UNIVERSITY OF RUHUNA

BACHELOR OF SCIENCE (GENERAL) DEGREE LEVEL I (SEMESTER II) EXAMINATION – JANUARY 2018

SUBJECT: PHYSICS

COURSE UNIT: PHY1214 **TIME: 2 hours & 30 minutes**

PART II

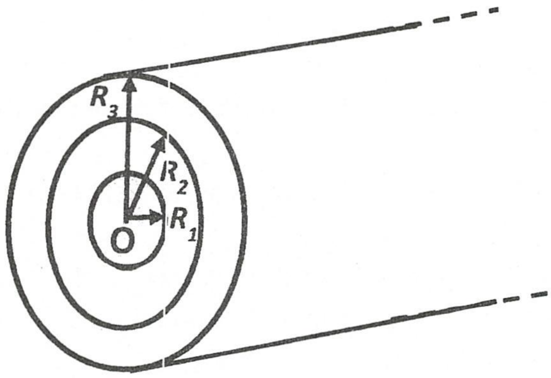
Answer FIVE (05) Questions only

All symbols have their usual meaning.

$\mu_0 = 4\pi\times10^{-7}\ \mathrm{Hm^{-1}}$, $\varepsilon_0 = 8.85\times10^{-12}\ \mathrm{C^2N^{-1}m^{-2}}$, $k = \dfrac{1}{4\pi\varepsilon_0}$

1. a) State Gauss's law in electrostatics in words and represent it in mathematical form. [03 marks]

   b) An infinitely long non-conducting cylinder of radius R_1 is uniformly charged with a volume charge density ρ. It is surrounded by a concentric non-conducting cylindrical tube of inner radius $R_2 = 2R_1$ and outer radius $R_3 = 3R_1$ as shown in the figure below. It also carries a uniform charge density ρ.



(i) Determine electric field, E as a function of distance, r from the center O, for each of the following positions of r.

(i) $0 < r < R_1$

(ii) $R_1 < r < R_2$

(iii) $R_2 < r < R_3$

(iv) $r > R_3$

[10 marks]

(ii) Show how electric field varies with r using a sketch. [05 marks]

(iii) Suppose that the outer cylindrical tube is removed. Assume that the volume charge density of the cylinder varies with radius, r as $\rho = \rho_0\left(a - \dfrac{r}{b}\right)$, where ρ_0, a and b are positive constants. Determine the magnitudes of the electric field at $r < R_1$ and $r > R_1$.

[07 marks]

2. a) Derive an expression for the capacitance for a parallel plate capacitor of plate area A and separation d.
[05 marks]

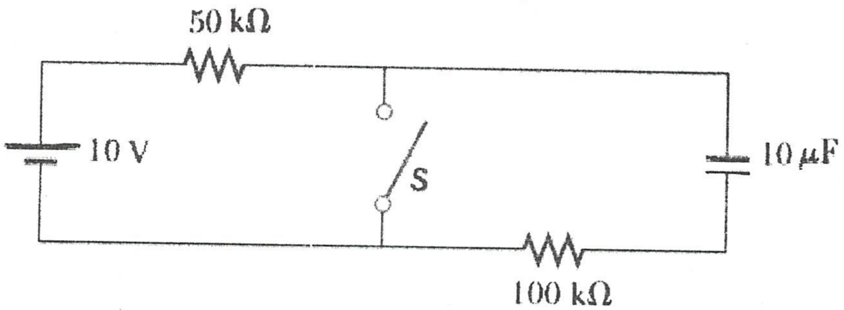
b) A parallel plate capacitor has a plate separation d and plate area A. An uncharged metallic slab of thickness a ($a < d$) is inserted exactly midway between the plates.

(i) Find the capacitance of the device after the slab is inserted. [04 marks]

(ii) Show that the capacitance of the original capacitor is unaffected by the insertion of the metallic slab, if the slab is infinitesimally thin. [02 marks]

(iii) If a charge q is maintained on plates, how much work has to be done on the slab for it to be inserted? Does the slab get sucked inside or does it have to be pushed inside?
[05 marks]

c) In the circuit below, the switch S had been open for a long time. Then it was closed.



(i) Find time constants before and after the switch is closed. [03 marks]

(ii) If the switch is closed at time $t = 0$, find the current in the switch as a function of time.
[06 marks]

3. a) State Ampere's Law in magnetism in words and represent it in mathematical form.
[03 marks]

b) A long, straight wire of radius R carries a steady current I that is uniformly distributed through the cross section of the wire.

(i) Using the Ampere's law, obtain expressions for the magnetic field at a distance r from the center of the wire in the regions $r > R$ and $r < R$. [07 marks]

(ii) Sketch your results against r. [03 marks]

c) A long wire, P, placed on the X-axis caries a current of 30 A in the negative X-direction. A second long wire, Q, placed parallel to P at y = 0.4 m carries a current of 50 A in the positive X-direction.

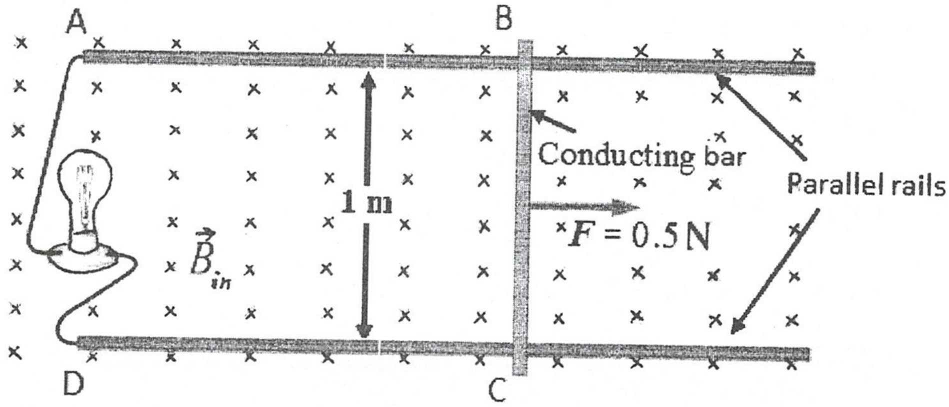
(i) Find the location in the plane of the two wires where the total magnetic field equals zero.
[06 marks]

(ii) Assume that a particle with a charge -2 μC is moving with a velocity of 150×10^6 ms^{-1} parallel to wires in the positive X-diraction along the line y = 0.2 m. Calculate the vector magnetic force acting on the particle.
[04 marks]

(iii)A uniform electric field is applied to allow this particle to pass through this region undeflected. Calculate the required vector electric field. [02 marks]

4. a) Write down Faraday's law of electromagnetic induction in mathematical form defining all terms. [03 marks]

b) Consider the apparatus shown in the figure below in which a conducting bar (BC) is allowed to move along two parallel rails connected to a light bulb. The whole system is placed in a magnetic field ($\vec{B}_{in}$) of 0.5 T. The vertical distance between the horizontal rails is 1 m. The resistance of the light bulb is 50 Ω. The bar and rails have negligible resistance. The bar is moved toward the right by a constant force (F) of magnitude 0.5 N.



(i) What is the direction of the induced current in the circuit? [01 mark]

(ii) If the instantaneous speed of the bar is 15 m/s, find the instantaneous induced current. [03 marks]

(iii) Argue that the constant force causes the speed of the bar to increase and approach a certain terminal speed. Find the value of this maximum speed. [06 marks]

(iv) Find the power delivered to the light bulb when the bar is moving at its terminal speed. [02-marks]

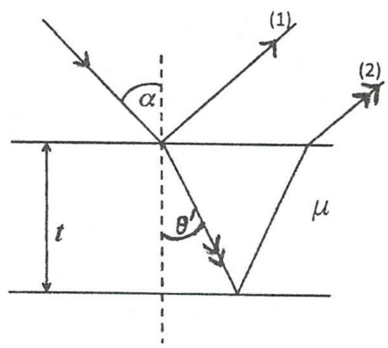
(v) Find the mechanical power delivered by the force F when the bar is moving at its terminal speed. [02-marks]

(vi) Explain the relationship between quantities computed in parts (iv) and (v). [02-marks]

(vii) Suppose that there is no applied force F acting on the bar. The bar is given an initial velocity $\vec{v}_i$ to the right at time $t = 0$. If the bar has mass m, find the velocity of the bar as a function of time. [06-marks]

5. Light of wavelength λ is incident on to a uniform thin glass plate of refractive index μ and thickness t as shown in the enlarged sketch. The thin plate is surrounded by air. The total phase difference between reflected rays (1) and (2) is given by $\delta = \left(\frac{4\pi t}{\lambda}\sqrt{\mu^2 - \sin^2\alpha}\right) - \pi$.

(note: derivation is not required)



a) Using the given expression for δ, show that the corresponding path difference is $\Delta p = 2\mu t\cos\theta' - \dfrac{\lambda}{2}$. [08-marks]

b) Write down conditions needed for Δp to produce

(i) constructive interference

(ii) destructive interference

of rays (1) and (2). Further, write down the corresponding orders (m) in each case. [10-marks]

c) If the refractive index, $\mu = 1.5$ and $\theta' = 30$ degrees, what is the minimum value of t, for which there will be destructive interference of rays (1) and (2) if incident wavelength is 300 nm ? [07-marks]

6. a) (i) Use the grating equation to show that the highest order of principal maxima is $m = \dfrac{d}{\lambda}$ for a given grating. [04-marks]

(ii) Monochromatic light of wavelength 500 nm falls normal on to a transmission grating with 1200 lines/mm. Find angles, θ, of **possible** principal maximas. [06-marks]

b) An **unpolarized** beam of natural light with intensiy I_0 is incident normal on to three different stacks of perfect linear polarizers as described below.

(i) A stack consists of two polarizers with axis of the second one is placed at an angle 60° to the first one which is infront. Find the intensity of the beam that leaves the stack. [04-marks]

(ii) A stack consists of three polarizers with axis of second making an angle 30° to the first one and the 3rd making an angle 30° to the axis of the second. Find the intensity of the beam that leaves the stack. [05-marks]

(iii) Similarly, a stack consists of 101 polarizers, with axis of each one making an angle of 0.01 *radians* to the axis of the one in front. Find the intensity of the beam that leaves the stack. If θ is a very small radian value, assume that $\cos^2\theta \approx 1-\theta^2$ and $(1-x)^N \approx 1 - Nx \text{ when } -1 \le x \le 1$. [06-marks]

(note : Intensity of an ***unpolarized*** light is reduced by 50% after transmitting through a polarizer)