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

Integrated BSMS Program

Mid-Semester Examination-2023 (Spring Semester-UG II)

Subject: Electricity, Magnetism and Optics
Full Marks: 25

Subject Code(s): PHS 1201
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) Sitting in the examination hall, you cannot see anything on the other side of the walls of the room. Would you then conclude that EM waves, in general, do not travel through the walls ? Why ?

   (b) Does your sensation of feeling hot on a summer's day have anything to do with electricity and magnetism ? Briefly explain the reason for your answer.

   (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 (chargeless). So why should they respond to the incoming light wave ?

   (d) Your mobile phones work on EM signals in the microwave range (wavelength 0.02 - 1 m). If you wanted to design a mobile phone which works instead on EM signals in the range of visible light (wavelength $10^{-8} - 10^{-6}$ m), would expect your phones to be bigger or smaller ? Why ?

   (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]

$Q = Q(0)\, e^{-\frac{t}{RC}}$

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

$$\vec{A} = \Re[\vec{A}_0 \exp i(\omega t - \vec{k}\cdot\vec{r})] \ , \ \vec{e}_k \cdot \vec{A}_0 = 0$$

Using the definitions $\vec{E} = -(\partial \vec{A}/\partial t)$, $\vec{B} = \nabla \times \vec{A}$ 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 with circular plates of radius a and separation d, containing air as dielectric, initially charged to a voltage V_0 is discharging through a resistor R. Ignoring edge effects, compute the magnetic field between the plates at a radial distance $b < a$, in magnitude and direction. [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. ~~T~~wo long parallel wires carrying steady currents I_1 and I_2 in the same direction, are initially situated a distance d apart. If the magnetic attraction between the wires is to be balanced by an electrostatic repulsion due to coating the insulation of the wires with electric charges smeared uniformly all along their length, what is the ~~ratio~~ product of the charge densities per unit length that must be used ? Ignore any interaction between the fixed charges and the currents. [5]

6. A positive and a negative point charge, both of magnitude q, are separated by a distance r_0. If a negative charge $-Q$ is to be placed along a direction of θ to the line connecting the charges q and $-q$, at a distance r from the mid-point of this line, what is the potential energy of this system ? Is the force on $-Q$ towards the pair of equal charges or away from them ? [3+2]

7. ~~T~~wo capacitors with capacitances C_1, C_2 are initially charged, having charges q_1, q_2 respectively. Show that, except in special situations, if the capacitors are connected in parallel, the stored electrostatic energy decreases. Where does the lost energy appear ? Find the conditions under which they can be joined without loss of energy ?

$\Gamma_{\vec{B}} = \frac{1}{c^2}\frac{\partial \Phi_E}{\partial t}$

$\oint \vec{B}\, d\vec{l} = \frac{1}{c^2}\frac{\partial}{\partial t}\oint \vec{E}\cdot da$

$\vec{B} \int d\vec{l}$

$\vec{B} + 2\pi a^2 = \frac{1}{c^2}\frac{Q}{\epsilon_0 d}\frac{\partial}{\partial t}\oint da$