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

MATRICULATION CERTIFICATE EXAMINATION
ADVANCED LEVEL
MAY 2012

SUBJECT:	PHYSICS
PAPER NUMBER:	I
DATE:	23rd May 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	G	=	$10\ \text{m s}^{-2}$
Charge on an electron	e	=	1.60×10^{-19} C
Planck's constant	h	=	6.63×10^{-34} J s
Speed of light in vacuum	c	=	$3.00 \times 10^{8}\ \text{m s}^{-1}$
Avogadro's number	N_A	=	$6.02 \times 10^{23}\ \text{mol}^{-1}$
Mass of an electron	m_e	=	9.10×10^{-31} kg
Atomic mass unit	u	=	931×10^{6} eV
Mass of aluminium nucleus	m_{Al}	=	28.97330u
Mass of silicon nucleus	m_{Si}	=	28.96880u
Mass of beta particle	m_{β}	=	0.000549u
Mass of electron antineutrino	$m_{\bar{\nu}_e}$	=	0u

Section A

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

Question 1

a. Express the ohm in terms of its base units. [2 marks]

b. What is the difference between derived units and base units? [3 marks]

c. The equation $F = ½\ A\ C_d\ D\ v^2$ may be used to calculate the air resistance a car experiences while driving. Given that F is the air resistance, A is the frontal area of the car, C_d is the drag coefficient and has no units, D is the density of air and v is the speed of the car, confirm that the equation is homogeneous. [4 marks]

d. Calculate the speed of a car which is experiencing air resistance equivalent to 299 N. It may be assumed that the frontal area is $2.07\ \text{m}^2$, the car has a C_d value of 0.31 and the air density is $1.29\ \text{kg m}^{-3}$. Give your answer in km h^{-1}. [3 marks]

Question 2

A projectile is fired horizontally at 8 m s^{-1} towards a target which is some distance away. The target is a small disc hanging on a vertical wall and 2.5 m below the original level of the projectile.

a. What is a projectile? [2 marks]

b. Calculate the time of flight of the projectile, if the projectile hits the target. [2 marks]

c. How far is the target from the point of projection? [2 marks]

d. What assumption have you made to obtain your answer? [1 mark]

e. Had a strong wind been blowing opposite to the direction of travel of the projectile, how would this have affected answers (b) and (c)? Explain. [4 marks]

f. Calculate the velocity with which the projectile actually hits the target. [4 marks]

g. What is the angle to the horizontal with which the projectile hits the target? [2 marks]

Question 3

A machine lifts 1.5 kg rubber blocks through a height of 15 m.

a. State the principle of *conservation of energy*. [2 marks]

b. If it takes the machine two minutes to lift 20 blocks, calculate the power of the machine. [2 marks]

c. Is this value the actual power of the machine? Explain. [2 marks]

d. Accidentally, one of the lifted blocks falls from the maximum height of 15 m. What is its velocity as it hits the floor? [2 marks]

e. On impact with the floor, the rubber block rebounds, in the process losing 25% of its energy. Determine the height through which it will rise? [3 marks]

f. Some of the energy is lost as sound when the block hits the ground. What happens to the rest? Explain. [2 marks]

Question 4

A small particle is moving in a circular path at a distance r from the centre of rotation.

a. Explain why the particle is accelerating. [2 marks]

b. Show that the acceleration a, of the particle is given by $a = v^2 / r$ where v is the tangential velocity of the particle. [5 marks]

c. If the particle has a mass of 5.5×10^{-3} kg, moves in a circular path of radius 3.3 mm and goes round 20 times per second, calculate:
   i. its angular velocity; [2 marks]
   ii. its acceleration; and [2 marks]
   iii. the centripetal force needed to keep it moving along this path. [2 marks]

Question 5

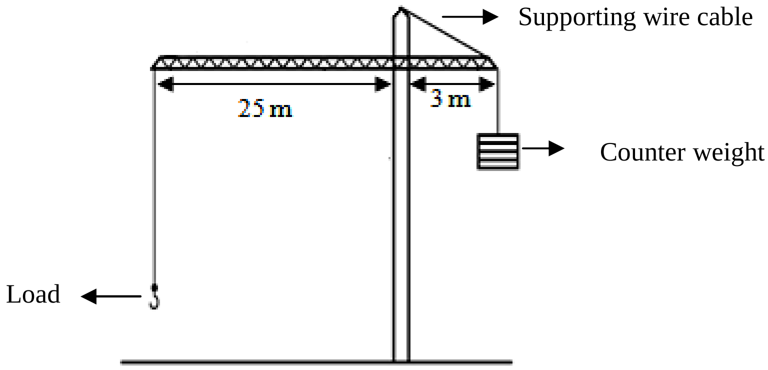

Figure 1

A tower crane, five storeys high has a long jib on one side which is 25 m long and a short one of 3 m on the opposite side from which a large counter weight hangs. The end of the short jib is tied to the top of the tower by means of a supporting wire cable. The crane is considered safe as it is in equilibrium.

a. State the conditions for equilibrium. [2 marks]

b. Ignoring the tension in the cable, what should be the minimum value of the counter weight when the tower crane lifts a load of 12 stone blocks each of 20 kg. Assume that the stones are hanging from the very end of the crane and the counter weight hangs from the end. [2 marks]

c. If the angle the supporting wire cable makes with the short jib is 45^{o}, calculate the tension in the wire cable when the load is hanging 12.5 m away from the centre of the crane. [3 marks]

Question 6

a. Define *electric current*. [1 mark]

b. Distinguish between *conductors, semi-conductors* and *insulators* in terms of free electrons. [6 marks]

c. Explain how the conduction properties of silicon change with temperature and presence of impurities. [5 marks]

Question 7

a. Sketch, label and explain a current-voltage graph for a metal wire at constant temperature and another for a filament lamp. [4 marks]

b. Derive an expression for the *combined resistance* of three resistors connected in parallel. [4 marks]

c. A 6 V cell is connected in series with a 5 Ω resistor and a branch made up of two parallel 6 Ω resistors.
   i. Determine the current flowing in the circuit. [3 marks]
   ii. Calculate the p.d. across each resistor. [3 marks]

Question 8

a. A radioactive isotope of cobalt ${}^{60}_{27}\mathrm{Co}$ decays by emission of a beta particle followed by emission of one or more gamma photons.

i. Define the term *isotope*. [2 marks]

ii. Write down a suitable equation for this decay process. [2 marks]

b. Briefly describe the process of *deep inelastic scattering* and its use. [3 marks]

c. What is a positron? [2 marks]

d. Give **two** sources of background radiation and explain why the monitoring of this radiation is considered to be important. [3 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. i. State the principle of *conservation of linear momentum* and show how it follows from one of Newton's laws of motion. [2, 3marks]

ii. Describe briefly how this principle may be demonstrated. Your answer should include:
a labelled diagram of the apparatus; [2 marks]
a list of measurements to be taken; [2 marks]
the method used; and [2 marks]
the formula to be tested. [2 marks]

b. A boat of mass 5×10^4 kg pulls a smaller boat of mass 1×10^3 kg. The boat accelerates at 0.5 m s^{-2}.

i. If the bigger boat experiences a frictional force of 500 N and the smaller boat a frictional force of 100 N, find the forward force exerted by the engine. [4 marks]

ii. Draw separate force diagrams for each boat and identify a pair of forces satisfying Newton's third law of motion. [4 marks]

c. Two boats are at rest near each other. A boy jumps from the first boat to the second. State what happens to the speed of each boat during the three phases of the process listed below:

i. when the boy starts the jump from the first boat;
ii. while the boy is in the air between the boats; and
iii. during the landing on the second boat.

[3 marks]

d. Which one of Newton's laws of motion relates to the situation described in part (c)? [1 mark]

Question 10

a. Define the *moment of inertia* of a rigid body about a fixed axis, giving the base units of this quantity. [3 marks]

b. A ball of mass *m* and radius *b* rolls down a slope without slipping. It is initially at rest at a height h_0 and rolls with negligible friction. If the moment of inertia is given by $I = m\,r^2$:

i. write an expression for the initial potential energy of the ball; [2 marks]

ii. give the kinetic energy at height h_0; and [2 marks]

iii. show that the speed of the ball at the bottom is given by

$$v = \sqrt{\frac{2gh_0}{1+\frac{1}{mr^2}}}$$

[3 marks]

c. i. State the *principle of conservation of angular momentum* and the condition under which it applies. [3 marks]

ii. A skater is spinning at an angular velocity of 32 rad s^{-1} with her arms extended outward. Her moment of inertia with respect to the vertical axis about which she is spinning is 45 kg m^2. She pulls her arms in, close to her body, changing her moment of inertia to 17 kg m^2. Explain, giving reasons what happens to her new angular velocity. Calculate her new angular velocity. [3 marks]

d. A mass of 100 g at the end of a 0.8 m string is spun vertically in a circle at a constant angular velocity of 4 rad s^{-1}. Calculate the tension in the string at:

i. the top of the path; and

ii. the bottom of the path. [4 marks]

e. Two identical spaceships each of mass *M* are attached by a cable of negligible mass of length 2*R*. The spaceships are rotating at a linear speed of v_o = 17 m s^{-1} about their common centre of mass. They both pull on the cable. If the cable is reduced in length by a factor of two, by taking conservation considerations or otherwise, deduce their new linear speed. [5 marks]

Question 11

a. i. By making use of an appropriate stress-strain sketch, distinguish between *elastic* and *plastic* behaviour. [4 marks]

ii. Explain the terms *ductile* material and *brittle* material using appropriate diagrams. Give **one** example of **each** type of material. [4 marks]

b. i. A spring is stretched within its limit of proportionality. Considering Hooke's law and the expression for Young's modulus, deduce a relationship between the spring constant and Young's modulus for a material of cross-sectional area *A* and unstretched length, *L*. [4 marks]

ii. A cylindrical bar is 500 mm long and has a diameter of 10 mm. If the bar stretches to 505 mm when a force of 50 kN is applied, determine its Young's modulus, assuming the material remains within its elastic limit. [3 marks]

c. Springs A and B have spring constants k_1 and k_2 respectively. It is known that k_2 is twice k_1.

i. If spring A is compressed by 1cm, find by how much must spring B be compressed in order to store the same amount of energy as spring A. [4 marks]

The springs are now connected in parallel between two plates.

ii. Calculate the new effective spring constant of the system in terms of k_1. [2 marks]

iii. If the springs store energy E_1 and E_2 respectively, determine the value of the ratio E_1 / E_2. [2 marks]

iv. If the springs are connected end to end, which one would be extended more when loaded? [2 marks]

Question 12

a. i. In the current equation $I = n A v e$, n represents the number of charge carriers per unit volume, A the cross-sectional area, e the charge of each carrier and v the drift velocity. Define *drift velocity*. [1 mark]

ii. The electron drift velocity is estimated to be a few mm s^{-1} for current flow. How is the current established almost instantly when the circuit is closed? [1 mark]

iii. The electron drift velocity arises due to the force experienced by electrons in the electric field inside a conductor. If a force should cause acceleration, explain why electrons acquire a steady drift velocity. [2 marks]

b. i. Distinguish between the *electromotive force* and *terminal potential difference* of a cell. [2 marks]

ii. A cell in a hearing aid supplies a current of 25 mA through a resistance of 400 Ω. When the volume of the hearing aid is increased, the resistance is changed to 100 Ω and the current rises to 60 mA. Calculate the emf and internal resistance of the cell? [3 marks]

iii. A student experimenting with a solar cell connects a 1000 Ω voltmeter across it and observes a potential difference of 1.0 V. Using another, extremely high resistance digital voltmeter, the reading is 1.2 V. Explain this difference in measurement and calculate the internal resistance of the solar cell? [3 marks]

c. i. State *Kirchhoff's laws* and relate each one to a conservation law, giving reasons. [6 marks]

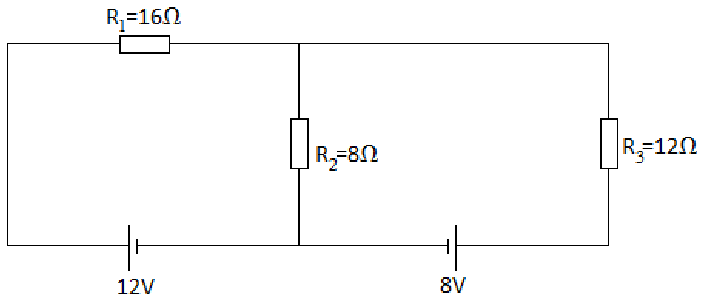

Figure 2

ii. Two batteries of negligible internal resistance are connected as shown in Figure 2. Using Kirchhoff's laws, calculate the current and the electrical power through each resistor. [7 marks]

Question 13

a. i. Define the *temperature coefficient of resistance* α, distinguishing between positive and negative values of α .Give **one** example of a material with a positive α value. [5 marks]

ii. Define the *resistivity* of a material. [2 marks]

iii. A length of wire has cross-sectional area 2×10^{-7} m^2 and is 1.3 m long. The material has a resistivity of 1.7×10^{-8} Ω m at 20 ^{o}C. If the material has a temperature coefficient of 4.0×10^{-3} ^{o}C^{-1}, find the resistivity at 60 ^{o}C. Ignore **any** expansion in the wire. [5 marks]

b. Light bulb A has four times the power rating of light bulb B when operated at the same voltage.

i. Is the resistance of bulb A greater than, less than or equal to the resistance of bulb B? Explain your answer. [3 marks]

ii. Find the ratio of the resistance of bulb A to the resistance of bulb B. [3 marks]

c. A load of 2000 Ω is connected to a linear potential divider of 4000 Ω and to a supply of 10 V, as shown in Figure 3.

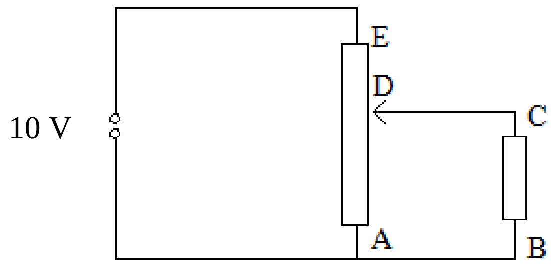

Figure 3

Find the potential difference across the load BC when the slider D lies:

i. at end A of the divider;

ii. one-quarter up from end A; and

iii. half-way up the divider. [7 marks]

Question 14

a. Explain under what conditions and how a line spectrum is emitted by an atom. [2 marks]

b. i. Explain briefly the photoelectric effect stating the formula and indicate the meaning of each term. [3 marks]

ii. What is the work function, and how does it relate to the threshold frequency? [2 marks]

c. Sodium has a work function of 2.0 eV. If sodium is illuminated by radiation of wavelength 150 nm. Calculate:

i. the maximum kinetic energy of the escaping electrons; [3 marks]

ii. the maximum speed of the escaping electrons; and [1 mark]

iii. the threshold frequency of the radiation. [2 marks]

d. i. Briefly outline **two** experiments in which electromagnetic radiation behaves as a wave and as a particle respectively. [3, 3 marks]

ii. In an experiment, electrons of mass m_e and charge e, are accelerated to a velocity v_e by a potential difference between an anode and a cathode of V volts. Express the linear momentum of the electron in terms of the above quantities. Hence show that the de Broglie wavelength is given by

$$\lambda = \frac{h}{\sqrt{2eVm_e}}$$

[4 marks]

iii. For a potential difference, V of 3600 V, find the de Broglie wavelength. State whether the beam visible to the human eye. [2 marks]

Question 15

a. i. What is meant by the *half-life* of a radioactive substance? [1 mark]

ii. If a sample radioactive element is originally composed of 1000 nuclei and after 16.549 years it has only 998 nuclei left, calculate its decay constant and its half-life. Would this substance pose a serious health risk if it were to be found abundantly on Earth? Consider a **year** is 365 days long. [5 marks]

b. Distinguish between *stable* and *unstable* nuclei. Sketch a labelled graph showing how the stability of nuclei changes with increasing numbers of protons and neutrons.

[4 marks]

c. i. Distinguish between *alpha* and *beta particles* and *gamma radiation*. [4 marks]

ii. An isotope of aluminium decays into an isotope of silicon by undergoing radioactive decay as shown below:

$$^{29}_{13}Al \rightarrow ^{29}_{14}Si + e^- + \bar{v}_e$$

Calculate the energy released during the decay in MeV, indicating the form of energy that it takes. [4 marks]

d. In Rutherford's alpha scattering experiment, a beam of alpha particles is directed on a thin gold leaf and the scattering is observed.

i. What scattering pattern is expected? Which fundamental force produces this outcome? [2 marks]

ii. If the alpha particles had been replaced by neutrons, how would the pattern change? [1 mark]

iii. Considering that that the charge of the aluminium nucleus is much smaller than that of a gold nucleus, what would be the effect on the scattering if the gold leaf is replaced by aluminium foil? [1 mark]

iv. List **three** properties of the nucleus that Rutherford deduced from the scattering experiment. [3 marks]

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MATRICULATION CERTIFICATE EXAMINATION
ADVANCED LEVEL
MAY 2012

SUBJECT:	PHYSICS
PAPER NUMBER:	II
DATE:	24th May 2012
TIME:	4.00 p.m. to 7.00 p.m.

A list of useful formulae and equations is provided.
This paper carries 40% of the marks for the examination.
It is expected that answers be accompanied by the proper units.

The following constants may be needed in the problems:

Acceleration due to gravity	g	=	10 m s^{-2}
Charge on an electron	e	=	1.60×10^{-19} C
Speed of light in vacuum	c	=	$3.0 \times 10^{8} \text{ m s}^{-1}$
Mass of Earth	m_E	=	5.98×10^{24} kg
Radius of Earth	r_E	=	6.37×10^{6} m
Gravitational constant	G	=	$6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
Molar gas constant	R	=	$8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Mass of an electron	m_e	=	9.10×10^{-31} kg
Permittivity of free space	ε_0	=	$8.90 \times 10^{-12} \text{ F m}^{-1}$

Section A

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

Question 1

a. Explain what is meant by *thermal equilibrium* between two bodies. [1 mark]

b. Outline a test that you would carry out to investigate whether two bodies A and B, which are not in contact with each other, are in thermal equilibrium. [3 marks]

c. Explain briefly how a constant volume gas thermometer is used to establish the ideal gas temperature scale. Your answer should include:
   i. a brief explanation of the method; [2 marks]
   ii. the physical equation used and the condition under which this equation holds; and [2 marks]
   iii. a sketch of the graph used to establish the ideal gas temperature scale. [2 marks]

d. The pressure recorded by a constant volume gas thermometer at a temperature of T Kelvin is $4.80 \times 10^4 \text{ N m}^{-2}$. Find T, if the pressure at the triple point, 273.16 K, is $4.20 \times 10^4 \text{ N m}^{-2}$. [2 marks]

Question 2

a. Define *specific heat capacity* of a material. [2 marks]

b. Describe briefly how the specific heat capacity of copper can be determined experimentally using an electrical method. Your description should include:
   i. a labelled diagram of the apparatus used; [3 marks]
   ii. a brief outline of the method used including the measurement taken; and [2 marks]
   iii. the calculations involved to determine the specific heat capacity. [2 marks]

c. 500 g of hot water at 85 ^{o}C are poured over some ice cubes which are in a 100 g aluminium can. Both the ice cubes and the can are at 0 ^{o}C. If the final temperature reached is 23 ^{o}C and it is assumed that no heat energy is transferred to the surroundings, find the mass of ice that was placed in the aluminium can.
[specific heat capacity of water is 4200 J kg^{-1} K^{-1}, specific heat capacity of ice is 2108 J kg^{-1} K^{-1}, latent heat of fusion of ice is 3.4×10^{5} J kg^{-1} and specific heat capacity of aluminium is 900 J kg^{-1} K^{-1}] [5 marks]

Question 3

a. Define the **three** terms *conduction*, *convection* and *radiation* when applied to the transfer of heat energy. [3 marks]

b. Explain what is meant by a perfectly *black body*. Sketch curves to show how the distribution of energy against wavelength emitted from a perfectly black body varies at three different temperatures. [3 marks]

c. A copper bar of thermal conductivity 401 W m^{-1} K^{-1} has one end placed in a temperature bath at 104 °C and the other end placed in another temperature bath at 24 °C. The length of the bar is 0.10 m and its cross-sectional area is 1.0×10^{-6} m^{2}.
   i. What is the rate of heat conduction along the bar? [2 marks]
   ii. What is the temperature gradient in the bar? [1 mark]
   iii. If two such bars were placed in series (end to end) between the same temperature baths, calculate the rate of heat conduction. [1 mark]
   iv. If two such bars were placed in parallel (side by side) with their ends in the same temperature baths, calculate the rate of heat conduction. [1 mark]

Question 4

a. State in words Newton's law of gravitation. [2 marks]

b. Use the equation representing Newton's law of gravitation to derive a value for *g*, the acceleration due to gravity, at the Earth's surface. [2 marks]

c. A geostationary satellite has to be placed above the equator.
   i. Explain what is meant by *geostationary*. [1 mark]
   ii. State the direction of rotation of the satellite around the Earth's axis. [1 mark]
   iii. Explain why the satellite must be above the equator. [2 marks]

d. A geostationary satellite is to be put in an orbit at a distance of 4.60×10^{7} m from the centre of the earth. Calculate:

i. the Earth's gravitational field strength at this distance; [2 marks]
ii. the speed of the satellite; and [2 marks]
iii. the acceleration of the satellite. [2 marks]

Question 5

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

b. A 4 μF capacitor was charged to a p.d. of 50 V and another 6 μF capacitor was charged to a p.d. of 100 V. After charging, the two capacitors were connected together as seen in Figure 1.

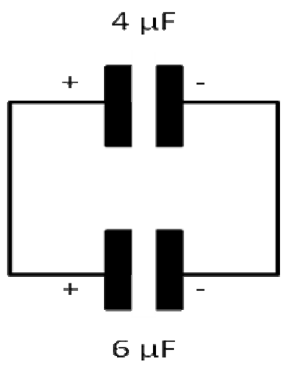

Figure 1

i. Calculate the charge on each capacitor before these were connected together. [2 marks]
ii. By calculating the energy stored in each capacitor before these were connected together, determine the total energy of both capacitors before connection. [3 marks]
iii. Calculate the p.d. across the capacitors and the total energy in the system when they are connected as shown in Figure 1. [3 marks]
iv. Determine the loss of energy that occurs when the two capacitors are connected together. Give a reason for this loss of energy. [3 marks]

Question 6

a. Explain what is meant by *self inductance.* [1 mark]

b. A series circuit consists of a 2.0 V cell, a switch *S*, a 0.25 Ω resistor *R*, an inductor *L* and an ammeter. The internal resistance of the cell and of the inductor *L* are negligible.
i. Explain why after closing the switch *S*, a student observes that the current rises slowly until eventually it becomes a steady current. [2 marks]
ii. When the current is increasing from 0 A to 0.20 A, the rate of change of current was constant at 40 A s^{-1}. Calculate the potential difference across the resistor *R* and across the inductor *L* when the current is exactly 0.20 A. [2 marks]
iii. Calculate the inductance of *L*. [1 mark]

The current in the circuit eventually becomes steady.
iv. Calculate the magnitude of the steady current. [1 mark]
v. State why the inductor *L* plays no part in determining the magnitude of this steady current. [1 mark]
vi. Determine how long it will take for the current to reach 99% of its maximum value. [2 marks]
vii. Using the data obtained above, sketch a labelled graph to show the growth of current with time in the circuit. [2 marks]

Question 7

a. Distinguish between *longitudinal* and *transverse* waves. State which phenomenon is associated with transverse waves but cannot be observed with longitudinal waves.
[3 marks]

b. A progressive wave has an amplitude of 0.9 m and a wavelength of 2.0 m. At a given time the displacement of the wave y is 0.9 m when the distance x from the origin is 0 m.
   i. Write down the wave equation for displacement as a function of distance at any time *t* defining any symbol used. [2 marks]
   ii. Calculate the displacement y when x = 0.50 m and when x = 1.4 m. Explain the meaning of the signs in both answers. [3 marks]
   iii. Calculate the phase difference between any two points which are 0.30 m apart along the wave. [1 mark]

c. Figure 2 shows a stationary wave on a string stretched between two fixed points A and F which are at a distance S apart.
   i. State what is meant by a *stationary wave*. [1 mark]
   ii. Describe the oscillations at the points B, C, D and E. Compare these oscillations in terms of their relative phases and amplitudes. [2 marks]

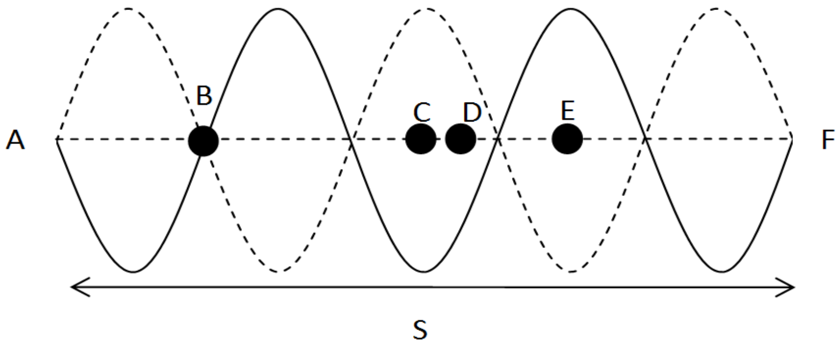

Figure 2

Question 8

a. Explain, with the aid of diagrams, the *principle of superposition of waves*. [2 marks]

b. Monochromatic light from a source passes through a single slit S and then through two narrow, parallel slits S_1 and S_2, separated by a distance *a*. The light falls on a screen a distance *d* from the slits as seen in Figure 3 below. A fringe pattern is formed on the screen.

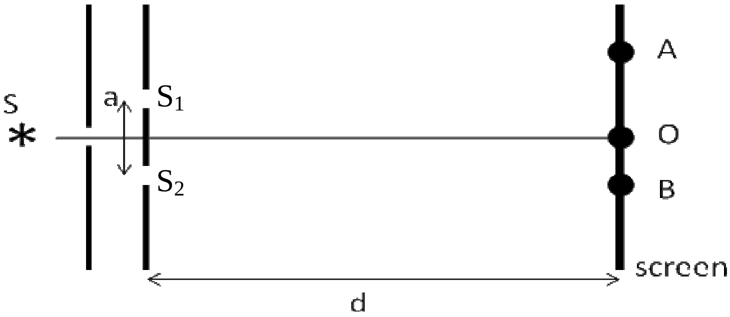

Figure 3

i. The light from slits S_1 and S_2 is said to be *coherent*. Define the term *coherent* in this context. [2 marks]

ii. In Figure 3, A is a point on the screen where constructive interference occurs between waves coming from S_1 and S_2. B is a point where destructive interference occurs. State what would be observed on the screen at these two points. [1 mark]

iii. If the light has a wavelength λ, write down the equation relating the quantities λ, d, a and the fringe spacing [1 mark]

c. The separation of the slits a is 0.80 mm, and the distance between the slits and the screen d is 3.6 m.

i. Calculate the fringe separation if the light has a wavelength of 4.4×10^{-7} m. [2 marks]

ii. A point C on the screen is 9.9 mm away from the central bright fringe at O. Show that a bright fringe is formed at C. [2 marks]

iii. How far from C is the next dark fringe? [1 mark]

d. Figure 4 below shows another way of obtaining fringes. A single slit is viewed both directly and by reflection from a mirror surface. Explain why this system produces a fringe pattern. [2 marks]

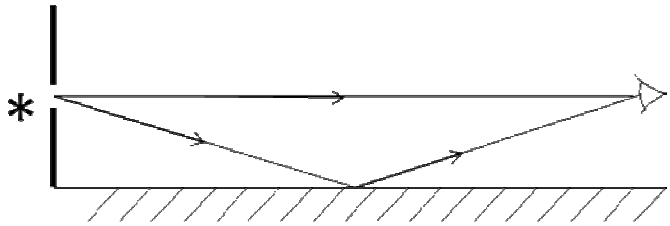

Figure 4

Section B

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

Question 9

a. State in words the *first law of thermodynamics*. [2 marks]

b. The specific heat capacities of air are 1040 J kg^{-1} K^{-1} if measured at constant pressure and 740 J kg^{-1} K^{-1} if measured at constant volume. Explain briefly why the values are different and indicate the relation between the molar heat capacity at constant pressure C_P and the molar heat capacity at constant volume C_V. [2 marks]

c. A sample of 20 moles of helium gas in a piston undergoes a cycle of changes of pressure, volume and temperature. One such cycle is shown in Figure 5 where the gas was taken from state A to state B to state C and back to state A. Helium gas may be assumed to behave as an ideal gas.

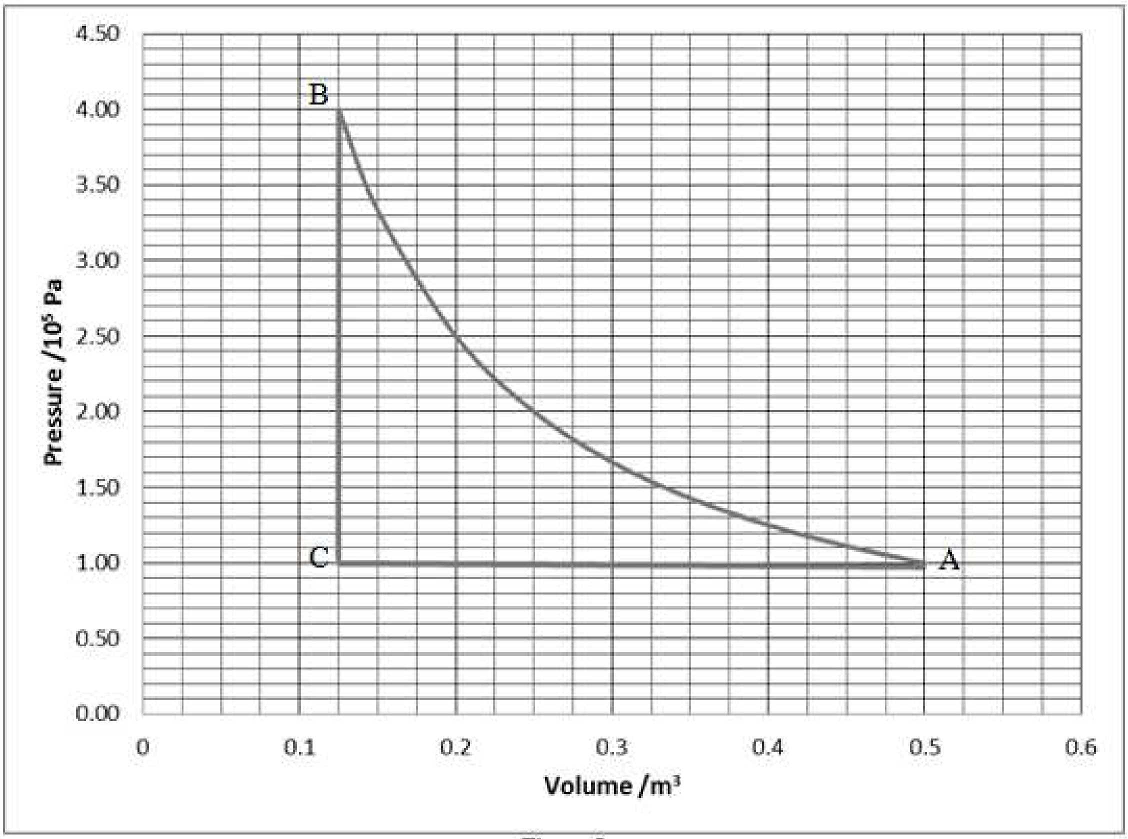

Figure 5

i. The change from state A to state B was isothermal. Explain what is meant by an *isothermal change* and use the ideal gas equation to calculate the temperature under which this change was performed. [2, 2 marks]

ii. Use the graph to estimate the work done on the gas to change it from state A to state B. Explain how you arrive at your answer. [2, 1 marks]

iii. Calculate the increase in internal energy of the gas due to the change from state A to state B where no heat energy was supplied to the system. [1 mark]

iv. Determine the temperature of the gas at state C and describe briefly the energy process which took place between states B and C. [2, 2 marks]

v. The change in internal energy of the sample in the process from state B to state C is 56 kJ. Find the heat energy going out of the system during this change and hence calculate the molar heat capacity at constant volume C_V of helium gas. [1, 2 marks]

vi. Use the graph to estimate the work done during the change from state C to state A. Indicate whether the work is done on or by the gas during this part of the cycle. [2 marks]

vii. Use the molar heat capacity at constant volume determined in part c(v) to determine a value for the molar heat capacity at constant pressure for helium. Hence calculate the heat supplied to the gas during the change from state C to state A. [2, 2 marks]

Question 10

a. State **three** assumptions concerning the motion of molecules in the kinetic theory of gases. [3 marks]

b. Figure 6 shows a single molecule of mass *m* in a cubical container of internal side length *L*. The molecule is travelling with velocity *v* directly towards one of the walls S of the container. By considering the assumptions in the kinetic theory of gases deduce:

   i. the change in the molecule's momentum when it collides with the wall S; [2 marks]
   ii. the time between collisions with the same wall S; [2 marks]
   iii. the change in momentum per unit time of the molecule at the wall S; [2 marks]
   iv. the average force on wall S as a result of impacts by the molecule; and [1 mark]
   v. the average pressure on the wall S, due to the molecule impacts. [2 marks]

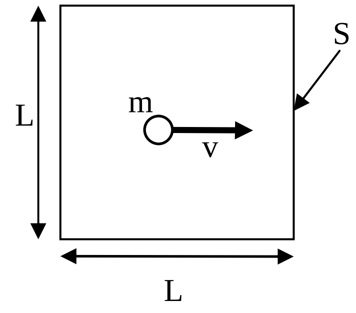

Figure 5

c. The pressure *p* of an ideal gas is given by the equation,

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

where *N* is the number of molecules in the container of volume *V* and $\langle c^2 \rangle$ is the mean square speed of the molecules. Explain briefly how this result can be deduced by modifying the equation derived in part b(v). [4 marks]

d. Use the equation of state for an ideal gas together with the equation given in part (c) to show that the kinetic energy of the molecules is directly proportional to the absolute temperature *T*. [3 marks]

e. A rigid container of volume 4.0×10^{-2} m^3 contains two moles of argon gas of mass 0.036 kg at a pressure of 1.0×10^5 Pa. Calculate:

   i. the root mean square speed of an argon molecule; [2 marks]
   ii. the temperature of the argon gas; and [2 marks]
   iii. the total internal energy of the gas molecules. [2 marks]

Question 11

a. Define:

   i. e*lectric field strength* at a point; [1 mark]
   ii. e*lectric potential* of a point in an electric field; and [2 marks]
   iii. state which of the two is a vector quantity. [1 mark]

b. A small positive charge $+q$ is moved a distance d from one conducting plate to another against a uniform electric field E.

i. Show that the work done W in moving the charge against the field is given by:

$$W = Eqd$$

[2 marks]

ii. If the potential difference between the conducting plates is V, show that the potential difference per unit distance in the electric field is given by the relation,

$$E = \frac{V}{d}$$

[3 marks]

iii. State how the electric field strength at a point may be determined from a graph of the variation of electric potential with distance from the point. [1 mark]

iv. Using the equations derived in parts b (i) and (ii), show that the kinetic energy of the positive charge travelling from one plate to another is qV. [3 marks]

c. The voltage between the anode plate and the cathode plate of an electron gun is 2400 V. Show that the electrons that are emitted from the cathode arrive at the anode of the electron gun at a velocity of 2.9×10^{7} m s^{-1}. [3 marks]

d. A charged sphere is moved towards the electron gun mentioned in part (c) along a line perpendicular to the direction in which electrons leave the gun as shown in Figure 7. When the centre of the sphere is about 0.28 m from the gun, the path of the beam is an arc of a circle.

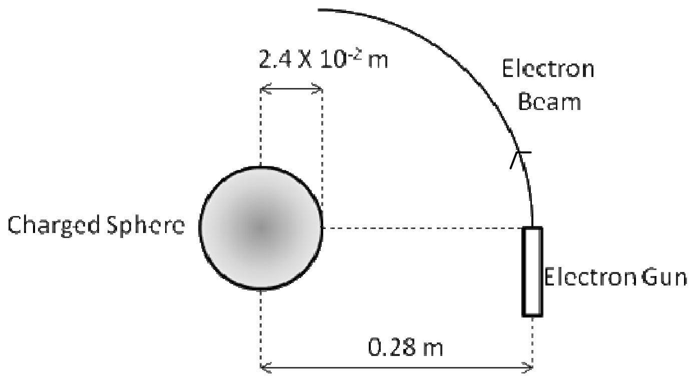

Figure 6

i. State whether the sphere is positively or negatively charged. Sketch the electric field lines, indicating direction, of the sphere. Explain your reasoning [3 marks]

ii. Explain why the speed of each electron remains constant while it is following a circular path. [1 mark]

iii. Show that the centripetal force on each electron is about 2.7×10^{-15} N. [3 marks]

iv. Calculate the strength of the electric field 0.28 m from the centre of the sphere. [2 marks]

Question 12

a. Define the term *magnetic flux density* and write down the equation representing this quantity acting on a wire of length L carrying a current I. [2, 1 marks]

b. A charge q moves through a magnetic field at right angles to the direction of the field. It experiences a force at right angles both to its direction of travel and to the direction of the magnetic field. Explain why this is so and state any physical rule you are using. [2 marks]

c. Figure 8 shows a positive charge q travelling at a constant speed v at right angles to a uniform magnetic field of flux density B pointing into the paper. Assume that the charge covers a distance x in time t:

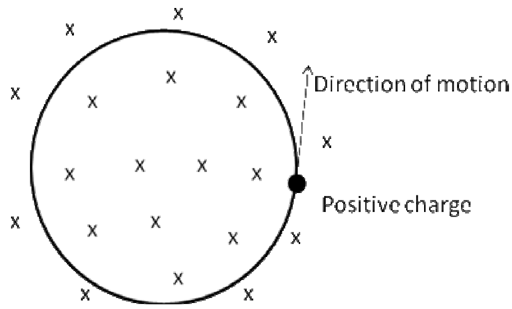

Figure 7

   i. write down a formula for the current I due to the moving charge; [1 mark]
   ii. use the formula for the magnetic force exerted by this current to show that the magnetic force on a moving charge can be given by the equation:

$$F = Bqv$$ [3 marks]

   iii. copy the figure and indicate the direction of the force. Explain why the conditions for circular motion are met and hence show that the radius r of the orbital motion of the positive charge having mass m is given by:

$$r = \frac{mv}{Bq}$$

[1, 2, 2 marks]

d. Use the example described in part (c) to describe briefly two physical principles of ring accelerators. [3 marks]

e. Use the equation derived in part c(ii) for a particle of charge q and mass m undergoing circular motion with velocity v in a cyclotron to show that the supply frequency f is given by:

$$f = \frac{Bq}{2m\pi}$$

[3 marks]

f. What can be deduced about the supply frequency of the cyclotron and its radius? [1 mark]

g. An electron is moving with a speed of 1.5×10^7 m s^{-1} perpendicular to a uniform magnetic field of flux density 0.0012 T.
   i. Calculate the force acting on the electron. [2 marks]
   ii. Calculate the radius of the circular path followed by the electron. [2 marks]

Question 13

a. Distinguish between the *root-mean square value* and the *peak value* of an alternating current and write down the equation showing the relation between both values. Identify any symbols used. [3 marks]

b. A washing machine is designed to withstand a maximum voltage of 350 V. Determine whether this domestic appliance can be connected safely to the a.c. mains supplying an r.m.s. voltage of 240 V. [2 marks]

c. When an oscilloscope is connected to the output of a transformer the image shown in Figure 9 is obtained. The sides of the squares in the diagram represent 1 cm. The Y-plate sensitivity is set to 5 V cm^{-1} and the time -base is set so that the horizontal deflection is 2 ms cm^{-1}. Deduce the values of the quantities listed below for the alternating potential difference applied to the Y-plates:

- i. period of oscillation; [2 marks]
- ii. frequency of oscillation; [1 mark]
- iii. peak value; and [1 mark]
- iv. the root mean square value. [1 mark]

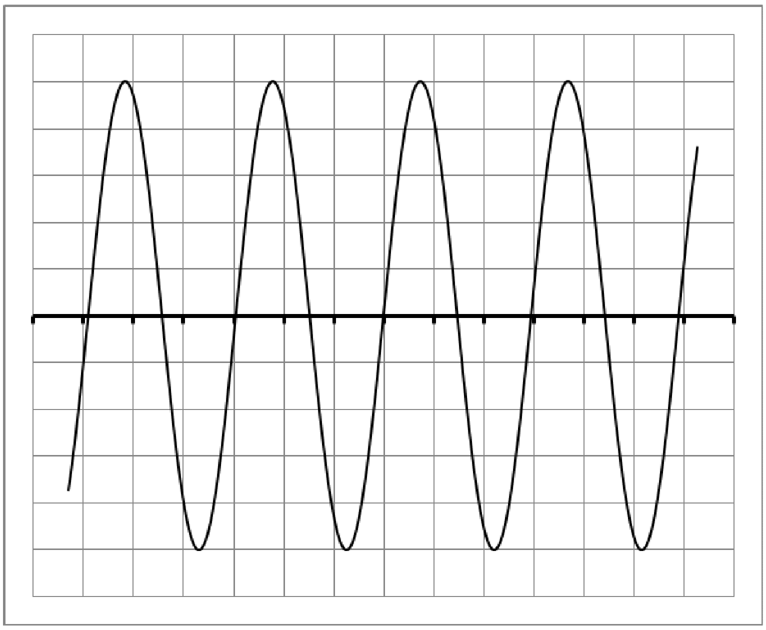

Figure 8

d. A battery with an e.m.f. greater than the *barrier p.d.* across the *depletion layer* in a p-n junction diode is connected with its positive pole to the p-semiconductor P and its negative pole to the n-semiconductor N as shown in Figure 10.

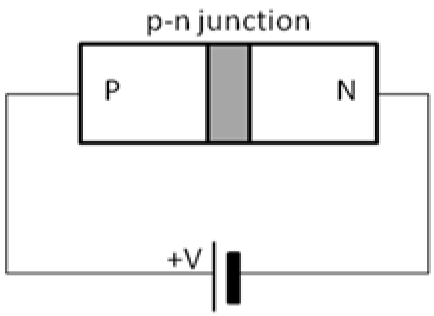

Figure 9

- i. Explain briefly what is meant by the *barrier p.d.* and the *depletion layer* of a p-n junction diode. [3 marks]
- ii. State whether the diode in this configuration is connected in reverse or forward bias mode. [1 mark]
- iii. Describe what happens to the majority and minority charge carriers in both types of semi-conductors when the battery is connected to the p-n junction diode. [3 marks]

e. Draw a circuit diagram showing how a set of diodes can be connected to give full wave rectification of an a.c. signal. [3 marks]

f. Sketch the full wave rectification obtained from such circuit. Label the axes clearly. [2 marks]

g. State which component should be added to the circuit to have a smoother rectified output. Describe briefly how this smoothing effect is created. [1, 2 marks]

Question 14

a. State **two** conditions that must be obeyed by a body to perform simple harmonic motion. [2 marks]

b. Define the terms *amplitude*, *period* and *frequency*. [3 marks]

c. Diagram (a) in Figure 11 shows a vertical spiral spring with its lower end attached to a fixed horizontal surface and its upper end carrying a platform. The force required to produce a unit compression in the spring is k. It can be assumed that the masses of the spring and the platform are negligible.

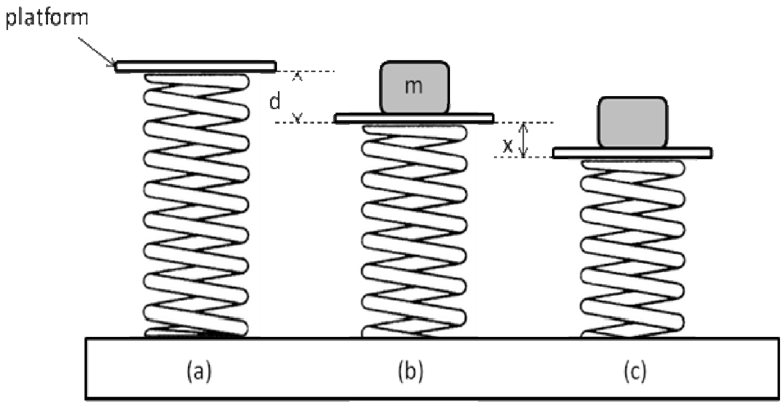

Figure 10

i. Diagram (b) in Figure 11 shows the spring system in equilibrium position when a mass m has been placed on the platform. Draw a labelled diagram showing the forces acting on the mass m and write down an equation that gives the relation between m and d. [2, 2 marks]

ii. The mass is then pushed down through a short distance x and released. Vertical oscillations take place. Diagram (c) in Figure 11 shows the mass at a distance x below its equilibrium position. Deduce an equation for the acceleration of the mass at this position and hence show that the motion of the mass is simple harmonic. [3 marks]

iii. Derive an expression for the period T of the oscillation. [3 marks]

d. Sketch **two** graphs showing how the displacement of the mass and its velocity change with time from the moment it is released. Use the same time axis for both graphs. [3 marks]

e. If $m = 5.0$ kg and $k = 1000$ N m^{-1}, calculate the maximum amplitude of the oscillation if the mass is just to remain in contact with the platform at all times. Explain carefully how you obtained your answer. [3 marks]

f. Using the same set of axes, sketch **three** energy against displacement graphs showing the variations of the kinetic energy, the potential energy and the total energy with displacement for one complete oscillation. Indicate clearly the positions of the maximum and minimum displacement. [4 marks]

Question 15

a. Explain with the aid of a ray diagram what is meant by the *principal focus* and *focal length* of a converging lens. [3 marks]

b. Outline an experiment to determine the focal length of a thin converging lens by a graphical method. Your description should include:
   i. a labelled diagram of the experimental setup; [2 marks]
   ii. a brief description of the method used; [3 marks]
   iii. the quantities to be plotted; and [2 marks]
   iv. how the graph obtained can be used to determine the focal length of the lens. [1 mark]

c. An object is placed at a distance of 25.0 cm from a converging lens of focal length 15.0 cm.
   i. Calculate the image distance and magnification produced. [2, 1 marks]
   ii. State the type of image produced. [1 mark]
   iii. If the object is moved to a distance 10.0 cm away from the lens, determine the new magnification factor produced and state the type of image produced in this case. [3 marks]

d. Draw a labelled diagram of the cross-section of a step-index fibre cable and indicate clearly the media with the larger refractive index. [2 marks]

e. Briefly describe how information is transmitted through fibre optics. Your description should outline the main steps involved in the transmission of a signal. [5 marks]

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

MATRICULATION CERTIFICATE EXAMINATION
ADVANCED LEVEL
MAY 2012

SUBJECT:	PHYSICS
PAPER NUMBER:	III – Practical
DATE:	5th June 2012
TIME:	2 hours

Experiment: Boyle's Law

Apparatus: Two supporting wooden beams, silicone pipe, 5 ml syringe, clip, 30 cm ruler, F-Clamp, stand and clamp.

Important Note: If during the experiment, the plunger should become detached from the rest of the syringe, follow this procedure to fix it back in:

- **Disconnect the syringe from the pipe.**
- **Re-insert the plunger all the way into the syringe.**
- **Re-connect the syringe to the pipe.**

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

Diagram:

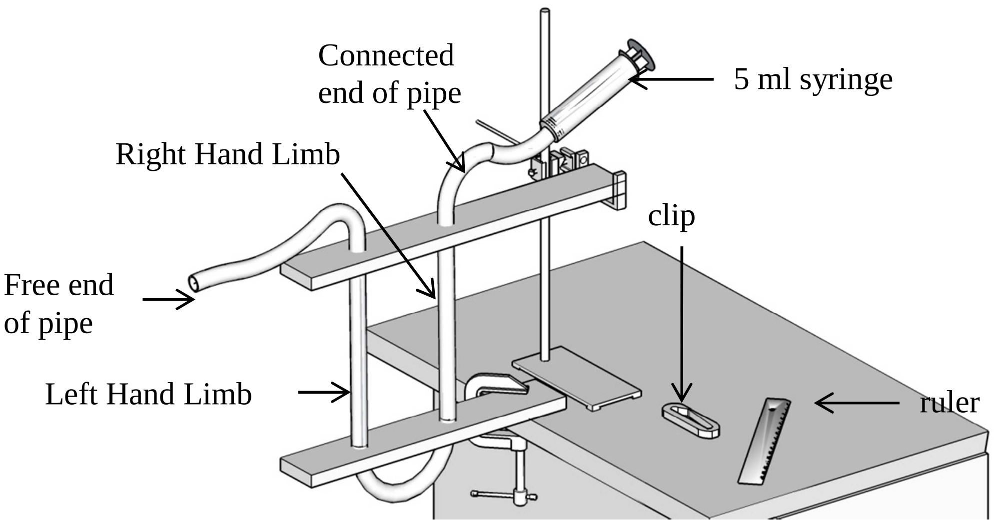

Figure 1. The experimental set-up

Method – Part I:

1. The apparatus is already set up. Check that the syringe and clip are detached from the manometer (the U-shaped pipe).

2. Push the plunger of the syringe all the way in (0 cm^3) and then connect it to the pipe extending from right hand limb of the manometer. See Figure 1.
3. The free end of the pipe extending from the left hand limb of the manometer should remain open to atmospheric pressure. See Figure 1.
4. Check that the water level in both limbs of the manometer is at the same level.
5. Start pulling out slowly the plunger of the syringe and describe briefly what happens to the water in the manometer.

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[6 marks]

6. The volume of air that fills the syringe is equal to the volume of air that is removed from the U-shaped pipe.
7. Push the plunger all the way back in.
8. Record the height of the water level on the **right hand limb that is connected to the syringe** by using the vertical ruler. Write this down in the row for x_0 in Table 1. (**Note:** The height of the water level should be taken from the lower wooden beam to the position of the water level).

[1 mark]

9. What difficulties did you encounter when measuring the height of the water level? What did you do to minimize this difficulty and to obtain a more accurate measurement.

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[4 marks]

10. For the different volume changes ΔV for the syringe given in Table 1, record the height of the water level in the right hand limb that is connected to the syringe in the column labelled x of Table 1. (Hint: for $\Delta V = 0\ cm^3, x = x_0$)

Table 1

$x_0\ /cm$		
$\Delta V\ /cm^3$	$x\ /\ cm$	$\Delta l = x - x_0\ /\ cm$
0.0		
0.4		
0.8		
1.2		
1.6		
2.0		

[8 marks]

11. It is given that $\Delta V = \pi r_p^2 \Delta l$, where r_p is the internal radius of the pipe making up the manometer and Δl is the distance travelled by the water level in the manometer.
12. Plot a graph of $\Delta V/cm^3$ on the y-axis against $\Delta l\ /cm$ on the x-axis.

[15 marks]

13. Use the gradient of the graph to determine the cross-sectional area A of the pipe in m^2 and the internal radius of the pipe in metres.

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[8 marks]

Method – Part II:

14. Disconnect the syringe from the pipe.
15. Place the free end section of pipe (see Figure 2) in between the jaws of the provided plastic clip and close the clip so as to create an air tight section of pipe.

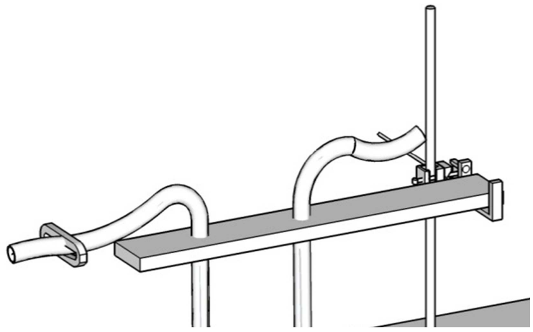

Figure 2.

16. Use the ruler to measure the length, l_1, of pipe from the water level in the left hand limb (the limb that has the clip attached to it) up to the position of the plastic clip. $l_1 =$ _______________ m.

[2 marks]

17. Again use the ruler to measure the length of pipe, l_2, from the water level on the right hand limb (the limb that was previously connected to the syringe) up to the end of pipe. $l_2 =$ _______________ m.

[2 marks]

18. Push the plunger of the syringe all the way in and connect it to the pipe extending from right hand limb of the manometer.

19. Briefly state what will happen to the pressure and volume of the air enclosed between the water and the clip if the plunger of the syringe is pulled out.

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[6 marks]

20. Using the ruler, read the position of the water level on the right hand limb connected to the syringe. $x_0 =$ _______________ m.

[1 mark]

21. For the values of the volume of the syringe given in Table 2, record the height of the water level in the right hand limb connected to the syringe in the column labelled x.

Table 2

$l_1\ /m$			
$l_2\ /m$			
$V\ /cm^3$	$V\ /m^3$	$x\ /m$	$h = x - x_0$
0	0		
0.6	0.6×10^{-6}		
1.2	1.2×10^{-6}		
1.8	1.8×10^{-6}		
2.4	2.4×10^{-6}		
3.0	3.0×10^{-6}		
3.6	3.6×10^{-6}		

[8 marks]

22. Given that the density of water is $\rho = 1000\ \mathrm{kg\ m^{-3}}$ the atmospheric pressure is approximately $P_{ATM} = 1.01 \times 10^5\ Pa$ and using the cross-sectional area of the pipe, A obtained from Part I, fill in the missing values for X, Q, S and Y in Table 3.

Table 3

$X = \dfrac{1}{\left(1 + \frac{h}{l_1}\right)}$	$Q = \dfrac{1}{\left(1 - \frac{h}{l_2} + \frac{V}{Al_2}\right)}$	$S = \dfrac{2\rho g h}{P_{ATM}}$	$Y = Q + S$

[12 marks]

23. Plot a graph of X on the x-axis against the values of Y on the y-axis.

[15 marks]

24. Find the gradient of your graph and deduce why the gradient has no units.

[8 marks]

25. Mention **any two** sources of error (can be from Part I or from Part II) and indicate clearly whether they are systematic or random errors.

[4 marks]

DO NOT WRITE ABOVE THIS LINE