CC-3 (Electricity & Magnetism)

Electrostatics

<u>Short type questions:</u>

1. What is the superposition principle in electrostatics?
2. How can you express a point charge using the Dirac delta function?

3. What are the dimensions of E in terms of the fundamental quantities M, L, T and I?
4. Obtain Coulomb's law from Gauss's theorem.

5. Can an electrostatic field have the form $\vec{E} = a(y\hat{i} - x\hat{j})$, where a is a constant?
6. The electric field $\vec{E}$ in the (x-y) plane is given by $\vec{E} = 2ax\,\hat{x} + by\,\hat{y}$. What is the charge density responsible for this field?
7. Find the force exerted on an electric dipole of moment $\vec{p}$ placed in a nonuniform electric field $\vec{E}$.

<u>Long type questions:</u>

1.(a) Define Electric field E at a point and show that curl **E**= 0. (b) Show that the electrostatic field is conservative.

2. State and prove Gauss's theorem in electrostatics. Apply this theorem to calculate the electric field due to a (i) uniformly charged sphere and (ii) uniformly charged infinite cylinder.

3. (a) What is the differential form of Gauss's law? (b) Apply Gauss's law to calculate the electric field in the case of a charged infinite plane.

4. (a) What do you mean by electrostatic potential and equipotential surfaces? (b) Express the electrostatic potential in terms of the fundamental dimensions (M,L,T,I).

5. (a) What is an electric dipole? Calculate the electric field in free space due to a dipole. (b) Determine the potential energy of a dipole in an external electric field. (c) Calculate also the torque on the dipole in a uniform electric field.

6. (a) Show that the charge resides on the outer surfaces of a charged conductor.
(b) Prove that the electric field just outside a charged conductor is perpendicular to its surface. Also determine the magnitude of this field.

7. If a total charge Q is uniformly distributed throughout the volume of a sphere of radius a, what would be the electric field at a distance r from the centre of the sphere?

8. Using Gauss's law in electrostatics, determine the electric field at a distance r from a straight infinitely long wire having a charge λ per unit length.

9. A spherical shell of inner radius r_1 and outer radius r_2 is uniformly charged with charge density ρ. Calculate the electric field and potential at a distance r from the centre of the spherical shell for $r > r_2$, (ii) $r_1 \leq r \leq r_2$, and (iii) $r \leq r_1$.

10. A thin circular ring of radius R carries a uniform surface charge density σ. Calculate the electric potential and field at a point on the axis of the ring. An electron of mass m and charge e oscillates along the axis of a large circular ring of radius R carrying a uniformly distributed charge Q. Show that the angular frequency of oscillation of the electron is $\omega = \left(\frac{eQ}{4\pi\epsilon_0 m R^3} \right)^{1/2}$

III. Numerical problems:

1. Two particles, each of mass m and carrying charge q, are suspended by strings of length l from a common point. If θ is the angle that each string makes with vertical and g is the acceleration due to gravity, show that $16\pi\varepsilon_0 mgl^2 \sin^3\theta = q^2 \cos\theta$.

2. Point charges of 3, -6√2, and 3 Coulombs are placed respectively at the three corners A, B and C of a square ABCD of side length 2 cm. Find the electric field at the point D.

3. A charge q is distributed uniformly over the surface of a thin circular insulating disc of radius 'a '. Find the potential at a point on the rim of the disc.

4. A straight wire segment AB of length 'a' carries a uniform line charge of density λ per unit length. Determine the electrostatic potential and field at a point lying on the perpendicular bisector of AB at a distance z from it.

5. The potential in a medium is given by $\Phi(r) = \frac{q}{4\pi\varepsilon_0} \frac{e^{-r/\lambda}}{r}$. Obtain the corresponding electric field and charge density. (b) Also calculate the total charge.

6. Calculate the force per unit area of a conductor carrying a surface density 2.5 nano coulomb per cm^2 of electric charge. What is the direction of this force?

Magnetostatics, Electromagnetic Induction, Alternating Current

Short type questions:

1. Compare the magnetic field due to a current element and electric field due to a point charge.
2. Why magnetic force acting on a charged particle is no-work force?
3. Show qualitatively that two parallel currents attract each other and two anti-parallel current repel each other.
4. Find the units and dimensions of permeability of free space.
5. Explain what happen when a moving charged particle enters a uniform magnetic field (I) at right angle to the magnetic field, (ii) making an angle with the magnetic field.
6. What is the essential difference between electric field lines and magnetic field lines?
7. Suppose $\vec{A}$ and $\vec{A}'$ are the vector potentials representing the same magnetic field $\vec{B}$. Explain how it can be possible.
8. Explain in which condition magnetic vector potential may be related to current density as $\nabla^2 \vec{A} = -\mu_0 \vec{J}$
9. Why all materials should show some kind of response to an applied magnetic field?

10. Which are two current densities by which a magnetized material may be replaced, so far as the field produced by it is concerned? What is the difference, if any, of these current densities with familiar current densities?
11. Define magnetic susceptibility, absolute permeability, and relative permeability of a material.
12. Why diamagnetism is a general property all materials?
13. Draw M-H curve and B-H curve for diamagnetic and paramagnetic substances and discuss about the slope of these curves.
14. How susceptibilities of diamagnetic and paramagnetic substances change with temperature?
15. What magnetic saturation, retentivity and coercivity of a ferromagnetic material?
16. What is the work done to drive a ferromagnetic material once through a hysteresis loop? What happens to this energy?
17. What is Curie temperature of a ferromagnetic material? What happens when a ferromagnetic material crosses its Curie point? Why it is called phase transition?
18. Explain how hysteresis loops of ferromagnetic materials are useful to choose the right material for different practical uses of them.
19. According to Newton's second law current should grow with time under the action of a given field. Then how Ohm's law is valid which suggests that a constant field produces a constant current. Discuss briefly.
20. What is electromotive force? In case of motional emf who supplies the the energy to do work?
21. What will happen if you place a metal ring on the top of a solenoidal coil around an iron core and pass current through it?
22. What difference will you observe when a cylindrical bar magnet and an identical piece of unmagnetised iron are dropped down through a vertical aluminum pipe of slightly bigger diameter?
23. Why we often see a spark when high current carrying electrical appliance is suddenly unplugged?
24. Is there any difference between induced electric field and the electric field produced by a static charge?
25. How are non inductive coils are prepared? Discuss the principle underlining it.
26. The self inductance of a circuit is analogous to inertia of an inert body. Explain.
27. Explain the terms power factor and wattless current in connection with ac circuits.
28. The equation of current in an a.c. circuit is $i=50\sin(400\pi t)$. What is the rms current and frequency?
29. Define the terms reactance and impedance in an ac circuit.
30. Explain physically why the reactance of an inductor increases and that of a capacitor decreases with the increase in frequency.
31. What are current and voltage resonances?
32. Why a series LCR circuit is called an acceptor circuit?
33. Why a parallel LCR circuit is called a rejector circuit?

Long type questions:

1. Derive an expression for the magnetic field intensity at a point on the axis of a circular coil of wire carrying electric current.
2. In the case of a long solenoid, prove that the intensity of magnetic field at a point well inside the solenoid is double that at any end.
3. What is Ampere's circuital theorem. Explain it. Use the theorem to find the magnetic induction (I) inside (ii) on the surface and (iii) at any point outside a long straight current carrying conductor.Starting from Biot-Savart's law deduce the magnetic field at point due to straight conductor carrying steady current. What would be the field if the conductor is infinitely long?
4. Find the force of interaction between two straight wires carrying parallel and anti-parallel currents. Define the unit of current from the result.

5. Illustrate the nature of the hysteresis loop of a sample of steel and that of a soft iron piece. Indicate from these how the two materials differ in their magnetic behaviours.
6. If μ_r and K be the relative permeability and susceptibility of a magnetic specimen show that $\mu_r = 1 + K$
7. State Faraday's law of electromagnetic induction. Express it in integral and differential forms. What is Lenz's law?
8. Find an expression for emf induced in a vertical loop of wire placed in horizontal magnetic field and rotating with constant angular velocity about a vertical axis.
9. What do you mean by Self and mutual inductances? Self inductances of two coils are L_1 and L_2 respectively and their mutual inductance is M. Show from energy consideration that in general $M^2 \leq L_1 L_2$. What is coefficient of coupling k of two magnetically coupled coils? Explain in which conditions the two coils have k=0, k<1 and k=1.
10. Derive Neumann's formula for mutual inductance between two arbitrary loops. From the result prove the reciprocity theorem in mutual inductance.
11. Calculate the self inductance of (I) solenoid, (ii) toroid, (iii) two parallel wires. Find the mutual inductance of two co-axial coils.
12. Find the equivalent inductance of two magnetically coupled coils when these are joined in (I) series and (ii) parallel.
13. Starting from the energy stored in the magnetic field of a coil carrying current, derive the energy per unit volume in a magnetic field.
14. Distinguish between the mean value and root-mean-square (rms) value of a sinusoidal emf and obtain expression for them. What is the advantage of mentioning rms value of current or voltage.
15. Show that the current through a pure inductor lags by 90˚ behind the impressed ac emf and that through a pure capacitor leads by 90˚ over it.
What is a choke? 'A choke is more economical than a resistor' - explain the statement.
16. A sinusoidal emf is applied to circuit containing an inductor, a capacitor and a resistor in series. Derive an expression for the instantaneous current and power factor. Show that the power is dissipated only in the resistance.
17. A sinusoidal voltage $v = V_0 \cos(\omega t)$ is applied to a series LCR circuit. (a) How do the rms value of current and its phase vary with ω ? Under what condition does the voltage lead the current? (b) Find the value of ω at which power consumed by the circuit becomes maximum. (c) Find the two half power frequencies and hence, Q of the circuit. (d) Explain the term sharpness of resonance. How can it be achieved?
18. A sinusoidal voltage $v = V_0 \cos(\omega t)$ is applied across a circuit where a capacitor is connected in parallel to a inductor and a resistor connected in series. (a) Find an expression of the impedance of the circuit. If the resistance is negligible then find the condition when no current will flow through the circuit. (b) What do you mean Q of the circuit? Find the Q value as a current magnification factor.
19. Show that the maximum potential across the condenser of a series resonant circuit occurs at the frequency $\omega = \omega_0 \left[1 - \frac{1}{2Q_0^2}\right]^{\frac{1}{2}}$ and the maximum potential across the inductance occurs at $\omega = \omega_0 \left[1 - \frac{1}{2Q_0^2}\right]^{-\frac{1}{2}}$