NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

FACULTY OF SCIENCE AND TECHNOLOGY EDUCATION

DEPARTMENT OF SCIENCE, MATHEMATICS AND TECHNOLOGY EDUCATION

PST 6173 ELECTRICITY AND MAGNETISM 5

NOVEMBER 2024 EXAMINATION

This Examination Paper consists of 4 printed pages

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Time Allowed:	3 hours
Total Marks:	100
Special Requirements:	None Internal
Examiner:	Mrs. N. Moyo
External Examiner:	Dr N. Zezekwa

INSTRUCTION

1. This paper consists of **6** questions.

2. Answer **any 5** questions from this question paper.

3. Begin each full question on a new page.

4. Show all your working steps clearly in any calculation.

MARK ALLOCATION

QUESTION	MARKS
First question	20
Second question	20
Third question	20
Fourth question	20
Fith question	20
TOTAL	100

1. (a) What is the relationship between the electric field and the electric potential? [1]
   (b) Consider the diagram below showing a series of equipotential curves.
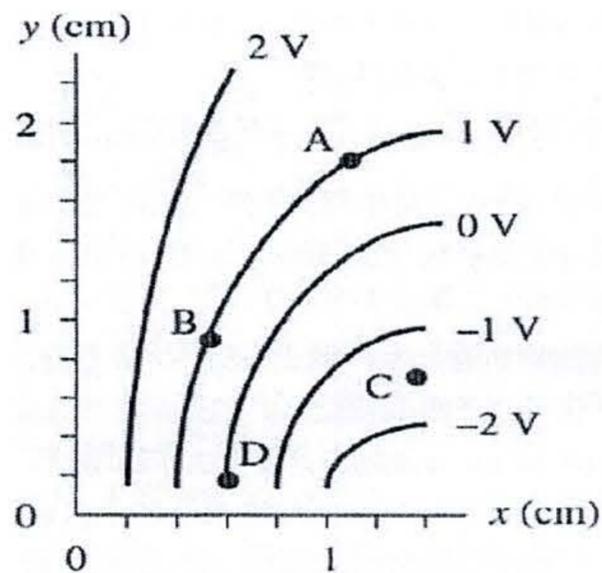
   (i) Is the electric field strength at a point A larger, smaller, or equal to the field strength at point B? Briefly explain. [2]

   (ii) Is the electric field strength at point C larger, smaller or equal to the field strength at point D, briefly explain. [2]

   (iii) Draw a field line passing through point B. Be sure to extend your field line through all five equipotential curves and clearly indicate the direction of the field. [2]

   (iv) From the information in the figure, determine the electric field, **E**, at a point D. [3]

2. (a) A hollow spherical shell carries charge density $\rho = \dfrac{k}{r^2}$ in the region $a \leq r \leq b$. By drawing the diagram of the situation and indicating the regions, find the electric field in the three regions.
   (i) $r < a$ [3]
   (ii) $a < r < b$ [6]
   (iii) $r > b$ [4]
   (iv) Plot E as a function of r. [3]

   (b) What are the boundary conditions of **E** and **D**. Give one example of their application. [4]

3. (a) Describe the energy relationships between an inductor and a capacitor in an L-C circuit. [6]

   (b) The space between the plates of a parallel –plate capacitor is filled with two slabs of linear di-electric material. Each slab has thickness a, so the total distance between the plates is 2a. Slab 1 has a di-electric constant of 2, and slab 2 has a di-electric constant of 1.5. The free charge density on the top of the plate is σ and on the bottom of the plate is $-\sigma$.
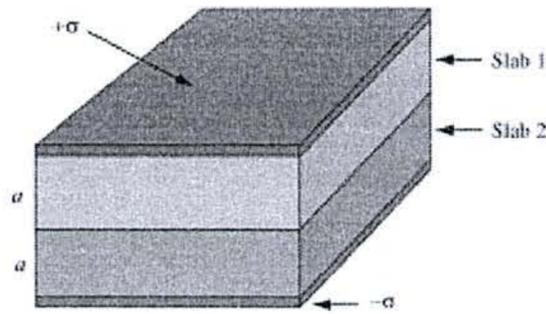
(i) Find the electric displacement D in each slab. [2]
(ii) Find the electric field E in each slab. [2]
(iii) Find the polarization, P in each slab. [4]
(iv) Find the potential difference between the plates. [4]
(v) Find the location and the amount of all the bound charge. [2]

4. (a) The diagram below fig 4.1 shows a metal road of radius r_1 which is concentric with a metal cylindrical shell of radius r_2 and length. The space road and cylinder is tightly packed with a high resistance material of resistivity, ρ. A battery having a terminal voltage v is connected as shown.
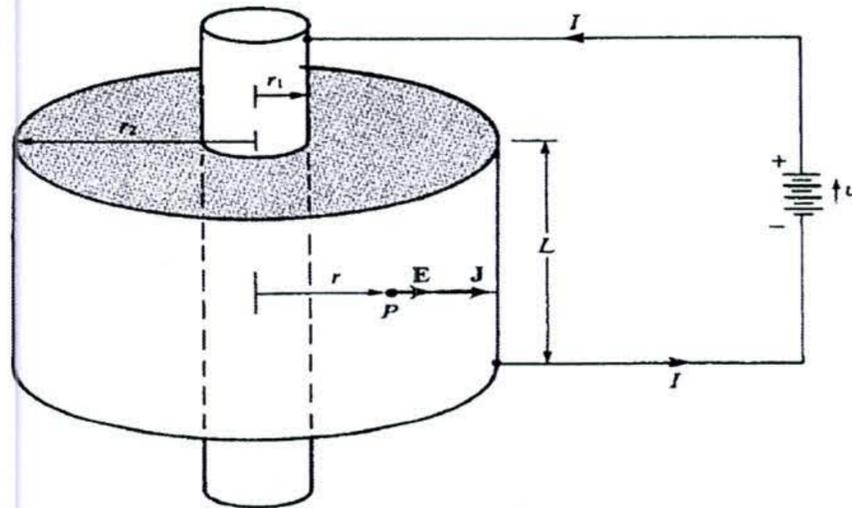

Fig 4.1

Neglecting the resistances of rod and cylinder, derive expressions for:
(i) The total current I, [3]
(ii) The current density J and the electric field **E** and point P between the rod and the cylinder. [6]
(iii) The resistance R between the rod and the cylinder. [3]
(iv) How is current and current density related.
(v) why is the information on current density useful to electrical engineers? [2]

(b) Define the impedance in an R-L-C circuit in terms of *rms* voltage and current, hence show the phase angle between the voltage and the current is given by

$$\tan \emptyset = \frac{X_L - X_C}{R}$$ [6]

5. (a) Gauss's law in magnetism states that ''the net magnetic flux through any closed surface is always zero'' in symbols: $\oint B . d\vec{A} = 0$. Write this law using vector analysis notation. What is the physical interpretation of such a result? [4]

(b) Starting from the integral form of Faraday's law: $\varepsilon = \frac{d\Phi}{dt}$, Apply Strokes' law

theorem and write it in the differential form in terms of the curl of the electric field.

[4]

(c) Starting from the integral form of Gauss's law: $\oint_s E.da = \frac{1}{\varepsilon_0} Q$, Apply the Gauss's law theorem and write it in the differential form in terms of the divergence of the electric field.

[4]

(d) Starting from the integral form of Ampere's law: $\oint B. dl = \mu_0 I_{enc}$. Apply Strokes' law theorem and write it in differential form in terms of curl of the magnetic field.

[4]

(e) Show that the magnetic field of a steady line current is given by:

$$\mathbf{B(r)} = \frac{\mu_0}{4\pi} \int \frac{\mathbf{I} \times \hat{\imath}}{\imath^2} dl' = \frac{\mu_0}{4\pi} I \int \frac{d\mathbf{l'} \times \hat{\imath}}{\imath^2}.$$

[4]

What law is represented by this above.

6. (a) A metal bar of mass m slides frictionlessly on two parallel conducting rails a distance ℓ. A resistor is connected across the rails at one end on the left while the metal bar slides away from it towards the right. The uniform magnetic field is pointing into the page, and fills the entire region.

   (i) If the bar moves with speed v, what is the current in the resistor and in what direction does it flow?

[3]

   (ii) Show that the kinetic energy delivered to the resistor is exactly $\frac{1}{2}mv_0^2$.

[3]

(b) What is the fundamental course of electromagnetic radiation?

[2]

(c) (i) What is a pointing vector, $\bar{S}$ in electromagnetic radiation? Show that $\bar{S}$ is given by

$$\bar{S} = \frac{c}{4\pi} E \times \bar{B}$$

[4]

   (ii) Carryout a dimensional analysis to prove that the units of $\bar{S}$ are of intensity,

[3]

(d) Calculate B, H, and M in a system like an electromagnet with an air-gap. Consider a number of turns, some steady current, I circulating in a magnetic linear material with relative permeability, μr.

[5]

END OF PAPER