circuit changes with time:
      i. at $t = 0$; (2)
      ii. as time increases. (2)

   c. Write down an expression for the current achieved across the circuit after a very long time has passed, giving a reason for this answer. (2)

   d. Sketch a current-time graph representing the change of current across the circuit. On your graph, clearly indicate any notable values. (2)

(Total: 10 marks)

Please turn the page.

3. An alternating current supply with a frequency of $f_1 = 50$ Hz is connected across a pure inductor with inductance 1.6 H in series with an ammeter. The peak voltage across the inductor is 325 V.

   a. Explain the meaning of the term root mean square voltage, and compute the root mean square voltage across the inductor. (3)

   b. Calculate the value of resistance required to obtain the same opposition to the alternating current as that obtained with the inductor, if the inductor were to be replaced by a resistor. (3)

   c. Calculate the root mean square current in the circuit. (2)

   d. If the frequency is increased to $f_2 = 100$ Hz, state how the opposition to the alternating current changes for the inductor, using the relevant laws of physics to explain the change. (2)

(Total: 10 marks)

4. Several galaxies have been used by astronomers to determine their recession velocity, v, and their distance, d, as measured from Earth. A set of data points are compiled in Figure **3**.

   a. Briefly explain the cause as to why galaxies appear to be receding away. In your explanation, include a suitable analogy. (2)

   b. Use the given graph to determine an estimate of the Hubble constant. (3)

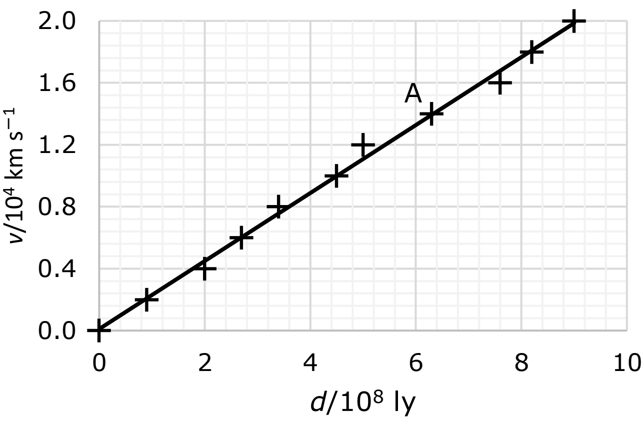

Figure 3

   c. Electromagnetic waves originating from Galaxy A led to an observed absorption line of wavelength 490 nm. Calculate the wavelength of the original wave signal. (3)

   d. Another observation from Galaxy B revealed that the absorption line was blueshifted. Explain what is meant by blueshift and determine whether the galaxy is approaching towards or receding away from Earth. (2)

(Total: 10 marks)

5. The Lenoir cycle is an idealised thermodynamic cycle used to model jet engines. Its pV-diagram is depicted in Figure **4**. The cycle undergoes the following three steps:
   i. isochoric heat addition
   ii. adiabatic expansion
   iii. isobaric heat rejection

   a. Define all quantities appearing in the first law of thermodynamics. (1)

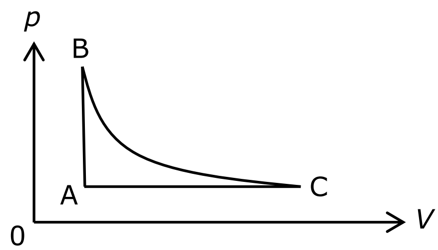

Figure 4

   b. Explain the terms describing steps i, ii and iii, using equations where relevant, and hence identify which path in the pV-diagram corresponds to each step. (6)

   c. Indicate for each step in the Lenoir cycle if the change in work done and heat transfer is smaller than zero, larger than zero, or equal to zero. (3)

(Total: 10 marks)

6. A well-insulated metal structure is composed of two cylindrical rods each of diameter 1 cm, joined end-to-end. The first rod is made of aluminium with a length of $l_1 = 12$ cm and a thermal conductivity of $k_1 = 239$ W m^{-1} K^{-1} while the second rod is of length $l_2 = 18$ cm and unknown material. The aluminium rod is heated at its outer end to a temperature of $\theta_S = 573$ K and the outer end of the second rod is cooled by ice to a temperature of $\theta_E = 273$ K.

   a. Given that the structure has established steady state conditions, state the equation that governs heat transfer in the first rod. (1)

   b. Calculate the temperature at the interface θ_I for a rate of heat transfer of 25 W. (3)

   c. Compute the thermal conductivity of the second rod. (3)

   d. Sketch an annotated graph of temperature against length for the entire structure under steady state conditions. (3)

(Total: 10 marks)

7. Tourists visit the coastal city of Aqaba in Jordan to view the coral during a boat trip. Passengers stay seated while viewing the underwater life through a glass bottomed boat. A passenger views a fish positioned at point A as shown in Figure 5 (not to scale).

   a. Calculate the angle of the emergent light ray which enters the passenger's eye as measured from the normal of the air-glass boundary which allows them to view the fish. (4)

   b. Copy Figure 5 and complete the ray path starting from point A. (2)

   c. The light ray from a coral positioned at point B enters the glass at an incident angle of 60°. Determine whether the passenger can view the coral from their current position. Give reasons for your answer. (3)

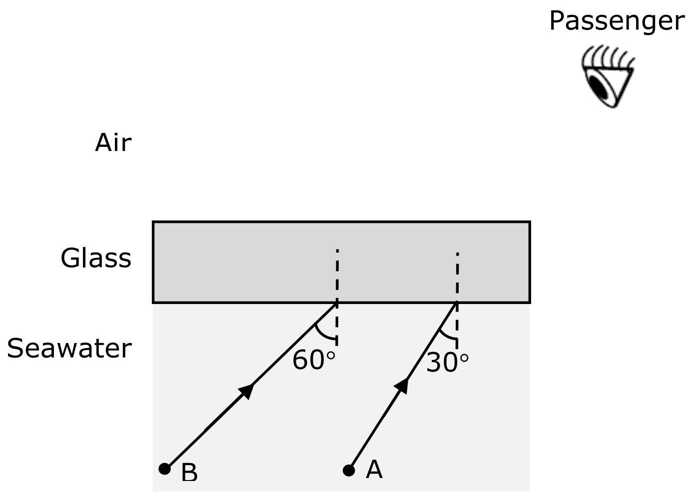

Figure 5

   d. The glass is replaced with a denser optical material. Explain whether this influences the apparent position of the fish as viewed by the passenger. (1)

   [Refractive indices: Glass η = 1.52, Seawater η = 1.34; Critical angle of glass = 41.14°]

(Total: 10 marks)

8. A guitarist produces a sound wave of frequency 330 Hz in the air by plucking a guitar string causing a mechanical wave in the string.

   a. Explain what is meant by a mechanical wave in the guitar string. (2)

   b. Describe what longitudinal and transverse waves are. (1)

   c. State the type of wave set up in the guitar string. (1)

   d. The produced sound wave is the first harmonic of the string of length 0.65 m. Given the string has a mass density of 0.31 g m^{-1}, calculate the tension force required to produce such a wave. Determine the speed of the transverse wave on the string. The speed of sound in air is 330 m s^{-1}. (4)

   e. Determine the wavelength of the sound wave emanating perpendicularly from the guitar. (2)

(Total: 10 marks)

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

9. A student is conducting an experiment to determine the specific heat capacity of water by heating a fixed mass of water in a well-lagged container. Instead of using a mercury-in-glass thermometer, the student uses a thermocouple, an instrument which uses resistance as a thermometric property. Before conducting the experiment, the student first needs to calibrate the thermocouple.

   a. Describe the difference between heat and temperature. (2)

   b. The water is heated to some fixed temperature. After reaching this temperature, the student inserts the thermocouple into the water and observes that after a short period of time, the thermocouple's resistance reading stopped changing. Explain how this is achieved. In your explanation, make use of the terms heat and temperature. (3)

   c. To calibrate the thermocouple, the student obtained the following data. At the ice point, the resistance of the thermocouple is 100 Ω and at the steam point, the resistance is 138.5 Ω. Use this information to determine the expected temperature when the thermocouple achieves a resistance of 120 Ω, stating the assumption made. (3)

   d. Suggest another temperature fixed point that could be used for calibration. (1)

   e. After calibrating the thermocouple, the student conducted the experiment and found that the time taken to increase the temperature of 200 g of water from 24 °C to 52 °C using a 100 W heater was 4 min. Assuming no losses, and neglecting the heat capacity of the container, calculate the specific heat capacity of water. (4)

   Later, the student investigates the thermal properties of an ice-water mixture placed in a glass beaker in a room at 300 K. The ice-water mixture has a combined mass of 400 g. Figure 6 illustrates the change in temperature against time.

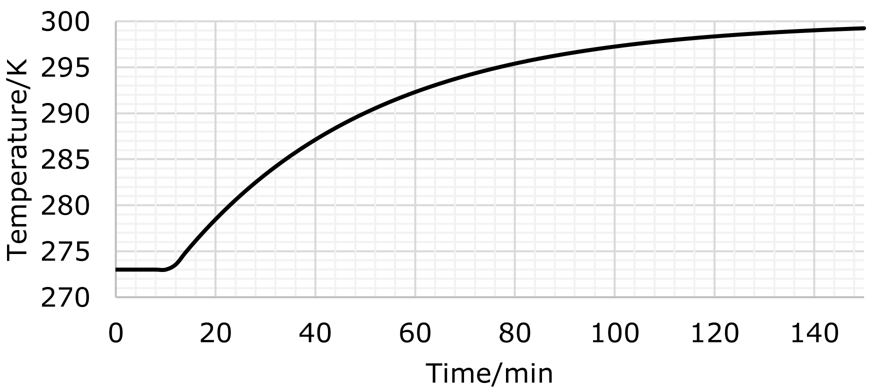

Figure 6

   f. Explain why the temperature of the ice-water mixture remains unchanged for the first 11 minutes. (2)

   g. Given that the beaker receives an amount of 75 J of heat energy per second from the surroundings, estimate the initial amount of ice in the mixture. (3)

   h. Explain why the temperature takes a long period of time to approach a constant value of 300 K. (2)

[Latent heat of melting ice = 3.34×10^5 J kg^{-1}]
(Total: 20 marks)

10. An experiment was conducted to investigate the properties of visible light using slits. Initially, a monochromatic red light source of wavelength 650 nm is focused through a thin rectangular slit aperture of 0.1 mm. An intensity pattern is obtained on a screen as shown in Figure 7, where the distance represents the position of the pattern on the screen.

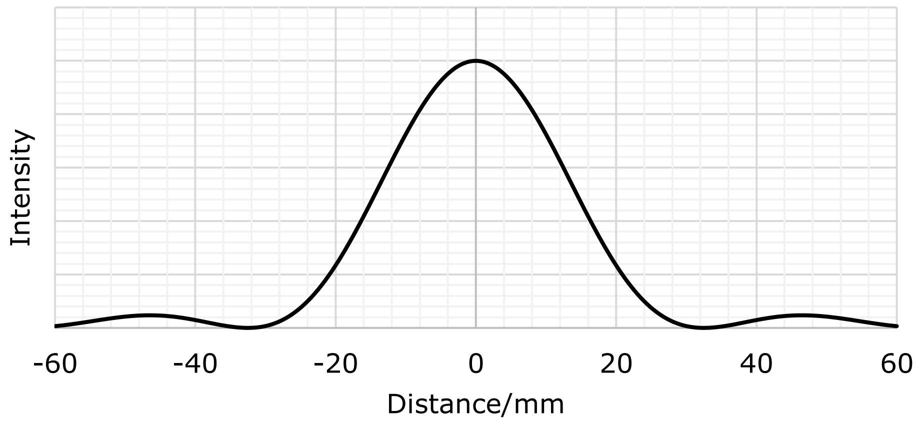

Figure 7

a. Explain the meaning of the term monochromatic light. (1)

b. Calculate the angular distance between the normal and the first minimum. (2)

c. Determine the distance between the single-slit and the screen. (4)

d. Describe, giving reasons, how the intensity pattern changes if:
   i. the aperture of the slit is halved; (2)
   ii. a blue monochromatic light source is used. (2)

e. If a circular aperture having a diameter 0.1 mm were to be used instead of the rectangular slit, explain, giving reasons, whether the position of the first diffraction minimum changes. (3)

The rectangular slit was later replaced by a double slit, each slit having an aperture of 0.1 mm. The distance between their centres is 40 mm.

f. Describe in detail the formation of the interference pattern due to a double slit. Your description must include the terms: phase, constructive and destructive interference. (4)

g. Describe, giving reasons, how the interference pattern changes if the separation between the double-slit increases. (2)

(Total: 20 marks)

11. Hot air balloons are methods of transportation which use the thermodynamical properties of gases. To operate, air is heated to produce the necessary force to lift the cargo off the ground, as illustrated in Figure 8. A typical balloon, once fully expanded, encloses 2000 m^3 of air.

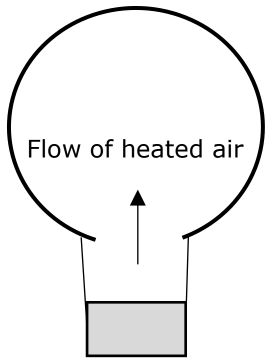

Figure 8

a. Use Archimedes' principle to show that the balloon remains afloat at a fixed altitude provided that,

$$\rho_o V g = mg + \rho_i V g,$$

where *m* is the mass of the cargo to be lifted, *V* is the volume of the hot air balloon, ρ_o is the density of external air, and ρ_i is the density of the internal heated air. (3)

It can be shown that the internal gas temperature, T_i, required to lift the cargo obeys the relationship,

$$T_i = \frac{P_i}{P_o}\frac{T_o}{\left(1 - \frac{mRT_o}{P_0 MV}\right)},$$

where P_o is the external pressure, P_i is the internal gas pressure, R is the molar gas constant, M is the molar mass of air, and T_o is the external temperature of the air at ground level.

b. State the relationship between the internal and external gas pressures. Give a reason for your answer. (2)

c. Calculate the internal temperature required to lift a 500 kg cargo when the air temperature is 300 K. (2)

d. State how the pilot should adjust the internal temperature to slowly descend. Support your reasoning by commenting on the changes of the internal gas density. (3)

The above calculations assume that air behaves as an ideal gas, which can be modelled according to the kinetic theory of gases.

e. State **THREE** assumptions considered in the kinetic theory of gases. (3)

f. It can be shown that the pressure of an ideal gas satisfies the equation $P = \frac{1}{3}\rho\langle c^2\rangle$ where ρ is the density of the gas.

   i. State the meaning of the term $\langle c^2\rangle$. (1)

   ii. Derive the relation $\langle c^2\rangle = \frac{3RT}{M}$. (3)

g. On the same axes, sketch a graph clearly illustrating the frequency distribution of the molecular speeds of a gas at a low temperature, T_1, and a high temperature, T_2 (that is $T_1 < T_2$). (3)

[Atmospheric Pressure = 101 kPa, Molar Mass of Air = 29 g mol^{-1},
Molar Gas Constant = 8.31 J K^{-1} mol^{-1}]

(Total: 20 marks)

12. The *electric eel* has electric organs which extend nearly throughout its whole-body length. These eels, depicted in Figure 9, use the organs to accumulate negative electric charge at the end of its tail and positive electric charge of equal magnitude in its head. They can rapidly discharge the electric charge accumulated. While discharging, the electric organs can be modelled as a parallel plate capacitor with one plate containing positive charge located in the head and the other plate with negative charge located in the tail. These eels can accumulate a charge of 1.50 mC and create a potential difference of 550 V.

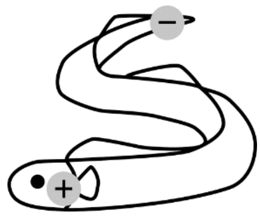

Figure 9

a. Compute the capacitance and the electric energy that is contained within the eel's electric organs. (5)

b. Experiments with electric currents are considered hazardous for humans when the involved voltage exceeds 60 V and the electric energy exceeds 350 mJ. Determine whether electric eels pose a threat to human swimmers. (2)

c. When hunting alone, an electric eel tries to bend and trap its prey between its head and tail as depicted in Figure 10. This minimises the distance of the capacitor's plates while keeping the same charge in the electric organs. Explain with formulae how the capacitance and the electric field are affected with this hunting strategy. (3)

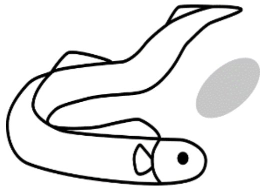

Figure 10

d. Electric eels feed on freshwater shrimps which can be modelled as 100 Ω resistors. When an eel catches one shrimp, the shrimp effectively short circuits the capacitor.
   i. Determine the time constant for this discharging process. (3)
   ii. Sketch an annotated graph of the voltage across the capacitor against time for a duration of three time constants of the process. (3)

e. When hunting in pairs, electric eels swim parallel to each other. They encircle their prey to trap it. Decide which of the trapping formations in Figure 11 is more hazardous for the prey, giving a physical explanation. (4)

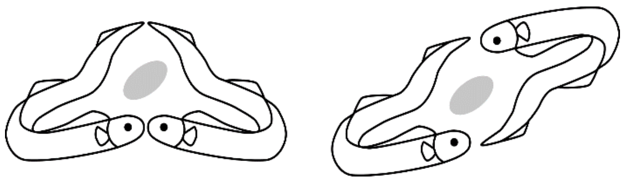

Figure 11

(Total: 20 marks)

13. A Hall probe is used to investigate the magnetic flux density produced by a long wire carrying a current I. The Hall probe is connected to a voltmeter and placed a distance x away from the wire facing out of the paper as shown in Figure 12.

a. Copy Figure 12 and draw the magnetic field lines around the wire. (2)

b. Explain, giving reasons, what happens to the reading on the voltmeter when the Hall probe is:
   i. moved further away from the wire; (2)
   ii. rotated to face upwards. (2)

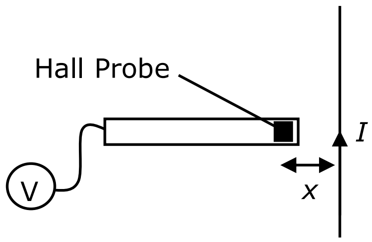

Figure 12

c. The Hall probe's thin plate is replaced by another plate having double the thickness. Describe the changes, if any, to the reading on the voltmeter when the Hall probe is placed at the distance x. (2)

d. Explain why it is recommended to use a semiconductor, not a metal, as a Hall probe. (3)

A second long wire is now placed straight, parallel and 1 m away from the wire carrying a current I, as shown in Figure 13. The point A is at the midpoint between the two wires.

e. State the direction and magnitude of the current in the second wire such that the magnetic field strength is zero at:
   i. point A; (2)
   ii. point B. (3)

f. Explain, with reasons, whether the wires attract or repel each other when the second wire carries a current of $2I$ flowing downwards. In addition, state the rules used. (4)

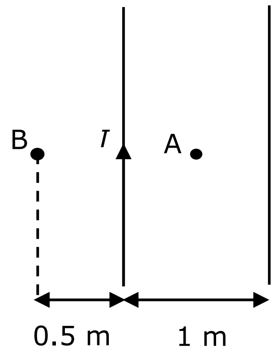

Figure 13

(Total: 20 marks)

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14. A student aims to inspect the effects of opposite electric charges on two metallic spheres embedded in glycerol. The centres of the spheres are 20 cm apart and each carries an electric charge $|Q| = 1.7$ mC. The resulting electrostatic field can be modelled as two opposite point charges of equal magnitude at the appropriate points.

    a. Draw a sketch of the electric potential ϕ and electric field $\boldsymbol{E}$ surrounding the setup. In your sketch:

       i. indicate the point charges, the equipotential line corresponding to $\phi_0 = 0$ V, another equipotential line with $\phi_+ > 0$ V, and the equipotential line with $\phi_- = -\phi_+$; (4)

       ii. draw **TWO** distinct lines of force for a positive charge on this sketch and justify their direction. (2)

    b. State Coulomb's law of electrostatics mathematically and explain the physical significance of each quantity. (4)

    c. Assuming a relative permittivity of $\epsilon_r = 40$ of the glycerol, compute the force that the two charges exert on each other. (3)

    A test charge q is placed centrally between the two poles.

    d. Compute the electric field strength that the two poles create for the test charge. (4)

    e. How much work must be done to move the test charge 10 cm perpendicular to the axes between the two poles? (3)

(Total: 20 marks)

15. A mass of 250 g is attached to a spring with spring constant 0.40 N m^{-1} is placed horizontally on a table. The spring exerts a restoring force $F_S = -kx$ on the mass. A student decides to stretch the spring such that the mass is brought out of its equilibrium position to $x_0 = 40$ cm and lets the mass go at $t = 0$.

    a. Define simple harmonic motion. (1)

    b. Show that the mass-spring system performs simple harmonic motion. Hence calculate the system's periodic time. (5)

    c. Sketch the mass's displacement as a function of time starting from $t = 0$ for **TWO** time periods. (3)

    Meanwhile, the student's friend plays with a toy that undergoes simple harmonic motion which is <u>exactly out of phase</u> with the mass on the spring. The toy (like a yoyo) oscillates in a vertical motion.

    d. Explain briefly in words the underlined phrase. (2)

    e. Sketch the toy's displacement as a function of time starting from $t = 0$ for **TWO** periodic times if the toy's maximal displacement is 30 cm. (3)

    f. The student decides to take the spring mass system out of the setup and wants to use it as a toy. Describe the motion of the spring mass system when the student shakes their hand up and down at a given frequency. (3)

    g. The student starts shaking the system with a periodic time that is much shorter than the system's natural periodic time. The student gradually increases the period of his shaking and after a while, matches the system's periodic time without changing anything else. Explain how the amplitude of the mass spring system changes from the beginning to the end of this process and state the name of the observed phenomenon. (3)

(Total: 20 marks)

L-Università ta' Malta

MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

ADVANCED MATRICULATION LEVEL
2024 FIRST SESSION

SUBJECT:	**Physics**
PAPER NUMBER:	III - Practical
DATE:	4th June 2024
TIME:	2 hours 5 minutes

Experiment: Investigating the physical properties of springs.

Apparatus: Stand and clamp, two (2) steel springs joined in series, one steel spring connected to a threaded stud with nuts on both ends, weights, mass hanger, stopwatch and 30 cm ruler.

Diagram:

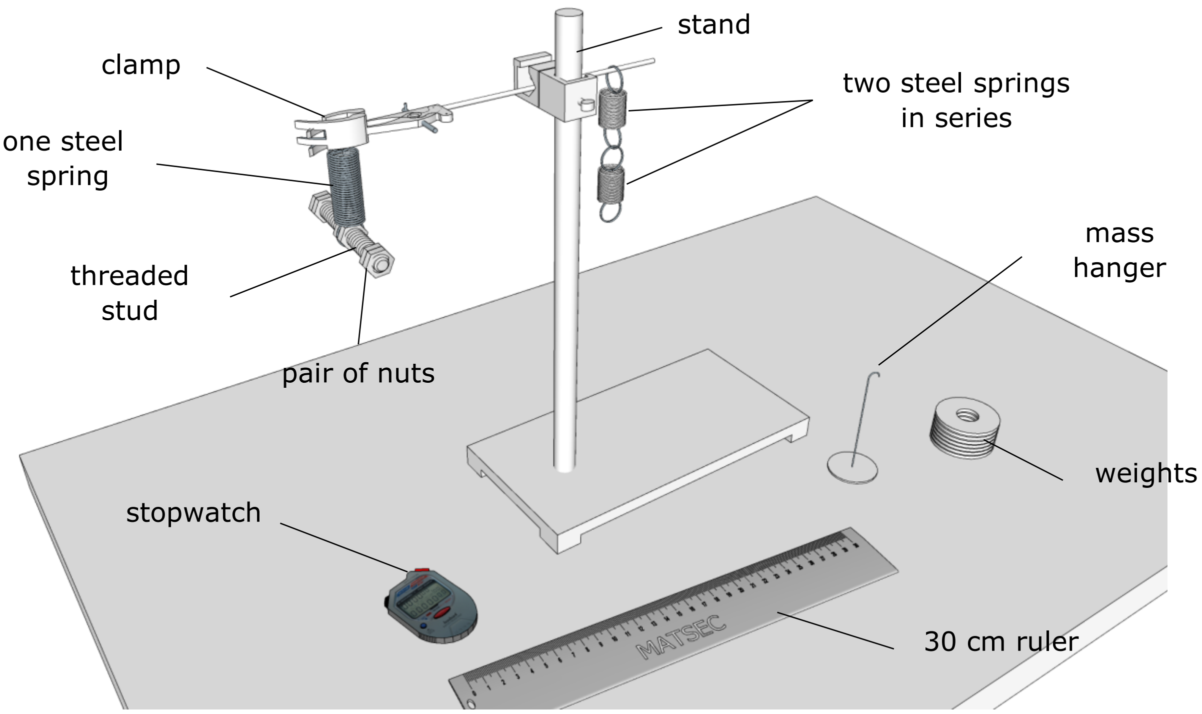

Figure 1: The experimental setup

Method – Part A:

1. The apparatus shown in Figure 1 has been set up. In the first part of the experiment, the two connected steel springs will be used.

2. Simple harmonic oscillations of the two-spring system will be used to determine the spring constant of each spring and the torsional spring constant of the wire making up the spring.

3. Add two weights to the hanger and attach the hanger to the bottom spring such that the two-spring system can perform free vertical oscillations.

Please turn the page.

4. The springs, that are connected in series, are identical. Each of the weights has a mass of $0.0252\,\mathrm{kg}$ and the hanger has a mass of $0.0107\,\mathrm{kg}$. Calculate the value of the force acting down on each of the springs when loaded with two weights and the hanger.

____

____

____ (1)

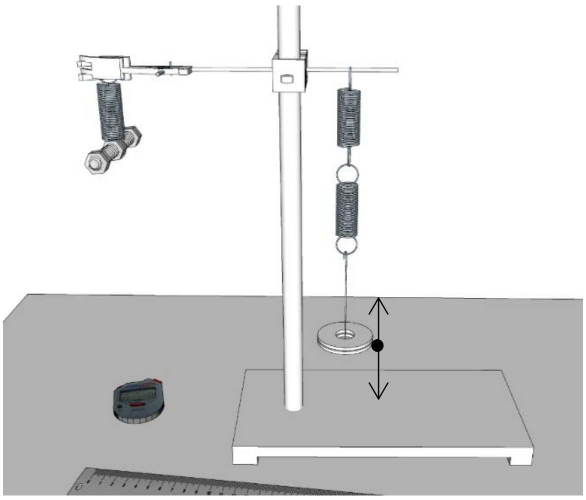
Figure 2

5. Each of the springs has a spring constant k. The two-spring system has a spring constant k_{eq}. Show that $k_{eq} = \frac{k}{2}$.

____

____

____

____ (3)

6. Gently displace the weights downwards and release so that the mass-spring system starts to perform small vertical oscillations, as shown in Figure 2. Record the time it takes the mass-spring system to complete 20 oscillations. Insert the readings in the column for the "1st reading" in Table 1. (1)

7. Repeat another two times to have three repeated readings and record these repeated readings for twenty oscillations in the columns for the 2nd and 3rd reading. (2)

8. Add weights to the hanger until the maximum number of weights indicated in first column of Table 1 is reached (n indicates the number of weights added to the hanger). Each time, repeat steps 6 and 7. Record your results in Table 1. (12)

Table 1

	Mass	Mass of hanger	Total Mass	1st Reading	2nd Reading	3rd Reading			
n	m/kg	m_H/kg	m_T/kg	T_{20}/s	T_{20}/s	T_{20}/s	$\overline{T_{20}}/\mathrm{s}$	$T\ /\mathrm{s}$	$T^2\ /\mathrm{s}^2$
2									
3									
4									
5									
6									

9. Using also the data provided in step 4, complete Table 1 by working out the mass of the weights m, the total mass m_T, the average value for twenty oscillations $\overline{T_{20}}$, the periodic time T and T^2. (5)

10. It is known that the periodic time of the mass-spring system as set up in this experiment is given by $T = 2\pi\sqrt{\frac{m_T}{k_{eq}}}$.

11. Express the relation between T, m_T and k_{eq} given in step 10 in the form $y = mx + c$.

____ (1)

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

13. Use the graph to determine the value of the equivalent spring constant k_{eq}.

____

____

____

____ (3)

14. Use the information in step 5 to calculate the value of the spring constant k.

____ (1)

15. It is also known that the torsional constant of the steel wire that makes up the spring κ_{wire} , is related to the spring constant k by the expression $\kappa_{wire} = kR^2$ where R is the radius of the coils forming the spring. Make any additional necessary measurements and calculate the torsional constant of the wire κ_{wire} .

____

____

____

____ (2)

16. Unload any weights that may still be hanging from the two springs before proceeding to the next part of the experiment.

Please turn the page.

Method – Part B:

17. In this part of the experiment, a threaded stud with a variable moment of inertia attached to the free end of a spring will be used to determine the torsional spring constant κ_{spring} of the spring.

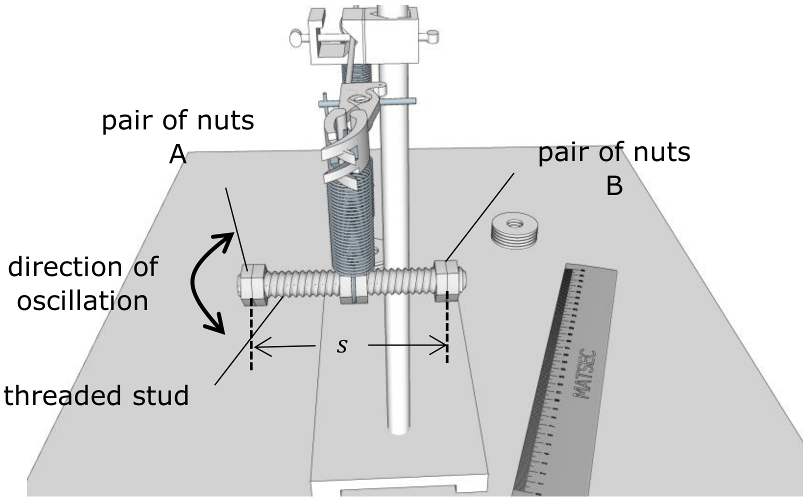

Figure 3

18. The pairs of nuts labelled A and B, located on either side of the two central nuts, will each act as a 'single' mass. The distance, s, between the masses A and B will be measured as shown in Figure 3. When adjusting the nuts along the stud, ensure that the pairs of nuts A and B remain equidistant from the centre.

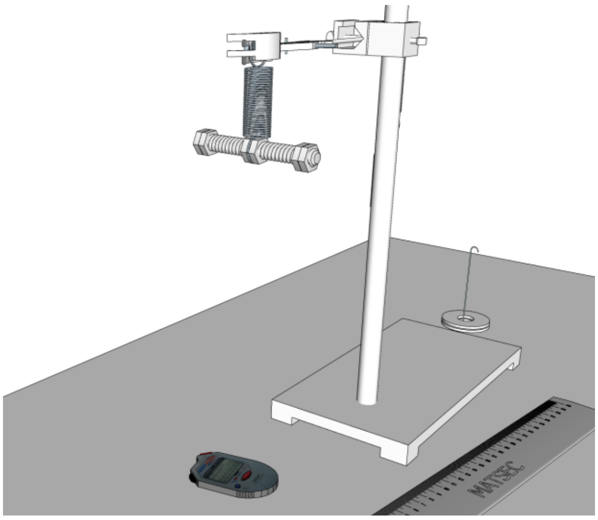

Figure 4 (a)

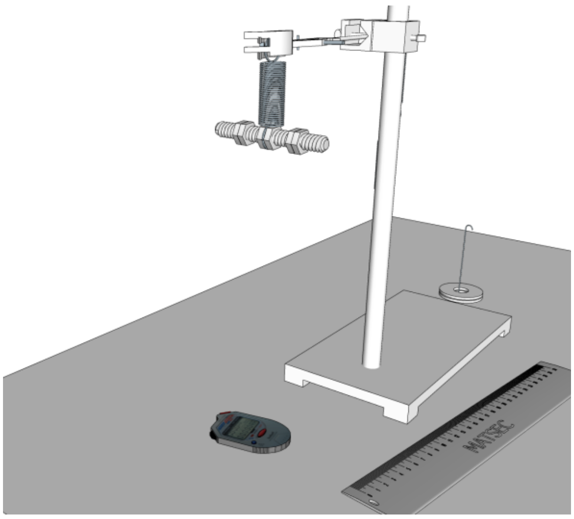

Figure 4 (b)

19. Which of the diagrams, Figure 4 (a) or (b), shows the setup with the larger moment of inertia of the stud? Explain your choice.

____

____ (1)

Please turn the page.

20. The rotational oscillations will take place in a horizontal plane, as shown in Figure 4. It is best to set the stud oscillating by pushing gently on one end and releasing it.

21. Set the distance s between A and B to be 0.085 m (8.5 cm).

22. Set the stud oscillating and measure the time it takes to perform 20 oscillations. Record this in the column marked "1st reading" of Table 2. (1)

23. Repeat another two times to have three repeated readings and record these repeated readings for twenty oscillations in the columns for the 2nd and 3rd reading. (2)

24. Set the distance between the pairs of nuts A and B to the remaining values of s shown in Table 2. For each value of s, repeat steps 22 and 23. (12)

Table 2

			1st Reading	2nd Reading	3rd Reading			
s /m	$d = \frac{s}{2}$ /m	d^2 /m^2	T_{20}/s	T_{20}/s	T_{20}/s	$\overline{T_{20}}$/s	T/s	T^2/s
0.085								
0.075								
0.065								
0.055								
0.045								

25. Complete Table 2 by working out the average value for twenty oscillations $\overline{T_{20}}$, the periodic time T, T^2, d and d^2. (5)

26. The relationship between the periodic time of the torsional oscillations of the spring and the distance d is given by

$$T^2 = \frac{16\pi^2 m d^2}{\kappa_{spring}} + \frac{4\pi^2 I_0}{\kappa_{spring}}$$

where m is the mass of a single nut and I_0 is a constant.

27. Plot a graph of T^2 on the y-axis against d^2 on the x-axis. (8)

28. What does the constant I_0 represent in the expression of step 26?

____ (1)

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29. Use the graph and the value of $m = 0.00477\,\mathrm{kg}$ to determine the torsional spring constant κ_{spring} and state its unit.

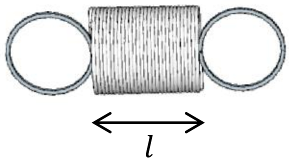
____

____

_______________ (3)

30. The torsional spring constant κ_{spring} can also be determined from the physical dimensions of the spring. In fact, $\kappa_{spring} = \frac{Yt^4}{64DN}$, where Y is the Young modulus of the material of the wire making up the spring, t is the diameter in metres of the wire making up the spring, D is the diameter in metres of the coils forming the spring and N is the number of effective coils.

31. Measure the length l of the coils making up a spring in its original form and determine the diameter t by the equation $t = l/N$.



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_______________ (3)

32. Given that $Y = 99.5 \times 10^9\,\mathrm{Pa}$, use the expression in step 30 and the value of t obtained in step 31 to determine another value of the torsional spring constant κ_{spring} and compare it with the one obtained in step 29.

____

_______________ (2)

33. State and explain whether there is any relationship between the torsional constant of the wire κ_{wire} making up the steel spring and the torsional spring constant κ_{spring} of the spring itself.

____

_______________ (2)

34. Which of the physical quantities, in the expression for κ_{spring} given in step 30, would significantly affect the value of κ_{spring} even if its value changes slightly? Explain briefly.

____

_______________ (1)