SURNAME:_________________________ **INITIALS**________

STUDENT NUMBER:___________________________________

Marks

Q1		
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Q4		
Q5		
		100

UNIVERSITY OF JOHANNESBURG

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

MODULE: **PHY1B01**

CAMPUS **APK**

EXAM **10 November 2014**

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DURATION 150 min **MARKS 100**

INSTRUCTIONS: Answer ALL questions IN THE SPACES PROVIDED
THIS PAPER CONSISTS OF 16 PAGES INCLUDING THIS ONE.

Question 1 [20]

1.1) Three point charges are located at the corners of an equilateral triangle as in Figure 1. Calculate the net electric force on the 7.00-μC charge. (8)

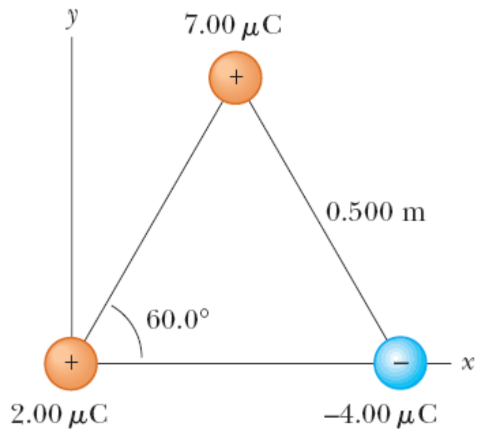


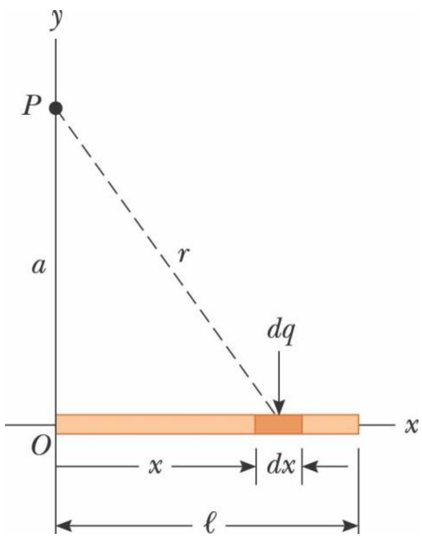
Figure 1

1.2) Gauss's law states that $\Phi_E = \oint \boldsymbol{E} \cdot \boldsymbol{dA} = \frac{q_{in}}{\epsilon_0}$. Explain the physical significance of this law. (3)

1.3) If a potential of 2.20 kV is measured on an equipotential surface with radius 14.3 m, surrounding a point charge, what must the magnitude of the point charge be? (3)

1.4) A rod of length ℓ, is placed along the x axis, with one end of the rod at the origin of the x-y frame. The rod has a total charge Q and a uniform linear charge density λ. Find the electric potential at a point P located on the y axis, a distance a from the origin.

Hint: $\int \frac{dx}{\sqrt{a^2+x^2}} = \ln\left(x+\sqrt{x^2+a^2}\right)$ (6)



Question 2 [19]

2.1) A capacitor is connected to a 12-V battery. If the plate separation is tripled and the capacitor remains connected to the battery, by what factor does the charge on the capacitor change? (3)

2.2) A parallel plate capacitor is constructed from two metal plates, each with an area *A,* and separated by a distance $d \ll A^{1/2}$. Derive an expression for the capacitance of this device given that the electric field produced by a uniformly charged plate is everywhere perpendicular to the plate and has a magnitude

$$E = \frac{\sigma}{2\epsilon_0}$$

at a small distance away from the plate. (5)

2.3) Filaments in light bulbs usually fail just after the bulbs are turned on rather than when they have already been on for a while. Why? (2)

2.4) In a simple circuit, a battery is connected in series to an Ohmic resistor R. The battery has an EMF $\mathcal{E}$ and internal resistance r.

2.4.1) Use energy considerations to derive an expression for the power output of the battery in terms of $\mathcal{E}, R$ and, assuming that a current I flows through the circuit. (4)

2.4.2) If the internal resistance of the battery is negligible, will the power output of the battery increase if the value of R is increased? Explain your answer. (2)

2.5) Use Kirchhoff's loop theorem to explain why a 60 W light bulb produces more light than one rated at 100 W when they are connected in series to a 120 V source. [*Hint*: Recall that the power ratings are meaningful only at 120 V.] (3)

Question 3 [20]

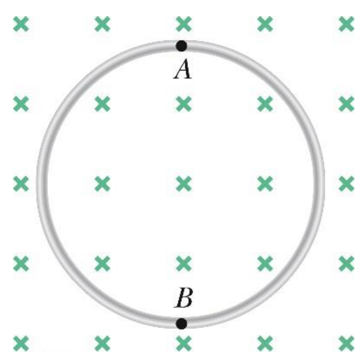
3.1) What is a *velocity selector*? Explain how the combination of a magnetic field and an electric field can be used to construct a velocity selector. You must derive the equation for the particle velocity. (5)

3.2) A rectangular coil of dimensions 5.00 cm × 8.00 cm consists of 35 turns of wire and carries a current of 17.0 mA. A 1.350 T magnetic field is applied parallel to the plane of the coil. Calculate the magnetic dipole moment of the coil. (4)

3.3) Derive Ampere's law. (4)

3.4) State Gauss' law in magnetism, and explain why the magnetic flux through any closed surface is always zero. (3)

3.5) A circular loop of wire of radius 15.0 cm is placed in a magnetic field directed perpendicular to the plane of the loop, as shown in the accompanying figure. If the field decreases at the rate of 0.060 T/s in some time interval, find the magnitude of the emf induced in the loop during this interval. (4)



Question 4 [20]

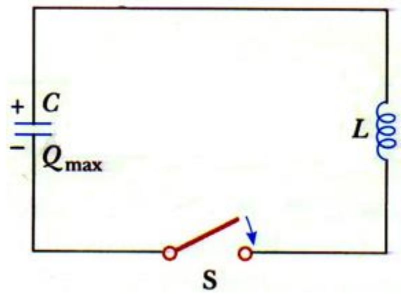
4.1) Consider a uniformly wound solenoid having N turns and length ℓ. Assume that the length ℓ is much longer than the radius of the windings and the core of the solenoid is air. Given: $\mu_0 = 4 \times 10^{-7}$ T.m/A. Explain all your steps in the following.

4.1.1) What can you say about the magnetic field outside the solenoid? (2)

4.1.2) Derive an expression for the inductance L of this solenoid, in terms of N, ℓ and the radius of the solenoid. (3)

4.1.3) Now that you have your expression for L, calculate the self-induced emf in the solenoid if the current is increasing at a rate of 30 A/s. Let $N = 400$, $\ell = 1$ m and let the turns of the solenoid be circular with a radius of 1 cm. (4)

4.2) Consider the circuit, shown in the accompanying figure, consisting only of a capacitor, with capacitance C, and an inductor, with inductance L. Assume that at the initial time t = 0, the capacitor is fully charged and the magnitude of charge on each plate is Q_{max}. Ignore all kinds of resistance in the circuit.



4.2.1) Write down an expression for the total energy contained in the circuit under these circumstances, and state how this total energy changes with time.
(2)

4.2.2) Now derive the equation describing the charge Q on the capacitor plates as a function of time. Explain all your steps. Hint: Your equation should contain derivatives of Q with respect to time. (4)

4.2.3) From your equation, write down the angular frequency for $Q(t)$. (1)

4.2.4) The solution to your equation should be $Q(t) = A\cos(\omega t)$, where A is a constant. How is A related to the charge on the capacitor plates? (1)

4.3) From two of Maxwell's equations, one is able to derive wave equations for the electric field **E** *and* for the magnetic field **B** respectively. These two wave equations are:

$$\frac{\partial^2 E}{\partial x^2} = \mu_0 \epsilon_0 \frac{\partial^2 E}{\partial t^2} \qquad and \qquad \frac{\partial^2 B}{\partial x^2} = \mu_0 \epsilon_0 \frac{\partial^2 B}{\partial t^2}$$

Calculate the speed at which these electromagnetic waves propagate and state Maxwell's prediction that united electromagnetism and the theory of light.
Given: $\varepsilon_0 = 8.8542 \times 10^{-12}$ $C^2/N.m^2$ (3)

Question 5 [21]

5.1) State Snell's law of refraction. (1)

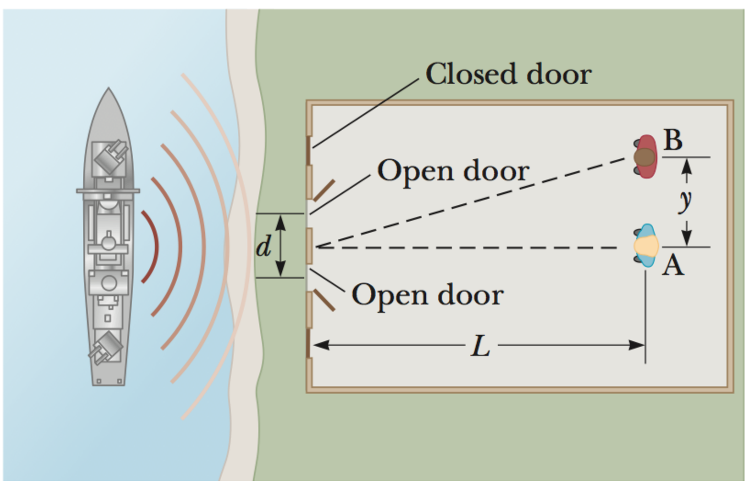
5.2) Use this law to derive an expression for the critical angle for total internal reflection for light travelling in a transparent block with a refractive index larger than the surrounding medium. (3)

5.3) A simple hand-held magnifying lens has a focal length of 5.00 cm.

5.3.1) To obtain maximum magnification and an image that can be seen clearly by a normal eye, where should the object be placed? (3)
(Take the near point of the eye as 25 cm.)

5.3.2) What is the magnification when the object is placed there? (3)

5.4) A riverside warehouse has several small doors facing the river. Two of these doors are open as shown in the figure below. The walls of the warehouse are lined with sound-absorbing material. Two people stand at a distance L = 150 m from the wall with the open doors. Person A stands along a line passing through the midpoint between the open doors, and person B stands a distance y = 20 m to his side. A boat on the river sounds its horn. To person A, the sound is loud and clear. To person B, the sound is barely audible. The principal wavelength of the sound waves is 3.00 m. Assuming person B is at the position of the first minimum, determine the distance d between the doors, centre to centre. (6)



5.5) A laser produces a beam a few millimetres wide, with uniform intensity across its width. A hair is stretched vertically across the front of the laser to cross the beam. How could you determine the width of the hair from measurements of its diffraction pattern? (5)