MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

UNIVERSITY OF MALTA, MSIDA

MATRICULATION EXAMINATION
ADVANCED LEVEL
SEPTEMBER 2014

SUBJECT:	PHYSICS
PAPER NUMBER:	I
DATE:	2nd September 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. In the kinetic theory of gases, the absolute temperature of a gas is given by

$$T = \frac{m\overline{c^2}}{3k}$$

where m refers to the mass of the gas, $\overline{c^2}$ is the mean square speed of the gas particles and k is Boltzmann's constant. Show that the equation is homogenously correct and briefly describe the importance of homogeneous units in physical equations. **[3, 2 marks]**

b. An archer fires arrows at a target 80 m straight in front of her at a speed of 25 m s^{-1}.
   (i) Assuming that there is no wind and the air resistance is negligible, calculate the duration of the flight of the arrow. **[2 marks]**
   (ii) The archer fires a second arrow in the same direction as before but this time a light westerly wind makes the arrow deflects to the right of the target such that the new path makes an angle of 1° relative to the path taken by the first arrow. Assuming the wind and arrow speeds are constant throughout the motion, determine the wind speed. **[3 marks]**
   (iii) The wind direction changes and it now faces the archer. A third arrow takes 4 s to reach the target. What is the new wind speed? **[2 marks]**

Question 2

In the final scenes of the movie "Need for Speed", a sports car (A) is moving with a constant velocity of 40 m s^{-1} when it overtakes a police car (B) that is stationary on the same straight road. At this instant, the police car begins to accelerate at 2.5 m s^{-1} to a constant speed of 45 m s^{-1}.

a. On the same axis, sketch two labelled graphs that show how the velocities of the two cars change with time. The time axis should start from when the two cars first meet. **[3 marks]**
b. Calculate the time it takes car B to reach the constant speed of 45 m s^{-1} and the distance it covers while accelerating. **[4 marks]**
c. Show that the total time it takes car B to catch up with car A is 81 s. **[5 marks]**
d. Find the distance each car will have travelled when car B catches up car A. **[2 marks]**

Question 3

a. A polystyrene coffee cup has its bottom attached to a light spring of length l. The cup is fixed to the upper end of the spring while the lower end of the spring is fixed to the ground. The spring and cup are in a vertical position. A large ball bearing of mass M is then dropped from a height h above the ground straight down into the cup and causes the spring to compress to a distance d, when it comes momentarily to rest.

(i) If the spring constant is k, show that an expression that relates the maximum compression is given by $\frac{1}{2}kd^2 = Mg(h - l + d)$ **[3 marks]**

(ii) Use the expression in (i) to determine k if the spring length is 0.15 m and the ball bearing of mass of 0.1 kg is dropped from a height of 0.50 m. The spring compresses by 0.05 m when hit by the ball. **[2 marks]**

(iii) Calculate the energy stored in the spring at maximum compression. **[2 marks]**

b. A second identical spring is connected in parallel to the first spring. State, if any, the effects this has on the maximum compression distance and the energy stored in the springs. **[2 marks]**

Question 4

a. A particle of mass m is moving on a circular path of radius r with a linear velocity v. Briefly explain how the particle experiences a centripetal force F and write down the expression for the magnitude of the centripetal force. **[1, 3 marks]**

b. A car of mass 700 kg starts from rest and accelerates at 7 m s^{-2} along a straight horizontal road for a distance of 200 m. It then enters at constant speed a horizontal circular track of radius 100 m.

(i) Calculate the speed of the car as it enters the round track. **[1 mark]**

(ii) Determine its angular velocity on the round track. **[1 mark]**

(iii) What is the magnitude and direction of the resulting force acting on the car? **[2 marks]**

The car begins to accelerate forward at 4 m s^{-2} at some point on the circular track.

(iv) Calculate the magnitude of the associated forward force. **[1 mark]**

(v) Draw a diagram that shows the forces acting on the car and calculate the magnitude of the resultant force on the car. **[2,1 marks]**

(vi) At what angle to the track is this resultant force directing the car? **[2 marks]**

Question 5

a. For a rigid system, state the conditions for static equilibrium. **[2 marks]**

b. Define the term *centre of gravity*. **[1 mark]**

c. The system shown in Figure 1 consists of two weights fixed at points A and B and held in static equilibrium by inextensible strings. The centre string is aligned exactly horizontal. Find the tensions, T_1, T_2 and T_3 in the three strings and the angle θ that the tension T_3 makes with the vertical. **[6 marks]**

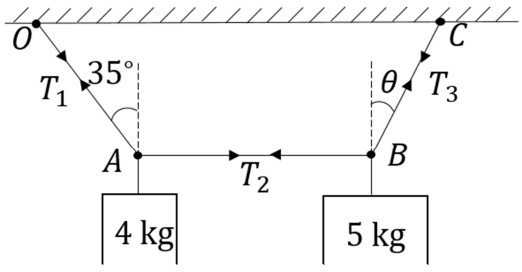


Figure 1

Question 6

a. State Kirchhoff's two circuit laws. **[4 marks]**

b. Figure 2 shows a circuit diagram consisting of 3 batteries and a number of resistors.

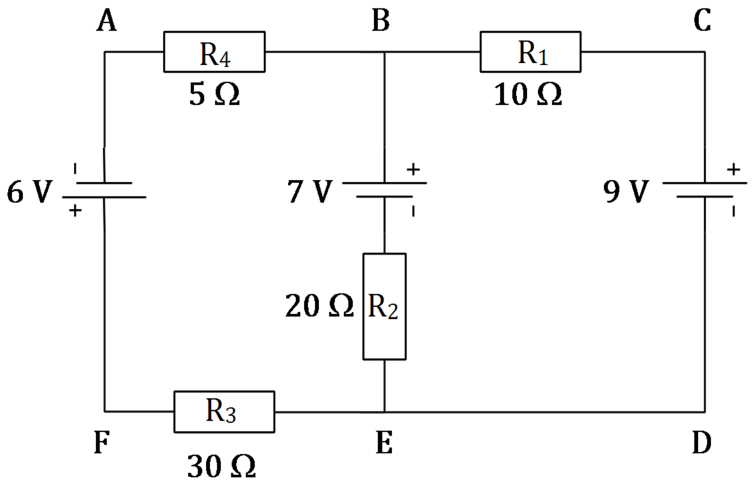


Figure 2

(i) On a copy of the diagram, indicate the currents flowing through the circuit, label them and use Kirchhoff's second law to find a relationship between the currents flowing in the loops ABEF and CBED. **[4 marks]**

(ii) Considering any junction in the circuit, use Kirchhoff's first law to find a relationship between the currents. **[1 mark]**

(iii) Determine the magnitudes of the three currents. **[4 marks]**

(iv) Calculate the power used by resistor R_4. **[1 mark]**

Question 7

a. According to rumours, the next generation smart phone will be powered by a 3.82 V battery that can deliver 1.81 A of current for one hour. The phone automatically turns off when the battery has less than 2% of charge remaining.

(i) Calculate the amount of charge that can be delivered by the battery. **[1 mark]**

(ii) How much charge has passed before the phone loses power? **[1 mark]**

(iii) Show that if a charge Q is transferred across a p.d. V, the energy consumed is equal to QV. **[2 marks]**

(iv) In an idle state the phone uses a constant 70 mW of power. How many days will pass before the phone loses power completely? **[3 marks]**

b. The majority of components inside the smart phone are made up of semiconducting material.

(i) Briefly explain how the electrical conductivity of an intrinsic semiconductor increases as the temperature rises. **[3 marks]**

(ii) Explain the origin of holes in intrinsic semiconducting materials and explain the process by which holes participate in current flow. **[4 marks]**

Question 8

In his investigation of Einstein's photoelectric effect, Millikan conducted the following experiment. Monochromatic light is shone onto a clean sodium surface. A negative potential (the stopping potential) is applied to the anode until the current resulting from electrons reaching the anode when liberated from the irradiated cathode drops to zero. This was repeated for monochromatic light of different wavelengths and the results of Millikan's experiment is shown in Figure 3.

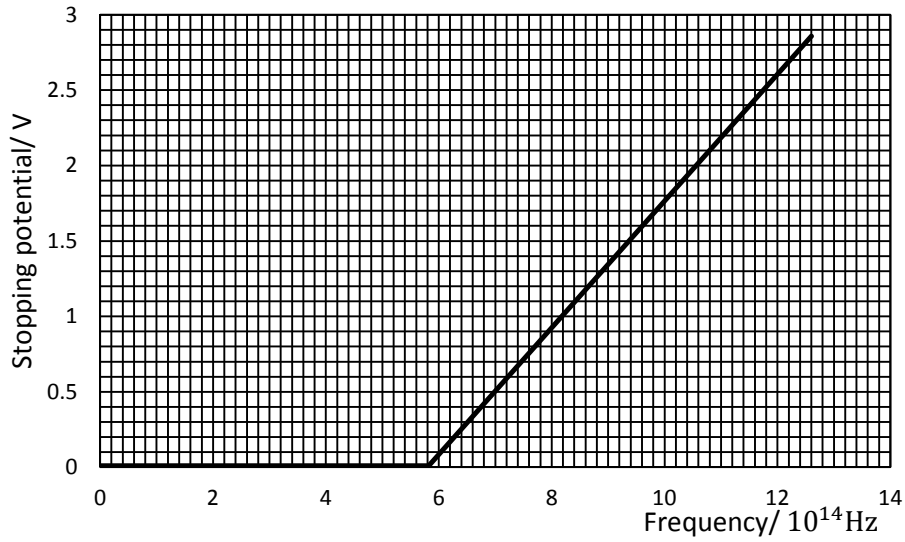


Figure 3

a. Use the graph to find:
   (i) the threshold frequency of sodium; **[1 mark]**
   (ii) the charge of an electron. **[3 marks]**

b. Determine the work function for sodium. **[2 marks]**

c. Find the maximum kinetic energy in Joules and the escape velocity of the ejected electrons when sodium is irradiated with monochromatic light of frequency 10×10^{14} Hz. **[2, 2 marks]**

d. Using de Broglie's relation, find the associated wavelength of the electrons being ejected at a frequency of 10×10^{14}Hz. **[2 marks]**

e. Beryllium has a higher work function than sodium. How will the graph in Figure 3 differ when Millikan's experiment is carried out on Beryllium? **[2 marks]**

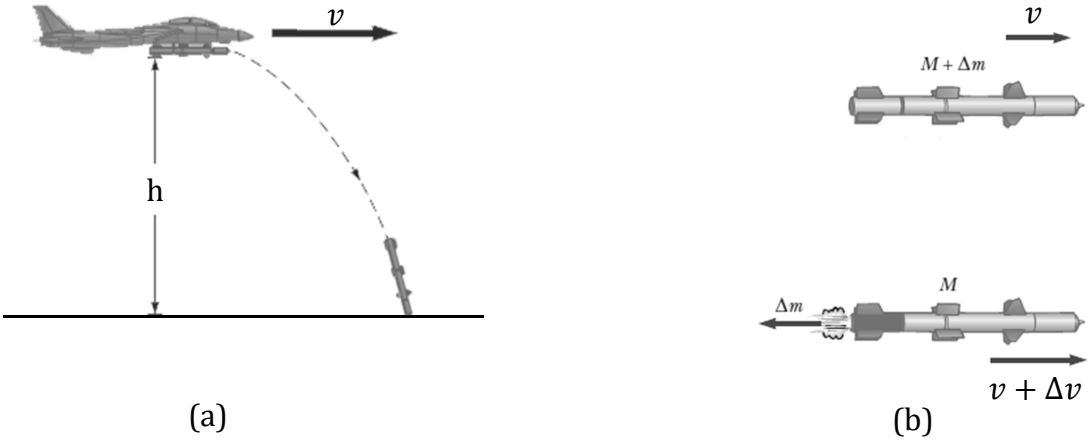
<u>Section B</u>

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.
   (i) State Newton's second law of motion. **[2 marks]**
   (ii) How does this lead to the definition of the Newton as a unit of force? **[2 marks]**
   (iii) Show how this law leads to the principle of conservation of linear momentum. What condition must be assumed in your derivation? **[2, 1 mark]**

b. A student programmed a computer simulation of a jet fighter that can drop bombs and also fire rockets. In one of the tests, the jet fighter is flying at a constant altitude h at a velocity v when it drops a bomb (see Figure 4 (a)). The bomb follows a projectile path until it hits the ground.



(a) (b)

Figure 4

(i) Derive an expression for the time it will take the bomb to hit the ground. **[2 marks]**

(ii) Show that the bomb will hit a target that is at a distance s_x given by $s_x = v\sqrt{\frac{2h}{g}}$ from the point from where it is dropped. State one assumption taken to arrive at this expression. **[2 marks]**

(iii) Given that in one of the simulations the jet fighter is moving at a speed of 400 m/s at an altitude of 3000 m. Calculate the magnitude of the resultant velocity with which the bomb hits the ground and the angle that this makes with the vertical. **[5 marks]**

c. The student then uses his simulation to fire a rocket, see Figure 4 (b). When deployed from the wing of the aircraft, the rocket of mass $M + \Delta m$ is moving with velocity v. In a short time Δt the rocket ejects Δm of burning fuel with a velocity $v_e - v$ and the speed of the rocket increases to $v + \Delta v$.

(i) Write down an expression for the momentum of the rocket before ejecting the burning fuel. **[1 mark]**

(ii) What is the total momentum of the rocket and ejected burnt fuel after a time equal to Δt has passed? **[3 marks]**

(iii) Explain the term impulse of a force. **[2 marks]**

(iv) Show that the forward force acting on the rocket is given by $F = \frac{\Delta m v_e}{\Delta t}$. **[3 marks]**

Question 10

a. Two identical objects lie on a turntable at different distances from the centre in Figure 5.

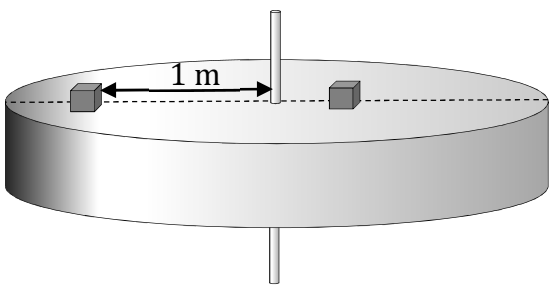


Figure 5

(i) Identify the force which provides the centripetal force on the objects. **[1 mark]**

(ii) Explain why the outer object is thrown off the table at a lower rotational speed. **[2 marks]**

(iii) Both objects have a mass of 1 kg. The outer object is positioned at a distance of 0.5 m

from the centre of the turntable and is thrown off it when the turntable reaches a rotational speed of 5 rad s^{-1}. If the inner object is thrown off the table at a rotational speed of 15 rad s^{-1}, calculate the distance that the inner object is from the centre. **[3 marks]**

(iv) If the turntable starts rotating from rest and accelerates at 50×10^{-3} rad s^{-2}, how much time will pass before the inner object is thrown off the table? **[2 marks]**

b. A roller coaster track contains a circular loop segment.

(i) Draw a diagram that shows the forces acting on one carriage of the roller coaster when it is at the highest and lowest points of the loop. **[4 marks]**

(ii) Derive an expression for the linear velocity of the roller coaster if it is to remain in contact with the track at the top of the loop. **[2 marks]**

(iii) What would happen if the roller coaster were to be moving at a very low speed at the top of the loop? Derive an expression for this minimum speed. **[1, 2 marks]**

(iv) Show that the angular velocity of the carriage at the bottom of the loop is given by $\omega = \sqrt{\frac{\frac{N}{m}-g}{r}}$, where N is the normal force acting on the carriage and r is the radius of the circular loop. **[3 marks]**

(v) At which points along the circular loop will the riders in the carriage feel heavier? Explain your answer. **[1, 1 marks]**

(vi) The riders inside the carriage can withstand accelerations up to $7g$ before they become unconscious, where g is the acceleration due to gravity. If the loop radius is given by 20 m, what is the safe maximum angular speed that the carriage can reach? **[3 marks]**

Question 11

a.

(i) Explain the term moment of inertia. **[1 mark]**

(ii) A point mass m is attached to the midpoint of a light string of length l. A second point mass $3m$ is attached to one of the ends of the same string and the two masses are set in rotation about the free end of the string. Calculate the moment of inertia of this system of masses. **[2 marks]**

(iii) In which conservation relation does the moment of inertia appear? **[1, 1 mark]**

b. To demonstrate the concept of conservation of angular momentum, a teacher sits on a stool that is free to rotate about a vertical axis with negligible friction. The moment of inertia of the teacher with his arms holding the weights close to his chest and stool is 1.60 kg m^2. The teacher is set in rotation by his students and he completes 10 rotations in 12.6 seconds.

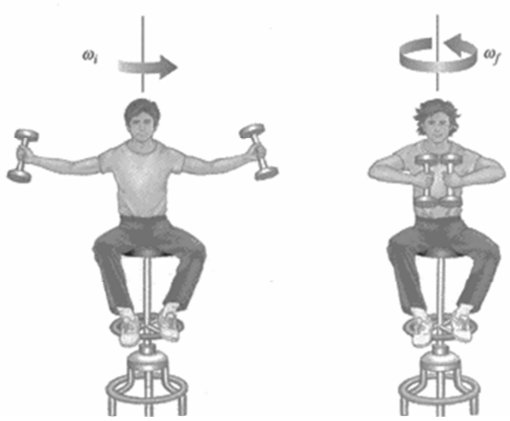


Figure 6

(i) What is the initial angular speed of the teacher? **[2 marks]**

(ii) As he rotates, he extends his arms outwards so that the new moment of inertia of the system becomes 2.75 kg m^2. What is the new angular speed of the system? **[3 marks]**

(iii) Find the work done by the system on the teacher while extending the weights. (Ignore energy lost through dissipation in his muscles.) **[3 marks]**

c. In Figure 7 a flywheel of radius 5 cm can rotate about a horizontal axis on friction free bearings. An inextensible cable passes over the flywheel and is attached to a uniform cylinder, of mass 1.5 kg that rolls down the plane, which is inclined at 45°. On the cylinder the cable connection segment does not rotate or touch the plane leaving the cylinder free to roll down the plane without slipping.

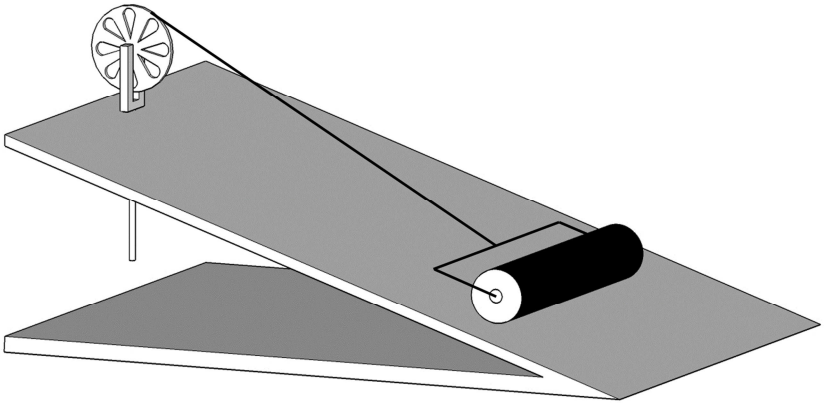


Figure 7

(i) Describe the energy transformations of the system as the cylinder begins to roll down the plane. **[3 marks]**

(ii) Find a relation to determine the angular velocity of the cylinder while it is rolling down the plane surface. **[4 marks]**

The cable is wrapped ten times round the flywheel and looped round a pin. The cable is under a constant tension of 10 N.

(iii) By finding the forces that act parallel with the plane, determine the acceleration experienced by the cylinder and the linear velocity just after the cable detaches from the flywheel. **[3 marks]**

(iv) The moments of inertia of the cylinder and flywheel are $0.15\ \text{kg m}^2$ and $0.05\ \text{kg m}^2$ respectively. Given that the flywheel has an angular velocity of $26\ \text{rad s}^{-1}$ at the instant the cable detaches, find the angular velocity of the cylinder. **[2 marks]**

Question 12

a.

(i) What is the difference between Hooke's spring constant and Young's modulus? **[2 marks]**

(ii) On the same graph area, sketch stress-strain graphs for metal and glass materials, clearly indicating the elastic limit and the breaking point for each material. **[4 marks]**

(iii) What do the terms *elastic behaviour* and *plastic behaviour* refer to? **[2 marks]**

b. Graphene nanotubes offer the possibility of constructing a material that is stronger than traditional materials with the added benefit that it is much lighter. However it is still limited in terms of length. One possible way to overcome this hurdle may be to attach end-to-end many such tubes to create fibres. One such nanotube with cross-sectional area A and length l_0 extends Δl_0 when a force F is applied normally to one of the cross-sectional surfaces.

(i) Show that if N tubes are connected end-to-end then the Young's modulus of the fibre does not change. **[4 marks]**

(ii) Write down an expression for the spring constant of one individual tube, and of a fibre made up of N tubes when the same force F is applied. Hence express the effective spring constant of the fibre in terms of the spring constant, k_0 of an individual tube. **[3 marks]**

(iii) These tubes are actually hollow cylinders with inner radius r_i and outer radius r_o. Show that the cross-sectional area of each tube is given by $A = \pi(r_o^2 - r_i^2)$. **[1 mark]**

(iv) 1000 such tubes, each with original length 1 cm, are connected end-to-end together. Each has a Young's modulus of 1×10^{12} Pa. For a typical nanotube, the inner and outer radii are given by 0.18 nm and 0.52 nm respectively. If a force of 8×10^{-9} N is applied, what will be the resulting change in length of the fibre? **[3 marks]**

c. A number of the fibres in part b, are now connected together in parallel to form a cable. Consider a force F acting on one such cable.

(i) The cable consists of M fibres, each composed of N end-to-end connected nanotubes. Show that the effective spring constant is now $\frac{Mk_0}{N}$. **[3 marks]**

(ii) The cable described in part b (iv) is to lift a 1 N weight. The maximum allowed extension for each fibre after which it will snap is given by 50 cm. What is the minimum number of fibres that this cable must have? **[3 marks]**

Question 13

a.

(i) Define the term *drift velocity* with reference to a current in a circuit. **[1 mark]**

(ii) Derive an expression to describe the current passing through a metallic conductor of cross-sectional area A having n charge carriers per unit volume. **[5 marks]**

b.

(i) Two cylindrical conductors of the same material are connected together as shown in Figure 8. Current passes through the first conductor which has a cross-sectional radius of r_1 and an associated drift velocity of v_1. The second conductor has a cross-sectional radius of r_2. Express the drift velocity, v_2, of the electrons in second material in terms of the other quantities. **[3 marks]**

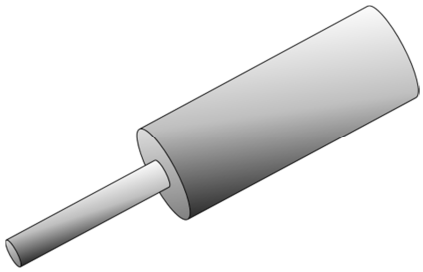


Figure 8

(ii) The conductors are made of iron which has 10^{28} charge carriers per unit volume. The conductors carry a current of 1 A. Given that the radii of the first and second cylinders are given by 0.5 mm and 3.0 mm respectively, determine the drift velocity within each conductor. **[4 marks]**

c. In Figure 9, a battery with an e.m.f 12 V and an internal resistance of 1.1 Ω is shown. **The two voltmeters are identical.**

(i) Briefly explain what is meant by the terms *emf*, *internal resistance* and *terminal potential* and how they are related to each other when reference is made to a power source that has an internal resistance. **[3 marks]**

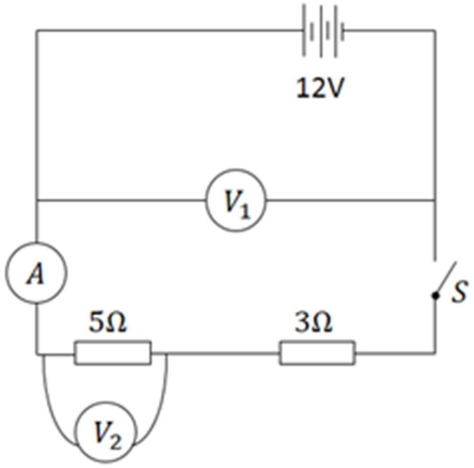


Figure 9

(ii) With switch S open, voltmeter V_1 measures a potential difference of 11.89 V. Determine the current in the circuit and hence the resistance of voltmeter V_1.
[2 marks]

(iii) Had the voltmeter V_1 been ideal, what would have been the reading on it? **[1 mark]**

(iv) The switch S is then closed and the voltmeter, V_1, gives a reading of 11.57 V while the ammeter measures a current of 0.29 A. Determine the resistance of the ammeter.
[4 marks]

(v) Compare the resistance of an ideal ammeter and of an ideal voltmeter. **[1, 1 mark]**

Question 14

a. Two resistors R_1 and R_2, are connected in series with a total potential difference, V, across them.

(i) Show that the power dissipated by resistor R_1 is given by

$$\frac{R_1(V^2)}{(R_1 + R_2)^2}$$

Clearly explain any other symbols used in your derivation. **[4 marks]**

(ii) Will the power used by resistor R_1 increase or decrease if the same potential difference is applied to the two resistors connected in parallel? Write down an expression for the power used by resistor R_1 when connected in this configuration.
[3 marks]

b.

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

How does the resistance of a substance vary when this coefficient is

(ii) positive; **[1 mark]**

(iii) negative. **[1 mark]**

c. In certain intervals of temperature the resistance, R, of some metals varies linearly with temperature, θ, through the relation $R_\theta = R_0(1 + \alpha\Delta\theta)$. Describe an experiment to test this relationship. Your description should include:

(i) a list of equipment and materials to be used;

(ii) a labelled diagram of the set-up;

(iii) a description of the procedure to follow and the measurements that need to be taken;

(iv) a table of results;

(v) a sketch of the graph expected to be obtained from the results;

(vi) an indication of how to validate the relationship. **[3, 3, 2, 2, 2, 2 marks]**

Question 15

a. A radioactive source that emits low energy gamma radiation is placed a short distance away from a detector. Lead sheets of different thicknesses are inserted between the radioactive source and detector. The graph of Figure 10 shows how the count rate changes with increasing lead thickness.

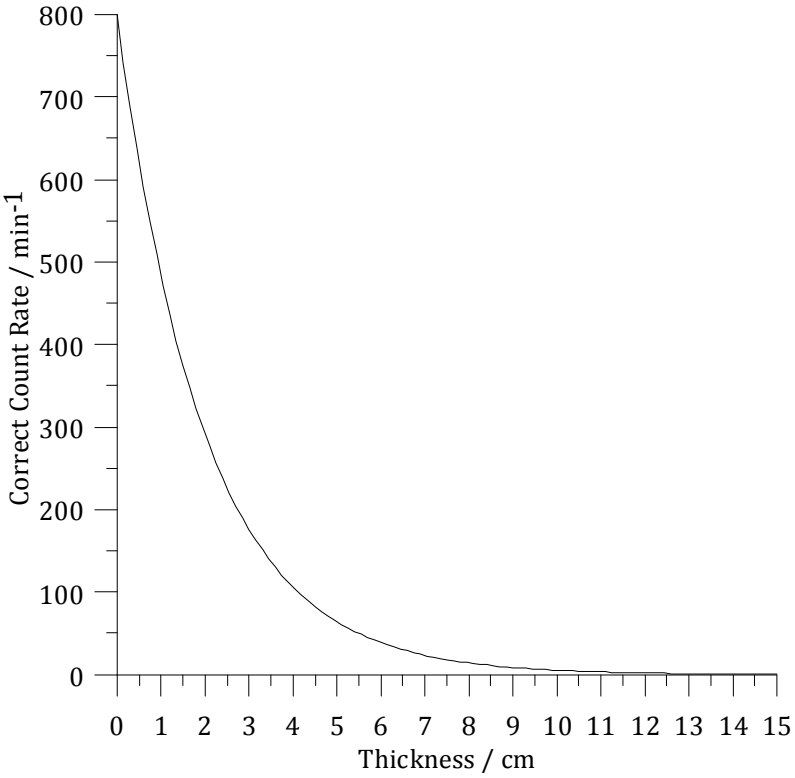


Figure 10

(i) The vertical axis of the graph shows the *corrected count rate.* Explain briefly the physical significance of the statement in italics. **[2 marks]**

(ii) Use the graph to determine the half-value thickness of lead. **[2 marks]**

(iii) Determine the linear absorption coefficient of lead. **[3 marks]**

(iv) If the lead sheets are removed, how would the intensity of the gamma radiation change with increasing distance from the detector? **[2 marks]**

b. Rutherford's alpha scattering experiment is performed by firing a parallel beam of alpha particles onto a thin gold leaf. The scattering pattern is then measured over all possible angles.

(i) What scattering pattern is observed in Rutherford's experiment? **[2 marks]**

(ii) What three properties concerning the nucleus of atoms did Rutherford postulate after analysing the results? **[3 marks]**

(iii) How did the negative charge carriers fit in this model of the atom? **[1 mark]**

(iv) Describe the model that this experiment falsified. What scattering pattern was expected using this model? **[2, 1 mark]**

(v) If the alpha particles were to be replaced by neutral particles, how would the scattering pattern change? **[2 marks]**

c. In Rutherford's experiment the most affected alpha particles are those that are stopped completely from moving forward. In these head on interactions all the kinetic energy of the alpha particles is transferred into potential energy. This is the closest the alpha particles get to the gold leaf.

(i) Find a relationship for the distance of the closest approach of the alpha particles to the gold leaf particles. Explain all symbols used. **[3 marks]**

(ii) The alpha particles are fired with a velocity of $2 \times 10^{7} \mathrm{m\,s^{-1}}$. These particles have a mass of 6.7×10^{-27} kg. Given that the atomic number of gold is 79, find the minimum distance that the alpha particles can get to the gold nucleus. **[2 marks]**

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DATE:	3rd September 2014
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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 specific heat capacity of water is* $4200\ J\ kg^{-1}\ K^{-1}$ *while the specific latent heat of steam is* $2.26 \times 10^6\ J\ kg^{-1}$*.* Explain what is meant by the statement in italics. **[2 marks]**

b. Explain, in terms of molecular motion, the large difference between the two values. **[4 marks]**

c. A polystyrene cup contains 80 g of water at 20°C. Steam at 100°C is passed into the water until the final temperature of the water rises to 80.0°C. Determine the mass of steam which has been passed into the water. **[4 marks]**

d. The heat transfer to the cup may be neglected in the calculation. Why? **[2 marks]**

Question 2

a. Heat transfer occurs by three mechanisms: *conduction, convection,* and *radiation*. In what ways are the three mechanisms different from each other? **[6 marks]**

b. Answer the following questions about everyday observations:
   (i) Aluminium foil used for cooking has a shiny side and a side with a matt finish. How would you wrap a potato to be baked? Explain your answer. **[3 marks]**
   (ii) On a hot summer day, why does the metal roof of a car feel hotter than the plastic door handle? **[4 marks]**

Question 3

a. Draw the pattern of the gravitational flux passing through a horizontal surface, *A*, of area 1 m^2 close to the Earth's surface. **[3 marks]**

b. What is meant by the phrase "*Gravitational potential at a point in a gravitational field"*? **[2 marks]**

c. Explain why the surface A is an equipotential surface. **[2 marks]**

d. If a surface B, situated 2.00 m directly below A and parallel to A, is taken to be at zero gravitational potential, what is the potential of surface A? Take the acceleration of free fall at the Earth's surface to be 10.0 m s^{-2}. **[2 marks]**

e. If a body is allowed to fall from surface A to surface B along a smooth, curved path, what will be its velocity on reaching surface B? **[2 marks]**

Question 4

a. Two small identical spheres each carrying a charge, $+q$ C, are placed on the line LM as shown in the diagram:

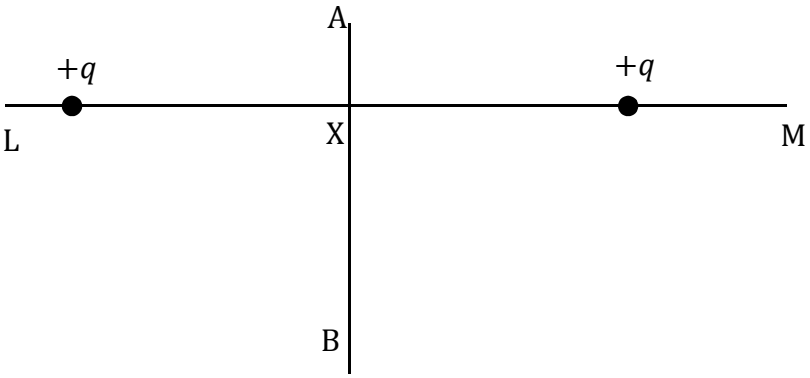

Figure 1

Describe how the intensity and direction of the electric field produced by the two charges varies:

(i) along the line LM, and **[4, 2 marks]**

(ii) along the line AB, which is perpendicular to LM and at the same distance from each of the charges. **[2, 2 marks]**

b. Describe how the acceleration and velocity of a positively charged particle initially at rest on the line LM very close to one of the charges $+q$, changes as the particle moves away from the charge. **[3, 3 marks]**

Question 5

Eddy currents are used in some vending machines to distinguish between genuine and counterfeit coins. The coin rolls past a stationary magnet so that eddy currents are induced in it and the coin is slowed down. The retardation depends on the coins' metal. Counterfeit and genuine coins are slowed down to different degrees. This difference makes it possible to reject counterfeit coins.

a. What are eddy currents and how are they produced in a metal? **[2 marks]**

b. Explain why coins are slowed down as they pass past the stationary magnet. **[3 marks]**

c. Why are counterfeit and genuine coins retarded to different degrees? **[3 marks]**

d. Describe how you would demonstrate experimentally the retardation produced in metals by eddy currents. **[4 marks]**

Question 6

A trolley A is attached by means of identical springs of spring constant k to two fixed nails P and Q so that it can travel along a smooth horizontal surface.

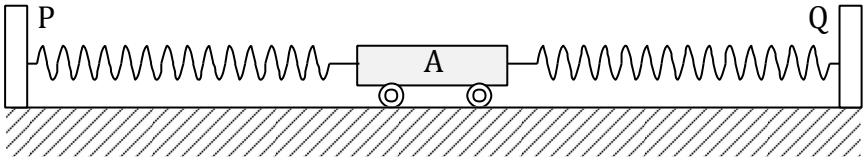

Figure 2

a. If the extension of each spring is X, what force does each spring exert on the trolley? **[1 mark]**

b. The trolley is pulled to one side and released. At one instant of its motion, the trolley has a displacement x from its rest position. What is the force exerted by each spring at this instant? Assume that both strings remain extended throughout. **[2 marks]**

c. What is the resultant force acting on the trolley? **[2 marks]**

d. Prove that the trolley performs simple harmonic motion. **[3 marks]**

e. If the mass of the trolley is M, write down an equation for the period of oscillation T of the trolley. **[2 marks]**

Question 7

The diagram shows a transverse wave on a rope. It is moving to the right. Several particles on the rope have been labelled.

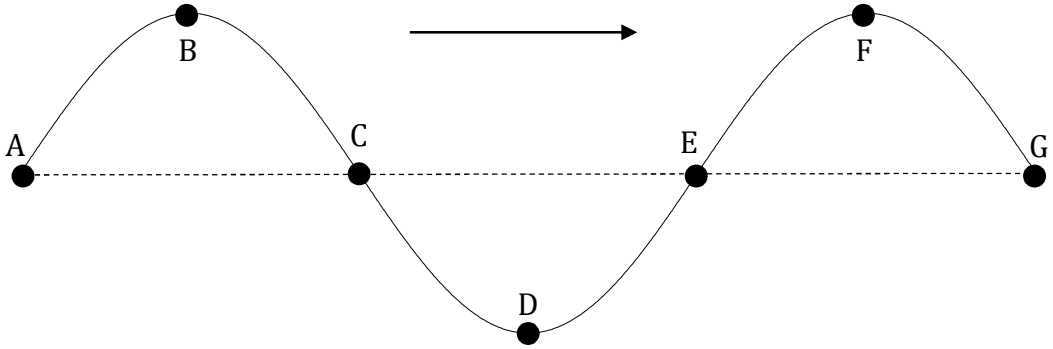

Figure 3

a. Distinguish between *transverse* and *longitudinal* waves. **[2 marks]**

b. Copy the diagram and draw arrows to show the direction in which particles *A,C, E,* and *G* are moving at the instant shown. **[2 marks]**

c. Which particles have:
   (i) maximum,
   (ii) minimum velocity at the instant shown? **[2 marks]**

d. Which particles are
   (i) in phase,
   (ii) out of phase by 180°? **[2 marks]**

Suppose now that the diagram shows the instantaneous displacement of the particles of the rope when it carries a stationary transverse wave.

e. Describe the motion, if any, of the particles *A* and *B.* **[2, 2 marks]**

f. Which of the particles are:
   (i) in phase,
   (ii) out of phase by 180° ? **[2 marks]**

Question 8

a. Light from distant *galaxies* shows *absorption spectra*. Absorption lines in such spectra show a shift towards the red end of the spectrum called a *redshift.*
   (i) Explain the terms in italics. **[4 marks]**
   (ii) Explain why light from stars in our own Galaxy may show a red or a blue shift. **[2 marks]**
   (iii) What can be deduced from measurements of the redshift of distant galaxies? **[2 marks]**

b. "The *Cosmic Microwave Background* is very well fitted by a *blackbody spectrum* with a temperature of 2.725 K". Explain the phrases in italics. **[2, 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. A sample of gas is enclosed in a cylinder by a piston. The cylinder is given 225 J of energy which expands and pushes the piston 16 cm outwards against an atmospheric pressure of 1.01×10^5 Pa.

   (i) Give the equation for the first law of thermodynamics and clearly state the meaning of each symbol used. **[3 marks]**
   (ii) Show that for an enclosed fixed mass of gas, the change in work done, ΔW, is equal to $P\Delta V$ where P is the pressure of the gas and ΔV the change in volume. **[4 marks]**
   (iii) Assuming that the piston is frictionless and has an area of 90 cm^2, calculate the external work done by the gas and the increase in internal energy of the gas. **[4 marks]**

b. An ideal gas of density 0.3 kg m^{-3} at 300 K and pressure 1.5×10^5 Pa occupies a volume of 1.25×10^{-3} m^3. The gas first expands isobarically to a volume of 1.55×10^{-3} m^3 and then it is compressed isothermally to its original volume.
   (i) What is isobaric expansion and isothermal compression? **[2 marks]**
   (ii) Sketch a suitable graph to show these changes. **[3 marks]**
   (iii) Calculate the energy added during the isobaric expansion. **[2 marks]**
   (iv) What is the temperature and pressure after the isothermal compression? **[4 marks]**
   (v) Calculate the difference between the initial and final internal energy if the specific heat capacity of the gas at constant volume is 7×10^2 J kg K^{-1}. **[3 marks]**

Question 10

a. In the Brownian motion experiment, small particles of matter are seen moving randomly. Give an explanation for this motion. **[2 marks]**

b. Boyle's law is fundamental when discussing the gas laws.
   (i) State Boyle's law. **[1 mark]**
   (ii) Draw a labelled diagram of the apparatus used in an experiment to verify this law. **[2 marks]**
   (iii) Sketch the graph which is obtained from such an experiment. **[1 mark]**

c. The pressure exerted on a surface by gas molecules is given by $P = \frac{1}{3}nm\langle c^2 \rangle$ where n is the number of molecules per unit volume, m is the mass of a molecule and $\langle c^2 \rangle$ is the mean square velocity of the molecules.
   (i) State four assumptions used to derive this equation. **[4 marks]**
   (ii) Derive the above equation for the pressure exerted by gas molecules. **[8 marks]**

d. A quantity of an ideal mono-atomic gas of density $1.2\ \text{kg m}^{-3}$ occupies a volume of $1.2 \times 10^{-2}\ \text{m}^3$ at a pressure of 1×10^5 Pa and a temperature of 255 K.
   (i) How many moles of gas are present? **[1 mark]**
   (ii) What is the internal energy of this gas? **[2 marks]**
   (iii) Calculate the root mean square speed of the molecules. **[2 marks]**
   (iv) What is the significance of the root mean square speed? **[2 marks]**

Question 11

a. Capacitors are essential components in many electronic devices.
   (i) Define the capacitance of a capacitor. **[2 marks]**
   (ii) Describe three factors on which the capacitance of a parallel plate capacitor depends and state how each effects its value. **[3 marks]**
   (iii) State two important characteristics of a dielectric. **[2 marks]**

b. Explain how electrolytic capacitors have high capacitance values. **[3 marks]**

c. Three identical capacitors, each of capacitance C, are connected in parallel and a 12.0 V potential difference is applied across their plates. Each capacitor carries a charge of 10.0 μC.
   (i) Obtain an expression for the combined capacitance of the three capacitors connected in parallel. **[4 marks]**
   (ii) Find the value of the capacitance C. **[2 marks]**
   (iii) Calculate the value of the combined capacitance. **[1 mark]**
   (iv) If the voltage source is removed without discharging the capacitors, and another identical capacitor is connected in parallel, what is the charge on this capacitor? **[2 marks]**

d. A resistor of value 15 kΩ is connected across a charged capacitor of 150 μF.
   (i) What is the value of the time constant of the circuit? **[2 marks]**
   (ii) What fractional value of the original voltage remains across the plates of the capacitor during discharge, after a time equal to its time constant has passed? **[2 marks]**

(iii) Calculate the charge which remains on the capacitor, 1.0 s after discharge is started, if the initial value of its charge was 5.0 μC. **[2 marks]**

Question 12

a. Explain the meaning of magnetic flux linkage. **[2 marks]**

b. State Faraday's law of electromagnetic induction. **[2 marks]**

c. A square loop of wire of side length 25 cm is placed in a horizontal plane within a vertical uniform magnetic field of wide extent. The uniform magnetic field has a flux density 0.35 T.
   (i) Calculate the magnetic flux linkage with the loop. **[2 marks]**
   (ii) Describe changes in the flux linkage, if any, when the loop is moved sideways or lowered down inside the field. **[2 marks]**
   (iii) How can an e.m.f. be induced in the loop? **[2 marks]**

d. A rectangular coil of area 14 cm^2 and 200 turns is rotated at a constant angular velocity ω in a magnetic flux density of 0.02 T.
   (i) If the angle that the normal to the coil makes with the field is ωt, write an expression for the flux linkage at this angle. **[2 marks]**
   (ii) Find the rate of change of flux linkage. **[2 marks]**
   (iii) What will be the e.m.f. at any instant if $\omega = 50\pi$ rad s^{-1}? **[2 marks]**
   (iv) Calculate the peak e.m.f. generated at this frequency. **[2 marks]**
   (v) What is the angle of the coil with the field to generate the peak e.m.f? **[2 marks]**
   (vi) In which direction would the induced flow? Explain. **[2 marks]**

e. A bicycle wheel turns at 3 revolutions per second and is made of metal spokes each 50 cm long. Assuming that the size of the horizontal component of the Earth's magnetic field is 1.6×10^{-3} T and the wheel rotates perpendicularly to the horizontal component of this field, calculate the e.m.f. induced in each spoke. **[3 marks]**

Question 13

a. The mains supply current is generated as alternating current.
   (i) Why is it called so? **[1 mark]**
   (ii) What is the difference between the peak value and the root mean square value of an alternating current? **[2 marks]**
   (iii) If the root mean square value of an alternating e.m.f. is 220 V, what is the peak value of this e.m.f.? **[2 marks]**
   (iv) If the frequency of this e.m.f. is 50 Hz, sketch a graph which clearly shows the peak value and periodic time. **[2 marks]**
   (v) When an alternating p.d. is connected across a 200 Ω resistor whose ends are connected to the Y-plates of a cathode ray oscilloscope, a trace, 25 mm peak to peak waveform is formed on the screen. If the cathode ray oscilloscope is set at 0.5 V mm^{-1}, calculate the r.m.s. voltage across the resistor and the r.m.s. current. **[3 marks]**

b. A.C. sources have to be rectified before they can be used as d.c. sources.
   (i) Clearly distinguish between half-wave and full-wave rectification. **[4 marks]**

(ii) The p-n junction diode may be used as a rectifier. Explain how its structure and the way it is used makes this possible. **[5 marks]**

c. An inductor is frequently used in a.c. circuits.
(i) Clearly distinguish between inductive and capacitive reactance. **[4 marks]**
(ii) A 12 V r.m.s. alternating current supply at a frequency of 500 Hz is applied to a coil of 0.55 H inductance and negligible resistance. Calculate the r.m.s. current in the circuit. **[2 marks]**

Question 14

a. When an object is placed in front of a plane mirror, an image may be seen.
(i) What happens to light waves when they are incident on the mirror? **[1 mark]**
(ii) The image from the plane mirror is said to be virtual. Distinguish this type of image from a real one. **[2 marks]**

b. Light waves may also be refracted.
(i) How is refraction different from reflection? **[2 marks]**
(ii) State the laws of refraction. **[4 marks]**

c. A narrow beam of light is incident at an angle of 20° on one of the internal surfaces of a rectangular glass block surrounded by air.
(i) If the refractive index of air and glass are 1.0 and 1.5 respectively, calculate the angle of refraction. **[2 marks]**
(ii) If a thin layer of water of refractive index 1.3 is placed on the block, calculate the angle of refraction for the light passing into the water. **[2 marks]**
(iii) Calculate the angle of refraction for the light passing from water into air. **[2 marks]**

d. A glass block is illuminated with white light at 40° to the normal. It is known that the refractive index of glass to blue light is 1.64 and for red light it is 1.62. Calculate the angle between the blue and red light after refraction. **[3 marks]**

e. Define the term *critical angle*. **[2 marks]**

f. A camera has a lens of focal length 45 mm which may be used to focus images from infinity to 1.30 m from the lens. Calculate the distance through which the lens must be able to move. **[5 marks]**

Question 15

a. Briefly explain the principle of superposition of waves. **[2 marks]**

b. State three differences between stationary waves and progressive waves. **[3 marks]**

c. One end of a 2.1 m long wire is connected to a vibrator while the other end is attached to 2.0 kg hanging mass which keeps it stretched. A stationary wave system is set up consisting of seven loops.
(i) What is the wavelength of the stationary wave? **[2 marks]**
(ii) Calculate the speed of the waves on the wire if the frequency of the vibrator is 150 Hz. **[2 marks]**

(iii) Assuming that the wave velocity $v = \sqrt{\frac{T}{\mu}}$ where T is the tension and μ is the mass per unit length, calculate the value of μ of the wire. **[3 marks]**

d. What are the conditions required for interference between two waves to take place? **[2 marks]**

e. After a source of monochromatic light passes through a double slit, an interference pattern is formed on a screen. State what happens to the interference pattern when:
(i) the slit separation is decreased; **[2 marks]**
(ii) the separation between the source and the screen is increased. **[2 marks]**

f. Wavefronts from two sources of light, one with a wavelength of 430 nm and another of 650 nm are incident on a diffraction grating of 600 lines per mm.
(i) Calculate the angular separation between the second-order fringes for these two wavefronts. **[4 marks]**
(ii) What is the maximum number of orders that can be obtained using this grating in conjunction with the 650 nm light source? Explain your reasoning. **[3 marks]**

MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

UNIVERSITY OF MALTA, MSIDA

MATRICULATION EXAMINATION
ADVANCED LEVEL
SEPTEMBER 2014

SUBJECT:	PHYSICS
PAPER NUMBER:	III – *Practical*
DATE:	29th August 2014
TIME:	2 hours

Experiment: Heat conductivity of polystyrene

Apparatus: Stand and clamp, liquid-in-glass thermometer, thermistor, multimeter, stopwatch, beaker, polystyrene cup, spirit lamp and matches.

Important Note:

- This experiment involves high temperature flames and highly flammable liquids. For this reason and at all times particular attention is needed to carry out the experiment.

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

Diagram:

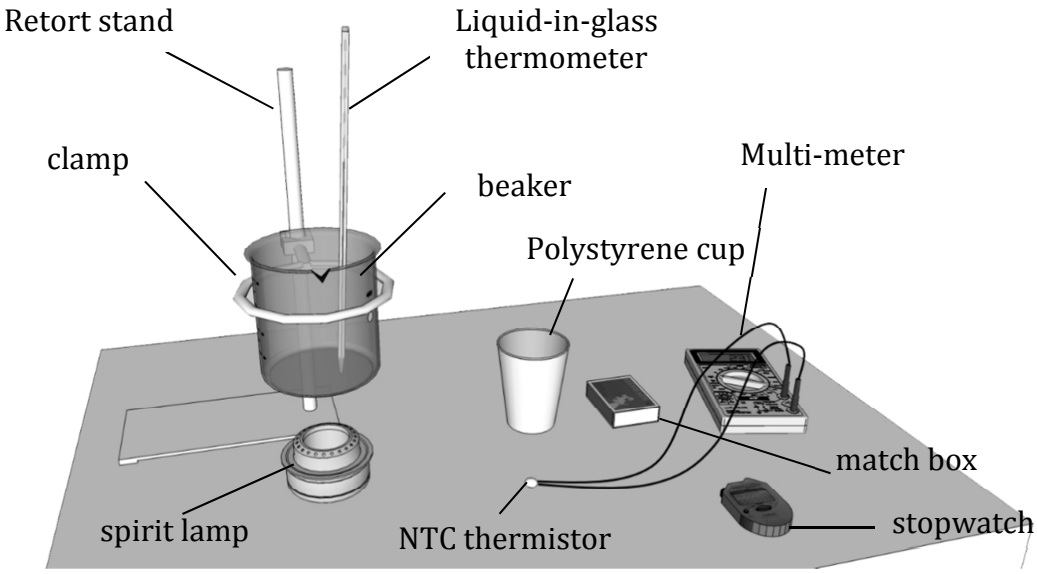

Figure 1 The experimental setup

Method – Part A:

1. The apparatus is set up for you. Make sure that you have all the apparatus that is shown in (actual setup may vary from the one shown) Figure 1.
2. This part of the experiment will calibrate a negative temperature coefficient (NTC) thermistor so that it can be used as a thermometer in the second part of the experiment.

3. Briefly explain how the resistance of a NTC thermistor changes with temperature by making particular reference to the movement of electrons between energy bands as described by the simple band theory on semiconductors.

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_____**[4 marks]**

4. Place the liquid-in-glass thermometer and the thermistor in the beaker partially filled with water.
5. Set the multi-meter to read resistance on the 20 kΩ range. *(Hint: the values read will be in kΩ)*
6. You will record in Table 1 the resistance of the thermistor, R, as it changes with increasing temperature, T, of the water.
7. With the help of the available technicians or using the match sticks provided light the spirit lamp and start taking your readings. Stir the water continuously throughout the whole process.

Table 1

T / K	R /Ω	$\frac{1}{T}$ / K^{-1}	$\log R$
313.15 (40°C)			
318.15 (45°C)			
323.15 (50°C)			
328.15 (55°C)			
333.15 (60°C)			
338.15 (65°C)			
343.15 (70°C)			
348.15 (75°C)			

[8 marks]

8. Turn off the spirit lamp when you are done taking readings.
9. Complete Table 1 by working out the values of $\frac{1}{T}$ and $\log R$.

[4, 4 marks]

10. Plot a graph of $\log R$ on the **y-axis** against $\frac{1}{T}$ on the **x-axis**.

[15 marks]

11. The relationship between the resistance R and temperature T of a thermistor is given by:

$$\log R = \frac{a}{T} + b$$

where a and b are constants.

12. Use the graph to determine the values of the constants a and b.

[3, 2 marks]

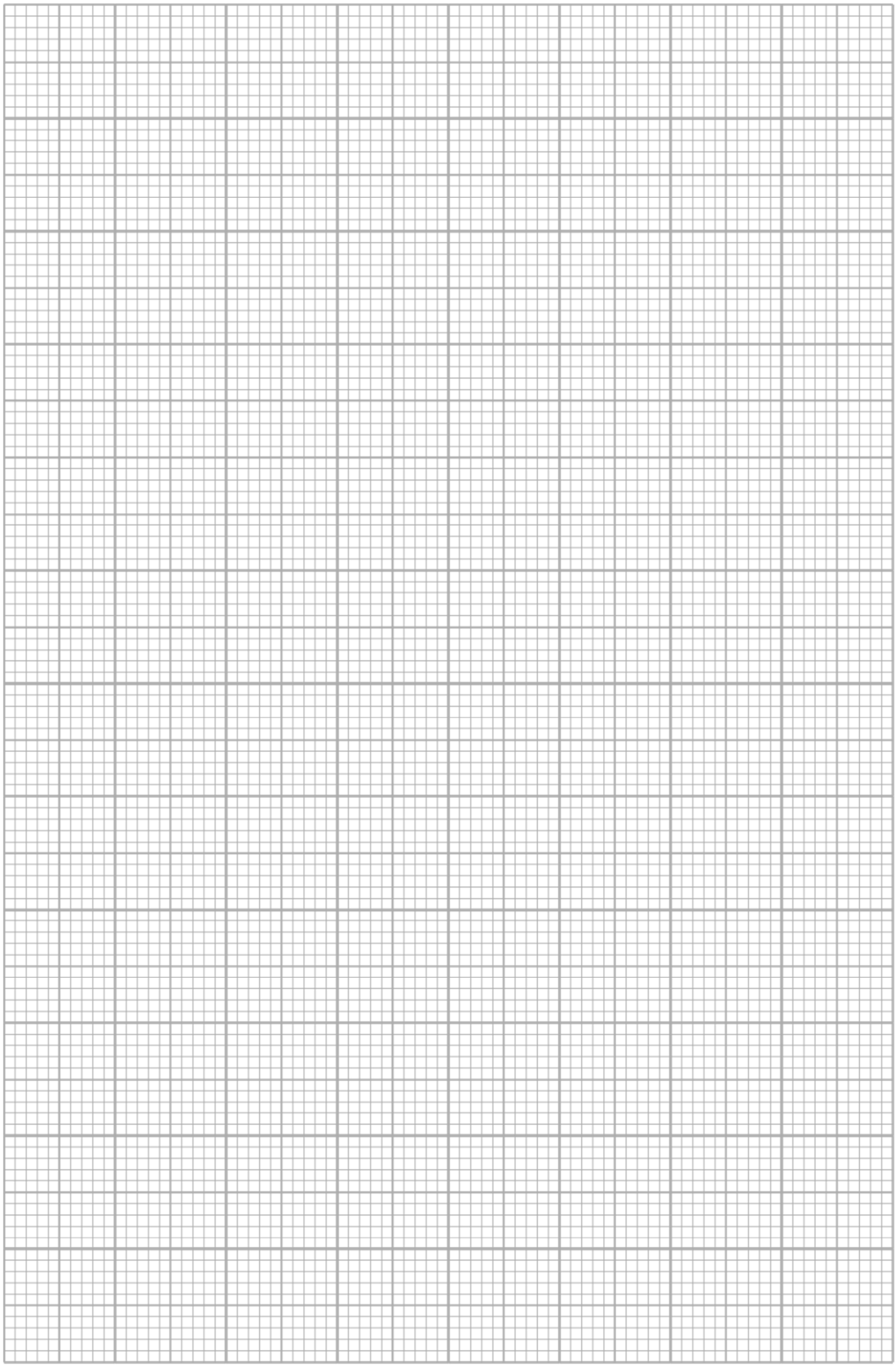
13. The equation

$$T = \frac{a}{\log R - b}$$

can now be used to determine the temperature when the resistance of the thermistor is measured.

14. Identify and state one source of error and a corresponding precaution undertaken to minimize the source of error. Indicate clearly whether it is a systematic or a random error.

[3 marks]



Method – Part B:

15. This part of the experiment will use both the thermistor and the liquid-in-glass thermometer to determine the conductivity of the polystyrene cup.
16. Place the thermistor in the polystyrene cup. The polystyrene cup contains 80 ml of water at room temperature.
17. Use the liquid-in-glass thermometer to measure the temperature of the water in the beaker. If the temperature of the water is less than 70°C, reheat the water until it reaches a temperature slightly above 70°C . Turn off the spirit lamp when ready.

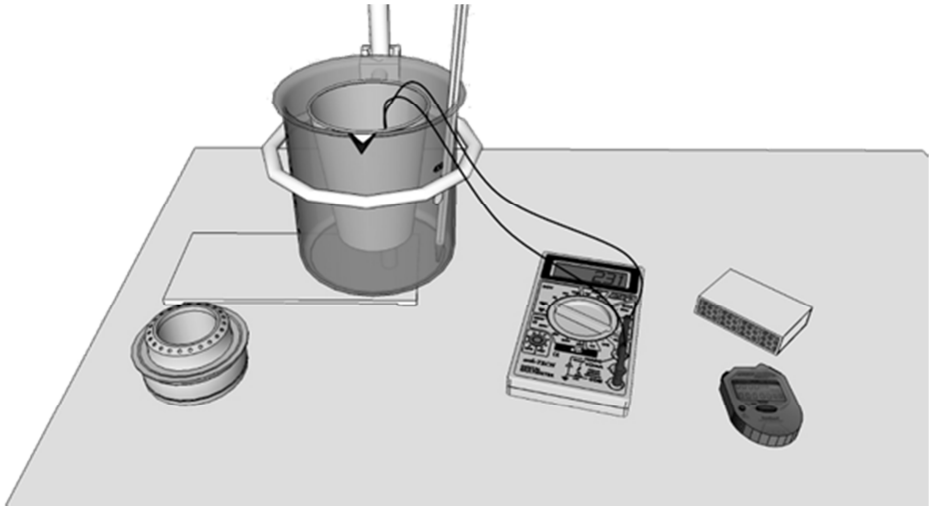


Figure 2

18. Read carefully beforehand the instructions from steps 19 to 21 before proceeding to carry out the experiment.
19. Place the polystyrene cup (with the thermistor inside) in the beaker with water at around 70°C . **As soon as you place the cup**, you will **start the stopwatch** and **record the initial resistance of the thermistor and the initial temperature read by the liquid-in-glass thermometer** in the row corresponding to the time $t = 0$ s of Table 2.
20. Record the resistance R read by the multimeter and the temperature, θ, read by the thermometer every minute for a total duration of 8 minutes in the corresponding rows of Table 2.
21. It is normal for the polystyrene cup to partially float in the water of the beaker.

Table 2

Time, t / s	R/Ω	$\theta/°\text{C}$
0		
60		
120		
180		
240		
300		
360		
420		
480		

[18 marks]

22. Use the equation in step 13 to work out the temperature on the inside of the polystyrene cup (as read by the thermistor). Record this in the column T_{in} of Table 3. *(Hint: Note that the equation of step 13 gives the temperature in Kelvin and hence there is no need to convert the values)*

[9 marks]

23. Convert the temperatures θ in °C read by the liquid-in-glass thermometer to Kelvin and record the values in the column T_{out} of Table 3.

[4 marks]

Table 3

Time, t /s	T_{in}/K	T_{out}/K	dQ/dt	$\Delta T = T_{out} - T_{in}$
0				
60				
120				
180				
240				
300				
360				
420				
480				

24. For this particular setup the rate of heat transfer $\frac{dQ}{dt}$ in the polystyrene is given by

    $\frac{dQ}{dt} = -0.008t + 6.06$,

    where t refers to the time values in the first column of Table 3.

25. Use the equation in step 24 to work out the values of $\frac{dQ}{dt}$ in Table 3 and work out also the values of ΔT.

[4, 4 marks]

26. The rate of heat transfer is related to the conductivity, k, of the polystyrene by the expression:

$$\frac{dQ}{dt} = kA\frac{\Delta T}{\Delta x}$$

    where A is the surface area of the cup covered by the water in the cup and Δx is the thickness of the polystyrene.

27. Plot a graph of $\frac{dQ}{dt}$ on the y-axis against ΔT on the x-axis.

[15 marks]

28. Given that the surface area $A = 0.0063\ \text{m}^2$ and the thickness of the polystyrene Δx is 0.002 m, use the graph to determine the conductivity of polystyrene.

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_____**[3 marks]**

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