Five Year Integrated M.Sc. Examination, 2024
Semester - III
Code: PH-2-3-1

Time: Three Hours | Subject: Electricity and Magnetism | Full Marks: 60

Questions are of values as indicated in the margin
Answer question number **one** and any **three** from the rest

1. Answer any **eight** questions

$8 \times 3 = 24$

(a) A particle moves in a circular path of radius r in the xy-plane with a constant angular speed $\omega = d\theta/dt$. Write down the position vector $\vec{r}(t)$ and calculate the velocity ($\vec{v}$) of a point, P on the circumference of the circle in polar coordinates.

(b) Draw the field lines and equipotential surfaces for an electric dipole i.e. a system of $+q$ and $-q$ charges separated at a distance d.

(c) If no work can be done on a charged particle by the magnetic field, how can the motion of the particle be influenced by the presence of a field? Explain.

(d) If a current is passed through a spring, does the spring stretch or compress? Explain.

(e) Check whether $\vec{B} = x^2y\hat{i} + 3yz^2\hat{j} - (2xyz + z^3)\hat{k}$ can represent a magnetic field or not ?

(f) Show that the electric field $\vec{E}$ is discontinuous at a surface which carries charge density σ.

(g) Calculate the force per unit length between two infinite straight wires separated by distance d and carrying current I and $-I$, respectively. Does the force depend on the current direction?

(h) Show that magnetic forces do no work.

(i) A metal disk of radius a rotates with angular velocity ω about a vertical axis, through a uniform magnetic field B, pointing up. A circuit is made by connecting one end of a resistor (R) to the axle and the other end to a sliding contact, which touches the outer edge of the disk. Find the current in the resistor.

(j) Four equal charges, q, are situated on each corner of a square of side-length a. What is the net force on a test charge Q at the centre?

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2. (a) State Stoke's theorem, and give its geometrical interpretation.

   (b) Calculate magnetic field due to an infinite solenoid currying steady current I by using Ampere's law. Explain why some of the components of the magnetic field are zero?

   (c) Using Gauss's divergence theorem evaluate surface integral $\int\int \vec{A}.d\vec{s}$, where $\vec{A} = x\cos^2 y\,\hat{i} + zx\,\hat{j} + z\sin^2 y\,\hat{k}$ over the surface of a sphere with centre at the origin, and of radius 5 unit.

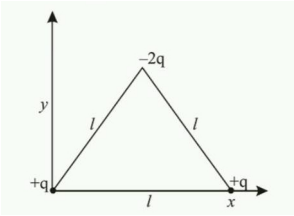
3+(2+3)+4=12

3. (a) Consider a system of N discrete charges with magnitudes $q_1, q_2, \ldots, q_N$ located at $\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N$ respectively. Show that the potential energy of this system is

$$U = \frac{1}{2}\sum_{i=1}^{N} q_i V(r_i)\,,$$

   where $V(r_i)$ is the electrostatic potential at $\vec{r}_i$ (location of q_i) due to all the charges.

   (b) Determine the monopole moment and dipole moment of the system of three charges, placed on the vertices of an equilateral triangle, as shown in the Figure:



   (c) Suppose a charge Q is distributed within a sphere of radius R in such a way that the charge density $\rho(r)$ at a distance r from the centre of the sphere is $\rho(r) = Kr$.

   i. Determine constant K in terms of Q and R.

   ii. Calculate the electric field at any point **inside** the sphere.

   iii. Calculate the electric field at any point **outside** the sphere.

3+4+(1+2+2)=12

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4. (a) Explain the limitations of Ampere's law with the help of capacitor charging experiment. Derive the expression for displacement current.

   (b) Show that the rate of change of work done by the electromagnetic field on a charge distribution confined within a volume V is given by

$$\frac{dW}{dt} = -\frac{d}{dt}\int_V \frac{1}{2}\left(\epsilon_0 E^2 + \frac{1}{\mu_0}B^2\right) d\tau - \frac{1}{\mu_0}\oint_S (\vec{E}\times\vec{B}).d\vec{a},$$

   where S is the surface bounding V. $\vec{E}$ and $\vec{B}$ are electric and magnetic field respectively.

   (c) What is the physical significance of Poynting vector?

(2+2)+6+2=12

5. (a) Starting from the Maxwell's equations prove that the electromagnetic fields satisfy wave equations in vacuum.

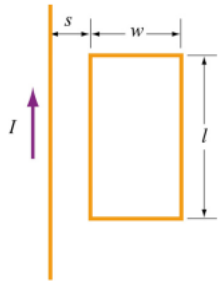
   (b) Suppose the electric field of a plane electromagnetic wave is given by

$$\vec{E}(x,t) = E_0 \sin(kx - \omega t)\hat{j}.$$

      i. Find the corresponding Magnetic field $\vec{B}(x,t)$.
      ii. Find the direction of wave propagation.

   (c) What is the physical reason for generation of Eddy current inside a conductor? How can one reduce the Eddy current?

   (d) An infinite straight wire carries a current I is placed to the left of a rectangular loop of wire with width w and length l, as shown in the figure below. Determine the magnetic flux through the rectangular loop due to the current I.



4+(2+1)+2+3=12