MATRICULATION AND SECONDARY EDUCATION CERTIFICATE EXAMINATIONS BOARD

UNIVERSITY OF MALTA, MSIDA

MATRICULATION EXAMINATION
INTERMEDIATE LEVEL
MAY 2014

SUBJECT:	PHYSICS
DATE:	29th May 2014
TIME:	4.00 p.m. to 7.00 p.m.

A list of useful formulae and equations is provided. Take the acceleration due to gravity $g = 9.81\,m\,s^{-2}$ ***unless otherwise stated.***

SECTION A

Attempt all <u>10 questions</u> in this section. Each question carries 5 marks. This section carries 50% of the total marks for this paper.

1. The force **F** acting on two charged particles q_1 and q_2 separated by a distance r is proportional to the product of the two charges and inversely proportional to the distance of separation squared. Mathematically this is represented using the following equation: $F = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}$.

   a. Given that the units of the permittivity of free space, ε_0, are $m^{-3}\,kg^{-1}\,s^4\,A^2$, use base units to show that the equation is homogeneous.
   b. An equation can be homogeneous in terms of base units but still incorrect. Explain this statement by using an example, other than the equation shown above.

[3, 2 marks]

2. A boy is standing on a balcony 15.0 m above street level. He throws a ball vertically upwards with an initial velocity of $20.0\,m\,s^{-1}$. The ball reaches maximum height and drops to street level. Calculate:
   a. the maximum height reached by the ball above the balcony;
   b. the total time needed for the ball to reach street level;
   c. the velocity and position of the ball 3.0 s after being thrown upwards.

[1, 2, 2 marks]

3. A child's toy consists of a 100 g soft ball attached to two 10 cm long strings, A and B. The ball is made to move along a circular path in a horizontal plane, as shown in Figure 1. The strings make an angle of 30° with respect to the horizontal.
   a. Given that the tension in string B is 0.80 N, calculate the tension in string A.
   b. Calculate the linear velocity with which the ball is moving along the circular path. **[2, 3 marks]**

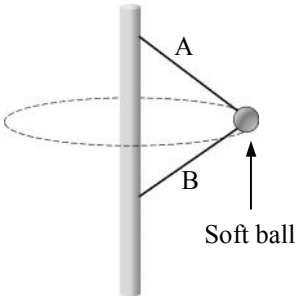

Figure 1

4. An ice cube of mass 50 g is added to 300 g of water in a polystyrene cup. The water is initially at a temperature of 25.0°C and the ice is initially at a temperature of -5°C.
   a. Calculate the final temperature of the water after the ice cube is allowed to melt.
   b. State an assumption made in your calculation to part (a).

   [3, 2 marks]

   (specific heat capacity of ice is $2108\,\text{J kg}^{-1}\,\text{K}^{-1}$, latent heat of fusion of ice is $334\,\text{kJ kg}^{-1}$, specific heat capacity of water $4187\,\text{J kg}^{-1}\text{K}^{-1}$)

5. A 65 kg bungee jumper is attached to a cord which is 26 m long. She steps off the edge of a platform which is held by a crane, 50 m above the water surface of a professional diving pool. She reaches the bottom of the jump 2 m above the surface of the water before bouncing back.
   a. Assuming that the bungee cord acts like an ideal spring once it starts to stretch, use energy considerations to find the value of the spring constant *k*, stating its units.
   b. As the jumper moves through the first oscillation and is at the lowest point of the jump, is the tension in the bungee cord equal to the jumper's weight? Explain your answer.

   [3, 2 marks]

6. a. Show that for a copper wire of cross-sectional area A, with n conduction electrons per unit volume, the current through the wire is given by the equation $I = nAve$ where v is the drift speed of the electrons and e is the electronic charge.
   b. A slice of doped semiconductor material contains 8.8×10^{22} conduction electrons per cubic metre and an insignificant number of holes. When the semiconductor strip carries a current of $140\,\mu\text{A}$, the drift speed of the electrons is $0.44\,\text{m s}^{-1}$. Given that the strip is $260\,\mu\text{m}$ wide, calculate the thickness of the strip.

   [2, 3 marks]

7. A small polystyrene ball of mass 5 g is covered with aluminum foil. The ball has a positive charge of $4.0\,\mu\text{C}$.
   a. Draw a diagram that shows the electric lines of force due the charged ball alone.
   b. The ball is now placed between two metal plates 0.04 m apart, as shown in Figure 2.
      (i) Calculate the electric field strength that would be needed to produce an electric force on the ball that balances its weight.
      (ii) If the potential difference between the plates is set at 750 V, calculate the acceleration of the ball.

      [1, 2, 2 marks]

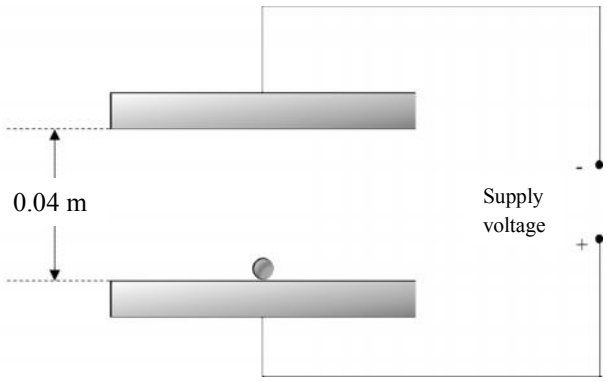

Figure 2

8. A pacemaker uses 1.0 mg of radioactive Plutonium, $^{238}_{94}\text{Pu}$, as a source of power. Plutonium decays by alpha particle emission forming Uranium, U. The half-life of Plutonium is 87.7 years. The atomic mass of plutonium is 238.0495 u and the energy of the α particles emitted is 5.6 MeV.
   a. Write down the nuclear equation that represents this decay.
   b. Show that the activity of Plutonium at the start of the decay process is 6.34×10^{8} Bq.
   c. Calculate the initial power output from radioactive Plutonium, assuming that all of the α-particle energy is used to run the pacemaker.

[1, 2, 2 marks]

9. A mass spectrometer is used to separate charged particles of different masses. The particles enter a magnetic field with the same velocity (see Figure 3).
   a. Show that the force acting on a particle carrying a charge q and entering the magnetic field region, experiences a force given by $F = Bqv$.
   b. A charged particle of mass 6.65×10^{-27} kg and carrying a charge of 3.20×10^{-19} C enters the magnetic field B of 1.5 T. Calculate the velocity with which the charge enters the field, given that it follows a circular path of radius 0.10 m when in the field.
   c. If the particle in (b) had a larger mass, would it follow a path with a larger or smaller radius of curvature when it enters the same magnetic field? Explain your answer.

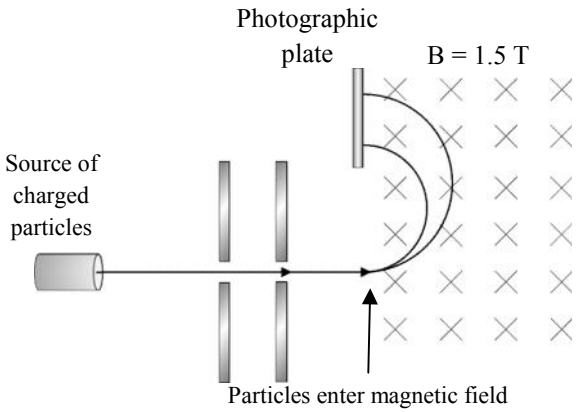

Figure 3

[2, 2, 1 mark]

10. Figure 4 shows a transverse water wave at two instances. The wave originated at the centre of a pond, moving outwards towards the edge. The solid line represents the wave at $t = 0$, and the broken line shows the wave 0.2 s later.
    a. Use the graph to calculate the speed of the wave.
    b. Determine the frequency of the wave.
    c. How many oscillations does a water particle undergo in 2 s? Explain your answer.

[2, 1, 2 marks]

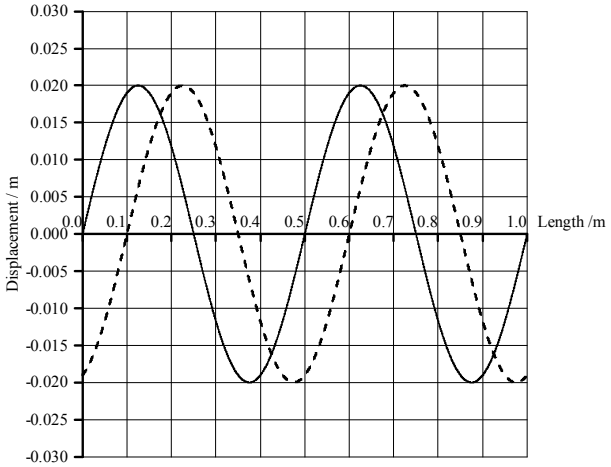

Figure 4

SECTION B

This question carries 14% of the total mark of this paper and must be attempted.

11. Figure 5 shows the setup of an experiment used to determine the acceleration due to gravity. Metal ball bearings of different sizes are placed near the edge of a smooth concave surface and then released. The diameter d of the ball bearings and the time, t_{10}, for each of the ball bearings to perform 10 oscillations are recorded.

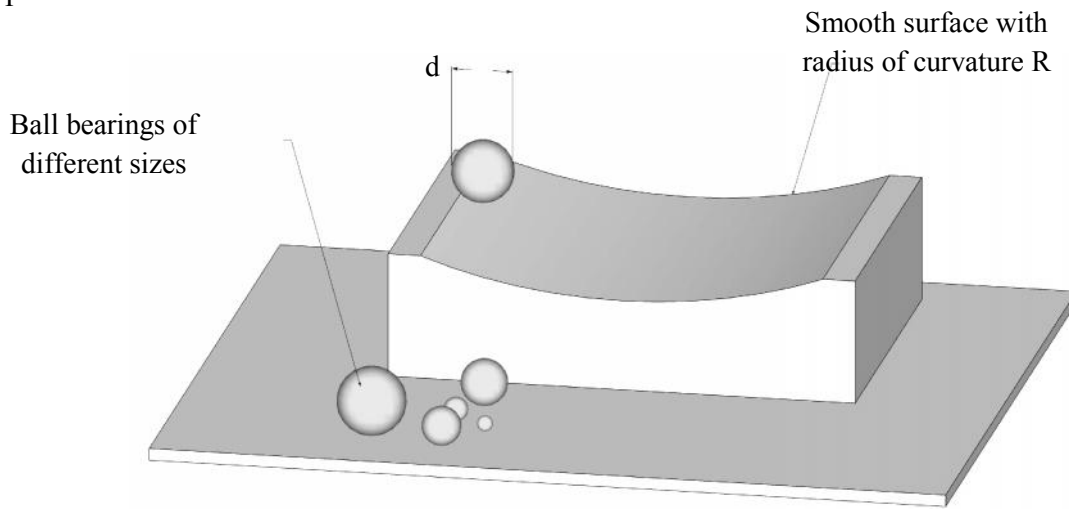

Figure 5

The equation relating the periodic time, ***T***, with the diameter d of the ball bearings is given by:

$$5T^2 = \frac{28\pi^2(R - d/2)}{g}$$

R is the radius of curvature of the smooth concave surface and is equal to 0.782 m.

d / m	t_{10} / s	$(R - \frac{d}{2})$ / m	T^2 / s^2
0.002	21.0		
0.017	20.9		
0.046	20.7		
0.075	20.5		
0.104	20.3		

Table 1

a. Copy Table 1 and fill in the missing values.

b. Plot a graph of T^2 / s^2 on the y-axis against $\left(R - \frac{d}{2}\right)$ / m on the x-axis.

c. Write the given equation in the form $y = mx + c$, clearly indicating the parts of the equation representing the gradient. Use the graph to determine the value of the acceleration due to gravity g.

d. Write down **one** precaution that should be taken during this experiment to ensure a more accurate result for g.

[5, 5, 3, 1 mark]

SECTION C

Answer any two questions from this section. Each question carries 18 marks. This section carries 36% of the total mark for this paper.

12.

a. The horizontal acceleration of an aircraft when flying at constant altitude may be found by using a piece of plasticene attached to a length of string. A physics student on an aircraft uses a ruler to determine the inclination from the vertical of a 5 cm length of string (see Figure 6).

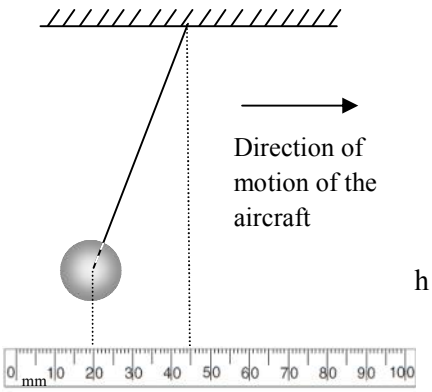

Figure 6

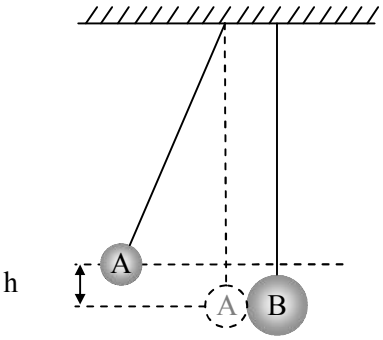

Figure 7

i. On a free body diagram, draw and label all the forces acting on the plasticene as shown in Figure 6.

[2 marks]

ii. Show that the acceleration of the airplane is given by $a = g\tan\theta$, where θ is the angle that the string makes with the vertical.

[3 marks]

iii. Use Figure 6 to calculate the horizontal acceleration of the airplane. Assume that at the altitude in which the airplane is flying the value of the acceleration due to gravity is equal to that on the surface of the Earth.

[2 marks]

b. When at home, the same student uses two pieces of plasticene, A and B, as bobs of two simple pendulii, to investigate inelastic collisions (see Figure 7). Bob A is released from a height h above its mean position, collides with bob B, and sticks to it after collision. The mass of bob A is half that of bob B.

i. Show that the velocity v_A with which bob A hits B is given by $v_A = \sqrt{2gh}$.

[3 marks]

ii. Given that bob A was released from a height $h = 0.05\,\text{m}$, calculate the velocity with which bobs A and B move off together after collision.

[3 marks]

iii. Calculate the maximum height reached by bobs A and B after collision.

[3 marks]

iv. Calculate the ratio of the kinetic energy of the two bobs after collision to the kinetic energy of A before collision.

[2 marks]

13.

a. A new company is claiming that it is able to produce smartphone touchscreen glass from sapphire that has a refractive index of 1.77. In an experiment using sapphire glass, a ray of light from a laser is directed on the glass as shown in Figure 8. Light emitted from a laser is ***monochromatic***.

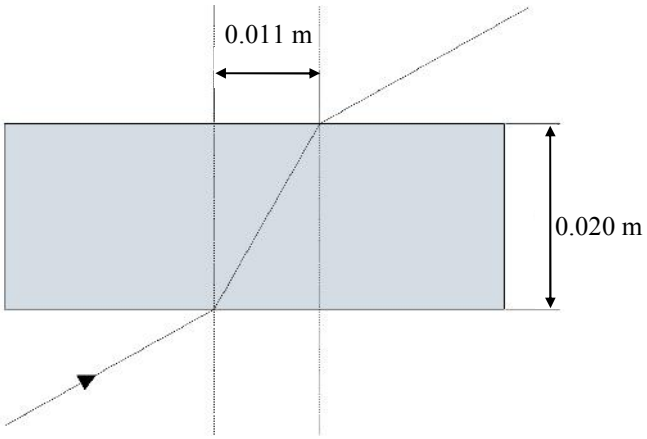

Figure 8

i. Give the meaning of the term ***monochromatic***.

[2 mark]

ii. If the incident light used were <u>not</u> monochromatic, what difference would this have on the refracted and emergent rays? Assume that the incident ray still hits the glass at the same angle of incidence, as shown in Figure 8.

[3 marks]

iii. Use the data in Figure 8 to calculate the angle that the incident ray makes with the normal.

[3 marks]

iv. Calculate the critical angle for the saphire glass – air boundary.

[2 marks]

b. A small pin that is used to secure the leather band to a wrist watch is held 4.5 cm under a magnifying glass. The pin is 15 mm high and the image produced is 60 mm high.

i. Draw a ray diagram to represent the arrangement of the lens, pin and its image. Clearly indicate the position of the object, image and focal points of the lens.

[3 marks]

ii. Is the image produced real or virtual?

[1 mark]

iii. Calculate the magnification of the lens in this configuration.

[1 marks]

iv. Calculate the focal length of the lens.

[3 marks]

14.

a. Describe an experiment which may be used to determine whether a filament lamp obeys Ohm's law. In your description include:
   i. a labelled diagram of the circuit used;
   ii. an explanation of how the experiment is carried out, describing the measurements that need to be taken;
   iii. a sketch of the graph expected to be obtained from the readings, explaining whether the lamp obeys Ohm's law or not;
   iv. one precaution that needs to be taken during the experiment, other than taking repeated readings.

[2, 2, 2, 1 mark]

b. Eight batteries, each having an e.m.f. of 1.50 V and an internal resistance of $0.10\,\Omega$, are connected in series. Calculate the maximum current that results in this circuit arrangement.

[2 marks]

c. A student sets up the circuit shown in Figure 9. A 12 V battery that has an internal resistance of $1\,\Omega$ is used.

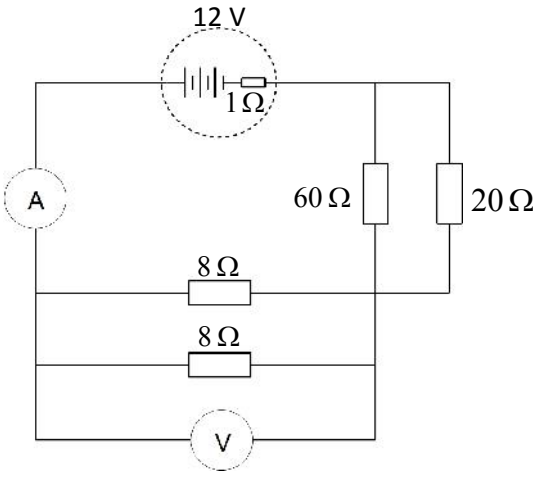

Figure 9

i. Calculate the total resistance of the circuit.

[3 marks]

ii. Find the current which passes through the ammeter.

[1 mark]

iii. Calculate the potential difference across the $8\,\Omega$ resistors.

[2 marks]

iv. Determine the total power dissipated as heat in the $8\,\Omega$ resistors.

[2 marks]

v. Determine the power delivered by the 12 V cell.

[1 mark]

15.

a. Lead acid batteries that are typically used in cars can store about 2.74×10^{5} C of electric charge. The potential difference between the terminals of a car battery is 12 V.

i. Determine the capacitance of a capacitor that can store a charge of 2.74×10^{5} C when the potential difference across it is 12 V. **[2 marks]**

ii. If this capacitor is a parallel-plate capacitor having square plates separated by a layer of air, 1.0 mm thick, determine the length of the sides of the plates.
(relative permittivity of air = 1.00) **[2 marks]**

iii. Would the capacitor described in part (ii) be a likely replacement of the car battery? Explain your answer.

[2 marks]

b. A variable capacitor consists of two parallel semicircular plates. One plate is fixed while the other can be rotated (see Figure 10). Air fills the area between the plates and the electric field can be assumed to be zero everywhere except in the region where the plates overlap each other. The radius of the semicircular plates is 0.007 m and the plates are 0.001 m apart.

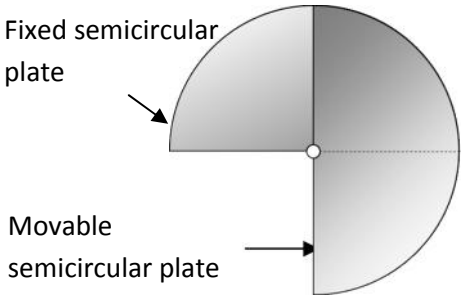

Figure 10

i. Calculate the capacitance of the capacitor when the two plates fully overlap each other.

[2 marks]

ii. Determine the capacitance of the capacitor when the movable plate is rotated such that only one half of its area covers the stationary plate.

[2 marks]

iii. Some models of this variable capacitor use also a moveable dielectric material to change the capacitance. How will the capacitance of a capacitor be affected when a dielectric is inserted between the metal plates? Explain your answer.

[2 marks]

c. A capacitor with a capacitance of 10×10^{-6} F is connected in series with a 12 V battery, a 470 kΩ resistor and a switch. The switch is closed and the capacitor starts charging.

i. Sketch a graph that shows how the voltage across the capacitor changes with time during the charging process, indicating the maximum voltage reached.

[2 marks]

ii. Calculate the time constant of the circuit.

[1 mark]

iii. Calculate the voltage on the capacitor, 9.4 s after the switch is closed.

[3 marks]