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

Integrated BSMS Program

End-Semester Examination-2024 (Spring Semester-UG II)

Subject: Electricity, Magnetism and Optics | Subject Code(s): PHS 1201
Full Marks: 50 | Time Allotted: 3hr

Attempt any <u>five</u> questions

1. *This question is about Electromagnetic waves*

   (a) Starting with the homogeneous waves equation for the scalar and the vector potentials and the transversality condition, and using the definitions of the electric and magnetic fields in terms of the potentials, show that the electric and magnetic fields must also obey the homogeneous wave equation. [**5**]

   (b) If stars in the sky all emitted plane EM waves, would you expect the night sky to be dark like it is, or would we have been dazzled by extremely bright starlight ? Why ? Can you guess how the amplitude of the vector potential solution of the wave equations has to be modified, so that the night sky is dark as it is observed to be ? [**2+3**]

2. *This question is about electrodynamics*

   (a) 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. What is the voltage across the capacitor, t seconds after it starts discharging ? Ignoring edge effects, compute the magnetic field in magnitude and direction, between the plates, at a radial distance a from an imaginary line joining the centres of the plates, t seconds after the capacitor starts discharging. [**2+3**]

   (b) 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**]

3. This question is about an electrical circuit with a mechanical analogy.

   (a) A capacitor C, charged initially to a voltage V_0 is connected to an inductor L in series. Write down the differential equations relating the time-dependent voltages $V_C(t)$ and $V_L(t)$, across C and L respectively, to the common current $I(t)$ flowing through them. Also relate V_C and V_L using Kirchoff's voltage rule. [2]

   (b) Eliminate $I(t)$ from these equations and obtain a second order linear differential equation for $V_C(t)$. Give a mechanical analogy of this equation, mentioning precisely what is anlogous to what. [2]

   (c) Use the mechanical analogy to solve for the voltage $V_C(t)$, using the initial data provided in part (a). Calculate $I(t)$ from $V_C(t)$ and sketch both $I(t)$ and $V_C(t)$ on the same plot as a function of time. [1+1+2]

   (d) Show that the magnetic energy in L and the electrical energy in C add up to a time-independent constant at every instant of time. [2]

4. This question is about stationary electromagnetism.

   (a) Two 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 of the charge densities per unit length that must be used ? Ignore any interaction between the fixed charges and the currents. [3]

   (b) Charges $\pm q$ are placed at the ends of a straight line of length r_0. Another charge, $-Q$ is placed on the perpendicular bisector of the joining line, at a distance of y from the mid-point of the joining line. What is the potential energy of the system ? What is the net force on $-q$ in magnitude and direction ? [2+1]

   (c) The electric potential on the walls of an empty room is ϕ_0. Suppose there are two solutions $\phi_1(\vec{r})$ and $\phi_2(\vec{r})$ of the Laplace equation which have the same value ϕ_0 on the walls. Is $\phi_1 = \phi_2$ everywhere inside the room ? Why ? [1+3]

5. (a) Find out the intensity due to Fraunhofer diffraction from a double slit. Hence determine the maxima, minima and missing orders associated with the pattern on the screen. [7]

   (b) Consider an elliptically polarized light incident normally on a quarter wave-plate (this just introduces a phase shift of $(\pi/2)$ for any light passing through its pass axis). Find the state of polarization of the transmitted light if the major axis of the ellipse makes an angle $30°$ with the pass axis of the wave plate. [3]

6. Solve the following two problems:

   (a) A double slit with a separation of 0.250 mm between centres is illuminated with green light of wavelength 570 nm from a cadmium-arc lamp. How far behind the slits must one go to measure the fringe separation and find it to be 0.80 mm between centres? If we decrease the separation between the slits by (1/2), how much does the fringe separation increase? What happens if we double the separation between the slits? [5]

(b) Calculate the ratio of spontaneous emission rate to the stimulated emission rate at $T = 10^3$ K for visible light of frequency 5×10^{14} Hz and microwave of frequency 10^9 Hz. Thus comment on the result. [5]

7. (a) Derive the ratio of the intensity of incident and transmitted light through a Fabry-Perot interferometer. What parameters does this ratio depend on? [7]

   (b) Describe the Llyod's mirror and how it produces interference pattern. What is the nature of the central fringe in this case? [3]