L-Università ta' Malta

MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

**ADVANCED MATRICULATION LEVEL**
**2022 FIRST SESSION**

| | |
|---|---|
| SUBJECT: | **Physics** |
| PAPER NUMBER: | I |
| DATE: | 28th May 2022 |
| 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 $\mathbf{g = 9.81\ m\ s^{-2}}$ 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 resistive force acting on an object falling freely in a fluid is called drag. This resistive force, $F_D$ can be expressed by the equation:

$$F_D = \frac{1}{2}\rho C A v^2$$

where $\rho$ is the density of the fluid, $A$ is the area of the moving object in contact with the fluid, $C$ is the coefficient of drag and $v$ is the velocity.

a. Show that the coefficient of drag has no units. (3)

b. Explain what is meant by terminal velocity. (2)

c. The object has a volume $V$. Write down an expression for the buoyancy force $F_B$. (2)

d. Hence, show that the terminal velocity of an object falling through the fluid is given by $v = \sqrt{\frac{2g(m-\rho V)}{\rho C A}}$, where $m$ is the mass of the object. (3)

**(Total: 10 marks)**

2. A basketball player has a free shot towards the net as shown in Figure 1. The net is $8.5\ \mathrm{m}$ away. The $1.85\ \mathrm{m}$ tall basketball player, projects the ball at an angle of $35.0°$. The net and basket are at a height of $2.95\ \mathrm{m}$ above the ground.

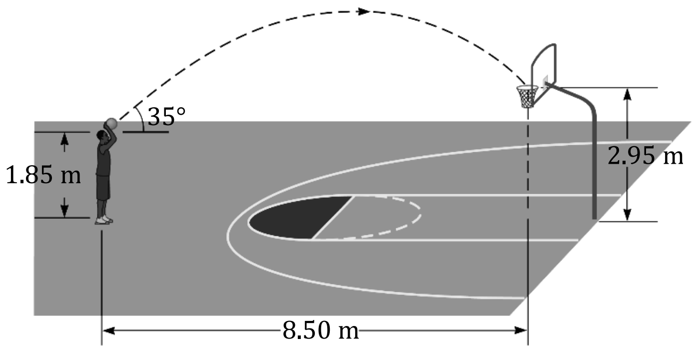


Figure 1

a. Sketch a velocity-time graph that shows how the vertical component $v_y$ of the initial velocity changes with time $t$ from the moment the ball is released till it reaches the basket. (3)

b. Show that the time it takes the ball to reach the basket is given by $t = \frac{8.5}{v \cos 35}$, where $v$ is the initial velocity with which the ball is thrown. (2)

c. Calculate the magnitude of the initial velocity $v$. (5)

**(Total: 10 marks)**

3. A man stands on a wooden uniform plank that serves as a bridge between a pier and a boat. The plank of mass $35.0$ kg is held in place by three ropes as shown in Figure 2. The man has a weight of $750$ N. All other lengths and distances are shown on the diagram.

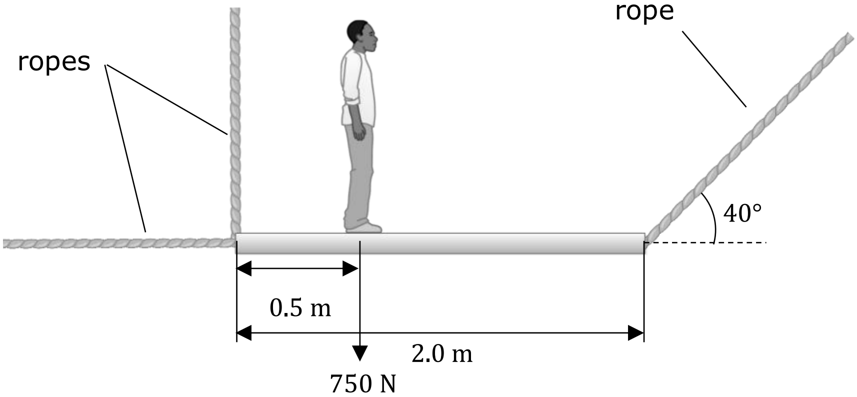


Figure 2

a. Draw a free-body diagram showing **all** the forces acting. (4)

b. State the conditions under which the system remains in mechanical equilibrium. (2)

c. Calculate the tension in **each** rope. (4)

**(Total: 10 marks)**

4. A puck of mass $m_1$ is revolving in a circle of radius $R$ on a horizontal and frictionless table. The centripetal force is provided by the tension in a light string that passes through a small hole and that has a mass $m_2$ attached to its other end, as in Figure 3.

a. Write down an expression for the tension $T$ in the string in terms of $m_2$ and $g$. (1)

b. Write Newton's second law for the air puck, using the variables $m_1$, $v$, $R$, and $T$. (2)

c. Eliminate the tension $T$ from the expressions given for parts (a) and (b) and find an expression for the speed of the puck in terms of $m_1$, $m_2$, $g$, and $R$. (3)

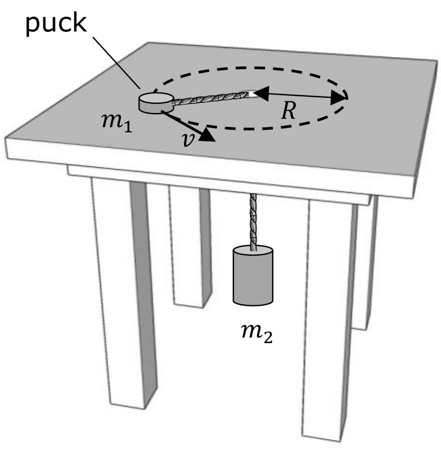


Figure 3

d. If the mass of the puck $m_1$ is $0.25$ kg and mass $m_2$ is $1.00\ kg$, calculate the radius of the circle that the puck must follow, if the puck completes one rotation every second. (4)

**(Total: 10 marks)**

5. Copper is one of the best electrical conductors. This is because it has about $8.34 \times 10^{28}$ free electrons per cubic metre. The atomic mass of copper is $63.546\,\mathrm{u}$ and its density is $8.93 \times 10^{3}\ \mathrm{kg\,m^{-3}}$.

   a. Define 'charge carriers'. (1)

   b. Calculate the effective number of free electrons contributed by each atom of copper. (4)

   c. Briefly explain what happens to the free electrons when a potential difference is applied across a copper conductor and describe how this gives rise to a current. (2)

   d. Derive the equation $I = nAvq$, where $n$ is the number of charge carriers per unit volume, $A$ is the cross-sectional area of the conductor, $v$ is the drift velocity and $q$ is the charge of the charge carriers. (3)
   $(1\ \mathrm{u} = 1.66 \times 10^{-27}\ \mathrm{kg})$

**(Total: 10 marks)**

6. A woman replaces the battery inside her pickup van. The new battery will be a source of e.m.f. of $12\ \mathrm{V}$ for the van. The charge stored in the battery makes it possible for the battery to supply $160\ \mathrm{A}$ of current for one whole hour. Assume that the battery is ideal.

   a. State **TWO** ways in which an ideal battery is different from a real battery. (2)

   b. Calculate the total amount of charge in Coulombs that can be delivered by the battery. (2)

   c. How much electric energy can the battery supply? (2)

   d. The radio in the pickup van can be operated with a potential difference of $12\ \mathrm{V}$ applied to its positive and negative terminals. Distinguish between e.m.f. and potential difference. (2)

   e. The power rating on the radio is stated at $30\ \mathrm{W}$. How long will it take the radio to drain the battery? Give your answer in hours and assume that the power consumption remains steady throughout. (2)

**(Total: 10 marks)**

7. Figure 4 shows a network of resistors connected together. The ring is made of conducting wire. Each resistor has resistance $R$.

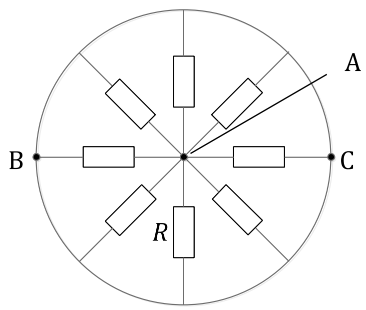

Figure 4

   a. In what way are the resistors connected? (1)

   b. What is the resistance between points A and B? (2)

   c. What is the resistance between points B and C? (1)

   d. A non-ideal voltmeter with a resistance of $700\ \Omega$ is used to measure the voltage across the resistor connected between points A and C. Why will the value of the voltage be different from the true value? Explain. (2)

e. A $6\,\text{V}$ battery with negligible internal resistance is now connected directly to terminals A and B. Each resistor has a resistance of $10\,\Omega$. Calculate the total current that is flowing through the circuit. (2)

f. What change needs to be effected to the number of resistors if the total current flowing through the circuit is to be increased? Explain your answer. (2)

**(Total: 10 marks)**

8. Figure 5 shows the setup of an experiment that involves the diffraction of electrons.

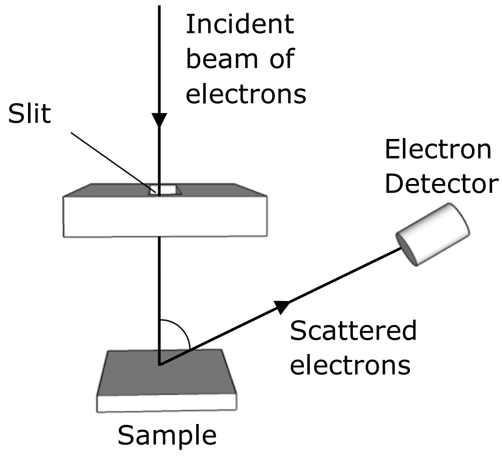

Figure 5

a. Briefly describe how this setup was used to verify the wave nature of electrons. (3)

b. Briefly describe how the observed pattern changes when the speed with which electrons hit the target is increased. (1)

c. The electrons in the beam in the setup were accelerated through a potential difference of $8.0\,\text{kV}$ towards the target made of crystalline nickel.

i. Calculate the kinetic energy of the electrons in Joules. (2)

ii. Determine the momentum with which the electrons hit the target. (2)

iii. State what the De Broglie wavelength represents and determine its value for the electrons. (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. A solid uniform sphere rolls down an inclined plane. The sphere has a mass $m$, radius $R$ and its moment of inertia $I$ is given by $I = \frac{2}{5}mR^2$. The top end of the incline is at a height $h$ and the sphere rolls without slipping. At one point in time, it is at height $y$ above the ground and is moving with linear speed $v$ and has angular speed $\omega$.

i. Sketch a diagram that shows the sphere rolling down the incline and include labels to show the information given above. (2)

ii. Apart from the rotational kinetic energy, express the **TWO** other forms of mechanical energy that are present as the sphere rolls down the plane, in words and symbolically, in terms of the quantities $m$, $g$, $y$ and $v$. (2)

iii. State the name of the force that is acting on the sphere and that is causing it to roll rather than slip. (1)

iv. Show that the ratio of the sphere's rotational kinetic energy to its total kinetic energy at any instant is $\frac{2}{7}$. (6)

b. Figure 6 shows a top A resting on its point. It can rotate freely about the axis XY. A string is wrapped around the upper part of the top. The string, of length $55.0\ \mathrm{cm}$, is pulled to give a spin to the top. It is pulled with a constant force of $7.50\ \mathrm{N}$. The top has a moment of inertia of $4.00 \times 10^{-4}\ \mathrm{kg\,m^2}$.

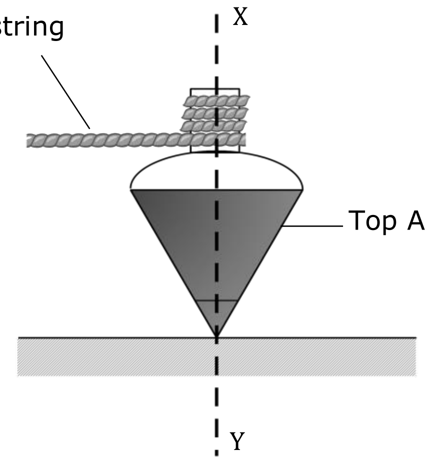


Figure 6

i. If the string does not slip as it is pulled, calculate the work done by the force in the string and hence calculate the angular speed of the top when **all** the length of the string is pulled off. (2, 2)

ii. For a brief moment, this top A hits another top B. The moment of inertia of top B is $5.00 \times 10^{-4}\ \mathrm{kg\,m^2}$ and it is rotating with an angular speed of $100\ \mathrm{rad\,s^{-1}}$ before collision. If the collision is inelastic, the tops are not moving laterally and top A loses 25% of its rotational kinetic energy, calculate the angular speed of top B after collision. (5)

**(Total: 20 marks)**

10.

a. A tooth is aligned with the rest of the other teeth using a steel wire that is stretched over it, as shown in Figure 7. The wire has an original length of $3.1\ \mathrm{cm}$ and a diameter of $0.11\ \mathrm{mm}$. The wire is stretched by $0.32\ \%$ of its original length. The Young modulus of stainless steel is $18 \times 10^{10}\ \mathrm{Pa}$.

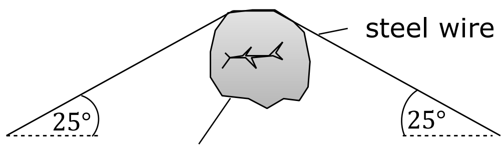


Figure 7

i. Sketch a graph that shows how the length of the wire changes as force is being applied to stretch the wire over the tooth. Clearly indicate the original length of the wire and the stretched length. (4)

ii. Calculate the extension of the wire in mm. (2)

iii. Determine the stress in the wire. (2)

iv. Disregard the width of the tooth. Determine the magnitude and direction of the force acting on the tooth. (4)

b. The graph in Figure 8 shows a generic stress-strain curve for an elastic solid.

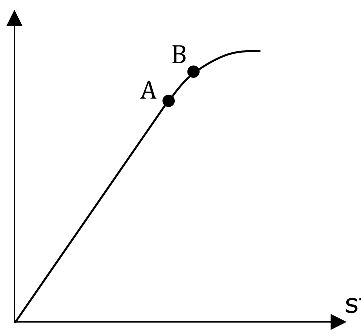


Figure 8

i. Name the points marked A and B on the curve and explain what each of the points represents. (2)

ii. Copy the graph and on it mark the yield point with the letter C. Extend the curve if needs be. (1)

iii. Briefly explain how the Young Modulus of the elastic solid can be determined from such a graph. (2)

iv. The ultimate tensile stress is the greatest stress that the solid can withstand without breaking. Explain briefly how the positions along the curve of the ultimate tensile stress point and the breaking point are different for ductile and brittle materials. (3)

**(Total: 20 marks)**

11.

a. During a jump, the centre of mass, which is the point in the body at which all the mass may be considered to be concentrated, moves as shown in the diagram of Figure 9. The typical mass of a person that may complete this jump is $68\ \mathrm{kg}$.

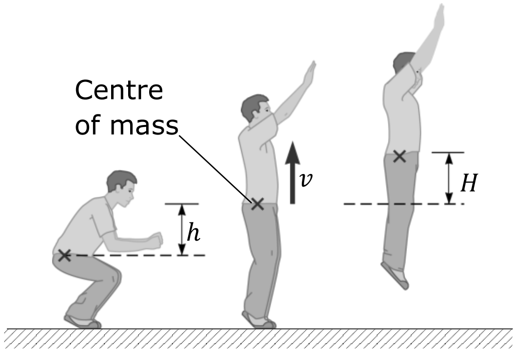

Figure 9

i. Derive an expression for the height $H$ in terms of $v$ and $g$, where $v$ is the upward speed as the person leaves the ground. (2)

ii. If the depth of the crouch is $h$ and it takes the jumper a time $\Delta t$ to extend, show that $v$ is given by $v = \frac{2h}{\Delta t}$. (2)

iii. In a typical jump, $h$ is around $0.40\ \mathrm{m}$ and and $\Delta t$ is about $0.25\ \mathrm{s}$. Calculate the values for $H$ and $v$. (2)

Muscles are at most 25% efficient at producing kinetic energy.

iv. Name the source of energy for the muscles and state where it comes from. (2)

v. Calculate the amount of energy needed by the muscles to produce a typical jump. (4)

b. Two blocks A and B are moving in opposite directions on a frictionless surface. Block B has a spring with negligible mass of spring constant $k = 6.00 \times 10^2\ \mathrm{N\,m}$ attached to it as shown in Figure 10. The blocks collide and the spring gets compressed by a distance $\Delta x$. Block A, of mass $m_1 = 1.70\ \mathrm{kg}$, is initially moving to the right with a velocity of $4.50\ \mathrm{m\,s^{-1}}$. Block B, of mass $m_2 = 2.00\ \mathrm{kg}$, is initially moving to the left with a velocity of $-2.80\ \mathrm{m\,s^{-1}}$.

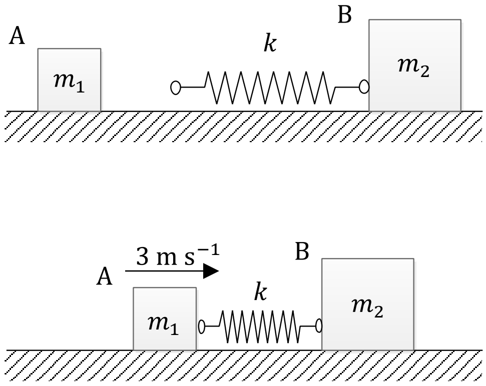

Figure 10

i. Determine the velocity of block B at the instant when block A is moving to the right with a velocity of $3.00\ \mathrm{m\,s^{-1}}$. (3)

ii. Find the compression of the spring at this time. (5)

**(Total: 20 marks)**

12.

a. Inside the nucleus, the protons repel each other due to electrostatic repulsion of like charges. For the nucleus to be stable there must exist other forces between the nucleons.

i. Name the force that keeps the nucleons together. (1)

ii. Compare and contrast **TWO** properties of this force with the electrostatic forces. (2)

iii. Briefly explain how the force mentioned in part (a)(i) gives rise to the so called 'mass defect' with particular reference to Einstein's mass-energy relation. (4)

b. Unstable nuclei may be radioactive and can decay through three different processes. A sample of radioactive substance polonium Po decays to form lead Pb. This is represented by the expression ${}^{210}_{84}\mathrm{Po} \rightarrow {}^{206}_{82}\mathrm{Pb} + {}^{4}_{2}\mathrm{He}$. Polonium has a half-life of 140 days.

i. State the **THREE** different processes through which a radioactive substance can decay and clearly identify the radiation that is emitted in each process. (3)

ii. The above reaction releases energy. Verify this statement through calculations. (4)

iii. Calculate the energy released in the decay of each radioactive Po nucleus. (2)

iv. If the molar mass of Polonium is $210\,\mathrm{g}$, calculate the mean power output per gram in the first half-life of the sample. (4)
(Atomic masses: Polonium $^{210}_{84}\mathrm{Po}$ is $209.982\,\mathrm{u}$; lead $^{206}_{82}\mathrm{Pb}$ is $205.969\,\mathrm{u}$; $^{4}_{2}\mathrm{He}$ is $4.004\,\mathrm{u}$)

**(Total: 20 marks)**

13. A diode is a semiconductor component that allows current to flow easily in one direction but opposes current flow when its polarity is reversed. The diode, also referred to as a p-n junction device, is made up by fusing together a p-type and an n-type semiconductor.

a. The p-type and n-type semiconductors are extrinsic semiconductors. Explain the meaning of this statement and briefly describe how an extrinsic semiconductor is obtained from an intrinsic semiconductor. (4)

b. Describe an experiment which could be carried out to obtain the I-V characteristics of a p-n junction diode. The description should include:
i. the list of equipment that is needed; (2)
ii. a diagram of the circuit to be used; (2)
iii. the procedure to be followed; (2)
iv. a table showing the data that needs to be observed and recorded; (2)
v. a sketch of the expected graph showing the behaviour of the diode both in forward and reverse bias configurations. (2)

c. Figure 11 shows a circuit that includes a diode. Assume that the diode is ideal, that is, it offers zero resistance when forward biased and an infinite resistance when reverse biased. The switch is closed.
i. Calculate the current through the ammeter. (2)
ii. The polarity of the battery is reversed. Determine the value of the voltage read by the voltmeter. (4)

**(Total: 20 marks)**

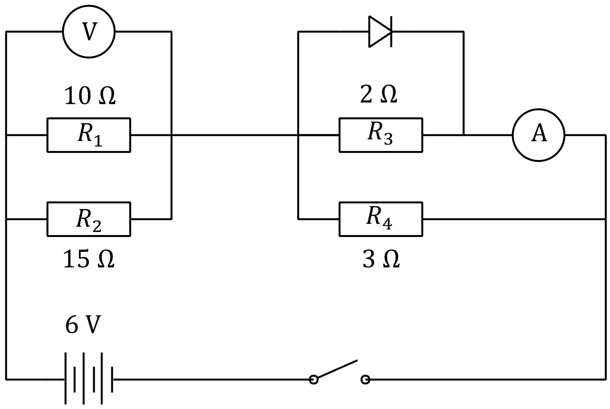

Figure 11

14.
a. In Figure 12a, the man is picking up a load from the ground with his back bent as shown. Lifting heavy loads in this manner may cause damage to the spine. The spine and the upper body are represented as a uniform horizontal rod of length $0.60\,\mathrm{m}$, of weight $350\,\mathrm{N}$ and pivoted at the base of the spine $\mathrm{O}$. The back muscle is attached at a point two thirds of the way up the spine and provides the tension $T$. The angle between the spine and this muscle is $12.0°$ and the load to be lifted, of weight $200\,\mathrm{N}$, is to be considered as acting at the free end of the rod.

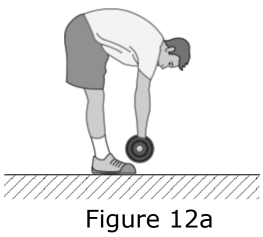
Figure 12a

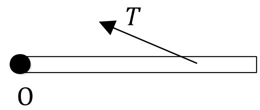

Figure 12b

i. Copy the diagram in Figure 12b and on it draw **all** the other forces present, including the components of the reaction force at the base of the spine. (4)

***This question continues on next page.***

ii. Calculate the tension in the back muscle. (3)
iii. Determine the magnitude of the force that is compressing the spine. (2)
iv. Hence calculate the magnitude and direction of the reaction at the pivot (base of the spine). (4)

b. Four masses are attached to the ends of light rods as shown in Figure 12.
   i. Calculate the moment of inertia about the $x$-axis. (2)
   ii. Without carrying out any calculations, state whether one expects the moment of inertia about the $y$-axis, to be smaller, larger or the same as the moment of inertia about the $x$-axis. Explain your reasoning. (2)
   iii. Determine the moment of inertia about an axis through O that is perpendicular to the page. (3)

**(Total: 20 marks)**

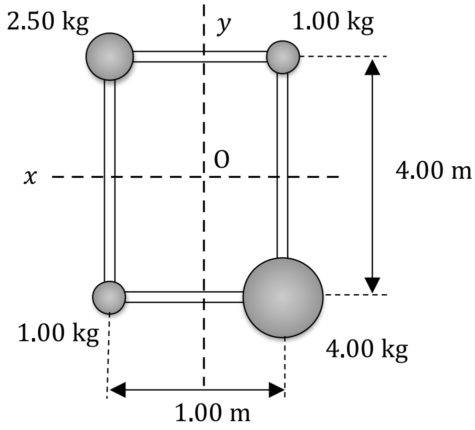


Figure 12

15. Figure 13 shows a simplified circuit diagram for the circuitry in a vehicle. $R_1$ and $R_2$ represent the total electrical load due to wiring and the lights, radio, fans, starter, rear window defroster, and the like.

a. Redraw the circuit to show how an ammeter would be connected to measure the current flowing through branch BE. (2)

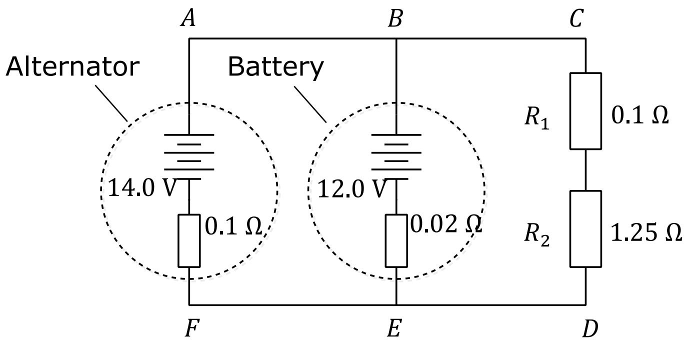


Figure 13

b. Add to the circuit diagram a voltmeter that measures the potential difference across the alternator. (1)

c. State Kirchhoff's laws and the conservation laws that form these laws. (4)

d. If $R_1 = 0.1\ \Omega$ and $R_2 = 1.250\ \Omega$, find the current flowing through the three branches AF, BE and CD. (7)

e. Calculate the terminal voltage of the battery. (2)

f. Is the battery charging or discharging? Explain your answer. (2)

g. Calculate the total power output of the system. (2)

**(Total: 20 marks)**

MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

L-Università ta' Malta

**ADVANCED MATRICULATION LEVEL**
**2022 FIRST SESSION**

| | |
|---|---|
| SUBJECT: | **Physics** |
| PAPER NUMBER: | II |
| DATE: | 28th May 2022 |
| 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 $\mathbf{g = 9.81\ m\ s^{-2}}$ 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. Define thermal contact and thermal equilibrium. (2)

b. By applying the Zeroth Law of Thermodynamics to the following situation, explain what happens in terms of energy, heat and temperature:

*Objects $A$ and $B$ are in thermal equilibrium. A third object $C$, is brought into thermal contact with $A$ and $B$ such that there is thermal contact between the three objects.* (3)

c. Convert:
i. zero Kelvin (K) to degree Celsius (℃); (1)
ii. change in temperature $\Delta\theta$ of $50$ ℃ to $\Delta T$ in K. (1)

d. Explain, on a molecular scale, the direction of net heat flow in a solid as a result of a difference in temperature. (3)

**(Total: 10 marks)**

2.
a. An electrical hot plate is used to boil water inside a saucepan.
i. Name the **THREE** heat transfer processes occurring in this situation and identify where **each** process is taking place. (3)
ii. Explain **each** process. (3)

b. Write down the equation for the transfer of heat through a solid, defining **all** terms used. Explain also what is meant by a 'steady state'. (4)

**(Total: 10 marks)**

3.
a. State Newton's Law of Gravitation and explain why the gravitational constant $G$ is called universal. (2)

b. Explain what is meant by the phrase 'gravitational potential at a point in a gravitational field'. (1)

c. A spy satellite is in circular orbit around Earth. It makes one revolution around the Earth in $360$ minutes. Calculate:
   i. the height of the satellite is above the Earth's surface; (3)
   ii. the angular speed of the satellite; (2)
   iii. the acceleration of the satellite. (2)

   [Mass of Earth $M_E = 6.00 \times 10^{24}$ kg; Gravitational Constant $G = 6.67 \times 10^{-11}$ N m$^2$ kg$^{-2}$; Radius of Earth $R_E = 6.37 \times 10^6$ m]

**(Total: 10 marks)**

4. Electrostatics is a branch of science that involves the investigation of phenomena related to what appear to be stationary electric charges.

a. Express Coulomb's Law of Electrostatics mathematically and explain **each** of the symbols used. (2)

b. The following are statements about electrostatic forces between charges. Copy the **TWO** correct statements from the below:
   i. opposite charges repel each other;
   ii. like charges attract each other;
   iii. like charges repel each other;
   iv. a net negative charge attracts a net neutral charge;
   v. a net neutral charge is not affected by nearby electrostatic fields. (2)

c. A positive point charge $q_1$ of $2$ C is located at the origin of the grid with $xy$-coordinates $(0,0)$, as shown in Figure 1. A negative point charge $q_2$ of $2$ C is located at the $xy$-coordinates $(2,0)$. Another point charge $q_3$ is to be placed somewhere in the shaded half of the grid, such that it is to be initially accelerated horizontally in the positive $x$-direction.

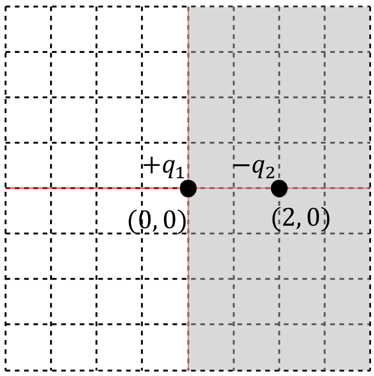

Figure 1

   i. State the sign of $q_3$ and give a reason for your answer. (1)
   ii. If $q_3$ cannot be placed anywhere on the line $y = 0$, copy the diagram and on it indicate where $q_3$ could be placed, giving a reason for your answer. Include on the diagram **all** the electrostatic forces acting on $q_3$ and the resultant force due to these electrostatic forces. (4)
   iii. Does the magnitude of $q_3$ affect the direction of the initial acceleration? Give a reason for your answer. (1)

**(Total: 10 marks)**

5. A student wants to develop a $6$ V power supply that has a direct current output for use in one of his electronics projects. His intention is to use Malta's alternating current supply, that is rated $230$ V r.m.s., as a source.

a. Explain what is meant by r.m.s. voltage. (1)

b. Calculate the peak voltage of the alternating current supply. (2)

c. Apart from the full-wave bridge rectifier, list **TWO** other components needed for his d.c. power supply. (2)

d. Draw the circuit of the full-wave bridge rectifier. (2)

e. Sketch a graph that shows how the output voltage changes with time if there are no smoothing components connected. Label this graph P. (1)

f. State in which way the output voltage can be smoothened and on the same graph of part (e), sketch the smoothened output voltage. Label this graph Q. (2)

**(Total: 10 marks)**

6.

a. Two of the following situations can be identified as describing motion in simple harmonic mode. Copy the **TWO** situations which are correct:
   i. freely oscillating simple pendulum;
   ii. car constantly decelerating and accelerating;
   iii. load attached to a spring oscillating freely about its equilibrium position;
   iv. aeroplane moving at constant velocity;
   v. cabin of a Ferris wheel moving in circular motion. (2)

b. A particle performing simple harmonic motion experiences an acceleration of $2\ \mathrm{m\ s^{-2}}$ at a maximum displacement of $0.1\ \mathrm{m}$ from its equilibrium position.
   i. Sketch a graph that shows how the acceleration of the particle changes with displacement from the equilibrium position. Include any relevant labels along both axes. (2)
   ii. Calculate the associated angular frequency and periodic time of the particle. (1, 1)
   iii. Sketch the displacement-time graph for the particle. Your graph should start with the particle at the equilibrium position. Label the periodic time on your graph. (1)
   iv. State the phase difference between displacement and acceleration. (1)
   v. On the same axes, sketch **TWO** graphs that show how the kinetic and potential energies change with displacement from the equilibrium position. (2)

**(Total: 10 marks)**

7.

a. State the effect that the diameter of a circular aperture and the wavelength of the incident wave have on the resolving power of an optical instrument. (2)

b. State the **THREE** phenomena that can occur when a ray of monochromatic light is incident on a boundary separating two different media. (3)

c. A bee is pollinating a plant and a photographer captures this on his camera. The bee is $1.2\ \mathrm{cm}$ long and is $90\ \mathrm{cm}$ from the converging lens of the camera. The focal length of the lens has magnitude $150.0\ \mathrm{mm}$.
   i. Sketch a ray diagram of the optical setup, showing the formation of the image. (2)
   ii. Find the distance between the lens and the image. (2)
   iii. Determine the height of the image of the bee. (1)

**(Total: 10 marks)**

***Questions continue on next page.***

8.

a. The light arriving to Earth from a star is observed to have its wavelength longer than expected from a star of its type.
  i. Give the name of the phenomenon described above. (1)
  ii. What can be concluded about the position of the star with respect to Earth? (1)
  iii. State how the answers in part (a)(i) and part (a)(ii) would differ if the wavelength was shorter instead of longer 'than expected from a star of its type'. (1)
  iv. Name the generic phenomenon. (1)

b. Star A is receding from Wasonka (an observer on Earth) at a speed of $0.05\mathrm{c}$, where $c$ is the speed of light $3 \times 10^8\ \mathrm{m\,s^{-1}}$. Star B is moving towards Wasonka at $0.02\mathrm{c}$. Assume that both stars A and B emit light only at a wavelength of $480\ \mathrm{nm}$. Calculate the difference in wavelength between the light received by Wasonka from star A and the light received from star B. (4)

c. State Hubble's Law and define the symbols used. (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. Distinguish between the terms 'specific heat capacity of a substance' and 'heat capacity of an object'. (2)

b. Describe a simple experimental procedure for measuring the specific heat capacity of a liquid. The description should include:
  i. a well labelled diagram of the setup; (3)
  ii. the procedure to be followed; (3)
  iii. the data that needs to be recorded; (2)
  iv. an explanation of how the data obtained is to be used to determine the specific heat capacity of the liquid; (2)
  v. identification of **ONE** significant source of error; (1)
  vi. provision of ways to minimise the source of error mentioned in part (b)(v). (1)

c. An ice cube of mass $38\ \mathrm{g}$ is stored in a freezer at a temperature of $-16\mathrm{°C}$. The cube is taken out and added to $250\ \mathrm{ml}$ of water contained in a copper calorimeter of mass $75\ \mathrm{g}$. Both the water and calorimeter are at a temperature of $22\mathrm{°C}$. Determine the final temperature of the system consisting of the ice, water, and calorimeter. (6)
[latent heat of fusion of water = $336000\ \mathrm{J\,kg^{-1}}$; specific heat capacity of ice = $2100\ \mathrm{J\,kg^{-1}K^{-1}}$; specific heat capacity of water = $4200\ \mathrm{J\,kg^{-1}K^{-1}}$; specific heat capacity of copper = $385\ \mathrm{J\,kg^{-1}K^{-1}}$]

**(Total: 20 marks)**

10.

a. A compressed fluid expands inside a cylinder with a moveable piston of cross-sectional area $A$. It displaces the piston by a small distance $\Delta x$. Assume that the pressure $P$ of the fluid remains constant during this process.
  i. Draw a labelled diagram showing the fluid inside the cylinder and the piston. (2)
  ii. State whether work is being done by the fluid or on the fluid. (1)
  iii. Derive an equation relating the work done to the pressure and the change in volume. (2)

b. The diagram in Figure 2 shows four processes A, B, C, D that an ideal gas can undergo. Assume that the quantity of the gas does **not** change in any of the processes.

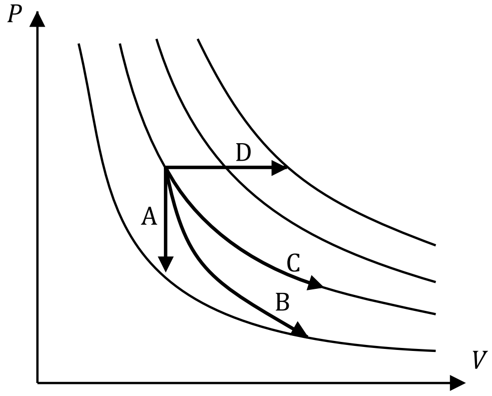


Figure 2

i. Identify the paths A, B, C, and D as isobaric, isothermal, isovolumetric, or adiabatic. (4)

ii. For any **THREE** of the paths, identify the terms from the first law of thermodynamics, if any, that do **not** change during each process. (3)

c.

i. Distinguish between a heat engine and a heat pump by drawing a flow diagram. (2)

ii. Define the thermodynamic efficiency of a heat engine. (1)

iii. The internal combustion engine of a light vehicle can propel it forward from rest to a speed of $27\ \mathrm{m\,s^{-1}}$ in $9.5\ \mathrm{s}$. The light vehicle has a mass of $1800\ \mathrm{kg}$ while its engine is $27\%$ efficient. Calculate the rate of heat flow into the engine at the high temperature and the rate of heat flow out of the engine at the low temperature. (5)

**(Total: 20 marks)**

11.

a. The gas laws relate the pressure, volume, and temperature of a gas.

i. State Boyle's, Gay Lussac's and Charles' ideal gas laws. (3)

ii. Use these laws to derive $\frac{PV}{T} = \text{constant}$. (3)

b. A warehouse consists of a room connected to an attic via a trapdoor and to an insulated cold storage via a door as shown in the diagram in Figure 3. Each room is a cube of side $3\ \mathrm{m}$. Initially all rooms contain the same number of moles of air.

The cold room is kept at a pressure of $89.58\ \mathrm{kPa}$ and a temperature of $260\ \mathrm{K}$. The main room is at standard atmospheric temperature and pressure. The attic is heated, and as a result its pressure increases, leading to both doors breaking open. The final equilibrium temperature is $290\ \mathrm{K}$.

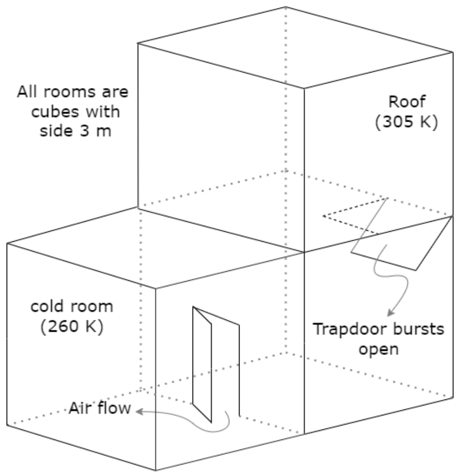


Figure 3

***Question continues on next page.***

Assume that:

- only the attic is heated, and the main room and cold room retain the same temperature and pressure before the doors break open;
- the air behaves as an ideal gas;
- both doors open simultaneously.

i. Calculate the final equilibrium pressure of the whole building. (6)
ii. Determine the number of air particles inside the whole building. (2)

c. Brownian motion is named after the botanist Robert Brown, who first observed this in 1827.
i. Define Brownian motion. (2)
ii. Sketch the graph of the frequency distribution of molecular speeds for two or more different temperatures. (2)
iii. State the quantity represented by the area under such graphs. (1)
iv. State the relationship between the areas under the graphs for different temperatures. (1)

**(Total: 20 marks)**

12.
a. A parallel plate capacitor is able to store $1 \times 10^{-10}$ C of charge when a potential difference of $10$ V is applied across it.
i. Sketch a labelled diagram of the structure of a parallel plate capacitor connected to a d.c. power supply. Draw charges and net field lines between the plates. (4)
ii. Calculate the capacitance of the parallel plate capacitor. (2)
iii. Suppose that the area of the plates is increased, but the capacitance is required to remain the same. State whether the distance between the plates should increase or decrease and give a reason by referring to the appropriate formula. (2)
iv. State the effect of dielectric polarisation on the electric field between the plates. (1)
v. How does the electrical polarisation of the dielectric affect the capacitance of the parallel plate capacitor? (1)
vi. Define dielectric constant. (2)

b. Consider a capacitor with a capacitance of $100\ \mu\text{F}$. This capacitor is charged through a $10\ \text{k}\Omega$ resistor.
i. Draw **THREE** separate graphs that show the variation with time of:
   - the charge stored on the capacitor; (1)
   - the voltage across it; (1)
   - the current flowing through the charging circuit. (1)

ii. Indicate the time constant on one of the graphs. (1)
iii. Calculate the time at which the voltage across the capacitor is at $80\%$ of the maximum voltage that can be achieved across it. (4)

**(Total: 20 marks)**

13.
a. Draw the magnetic field lines produced by:
i. a long straight current carrying conductor; (1)
ii. a current carrying long solenoid. (2)

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

c. Two long straight and parallel current carrying conductors carry currents $I_1$ and $I_2$. The two conductors are separated by a distance $r$.
   i. Describe the orientation of the force between the two wires when the current in the wires flows in opposite directions **and** in the same direction. (2)
   ii. Show that the equation for the force per unit length between these two long parallel current-carrying straight conductors is given by $\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r}$. (4)
   iii. Define the Ampere. (3)

d. The diagram in Figure 4 shows the setup for demonstrating the Hall Effect.

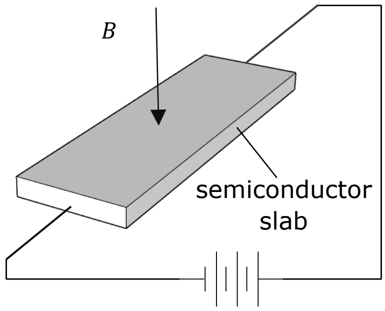


Figure 4

   i. Briefly describe the Hall Effect and a method to determine the sign (+ or -) of the charge carriers inside a conductor by using the Hall effect. (4)
   ii. On a copy of the diagram, show the directions for $E$, $B$ and $I$. (1)

**(Total: 20 marks)**

14. A monochromatic light source is used to produce Young's interference fringes at the focal plane of a travelling microscope.

a. Draw the experimental setup used to produce and observe a double slit interference pattern. Include a graph that shows the light intensity as would be observed in the plane of the microscope. (5)

b. State which part of the setup ensures that light arriving at the double slits is coherent. (1)

c. Explain the graph drawn in part (a) by referring to the different types of interference. (2)

d. Name **THREE** ways to increase the fringe separation. (3)

e. A parallel beam of light from an illuminated slit consists of two wavelengths, yellow of wavelength $560\ \mathrm{nm}$ and blue of wavelength $420\ \mathrm{nm}$. The beam is incident normally on the experimental setup described in part (a).
   i. The travelling microscope is set initially on the zeroth order bright fringe and then turned in one direction. State which spectral line will be observed first and justify your answer using the diffraction equation. (2)
   ii. The 3$^{rd}$ bright fringe of one of the wavelengths coincides on the 4$^{th}$ bright fringe of the other wavelength. The distance between the double slits and the screen is $1\ \mathrm{m}$. If these fringes coincide at $1\ \mathrm{mm}$, calculate the angle at which the fringes coincide. (4)

f. A white beam of light is now used. Compare the spectrum produced by white light to the spectrum produced by monochromatic light. (3)

**(Total: 20 marks)**

***Question continues on next page.***

15.

a. State Faraday's and Lenz's laws of electromagnetic induction. (2)

b. Describe a simple experiment using a solenoid and a magnet together to investigate how the rate of change of flux induces an electromotive force (e.m.f.) in a circuit. Qualitatively describe the observations to be made and include a simple diagram to illustrate the setup to be used. (6)

c. A conducting rod, of length $R$, is pivoted at one end P so that its free end $Q$ can rotate freely in a plane perpendicular to a uniform magnetic field $B$, as shown in Figure 5.

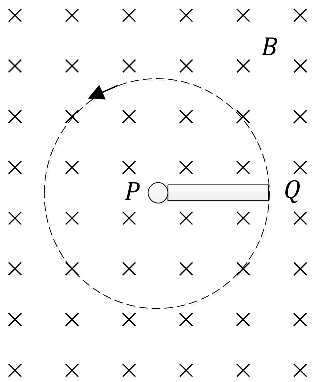


Figure 5

i. State:
- the direction in which current will flow through the rod; (1)
- the law used to arrive at your answer. (2)

ii. By considering the area that the rod sweeps out in one whole turn, show that the e.m.f induced across the ends of the rod is given by $\frac{B\omega R^2}{2}$, where $\omega$ is the angular velocity of the rod. (3)

iii. Express the magnitude of the e.m.f. in terms of the speed $v$ of the tip of the rod. (2)

iv. Compare the expression obtained in part (c)(iii) to the magnitude of the e.m.f. generated by a rod moving at constant velocity perpendicular to a uniform magnetic field and explain any differences. (2)

d. Consider a rectangular coil with 10 turns and an area of $10\ \mathrm{cm}^2$. The coil is placed in a magnetic field of $1\ \mathrm{T}$. Calculate the angular frequency required to induce a peak e.m.f. of $2\ \mathrm{V}$. (2)

**(Total: 20 marks)**

MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

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**ADVANCED MATRICULATION LEVEL**
**2022 FIRST SESSION**

| | |
|---|---|
| SUBJECT: | **Physics** |
| PAPER NUMBER: | III |
| DATE: | 1st June 2022 |
| TIME: | 4:00 p.m. to 5:35 p.m. |

**Experiment:** Investigating the physical properties of a wooden metre ruler.

**Apparatus:** 1 m wooden ruler, stands and clamps, helical light springs, weights.

**Diagram:**

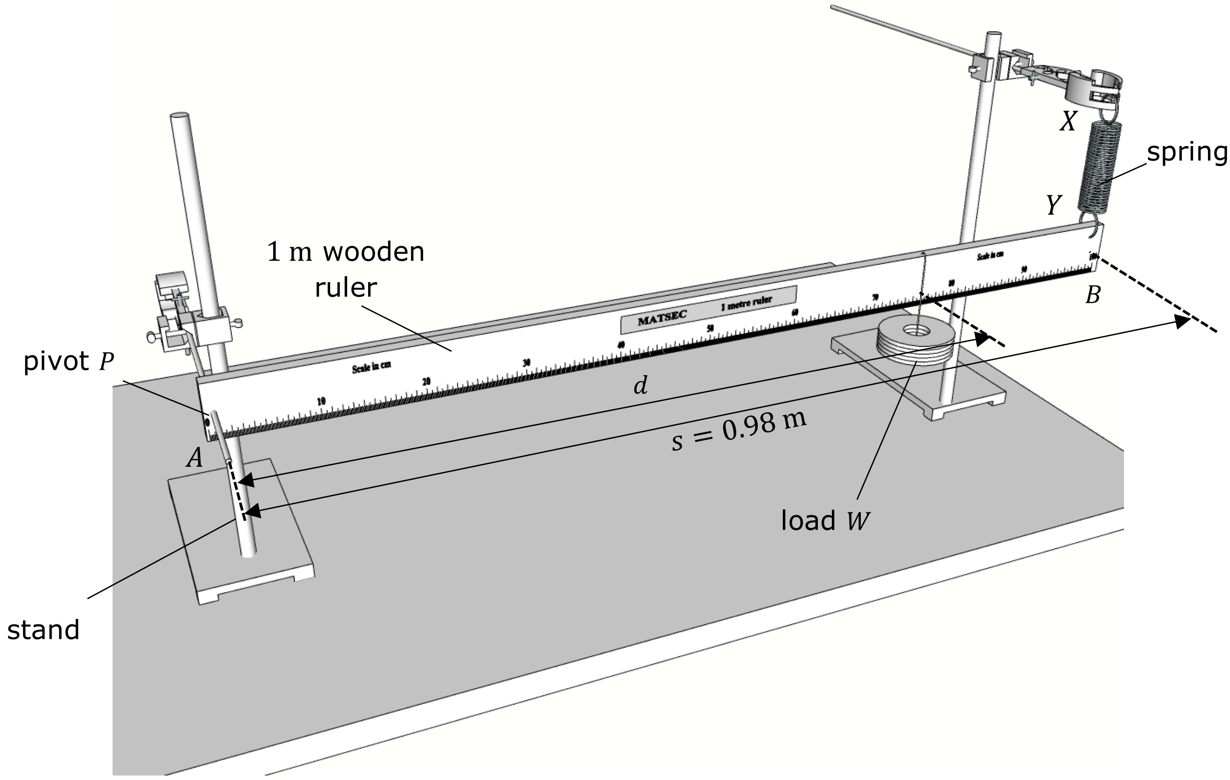


Figure 1: The experimental setup

**Method – Part A:**

1. The apparatus shown in Figure 1 was set up.
2. The wooden metre ruler is pivoted through a hole $1\ \mathrm{cm}$ from end $A$.
3. A moveable known weight $W$ of $4.905\ \mathrm{N}$ hangs at a distance $d$ from the pivot and the wooden metre ruler is kept horizontal by the support from a light helical spring $XY$.
4. The end $Y$ of the spring is attached to the metre ruler vertically $1\ \mathrm{cm}$ from end $B$ while end $X$ of the spring can be moved up and down to adjust the tension in the spring that would be needed to keep the wooden metre ruler horizontal.

5. State the principle of moments.

________________________________________

________________________________________

________________________________________

______________________________________ (3)

6. Draw a free body diagram showing **all** the forces acting on the wooden metre ruler.

(3)

7. With the wooden metre ruler in equilibrium in a horizontal position, apply the principle of moments to derive a relationship between the forces acting and the distances of these forces from the pivot. Explain any symbols used.

________________________________________

________________________________________

______________________________________ (2)

8. The weight $W$ is moved towards end $A$ of the wooden metre ruler. The following are situations that describe what happens. Underline the **TWO** situations that are correct.

- The wooden ruler turns anticlockwise about the pivot.
- The wooden ruler remains horizontal.
- To restore the horizontal position of the wooden ruler, end $X$ of the spring is lowered.
- To restore the horizontal position of the wooden ruler, end $X$ of the spring is raised.
- The wooden ruler turns clockwise about the pivot. (2)

9. The weight $W$ is moved along the wooden metre ruler to the specific distances $d$ shown in Table 1. For each distance $d$, the top end $X$ of the spring is adjusted to restore the horizontal position of the wooden metre ruler and each time the total length $L$ of the stretched spring is measured and recorded in Table 1.

10. It is known that the extension $e$ of the spring is related to the distance $d$ by the equation:

$$e = \left(\frac{W}{k}\right)\left(\frac{d}{s}\right) + \left(\frac{0.49m_r g}{ks}\right)$$

where $k$ is the spring constant, $m_r$ is the mass of the ruler and $s$ is the distance between the spring and the pivot $P$. The original length of the spring is $0.05$ m.

Table 1

| $d$ /m $\pm 0.001$ m | $L$ /m $\pm 0.001$ m | $\frac{d}{s}$ | $e$/m |
|---|---|---|---|
| 0.250 | 0.117 | | |
| 0.300 | 0.128 | | |
| 0.350 | 0.142 | | |
| 0.400 | 0.150 | | |
| 0.450 | 0.161 | | |
| 0.500 | 0.169 | | |
| 0.550 | 0.185 | | |
| 0.600 | 0.194 | | |
| 0.650 | 0.205 | | |
| 0.700 | 0.218 | | |

11. Work out and fill in the values of $e$ and $\frac{d}{s}$. (10)

12. Plot a graph of $e$ /m on the y-axis against $\frac{d}{s}$ on the x-axis. (10)

13. Use the graph to determine a value for the spring constant $k$.

________________________________________

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________________________________________ (5)

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14. Use the graph again to determine the value of the mass $m_r$ of the ruler. This value will be used in Part B of this paper.

____________________________________________________________

____________________________________________________________

____________________________________________________________

_________________________________________________________ (5)

**Method – Part B:**

15. In this part of the experiment, the Young's modulus of the wooden metre ruler will be determined.

16. The wooden ruler is placed on two supports that are approximately $0.90\ \mathrm{m}$ apart, as shown in Figure 2.

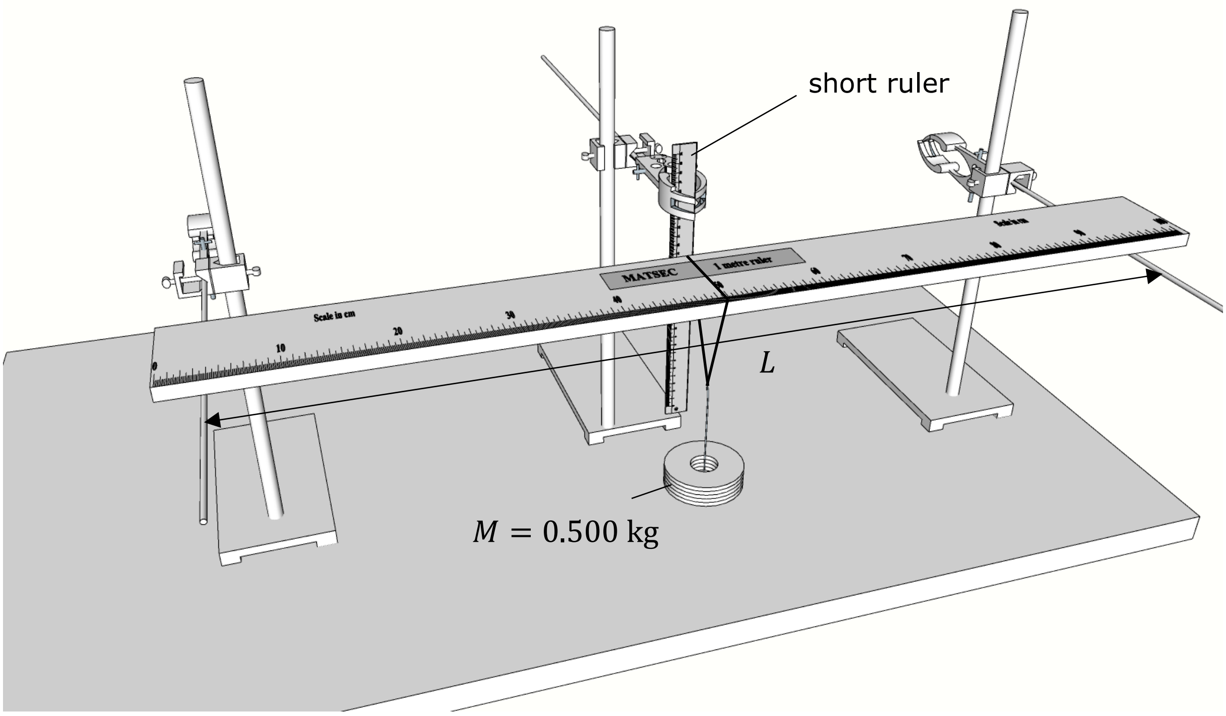


Figure 2

17. A mass $M$ of $0.500\ \mathrm{kg}$ is loaded at the centre of the ruler by a string.

18. The short ruler clamped in the middle is used to measure the depression of the centre of the ruler from the horizontal.

19. The distance $L$ between the supports is set to the values shown in Table 2. For each value of $L$, the depression $d$ of the centre of the ruler from the horizontal is recorded.

***Please turn the page.***

20. It is thought that the depression $d$ is related to the distance $L$ between the supports by the equation

$$d = ZL^n$$

where $Z$ and $n$ are constants.

Table 2

| $L$ /m $\pm$ 0.001 m | $d$ /m $\pm$ 0.001 m | $\log L$ | $\log d$ |
|---|---|---|---|
| 0.900 | 0.022 | | |
| 0.850 | 0.018 | | |
| 0.800 | 0.014 | | |
| 0.750 | 0.012 | | |
| 0.700 | 0.011 | | |
| 0.650 | 0.008 | | |
| 0.600 | 0.006 | | |

21. Explain how a graph of $\log d$ against $\log L$ will enable one to test that the relationship given in part 20 is correct.

________________________________________

________________________________________

________________________________________

________________________________________ (3)

22. Explain how one could determine the values of $Z$ and $n$.

________________________________________

________________________________________

________________________________________

________________________________________ (3)

23. Complete Table 2 by working out the missing values of $\log L$ and $\log d$. (7)

24. Plot a graph of $\log d$ on the y-axis against $\log L$ on the x-axis. (10)

25. Use the graph to obtain values for $Z$ and $n$.

(6)

26. It is given that the constant $Z$ depends on the elastic characteristics of the wooden ruler, its dimensions and the weight applied. In fact,

$$Z = \frac{(M + m_r)g}{4Y}\left(\frac{1}{bt^3}\right)$$

where $Y$ is the Young's modulus of wood, $b$ is the breadth and $t$ is the thickness.

27. Explain how and why the Young's modulus of the material affects the depression of the loaded wooden metre ruler.

(5)

28. If $b$ is equal to $0.025\ \mathrm{m}$ and $t$ is equal to $0.006\ \mathrm{m}$, use the value of $m_r$ obtained in part 14, to determine the Young's modulus of the wooden metre ruler.

(4)

29. For part B, state **ONE** source of error and **ONE** corresponding precaution that could be taken to improve the setup or the procedure.

(2)