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

MATRICULATION CERTIFICATE EXAMINATION
ADVANCED LEVEL
SEPTEMBER 2012

SUBJECT:	PHYSICS
PAPER NUMBER:	I
DATE:	4th September 2012
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.

The following constants may be needed in the problems:

Acceleration due to gravity	$\boldsymbol{g}$	=	10 m s^{-2}
Boltzmann's constant	$\boldsymbol{k}$	=	1.38×10^{-23} J K^{-1}
Charge carrier density	$\boldsymbol{n}$	=	$4.67 \times 10^{28} m^{-3}$
Charge on an electron	$\boldsymbol{e}$	=	1.60×10^{-19} C
Gravitational constant	$\boldsymbol{G}$	=	6.67×10^{-11} N m^2 kg^{-2}
Mass of a proton	$\boldsymbol{m_p}$	=	1.67×10^{-27} kg
Mass of an electron	$\boldsymbol{m_e}$	=	9.10×10^{-31} kg
Permittivity of free space	$\boldsymbol{\mathcal{E}_0}$	=	8.85×10^{-12} F m^{-1}
Planck's constant	$\boldsymbol{h}$	=	6.63×10^{-34} J s
Resistivity of nichrome at 0°C	$\boldsymbol{\rho}$	=	$1.08 \times 10^{-6} \Omega$
Speed of light in vacuum	$\boldsymbol{c}$	=	3.00×10^8 m s^{-1}
Temperature coefficient of resistance of nichrome	$\boldsymbol{\alpha}$	=	$8.0 \times 10^{-5} K^{-1}$
Young's modulus of rubber	$\boldsymbol{E_{rubber}}$	=	$6 \times 10^8\ Nm^{-2}$
Young's modulus of steel	$\boldsymbol{E_{steel}}$	=	$2.0 \times 10^{11}\ Nm^{-2}$

Section A

Attempt all <u>eight</u> questions in this section. This section carries 50% of the total marks for this paper.

Question 1

a. The temperature, T, of a particular black body system is given by

$$T = \frac{h\,c^3}{16\,\pi^2 G M k_b}$$

where h is Planck's constant, c is the speed of light, G is Newton's gravitational constant, M is a mass term and k_b is Boltzmann's constant. Considering the base units of the above relation, show that the temperature T is measured in Kelvin. [6 marks]

b. A toy helicopter has the forces as shown in Figure 1 acting on it. Given that the helicopter does not rise, determine the forward acceleration of the helicopter if its mass is 1 kg. [4 marks]

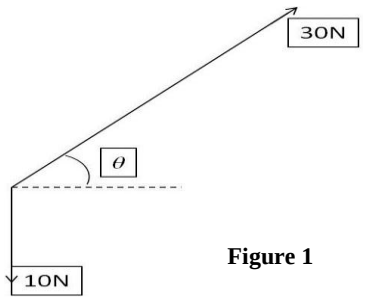

Figure 1

Question 2

In the popular video game "Angry Birds", where a group of birds attempt to attack sheltered enemy pigs while creating as much damage as possible, a red bird projectile is directed at a green pig as shown in Figure 2.

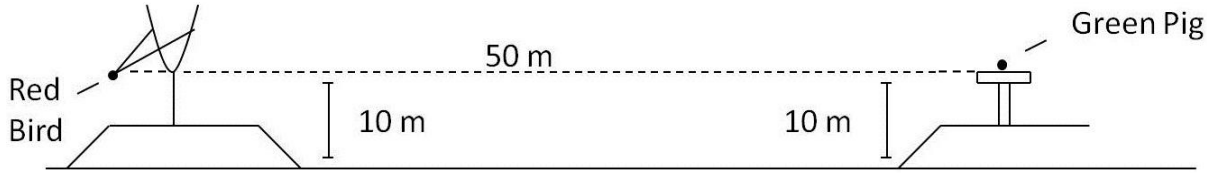

Figure 2

a. What should the launch angle be with respect to the horizontal if the time of flight is 2.50 s? [5 marks]

b. If the green pig is elevated 2 m above the red bird level and the red bird hits the pig when the height of trajectory is maximum, calculate the new angle to the horizontal if the time the red bird takes to hit the pig is 2.50 s. [6 marks]

Question 3

A 1 kg mass steel ball falls from rest at 5 m above a spring.

a. Draw a clear diagram of the system. [2 marks]

b. Calculate the velocity of the ball just before it falls onto the spring. [3 marks]

c. After the ball falls onto the spring, it momentarily comes to rest when the compression of the spring is 0.25 m. Assuming that mechanical energy is conserved:
   i. determine the spring constant by energy considerations or otherwise; [3 marks]
   ii. write down the general energy equation at any point on this path in terms of the velocity, height and compression; [3 marks]
   iii. hence find the energy when the ball is at the lowest point of its path. [3 marks]
   iv. find the velocity of the ball when the spring is compressed 0.10 m by the ball. [4 marks]
   v. which principle do the above calculations depend on? [2 marks]

Question 4

a. Define the term *centripetal force*, stating its direction and dimension. [2, 1, 1 marks]

b. Consider the Earth to be making circular rotations about a point around the Sun. Derive a relationship between the period of Earth and the mass of the Sun, taking the Sun to be stationary. [5 marks]

c. If the Earth is an average 149.60×10^6 km away from the Sun and also considering a year to have 365 days, estimate the mass of the Sun. [5 marks]

Question 5

a. i. Define the term *moment of a force*. [2 marks]

ii. Explain what is meant by *couple* and *torque of a couple*. [2, 1 marks]

iii. Give an example in which the torque acting on an object is zero, yet the net force is nonzero. [2 marks]

b. The system shown in Figure 3 is in equilibrium. A mass of 225 kg hangs from the end of the uniform strut whose mass is 50 kg and length L of 5.0 m. The horizontal distance of the cable from the hinge is 2.6 m.

i. Copy the diagram and label the forces acting on the system. [2 marks]

ii. By taking moments, write an expression to find the tension T in the cable. [3 marks]

iii. Hence, calculate the tension T in the cable; [2 marks]

iv. Find the horizontal force exerted on the strut by the hinge. [2 marks]

v. Calculate the vertical force exerted on the strut by the hinge. [2 marks]

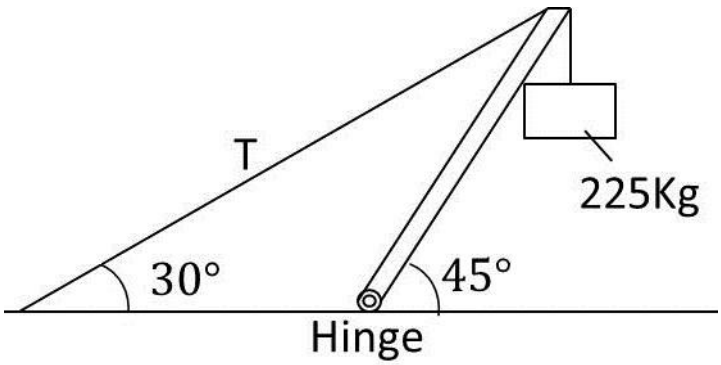

Figure 3

Question 6

a. How does the resistance to the flow of electrons in good conductors compare with the resistance to the flow of electrons in semiconductors as temperature decreases? [4 marks]

b. Briefly explain the relationships stated in part (a). [4 marks]

Question 7

a. Derive a relationship for the power output from a resistance wire of length l, cross-sectional area A, temperature coefficient α and resistivity is ρ_0, if the pd across it is V. [5 marks]

b. A coil of wire has a temperature coefficient of $6.2 \times 10^{-3}\ °C^{-1}$ and a resistance of 37.8 Ω at 27.8 °C.

i. Calculate the resistance of the coil at 56.0 °C. [2 marks]

ii. Find the power at this temperature when the coil is connected to a 120 V supply. [2 marks]

iii. Hence find the energy dissipated in Kwh if the coil is connected to the supply for 320 minutes. [2 marks]

Question 8

a. Given that the radius of a nucleus is $r = 1.25 \times 10^{-15} \times A^{1/3}$ m, where A is the number of nucleons, determine the density of the nucleus if the protons and neutrons both have an approximate mass of 1.67×10^{-27}kg. [5 marks]

b. Normal mass does not have this density level, how can the disparity be explained? [3 marks]

Section B

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

Question 9

a. i. Electrons in a beam with circular cross section of radius *r*, are propelled forward by means of a uniform electric field. Show that the number density *n* of the electrons in the beam is proportional to $\frac{1}{r^2\sqrt{K}}$ where *K* is the kinetic energy of the electrons. [4 marks]

ii. Two lengths of wire of the same metal are connected in series with a 2.0 A current passing through the first one as shown in Figure 4. Both lengths have square cross-sectional area, the first with sides 1 mm long and the second with sides 2 mm long. Find the current through the second length of wire and the drift velocity of each wire individually. [5 marks]

iii. Considering the current passing through the conductors or otherwise find a relation between the areas and drift velocities in the two conductors. [4 marks]

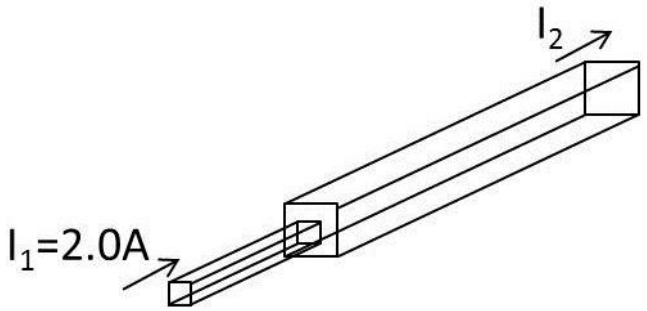

Figure 4.

b. i. Explain the band theory of solids and distinguish between insulators, conductors and semiconductors using this theory. [3 marks]

ii. What are intrinsic and extrinsic semiconductors? State the two types of extrinsic semiconductors? [2, 2 marks]

c. A current of 0.75 A is carried in a copper wire of cross sectional area $4.0 \times 10^{-7}\text{m}^2$. The drift velocity of free electrons in the wire is 1.4×10^{-4} m s^{-1}. Calculate n, the number of free elections per unit volume in copper. Calculate the new drift velocity when the current is changed to 0. 25 A. [2, 3 marks]

Question 10

a. A heating coil is to be made from nichrome wire which will operate on a 12 V supply and will have a power of 36 W when immersed in water at 100 °C. The length of wire available has an area of cross-section of 0.1 mm^2. What length of wire will be required if the resistivity of nichrome is $1.08 \times 10^{-6}\ \Omega$ m and the temperature coefficient of 8×10^{-5} °C^{-1}? [5 marks]

b. A current meter is set-up as shown in Figure 5 where R_1 and R_2 are uniform resistor wires of length $L_1 = 34$ cm and $L_2 = 66$ cm respectively.

i. If $V_0 = 10$ V, $R_k = 5\ \Omega$ and no current is recorded passing through the Galvanometer G, find the value of R_x. Find also the current passing through resistor R_x. [4 marks]

ii. Why is this method to measure current more accurate than a galvanometer? [2 marks]

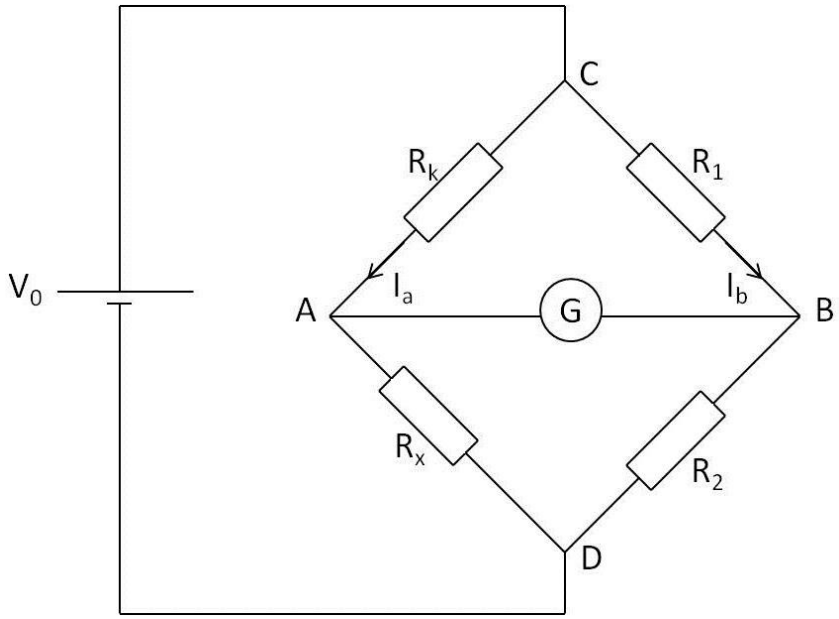

Figure 5

c. i. Describe briefly how the temperature coefficient of a metal wire may be determined experimentally. Include a labelled diagram of the apparatus, a list of measurements to be taken, the method used and the formula to be tested. [2, 2, 4, 2 marks]

ii. The temperature coefficient of resistivity for the metal gold is 0.0034 °C^{-1}, and for tungsten is 0.0045 °C^{-1}. The resistance of a gold wire increases by 4.3% due to an increase in temperature. For the same increase in temperature, what is the percentage increase in the resistance in a tungsten wire? [4 marks]

Question 11

a. The average distance between protons in a proton beam is 10^{-4} m.

i. Calculate the magnitude and direction of the electrostatic force between them. [3 marks]

ii. Is the range of the strong forces big enough to keep this beam from dispersing? Explain. [2 marks]

iii. In the classical model of the hydrogen atom, the electron revolved around the proton with a radius of $r = 0.53 \times 10^{-10}$ m. What is the magnitude and direction of the electrostatic and gravitational force between the two particles? [3 marks]

iv. What is the name of the force that keeps the hydrogen atom from imploding? [1 mark]

b. i. What is meant by the half-value thickness of lead? [1 mark]

ii. If the rate intensity varies as

$$I = I_0 e^{-\mu x}$$

where I_0 is the intensity of radiation without the lead shielding, μ is an absorption coefficient and x is the thickness of the shielding. What are the units of the absorption coefficient? [1 mark]

iii. If $x = 1.37$ cm for the half-value thickness, then calculate the absorption coefficient. [3 marks]

c. i. Briefly describe what is nuclear fusion and fission. [2, 2 marks]

ii. Mention three advantages of nuclear fusion as a future source of energy and two disadvantages [4, 3 marks]

Question 12

a. i. State Newton's first law of motion. [1 mark]

ii. A car of mass 1000 kg is initially at rest. It first accelerates to 20 m s^{-1} in 10 s, then moves at a constant speed for 5 s and finally uniformly decelerates to rest over 5 s. Sketch a suitable speed-time graph to graphically depict the motion of the car. [2 marks]

iii. Basing your calculations on the graph, find the total distance travelled. [3 marks]

iv. What is the force of the car during the deceleration segment of the motion? [2 marks]

v. What is the forward momentum of the car during the constant motion segment of the motion? [2 marks]

vi. How does this relate to the force measured in part (iv)? Which of Newton's laws of motion is relevant here? [2 marks]

vii. The car undergoes the same initial acceleration and remains at 20 m s^{-1}. It then collides with a stationary vehicle of mass 1500 kg and they move forward interlocked. What is the speed of the couple immediately after the collision? What principle does this calculation depend on? [1, 1 marks]

viii. Calculate the kinetic energy of the vehicles before and after the collision. Comment on the values obtained. [1,1 marks]

b. i. Define the impulse of an object undergoing a change in momentum. [1 mark]
ii. A tennis ball of mass 0.144 kg approaches a player with a speed of 30 m s^{-1}. It is hit directly and is returned with a speed of 40 m s^{-1}.Calculate the magnitude of the impulse exerted on the ball. [1 mark]
iii. If the racquet and ball are in contact for 0.012 s, find the average force exerted on the ball during this period. [1 mark]
iv. If the racquet exerts the same average force, how much time would it have to be in contact with the ball so that it returns the ball with the same speed as it approaches with? [2 marks]

c. A book lying at rest on a table experiences a downward acceleration of g m s^{-2} on the table, while the table is exerting an upward force on the book. With reference to Newton's Laws of motion explain why the book remains stationary. [4 marks]

Question 13

a. i. A boy is sitting on a spinning piano stool with arms folded. Explain what happens to the boy's moment of inertia, angular speed and angular momentum as he extends his arms. [2, 1, 1 marks]

The moment of inertia, I_1, is measured by the set-up as shown in Figure 6.

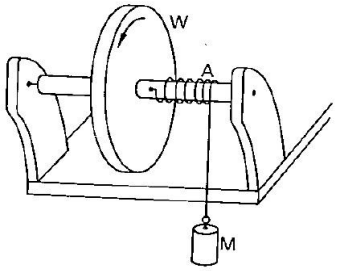

Figure 6

In this scenario flywheel W is rotated from rest about the axis A by a falling mass M.

ii. By taking energy considerations or otherwise derive a relationship between the moment of inertia I of the flywheel, its angular momentum ω and the linear velocity v of the mass M as it falls down from rest through a height h. [4 marks]
iii. The mass M is 1.0 kg while the rotating flywheel has a radius of $r = 2.0$ cm. If the mass falls from rest down a height of 5 m and after 1 s the flywheel rotates at 3 rad s^{-1}, find the moment of inertia. [3 marks]

b. i. State the principle of conservation of angular momentum. [3 marks]
ii. A comet revolves around a massive star in a highly elliptical orbit. Is its angular momentum constant over the entire orbit? Explain. [2 marks]
iii. Two flywheels with moments of inertia I_1 and I_2 are rotating with angular velocity ω_1 and ω_2. If they are brought together as shown in Figure 7 such that effectively one flywheel results, Figure 8, find the resulting angular velocity.

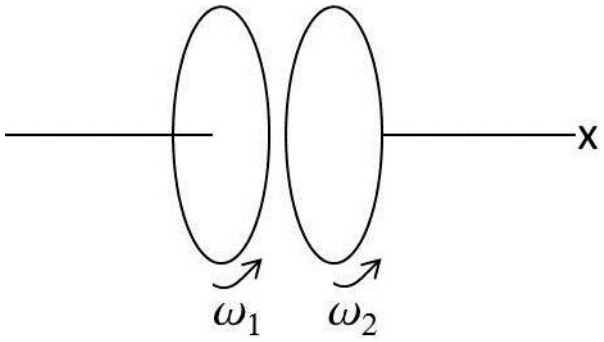

Figure 7

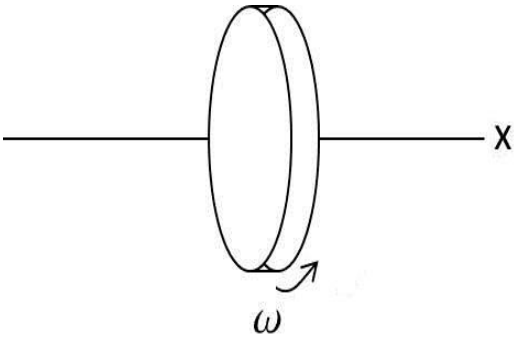

Figure 8

[6 marks]

c. Three particles are connected by rigid rods of negligible mass lying along the y-axis as shown in Figure 9. If the system rotates about the x-axis with angular velocity of 2 rad s^{-1}, find the moment of inertia about the x-axis. [3 marks]

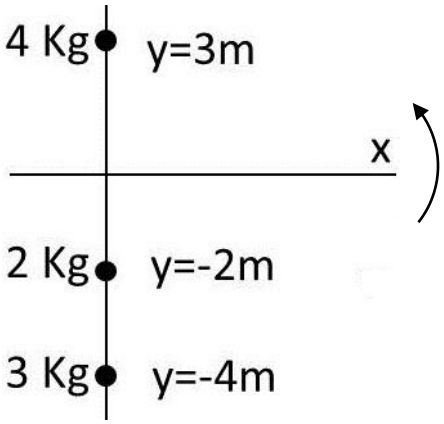

Figure 9

Question 14

a. A uniform steel wire of length 4.0 m and area of cross-section 3×10^{-6} m^2 is extended by 1 mm. Calculate the energy stored in the length of wire if Hooke's law is obeyed in this region. [6 marks]

b. A rubber cord of a catapult has a cross-sectional area of 2.0 mm^2 and an initial length of 0.2 m. It is stretched to a final length of 0.24 m to fire a small object of mass 10 g. Neglecting energy losses, calculate the initial velocity of the object when it is released if Hooke's law is obeyed in this region. [6 marks]

c. Two vertical lengths of wire X and Y parallel to each other, suspended at the same horizontal level, are connected by a light rod XY at their lower ends. The lengths have the same initial value l and area of cross-section A. A weight of 30 N is placed at a point O, where $XO : OY = 1 : 2$. Both lengths are stretched and the rod XY then remains horizontal.

i. Draw a diagram of the scenario. [2 marks]

ii. If wire X has a Young's modulus of $1.0 \times 10^{11}\ \text{Nm}^{-2}$, calculate the Young's modulus of wire Y if Hooke's law is obeyed in this region. [6 marks]

d. Determine the force required to double the length of a steel wire of cross-sectional area $5 \times 10^{-5}\ \text{m}^2$. State any assumptions you made to arrive at your answer. [3, 1 marks]

e. Define the term breaking stress. [1 mark]

Question 15

a. Explain briefly what is meant by wave particle duality, illustrating your answer by a suitable example of each phenomenon. [3 marks]

b. i. List three properties that are a result of the photoelectric effect . [3 marks]

ii. Caesium has a work function of 2.1 eV. Calculate the maximum energy in Joules and the maximum speed of the emitted electrons when Caesium is illuminated by radiation of wavelength 150 nm. [3 marks]

iii. What is the least frequency of radiation for which electrons are emitted? [2 marks]

c. i. In an experiment to verify Einstein's photoelectric equation, a source of light is placed at a distance of 1m from the cathode from which electrons are ejected and the stopping potential is found to be V_0. If the source of light is placed 2 m apart explain if the stopping potential will change. [2 marks]

ii. An increase in frequency increases the velocity of the ejected photoelectron. Explain this statement. [2 marks]

d. i. An electron can behave as a wave or as a particle. State the relationship between one wave-like property and one particle-like property of an electron explaining each of these factors. [3 marks]

ii. Using your answer in part d(i) calculate the associated wavelength of a bullet of mass 0.01 kg and velocity of $400\ \text{m s}^{-1}$. [2 marks]

iii. Electrons gain kinetic energy by moving across a potential difference *V.* Find a relationship between the kinetic energy and the potential difference. Show also that their momentum is proportional to $\sqrt{V}$, and their associated wavelength is proportional to $\frac{1}{\sqrt{V}}$. [5 marks]

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Avogadro constant	N_A	=	$6.02 \times 10^{23}\ mol^{-1}$
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Charge on an electron	e	=	1.60×10^{-19} C
Mass of an electron	m_e	=	9.10×10^{-31} kg
Permittivity of free space	ε_0	=	8.85×10^{-12} F m^{-1}
Speed of light in vacuum	c	=	3.0×10^{8} m s^{-1}

Section A

Attempt all <u>eight</u> questions in this section. This section carries 50% of the total marks for this paper.

Question 1

a. Define temperature. [2 marks]

b. When using a constant volume gas thermometer, the pressure in a chamber was found to be 8.51×10^4 Pa at an unknown temperature, and 8.00×10^4 Pa at the triple point of water (273.16K).

i. What is the temperature in the chamber in degrees Celsius?
[3 marks]

ii. If the temperature inside the chamber is 350 K, what is the pressure of the gas?
[2 marks]

c. The constant volume gas thermometer is not a very convenient thermometer to use. Suggest a suitable thermometer to read the temperature calculated in part b(i). Explain your choice. [2 marks]

Question 2

a. Define the specific latent heat of vaporization of a liquid. [2 marks]

b. Describe briefly an experiment to determine the value of the specific latent heat of vaporization of water using an electric method. Your answer should include a labelled diagram of the apparatus used, an indication of what measurements need to be made and how the final value is calculated. [5 marks]

c. A 200 g ice block is taken from a freezing compartment set at -10 ^{o}C and placed in a litre of water at 20 ^{o}C. After all the ice melts, what is the final temperature of the mixture? Assume that the specific heat capacity of ice is 2.108 KJ kg^{-1} K^{-1} , that of water is 4.2 KJ kg^{-1} K^{-1}, the specific latent heat of fusion of water is 334 kJ Kg^{-1} and the density of water is 1000 kg m^{-3} . [4 marks]

Question 3

An aquarium, 0.75 m long, 0.50 m high and 0.50 m wide, is made from sheets of glass 5 mm thick of thermal conductivity 1.05 W m^{-1}K^{-1}. The water temperature is kept constant at 24 ^{o}C by an electric heater.

a. Calculate the rate of heat loss from the four vertical glass sides if the room is at a temperature of 15 ^{o}C. [3 marks]

b. What should the minimum power rating of the electric heater be to maintain a constant temperature? Explain. [2 marks]

c. In order to minimise heat losses, three vertical sides are covered with a 2 cm sheet of polystyrene of thermal conductivity 0.03 W m^{-1} K^{-1}, while the elongated front side is kept uncovered. If water temperature is to be kept at 24 ^{o}C:
   i. What is the temperature at the polystyrene-glass boundary? [3 marks]
   ii. Calculate how much heat energy is lost from the aquarium per second when using the polystyrene. [4 marks]
   iii. Determine how much energy is saved per hour when polystyrene is used. [2 marks]

Question 4

a. Define the gravitational field strength *g* at a point above the Earth's surface. [2 marks]

b. Sketch a labelled graph to show how the value of g varies with distance from the Earth's surface. [2 marks]

c. Show that for a circular orbit of radius r around a planet of mass M, a satellite of mass m needs to have an orbital speed given by

$$v = \sqrt{\frac{G\,M}{r}}$$

[2 marks]

d. If the Universal Gravitational constant is 6.7×10^{-11} N m^3 kg^{-2}, the mass of the planet is 6×10^{24} kg and the orbital period of the satellite is 90 minutes, calculate the radius of its orbit. [3 marks]

e. Calculate the orbital speed of the satellite. [2 marks]

Question 5

a. Define the capacitance of a parallel plate capacitor. [2 marks]

b. Derive an equation for the total capacitance of two capacitors connected in parallel. [3 marks]

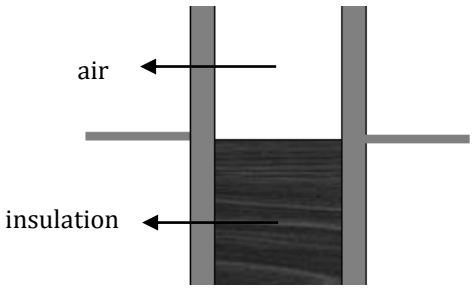
c. 

Figure 1

A capacitor is suspected to be faulty because half of the insulation slipped out so that part of the space between the plates is filled with air. If the size of the plates is 5 cm by 5 cm, the plates are 1 mm apart and the insulation has a relative permittivity of 3, calculate the new capacitance of the capacitor. [4 marks]

d. If the p.d. across the capacitor is 12 V, calculate the difference in the amount of stored energy as a result of part of the insulation moving out. [4 marks]

e. Why is it possible for an electrolytic capacitor to have high values in spite of their small size? [2 marks]

Question 6

a. Define Lenz's Law of electromagnetic induction. [2 marks]

b. What is meant by the term by self induction? [2 marks]

c. A 3 V cell is connected in series with a switch, a 0.25 Ω resistor and an inductor. When the switch is closed, the current in the circuit increases from 0 to 0.15 A. After that it keeps on increasing but eventually becomes constant.

   i. For the instant when the current is 0.15 A, calculate the potential difference across the resistor and the inductor. [3 marks]

ii. Assuming that the initial rate of change of current is 30 A s^{-1}, use your result from part c(i) to calculate the size of the inductor. [2 marks]

d. If the resistance of the inductance is negligible, calculate the magnitude of the current when this reaches a constant value. [2 marks]

e. Explain the role of the inductor at this stage. [2 marks]

Question 7

a. What is a progressive wave? [1 mark]

b. Describe three differences between a progressive wave and a stationary wave. [6 marks]

c. A plane progressive wave travelling in the x-direction may be represented by the following equation:

$$y = a \text{ Sin } 2\pi \frac{[vt - x]}{\lambda}$$

i. State what the symbols *y, a,* λ, and *v* represent. [2 marks]

ii. Give the period of the wave motion in terms of two of these four quantities. [2 marks]

iii. Write down the equation of the wave travelling in the opposite direction. [1 mark]

d. Explain how according to Huygen's construction for wave propagation, a new wavefront is set up. [2 marks]

e. What test can be carried out to determine whether a wave is longitudinal or transverse? [2 marks]

Question 8

a. A 2 m string is kept vertically taut by a 20 N weight hanging from one of its ends whilst keeping the other end fixed. When the string is plucked from the middle, it starts vibrating at its fundamental frequency.

i. What is meant by the term fundamental frequency? [1 mark]

ii. If the string has a mass of 10 g, what is its mass per unit length? [2 marks]

iii. Calculate the fundamental frequency emitted. [2 marks]

iv. What would the frequency of the second harmonic be? [1 mark]

v. The hanging weight is immersed in water and experiences an upthrust (upward force) of 5 N. Calculate the new emitted frequency. [2 marks]

b. An optical instrument is said to have very good magnification but poor resolving power. Distinguish between these two characteristics. [3 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 mass of gas contained in a piston is expanded isothermally from state A to state B. It is then compressed to its original volume adiabatically to state C.

i. Distinguish between the terms *isothermal change* and *adiabatic change*. [2 marks]

ii. What further operation must be done on the gas in order to take it from state C to its original state A? [2 marks]

iii. Sketch a labelled p-V graph to represent the various states of the gas. [2 marks]

iv. What quantity does the area enclosed represent? [1 mark]

b. An ideal gas at an initial temperature of 15 ^{o}C and pressure of 1.10×10^5 Pa is compressed isothermally to one quarter of its initial volume. Determine its final pressure and temperature. [2 marks]

c. i. Briefly explain how a heat engine functions. Your description shall include a flow diagram of a heat engine supplied with a quantity of heat Q_H from a hot reservoir at a temperature T_H and which loses a quantity of heat Q_C to a cold reservoir at a temperature T_C. [2, 2 marks]

ii. Derive an expression for the maximum efficiency of a heat engine in terms of Q_H and Q_C. [2 marks]

iii. For an ideal heat engine, it can be shown that

$$\frac{Q_H}{Q_C} = \frac{T_H}{T_C}$$

where T_H and T_C are absolute temperatures. Write down the maximum efficiency of a heat engine in terms of these temperatures. [2 marks]

iv. Explain how this expression for the maximum efficiency leads to a statement of the second law of thermodynamics. [2 marks]

v. State how you would theoretically increase the maximum efficiency of a heat engine and give two limitations of this efficiency increase. [3 marks]

vi. A heat engine is designed to operate between 480 K and 300 K. Assuming that the engine actually produces 1.2 kJ of mechanical energy per 4.2 kJ of heat absorbed, compare quantitatively the actual efficiency with the theoretical maximum efficiency. [3 marks]

Question 10

a. i. Explain briefly how the molecules of a gas in a container exert a pressure. [1 mark]

ii. With reference to the kinetic theory state one reason why the pressure exerted by molecules of a gas maintained at constant volume increases as the temperature increases. [2 marks]

iii. A container of gas has a pressure of 303 kPa above atmospheric pressure at a temperature of 0 ^{o}C. The container is inserted into an oven where the gas temperature rises to 60 ^{o}C. Given that atmospheric pressure is 101 kPa, calculate the new pressure of the gas inside the container. [2 marks]

b. In the kinetic theory of gases, the pressure p of an ideal gas is given by the equation

$$p = \frac{1}{3}\rho\langle c^2\rangle$$

Where ρ is the gas density and $\langle c^2\rangle$ is the mean square speed of the molecules.

i. State four assumptions made in the Kinetic Theory of gases. [4 marks]

ii. Express ρ in terms of the number of molecules N, each of mass m, in a volume V. [1 mark]

iii. Use the equation of state for an ideal gas, together with the given equation for pressure, to show that the total internal energy U of an ideal gas is given by the equation

$$U = \frac{3}{2}nRT$$

where n is the number of moles present in the gas, R is the molar gas constant and T is the absolute temperature. State any assumption you have made on the internal energy of an ideal gas. [3, 1 marks]

iv. Hence show that the average kinetic energy of one molecule is given by

$$average\ K.E. = \frac{3kT}{2}$$

Where k is Boltzmann Constant. [2 marks]

c. At a certain time, the speeds of six molecules of an ideal gas are as follows;

Speed /m s^{-1}	2.0	3.0	4.0	5.0	6.0
Number of molecules	1	2	1	1	1

i. Explain what is meant by the root mean square speed of the molecules. [1 mark]

ii. Calculate the root mean square speed of all the six molecules. [2 marks]

iii. Derive an expression for the speed of the molecules of an ideal gas in terms of its absolute temperature T, Boltzmann Constant k and the mass m of one molecule. [2 marks]

iv. Hence use the expression to calculate the root mean square speed of Helium molecules at 27 °C. The mass of one mole of Helium molecules is 4.003 g. [2 marks]

v. Hence or otherwise find the total internal energy of one mole of Helium molecules at 27 °C. [2 marks]

Question 11

a. Explain briefly the basic operations you would perform in an experiment to charge a metal sphere by induction. The metal sphere shall remain negatively charged. You are equipped with a glass rod, a silk cloth, a piece of conducting wire and an insulating base to hold the metal sphere. Your explanation should include diagrams where necessary and should specify the nature and movement of charged particles. [4 marks]

b. Define electrical potential of a point in an electric field. [2 marks]

c. The diagram in Figure 2 shows a set of electric field lines and the direction of the electric field $\vec{E}$. Explain which two points are closest to being of the same potential and which point is at the lowest potential? [4 marks]

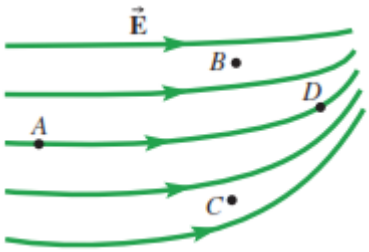


Figure 2

d. An isolated point charge of magnitude Q is situated in a vacuum. The electric potential at a distance of 1.0×10^{-10}m from this charge, is + 14.3 J C^{-1}.

i. Explain why electric potential may be a positive or a negative quantity. [2 marks]

ii. Calculate the magnitude of Q. [2 marks]

iii. Hence calculate the electric potential due to Q at a distance of 2.0×10^{-10}m and at a distance of 3.0×10^{-10}m. [2 marks]

e. An electron of charge -1.6×10^{-19}C is moved from a distance of 3.0×10^{-10}m to a distance of 1.0×10^{-10}m from the isolated point charge Q.

i. Use your answer to part d(iii) to determine the work done in moving the electron. State whether this work is done on or by the field. Give a reason for your answer. [2, 1, 2 marks]

ii. State how this work gives rise to the definition of the electron volt and hence determine the speed of the electron when it moves from a distance of 3.0×10^{-10}m to a distance of 1.0×10^{-10}m from the isolated point charge Q. [2, 2 marks]

Question 12

a. Briefly explain qualitatively the origin of the Hall Effect. [2 marks]

b. A slice of conducting material is put in a magnetic field B which is perpendicular to the direction of the current passing through it as shown in Figure 3.

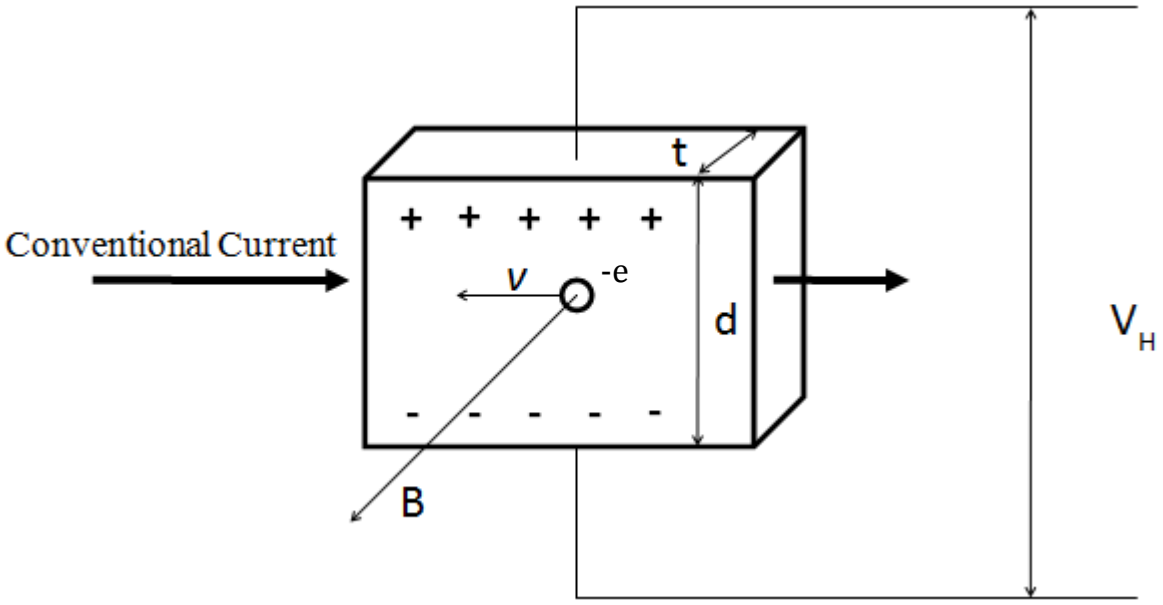


Figure 3

By using the quantities given in the figure:

i. Obtain an expression for the electric force F_E acting on the electron $-e$, by the electric field setup due to the Hall Voltage V_H across the slab perpendicular to the direction of the current. State also its direction; [2 marks]

ii. Write down an expression for the magnetic force F_B acting on the electron moving with a drift speed v; [2 marks]

iii. hence show that the Hall voltage V_H can be given by the expression

$$V_H = \frac{BI}{net}$$

[3 marks]

iv. Describe and explain the effect on the value of the Hall voltage of first increasing the current in the slice and then by replacing the slice of copper by a slice of semiconductor material of the same dimensions and carrying the same current I. [4 marks]

v. The semiconducting slice has a thickness of 0.15 mm and contains 1.0×10^{23}conducting electrons per cubic metre. Calculate the Hall voltage when B is 95 mT and I is 120 mA. [2 marks]

c. Figure 4 shows a rectangular coil ABCD with N turns and sides of length x and y which can rotate about the axis represented by the dotted line. The coil carries a current I in the direction shown. The coil is located in a uniform magnetic flux density B, with the plane of the coil making an angle θ with the direction of the flux density.

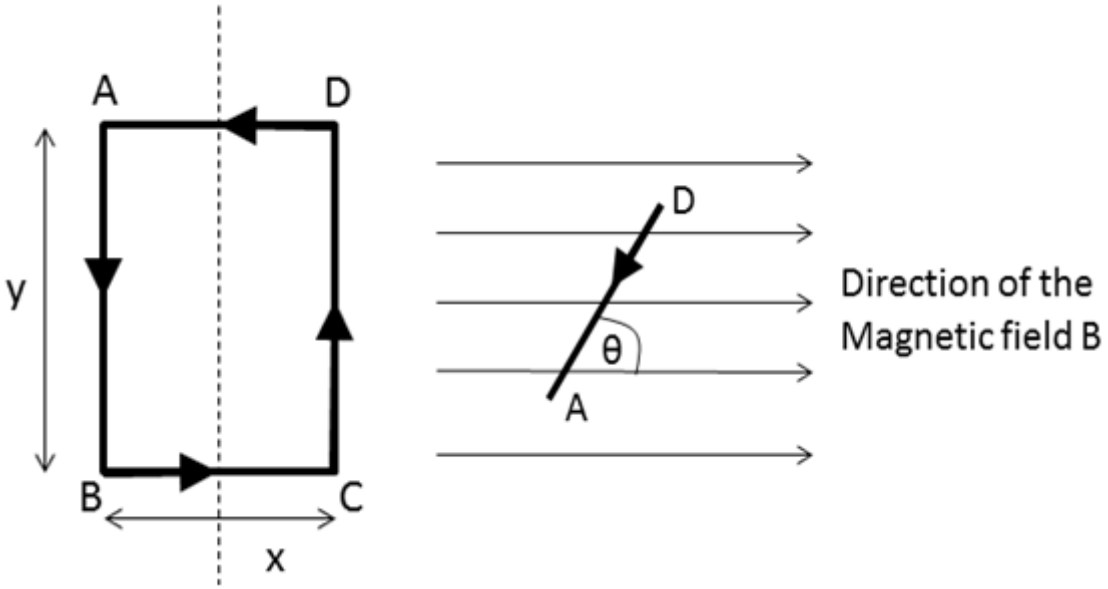


Figure 4

i. State the magnitude and direction of the forces acting on each side of the coil. [2 marks]

ii. Hence, derive an expression to show that the Torque T acting on the coil in the position shown in Figure 4 is given by

$$T = BINA\cos\theta$$

where A is the area of the coil. [4 marks]

iii. State the direction of the plane of the coil at which maximum torque acts on the coil. Calculate the maximum torque on a 20 turn coil having an area of 20 cm^2 carrying a current of 1.5 A in a magnetic flux density B of 100 mT. [4 marks]

Question 13

a. Explain what is meant by peak voltage and root-mean-square voltage in an alternating current circuit. [1, 2 marks]

b. The output voltage V of an AC generator is given by $V = 100\ sin 50\pi t$.

i. State the frequency, peak voltage and root-mean-square voltage for this AC generator. [3 marks]

ii. State which instrument is used to show graphically the peak value of a varying sinusoidal voltage. Explain briefly how one could use this instrument to measure this value. [2 marks]

c. Distinguish between p-type and n-type semiconductor materials in terms of conduction and charge carriers. [3 marks]

d. Describe the charge flow that takes place when a junction is formed between p-type and n-type material, and explain how a barrier p.d. is created. [3 marks]

e. Hence explain what is meant by the depletion layer. [2 marks]

f. Explain what happens to the majority and minority charge carriers when a p-n junction is:
   i. forward biased;
   ii. reverse biased. [2, 2 marks]

g. Sketch two circuit diagrams to show a diode in the two configurations mentioned in part (f) and hence sketch a graph to show the IV characteristic of a diode in both configurations. [2, 3 marks]

Question 14

a. Define simple harmonic motion. [1 mark]

b. A spring rests on a large frictionless horizontal surface. One end of the spring is fixed to the surface and a mass of 0.25 kg is fixed to the other end. The mass is suitably displaced a distance of 0.01 m from its equilibrium position O and released to vibrate in simple harmonic motion with a period of 4 seconds. Determine:
   i. the velocity and acceleration of the mass when it is 0.008 m from O; [4, 2 marks]
   ii. the shortest time it takes to travel from a point 0.005 m on one side of O to a point 0.005 m from O on the other side; [3 marks]
   iii. the maximum kinetic energy of the system; [2 marks]
   iv. the total energy of the system and state whether this energy varies with time. [2 marks]

c. Explain briefly what is meant by damped oscillating system. [1 mark]

d. Distinguish between light, critical and over-damped oscillations. Sketch three graphs on the same axis to show the effect on the amplitude of oscillations with time for each type of damped oscillations. [6 marks]

e. Explain briefly what is meant by mechanical resonance in vibrating systems and sketch a graph to show the effect on the amplitude of forced oscillations with increasing frequency. [2, 2 marks]

Question 15

a. State Snell's law of refraction and define refractive index in terms of the velocity of light. [3 marks]

b. Explain what is meant by critical angle and state the conditions under which a wave will be totally internally reflected on meeting a boundary between two transparent media, both of which will allow the passage of the wave. [4 marks]

c. A beam of light travelling through a transparent medium *M* is incident on a plane interface into air at an angle of 20^{o} to the normal. The speed of light in the medium *M* is 60% of that in air.

   i. Calculate the angle of refraction in air. [3 marks]

   ii. Medium *M* is replaced with medium *N* and the beam of light is incident again at an angle of 20^{o} at the plane air interface. This time it is found that the beam is just totally internally reflected at this interface. Calculate the speed of light in medium *N* as a percentage of the speed of light, *c*, in air. [5 marks]

d. A thin converging lens of focal length *f,* forms a sharp image *I* of a small object *O* on a screen *S.*

   i. Explain what is meant by principal focus and write down the mathematical relationship between the focal length *f*, the object distance *u* and the image distance *v*. [2, 1 marks]

   ii. The distance from object *O* to the screen *S* is fixed at 1.0 m. The focal length *f* of the lens is 160 mm. It is possible to adjust the lens so as to obtain an image *I* focused on the screen. Find two values of the object distance *u,* for which a sharp image of *O* is formed on the screen. [4 marks]

   iii. If the object *O* is a small circle of radius 4 mm, what is the radius of the image for the two values of *u*? [3 marks]

MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

UNIVERSITY OF MALTA, MSIDA

MATRICULATION CERTIFICATE EXAMINATION
ADVANCED LEVEL
SEPTEMBER 2012

SUBJECT:	PHYSICS
PAPER NUMBER:	III – *Practical*
DATE:	31st August 2012
TIME:	2 hours

Experiment: Charging and Discharging a capacitor

Apparatus: $9\,V$ battery, digital meter, capacitor and resistor on a Vero Board, additional resistor

DO NOT PROCEED BEFORE READING VERY CAREFULLY THESE INSTRUCTIONS.

Important Note: To avoid damaging the apparatus, please make sure that you **follow carefully the following steps at all times** during the experiment.

- **The battery should be connected lastly**, that is, after you have checked that the circuit is properly connected and that the digital meter is set to read the voltage or current required and is set on the proper 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 the wires.

- If you intend to measure a current of say 2 A, **do not set the meter to a range less than that value**, for example 200 mA, as this will cause the internal fuse to blow. If you do not know the magnitude of the current you are measuring, then **start using the larger range and decrease it** appropriately until you can get a good accurate reading for your current.

- The same applies for measurements of voltage. If, for example, the digital meter is set on 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.

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 readings.**

Circuit Diagram:

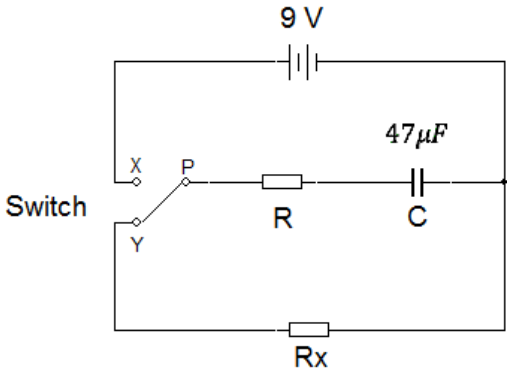


Figure 1 The CR Circuit

Method – Part A: CHARGING

1. Set up the digital meter to read DC voltage and connect it to the pair of wires that have plugs at the end. Make sure that you **set it up to the correct range**.
2. The capacitor is set to **charging mode by connecting point point P to point X** and to **discharging mode by connecting point P to point Y**.
3. Connect the 9 V battery to the circuit.
4. Start the charging process and take readings of the voltage on the capacitor, V_{C1}, as it changes with time, t, every 15 seconds for a period of 3 minutes. **Do not disconnect point P from point X** (unless you have to repeat some readings). Leave it charging even after the period of 3 minutes has been exceeded. Record the values of V_{C1} in Table 1.

[12 marks]

5. You should notice that after a while the voltage on the capacitor almost stops changing. Record this value of the voltage on the capacitor V_0 = _____.

[2 marks]

6. Hence, complete Table 1 by filling in the values of the voltage V_R across the charging resistor R. The voltages for V_R are given by $V_R = V_0 - V_{C1}$.

[6 marks]

Table 1

$t\ /\ s$	$V_{C1}\ /\ V$	V_R/V
0		
15		
30		
45		
60		
75		
90		
105		
120		
135		
150		
165		
180		

7. Plot, ***on the same axis***, graphs of
    a. $V_R\ in\ V$ against time $t\ in\ s$; and
    b. $V_{C1} in\ V$ against time in s.

[25 marks]

DO NOT WRITE ABOVE THIS LINE

8. Using graph (a) calculate the time constant, CR, for the charging circuit.

_____

_____

_____

[6 marks]

Method – Part B: DISCHARGING

9. An additional resistor R_X is used in series with the resistor R (used for charging) to form the discharging circuit. (Note - there is no need to connect any additional resistor as it is already soldered on the vero board).
10. The capacitor should now be fully charged. If not, connect Point P to Point X until the voltage on the capacitor indicated by the voltmeter almost stops changing.
11. With the capacitor fully charged, start the discharging process by connecting point P to Point Y. As soon as you start the discharging process, start to record the voltage on the capacitor V_{C2} as it changes every 20 seconds for a period of 4 minutes. Record these values in Table 2.

[12 marks]

Table 2

t / s	V_{C2} /V	$\ln(V_{C2})$
0		
20		
40		
60		
80		
100		
120		
140		
160		
180		
200		
220		
240		

DO NOT WRITE ABOVE THIS LINE

12. Complete Table 2 by working out the values in the third column.

[6 marks]

13. Theory states that the exponential discharge of a capacitor is given by

$$\ln(V_{C2}) = -\frac{t}{(R + R_{X)}C} + k$$

where V_{C2} is the voltage at time t, k is a constant and $(R + R_X)C$ is the time constant for the discharging circuit.

14. Plot a graph of $\ln(V_{C2})$ against time t and use the graph to determine the time constant $(R + R_X)C$ of the discharging circuit.

[15 marks]

15. Given that the value of the capacitor is $47\ \mu F$ and by making use of the time constant CR obtained in Part A, determine a value for the resistance R_X in $k\Omega$.

[8 marks]

16. The maximum voltage V_0 on the capacitor when it was fully charged in Part A is greater than the stated value of the voltage supplied by the battery. By using keywords like *internal resistance*, *current*, *voltage drop* and *others*, briefly explain why this is so.

[8 marks]

DO NOT WRITE ABOVE THIS LINE