**MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD**

**UNIVERSITY OF MALTA, MSIDA**

**MATRICULATION EXAMINATION**
**ADVANCED LEVEL**
**MAY 2016**

| | |
|---|---|
| **SUBJECT:** | PHYSICS |
| **PAPER NUMBER:** | I |
| **DATE:** | 23rd April 2016 |
| **TIME:** | 9.00 a.m. to 12.05 p.m. |

**A list of useful formulae and equations is provided.**

**This paper carries 40% of the marks for the examination.**
**It is expected that answers be accompanied by the proper units.**

## Section A

**Attempt all eight questions in this section. This section carries 50% of the total marks for this paper.**

### Question 1

a. The volume per second, $V/t$, of water flowing through a horizontal pipe of length $l$ and radius $r$, depends on the difference in pressure, $\Delta p$, between the ends of the pipe. It also depends on a quantity $\eta$, related to friction in liquids. It is given by

$$\frac{V}{t} = \frac{\pi r^4 \Delta p}{8\eta l}$$

Making use of the fact that the equation is homogeneous, find the base units of $\eta$.

**[6 marks]**

b. A girl delivering door-to-door advertising magazines covers her route by traveling 3.00 blocks west, 4.00 blocks north, and then 6.00 blocks east.

(i) Sketch the path taken by the girl. **[2 marks]**

(ii) What is her resultant displacement? **[3 marks]**

(iii) What is the total distance she travels? **[1 mark]**

### Question 2

A rocket is fired vertically upwards from rest with a net upward acceleration of 29.4 m $s^{-2}$. It runs out of fuel at the end of 4.00 s and continues to rise upward, reaching a maximum height before falling back to Earth.

a. Find the rocket's velocity and position at the end of 4.00 s. **[4 marks]**

b. Find the maximum height the rocket reaches. **[4 marks]**

c. Find the magnitude of the velocity with which the rocket crashes on the ground. **[2 marks]**

d. Sketch a labelled graph of displacement $s$ against time $t$ showing its trajectory from when its fuel burns out to when it crashes into the ground. **[4 marks]**

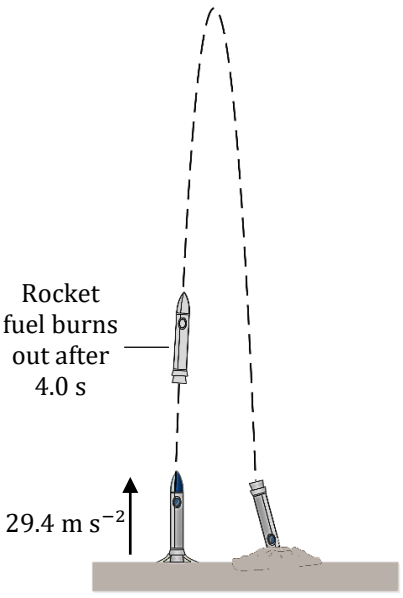


**Figure 1**

## Question 3

A screw, attached to a long lever, is used to raise a load of 45 kg. A force of 4.8 N applied perpendicularly to the lever at a distance of 1.9 m from the centre is just sufficient to raise a load of 45 kg. The screw has a pitch of 1.2 cm, that is, it moves vertically 1.2 cm every time it undergoes a complete turn.

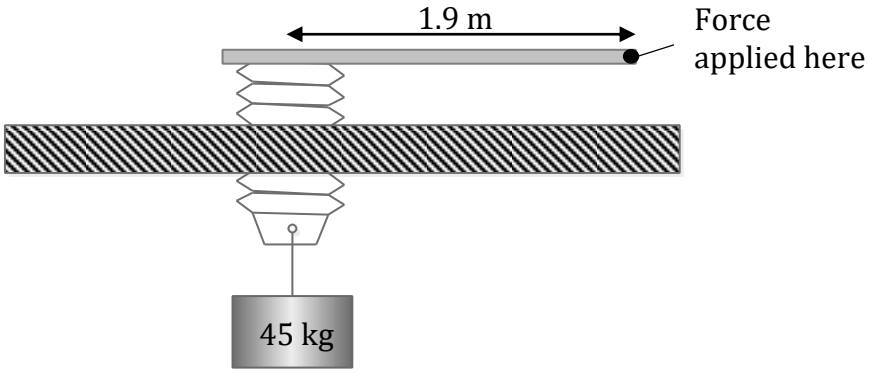


**Figure 2**

a. Calculate the work done on the lever during a complete turn of the screw. **[3 marks]**

b. Find the work done against gravity during one complete turn. **[3 marks]**

c. Account for the difference in work done on the lever and on the load. **[2 marks]**

d. Calculate the efficiency of this machine and state how this efficiency can be improved. **[4 marks]**

## Question 4

A cyclist of mass $m$ is going round a circular track of radius $r$ with a constant speed $v$. The cyclist has to lean towards the centre, making an angle $\theta$ with the vertical. When he is cycling in a straight line, his centre of gravity lies at a height $h$ above the ground.

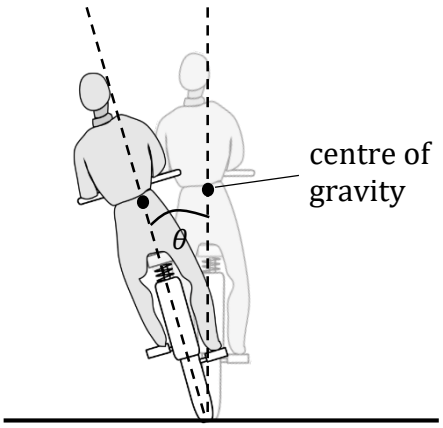


**Figure 3**

a. Sketch a diagram showing all the forces acting on the cyclist while cycling. **[3 marks]**

b. Which of the forces in your diagram is acting as the centripetal force? **[2 marks]**

c. By taking moments about his centre of gravity, or otherwise, show that $\tan\theta = \frac{v^2}{rg}$. **[5 marks]**

d. Given that the radius of the track $r$ is 6.7 m and the cyclist is moving with a constant speed $v$ of 4.5 m $s^{-1}$, calculate the angle $\theta$ that the cyclist makes with the vertical. **[2 marks]**

## Question 5

a.

(i) Define the term couple. **[1 marks]**

(ii) Derive an equation for the work done by a couple of torque $\tau$, when it turns through an angle $\theta$ radians. **[3 marks]**

b. Figure 4 shows a uniform beam of mass $m$ and length $L$ pivoted at its lower end, with a horizontal spring, of spring constant $k$, attached between its top end and a vertical wall. When the system is in equilibrium, the beam makes an angle $\theta$ with the horizontal.

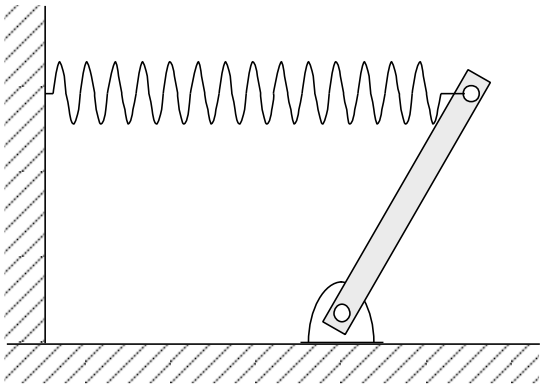

**Figure 4**

(i) Do the tension in the spring and the weight of the beam constitute a couple? Explain. **[2 marks]**

(ii) Show that the extension, $x$, of the spring is given by $x = \frac{mg}{2k \tan\theta}$. **[2 marks]**

(iii) Derive an expression, in terms of $\tan\theta$, for the magnitude of the force exerted by the pivot on the beam. **[2 marks]**

(iv) Determine the angle $\theta$ for a beam of mass 5 kg and a spring constant of 15 N m$^{-1}$ if the spring stretches by 0.5 m. **[2 marks]**

## Question 6

a. State Kirchhoff's laws for electric circuits **[4 marks]**

b. A cell with an electromotive force (e.m.f.) of $\varepsilon$ volts is connected to an external resistor $R$ producing a current $I$ through the resistor. The electric potential difference (p.d.) across the terminals of the cell or resistor is $V$.

(i) Explain clearly the difference between e.m.f. and electric potential difference. **[3 marks]**

(ii) Explain why the potential difference across the terminals of a cell connected to an external circuit is smaller than its e.m.f.? **[2 marks]**

(iii) The potential difference across the terminals of the cell will approach the e.m.f. of the cell if the resistance in the external circuit is increased. Explain this statement. **[2 marks]**

c. The graph in Figure 5 shows the amount of charge that has flowed through a circuit over a period of 10 seconds.

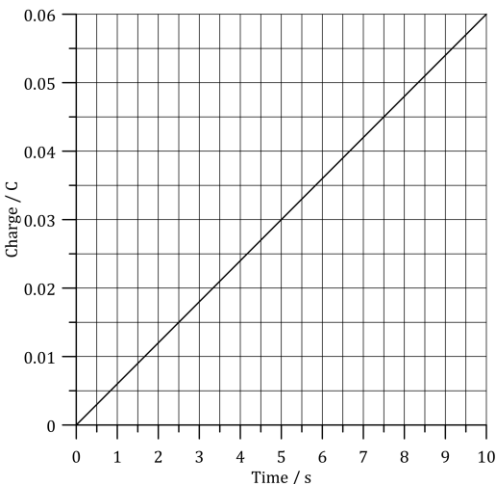


**Figure 5**

(i) How can the current flowing through the circuit be obtained from the graph? **[1 mark]**

(ii) Sketch a well labelled graph that shows how the current changes with time during the same 10 second time interval. **[2 marks]**

## Question 7

a.

(i) State Ohm's law. **[2 marks]**

(ii) Indicate, by means of graphs drawn on the same axis, the relation between the current $I$ and the potential difference $V$ for a resistance wire and a filament lamp. **[4 marks]**

(iii) With reference to what happens to the resistance of the wire and filament lamp as the potential difference across them increases, justify the differences in the shapes of the two curves. **[2 marks]**

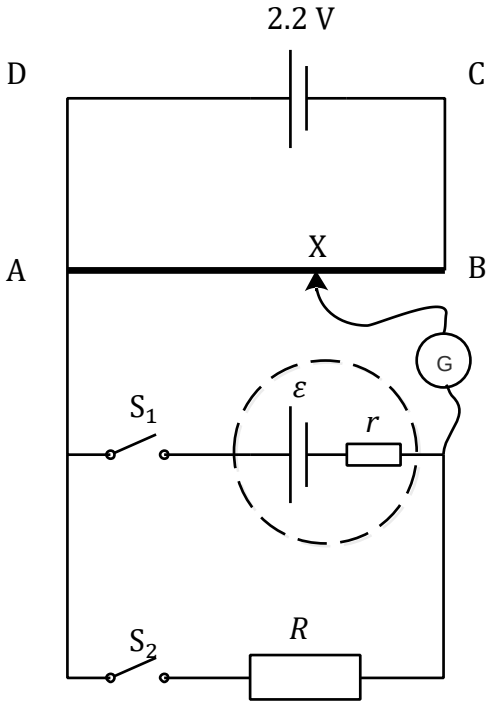


**Figure 6**

b. A circuit ABCD consists of a uniform 100 cm long resistance wire AB, and a 2.2 V power source of negligible internal resistance.

(i) If $S_1$ and $S_2$ are both open and AX is 70 cm, what is the potential difference across AX? **[1 mark]**

(ii) If $S_1$ is closed and $S_2$is open, and the galvanometer G shows zero deflection, what is the emf of cell $\varepsilon$? **[1 mark]**

(iii) $S_2$ is now closed as well. For G to register zero deflection, AX has to be adjusted to 63 cm. What is the p.d. across the terminals of the cell $\varepsilon$? **[1 mark]**

(iv) If $R$ is 18 Ω, calculate the internal resistance $r$ of the cell. **[3 marks]**

## Question 8

A clean potassium surface is irradiated with light of wavelength $3.6 \times 10^{-7}$ m. Electrons are emitted from the surface into the surrounding vacuum. A sketch of the graph of photoelectric current against incident light intensity is shown in Figure 7.

a. What can be deduced from its slope? **[2 marks]**

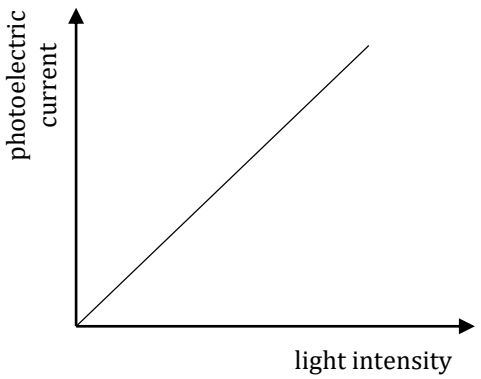


**Figure 7**

b. If the work function for ejecting these electrons has a value of 2.0 eV,
   (i) find the value of the stopping potential; **[4 marks]**
   (ii) find the kinetic energy in joules of the most energetic electrons ejected; **[2 marks]**
   (iii) calculate the velocity of these electrons. **[2 marks]**

## Section B

**Attempt any four questions from this section. Each question carries 25 marks. This section carries 50% of the total marks for this paper.**

### Question 9

a.
   (i) State Newton's second law of motion in terms of momentum. **[2 marks]**
   (ii) Explain how the Newton is defined so as to make the constant of proportionality implied in Newton's second law, equal to one. **[3 marks]**

b. Masses $m_1$and $m_2$ are placed on a horizontal frictionless surface. The objects compress a spring of negligible mass. The spring has a spring constant of 320 N m$^{-1}$. The spring is not attached to either object and is compressed a distance of 10.3 cm. The objects are released from rest and move as shown in Figure 8.

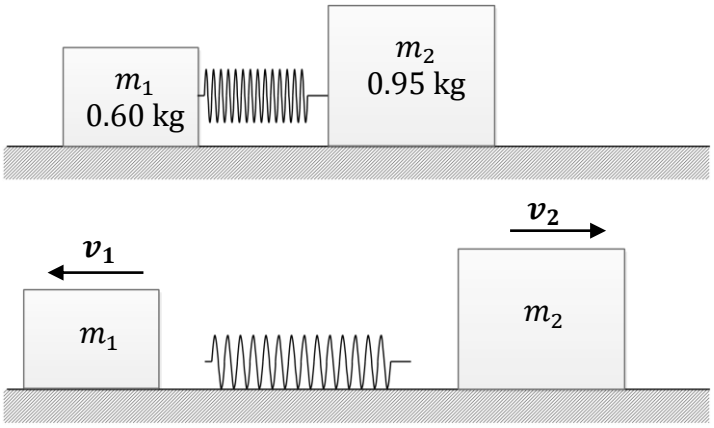


**Figure 8**

   (i) Calculate the energy stored in the spring. **[2 marks]**
   (ii) State the principle of conservation of momentum. **[2 marks]**
   (iii) Derive an expression for the velocity $v_1$ in terms of $m_1$, $m_2$ and $v_2$. **[2 marks]**
   (iv) Calculate the final velocity of each object. **[5 marks]**

c. The ballistic pendulum is a device used to measure the speed of a fast-moving projectile such as a bullet. One such bullet, of mass 18 g, is fired into a block of wood of mass 1.6 kg suspended from a light wire of length 1.15 m. The bullet is stopped by the block, and the entire system swings up to a maximum angle $\theta$. The bullet is travelling horizontally with a velocity of 95 m s$^{-1}$ when it hits the block.
   (i) Why can the law of conservation of linear momentum still be used even though there are external forces (such as their weights) acting? **[2 marks]**
   (ii) Calculate their common velocity, when the relative velocity between block and bullet just ceases. **[2 marks]**
   (iii) Find the value of the angle $\theta$. **[5 marks]**

## Question 10

a.

(i) Define angular velocity $\omega$ of an object moving in a circular path. **[2 marks]**

(ii) An object moves in a circular path of radius $r$, with constant tangential velocity $v$. Show that the acceleration $a$, towards the centre is $a = \frac{v^2}{r}$. A labelled diagram is expected. **[7 marks]**

b. A pendulum bob of mass 65 g is attached to a string of length 80 cm. It is made to rotate with constant velocity, as a conical pendulum. If the angle the string makes with the vertical is 25°, calculate:

(i) the radius $r$, of the circular path followed by the bob; **[2 marks]**

(ii) its tangential velocity along the circle; **[4 marks]**

(iii) the tension T, in the string. **[2 marks]**

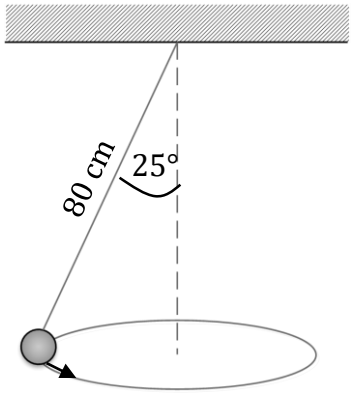


**Figure 9**

c. The bob is now pulled sideways until the string makes an angle of 25 ° with the vertical. It is released from rest so that it swings in a vertical plane. Calculate:

(i) the angular velocity of the bob when the string is vertical; **[5 marks]**

(ii) the magnitude and direction of its centripetal acceleration when the string is vertical. **[3 marks]**

## Question 11

a.

(i) Define the moment of inertia of a rigid body. **[2 marks]**

(ii) Explain why the moment of inertia of a solid disc is smaller than that of a ring of the same mass and radius. **[3 marks]**

b. A water irrigation system uses a sprinkler with three spouts that spray water over a lawn. The spouts are each 15.0 cm long. As the water is sprayed, the sprinkler rotates in a circle. The moment of inertia of the sprinkler is $9.2 \times 10^{-2}$ kg m$^2$. If the sprinkler starts from rest and takes 3.20 s to reach its final angular speed of 2.2 revolutions per second, calculate:

(i) the angular acceleration of the sprinkler; **[3 marks]**

(ii) the force that each spout exerts on the sprinkler. **[4 marks]**

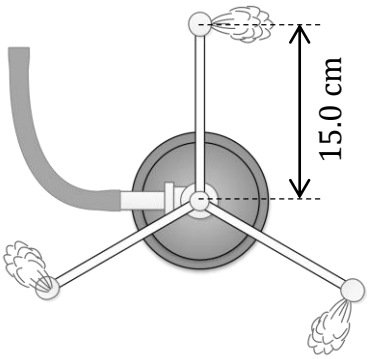


**Figure 10**

c. A bucket containing cement has a mass of 3.0 kg. One end of a rope is attached to the handle of the bucket and the other end is wound around a horizontally mounted cylinder on frictionless bearings. The mass of the cylinder is 6.0 kg and its radius is 0.10 m. The moment of inertia of the cylinder is given by $I = \frac{1}{2}MR^2$, where $M$ is its mass and $R$ is its radius. Given that the bucket is released from rest, calculate:

(i) the moment of inertia of the cylinder; **[2 marks]**

(ii) the acceleration of the bucket. **[5 marks]**

(iii) the tension in the rope; **[2 marks]**
(iv) the rotational kinetic energy of the cylinder after 5 s. **[4 marks]**

## Question 12

a. Define tensile stress, tensile strain and the Young modulus of elasticity. **[3 marks]**

b. Compare and explain the different parts of the stress-strain graphs for:
(i) a copper wire; **[3 marks]**
(ii) a rubber cord; **[3 marks]**
(iii) a glass fibre. **[3 marks]**

c. A copper wire obeys Hooke's Law if the stress and strain values lie within the proportionality limit. Show that the 'spring constant' $k$ implied by Hooke's law is given by $k = \frac{YA}{L_0}$, where $Y$ is the Young modulus, $A$ is the cross-sectional area and $L_0$ is the original length of the wire. **[4 marks]**

d. The Young modulus of the material used in making the string in an archer's bow is $8.40 \times 10^9$ N m$^{-2}$. The diameter of the string is $3.8 \times 10^{-4}$ m and the maximum strain before breaking is 0.45. Assume that strain is proportional to stress up to the breaking point, calculate:
(i) the maximum breaking stress; **[2 marks]**
(ii) the maximum tension that the string can withstand; **[3 marks]**
(iii) the extension of the string at maximum tension, if the original length of the string is 1.60 m; **[1 marks]**
(iv) the energy stored per unit volume of string when it is subjected to maximum tension. **[3 marks]**

## Question 13

a. Explain fully the difference between an insulator, a metallic conductor and a semiconductor. Reference should be made to:
(i) energy bands in solids (description of these bands expected); **[2 marks]**
(ii) the population in these bands; **[2 marks]**
(iii) the widths of these bands where applicable; and **[2 marks]**
(iv) the effect of a rise in temperature on the population in these bands. **[2 marks]**

b. A silicon atom has 14 electrons surrounding the nucleus. Four of these electrons lie in the outermost shell.
(i) Explain the structure of a silicon crystal. **[2 marks]**
Due to a rise in temperature, one of the outermost electrons gains enough energy to escape from this shell.
(ii) Explain what is meant by a hole. **[2 marks]**
(iii) An e.m.f. source is connected across the silicon crystal. State what happens to the escaped electron and to the hole. **[2 marks]**

c. Silicon crystals are doped with atoms of antimony, which have five outer shell electrons. This doping makes the silicon an extrinsic semiconductor. Explain fully using a diagram, how the number of free electrons is increased by this method. **[4 marks]**

d. A 12 volt battery is connected in series with a uniform nichrome resistance wire of cross-sectional area $A = 4.54 \times 10^{-9}\ \text{m}^2$ and $n = 4.57 \times 10^{28}$ conduction electrons per unit volume.

(i) For a current $I$ flowing through the resistance wire, show that the drift velocity $v_D$ of the conduction electrons in the nichrome wire is given by $v_D = \frac{I}{nAe}$. **[3 marks]**

(ii) If the resistivity of nichrome is $1.04 \times 10^{-6}\ \Omega\,\text{m}^{-1}$, calculate the current flowing through 0.5 m length of nichrome wire. **[2 marks]**

(iii) Calculate the drift velocity of electrons in the nichrome wire. **[2 marks]**

## Question 14

a. A battery of e.m.f. $\varepsilon$ and internal resistance $r$, is connected across a load resistance $R$.

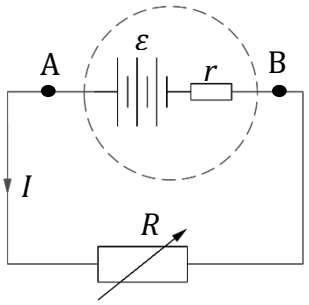

**Figure 11**

(i) What is the terminal p.d. $V_{AB}$ in terms of the current $I$ and resistance $R$? **[1 mark]**

(ii) What is the power generated $P_{gen}$, and the power output $P_{out}$,in terms of the given symbols? **[2 marks]**

(iii) If the efficiency $\eta$, of the battery is defined as $\eta = \frac{P_{out}}{P_{gen}}$, show that $\eta = \frac{R}{R+r}$. **[2 marks]**

(iv) Using the same x-axis, sketch two labelled graphs to show how:

- terminal p.d. $V_{AB}$ changes with load resistance $R$; **[2 marks]**
- current $I$ changes with load resistance $R$. **[2 marks]**

(v) Explain the features of these graphs. **[2 marks]**

(vi) Sketch another graph of $P_{out}$ against load resistance $R$ and indicate clearly the value of $R$ where there is maximum power output $P_{out}$. **[5 marks]**

b. Figure 12 shows a circuit with three e.m.f. sources and four resistors.

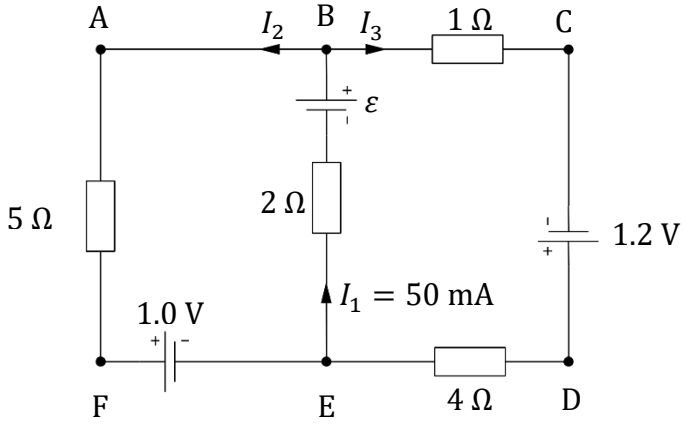

**Figure 12**

Determine the unknown e.m.f. $\varepsilon$ and the unknown currents $I_2$ and $I_3$. **[9 marks]**

## Question 15

a. Describe the properties of $\alpha$, $\beta$ and $\gamma$ radiations. **[6 marks]**

b. In an $\alpha$-scattering experiment, $\alpha$-particles emitted from radon were directed onto a thin gold foil placed in an evacuated container. Scintillations on a fluorescent screen placed on the opposite side of the gold foil were observed. It was found that:

- most of the $\alpha$-particles passed straight through the gold foil;
- some particles were scattered through a small angle;
- on rare occasions $\alpha$ −particles were almost repelled back.

(i) Give an explanation for the above observations. **[5 marks]**

(ii) An $\alpha$ particle emitted with a kinetic energy of 4.0 MeV was reflected back from the gold foil. Calculate the distance of closest approach that the $\alpha$-particle got to the gold foil atoms before it was reflected back. The gold nucleus has 79 protons. **[5 marks]**

c. The binding energy per nucleon is shown in Figure 13.

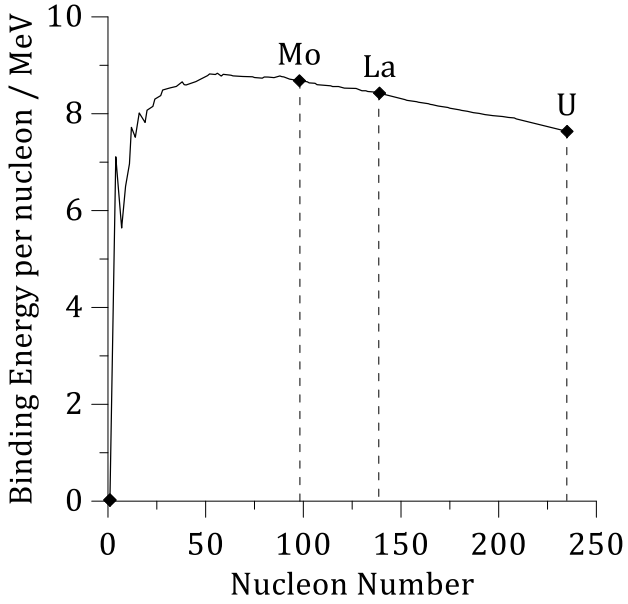


**Figure 13**

When an atom of Uranium-235 absorbs a bombarding neutron, it splits into Lanthanum 139 and Molybdenum-95, at the same time releasing 2 neutrons.

(i) Use the graph or otherwise to explain how energy is released in this reaction. **[5 marks]**

(ii) Explain also how the reaction can continue as a chain reaction. **[4 marks]**

**MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD**

**UNIVERSITY OF MALTA, MSIDA**

**MATRICULATION EXAMINATION**
**ADVANCED LEVEL**
**MAY 2016**

| | |
|---|---|
| **SUBJECT:** | PHYSICS |
| **PAPER NUMBER:** | II |
| **DATE:** | 23rd April 2016 |
| **TIME:** | 4.00 p.m. to 7.05 p.m. |

**A list of useful formulae and equations is provided.**

**This paper carries 40% of the marks for the examination.**
**It is expected that answers be accompanied by the proper units.**

## Section A

**Attempt all eight questions in this section. This section carries 50% of the total marks for this paper.**

### Question 1

a. A student made the following statement: *"Temperature measures the amount of heat in a body."*
In what ways is this statement incorrect? Your answer should include the terms: *thermal equilibrium, internal energy* and *heat transfer*. **[6 marks]**

b. The low pressure of a gas in a constant volume gas thermometer is measured at the boiling point of Sulfur and at the triple point of water. The pressure of the gas at the triple point of water is $4.20 \times 10^4$ Pa.
(i) State TWO ways that make the constant volume gas thermometer not suitable for routine temperature measurements. **[4 marks]**
(ii) Given that the pressure of the gas at the boiling point of Sulfur is $1.10 \times 10^5$ Pa, calculate the boiling point temperature of Sulfur. **[3 marks]**

### Question 2

In an experiment, steam from a boiler is allowed to mix with 0.30 kg of water at a temperature of 20 °C that is contained in a thick polystyrene cup. By the end of the experiment, the mass of water increased to 0.32 kg and its temperature rose to 56 °C.

a. Calculate:
(i) the heat energy gained by the 0.30 kg mass of water in the cup; **[2 marks]**
(ii) the heat lost by the 0.02 kg condensed steam; **[2 marks]**
(iii) the specific latent heat of vaporization of water. **[3 marks]**
(Assume that the temperature of steam is 100 °C and that the specific heat capacity of water is 4200 J $kg^{-1}K$)

b. The thermal capacity of the thick polystyrene was neglected in your calculation. State TWO advantages of using a *thick polystyrene* cup rather than a copper can for such an experiment. **[4 marks]**

## Question 3

The kinetic theory of an ideal gas shows that the pressure $P$ of one mole of the gas of volume $V$ is given by the equation

$$PV = \frac{1}{3} N_A m < c^2 >$$

where $N_A$ is the Avogadro's number, $m$ is the mass of each molecule and $< c^2 >$ is the mean square speed of the molecules.

a. Use the equation above to derive an equation for the pressure of the gas in terms of its density, $\rho$, and its mean square speed. **[3 marks]**

b. The graph in Figure 1 shows how the pressure of one mole of a certain gas depends upon its density. Assume that the gas behaves like an ideal gas.

(i) Use the graph to calculate a value for the root mean square speed of the molecules of the gas. **[5 marks]**

(ii) If one mole of the gas has a mass of 0.032 kg, calculate the temperature of the gas. **[3 marks]**

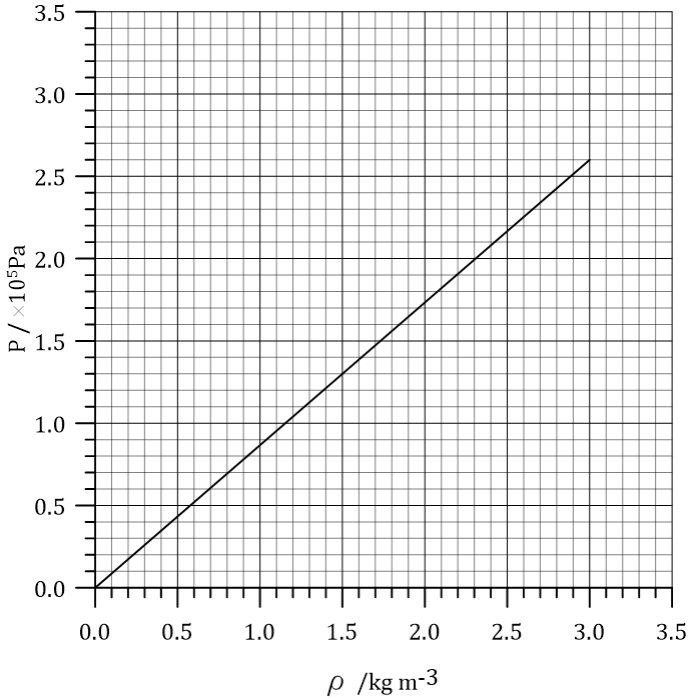


**Figure 1**

## Question 4

An alternating current supply of variable frequency is connected across a capacitor of capacitance 5.0 μF in series with an ammeter. The voltage across the capacitor is kept constant at 10 V.

a. Calculate the current through the circuit when the frequency of the supply is 500 Hz. **[4 marks]**

b. The space between the plates of the capacitor is filled with an insulator. How is it possible for the ammeter to show a current? **[4 marks]**

c. Explain why the current increases as the frequency is increased. **[3 marks]**

d. The capacitor is replaced by an inductor. How does the current change as the frequency is increased? Explain your answer. **[3 marks]**

## Question 5

The diagram in Figure 2 shows a positively charged large metal plate.

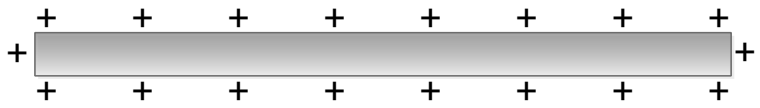

**Figure 2**

a. Copy the diagram and sketch the electric flux of the electric field near the plate. **[3 marks]**

b. Explain why the surface of the plate is an equipotential surface. **[3 marks]**

A similar, neutral metal plate is placed a few millimeters above, and with its plane parallel to the charged plate so that the two plates form a parallel plate capacitor.

c. Draw a diagram to show how the charges on the two plates are distributed when the upper plate is earthed. **[3 marks]**

d. If the plates are brought closer together, what will be the effect on
   (i) the electric field strength; **[3 marks]**
   (ii) the potential difference between the plates? **[3 marks]**

## Question 6

A radio waves detector D is placed at the top of a cliff. D detects waves directly from the source under study and waves reflected off the sea surface. The diagram in Figure 3 shows two wave trains which interfere at the detector.

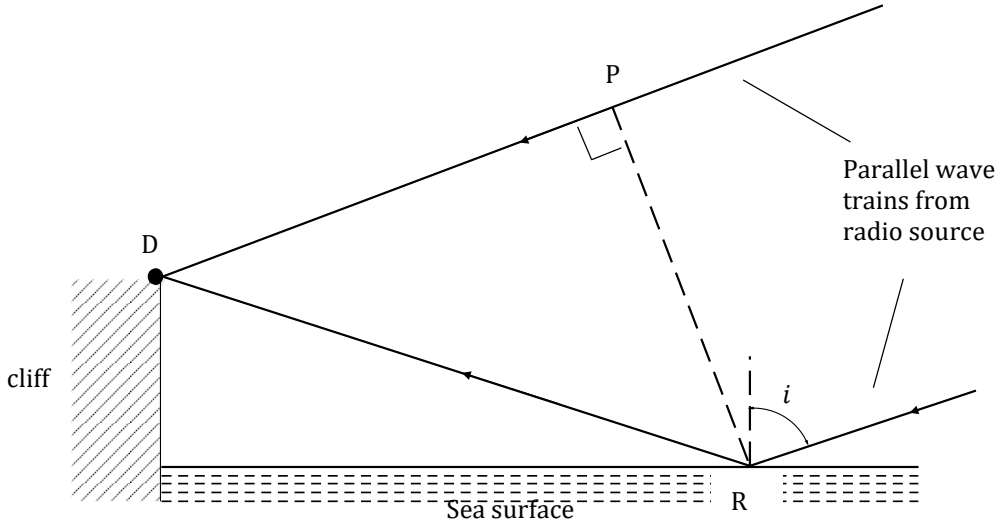


**Figure 3**

a. Explain why the path difference between the two wave trains is given by DR − DP. **[2 marks]**

b. Radio waves undergo a phase change of $\pi$, corresponding to half a wavelength, when reflected at the water surface at $R$. Describe how the intensity at the detector varies as a radio source emitting a single frequency rises above the horizon. **[5 marks]**

c. In one observation radio waves of frequency 23 MHz are received at the instrument. The angle of incidence, $i$ ,at $R$ is 85.00°. If the height of the cliff is 150.0 m, show that the signal at D is a minimum. **[6 marks]**

## Question 7

A ray of green light enters normally a glass block of refractive index 1.50 for green light. It then meets an air bubble inside the block at an angle of incidence of 20°.

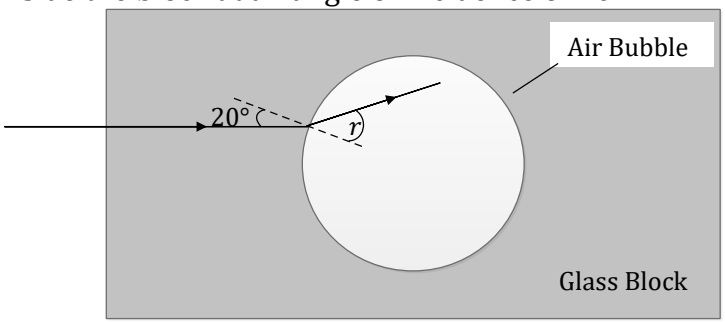


**Figure 4**

a.

(i) Calculate the angle of refraction, $r$, inside the air bubble. **[3 marks]**

(ii) Calculate the maximum angle of incidence, $c$, at which the green light can enter the air bubble. **[3 marks]**

(iii) A ray of *white light* is incident on the air bubble at the maximum angle of incidence, $c$, for green light determined in part (ii). Describe what happens to the white light at the point of incidence. **[3 marks]**

b. Green light enters and emerges from a water droplet in air. Assume that the water droplet has a spherical shape.

(i) Draw a diagram to show a ray of light travelling through the droplet. **[3 marks]**

(ii) Describe and explain, by using the diagram you have drawn in (b)(i), how the light which enters the water droplet may be partially reflected inside the droplet to emerge in a new direction. **[4 marks]**

## Question 8

In a simple metal detector an alternating current flows through a main coil. The magnetic field produced by the coil induces eddy currents in the metal. The eddy currents produce their own magnetic field which induces an e.m.f. in the pick-up coil.

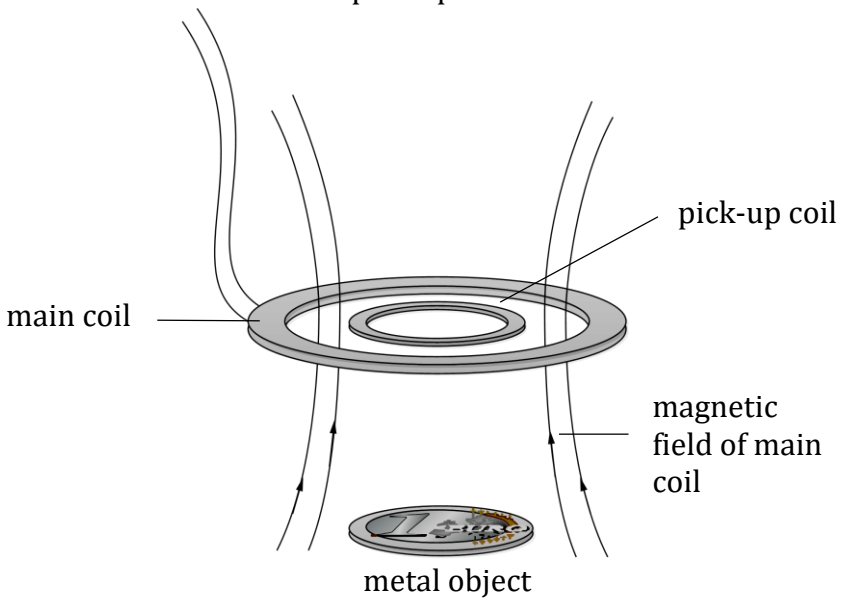


**Figure 5**

a.

(i) Why is an alternating current necessary for the detector to work? **[2 marks]**

(ii) Which would produce a stronger signal a lead or copper coin at the same depth in soil? Explain your answer. **[1 mark]**

b. When the detector detects a metal, there may be a *phase difference* between the transmitted and received signals. The phase difference depends on the *inductance and resistance* of the metal and can be used to distinguish between metals.

(i) Explain what is meant by *phase difference* through sketches of graphs that show how two varying voltages change with time. **[3 marks]**

(ii) What factors determine the *inductance* of a piece of metal? **[1 mark]**

## Section B

**Attempt any four questions from this section. Each question carries 25 marks. This section carries 50% of the total marks for this paper.**

### Question 9

The photograph and diagram show a toy boat powered by a heat engine. The copper tube is initially filled with water. When the water in the coil boils, the steam expands pushing water out of the tubes. The reaction pushes the boat forward. When the steam reaches the cold part of the tubes it condenses, pulling water back into the tubes to repeat the cycle.

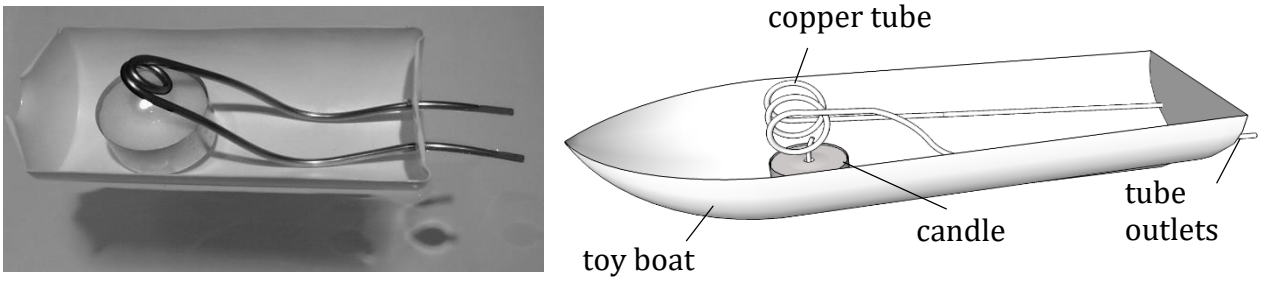


**Figure 6**

a.

(i) What is a heat engine? **[1 mark]**

(ii) Describe the energy conversions taking place as the toy boat moves through water. **[3 marks]**

(iii) The physics of heat engines is based on the Second Law of Thermodynamics. State this law in terms of heat engines. **[2 marks]**

(iv) An ideal heat engine takes in $\Delta Q_{hot}$ from a high temperature reservoir and rejects $\Delta Q_{cold}$ to a low temperature. Starting from the equation

$$\frac{\Delta Q_{hot}}{T_{hot}} = \frac{\Delta Q_{cold}}{T_{cold}}$$

obtain an equation for the efficiency of the heat engine working between the temperatures $T_{hot}$ and $T_{cold}$. **[4 marks]**

(v) By assuming that the water surrounding the toy boat is at a temperature of 20 °C, calculate the efficiency of an ideal heat engine working between the same temperatures as the toy boat engine. **[3 marks]**

b. Figure 7 represents an idealized Pressure-Volume diagram for the heat engine powering the toy boat.

Consider the following steps in the cycle:
AB: Converting water to steam,
BC: Expansion of steam,
CA: Condensation of steam to water at the cold temperature.

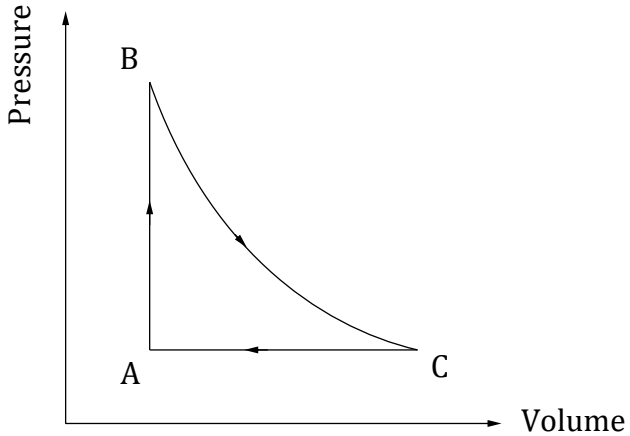


**Figure 7**

(i) In which part of the cycle is heat transferred (1) to the system; (2) from the system? **[2 marks]**

(ii) In which part of the cycle is work done (1) on the system; (2) by the system ? **[2 marks]**

(iii) What is the change in internal energy during one complete cycle ABC? Explain your answer? **[2 marks]**

c. In an experiment to determine the overall efficiency of the toy boat heat engine, the following data was obtained:

$$Enclosed\ area\ of\ P-V\ diagram = 0.15\ \text{mJ}$$
$$Number\ of\ cycles\ in\ 2\ minutes\ = 540$$
$$Mass\ of\ wax\ burned\ in\ 10\ minutes\ = \ 0.75\ \text{g}$$
$$Heat\ energy\ obtained\ by\ burning\ 1.0\ \text{g}\ of\ wax = 3200\ \text{J}$$

(i) Calculate the overall efficiency of the toy boat engine. **[5 marks]**

(ii) Comment on your result. **[1 mark]**

## Question 10

Figure 8 shows a skateboarder in a half pipe with a flat central portion.

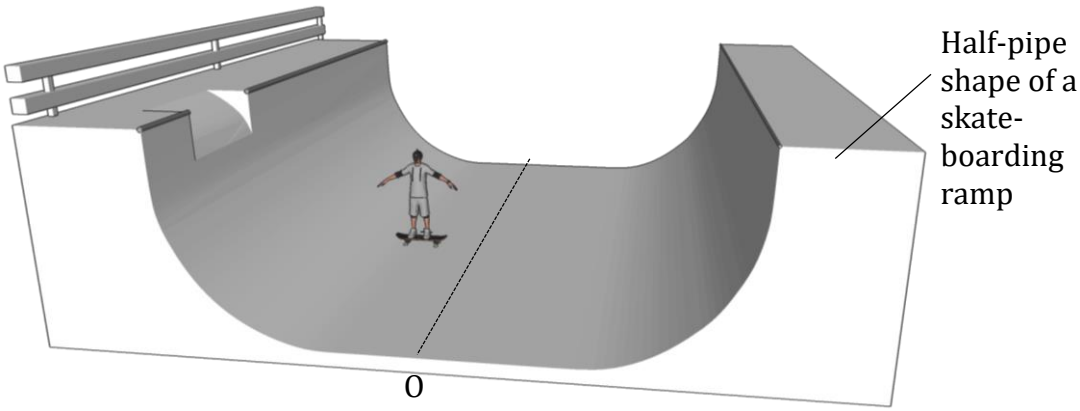


**Figure 8**

As a first approximation, **assume** that the motion of the skateboarder is *simple harmonic*. Figure 9 shows a displacement-time graph for the simple harmonic motion of the skateboarder.

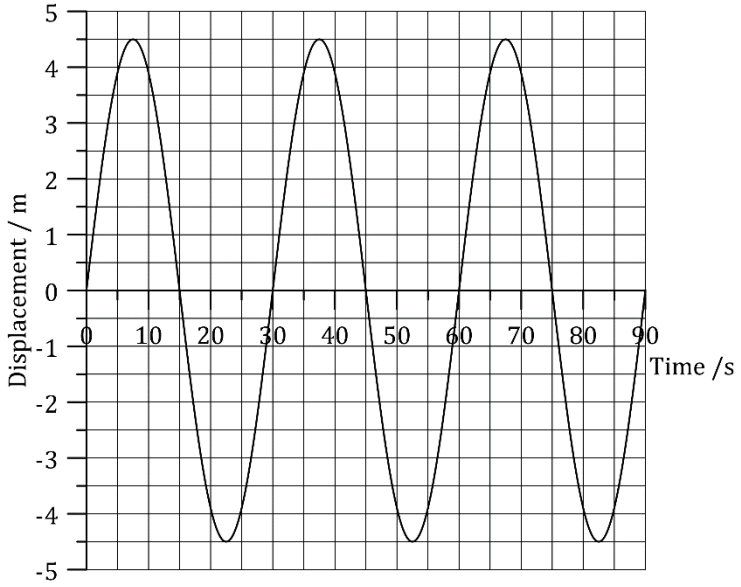


**Figure 9**

a. State the meaning of the terms *simple harmonic motion, period, amplitude.* **[4 marks]**

b. Use the graph to calculate the following quantities for the skateboarder:
   (i) maximum velocity; **[5 marks]**
   (ii) maximum acceleration; **[3 marks]**
   (iii) total energy if the mass of the skateboarder and skateboard is 75.0 kg. **[3 marks]**

c. If it is assumed that the motion is simple harmonic, the skateboarder has potential energy at any point away from the centre of oscillation $O$.
   (i) What is the source of this potential energy? **[2 marks]**
   (ii) Sketch a graph to show how the potential energy of the skateboarder changes with time over one complete cycle of the motion.(Assume that at time $t$ = 0, the skateboarder is at the centre of the oscillation). **[2 marks]**
   (iii) On the time axis, indicate the time values when the potential energy is zero. **[2 marks]**

d. Detailed analysis shows that the motion is not simple harmonic. Study the shape of the half pipe ramp and then, by considering the restoring force on the skateboarder, explain carefully the features of the half pipe which do not allow the motion to be simple harmonic. **[4 marks]**

## Question 11

a. An important measurement for a star, galaxy or a cluster (group) of galaxies is their Mass-to-Light ratio, that is, the mass of the star, galaxy or cluster divided by the total radiation emitted. The radiation emitted from stars, galaxies or clusters obeys the inverse square law relation.
   (i) Given that the intensity of solar radiation falling on the Earth's atmosphere is 1.37 kW $m^{-2}$ and that the Earth's orbit around the Sun, $R_E$, is $1.50 \times 10^{11}$ m, calculate the total radiant energy emitted by the Sun per second.
   (Surface area of a sphere of radius $r$ is given by $4\pi r^2$.) **[4 marks]**
   (ii) Write down an equation for the centripetal force acting on the Earth in terms of the period, $T$, of the Earth's orbit about the Sun. **[4 marks]**

(iii) Hence show that the mass of the Sun is given by $M_S = \frac{4\pi^2 R_E^3}{GT^2}$, where $G$ is the universal gravitational constant. **[3 marks]**

(iv) Calculate the mass of the Sun and hence the value of the Mass-to-Light ratio for the Sun.
(Take 1 year to be $3.2 \times 10^7$ seconds) **[3 marks]**

b. The mass of a cluster of galaxies may be obtained through measurements of the red shift of each galaxy. The red shift gives the line of sight velocity of the galaxy and hence the root mean square velocity, $\sqrt{< v^2 >}$, of the galaxies. The mass of the cluster is then obtained from the equation

$$M_C = \frac{< v^2 > R}{0.4\, G}$$

where $R$ is a dimension of the cluster called its half mass radius.

(i) Explain the meaning of *red shift* and describe how its measurement gives the line-of-sight velocity of the object. **[3 marks]**

(ii) Explain what is meant by the root mean square velocity of the galaxies. **[3 marks]**

(iii) For a cluster of galaxies, called the Coma cluster, $< v^2 >$ is $2.3 \times 10^{12}$ m$^2$ s$^{-2}$ and $R$ is $4.6 \times 10^{22}$ m. Calculate the Mass-to-Light ratio for this cluster if it is observed to emit a total radiant energy of $3.5 \times 10^{39}$ J per second. **[4 marks]**

(iv) Comment on the values of the two Mass-to-Light ratios you have calculated. **[1 mark]**

## Question 12

Figure 10 shows an evacuated circular tube in which protons can be accelerated. A uniform magnetic field of flux density $B$ acts in a direction perpendicular to the cross-sectional plane of the tube. The protons of mass $m$ move with speed $v$ in a circular path of radius $r$ in the direction shown by the arrows.

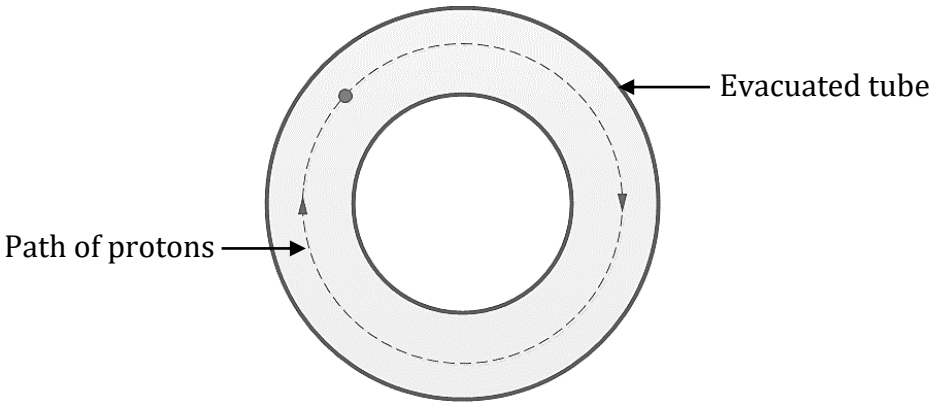


**Figure 10**

a.

(i) What is the direction of the magnetic field? **[1 mark]**

(ii) Show that the period of rotation, $T$, of the protons is given by $T = \frac{2\pi m}{Be}$. **[6 marks]**

(iii) In each case, state the effect, if any, on the period $T$ if,

- the radius of the proton orbit decreases, and
- the flux density of the magnetic field is doubled.

Assume all other factors remain constant. Explain your answers. **[4 marks]**

(iv) State and explain what action must be taken to contain protons injected at speed $2v$ within the tube. **[2 marks]**

(v) Explain why an electric field can change the energy of a charged particle, but although a magnetic field may accelerate a charged particle it cannot change its energy.

**[4 marks]**

b. To produce a beam of protons each with the same velocity $v$, the protons are allowed to travel through the velocity selector shown in the figure below:

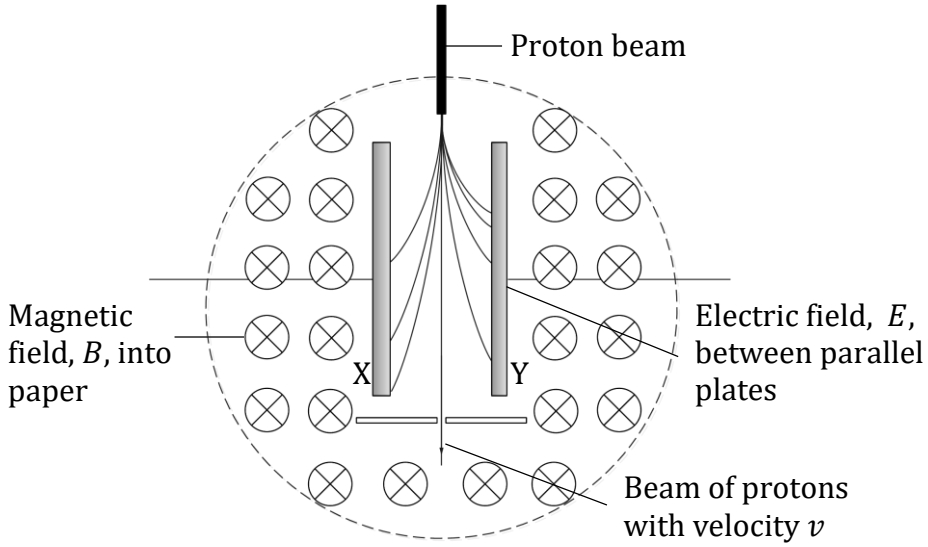


**Figure 11**

(i) What is the polarity of plate X? Explain your answer. **[4 marks]**

(ii) Obtain an equation for the speed of the protons when they leave the velocity selector, in terms of $E$ and $B$. **[2 marks]**

(iii) How may a proton beam of velocity higher than $v$ be selected? **[2 marks]**

## Question 13

a. The diagram in Figure 12 shows a solenoid carrying a current, $I_1$.

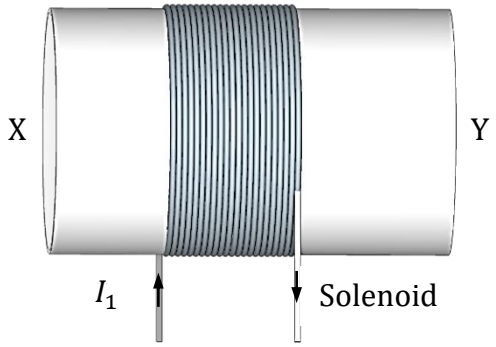


**Figure 12**

(i) Copy the diagram in Figure 12 and draw the magnetic flux around the solenoid. **[4 marks]**

(ii) Indicate the magnetic polarity of each face (X and Y) of the solenoid. **[2 marks]**

b. A pivoted wire frame is partly inserted inside the solenoid as shown in Figure 13. The plane of the frame and the axis of the solenoid are initially horizontal. The frame can be returned to the horizontal plane by loading side CD.

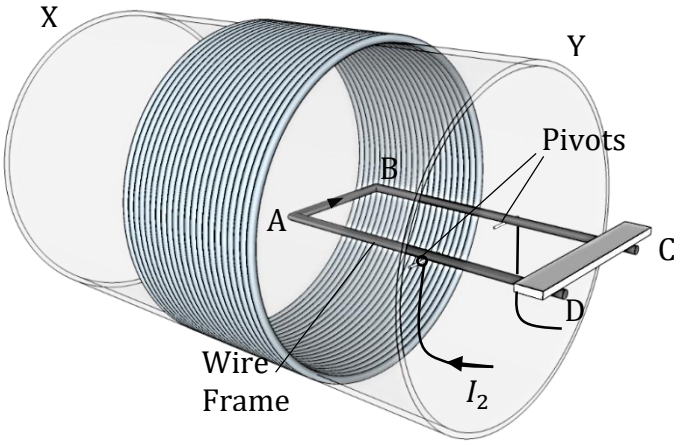


**Figure 13**

(i) Sketch the magnetic flux around the current carrying wire AB when situated close to the centre of the solenoid while current $I_2$ is flowing through it. **[4 marks]**

(ii) With reference to the sketch drawn in part (i), describe and explain what you would observe when a current, $I_2$ , flows through the frame in the direction shown in the diagram. **[4 marks]**

(iii) Describe how the apparatus may be used to measure the flux density, $B$, inside the solenoid when the current through the solenoid is $I_2$. Your account should include:

- a circuit diagram to show how the wire frame may be connected to a source of current. **[3 marks]**
- a description of how the final result can be obtained from an appropriate graph. **[8 marks]**

## Question 14

A student devised a capacitor circuit to monitor the speed of moving blocks of wood on a conveyor belt. In the space between the moving blocks the position of the switch $S$ allows charging of the capacitor $C$ to a voltage $V_0$ supplied by the battery. As a wooden block moves over the switch, the charging stops and the capacitor starts discharging through the resistance box, $R$.

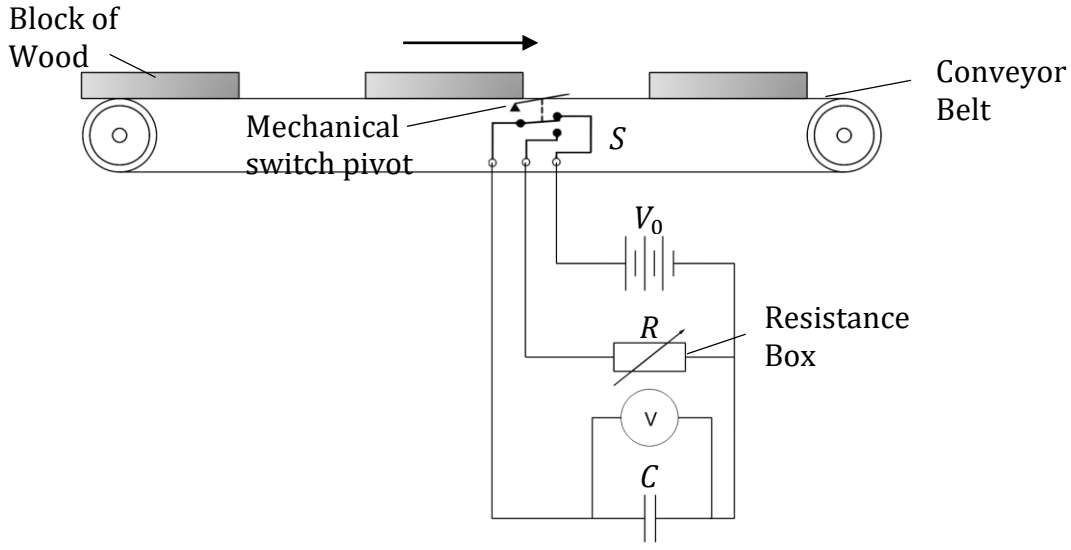


**Figure 14**

The time, $t$, during discharge is equal to the time taken by the wooden block to pass over the switch. During discharge, the voltage on the voltmeter falls to $V$. For a given length of wooden blocks, the speed of the blocks on the conveyor belt can be determined.

a.

(i) Write down an equation relating, the quantities $V$, $V_0$, $t$, $R$, and $C$. **[2 marks]**

(ii) Hence write down an equation for $\ln V$ in terms of the other quantities. **[2 marks]**

b.

(i) Describe briefly how, by changing the value of the resistance box, $R$, the student would repeat the experiment so that the time, $t$, can be obtained from a graph. **[5 marks]**

(ii) How is the value of time $t$ obtained from the graph? **[3 marks]**

c. The student knows that the velocity of the wooden blocks is about 10 m $s^{-1}$ and that the blocks are about 0.5 m long.

(i) Calculate the discharging time, $t$. **[3 marks]**

(ii) Determine the capacitance $C$ of the capacitor for a mean value $R$ of 5000 Ω if the student plans to have the discharging time about two times the time constant $RC$. **[4 marks]**

(iii) What do you expect to happen if the capacitance of the capacitor and the resistance of the resistance box are much higher than the values in part (ii)? **[3 marks]**

(iv) Explain why the voltmeter must have a very high resistance for this experiment to succeed. **[3 marks]**

## Question 15

A student observes a narrow slit, $S$, well-illuminated by monochromatic blue light, through an adjustable slit $S_a$ held close to one eye from a distance of about 4 m in a dark room.


**Figure 15**

a.

(i) With the help of appropriate diagrams describe what the student observes on looking at slit $S$ through slit $S_a$

- when $S_a$ is about 1 mm wide; **[4 marks]**
- when $S_a$is almost closed. **[3 marks]**

(ii) What change would be observed if the monochromatic blue source of light is replaced by a red source? **[1 mark]**

b. The student replaces the adjustable slit $S_a$ by a blackened microscope slide, shown in Figure 16, on which two parallel clear lines have been drawn to produce two narrow slits.

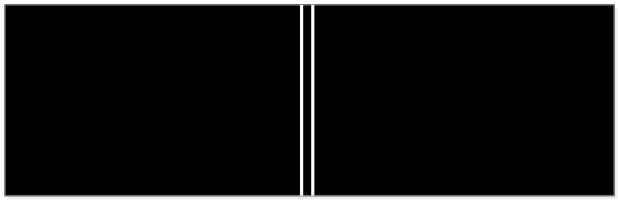

**Figure 16**

Describe how the pattern produced when slit $S$ is observed through a single slit is modified. Your description should include a sketch of a graph to show how the intensity varies across the field of view. **[5 marks]**

c. The slit S is now replaced by a metal foil with two pinholes, $P_1$ and $P_2$ illuminated by monochromatic light. The pinholes are several millimetres apart.

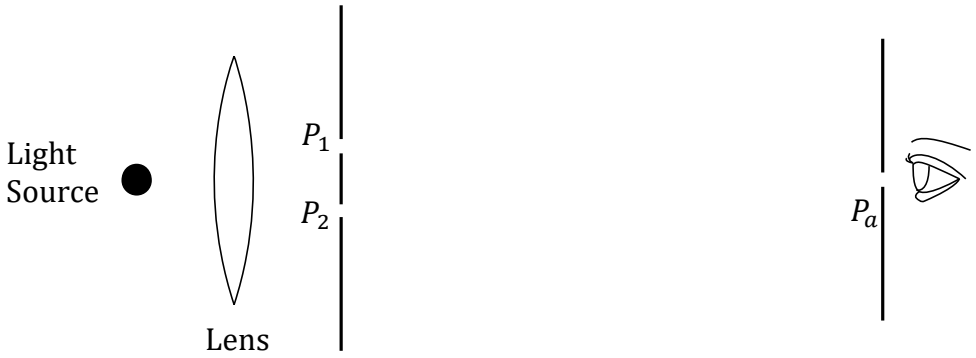


**Figure 17**

The two pinholes are observed through the circular aperture $P_a$. The diameter of the aperture can be varied. Initially the two pinholes are observed through the adjustable aperture when the latter is at its widest.

With the help of appropriate graphs, describe what is observed as the width of aperture is gradually decreased. **[7 marks]**

d. In one such experiment, the distance between the two pinholes was 3.0 mm, and they were illuminated by light of wavelength 600 nm. If the distance from the pinholes to the adjustable circular aperture was 4.50 m, what was the diameter of the aperture when the two pinholes were just resolved? **[5 marks]**

**Index No.:**_____ **AM 26/III.16m**

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| | |
|---|---|
| **SUBJECT:** | PHYSICS |
| **PAPER NUMBER:** | III - *Practical* |
| **DATE:** | 31st May 2016 |
| **TIME:** | 2 hours 5 minutes |

**Experiment:** Experiments with Springs

**Apparatus:** stand and clamp, stopwatch, coil springs, metre ruler, hanger and weights

**Important Note:**

- Do not leave the springs loaded with weights unnecessarily. Failure to follow these instructions may incur damage to the apparatus and loss of time.
- Take the acceleration due to gravity $g = 9.81\ \text{m s}^{-2}$ unless otherwise stated

**Diagram:**

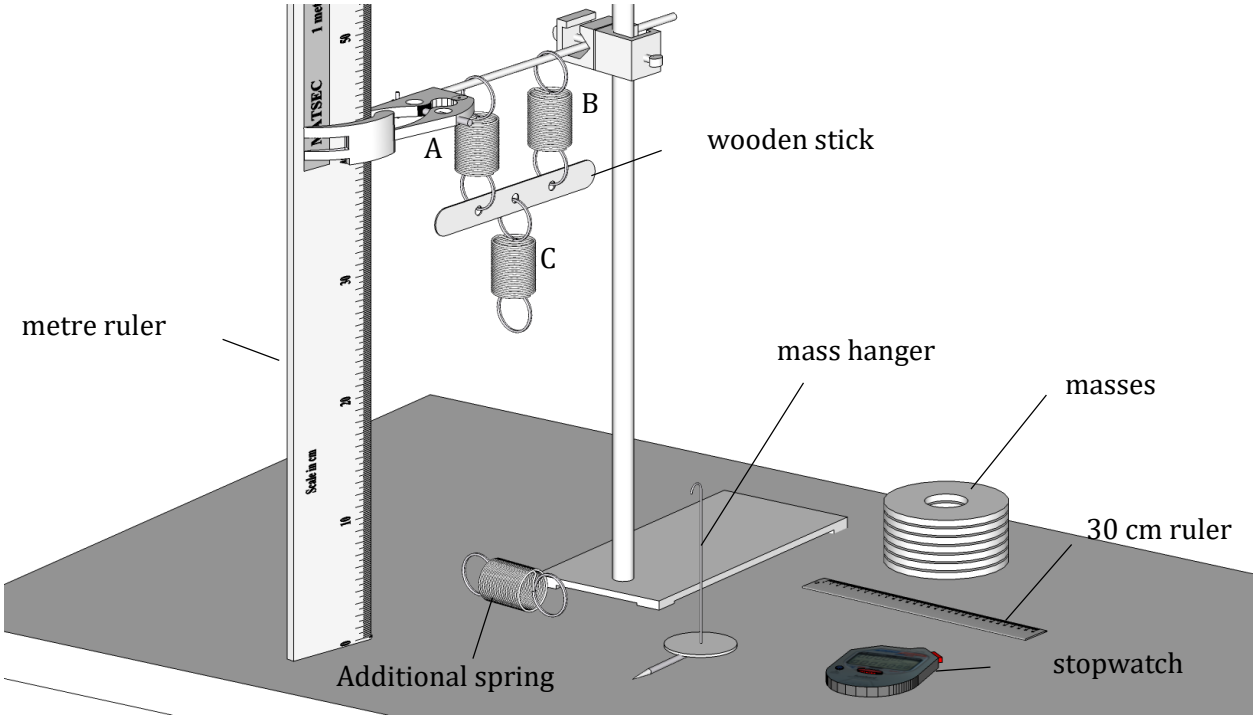


**Figure 1 The experimental setup**

**Method – Part A:**

1. The apparatus is set up for you. Make sure that you have all the apparatus that is shown in the diagram of Figure 1.
2. The four springs provided are made of a thin steel wire wound up in the form of a coil.

3. Use the 30 cm ruler to measure the length of the coiled part of the additional spring that is provided. Record your readings in Table 1.

**Table 1**

| Length $L_1$ /m | Length $L_2$ /m | Length $L_3$ /m | Average Length $L$/m |
|---|---|---|---|
| $\pm$ | $\pm$ | $\pm$ | |
| | | | |

**[5 marks]**

4. Use the ruler to measure the diameter of the coils of the spring. Record your readings in Table 2.

**Table 2**

| Diameter $D_1$ /m | Diameter $D_2$ /m | Diameter $D_3$ /m | Average Diameter $D$/m |
|---|---|---|---|
| $\pm$ | $\pm$ | $\pm$ | |
| | | | |

**[5 marks]**

5. Count the number of complete turns $N$ of wire that make the coiled part of the spring.

   $N =$ _____ **[1 mark]**

6. Use the space below to calculate the diameter $d$ of the steel wire that makes up the coiled part of the spring.

   _____

   $d =$ _____/ m **[1 mark]**

7. The spring constant of the spring depends on its dimensions by the equation $k = \frac{Gd^4}{8ND^3}$ where $G$ is the rigidity modulus.

8. Use the equation in part 7 to calculate the spring constant $k$, given that the rigidity modulus $G$ is $9.25 \times 10^{10}$ Pa.

   _____

   _____

   _____

   _____

**[2 marks]**

9. The system of springs that you are provided with consists of three identical springs A, B and C. Springs A and B are attached in parallel and the third spring C is attached in series with A and B.
10. Attach the hanger and ONE mass to spring C and read the position of the arrow on the metre ruler. Record this in the field $y_0$ of Table 3. Refer to Figure 2. **[1 mark]**

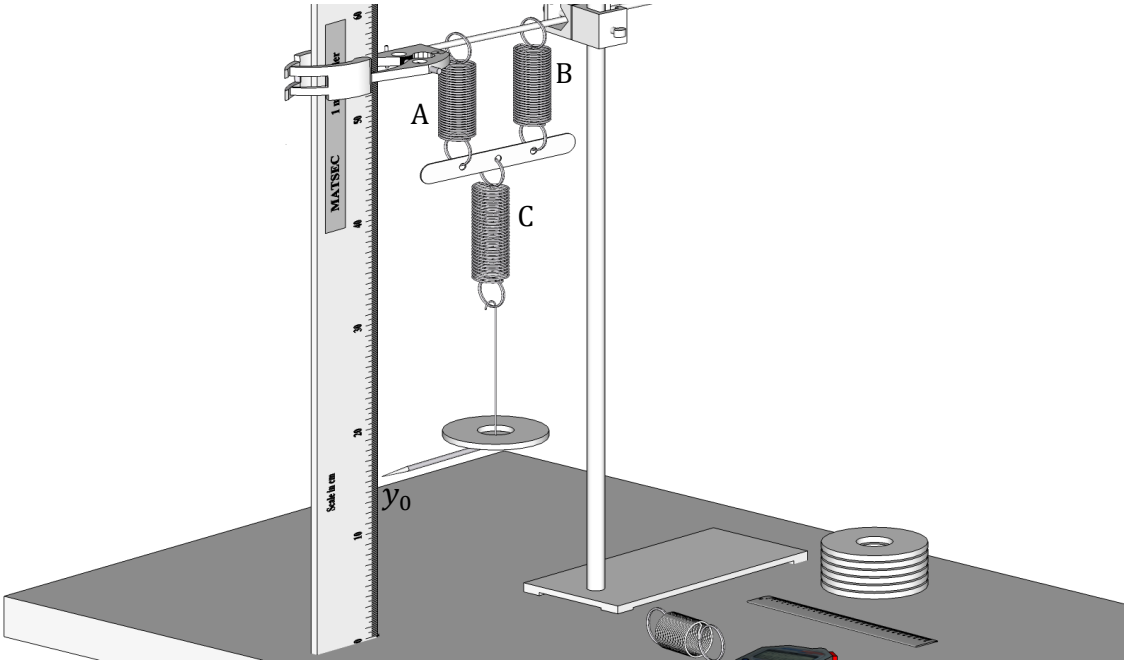


**Figure 2**

11. Start adding masses on to the hanger and each time record in Table 3 the position $y_1$ that the arrow settles on. **[6 marks]**
12. Repeat step 11 for the number of available masses.

**Table 3**

| $y_0$ /m | | | |
|---|---|---|---|
| Number of Masses | Mass $m$/ kg | $y_1$/ m | $y = \lvert y_1 - y_0 \rvert$/ m |
| | $\pm$ | $\pm$ | |
| 1 | | | 0.000 |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |

13. Given that each mass is $0.052 \pm 0.001$ kg, complete Table 3 by working out the missing values for $m$ and the extension of the spring $y$. **[11 marks]**
14. The system of springs obeys Hooke's law, that is, the total extension of the system of springs is proportional to the weight attached, unless the elastic limit is not exceeded. This is represented by the equation

$$mg = Ky$$

where $K$ is the equivalent spring constant of the system with three springs.

15. Plot a suitable graph that will enable you to determine the equivalent spring constant $K$ of the system of springs. **[10 marks]**
16. Use your graph to determine the equivalent spring constant $K$.

**[3 marks]**

17. The spring constant of the system with three springs is related to the spring constant of a single spring $k$ by the equation $K = \frac{2}{3}k$.
18. Use the space below and the values of $k$ and $K$, obtained from part 8 and part 16 respectively, to work out the ratio $\frac{k}{K}$. Comment on the result by making reference to the statement in part 17.

**[3 marks]**

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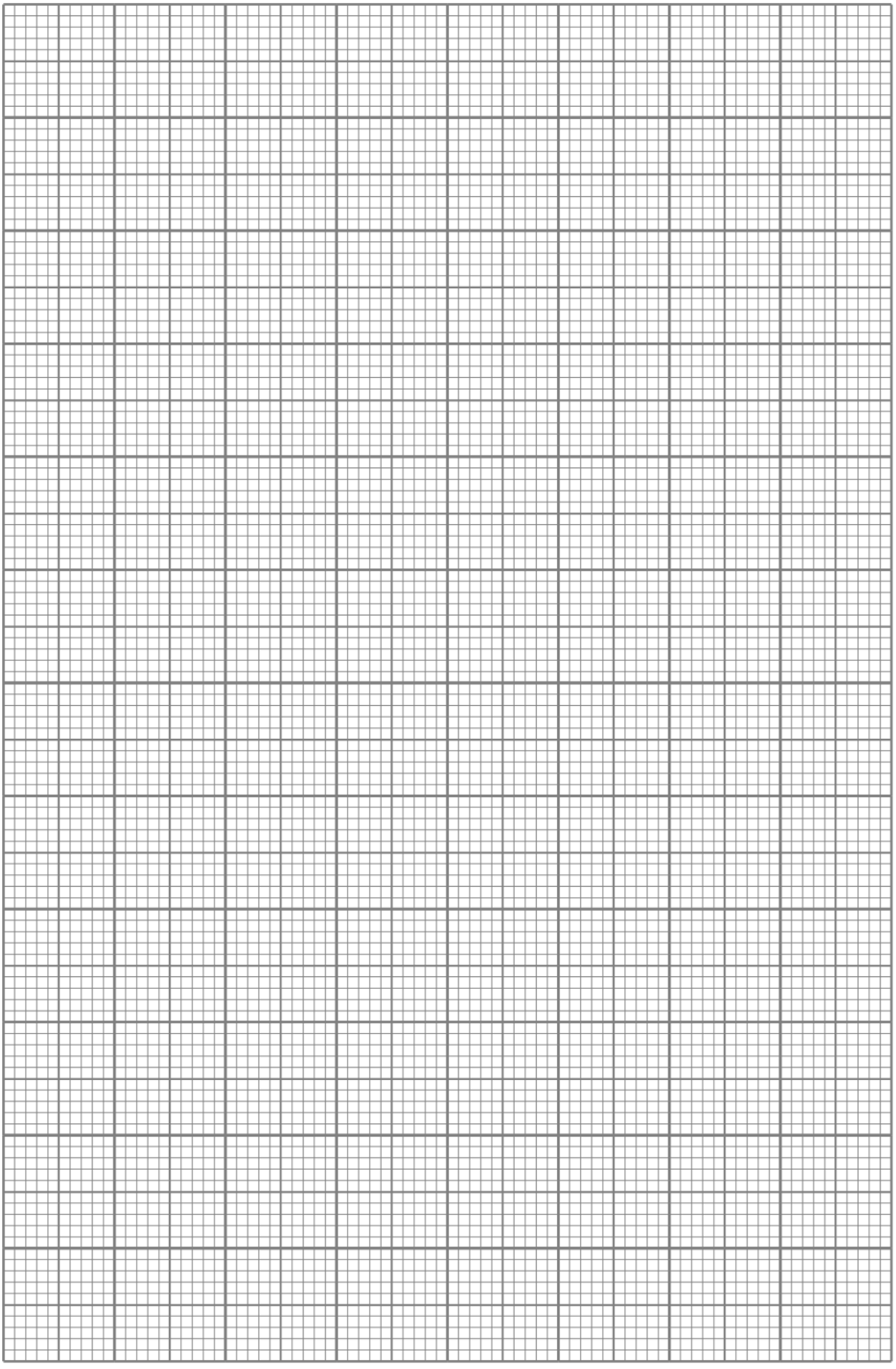


## Method – Part B:

19. In this part, the masses that will be loaded on the system with three springs will be made to perform small vertical oscillations.
20. Load TWO masses on the mass hanger and attach them to spring C.
21. Gently, pull down on the mass hanger and release it so that it performs small vertical oscillations.
22. Record the time in seconds for 20 oscillations of the suspended masses in one of the columns $T_{20}$/ s of Table 4. **[1 mark]**
23. Take repeated readings. **[2 marks]**
24. Repeat parts 21 to 23, each time adding a single mass on the hanger and recording the time for 20 oscillations. **[12 marks]**

**Table 4**

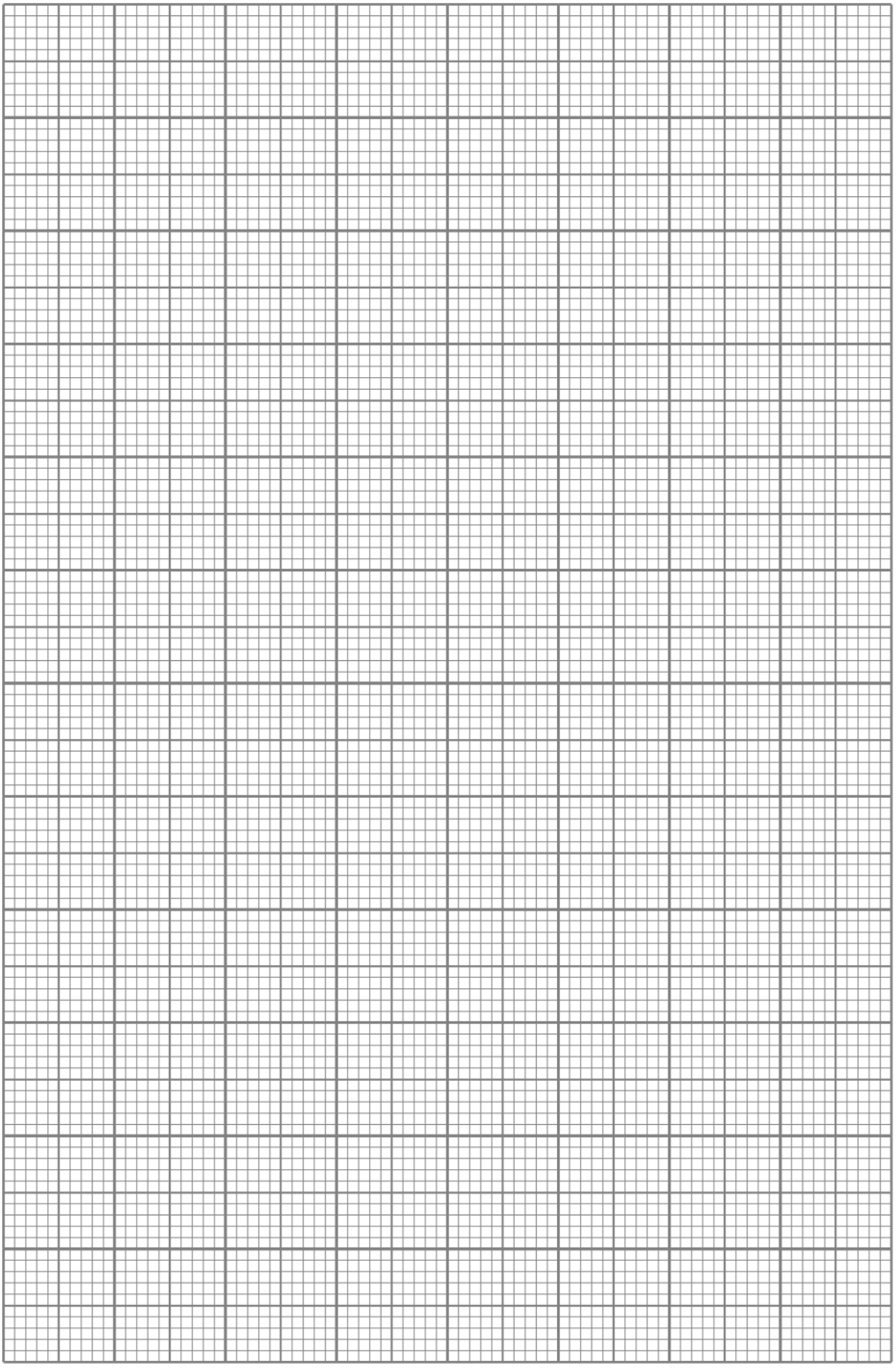
| Number of Masses | Mass $m$/ kg | $T_{20}$/s | $T_{20}$/s | $T_{20}$/s | $\overline{T_{20}}$/s | $T$ / s | $T^2$/s$^2$ |
|---|---|---|---|---|---|---|---|
| | $\pm$ | $\pm$ | $\pm$ | $\pm$ | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |

25. $\overline{T_{20}}$ is the mean value of the repeated readings taken and $T$ is the periodic time. Complete Table 4 by filling in the missing data. **[15 marks]**
26. It is given that the periodic time $T$ is related to the mass $m$ by the equation

$$T^2 = \frac{4\pi^2}{K}(m + m_h + m_{eff})$$

where $m_h$ is the mass of the hanger and $m_{eff}$ is the effective mass of the three spring system.

27. Plot a graph of $T^2$ on the y-axis against $m$ on the x-axis. **[10 marks]**



28. The mass of the hanger $m_h$ is equal to 0.017 kg. Rearrange the equation in part 26 in the form $y = mx + c$ and use your graph to obtain a value for the effective mass $m_{eff}$ of the three spring system.

**[6 marks]**

29. The effective mass $m_{eff}$ of the three spring system is one third the total mass of the three springs and wooden stick. Given that wooden stick has a mass of 0.0012 kg, determine the mass of one spring.

**[4 marks]**

30. State ONE source of error and ONE corresponding precaution undertaken during the experiment of part B.

**[2 marks]**