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

Integrated BSMS Program

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

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

Answer Q1 and any four other questions from the remaining six.

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

   (a) A compass needle anywhere on the earth's surface, say in Kolkata in particular appears to point north. Suppose one digs a hole at the Kolkata latitude into the earth's core and a compass is somehow transported to a place close to the earth's axis. In which direction should the compass needle point in this place ? Why ?

   (b) After a short shower, walking on a street you often notice small puddles near the sidewalk where cars may have been parked, from which the reflected light comes out in various colours. What optical phenomenon do you think produces these colours ? Why ?

   (c) In shallow pools in forests, fish swimming just below the surface of water are often seen to jump up in air to catch insects sitting on low branches of trees hovering above the surface. Do the fish, in general, estimate the vertical height of the insect to be lower or higher than the actual height ? Why ?

   (d) Old-fashioned transistor radios used to have telescoping long antennas, If an EM wave travels along such a long antenna, do you expect your radio to receive a signal ? Why ?

   (e) If a surface is made up of molecules which are all spherical, can such a surface reflect EM waves ? Why ?

   [5 × 2]

2. This question is about an electrical circuit and it's mechanical analogue .

(a) Consider a simple circuit in which an inductance L is connected to a capacitance C through a switch. Intially, the switch is in the 'off' position, and the capacitance is charged to a voltage V_0. Then the switch is turned on, connecting L and C in series. Show that the voltage across C , $V_C(t)$ obeys a linear, homogeneous, second order ordinary differential equation.

(b) Drawing an analogy with a known mechanical system, and using the solution of differential equation for that system, write down the solution for $V_C(t)$. Hence obtain the current $I(t)$ flowing through the circuit.

(c) Show that the total EM energy in the circuit is a constant independent of time. [3+2+2+3]

3. This question is about interference.

(a) Consider the interference pattern due to a Lloyd's mirror, where the source is placed at a vertical distance $r/2$ from the mirror, and a horizontal distance l from the screen. Determine the spacing between the 5th and 6th minima in terms of the given dimensions of the Lloyd's mirror, and the wavelength of the light used. Is the spacing larger for red light or for violet light ? [4+1]

(b) The radius of the nth circular maxima in a typical Newton's ring experiment obeys the formula $r_n^2 = \lambda R(2n \pm 1)$, where R is the radius of curvature of the lens and λ is the wavelength. If $n >> 1$, how does the radial spacing between successive maxima depend on n ? [5]

4. This question is about confocal hyperboloids describing interference maxima (specified by integer n), given by

$$(n\lambda)^{-2}y_n^2 - (d^2 - n^2\lambda^2)^{-1}(x_n^2 + z_n^2) = \frac{1}{4}$$

(a) What approximations must we apply to this formula such that the interference fringe pattern for a Fresnel biprism can be derived from it ? [5]

(b) LIGO, where gravitational waves were directly detected for the first time, uses Michelson interferometers for their observations. What sort of fringe patterns derived from the hyperboloid equation would one expect to observe there ? Why ? [2+3]

5. This question is about diffraction.

(a) The D-lines in the emission spectrum of sodium correspond to the wavelengths (approximately) of 5890 and 5896 angstroms. How large a grating, having 600 lines per mm, is needed to resolve these lines, in the first order spectrum ? [5]

(b) Calculate the position on the screen (a distance D away from the line of slits), away from the central maximum, where one can observe the mth minimum of the diffraction pattern from the N slit diffraction pattern. If one increases the wavelength, does this minimum move up or down ? [4+1]

6. This question is about polarization of EM waves.

(a) A plane EM wave, plane polarized in the z direction, propagates in the x direction with a frequency ω. If a charged particle of mass m and charge q, moving along the y axis with a constant velocity v_0, meets the wave, what is the instantaneous acceleration of the particle (magnitude and direction) ? [4+1]

(b) Commercial cellophane has a thickness roughly close to half a wavelength of most colours of white light. Suppose an incident light wave is linearly polarized at an angle of 60 degrees with the optic axis of this birefringent material. The light emerging from the cellophane is then sent through a polaroid. What angle should the final polaroid axis make with the optic axis of the cellophane, such that the final beam emerging from the polaroid has (a) 1/8 of the initial intensity at incidence; (b) zero intensity ?[3+2]

7. This question is also about polarization.

(a) Express the electric field of an EM wave linearly polarized along a direction θ to the X-axis as a linear combination of the electric fields in a right-circular and a left-circular polarized wave. [5]

(b) Brewster observed that if the polarization of a light beam, incident on a glass surface, is in the plane of incidence, then there is an angle of incidence (Brewster angle) for which there is no reflection from the glass surface. Give a brief but precise qualitative explanation of this phenomenon, based on the idea of reflection as EM radiation from the molecules of the glass surface. If the refractive index of glass is 1.4, what is the Brewster angle ? [3+2]