

Unique Paper Code : **32221201**
 Name of Paper : **Electricity and Magnetism**
 Name of Course : **B.Sc. (Hons) Physics**
 Semester : **II**

Duration: **3 Hours**

Maximum Marks: **75**

(Write your Roll No. on the top immediately on receipt of this question paper)

Question No. 1 is compulsory

Answer any **four** of the remaining six, attempting any **two** parts from each question.

1. Attempt **all** parts of this question.

(i) Suppose the electric field in some region is found to be, $\vec{E} = kr^3\hat{r}$ in spherical coordinates where, k is a constant with appropriate units.

(a) Find the charge density.

(b) Find the total charge contained in a sphere of radius R centered at the origin. 3

(ii) What is the physical significance of $\vec{\nabla} \cdot \vec{B} = 0$? 1

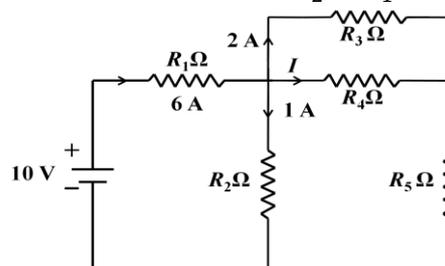
(iii) The plates of a parallel-plate capacitor are arranged so that the distance between them can be varied. When the distance between them is d , the capacitor is charged until the difference of potential is V . The plates are then separated until the distance between them is $2d$. Assuming that the charge Q on the plates is unchanged, determine the difference of potential between the plates of this capacitor. 3

(iv) A sphere of radius R has magnetization $\vec{M} = a\hat{k}(\hat{k} \cdot \vec{r})^2$, where \hat{k} a unit is vector along the z -direction, and a is a constant with appropriate units. Find,

(a) The bound volume current density in the sphere.

(b) The bound surface current density on the sphere. 3

(v) For the circuit given below, find I and calculate R_2 if $R_1 = 1\Omega$. 3



(vi) Identify which one of the following is an impossible electrostatic field. Give reason.

(a) $\vec{E} = k[xy\hat{i} + 2yz\hat{j} + 3xz\hat{k}]$

(b) $\vec{E} = k[y^2\hat{i} + (2xy + z^2)\hat{j} + 2yz\hat{k}]$

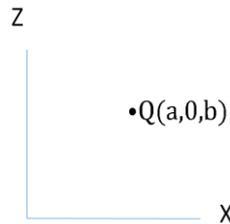
Here, k is a constant with appropriate units.

3

(vii) Find the resonance frequency, bandwidth and quality factor of a series LCR circuit having, $C = 0.1\mu F$, $L = 0.16 H$ and $R = 10\Omega$. 3

2. (a) Find the electric field at a distance s from an infinitely long straight wire which carries a uniform line charge λ . 7

(b) A point charge Q is located at point $(a,0,b)$ between two semi-infinite grounded conducting planes intersecting at right angles as shown in the figure. Find potential difference at a point (x,y,z) in the region $z \geq 0$ and $x \geq 0$ and force on Q .



(c) An infinite plane slab of thickness $2d$ lies in the $x - z$ plane. It carries a uniform volume charge density ρ . Find the electric field as a function of y , where $y = 0$ at the centre. Plot \vec{E} as function of y , taking \vec{E} as positive along $+y$ direction. 5, 2

3. (a) State and prove the second Uniqueness theorem. 2,5

(b) The total charge within a sphere of radius ' r ' is given by $q \frac{r^2}{a^2} (e^{-r/a} - e^{-2r/a})$, where ' q ' and ' a ' are constants. Determine the corresponding electric field, potential and the charge density. 7

(c) Suppose the electric potential is given by the following expression.

$$V(r, \theta, \phi) = \frac{V_o}{2} \left(3 - \frac{r^2}{R^2} \right); \quad r < R$$

$$= \frac{V_o R}{r} \quad ; \quad r > R$$

for all r where V_o and R are constants. Find the corresponding electric field distribution and to what charge distribution would this correspond? 4, 3

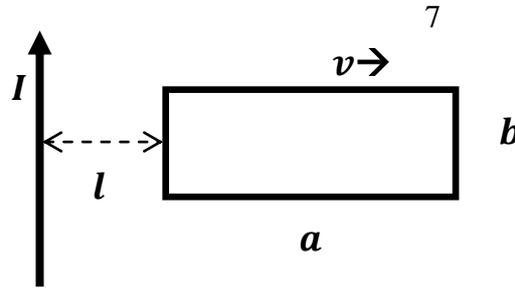
4. (a) Consider two infinite intersecting, conducting planes $x = 0$ and $y = 0$. A charge of $100 nC$ is placed at $(3,4,0)$. Find the electric potential and electric field at $(3,5,0)$. 4,3

(b) Show that the potential energy of a system of charges can be calculated from electric field by assigning an amount of energy $\frac{1}{2} \epsilon_0 E^2 d\tau$ to every volume element $d\tau$ and integrating over the entire space. 7

(c) Four point charges $q, 2q, 3q$ and $4q$ are placed at the corners of a square with side $\sqrt{2} m$. Calculate the electric potential and the electric field at centre of the square. 4, 3

5. (a) For a dielectric medium, derive a relation between electric displacement \vec{D} , electric field \vec{E} and polarization density \vec{P} . 3, 2, 2

(b) A current I flows through a long straight filamentary wire. A conducting rectangular loop of side, a and b , is placed at a distance l from the wire. The loop is moving with a velocity v in the direction as shown in diagram. Calculate the magnitude of e.m.f induced in the loop after a time t .



(c) A parallel-plate capacitor is filled with a non-uniform dielectric, such that the relative permittivity is given by,

$$\epsilon_r = \epsilon_0 + \alpha x$$

Here, α is a constant having units of (1/length) and x is distance from one plate. Assume that area of the plates is A and separation between them is d . What is the capacitance of the capacitor?

6. (a) Obtain the differential and integral form of Ampere's Circuital Law for an arbitrary current density \vec{j} .

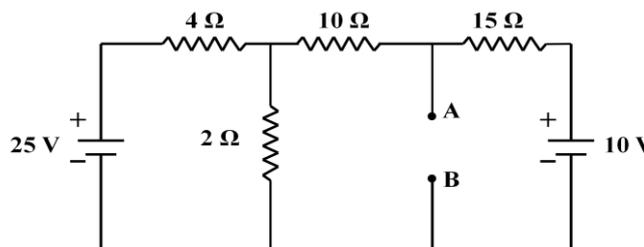
(b) A deuteron is travelling in a straight line along the x -direction with a speed 2×10^7 m/s. It enters a region of uniform magnetic field of strength 0.2 T along the z -direction. How much will be its displacement in the y -direction from the original position after it has travelled a distance of 1.0 cm in the x -direction? After how much time will the particle's velocity be instantaneously in the y -direction?

(c) A very long air core solenoid of radius b has n turns per unit length and carries a current $i = i_0 \sin \omega t$.

- (i) Write an expression for the magnetic field inside the solenoid as a function of time.
- (ii) Assuming the magnetic field to be zero outside, write an expression for the electric field inside and outside the solenoid as a function of time.

7. (a) Derive an expression for the resonance frequency of a series LCR circuit. How can we increase the quality factor of a series LCR circuit without changing its resonance frequency? Explain.

(b) State and prove the Thevenin theorem. Obtain the Thevenin equivalent for the circuit given below.



(c) A series LCR circuit has $R = 4\Omega$, $L = 0.5H$ and $V = 100 \cos \pi t$. Find the value of C for resonance. Also determine the voltage across C . Plot the variation of quality factor with resistance for a series LCR circuit.

3, 2, 2