Indian Association for the Cultivation of Science
(Deemed to be university under the *de novo* category)

Integrated BSMS Program

Mid-Semester Examination-2025 (Spring Semester 2-BSMS)

Subject: Electricity, Magnetism and Optics | **Subject Code(s): PHS 1201**
Full Marks: 25 | **Time Allotted: 2hr**

Answer Q1 and any four questions from the remaining six.

1. *Answer each part of this question as precisely and briefly as you can.*

   (a) If light were made up of Newtonian 'corpuscles' weighing about as much as sand grains, we know that our retinas would be punctured, rendering us blind ? Why does this not happen with light waves ?

   (b) If starlight is largely made up of plane EM waves with constant amplitudes independent of distance, and the energy of light is proportional to $|\vec{A}|^2$, how does one explain the huge observed difference in intensity between sunlight and light from Alpha Centauri ?

   (c) When a light wave falls on our retina, electro-chemical signals are generated in the rods and cones which are transmitted via the optic nerve to the brane. Now these rods and cones are electrically neutral, i.e., have no free charges. So why should they respond to the incoming light wave ?

   (d) We have often seen birds standing with both their feet on a high-voltage transmission line, without getting electrocuted. However, if I try to touch a high-voltage line with my feet on the ground, something disastrous will happen. Why this difference ?

   (e) An electron in a long vacuum tube moves with a uniform velocity. A plane EM wave propagating in an unknown direction, crosses the tube. It is observed that the motion of the electron is unaffected. Can you deduce the possible directions of propagation of the plane EM wave ? It is useful to think of the magnetic 'potential' energy of the electron to answer this question.

[**5** × **1**]

2. A plane wave solution of the source-free (homogeneous) Maxwell wave equations including the transversality condition, is given by the form

$$\vec{A} = \Re[\vec{A}_0 \exp i(\omega t - \vec{k}\cdot\vec{r})]$$

Using the definitions $\vec{E} = -(\partial \vec{A}/\partial t) - \nabla\phi$, $\vec{B} = \nabla \times \vec{A}$ show that

$$\begin{aligned} \vec{E} &= \Re[\vec{E}_0 \exp i(\omega t - \vec{k}\cdot\vec{r})] \\ \vec{B} &= \Re[\vec{B}_0 \exp i(\omega t - \vec{k}\cdot\vec{r})] \end{aligned}$$

Determine the explicit forms of the amplitude vectors $\vec{E}_0, \vec{B}_0$ in terms of $\vec{k}, c, \vec{A}_0$. Determine the inter-relationship between the magnitudes and directions of the amplitude vectors $\vec{E}_0$ and $\vec{B}_0$? **[1+2+2]**

3. A charged parallel plate capacitor C with circular plates of radius a and separation d, containing air as dielectric, initially charged to a steady voltage V_0, is discharging through a resistor R. Ignoring edge effects, compute the induced magnetic field halfway between the plates at a radial distance $b < a$, in magnitude and direction. What is the physical consequence of the time-dependence of this magnetic field ? **[4+1]**

4. A stopwatch with a time period T has a metal arm of length r, which rotates radially on a circular clockface of diameter $2r$. Electrodes are attached to the ends of the arm and connected to a resistance R. The stopwatch is placed within the poles of a large magnet such that a uniform magnetic field of magnitude B intersects the clockface normally. What is the current flowing through R ? **[5]**

5. Maxwell's wave equations are given by

$$\begin{aligned} \Box^2\phi &= \frac{\rho}{\epsilon_0} \\ \Box^2\vec{A} &= \frac{\vec{j}}{\epsilon_0 c^2} \\ \frac{1}{c^2}\frac{\partial\phi}{\partial t} + \nabla\cdot\vec{A} &= 0 \end{aligned}$$

Derive the long-time averaged form of these equations, appropriate to stationary EM. **[5]**

6. A tunable AC voltage source $V(t) = \Re[V_0 \exp i\omega t]$ is connected in series to a series circuit consisting of a resistor of resistance R, an inductor of inductance L and a capacitor of capacitance C. At what frequency $\omega = \omega_0$ does the impedance reduce to a purely resistive with no reactance ? Draw the current-voltage phasor diagrams for (a) $\omega > \omega_0$ and (b) $\omega < \omega_0$. **[3+2]**

7. If you look at the sun through a pair of polaroid lenses, one placed behind the other, you can rotate them relative to each other such that all the light from the sun is blocked. Which of the Maxwell wave equations would you trace this observational phenomenon to ? Explain why this happens, as quantitatively as you can, without doing long derivations. **[5]**