MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

UNIVERSITY OF MALTA, MSIDA

MATRICULATION EXAMINATION
ADVANCED LEVEL
MAY 2014

SUBJECT:	PHYSICS
PAPER NUMBER:	I
DATE:	27th May 2014
TIME:	9.00 a.m. to 12.00 noon

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. State the conditions for static equilibrium. **[2 marks]**

b. A uniform 6.0 m long pole has a mass of 50 kg. In order to move it around, two persons need to carry it. One holds it 0.2 m from one end and the other holds it 2.0 m from the other end.

(i) Draw a free body diagram that shows the pole while being supported horizontally. **[3 marks]**

(ii) Calculate the weight each person is supporting. **[4 marks]**

(iii) What must be the condition for the two people to carry the same weight? **[1 marks]**

Question 2

a. A small point mass m moves in a circular path of radius r at a constant speed v. Show that its acceleration a is equal to $\frac{v^2}{r}$. **[7 marks]**

b. A mass of 250 g is rotated in a horizontal circle at 6 revolutions per minute by means of a 1.5 m long string, as shown in Figure 1.

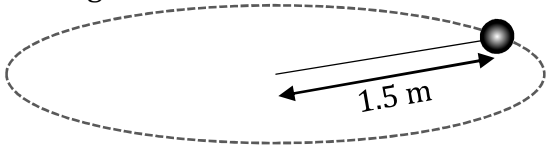


Figure 1

(i) Find the tension in the string. **[2 marks]**

(ii) Had the stone been rotated in a vertical circle, state whether the tension in the string would remain constant, and if not, where it would be maximum. Derive an expression that could be used to determine this maximum value of the tension in the string. **[3 marks]**

(iii) If the string breaks while the mass is being rotated horizontally, explain what happens to the mass. **[2 marks]**

Question 3

In 1905, Albert Einstein published an important paper to explain photoelectric emission.

a. What is photoelectric emission? **[2 marks]**

b. Why did classical wave theory fail to explain such a phenomenon? **[3 marks]**

c. In what way did Einstein's theory of photoelectric emission overcome the shortcomings of classical wave theory? **[2 marks]**

d. A piece of calcium is irradiated with a monochromatic source of light. If calcium has a work function of 2.87 eV, calculate:
   (i) the work function of calcium in joules; **[2 marks]**
   (ii) the threshold frequency for calcium; **[2 marks]**
   (iii) the maximum wavelength that produces photon emission. **[2 marks]**

Question 4

a. A student had to go up three flights of stairs for her classroom. If she is early, she goes up slowly but if she is late she goes up quickly. Explain a similarity and a difference between the two cases on the basis of the work done and power used. **[4 marks]**

b. As the girl goes up the stairs she feels her heart beating faster. If as a result of the activity her pulse rate increases to 82 beats per minute and 31 g of blood is accelerated from 0.19 m s^{-1} to 0.35 m s^{-1} during each beat, calculate:
   (i) the increase in kinetic energy of the blood with each heartbeat; **[3 marks]**
   (ii) the power of the heart when it is beating at 82 beats per minute. **[2 marks]**

c. Show that power may be written also as $force \times velocity$. **[2 marks]**

Question 5

a. Two balls of exactly the same mass and shape are released from a point 1.0 m above the ground at exactly the same time. One of the balls falls freely vertically down while the other is allowed to slide down a frictionless 3.0 m long incline, as shown in Figure 2. Which of the two balls will reach the ground first. Explain your answer. **[2 marks]**

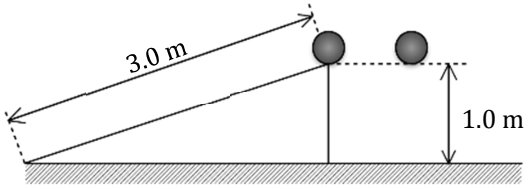


Figure 2

b. One of the balls is hit with a piece of wood such that it is projected at an angle of 45° with a velocity of 30 m s^{-1} across horizontal ground. Neglecting air resistance, calculate:
   (i) the vertical and horizontal components of the initial velocity; **[2 marks]**
   (ii) how long it takes to reach maximum height and the total time of flight; **[4 marks]**
   (iii) the maximum height reached and horizontal distance travelled; **[4 marks]**

c. What would have been the effect on the horizontal distance travelled had the angle been changed to another value assuming the same initial velocity? **[2 marks]**

Question 6

a. While the speed of a car going round a roundabout may be constant, its velocity will change. Explain this statement. **[4 marks]**

b. The equation to determine air drag is:

$$F_D = \tfrac{1}{2}\rho v^2 C_D A$$

Where: F_D = drag force
ρ = density of the air
v = speed of the object relative to the air
C_D = drag coefficient
A = frontal area

(i) Assuming that the equation is homogenous, determine the base units, if any, of C_D . **[4 marks]**

(ii) Explain why an equation which is homogenous with respect to its base units is not necessarily a correct physical equation. **[2 marks]**

(iii) From the equation, what is the factor that has the greatest effect on air drag? Explain your answer. **[2 marks]**

Question 7

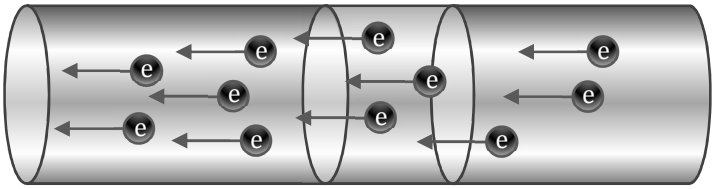


Figure 3

a. Figure 3 shows a conductor of cross sectional area A, length l, carrying n charges per unit volume each of charge e and moving with a velocity v. Derive an equation for the current I passing through the conductor. **[5 marks]**

b. Consider a piece of good conducting material and a piece of *extrinsic* semiconducting material of the same dimensions which are connected end to end, as shown in Figure 4.

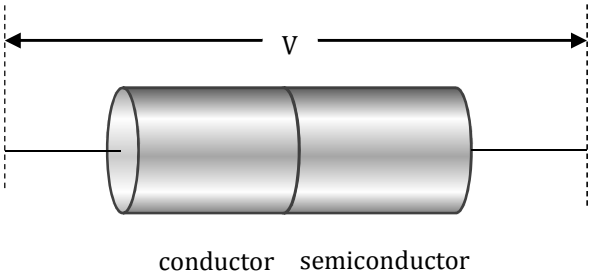


Figure 4

(i) By referring to the simple band theory, briefly explain how conduction occurs in conductors and in extrinsic semiconductors. **[4 marks]**

(ii) If a potential difference of V volts is applied across the combination, how would the drift velocities in the two materials compare. Explain your answer. **[3 marks]**

Question 8

a. In the circuit shown in Figure 5, with the resistance box set at 20.0 Ω, the high resistance voltmeter reads 12.0 V when switch S is open but only 8.0 V when closed. Explain these observations. **[3 marks]**

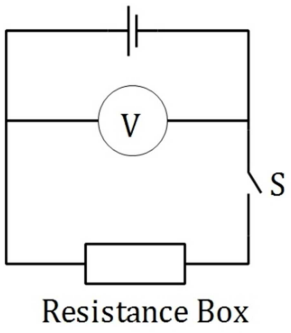


Figure 5

b. What is the current through the resistance box when it is set at 20.0 Ω and switch S is closed? **[1 mark]**

c. Describe qualitatively how the voltmeter reading changes as the resistance of the resistance box is increased to a high value. In your description, include a graph of voltmeter reading (V) against resistance (R), indicating clearly the value of V when R is very high. **[5 marks]**

d. The resistance box is replaced by a 12 V 48 W lamp.
   (i) Calculate the maximum current that can be supplied by the cell. **[3 marks]**
   (ii) Will the lamp light up at normal brightness? **[2 marks]**

Section B

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

Question 9

a. State Newton's Second Law of motion. **[2 marks]**

b. In order to change the motion of a body, an *impulse* must be applied.
   (i) Define the term impulse. **[2 marks]**
   (ii) Using the concept of impulse, explain the use of a thick air filled cushion as the landing platform by high jump athletes. **[4 marks]**

c. A water rocket is a type of model rocket which uses water as a propellant. A used plastic soft drink bottle is partly filled with water. The pressure of the air inside the bottle is increased by pumping in more air through a nozzle using a bicycle pump. When the pump is disconnected water rushes out of the nozzle and the rocket is propelled forward.

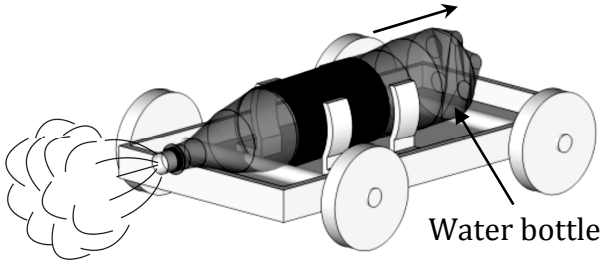


Figure 6

   (i) What is the advantage of using water rather than compressed air as a propellant? **[1 mark]**

One such rocket is tied to a carriage which can move on a pair of smooth, horizontal rails. At one instant of its motion, the rocket has a mass of $M + \Delta M$ and velocity V with respect to the ground and ejects a mass of water ΔM at velocity $v_e - V$ with respect to the ground.

(ii) What is the momentum of the rocket before ejecting the mass ΔM of water? **[1 mark]**

(iii) If after ejecting mass ΔM of water the rocket's velocity is V+ΔV, what is then the total momentum of the rocket and ejected water? **[2 marks]**

(iv) Show that the change in velocity of the rocket is $\Delta V = \frac{1}{M}\Delta M v_e$. **[3 marks]**

(v) If the above change takes place in time Δt, what is the forward force acting on the rocket at this instant? **[2 marks]**

d. As part of the operations in a quarry, gravel is moved from one side to another by means of a conveyer belt moving horizontally at 5 m s^{-1}.

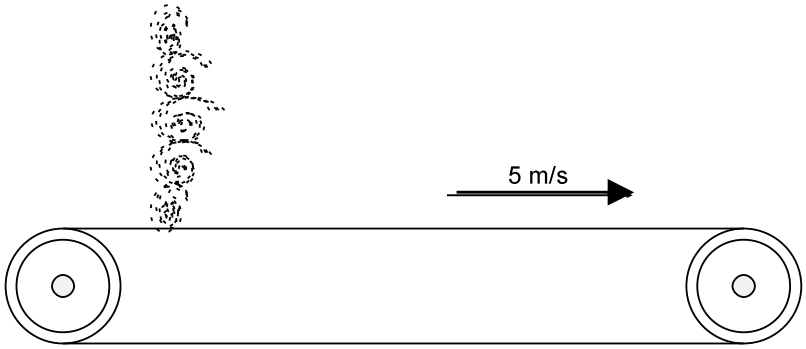


Figure 7

(i) If 750 kg of gravel are dropped vertically onto the conveyer belt per minute, calculate the extra power required to keep the conveyer belt moving. **[4 marks]**

(ii) Why is this extra power required? **[2 marks]**

(iii) What assumption have you made in your calculation? **[2 marks]**

Question 10

a. A moon orbits a planet in two Earth days at a distance of 5000 km.

(i) Draw a free body diagram to show the direction of the forces on the moon, its velocity and acceleration relative to the centre of the planet. **[3 marks]**

(ii) Define angular velocity. **[1 mark]**

(iii) Calculate the angular and linear velocities of the planet. **[4 marks]**

b. A driver, racing a small car of mass 400 kg has to navigate around a winding track. Part of the track includes a bend banked at 55° and radius 30.0 m.

(i) Draw a diagram to clearly show all the forces involved, including the components as the car is passing from the banked section. **[3 marks]**

(ii) Obtain an equation for the maximum velocity that the car can have when going round the bend and hence determine a value for this maximum velocity. **[6 marks]**

(iii) If the speed of the car increases beyond this value, what happens to the car? **[3 marks]**

(iv) What angle of banking would be needed for the speed of the car to increase to 100 km hr^{-1}? **[2 marks]**

(v) What did you assume to calculate this value? **[1 mark]**

(vi) Calculate the centripetal force under these conditions. **[2 marks]**

Question 11

a. For α, β^-, β^+, and γ radiation emitted by a radioactive nuclide, list:
   (i) the mass, in terms of the electron mass, m_e, associated with each radiation; **[2 marks]**
   (ii) the charge, in terms of the electronic charge, e, associated with each radiation; **[2 marks]**
   (iii) What effect, if any, does the emission of each of these radiations have on the nucleon number, A, and the proton number, Z, of the emitting nucleus. **[3 marks]**

b. The isotope of radon gas, $^{212}_{86}$Rn, emits α particles becoming the element Polonium (P_o). Write down a nuclear equation for this transformation. **[1 mark]**
   (i) If the atomic mass of ^{212}Rn is 211.990697 u, that of the daughter isotope of Polonium is 207.981222 u and that of the α particle is 4.002603 u, how much energy, in MeV, is available as kinetic energy? **[5 marks]**
   (ii) The energy of the α particles is found to be 6.27 MeV. Why is this value different from the one you have calculated above? **[1 mark]**

c. The half-life of radon may be determined by pumping some of the gas into an ionization chamber as shown in Figure 8.

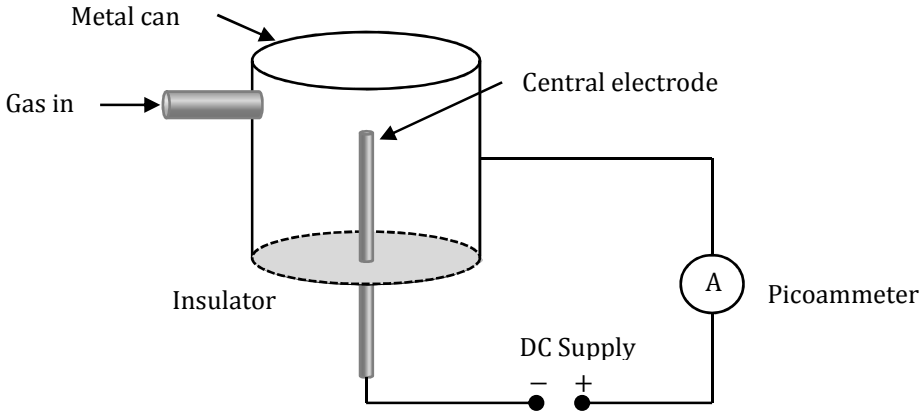


Figure 8

   (i) Explain why, when a certain mass of gas is forced into the chamber, the picoammeter registers a current which decreases with time. **[5 marks]**
   (ii) Describe how the half-life of radon may be determined and show how it can be calculated from an appropriate straight line graph. **[6 marks]**

Question 12

a. Briefly explain the concept of moment of inertia of a rigid body in a qualitative manner. **[2 marks]**

b. A flywheel of moment of inertia 25 kg m^2 is mounted on a horizontal axle. A constant torque of 450 N m is applied to the edge of the flywheel so that it rotates. Calculate:
   (i) the angular velocity gained in 3 s; **[3 marks]**
   (ii) the number of revolutions made by the wheel before coming to rest if, after 3 s, the applied torque is replaced by an opposing torque of 16 N m^{-1}. **[5 marks]**

c. State the principle of conservation of angular momentum. **[2 marks]**

d. Two cords are attached to a uniform cylinder that has a radius of 15 cm. The cords are wound around it and hung from the ceiling, as shown in Figure 9. The cylinder is released from rest and the cords unwind as the cylinder descends.

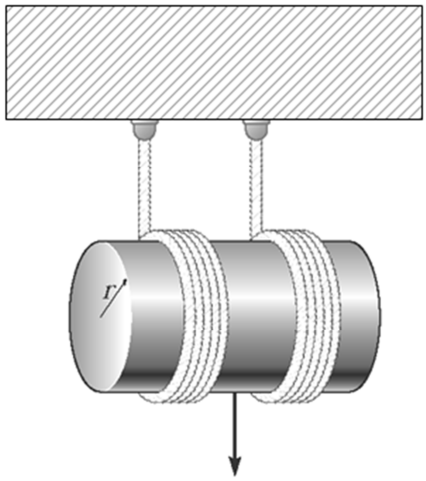


Figure 9

As the cylinder accelerates downwards with an acceleration a, the tension in each cord is T and the cylinder has an angular acceleration α.

(i) Derive an expression for T in terms of the mass of the cylinder m, its acceleration a and the acceleration due to gravity g. State any sign convention you adopt. **[2 marks]**

(ii) Given that the moment of inertia of the cylinder is I, show that the tension in each cord is given by $T = \frac{Ia}{2r^2}$. **[2 marks]**

(iii) If the moment of inertia of a cylinder is given by $I = \frac{1}{2}mr^2$, show that the angular acceleration α of the cylinder is given by $\alpha = \frac{2g}{3r}$ **[5 marks]**

(iv) Calculate the angular acceleration of the cylinder. **[1 mark]**

(v) If it takes 4 seconds for the cords to unwind, calculate the length of each cord that was coiled on the cylinder. **[3 marks]**

Question 13

a. What is resistivity? **[2 marks]**

b. How is resistivity related to conductivity? **[2 marks]**

c. An aquarium heater rated at 1000 W and 240V has a heating element made from a thin metal strip 0.2 mm wide and 0.15 mm thick.

(i) What is the resistance of the wire? **[2 marks]**

(ii) If the resistivity of this metal is 1.9×10^{-6} Ω m, what should be the length of the heating element? **[2 marks]**

(iii) Calculate the potential gradient along the metal strip. **[2 marks]**

d. A coil of wire has a resistance 7.00 Ω at 50°C and 5.00 Ω at 10°C.

(i) Define the temperature coefficient of resistance. **[2 marks]**

(ii) What is the value of the temperature coefficient of resistance of the wire? **[4 marks]**

e. State Kirchoff's first and second laws. **[2 marks]**

f. A student has set up the circuit shown in Figure 10. The circuit has one unknown emf source, E and an unknown resistor, R.

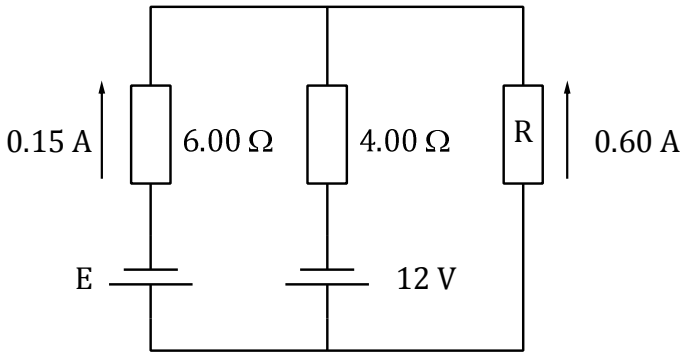


Figure 10

Determine the values of the unknown emf E and the unknown resistor R. **[7 marks]**

Question 14

a. Figure 11 shows a photocell consisting of an evacuated glass vessel in which there is a light-sensitive cathode, C, and a metal rod, A, which serves as anode. When light falls on C, electrons may be emitted.

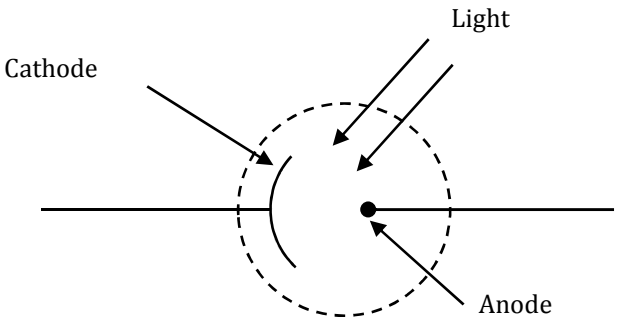


Figure 11

(i) Copy the figure, and add an electrical circuit to show how electrons emitted by the cathode, C, may be accelerated towards the anode, A. **[1 mark]**

(ii) Include in your circuit a potential divider so that the p.d. across the cell may be varied, and electrical instruments by which the current, I, through the cell and the p.d., V, across it may be measured. **[1 mark]**

(iii) Sketch a graph to show how the current (I) varies with the p.d. (V) for light of constant intensity. **[1 mark]**

(iv) Explain the shape of your graph. **[3 marks]**

b. Describe an experiment using the photocell by which Planck's constant, h, may be determined. Your experiment should include:

(i) a description of how the circuit drawn in part (a) must be modified;

(ii) a description of the procedure;

(iii) how the final result may be obtained from an appropriate graph. **[7 marks]**

c. The threshold wavelength for photoelectric emission in tungsten is 230 nm. What wavelength of light must be used in order for electrons with a maximum energy of 1.50 eV to be ejected? **[4 marks]**

d. The diagram in Figure 12 shows some of the electron energy levels of an atom.

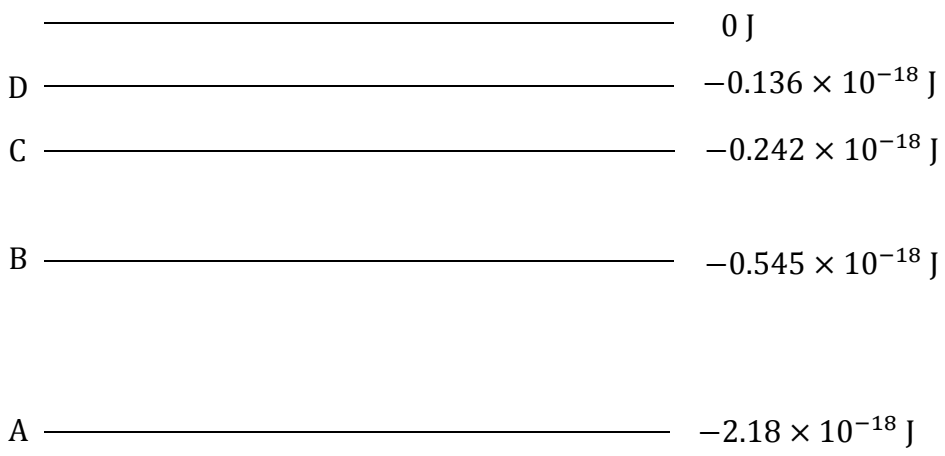


Figure 12

An incident electron moving with kinetic energy 12.5 eV collides with the atom represented in the diagram and excites an electron from level A to level C.

(i) Explain, in terms of energy changes, what you expect to observe when an electron collides inelastically with an atom. **[4 marks]**

(ii) What is the kinetic energy, in J, of the incident electron after collision? **[1 mark]**

(iii) When the excited electron returns to the ground state, it gives out a photon. What is the wavelength of the emitted photon? **[2 marks]**

(iv) Suppose that instead of an incident electron, a photon of energy also 12.5 eV is incident on the atom. Will this photon excite the atom in the same manner? Explain your answer. **[1 mark]**

Question 15

a. A science student wanted to investigate how the stress applied to a ductile piece of wire produces a strain in it.

(i) What is the meaning of the terms ductile material, stress and strain? **[6 marks]**

(ii) Sketch the expected stress-strain graph for a ductile wire stretched to breaking point. Clearly label the different parts of the graph. **[3 marks]**

(iii) Sketch another two graphs for a brittle material and a polymer. In each case explain the shape of the graph. **[4 marks]**

b. A young boy was playing with an elastic cord. Each time he pulled it with a force of approximately 2.5 N, its length was increased by 10 %.

(i) If the cord has a cross sectional area of 3.00 mm^2, find the Young modulus of the cord. **[2 marks]**

(ii) What assumption have you made in your calculation? **[1 mark]**

(iii) If the unstretched length of the cord is 0.40 m, find the energy stored when extended. **[3 marks]**

(iv) If the boy can use the cord to shoot a toy rocket of mass 50 g vertically upwards, calculate the initial velocity of the rocket. **[2 marks]**

(v) For the rocket to rise vertically by 1 m, calculate the extension that would be needed. **[4 marks]**

MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

UNIVERSITY OF MALTA, MSIDA

MATRICULATION EXAMINATION
ADVANCED LEVEL
MAY 2014

SUBJECT:	PHYSICS
PAPER NUMBER:	II
DATE:	29th May 2014
TIME:	4.00 p.m. to 7.00 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. Write an energy equation expressing the first law of thermodynamics. **[1 mark]**

b. Define the terms in this equation. **[3 marks]**

c. How is this equation modified when the law is applied to
   (i) a change at constant volume; **[1 mark]**
   (ii) an adiabatic change? **[1 mark]**

d. Hence explain why an adiabatic compression of a gas results in a rise in temperature of the gas. **[2 marks]**

e. Explain why heat transfer to a gas kept at constant volume will produce a higher rise in temperature than the same heat transfer to the same mass of gas kept at constant pressure. **[2 marks]**

f. Apply the first law to:
   (i) a filament lamp just after being switched on; **[3 marks]**
   (ii) a filament lamp minutes after being switched on. **[3 marks]**

Question 2

In order to measure the specific heat capacity, c, of oil, a student first lowers the temperature of a mass m of the oil by about 10°C below room temperature and then uses an electrical heater to raise the temperature of the oil and its container to about 10°C above room temperature, taking readings of the temperature every 30 s while doing so. The student then plots a graph of temperature against time and uses the graph to obtain the rate of rise of temperature, $\frac{\Delta\theta}{\Delta t}$ at room temperature.

a. Draw a circuit diagram to show how the heater may be connected to a d.c. supply. Include in your circuit an ammeter, a voltmeter, and a rheostat. **[2 marks]**

b. How may the power of the heater be measured? **[1 mark]**

c. Why is a rheostat included in the circuit? **[2 marks]**

d. Write down an equation which may be used to calculate the specific heat capacity of the oil given that the heat capacity of the container is C joules per kelvin. **[3 marks]**

e. Sketch a graph of temperature against time for the experiment. **[2 marks]**

f. Show how the rate of rise of temperature at room temperature may be obtained from the graph. **[2 marks]**

g. What is the advantage of finding the specific heat capacity at room temperature? **[2 marks]**

Question 3

A laser produces a narrow beam of monochromatic light. Red light from the laser, falling normally onto a grating, is diffracted as shown in Figure 1.

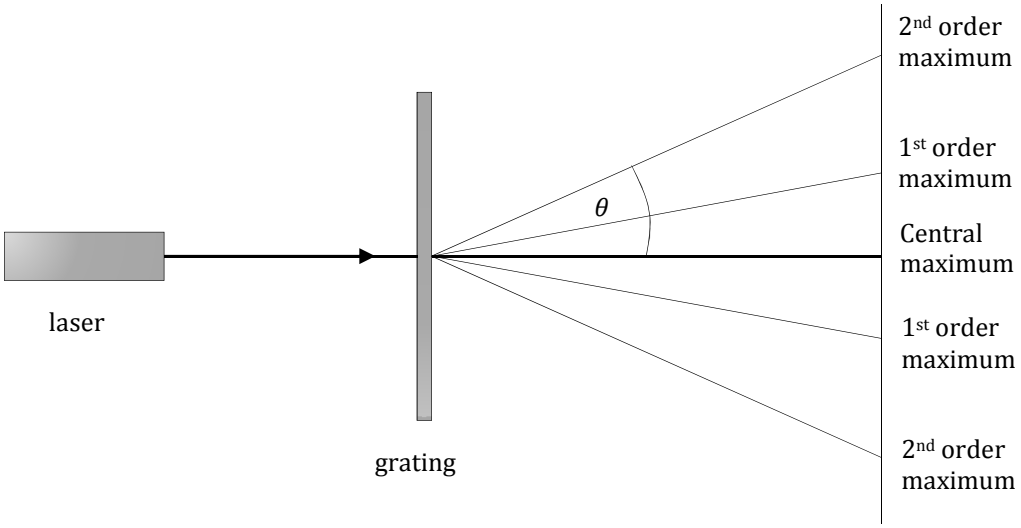


Figure 1

A series of maxima and minima is observed.

a. With the help of an appropriate diagram, explain briefly how the first order maximum is obtained. **[4 marks]**

b. The laser is now replaced by a second laser which emits green light of wavelength 633 nm. Why are the maxima closer together? **[1 mark]**

c. The number of lines per metre on the grating is 5.00×10^5. Calculate the angle, θ, for the 633 nm light between the central maximum and the second order maximum. **[3 marks]**

d. The experiment is repeated by placing the grating in water. If the speed of light in water is 2.26×10^8 m s^{-1}, what is the new angle between the central and second order maxima? **[4 marks]**

e. Explain why colours may be seen when looking at a distant point source of white light through a piece of stretched silk fabric. **[4 marks]**

Question 4

A light ray enters the core of a step index optical fibre at an angle θ and is then reflected at the core-cladding boundary at the critical angle c, as shown in Figure 2. The core is made of glass of refractive index 1.472 and the cladding is made of glass of refractive index 1.455.

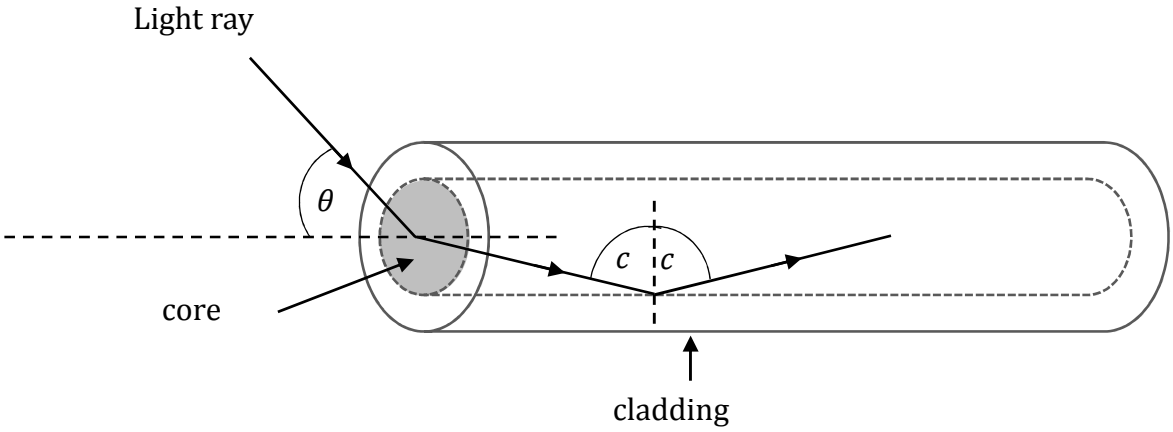


Figure 2

a. Show that the critical angle c is 81.28°, and hence find the angle θ. **[5 marks]**

b. The slowest speed with which light can travel along the fibre is when it zig-zags along the fibre making an angle of incidence at the core-cladding boundary equal to the critical angle. The fastest speed is when it travels along the axis of the fibre.
   (i) What is the speed of light in the core? **[2 marks]**
   (ii) If the time taken by the two routes is not to exceed 10^{-9}s, how long can the fibre be? **[4 marks]**

c. The diagram in Figure 3 shows a light pulse just after entering the core. The light pulse can be considered to be the superposition of a range of wavelengths. The refractive index of the core depends on the wavelength.

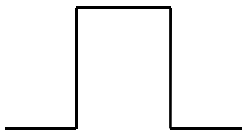


Figure 3

What will happen to the shape of the pulse after travelling a long distance inside the fibre? Explain. **[2 marks]**

Question 5

When a child's swing is pulled back slightly from its rest position and released, the motion of the swing's seat is approximately simple harmonic.

a. What condition must be satisfied for simple harmonic motion to occur? **[2 marks]**

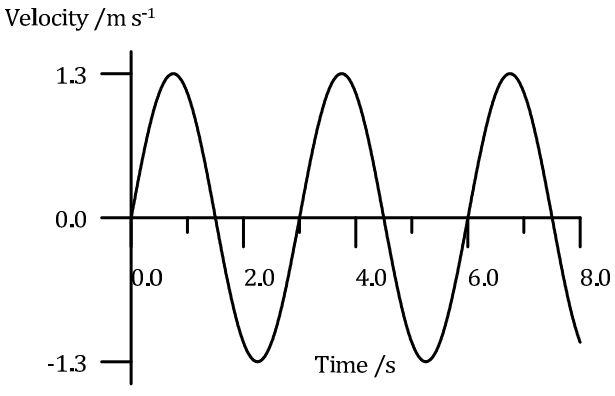


Figure 4

b. The velocity-time graph for the swing's seat is shown in Figure 4. (Energy losses are neglected).
   (i) Write down the period of oscillation of the swing. **[1 mark]**
   (ii) Write down an equation for the maximum speed of a particle undergoing SHM. Hence show that the amplitude of the seat is 0.62 m. **[2 marks]**
   (iii) Calculate the maximum acceleration of the seat, and state where this occurs. **[2 marks]**
   (iv) If the mass of the seat is 2.6 kg, calculate the total energy of the seat. **[2 marks]**
   (v) Hence calculate the displacement of the seat when the kinetic energy is exactly equal to the potential energy. **[4 marks]**
   (vi) How would you measure the potential energy of the seat from a graph of restoring force against displacement from the centre of oscillation? **[1 mark]**

Question 6

a. Using the principles of electromagnetic induction, explain qualitatively why an inductor impedes the flow of a high frequency alternating current more than the flow of a low frequency alternating current. **[3 marks]**

b. A 6 V lamp, in series with an inductor of inductance 0.20 H and negligible resistance, is connected across a 50 Hz alternating current supply of more than 6 V output so that the lamp works normally.
   (i) What is the inductive reactance of the inductor? **[2 marks]**
   (ii) What is the advantage of using an inductor instead of a resistor in order to limit the voltage across the lamp to 6 V? **[1 mark]**
   (iii) What is the capacitance of the capacitor which can be used to replace the inductor and still limit the voltage across the lamp to 6 V? **[2 marks]**

Question 7

A metal ring of radius, r, and resistance, R, falls symmetrically from rest so that it cuts a radial magnetic field whose source is a line along the axis of the ring. The magnetic field has flux density B at a distance equal to the radius of the ring.

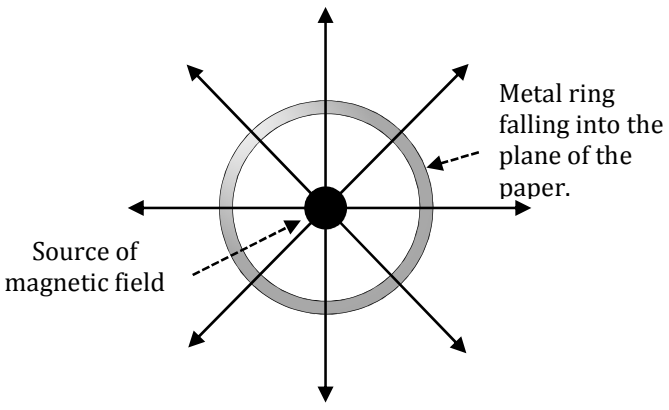


Figure 5

a. By comparing with the case of a straight conductor moving through a magnetic field, show that the emf induced in the ring is $2\pi rBv$ when its speed is v? **[2 marks]**

b. What is the current through the ring at this instant? **[1 mark]**

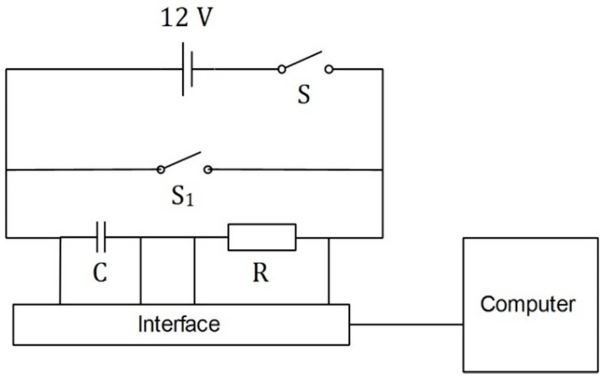
c. What are the direction and magnitude of the force on the ring due to this current? **[3 marks]**

d. How can the force on the falling ring be increased? **[1 mark]**

Question 8

An uncharged capacitor, C, is connected in a circuit as shown.

The 12 V battery has negligible internal resistance. The interface measures the voltage V_C across C and the current I_R through the resistor R. These measurements are then displayed as graphs on the computer.



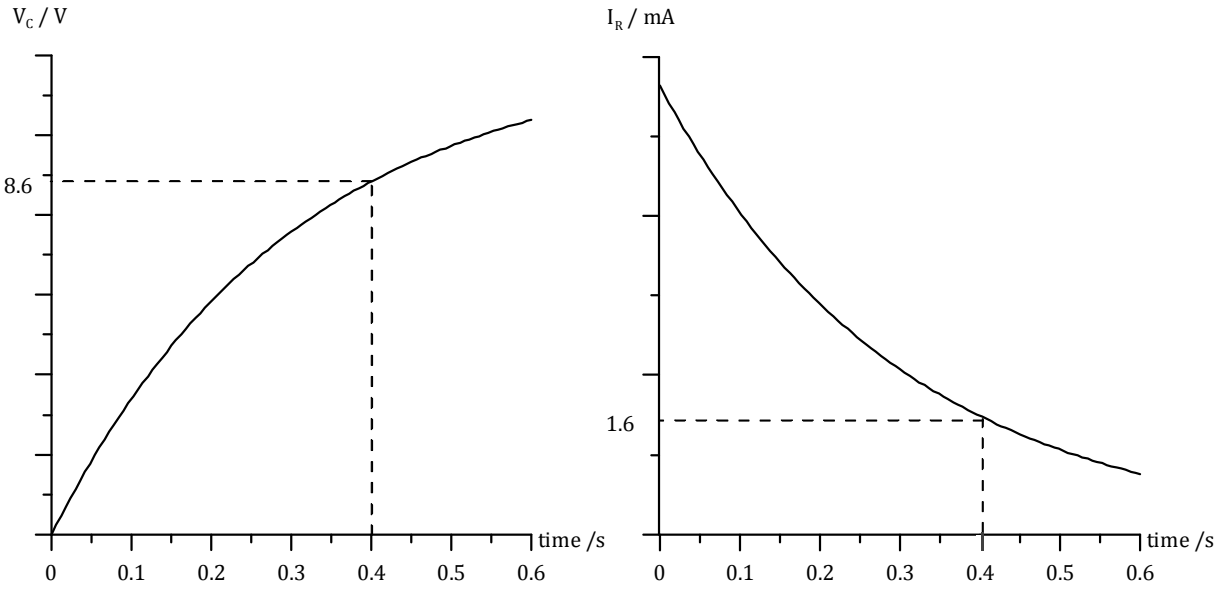


Figure 6

a. What is the voltage across the resistor when:
   (i) $t = 0.00$ s;
   (ii) $t = 0.40$ s? **[2 marks]**

b. What is the resistance of resistor, R? **[1 mark]**

c. When the capacitor is fully charged it stores 10.0 mJ of energy. What is its capacitance? **[2 marks]**

d. What is the time constant of the circuit? **[1 mark]**

e. Sketch a graph to show how the charge on the capacitor changes with time after switch S is closed. **[1 mark]**

f. An open switch S_1 is now connected across R and C. After switch S is opened, switch S_1 is closed.
   (i) On the same axes, sketch graphs to show how the p.d. across the capacitor and the p.d across the resistor change with time. **[2 marks]**
   (ii) What would happen if, inadvertently, switch S_1 is closed while switch S is still closed? **[1 mark]**

g. The capacitor takes only a few seconds to charge fully. Calculate a value of the resistance you would connect instead of R to increase the time taken by the charging process to *about* 1 minute. **[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 single gas molecule of mass m is moving in a cubic box of side L with a velocity u_x in the positive x-direction, as shown in Figure 7. The molecule moves backwards and forwards in the box, striking the end faces normally and making elastic collisions.

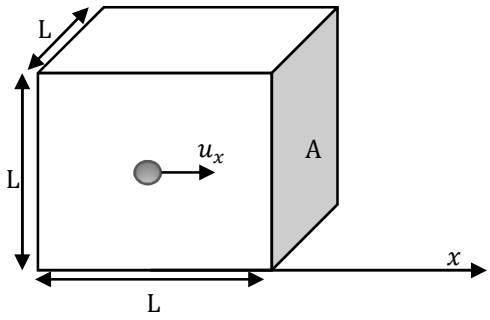


Figure 7

a. Show that the time t between collisions with face A is $t = \frac{2L}{u_x}$. **[1 mark]**

b. What is the change in momentum of the molecule per collision with face A? **[1 mark]**

c. If it is assumed that the box contains N identical molecules, each of mass m, all moving along the x-direction with speed u_x , and making elastic collisions at the ends, show that the average force F on wall A is $F = \frac{Nmu_x^2}{L}$. **[3 marks]**

d. A better model of molecular motion assumes that the motion is random. By making this assumption obtain the equation for F:

$$F = \frac{Nm\langle c^2\rangle}{3L}$$

where $\langle c^2\rangle$ is the mean square speed of the molecules in the box. **[3 marks]**

e. Hence show that the pressure of the gas inside the box is $= \frac{Nm<c^2>}{3V}$, where V is the volume of the cube. **[1 mark]**

f. Introduce the equation of state for one mole of an ideal gas to show that the mean molecular kinetic energy is $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$ where k is Boltzmann's constant. **[3 marks]**

g. Hence show that the internal energy of an ideal gas:
   (i) is proportional to its temperature; and
   (ii) does not depend on the volume**.** **[3 marks]**

h. Are the results obtained in part (g) true for all matter? Explain your answer. **[2 marks]**

i. A vessel contains a mixture of the monatomic gases helium, ^{4}He and neon, ^{20}Ne kept at constant temperature. Find the ratios of the:
   (i) kinetic energy of helium atoms to that of neon atoms; **[1 mark]**
   (ii) average speed of helium atoms to that of neon atoms. **[2 marks]**
   (iii) If the temperature of the mixture is 300 K, what is the r.m.s. speed of the helium atoms? **[3 marks]**

j. Do you expect the behaviour of real gases to approach that of an ideal gas at very low or very high temperatures? Explain your answer. **[2 marks]**

Question 10

a. State the Second Law of Thermodynamics. **[2 marks]**

b. An *ideal gas* is used as a working substance for a reversible heat engine cycle shown in the pressure-volume diagram of Figure 8.

One mole of the gas is compressed adiabatically from 0.0250 m^3 at C to 0.0114 m^3 at A, where its pressure becomes 3.00×10^5 Pa. It expands at constant pressure between A and B and cools down at constant volume from B to C.

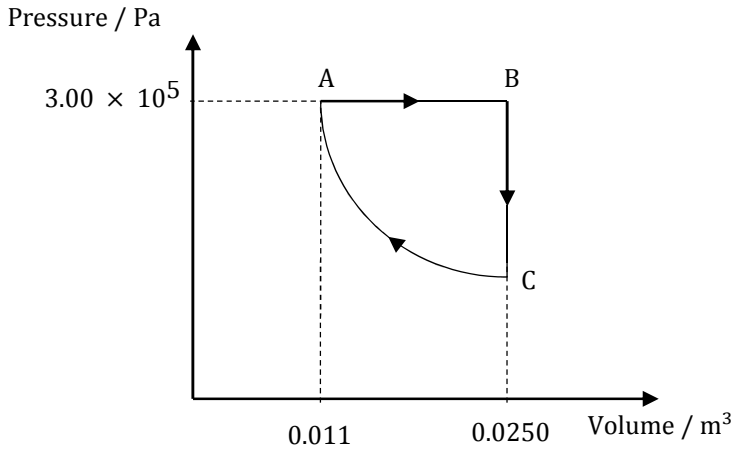


Figure 8

The ratio of the principal molar heat capacities, γ, of the gas is 1.40.

(i) What are the temperatures of the gas at A and B? **[4 marks]**
(ii) CA is an adiabatic compression. Calculate pressure and temperature of the gas at C. **[5 marks]**
(iii) If the molar heat capacity of the gas at constant volume is $\frac{5}{2}R$, show that the change in internal energy in the process CA is 2300 J. **[3 marks]**
(iv) What is the work done on the gas during the adiabatic process? Explain your answer. **[2 marks]**
(v) What is the work done in the processes AB and BC? **[3 marks]**
(vi) What is the net work done in the cycle? **[1 mark]**
(vii) Calculate the heat transfer during the process AB. **[3 marks]**
(viii) What is the efficiency of this heat engine? **[2 marks]**

Question 11

Two similar helium filled balloons, A and B, each carrying a charge of $+Q$, are tied by two strings each 1.00 m long to a 5.00 g mass and float in equilibrium. The balloons are spherical in shape and their centres are 0.600 m apart, as shown in Figure 9.

a.

(i) Write down the horizontal and vertical components of the tension, T, in the strings in terms of T and the angle θ, which each string makes with the vertical through the hanging mass. **[2 marks]**

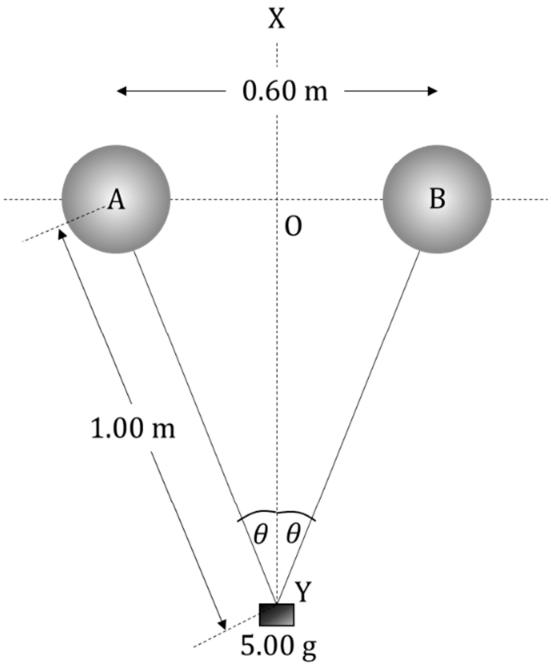


Figure 9

(ii) How is the vertical component of the tension related to the weight, mg, of the hanging mass? **[2 marks]**

(iii) Write down an equation for the electrical force between the two balloons in terms of T and θ. **[1 mark]**

(iv) Hence find the charge, Q, on each balloon. **[2 marks]**

b. Figure 10 shows an electric line of force crossing an equipotential surface.

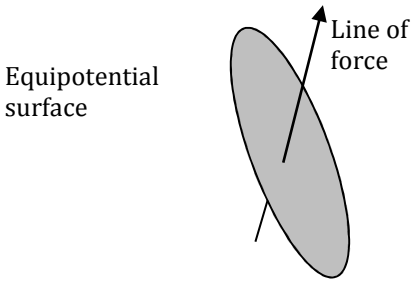


Figure 10

(i) In what way is the figure drawn incorrectly? Explain your answer. **[2 marks]**

(ii) Sketch a diagram to show the electric field lines around the two charged balloons in (a). **[4 marks]**

(iii) On the same diagram sketch one equipotential surface around the two charged balloons. **[2 marks]**

c. An electron moving along line XOY, in Figure 9, midway between the two balloons perpendicular to the line joining them, experiences a force.

(i) Describe briefly how the resultant force on the electron changes as it first approaches and then recedes away from the balloons. **[5 marks]**

(ii) Sketch the direction of the resultant force on the electron when it is:

- approaching the balloons from the direction of X;
- exactly at O and,
- receding from the balloons in the direction of Y. **[3 marks]**

d. The charge on balloon, A, is increased to $+ 2Q$. Will the strings still make equal angles with the vertical through the hanging mass? **[2 marks]**

Question 12

a.

(i) State Newton's Law of Gravitation. **[1 mark]**

(ii) Why is Newton's gravitational constant, G, called universal? **[1 mark]**

b.

(i) Write down an equation for the acceleration due to gravity, g, on the Earth's surface in terms of the mass of the Earth, M_E, the radius of the Earth, R_E, and the constant, G. **[1 mark]**

(ii) Under what assumptions is this equation true? **[2 marks]**

c.

(i) Show that the period T_M of the Moon is related to R_M, the radius of the Moon's orbit, and the quantities M_E and G by the equation $T_M^2 = \frac{4\pi^2 R_M^3}{GM_E}$. **[3 marks]**

(ii) What assumptions have you made in deriving this equation? **[2 marks]**

d. Using the equations you have obtained in (b) and (c), write down an equation for the acceleration of free fall at the Earth's surface in terms of R_M, T_M and R_E. **[2 marks]**

e. Given that $R_M = 3.84 \times 10^8$ m and $T_M = 2.36 \times 10^6$ s, find a value for the acceleration of free fall, g, on the Earth's surface. **[2 marks]**

f. Jupiter has many moons. Use the equation you have derived in (c) above to describe how one can determine the mass of Jupiter from observations of Jupiter's moons. **[7 marks]**

g. If the mass of Jupiter is 1.90×10^{27} kg and its mean radius 7.00×10^7 m, calculate the escape velocity on the surface of Jupiter. **[4 marks]**

Question 13

a. The diagram in Figure 11 shows a loudspeaker L which emits sound of frequency 500 Hz. The sketch graph represents the displacement of air layers in front of the loudspeaker as the sound wave travels in the positive x direction.

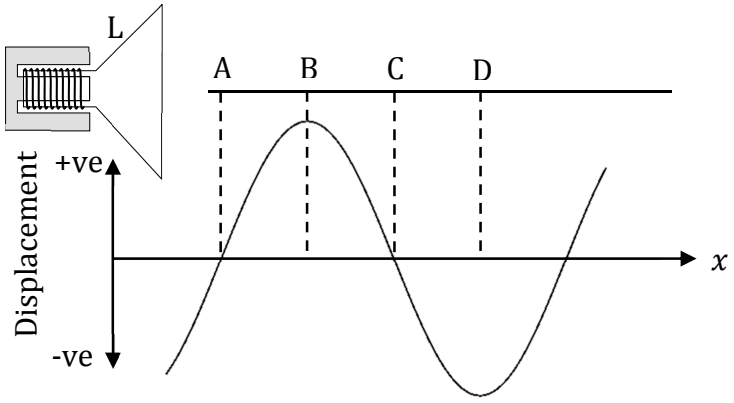


Figure 11

(i) At which of the four points A, B, C, and D is the instantaneous pressure at its maximum value? Explain your answer. **[2 marks]**
(ii) How long does it take sound to travel the distance AD? **[2 marks]**

b. The graph shown in Figure 11 is described by the equation:

$$y = A\sin(\omega t - kx)$$

(i) Give the meaning of each symbol in the equation. **[2 marks]**
(ii) Prove that the equation represents a wave travelling in the positive x-direction. **[2 marks]**
(iii) Write down the equation of a similar wave travelling in the negative x-direction. **[1 mark]**

c. Two such waves travelling in opposite directions along a wire interfere to produce a transverse stationary wave. State how plane progressive waves and stationary waves differ in respect of:
(i) energy transfer; **[1 mark]**
(ii) the amplitude at points along the wire; **[2 marks]**
(iii) the phase difference between points along the wave. **[2 marks]**

d. Microwaves may be used to form stationary waves.
   (i) How would you show experimentally that microwaves are transverse waves? **[4 marks]**
   (ii) Describe how you would set up a stationary wave pattern using microwaves and how you would use the pattern to measure the wavelength of microwaves. **[7 marks]**

Question 14

a. Figure 12 shows a long, vertical, straight wire carrying a current of 10.0 A downwards into the plane of the paper. The direction of magnetic North is also shown.

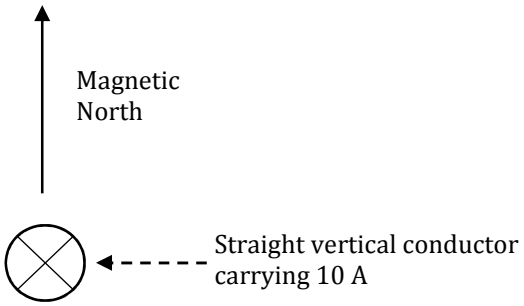


Figure 12

   (i) Copy the figure and mark the position of the neutral point, P. **[2 marks]**
   (ii) Write down an equation which gives the flux density, B, at a distance, r, from a straight conductor carrying a current, I . **[1 mark]**
   (iii) If in part (i) the distance of the neutral point from the conductor is 7.0 cm, what is the horizontal component of the Earth's magnetic field? **[1 mark]**

b. Figure 13 shows a rectangular coil ABCD of N turns which is pivoted at X and Y so that the coil is in equilibrium in the horizontal plane. The arms AD, CB are perpendicular to the horizontal component, B_H, of the Earth's magnetic field. The pivots at X, Y also serve as a means by which current enters and leaves the coil.

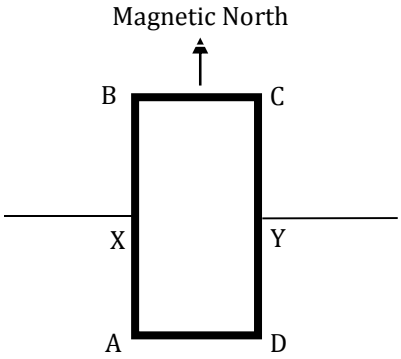


Figure 13

   (i) If the area of the coil is A and the direct current through it is I, derive an expression for the magnetic couple acting on the coil in terms of I, B_H, A and N, where N is the number of turns in the coil. **[3 marks]**
   (ii) Small weights (or riders) may be used to balance the magnetic couple. Describe in full how you would use the coil, together with other necessary apparatus, to measure the horizontal component of the Earth's magnetic field. **[6 marks]**

(iii) Explain what you would expect to observe if the direct current is replaced by an alternating current of frequency 0.2 Hz. **[3 marks]**

c. An electron gun fires 2.00 keV electrons at right angles to the direction of the Earth's magnetic field, B_E, inside an evacuated tube. If $B_E = 1.10 \times 10^{-4}$ T, what is the radius of the circular path in which the electrons travel? **[5 marks]**

d. Draw a diagram to show the path of an electron which enters a magnetic field at an acute angle to the field. Include in your diagram the magnetic flux of the field, the path of the electron, and the direction of motion of the electron. **[2 marks]**

e. Why cannot a magnetic field increase the kinetic energy of an electron moving inside it? **[2 marks]**

Question 15

a. List the conditions that must be fulfilled in order to demonstrate interference of light. **[3 marks]**

In Young's double slit experiment, monochromatic light from slit S is diffracted by the parallel slits S_1 and S_2 to fall onto the focal plane XY of a travelling microscope.

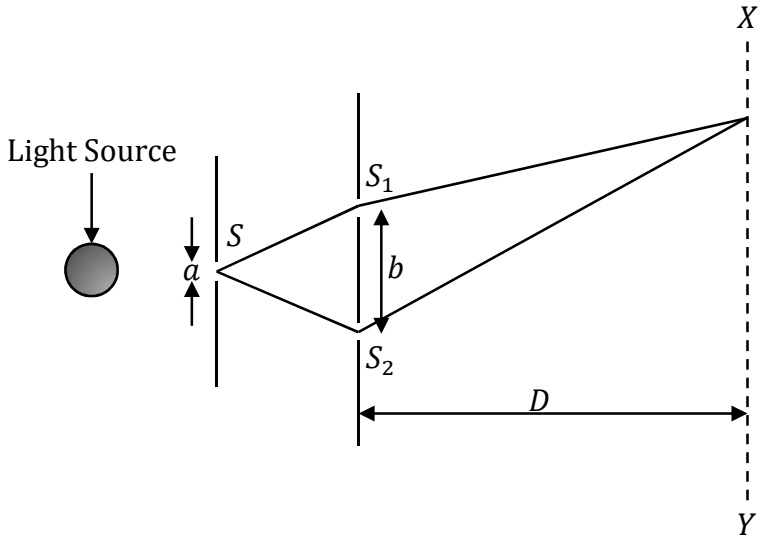


Figure 14

b. Describe how you would use the apparatus shown in Figure 14 to determine the wavelength of light from source S. **[8 marks]**

c. Write down appropriate values for the width of the aperture, a, of slits S, S_1, and S_2, the distance, b, between slits and the distance, D, from slits to the focal plane of the microscope. **[3 marks]**

d. In the two slit experiment,
(i) why must slits S_1, S_2 be parallel to each other and to slit S, and be approximately of the same width? **[2 marks]**
(ii) why is it **not** essential for slits S_1 and S_2 to be exactly equidistant from S? **[1 mark]**
(iii) why is it much easier to carry out the experiment using a laser rather than a thermal source such as a white light lamp and filter? **[1 mark]**

(iv) why is the number of fringes that can be observed much greater when a white lamp and a yellow filter are replaced by a sodium lamp? **[3 marks]**

e. Two parallel slits a few millimetres apart are illuminated by sodium light. An observer looks through an adjustable slit at the two slits from a distance of about 3 m.
Describe the appearance of the two slits as the width of the adjustable slit, initially about 4 mm wide, is gradually reduced to zero. **[4 marks]**

MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

UNIVERSITY OF MALTA, MSIDA

MATRICULATION EXAMINATION
ADVANCED LEVEL
MAY 2014

SUBJECT:	PHYSICS
PAPER NUMBER:	III – *Practical*
DATE:	4th June 2014
TIME:	2 hours

Experiment: Rigidity modulus of copper

Apparatus: Dumb bell, wooden beam, metre ruler, stopwatch, copper wire, metal discs, hanger, g-clamp.

Important Note:

- Please take note that a dumb bell falling from about a height of 1 m can do some damage and may cause pain if dropped on your feet. Take necessary precautions.
- The copper wire is very thin and may break. Handle with care.
- Take the acceleration due to gravity $g = 9.81\ \text{m s}^{-2}$ unless otherwise stated

Failure to follow these instructions may incur damage to the apparatus and loss of time.

Diagram:

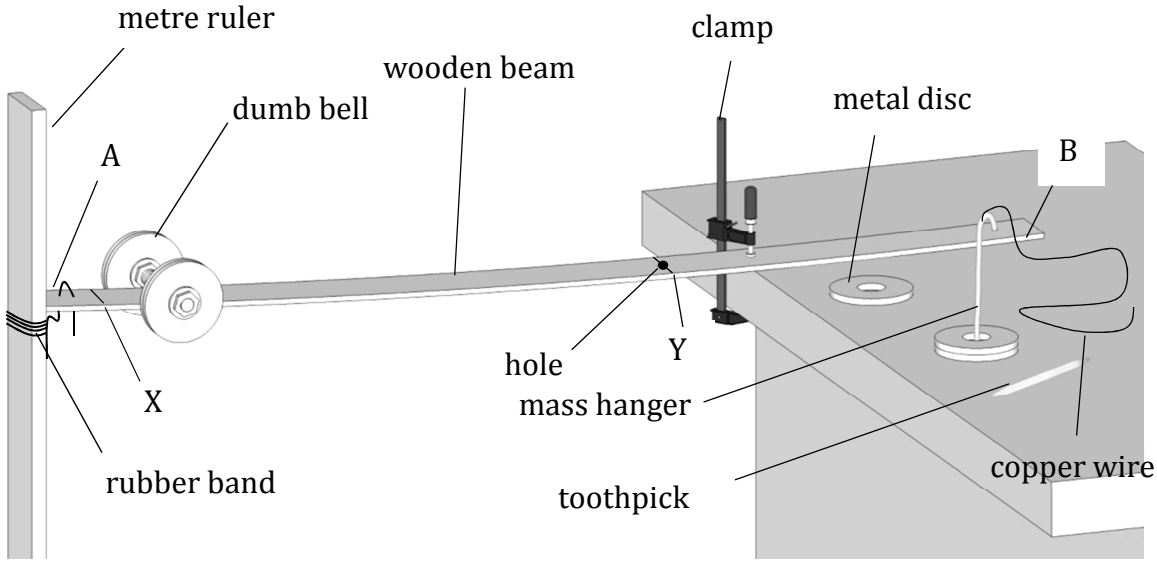


Figure 1 The experimental setup

Method – Part A:

1. Make sure that you have all the apparatus set up as shown in the diagram of Figure 1.
2. The dumb bell consists of four metal discs and a metal shaft. Two discs are held at one end of the shaft by two nuts and the other two held on the other end by another two nuts, as in Figure 2.

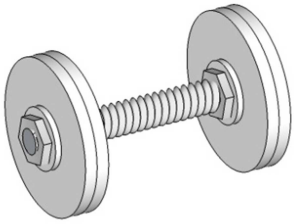
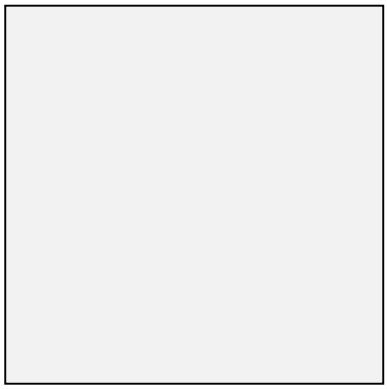


Figure 2

3. The four metal discs are identical in mass and dimensions.
4. Position the additional free metal disc that was provided inside the square drawn below. The metal disc should fit perfectly or almost perfectly inside the square.
5. Draw the outlines of the outer and inner edges of the metal disc.
6. Remove the metal disc and draw two lines diagonally across the square. The centre of the metal disk is where the two diagonal lines intersect.
7. Determine the inner radius (a) and outer radius (b) of the metal disc.



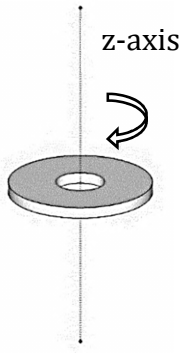
Inner Radius (a) =_____ m Outer Radius (b) =_____ m

[4 marks]

8. The moment of inertia I of a hollow metal disc about an axis through its centre (z-axis) is given by:

$$I = \frac{1}{2}M(a^2 + b^2)$$

where M is the mass of the disc.



9. Work out the moment of inertia of the disc, given that it has a mass of 0.0534 kg.

_____

_____

[2 marks]

10. The wooden beam in your setup has one of its ends (labelled B) clamped to the bench. The other end (labelled A) has a metal wire that is inserted in a rubber band wound around the metre ruler. You should be able to move the rubber band up and down along the ruler to adjust the height of end (A) of the wooden beam.
11. Adjust the position of end (A) of the wooden beam along the ruler so that it is aligned horizontally with the surface of the bench.
12. Read from the ruler the position of the upper edge of the wooden beam, h_0 and record it in Table 1. **[1 mark]**
13. Now raise end A of the wooden beam (by moving the rubber band and all) by 2 cm (0.02 m). This is the first value for the position of the beam as given in Table 1.
14. Place the dumb bell on the wooden beam near end A and position it such that it is placed on the visible mark X.

15. When the dumb bell is released, it should start rolling towards end B of the wooden beam. If not, a slight push will help it get rolling.
16. Measure the time it takes for the dumb bell to reach mark Y near the clamped end of the wooden beam and record it in Table 1. Repeat the time measurement three times to take an average.
17. To get the best results, it is recommended that you practice the above procedure and take any necessary precautions before you start recording your time measurements.
18. Repeat steps 13 to 16 to get a set of five readings, as indicated in Table 1.

Table 1

Position of beam when horizontal h_0/m					$h_0 =$ _____m	
Position on ruler of end A of wooden beam	Drop height (Δh) / m	t_1 /s	t_2 /s	t_3 /s	Average time, t/s	$\left(\frac{1}{t^2}\right)$ / s^{-2}
$h_0 + 0.02 =$	0.02					
$h_0 + 0.04 =$	0.04					
$h_0 + 0.06 =$	0.06					
$h_0 + 0.08 =$	0.08					
$h_0 + 0.10 =$	0.10					

[20 marks]

19. Describe briefly the energy changes taking place as the dumb bell moves from the raised end of the wooden beam to the clamped end of the wooden beam.

_____

_____

[3 marks]

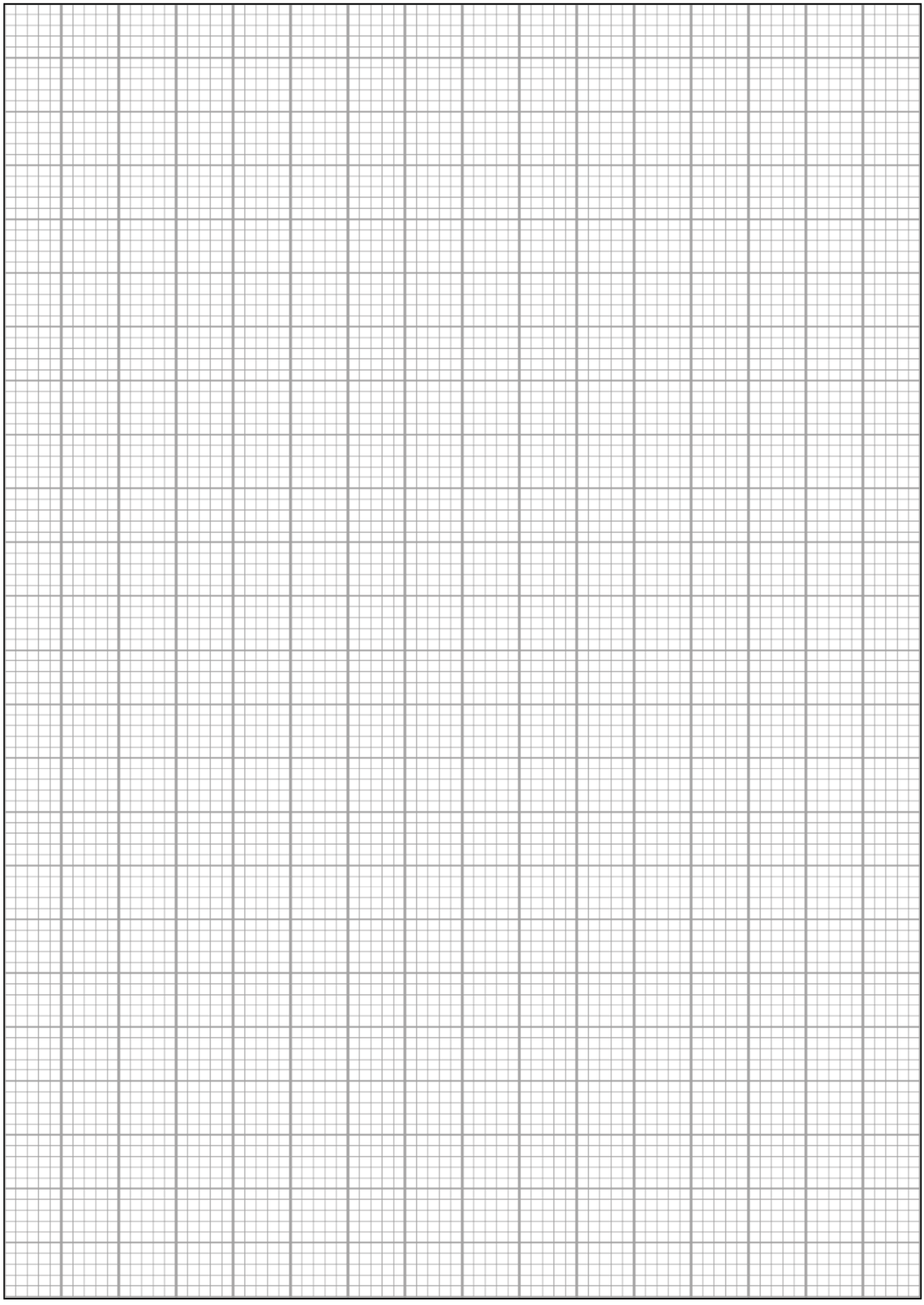
20. Complete the above table by filling in the missing data. **[10 marks]**
21. It is given that the height dropped by the dumb bell is related to the time taken by:

$$\Delta h = \frac{2s^2}{gt^2}\left(1 + \frac{I}{mR^2}\right)$$

where I is the moment of inertia of the dumb bell, m is the mass of the dumb bell, s is the linear distance travelled and R is the radius of the shaft.

22. Plot a graph of Δh /m on the y-axis against $\frac{1}{t^2}$ /s^{-2} on the x-axis. The graph is a straight line. **[15 marks]**

DO NOT WRITE ABOVE THIS LINE



23. Given that $R = 0.01$ m, the linear distance travelled $s = 0.60$ m and the total mass $m = 0.214$ kg, use the value of the gradient to determine the moment of inertia of the combined four metal discs .

[2, 2 marks]

24. By assuming that the mass of the nuts and washers is negligible when compared to the mass of the combined four metal discs, determine the moment of inertia of a single disc. You can use the fact that the moment of inertia of a single disc is one fourth the moment of inertia of the combined four discs.

[1 mark]

25. Discuss briefly the validity of the assumption stated in step 24 and write down one of the two values (step 9 and step 24) of the moment of inertia you obtained for a single disc that you think is more accurate, giving a reason for your answer.

[3 marks]

Method – Part B:

26. One end of the copper wire provided is attached to a mass hanger and two metal discs. The wooden beam has a drilled hole near the clamp.

27. Thread the free end of the copper wire through this hole and use the toothpick to secure it to the wooden beam. The toothpick should be inserted in the same hole through which the copper wire is threaded. This will create enough friction to keep it secure. Refer to Figure 3.

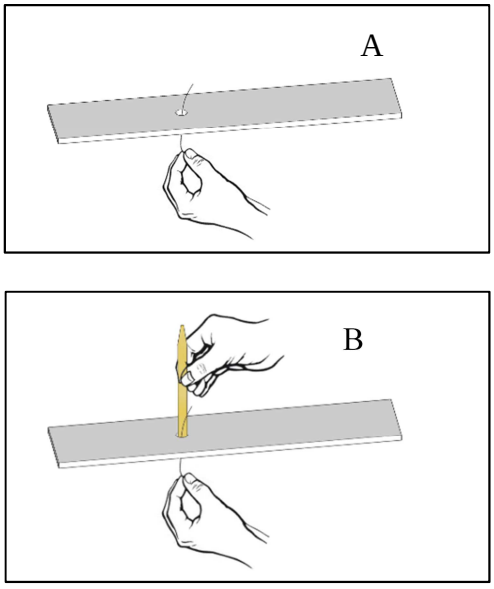


Figure 3

28. The final setup should be similar to the one shown in Figure 4.
29. Remove the ruler from its previous setup. **Do not remove** the rubber bands.
30. Use the ruler to adjust the length (L) of the copper wire such that it is equal to 0.15 m, the first value that is shown in Table 2.

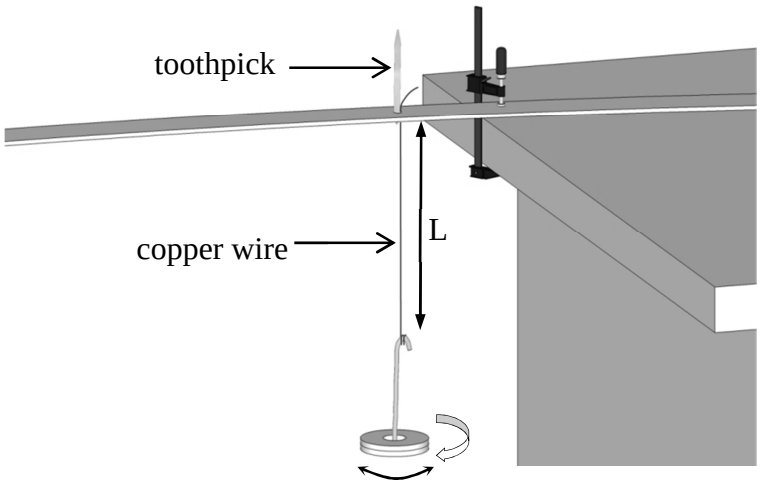


Figure 4

31. Slightly rotate the mass hanger and masses to one side **through a small angle**. When released, the mass hanger and masses should perform rotational oscillations, as shown in Figure 4.
32. Use the stopwatch to measure the time it takes the mass hanger and masses to perform 10 oscillations. Record these values in the column for T_{10} in Table 2.
33. Repeat steps 31 and 32 for the different lengths of copper wire given in Table 2.

Table 2

Length of copper wire L / m	T_{10}/s	T/s	T^2/s^2
0.15			
0.18			
0.21			
0.24			
0.27			

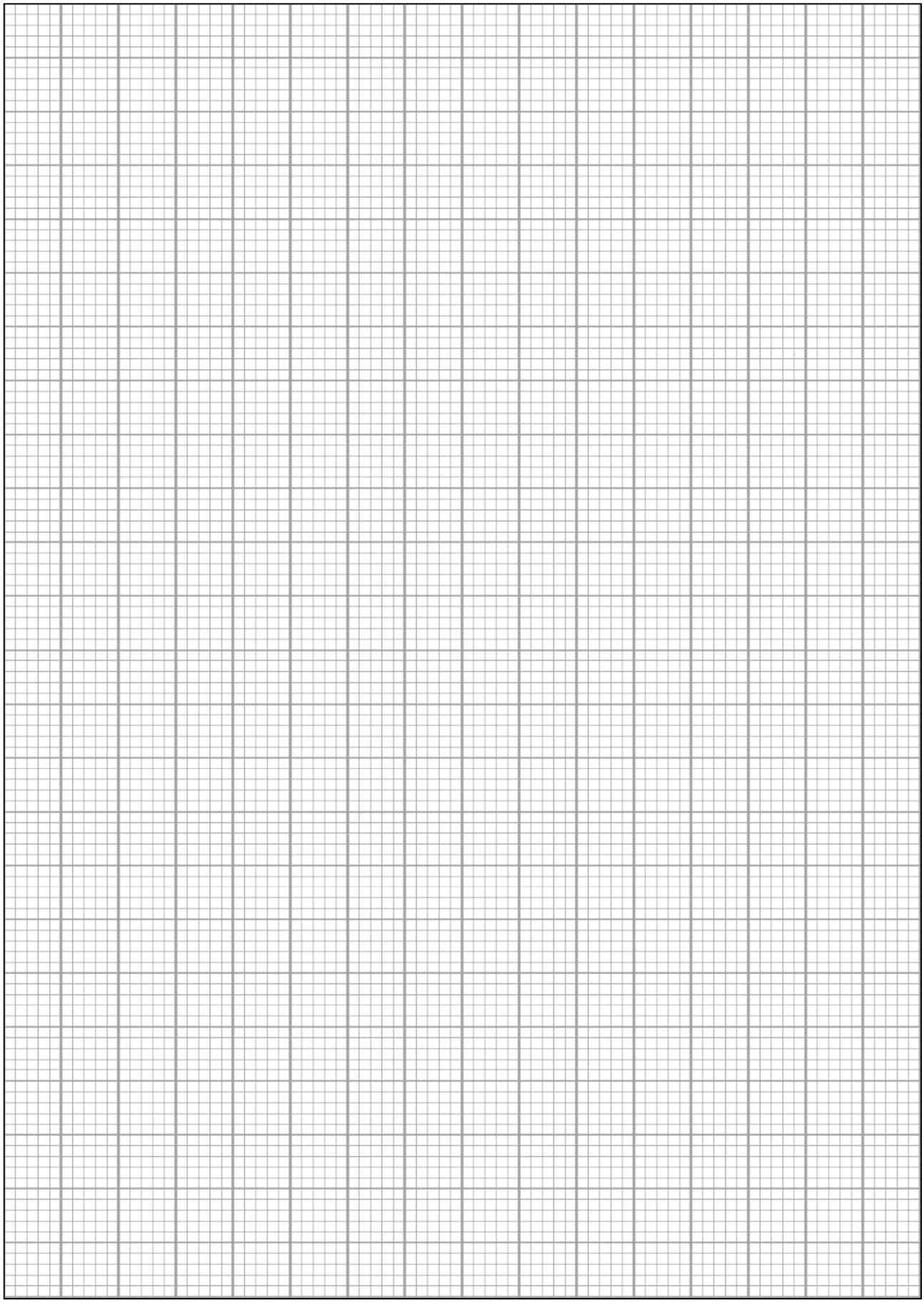
[5 marks]

34. Complete Table 2 by working out the periodic time T for one oscillation and the values for T^2. **[10 marks]**
35. Plot a graph of T^2 /s^2 on the y-axis against length L /m on the x-axis. **[15 marks]**
36. The relationship between the periodic time T of the oscillations and the length L of the copper wire is given by:

$$T^2 = \frac{8\pi IL}{\eta r^4}$$

where I is the moment of inertia of the two metal discs, η is the rigidity modulus of copper and r is the radius of the wire.

DO NOT WRITE ABOVE THIS LINE



37. Given that the radius of the copper wire $r = 1.25 \times 10^{-4}$ m, use the value of the moment of inertia of **two discs** which can be obtained from step 25 (neglecting the relatively small moment of inertia of the hanger) to determine the rigidity modulus of copper η. Give its proper units.

[2, 2, 1 mark]

38. State **two** precautions undertaken during the experiment of part B.

[2 marks]