MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD
UNIVERSITY OF MALTA, MSIDA

MATRICULATION EXAMINATION
ADVANCED LEVEL
SEPTEMBER 2015

SUBJECT:	PHYSICS
PAPER NUMBER:	I
DATE:	1st September 2015
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. The magnetic flux density around a current carrying conductor is given by

$$B = \frac{\mu_0 I}{2\pi r}$$

where B is the magnetic field density measured at a distance r when a current I flows through the conductor. Show that the equation is homogenously correct with respect to units.

[3 marks]

b. John wants to paddle his canoe across a river that is 200 m wide, as shown in Figure 1. He starts from the east side of the river and crosses to the west side. The water current flows from north to south at $0.50\ \mathrm{m\,s^{-1}}$. It takes John 252 seconds to cross the river.

(i) Draw a diagram to graphically represent the velocity vectors of the water, canoe and their resultant. **[3 marks]**

(ii) Calculate the direction in which John headed his canoe to follow a course due west across the river. **[3 marks]**

(iii) At what speed with respect to still water is John able to paddle? **[3 marks]**

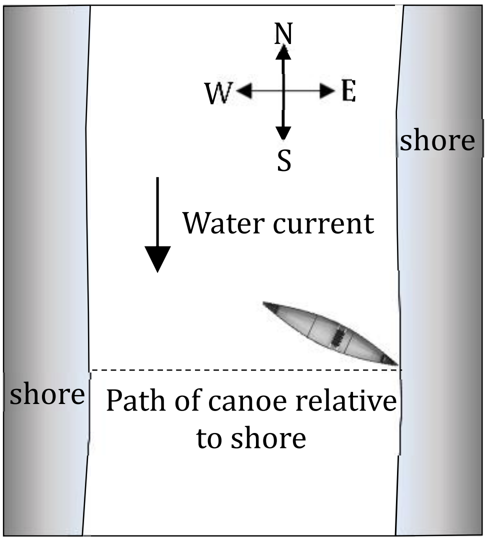

Figure 1

Question 2

The graph of Figure 2 shows a plot of the vertical velocity of an elevator as it moves from the ground floor to the second floor versus time.

a. Calculate the vertical acceleration of the elevator. **[2 marks]**

b. Determine the height between the ground floor and second floor. **[3 marks]**

c. The elevator remains stationary for 4 seconds at the second floor, then moves down to the first floor, reaching the same constant velocity on the way down as in part (a). The acceleration and deceleration on the way down are twice those on the way up. On a copy of Figure 2, sketch and label the velocity – time graph for the downward journey. **[5 marks]**

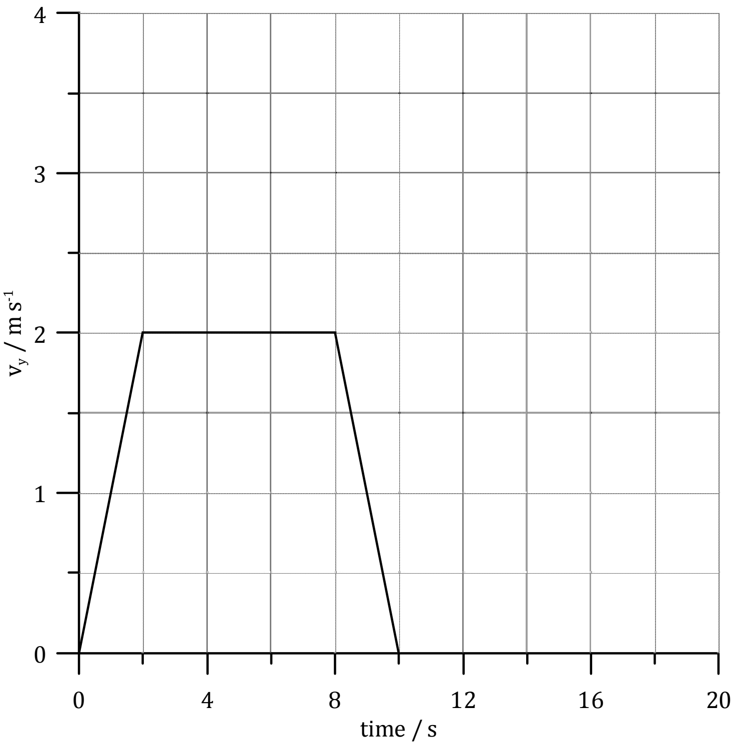

Figure 2

Question 3

A satellite of mass M freefalls vertically onto an asteroid with a gravitational acceleration g_p. The satellite base is in the shape of an equilateral triangle with three identical springs positioned at its vertices. Each spring has an initial length l_0. The freefall starts from rest, with the base at a height ⍰ above the surface.

a. On landing the springs are momentarily compressed by a distance l_c. Show that the energy stored in the springs is given by Mg_p ⍰ $+ \; l_c - \; l_0$. **[3 marks]**

b. Hence, show that the spring constant k is given by

$$k = \frac{2Mg_p}{3l_c^2} \; ⍰ + \; l_c - \; l_0$$

[2 marks]

c. Freefall decent starts from 0.5 km above the surface. If the satellite mass is 250 kg and the 0.40 m springs compress by a total of 0.10 m, determine the spring constant k. Take g_p to be equal 1 m s^{-2}. **[3 marks]**

d. Calculate the maximum energy stored in each spring. **[2 marks]**

Question 4

A street car racer wants to make a right 180° U-turn at constant speed by following a semi-circular path. He needs to do so in the least time possible. The minimum radius of the turn due to a limitation of the car's steering system is 5.0 m and the maximum radius of the turn limited by the width of the street is 20 m. The centripetal acceleration of the car cannot exceed 3.0 m s^{-2} or else it will skid.

a. Why does the driver feel that he is being pushed towards the passenger side of the car? **[2 marks]**

b. What is keeping the car from sliding? **[1 mark]**

c. Show that for a car moving with linear velocity v along a circular path of radius r, its centripetal acceleration is given $\frac{v^2}{r}$. **[5 marks]**

d. If v_1 is the linear velocity of the car when it takes the turn with the minimum radius and v_2 is the linear velocity of the car when it takes the turn with the larger radius, show that $\frac{v_1^2}{v_2^2} = \frac{1}{4}$. **[3 marks]**

e. Determine the minimum possible time for this U-turn and hence identify whether the driver should opt for the turn with the smallest or largest radius. **[5 marks]**

Question 5

a. State the two conditions necessary for a system to be in static equilibrium. **[2 marks]**

b. A steel beam 1.00 m long is attached to a hinge on the outside wall of a restaurant. A cord is tied to the centre of the beam and keeps the beam horizontal as shown in Figure 3. The weight of the beam is 200 N.

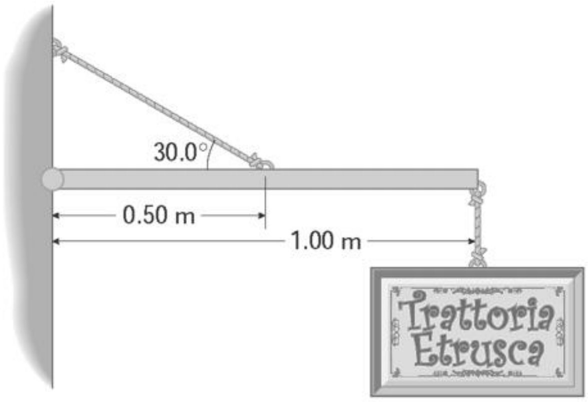

Figure 3

(i) Draw a free body diagram showing all the forces in the set-up. **[3 marks]**

(ii) The cord makes an angle of 30° to the beam and has a maximum breaking tension of 620 N. Calculate the vertical component of such a tension. **[2 marks]**

(iii) Determine how large the mass of the sign can be without breaking the cord. **[3 marks]**

(iv) Find the magnitude and direction of the reaction at the hinge when a sign with the mass found in part (iii) is attached to the beam. **[4 marks]**

Question 6

The diagram in Figure 4 shows a section, of length d, of a conducting material with cross-sectional area A_1. The material has n charge carriers, each of charge e, per unit volume. The charge carriers move with a drift velocity v_d.

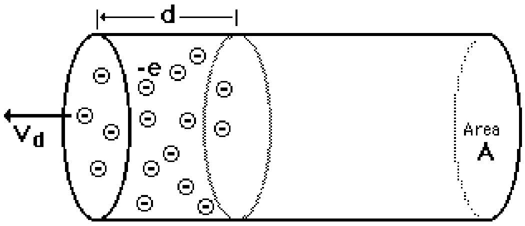

Figure 4

a. Explain the term *drift velocity* and how it comes about. **[2 marks]**

b. Derive an expression for the current, I, in terms of the drift velocity, stating clearly the meaning of any additional symbols used. **[4 marks]**

c. The drift velocity is generally very slow. How does this reconcile with the fact that a bulb turns on instantly when its switch is turned on? **[2 marks]**

d. Suppose that a second conductor with cross-sectional area A_2 is connected in series with the first conductor. Derive a relationship between the ratios of the different areas and the corresponding drift velocities when a steady-state current is flowing. **[2 marks]**

e. The first conductor is now replaced by one with a higher density of charge carriers but with the same cross-sectional area. How does the drift velocity change if the same current flows only through this conductor? **[2 marks]**

Question 7

a. Define the *temperature coefficient of resistance*. Explain how a material can have a negative temperature coefficient of resistance. **[2, 1 mark]**

b. In Figure 5, a circuit is shown where four resistors are connected to a 12 V battery. The resistor R_3 is a coil of resistance wire and is situated inside a heating unit kept at a constant temperature of 30°C. The voltmeter reads zero potential difference across the connection points.

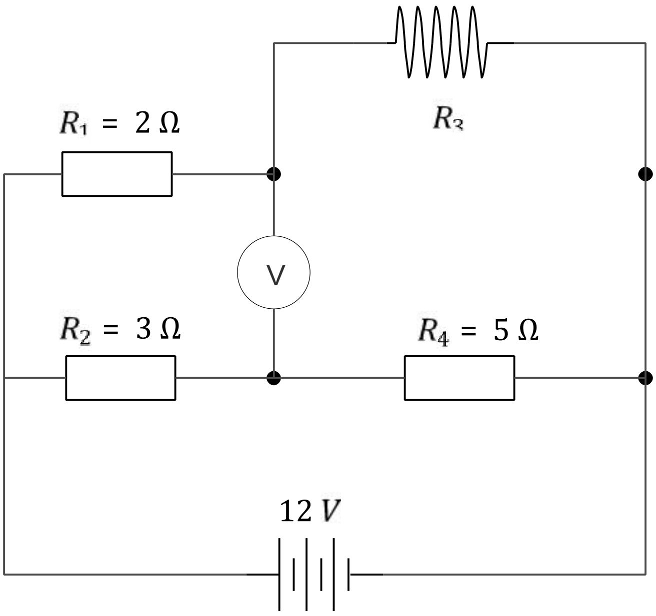

Figure 5

(i) Calculate the current flowing through resistor R_1. **[3 marks]**
(ii) Show that $R_1 = R_2R_3/R_4$ and hence determine the value of R_3. **[3, 1 marks]**
(iii) The temperature of the resistor R_3 is now raised to 50°C such that the resistance assumes the new value of 2 Ω. Calculate the temperature coefficient of resistance of resistor R_3. **[3 marks]**
(iv) What is the new potential difference read by the voltmeter? **[2 marks]**
(v) Determine a new value for the resistance R_4 so that the voltage read by the voltmeter is set back to 0 V. **[1 mark]**

Question 8

a. Describe briefly two aspects of the experimental results of the photoelectric effect that were puzzling to nineteenth century physicists. How does the photon model of light explain the experimental results in each case? **[4 marks]**

b. Electrons are accelerated from rest through a potential difference of 8000 V in a vacuum tube.
(i) Calculate the kinetic energy of the electrons in eV. **[2 marks]**
(ii) What is the wavelength of the associated electron waves? **[4 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. State Newton's first law of motion. **[1 mark]**

b. *A man pushing a car at a constant velocity may have to exert a large constant force.* State Newton's second law of motion and explain whether the statement is consistent with this law. **[3 marks]**

c. A steel ball bearing is released from rest just under the surface of liquid soap contained in a large measuring cylinder. As it is released, the ball bearing accelerates until it reaches terminal velocity. The ball bearing, of mass 4.1 g, has a diameter of 10 mm and the liquid soap has a density of 932 kg m^{-3}.
(i) Draw two free body diagrams showing all the forces acting on the ball bearing both when it is just released and when it is moving with terminal velocity. Clearly label and justify any forces drawn on the ball bearing. **[4 marks]**
(ii) Calculate the acceleration of the ball bearing as soon as it is released given that the upthrust force is equal to the weight of liquid displaced by the ball bearing. **[4 marks]**
(iii) What is the resultant force on the ball bearing when it reaches terminal velocity? **[1 mark]**
(iv) Calculate the value of the resistive forces acting on the ball bearing when it is moving with terminal velocity. **[2 marks]**
(v) Explain the motion of the ball bearing in the liquid soap using Newtons' first and second laws of motion. **[4 marks]**

d. A skier having a mass of 65 kg skis down a frictionless hill that is 5.0 m high as shown in Figure 6. At the bottom, the hill levels out horizontally. As the man reaches the horizontal section, he grabs a 20 kg backpack and skis off a 2.0 m high ledge.

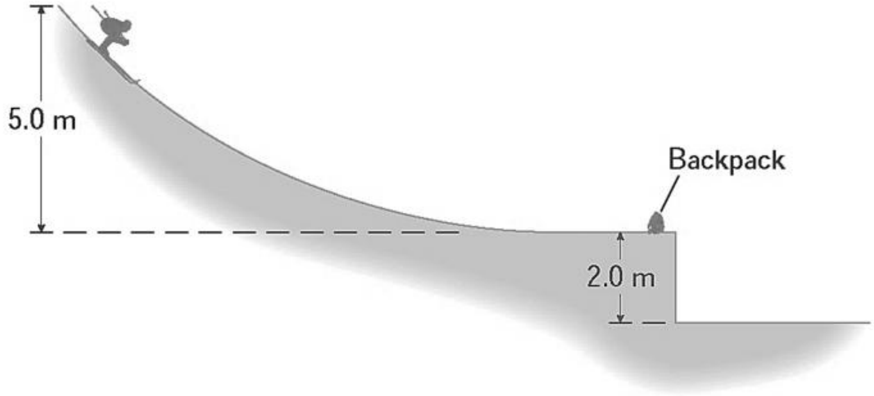

Figure 6

(i) Calculate the velocity with which the skier reaches the horizontal section. **[2 marks]**
(ii) State the principle of conservation of momentum and hence calculate the velocity with which the skier and backpack ski off the ledge. **[1, 1 marks]**
(iii) Determine the horizontal distance from the edge of the ledge where the man and his backpack land. **[2 marks]**

Question 10

a. Two identical objects lie on a turntable at different distances from the centre.
(i) Explain what is *centripetal force*. **[2 marks]**
(ii) Can an object moving with constant speed accelerate? Explain. **[1, 3 marks]**

b. A pendulum 0.80 m long is released from rest at point A. The lowest point in the path of the pendulum bob is point B. The pendulum bob has a mass of 0.5 kg.

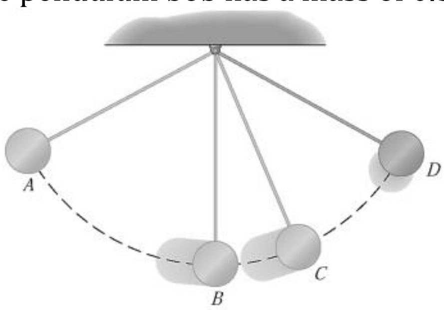

Figure 7

(i) Sketch two free body diagrams that show the forces acting on the pendulum bob at points B and C. On the same diagrams, indicate and justify the direction of the resultant acceleration of the pendulum bob at these two points. **[6 marks]**
(ii) At which point/s is the centripetal acceleration zero? Explain your answer. **[3 marks]**
(iii) Given that point A is 0.05 m above point B, calculate the tension in the string when the bob is at point B. **[5 marks]**
(iv) At point C the pendulum makes an angle of 12° with the vertical. Calculate the centripetal and tangential acceleration of the pendulum bob. **[3, 2 marks]**

Question 11

Two balls of mass M are released from the top of an inclined slope. One of the balls is solid and the other is hollow. The two balls roll without slipping down the slope which is inclined at angle θ to the horizontal. The moment of inertia of the solid ball $I_S = \frac{2}{5}MR^2$ and that of the hollow ball is $I_H = \frac{2}{3}MR^2$.

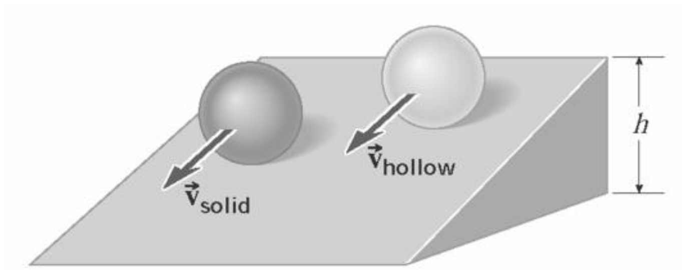

Figure 8

a. State the energy conversions taking place as the balls roll down the inclined slope. **[3 marks]**

b. Show that for the solid sphere, the total kinetic energy at the bottom of the slope is given by $\frac{7}{10}Mv_S^2$ where v_S is the linear velocity of the solid ball at the bottom of the slope. **[4 marks]**

c. Hence, show that at the bottom of the slope, the velocity v_S of the solid ball is greater than the velocity v_H of the hollow ball by a factor of 1.09. **[6 marks]**

d. Suppose that the force of friction between the solid ball and the slope is F, write down an expression for the torque τ that is causing the ball to roll. **[1 mark]**

e. Draw a free body diagram of the forces acting on the solid ball as it rolls down the slope. **[3 marks]**

f. Hence, or otherwise, show that the linear acceleration of the ball is given by

$$a = \frac{g\sin\theta}{1 + \frac{I_S}{MR^2}}$$

[6 marks]

g. Hence determine the linear acceleration, given that the slope is inclined at 10°. **[2 marks]**

Question 12

a. The first experimental evidence for the size of nuclei came from the Rutherford scattering of alpha particles from gold nuclei. It was determined that the radius r of the nucleus is related to its atomic mass A by the equation $r = r_0A^{\frac{1}{3}}$, where r_0 is a constant.

(i) Show that volume of a nucleus can be written as $V = \frac{4\pi r_0^3 A}{3}$ and state any assumptions made. **[2 marks]**

(ii) Given that $r_0 = 1.2 \times 10^{-15}$ m, calculate the volume of a radium-226 nucleus. **[2 marks]**

b. By making particular reference to the range of other forces present in the nucleus, briefly describe the importance of the strong nuclear force in keeping the nucleus together. **[3 marks]**

c. How could Henri Becquerel and other scientists determine that there were three *different* kinds of radiation *before* having determined the electric charges or masses of the α, β, and γ rays? Explain your answer. **[3 marks]**

d. Name and explain two mechanisms by which unstable nuclei can change into other nuclear isotopes. **[3, 3 marks]**

e. The diagram in Figure 9 shows how the binding energy per nucleon changes with nucleon number.

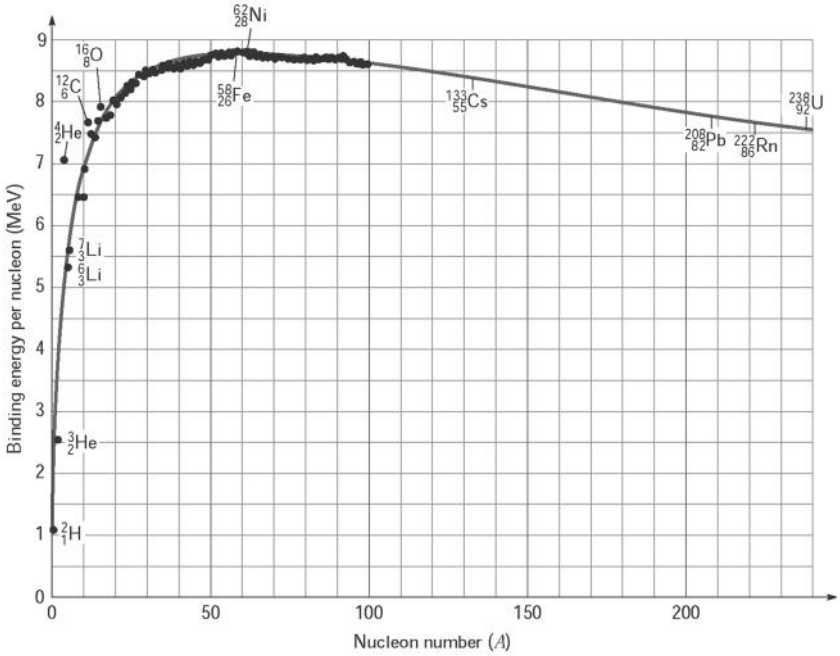

Figure 9

(i) Explain what is the *binding energy* of the nucleus. **[2 marks]**
(ii) Calculate the binding energy per nucleon for $^4_2$He. **[3 marks]**
(iii) The binding energy per nucleon is rather steep for small A and decreases gently for larger A. Explain this statement in terms of the nuclear forces binding the nucleons together. **[2 marks]**
(iv) What role does this binding energy per nucleon play in radioactive decay? **[2 marks]**

[Mass of proton= 1.00783 u; Mass of neutron= 1.00867 u; Mass of $^3_2$He $= 3.01664$ u;Mass of $^4_2$He $= 4.00387$ u]

Question 13

a. What is meant by
(i) elastic behaviour;
(ii) plastic behaviour of a wire when it is stretched. **[4 marks]**

b. Sketch a suitable graph and on it indicate the regions where elastic and plastic behaviours occur. **[4 marks]**

c. During the experimental determination of the Young Modulus of a wire, the following two precautions are usually taken:
(i) a long thin wire is usually preferred;
(ii) a second wire of the same material and of the same dimensions is hung next to the first.

Explain why each precaution is necessary for obtaining accurate data. **[2, 2 marks]**

d. A solid cylindrical rod of mass 30 kg and length 1.20 m is tied to a horizontal support. The string holding the rod to the support breaks and the cylinder falls vertically to the floor. The cross-sectional area of the cylinder is 8.3×10^{-5} m^2 and its base drops a height of 2.30 m. Assume the effects of air resistance are negligible. On hitting the ground, the rod behaves perfectly elastically and undergoes a maximum contraction of 1.6×10^{-3} m. Calculate:

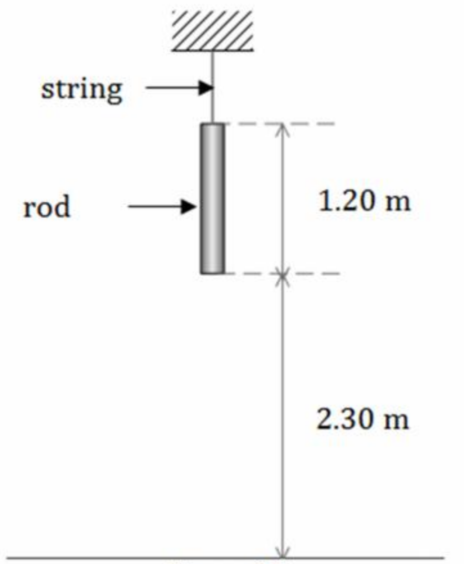

Figure 10

(i) the kinetic energy of the rod before it hits the ground; **[2 marks]**
(ii) the maximum strain on the rod; **[2 marks]**
(iii) the maximum elastic potential energy stored in the rod; **[2 marks]**
(iv) the Young modulus of the material of the cylinder assuming that the area of cross-section of the cylinder does not change; **[4 marks]**
(v) Assuming that 10% of the elastic potential energy stored in the cylinder changes to heat, calculate the height to which the cylinder rebounds. **[3 marks]**

Question 14

a. Define electric current. **[2 marks]**

b. Derive an expression for the power output, P, from a circuit with internal resistance, r, and circuit resistance, R, as a function of *emf*, E. **[4 marks]**

c. Two resistors are connected in series with a battery of e.m.f 12 V and an internal resistance of 1 Ω. The resistors have a resistance of 5 Ω and 7 Ω each.
(i) Draw a circuit diagram of the set-up. **[3 marks]**
(ii) Determine the terminal potential of the battery. **[2 marks]**
(iii) Calculate the energy converted to heat by the 5 Ω resistor in 1 minute. **[2 marks]**

d. State Kirchhoff's first and second circuit laws and relate each to a conservation law. **[2, 2 marks]**

e. Given the circuit diagram in Figure 11, find the current flowing through each resistor and the potential difference across each resistor. **[8 marks]**

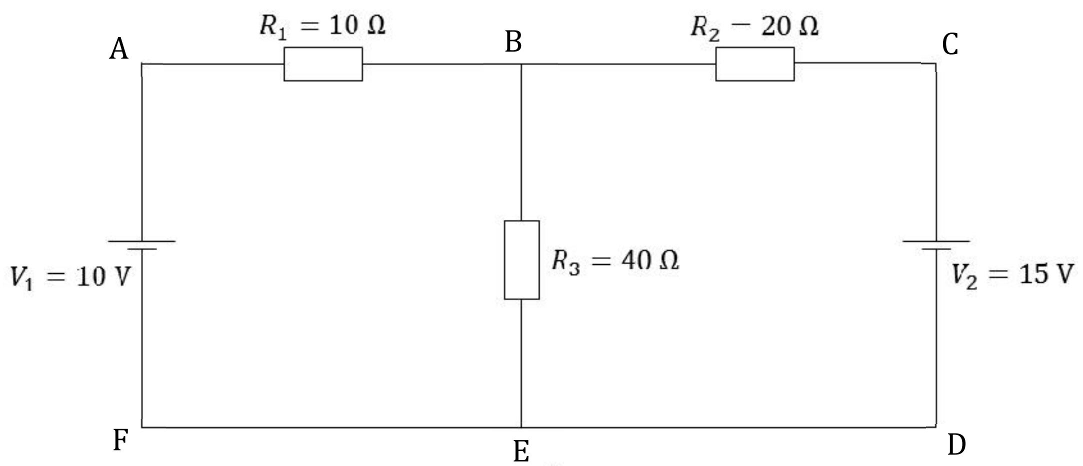

Figure 11

Question 15

a. Electrical conductivity of an intrinsic semiconductor increases both with an increase in temperature and with the introduction of certain impurities.
   - (i) Explain what is meant by intrinsic semiconductor. **[2 marks]**
   - (ii) Describe briefly an n-type or a p-type semiconductor and explain with reference to energy band theory the increase in conductivity as described by the above statement. **[4 marks]**
   - (iii) How is conductivity in metals different than in semiconductors? **[3 marks]**

b. AA and AAA rechargeable batteries are both rated at 1.2 V. But the two batteries are of different sizes and can pump different amounts of charge. The smaller AAA battery is rated at 800 mAh while the larger AA battery is rated 1500 mAh.
   - (i) Calculate the total charge stored on each battery when fully charged. **[2 marks]**
   - (ii) How much energy can each battery deliver, assuming they are ideal? **[2 marks]**
   - (iii) Calculate the time in hours it would take to discharge 50% of the AA battery through a bulb rated at 1.2 V and 0.4 A. **[2 marks]**
   - (iv) How would you connect two AA batteries to increase the amount of charge that they can deliver? **[2 marks]**

Figure 12

c. Describe a suitable experiment to test whether a particular component is Ohmic or not. Your description should include a list of equipment to be used, a sketch of the circuit, the procedure to be followed, a table that shows the measurements taken as well as a sketch of the expected graph. State how you would decide whether the component is ohmic or not. **[8 marks]**

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Section A

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Question 1

a. "Two thermodynamic systems are in thermal equilibrium". Explain what is meant by this statement. **[2 marks]**

b. Define "temperature" in terms of systems in thermal equilibrium. **[1 mark]**

c. How is "heat transfer" related to temperature? **[1 mark]**

d. Explain in terms of heat transfer and other large scale quantities the following:
   (i) When water is heated its temperature rises but then reaches a constant value;
   (ii) Heat transfer to a gas enclosed in a cylinder fitted with a piston may, or may not, produce a rise in temperature. **[4, 4 marks]**

Question 2

Explain the following observations:

a. A sheet of aluminium foil and the black plastic handle of a pan reach the same temperature when placed in a uniform temperature enclosure. **[4 marks]**

b. We are comfortable in air at 15°C, but find swimming in water at 15°C unpleasant. **[4 marks]**

c. The sea has a huge amount of internal energy but cannot be used to power a thermal power station. **[4 marks]**

Question 3

In an experiment performed by R. A. Millikan, an electric field is set up between two metal plates as shown in Figure 1. Oil from an atomizer is sprayed over the top plate and becomes negatively charged by friction. A few drops fall through the hole in the upper plate and can be viewed by a low power microscope.

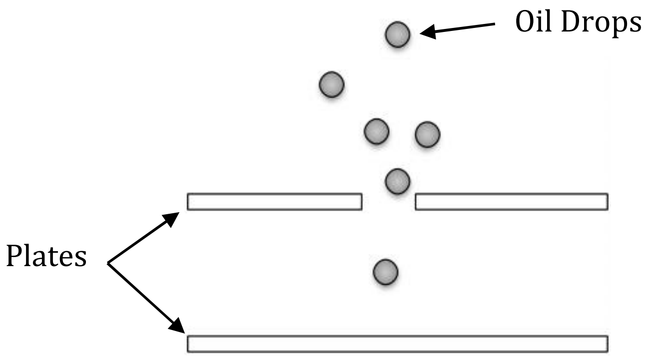

Figure 1

a. Draw a circuit diagram to show how a variable electric field may be set up between the plates. Indicate the polarity of the voltage of the plates if an oil drop is to remain stationary. **[3 marks]**

b. A stationary oil drop has a mass of 2.7×10^{-14} kg. If the separation of the plates is 5.00 mm and the voltage applied across the plates is 1040 V, how many electrons make up the charge on the oil drop? **[5 marks]**

c. What happens to the stationary oil drop if:
   (i) the separation of the plates is increased?
   (ii) the drop gains more electrons?
   (iii) the voltage between the plates is decreased ?
   Explain your answer in each case. **[6 marks]**

Question 4

In Figure 2, a conducting wire XY, perpendicular to a magnetic field of flux density B, moves with constant velocity v in the direction shown.

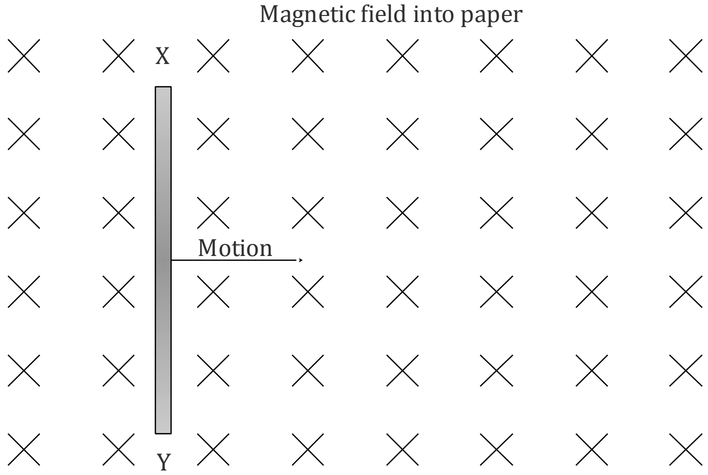

Figure 2

a. Indicate the direction (X or Y) in which the free electrons in the wire tend to move and state which end of the wire acquires a positive polarity. **[2 marks]**

b. What is the magnetic force on each of the free electrons? **[1 mark]**

c. As charge builds up at the ends of the wire XY, an electric field of electric field strength E is produced. Indicate the direction of this electric field. **[1 mark]**

d. Use a force diagram to explain why, at the steady state, a free electron will not move along the wire. Hence derive an equation relating v, B, and E. **[3 marks]**

e. Suppose that the potential difference due to the induced electric field, E, is V, and the length of the conductor is L. How are these three quantities related? **[1 mark]**

f. Hence, obtain an expression for the induced e.m.f., V, in terms of B, v, and L. **[2 marks]**

g. The wire XY moves to the right. Obtain an expression for the rate of cutting of magnetic flux in terms of B, v, and L. **[2 marks]**

Question 5

The diagram shows a narrow beam of light from a laser directed towards the point A on a vertical wall. A semi-circular glass block G is placed so that its straight edge is initially perpendicular to the beam, which is passing through the centre, O, of the block. The distance OA is 1.50 m.

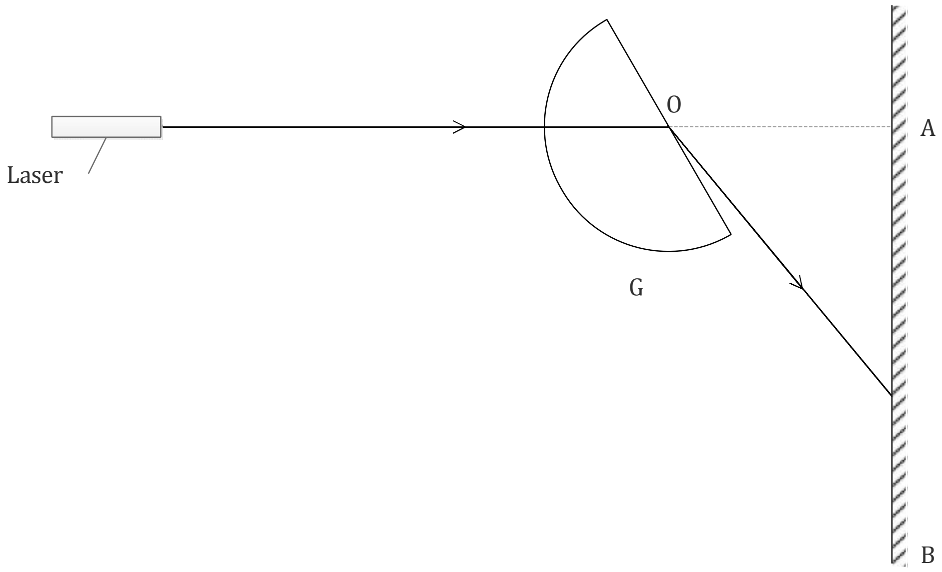

Figure 3

The glass block is rotated about the centre, O, and the bright spot where the beam hits the wall moves towards B and disappears when AB is 1.70 m.

a. Explain these observations. **[3 marks]**

b. Calculate the critical angle for the glass block, and hence its refractive index. **[5 marks]**

c. The laser emits light of wavelength 600 nm. Calculate the velocity, frequency, and wavelength of the laser light while inside the glass block. **[3 marks]**

Question 6

a. Write down an equation for the magnetic flux density, B, inside a long solenoid of N turns, and length, l, when the current through the solenoid is I. **[1 mark]**

b. If the cross sectional area of the solenoid is $\mathrm{A\ m^2}$, what is the magnetic flux, ϕ, through the solenoid? **[1 mark]**

c. Explain why a changing current in the solenoid produces a back e.m.f. **[3 marks]**

d. If the current is changing at a constant rate of $\frac{\Delta I}{\Delta t}$ $\mathrm{A\ s^{-1}}$, write down an equation for the rate of change of flux through the solenoid, and hence an equation for the back e.m.f. **[4 marks]**

e.
(i) Sketch a graph (P) to show how the current in the solenoid increases with time after switching on the circuit. **[2 marks]**
(ii) An iron rod is inserted inside the solenoid. Sketch a graph (Q), on the same axes as in (i), to show the new growth of current after switching on. **[2 marks]**

Question 7

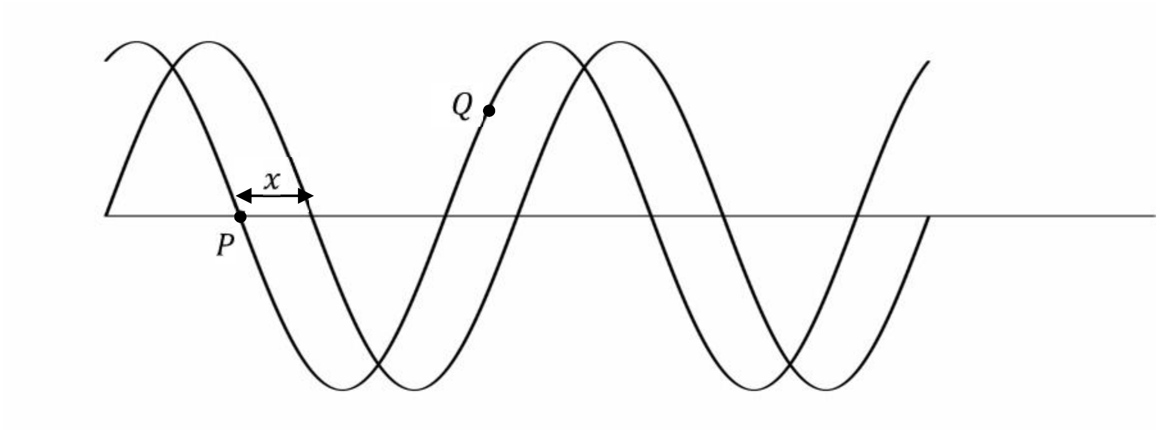

Figure 4

The diagram shows two photographs of a plane wave in a rope taken Δt seconds apart. The motion of the particles of the rope, such as particles P and Q, is simple harmonic.

a. If the wave velocity is v write down an equation for v in terms of
(i) x and Δt,
(ii) frequency, f, and wavelength, λ. **[2 marks]**

b. Write down the equation for the displacement, y_p, of particle P in terms of the amplitude A, and frequency f, assuming that the particle is at the centre of oscillation at time $t = 0$ s **[1 mark]**

c. What is the maximum velocity of particle P in terms of f and A? **[1 mark]**

d. The motion of particle Q lags behind the motion of P by Δt seconds.

(i) Write down the equation for the displacement, y_q, of particle Q, and hence show that your equation can be written down as $y_Q = A\sin\,\omega t - kx$ where $\omega = 2\pi f$, and $k = \frac{2\pi}{\lambda}$. **[4 marks]**

(ii) If $k = 2\pi\ m^{-1}$, what is the shortest distance between particles which are (i) in phase, (ii) out of phase by $\frac{\pi}{8}$? **[3 marks]**

Question 8

In the 1950s and 1960s, the Steady State model and the Big Bang model were used to explain astronomical observations of the Universe. In the Steady State model, it was assumed that the properties of the Universe, such as the mean density and the Hubble constant, remain constant with time.

a. What is the main feature of the Big Bang model of the Universe? **[2 marks]**

b. The microwave background radiation could not be explained by the Steady State model and the theory was abandoned. What is "the microwave background radiation"? **[3 marks]**

c. In 1929, Edwin Hubble published his observations of redshift and distance for about 50 nearby galaxies. What conclusion did Hubble draw from his observations? **[2 marks]**

d. What is meant by the 'Hubble constant'? **[2 marks]**

e. A modern value for Hubble's constant is $2.33 \times 10^{-18}\ s^{-1}$.

(i) Calculate the age of the Universe in billions of years. **[2 marks]**

(ii) If two galaxies are 3.0×10^{22} m apart, how much further apart will they be after 1 year? Take 1 year $= 3.2 \times 10^{7}$ s. **[4 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. The first law of thermodynamics can be applied to various situations.

(i) Write this law in the form of an equation and clearly identify each symbol used. **[3 marks]**

(ii) Use the law to explain the energy changes occurring from the moment current starts flowing through a filament lamp till when the filament lamp reaches a constant temperature. **[3 marks]**

b. Heat engines and heat pumps transfer heat in different ways between two heat reservoirs at different temperatures.

(i) Briefly outline the main characteristics that distinguish a heat engine from a heat pump. Reference to diagrams is expected. **[4 marks]**

(ii) Define the efficiency of a heat engine and use the second law to explain why it can never be 100%. **[2 marks]**

(iii) The combustion of a fuel-air mixture can reach temperatures as high as 3000°C while the exhaust gases generated leave at about 1000°C. Find the efficiency of an engine operating between reservoirs at those two temperatures and state one way in which the efficiency can be improved. **[3 marks]**

c. A gas at a pressure of 1.5×10^5 Pa expands isothermally from 0.6×10^{-3} m^3 to 2×10^{-3} m^3. The original pressure of the gas is restored by taking the gas through an adiabatic process. The ratio of the principal molar heat capacities is 1.4.
   (i) Explain why gases have two principal molar heat capacities. **[4 marks]**
   (ii) Sketch a labelled PV diagram to represent the above process. **[2 marks]**
   (iii) Calculate the volume of the gas at the end of the process. **[4 marks]**

Question 10

a. In 1827, Robert Brown observed that small particles suspended in water were in a state of random motion. At the time, Brown could not explain his observations. Explain why the small particles move randomly. **[2 marks]**

b. State Boyle's Law making clear reference to any condition/s that have to be observed and suggest a practical way how this condition/s may be satisfied. **[3 marks]**

c. Show that the pressure exerted on a surface by gas molecules is given by

$$p = \frac{1}{3} Nm\overline{c^2}$$

where p represents the pressure of the gas, N is the number of particles, m is the mass of each particle and $\overline{c^2}$ is the mean square speed of the particles. **[8 marks]**

d. It can be shown that the mean kinetic energy of the particles of a mono-atomic ideal gas is equal to $\frac{3}{2}kT$, where k is a constant and T is the thermodynamic temperature.
   (i) What does the constant represent? **[1 mark]**
   (ii) Calculate a value for the constant. **[1 mark]**
   (iii) If the molar mass of the gas is 0.2 kg, calculate the mass of a single molecule of the gas. **[2 marks]**

e. A diver releases a gas bubble of a spherical shape from the bottom of a lake 60.0 m deep. The temperature of the water at the bottom of the lake is 4°C. The bubble's initial diameter is 5.00 mm. The atmospheric pressure at the surface of the lake is 101 kPa and the temperature of the water at the surface is 18°C. Assume that the bubble warms as it rises to the same temperature of the water and that it retains the original spherical shape.
   (i) Show that the volume of the bubble at the bottom of the lake is 6.545×10^{-8} m^3. **[2 marks]**
   (ii) Calculate the pressure on the bubble at the bottom of the lake given that the lake water has a density of 1000 kg m^{-3}. **[2 marks]**
   (iii) Calculate the volume of the bubble when it reaches the surface. **[4 marks]**

Question 11

a. An astronaut is on a shuttle that is leaving the Earth to carry out a number of scientific tests on the International Space Station.
   (i) Explain what is meant by gravitational field strength and state the units in which it is measured. **[2 marks]**
   (ii) Starting with Newton's law of gravitation derive an expression for g, the acceleration of free fall on the surface of the Earth, explaining all the symbols used. **[2 marks]**

(iii) Sketch a graph to show how the value of the gravitational field strength g varies with distance above the surface of Earth. **[2 marks]**

(iv) State a characteristic of the gravitational field which makes it different from other fields. **[1 mark]**

(v) While orbiting around the Earth inside the International Space Station, a video link shows the astronaut floating inside. Is she weightless at this stage? Explain. **[3 marks]**

b. The moon orbits the Earth in an approximately circular path of radius 3.8×10^8 m. It takes about 27 days to complete one orbit.

(i) Derive an expression for the linear velocity v of the moon going round the Earth in terms of the mass M of the Earth and the orbital radius r. **[3 marks]**

(ii) Show that the angular velocity of the moon is 2.7×10^{-6} rad s^{-1}. **[2 marks]**

(iii) Use this data to calculate the mass of the Earth. **[4 marks]**

(iv) Briefly explain why at some point on the imaginary line joining the Earth and the moon, the gravitational field caused by the two bodies is zero. **[2 marks]**

(v) With reference to part (iv), if this point is 3.8×10^7 m away from the moon, calculate the ratio of the mass of the moon to the mass of the Earth. **[4 marks]**

Question 12

a. State Faraday's Law of electromagnetic induction. **[2 marks]**

b. A digital programmable bicycle speedometer makes use of a bar magnet with a magnetic flux density of 0.3 T attached to the spokes of the wheel and 150 turn coil of 2 cm diameter attached to the frame to measure the time between pulses of induced current for every revolution of the wheel.

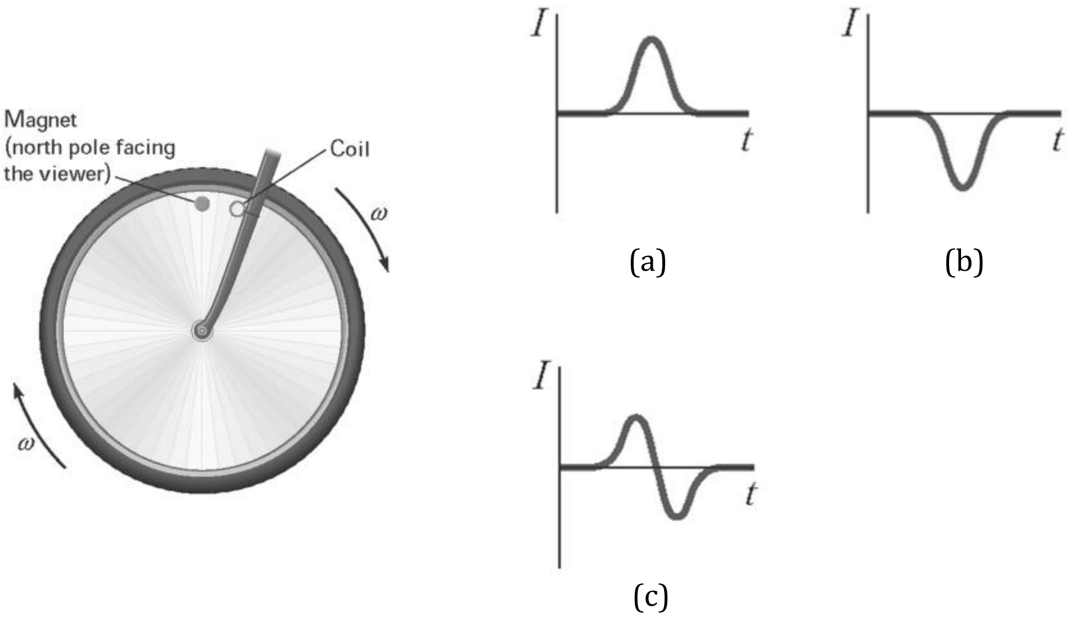

Figure 5

(i) Which of the graphs (a), (b) or (c) of Figure 5 shows the resulting current pulse? Explain your reasoning. **[3 marks]**

(ii) Calculate the maximum magnetic flux linkage through the coil. **[2 marks]**

(iii) If the magnet is placed 0.15 m from the centre of the wheel and the wheel is turning at 5 revolutions per second, calculate the time it takes the magnet to pass across the coil. **[3 marks]**

(iv) Calculate the maximum e.m.f generated by the coil. **[2 marks]**

(v) If the coil has a resistance of 25 Ω, determine the peak current that flows through the coil. **[2 marks]**

(vi) In practice, the digital speedometer measures also the distance travelled by the cyclist. What other physical quantity needs to be programmed to the speedometer to be able to measure the distance travelled? **[2 marks]**

c. A 3 V battery is connected to a solenoid of 200 turns and cross-sectional area 2 cm^2. The solenoid is to be used to magnetise a bar of steel. The solenoid has a resistance of 0.4 Ω and is 10 cm long.

(i) Calculate the flux density at the centre of the solenoid. **[3 marks]**

(ii) Sketch a graph to show how the magnetic field varies inside and outside the solenoid. **[2 marks]**

(iii) Sketch a graph to show how the current in the solenoid varies with time after the current is switched on. **[2 marks]**

(iv) Explain the shape of the graph in part (iii). **[2 marks]**

Question 13

a. Define magnetic flux density. **[2 marks]**

b. Describe an experiment to investigate the variation of the magnetic flux density with distance from a long straight current carrying wire. Your answer should include a diagram of the setup and a sketch of the graph you would expect to obtain from the experiment. **[6 marks]**

c. Show that the force F on a charge q moving at right angles to a magnetic field of strength B at a speed v is equal to Bqv. **[4 marks]**

d. A stream of charges travel through vacuum in a horizontal plane at a speed of 9×10^6 m s^{-1}. The charges enter a uniform magnetic field of flux density 0.6 mT directed vertically perpendicularly to their direction of travel.

(i) If the radius of the path of the charges is 10 cm, calculate the ratio of their charges to their mass. **[3 marks]**

(ii) What would the radius of the path be if the strength of the field is increased to 1 mT? **[2 marks]**

e. Two vertical wires carrying currents of 1.0 A and 2.0 A respectively in opposite directions are placed 20 cm apart in vacuum of permittivity $4\pi \times 10^{-7}$ N A^{-2}.

(i) Draw a diagram showing the wires and the magnetic field pattern around them. **[3 marks]**

(ii) Calculate the resultant magnetic flux density B at a point midway between the wires. **[3 marks]**

(iii) What would be the resultant magnetic flux density if the current in the two wires flowed in the same direction? **[2 marks]**

Question 14

a. State the principle of superposition as applied to two waves travelling in the same medium. **[2 marks]**

b. With respect to wavelength and wave profile, how do progressive waves and stationary waves compare? **[2 marks]**

c. One end of a steel wire is attached to a fixed support while the other end is attached to a mass of 0.5 kg that keeps it taut. A moveable slider is placed under the horizontally stretched wire as shown in the diagram. The wire has a diameter of 1.5 mm and a density of 7.85×10^3 kg m^{-3}.

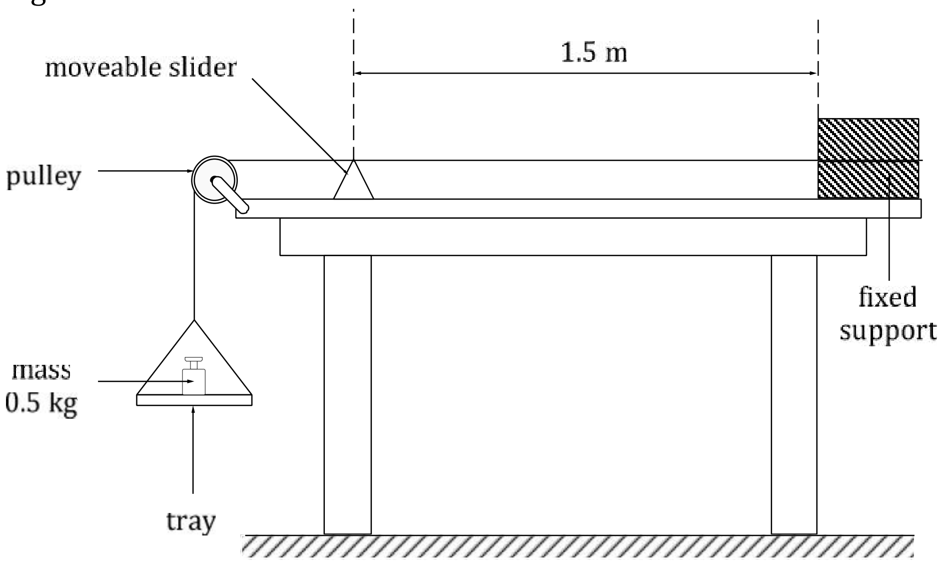

Figure 6

(i) Calculate the mass per unit length of the wire. **[2 marks]**

(ii) The wire is plucked midway between the fixed support and the moveable slider. Given that the distance between the fixed support and the slider is 1.5 m, calculate the fundamental frequency with which the wire vibrates. **[3 marks]**

(iii) What would the frequency of its third harmonic be? **[1 mark]**

(iv) The hanging mass is now lowered into a liquid and experiences an upthrust force of 0.3 N. Describe any changes that will happen to the frequency, velocity and wavelength of the stationary on the string. **[3 marks]**

d. What do you understand by diffraction in the context of wave propagation? **[2 marks]**

e. A source of microwaves is placed in front of a slit and a detector is placed on the other side. It is required to investigate the relationship between the slit width and the diffraction angle.

(i) Draw a diagram of the set up indicating clearly a suitable size for the slit width. **[2 marks]**

(ii) Describe how the set up may be used for this investigation. **[3 marks]**

(iii) Sketch a suitable graph which may be obtained from the experiment. **[2 marks]**

f. A student buys a low-end telescope to observe the skies. He is told that the telescope has a good resolving power for the price it is being sold.

(i) What is resolving power? **[1 mark]**

(ii) The circular aperture of the telescope has a diameter 6.00 cm. Calculate the angular resolution of this telescope when used to view light of wavelength 5.8×10^{-7} m. **[2 marks]**

Question 15

a. Define the capacitance of a capacitor. **[1 mark]**

b. An analogue radio receiver uses a variable capacitor to tune to the radio stations in the area. The capacitor consists of three parallel semi-circular plates as shown in Figure 7. The bottom plate is fixed and the middle and top plate can be rotated together. Air fills the space between the bottom fixed plate and the middle plate while an insulator of dielectric constant 3.2 fills the gap between the middle plate and the top plate. The radius of the semi-circular plates is 0.007 m and they are 0.001 m apart.

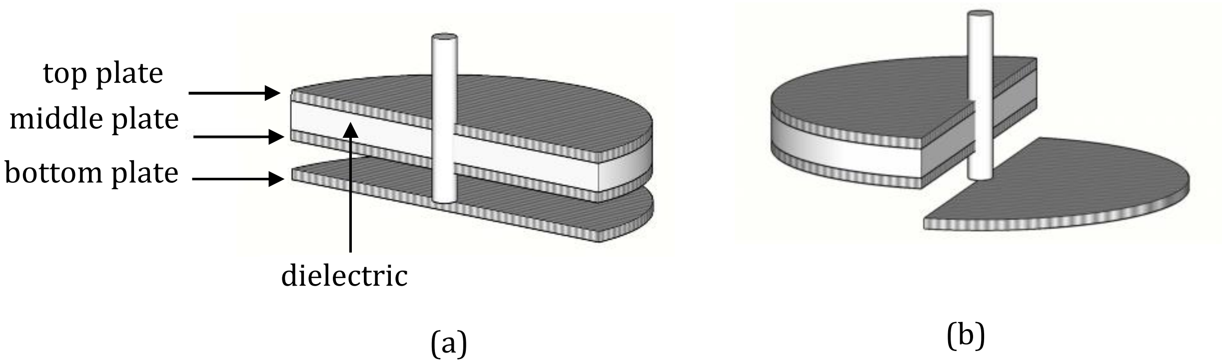

Figure 7

(i) The bottom plate, middle plate and second plate constitute two capacitors connected in series. Derive an equation for the combined capacitance of the two capacitors. **[3 marks]**

(ii) What would be the capacitance of the capacitor if there was no overlapping between the bottom plate and the first plate? Refer to Figure 7(b). **[3 marks]**

(iii) Calculate the capacitance of this capacitor when the plates fully overlap each other as shown in Figure 7 (a). **[3 marks]**

(iv) A second insulator with the same dielectric constant is introduced between the bottom plate and the first plate. What would the maximum value of the capacitance be? **[2 marks]**

c. A 5 μF capacitor, a 1.9 MΩ resistor and a 10 V battery are used to investigate the charging and discharging of a capacitor through the resistor.

(i) Draw the circuit required to carry out the investigation. Clearly identify any additional apparatus needed. **[3 marks]**

(ii) What is the p.d across the capacitor when it is fully charged? **[1 mark]**

(iii) On the same axis , sketch two graphs that show how the charge and voltage across the capacitor vary with time. **[4 marks]**

(iv) What is the time constant of a capacitor? **[2 marks]**

(v) Calculate the time constant of this circuit. **[1 mark]**

(vi) What would be the p.d. across the plates 0.5 s after discharge starts? **[2 marks]**

Index No.:________________ AM 26/III.15s

MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

UNIVERSITY OF MALTA, MSIDA

MATRICULATION EXAMINATION
ADVANCED LEVEL
SEPTEMBER 2015

SUBJECT:	PHYSICS
PAPER NUMBER:	III – *Practical*
DATE:	28th August 2015
TIME:	2 hours

Experiment: Charging a capacitor

Apparatus: 9V battery, circuit board with a capacitor and two resistors, a set of five resistors, a multimeter and a stopwatch

Important Note:

- To avoid damaging the apparatus, please make sure that you follow carefully the following steps at all times during your experiment.
- The battery should be connected **only when instructed to do so** and after that you have checked that the circuit is properly connected and that the digital meter is set to read the voltage or current on the appropriate range.
- Make sure that your connections are tight and that they cannot become disconnected and possibly create a short circuit during the experiment.
- Handle the battery clip with care. The wires connected internally inside the clip can become disconnected if the clip is removed from the battery by pulling at the wires.
- If the digital meter is set to 20 V, this means that the meter can read from 0 V to 20 V. Any voltages higher than that can damage the meter and show the overflow sign. The same applies to all current and resistance ranges that the meter is capable of measuring.
- Failure to follow these instructions may incur damage to the apparatus and loss of time. Please make sure that you disconnect the battery after you have finished taking your readings.

Diagram:

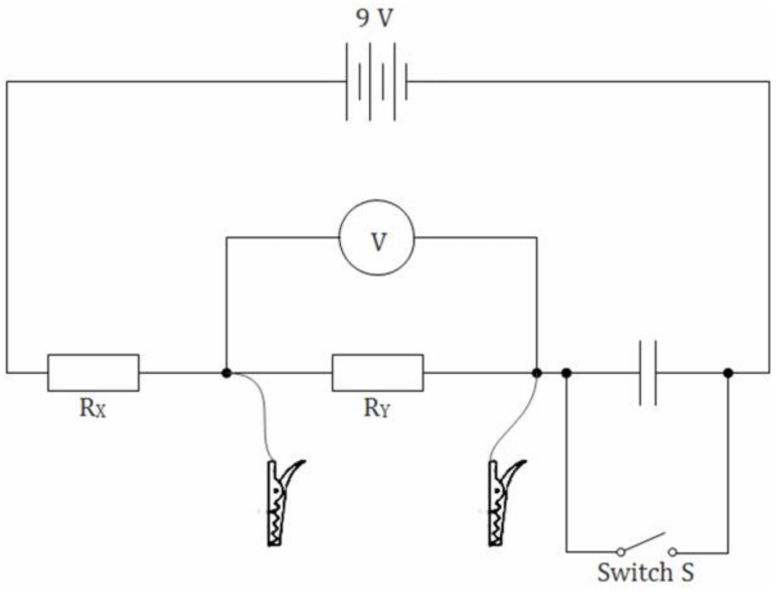

Figure 1 The experimental setup

Method – Part A:

1. The circuit board provided has the necessary components needed to investigate the charging of a capacitor.
2. There are three pairs of wires soldered to the circuit. They are labelled 'switch', 'to voltmeter' and 'to resistors'.
3. In the first part, you will determine the value of the resistance, R_Y, which is one of the resistors connected in series with the capacitor. Refer to Figure 1.
4. Connect together the crocodile clips labelled 'switch'. This should not be changed throughout the first part of the experiment.
5. Connect the pair of wires labelled 'to voltmeter' to the multimeter and set the multimeter to read d.c. voltage on the 20 V range.
6. Connect the battery to the battery clip.
7. Record the voltage V_0 read by the multimeter: $V_0 =$ __________ $\pm$ __________V.

[1 mark]

8. The e.m.f. ε of the battery is twice V_0: $\varepsilon =$ __________V

[1 mark]

9. You have been provided with a set of five resistors, R_Z, each of value 100 kΩ, soldered together at one end.
10. Using the leads with crocodile clips labelled 'to resistors', connect **one** of the resistors R_z across the resistor R_Y.

[1 mark]

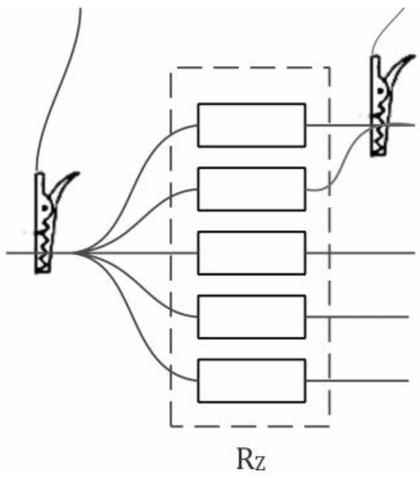

Figure 2

11. Measure and record the voltage V in Volts, shown on the voltmeter, as well as the value of the resistance R_z in Table 1.

[1 mark]

12. Repeat Step 11 but each time add a second resistor and then a third resistor, a fourth and a fifth resistor in parallel until you get five readings for R_Z and their corresponding voltages V. Refer to Figure 2.
13. Note that when n resistors each of resistance 100 kΩ are connected in parallel their combined resistance is $\frac{100\,\text{k}\Omega}{n}$.
14. Tabulate all your results.

[8 marks]

Table 1

n	R_Z /kΩ	V / V	$I_Z = \frac{\overline{V}}{R_Z}$ /A	$I_X = \frac{\overline{\varepsilon} - \overline{V}}{R_X}$ /A	$I_Y = I_X - I_Z$ /A
1					
2					
3					
4					
5					

15. I_X, I_Y and I_Z correspond to the currents flowing through the resistors R_X, R_Y and R_Z.
16. It is given that the value of the resistance of resistor R_X is 20 kΩ. Complete Table 1 by working out the missing values.

[15 marks]

17. Plot a graph of V in Volts on the y-axis against current I_Y in Amps on the x-axis.

[10 marks]

18. It is given that the voltage V is related to the current I_Y by Ohm's Law.
19. From the graph determine the resistance of the resistor R_Y.

____

____

____

____

[4 marks]

Method – Part B:

20. Disconnect and place aside the set of five resistors used in Part A.
21. Disconnecting the crocodile clips labelled 'switch' and observe what happens to the voltage read by the multimeter. Briefly explain these observations.

____

____

____

[2 marks]

22. The total resistance R in series with the capacitor is the sum of R_X and R_Y.

$R = R_X + R_Y =$ ____________________ $k\Omega$ **[1 mark]**

23. Reconnect the crocodile clips labelled 'switch' such that the reading on the voltmeter settles.
24. You will now charge the capacitor. Disconnect the switch and at the same instant start the stopwatch.
25. Record the voltage on the multimeter as it changes every 10 seconds in the column V_1.

[5 marks]

26. Repeat steps 23 to 25 to take repeated readings for the voltage. Record these in the columns V_2 and V_3.

[10 marks]

Table 2

Time /s	V_1 /V	V_2 /V	V_3 /V	$\overline{V}/V$	$V_R = 2\overline{V}$ /V	ln V_R
10						
20						
30						
40						
50						
60						
70						
80						
90						
100						

27. $\overline{V}$ is the mean voltage of V_1, V_2 and V_3 while V_R is the total voltage across the two resistors in series.
28. Complete Table 2 by working out the missing values.

[15 marks]

29. Given that the voltage V_C on the capacitor while charging is given by

$$V_C = \varepsilon \left(1 - e^{-\frac{t}{RC}}\right),$$

show that the voltage V_R across the two resistors is given by

$$V_R = \varepsilon e^{-\frac{t}{RC}}$$

[5 marks]

30. Plot a graph of $\ln V_R$ on the y-axis against t on the x-axis.

[10 marks]

31. Rearrange the equation for V_R given in step 29 in the form $y = mx + c$.

[3 marks]

32. Use the graph to determine the time constant of the circuit.

[4 marks]

33. Hence, calculate a value for the capacitance C of the capacitor.

[2 marks]

34. State **one** source of error and **one** corresponding precaution undertaken during the experiment of part B.

[2 marks]