[This question paper contains 6 printed pages.]

(16) Your Roll No. 2022

Sr. No. of Question Paper : 1116 A

Unique Paper Code : 32221601

Name of the Paper : Electromagnetic Theory

Name of the Course : B.Sc. (Hons) Physics–CBCS

Semester : VI

Duration : 3 Hours Maximum Marks : 75

Instructions for Candidates

1. Write your Roll No. on the top immediately on receipt of this question paper.
2. Question No. **1** is compulsory.
3. Answer any **four** of the remaining **six**.
4. Use of non-programmable calculator is allowed.

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1. Attempt any 5 parts of this question. (5x3)

(a) A conductor of square cross section and having conductivity 3.8×10^7 S/m is 50 m long. It measures 0.5 cm on either side. Calculate the skin depth if conductor carries current at 150 kHz.

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(b) The conduction current density in a material is given as $\overrightarrow{J_C} = 0.02 \sin(10^9 t)\ A/m^2$. Find the displacement current density if $\sigma = 10^5$ mho/m, $\epsilon_r = 6.5$.

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(c) What is plasma frequency and minimum penetration depth for collision free plasma having 10^{12} electrons/m^3.

(d) A 300 mm long tube containing 56 cm^3 of sugar solution produces an optical rotation of 12° when placed in a polarimeter. If the specific rotation of sugar solution is 66°, calculate the quantity of sugar contained in the tube.

(e) For glass air interface ($n_1 = 1.5$, $n_2 = 1.0$), find the reflection and transmission coefficients for normal incidence.

(f) A left circularly polarized wave ($\lambda = 5893$ A) is incident normally on calcite crystal of thickness 0.00514 mm. Find the state of polarization of the emergent beam. Take $n_0 = 1.65836$ and $n_e = 1.48641$.

(g) A circularly polarized electromagnetic wave is propagating in the z-direction in free space and is described by the following equation

$$\vec{E} = 5\cos(\omega t - kz)\hat{x} + 5\sin(\omega t - kz)\hat{y} \text{ Vm}^{-1}$$

The wavelength is 6×10^{-7}m. Find the corresponding magnetic field and the average of the Poynting vector.

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2. (a) State and establish the Poynting theorem for conservation of energy for electromagnetic fields. Explain the physical significance of each term in the equation. (6)

(b) Using electromagnetic scalar and vector potentials, show that the four Maxwell equations can be written as two coupled second order differential equations. (6)

(c) What is the ratio of amplitudes of conduction current density and displacement current densities density if applied field is $\vec{E} = \vec{E}_0 e^{-t/\tau}$, where τ is real. (3)

3. (a) Discuss the propagation of high frequency electromagnetic wave in plasma. Show that the critical frequency for the propagation of electromagnetic wave in plasma is given by $f_c = 9\sqrt{n_0}$, where n_0 is the electron density. (8)

(b) A material has $\sigma = 6.0 \times 10^{-2}\ \Omega^{-1}/m$, $\mu = \mu_0$ and $\varepsilon_r = 7.0$. A plane wave of frequency 10^9 Hz with amplitude 200V/m is propagating along positive z direction. Find (a) E_x at (x = 0 cm, y= 0 cm, z = 3 cm. t = 0.16 ns) (b) H_y at (x = 0 cm, y = 0 cm, z = 3 cm. t = 0.16 ns). (7)

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4. (a) Derive the Fresnel's equation for reflection and transmission of a plane electromagnetic wave at the boundary separating between two dielectric media when electric field vector is perpendicular to the plane of incidence. (9)

(b) An electromagnetic wave propagating in a dielectric medium with $\varepsilon = 16\varepsilon_0$ along the z direction. It strikes another dielectric medium with $\varepsilon = 4\varepsilon_0$ at z = 0. If the incoming wave has a maximum value of 0.2 V/m at the interface, and its angular frequency is 300 M rad/s, determine the power densities of the incident, reflected, and transmitted waves. (6)

5. (a) Derive Fresnel's formula for the propagation of light in Anisotropic crystals. Also explain how this leads to the phenomenon of double refraction. (9)

(b) Discuss the propagation of light in uniaxial crystals. Explain the difference between a positive uniaxial crystal and a negative uniaxial crystal. Also give one example of each. (6)

6. (a) Explain the construction and working of a Babinet Compensator. How is it used to analyze the elliptically polarized light? (9)

(b) A right-handed circularly polarized plane wave with electric field magnitude of 3 mV/m is travelling in the +Y direction in a dielectric medium with $\varepsilon = 4\varepsilon_0$ and $\mu = \mu_0 = 0$. If the frequency is 100MHz, obtain expressions for $\vec{E}(y,t)$ and $\vec{H}(y,t)$. (6)

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7. (a) Starting with Maxwell's equations, derive the wave equations for a symmetric planar dielectric waveguide with refractive index profile as :

$$n = n_1 \qquad -d/2 < x < d/2$$

$$n = n_2 \qquad -d/2 > x > d/2$$

Using the boundary conditions, obtain the eigenvalue equation for symmetric TE modes. (9)

(b) Consider a symmetric planar waveguide with the follow ing parameters.

$$n_1 = 1.5 \; ; \; n_2 = 1.48 \; ; \; d = 3.912 \; \mu m$$

How many TE modes exist for $\lambda_0 = 1 \; \mu m$? Determine the corresponding propagation constants. (6)

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Value of Constants:

$\varepsilon_o = 8.85\times10^{-12}$ farad/m $= \frac{10^{-9}}{36\pi}$ farad/m

$\mu_o = 4\pi\times10^{-7}$ henry/m

$c = 3 \times 10^8$ m/s

$\eta_o = 120\,\pi\Omega = 377\,\Omega$

Mass of electron= 9.11×10^{-31} kg

[This question paper contains 6 printed pages.]

(17) Your Roll No. 2022

Sr. No. of Question Paper : 1224 A

Unique Paper Code : 32227626

Name of the Paper : Classical Dynamics

Name of the Course : B.Sc. (Hons) Physics-DSE-4

Semester : VI

Duration : 3 Hours Maximum Marks : 75

Instructions for Candidates

1. Write your Roll No. on the top immediately on receipt of this question paper.
2. Question No. 1 which is compulsory.
3. Attempt any **three** questions from the remaining.

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1. Attempt any **four** of the following : (4×6=24)

(a) Show that phase of an electromagnetic wave is Lorentz invariant.

(b) Write the Hamiltonian of a one-dimensional harmonic oscillator.

(c) Define pathlines, streamlines and streaklines.

(d) A particle of mass m is constrained to move on the boundary of an ellipse $x^2 + 2y^2 = 2$. Identify the generalized coordinates of this system.

(e) An alpha-particle ($q = 3.2 \times 10^{-19}$ C) moves through a uniform magnetic field whose magnitude is 1.5 T. The field is directly parallel to the positive z-axis of the rectangular coordinate system. What is the magnitude and direction of the magnetic force on the alpha- particle when it is moving with a velocity $\vec{v} = (2.0\hat{\imath} - 3.0\hat{\jmath} + 1.0\hat{k}) \times 10^4\ m/s$.

(f) Given the fluid velocity components

$$v_x = -\alpha y/(x^2 + y^2),\quad v_y = \alpha x/(x^2 + y^2),\quad v_z = 0.$$

Verify that the fluid is incompressible.

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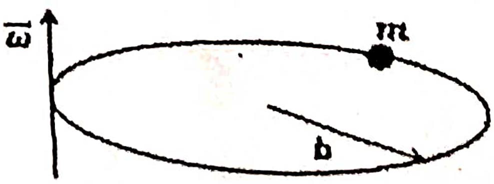
2. (a) A bead of mass m slides freely on a frictionless circular wire of radius b. The wire itself rotates in a horizontal plane about an axis passing through a point on perimeter of the wire with a constant angular velocity ω.



Find the Lagrangian of the system with a suitable choice of generalized coordinates. Deduce the Euler- Lagrange's equation of motion of the bead. Show that the bead oscillates as a pendulum of length $l = g/\omega)^2$. (10)

(b) For a time independent holonomic system, show that the Hamiltonian of the system represents total energy. (7)

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3. (a) Using cylindrical coordinates, write the Hamiltonian and Hamilton's equations for a particle of mass m moving on the inside of a frictionless cone $x^2 + y^2 = z^2 \tan^2 \alpha$. (10)

(b) Show that the energy conservation is nothing but a consequence of the time-shifit invariance of a system. (7)

4. (a) An observer A stands 1 light-second away from a tunnel of length L = 1 light-second. A high-speed train speeds through the tunnel at constant velocity $\beta = 0.5$. An observer inside the train measures the length of the train to be L = 2 light-second.

(i) Draw a spacetime diagram for observer A showing the worldlines of the front and rear of the train and the tunnel. Assume that at $t = 0$ the rear of the train has just crossed the observer.

(ii) Label the event at which the front end of the train emerge from the tunnel and the rear end of the train enter the tunnel. Using the spacetime diagram, show that the train fits the tunnel as observed by A.

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(iii) In the train frame, label the event along the worldline of the rear which is simultaneous to the event when the front end emerges from the tunnel and label the event along the worldline of the front which is simultaneous to the event when the rear end of the train enters the tunnel. (10)

(b) Show that in units such that $c = 1$, the 4-acceleration is given by $A = \gamma(d\gamma/dt, vd\gamma/dt + \gamma a)$ where α is the 3-acceleration. Prove that $v^{\mu}a_{\mu} = 0$ where v^{μ} is 4-velocity and a_{μ} is 4-acceleration.

(7)

5. (a) A particle of mass m moving at speed v collides with another particle of the same mass at rest. They stick together and move with speed V. What is V in terms of v? What is the mass of the final combined particle? (10)

(c) Let an observer B move relative to an observer A with fractional velocity v. For a photon moving in the v direction, show that energy $E' = E\sqrt{(1-\beta)/(1+\beta)}$ where $\beta = v/c$. Also derive the relativistic Doppler shift. (7)

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6. (a) Three masses m each, initially located equidistant from one another on a horizontal circle of radius R. They are connected in pairs by three springs of force constant k each and of unstretched length $2\pi R/3$. The spring threads the circular tract so that the mass is constrained to move on the circle. Find the normal modes with their frequencies and normalized coordinates. (10)

(b) Define stable and unstable equilibrium. In case of a simple pendulum, find the point of stable and unstable equilibrium. (7)

7. (a) Show that motion of a particle with mass m and charge q moving at a speed $\vec{v}$ in a magnetic field of strength $\vec{B}$ is helical. A proton enters a uniform magnetic field of with a speed of $v = 1.0 \times 10^{-4}$ T. At what angle must the magnetic field be from the velocity so that the pitch of the resulting helical motion is equal to the radius of the helix? (10)

(b) Show that the pressure at a point in an inviscid fluid is independent of direction. (7)

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[This question paper contains 3 printed pages.]

(18) Your Roll No. 2022

Sr. No. of Question Paper : 1304 A

Unique Paper Code : 32227612

Name of the Paper : Nano Materials and Applications

Name of the Course : B.Sc. Hons. Physics-CBCS-DSE

Semester : VI

Duration : 3 Hours Maximum Marks : 75

Instructions for Candidates

1. Write your Roll No. on the top immediately on receipt of this question paper.
2. Attempt five questions in all.
3. Question no. 1 is compulsory.
4. All questions cariy equal marks.
5. Symbols have their usual meanings.

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1. Attempt any five questions: (3x5=15)

(a) What is nanotechnology? What are the predictions of nanotechnology on the performance of conventional devices?

(b) One gram of highly porous material can have a surface area of 4500 m^2. How does this value compare with the surface area of a 1g cube of gold? (Density of gold is 19.3 gcm^{-3}).

(c) Draw in one single plot the typical XRD curve of a material exhibiting crystalline, polycrystalline and amorphous nature.

(d) Explain with suitable diagram the process of nucleation and growth of nanoparticles prepared using chemical method.

(e) Explain the formation of band structures in materials from the perspective of molecular orbital theory.

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(f) Sketch and label a schematic diagram of a single electron transfer device.

(g) What is the effect of the size of nanoparticles on the optical absorption spectra of a material? Explain with the help of a diagram?

(h) How nanoparticles improves the efficiency of conventional solar cells?

2. (a) Derive an expression for the density of states function for a 3-D material. Compare the derived density of states function with the 2-D and 1-D materials. (10)

(b) An electron of mass 9.1×10^{-31} kg is trapped in a cubical box each side 10nm. Calculate the energy of the ground state and first excited state. Is there any degeneracy in these states, if yes, determine it? ($h=6.626\times10^{-34}$Js) (5)

3.(a) A particle of mass m and energy E is incident on a step potential given by:

$$V(x) = \begin{cases} 0, & x < 0 \\ V_0, & x > 0 \end{cases}$$

Using Schrodinger equation, derive the expression for the reflection and transmission coefficient for the case of a particle having energy E greater than V_0. (10)

(b) For the above case, find out the ratio E/V_0 to achieve the transmission probability of 50%. (5)

4. Draw labeled diagram of a sputtering system. Explain the process of physical sputtering for the deposition of thin film of any material. What are the various parameters involved in the process which needs to be optimized. (15)

5. (a) What are scanning probe microscopes (SPMs)? Explain the construction and working of Atomic Force microscope in contact, non-contact and tapping mode. (12)

(b) An AFM cantilever is made of silicon material and has the dimensions of 4 mm (length) × 1 mm (width) × 10 μm (thick). It can measure a force as small as 10^{-10} N then estimate the minimum deflection measured by this cantilever. Young's modulus $E = 1.69 \times 10^{11}$GPa. (3)

6. (a) What is the importance of dielectric materials in semiconductor industry? How is the capacitance depends on the size of the particle? Calculate and tabulate the capacitance and charging energy of isolated metal particles with size 10nm, 100nm and 1 μm. ($\varepsilon_0 = 8.85 \times 10^{-12}$ F/m) (10)

(b) What do you understand by excitons? Draw the position of ground and next five excited excitonic levels in the band diagram of the material of your choice. (5)

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7. (a) What is a 2D Electron Gas (2DEG)? Explain how one can achieve a 2DEG system with suitable energy band diagram. Choose any material of your choice. (10)

(b) What do you understand by quantum confinement effect? What are the consequences of confinement of charges on the electronic and optical properties of the material. (5)

8. (a) Draw and explain the working of MEMS based sensor for measuring force/pressure or any other physical quantity. (8)

(b) What are CNTs? Discuss with basic diagram the working of a CNT based transistor device. (7)

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[This question paper contains 6 printed pages.]

(19) **Your Roll No.** 2022

Sr. No. of Question Paper : 1361 **A**

Unique Paper Code : 32221602

Name of the Paper : Department of Physics & Astrophysics STATISTICAL MECHANICS

Name of the Course : **B.Sc. (Hons) Physics – CBCS**

Semester : VI

Duration : 3 Hours Maximum Marks : 75

Instructions for Candidates

1. Write your Roll No. on the top immediately on receipt of this question paper.
2. Attempt any **four** questions in all.
3. **All** questions carry equal marks.
4. Non-programmable Scientific calculators are allowed.

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1. (a) Given a system of 5 weakly interacting distinguishable particles which can occupy any of the three energy levels of energy 0, ε, and 2ε. Let the total energy of the system be 5ε. Write

all possible macrostates and their corresponding number of microstates. Find the entropy of this system.

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(b) Consider equal amount of two identical ideal gases at the same temperature T but at different pressure P_1 and P_2 in two different containers of volume V_1 and V_2 respectively which are joined by the partition. Starting with Sackur-Tetrode relation, prove that If gases are allowed to mix each other by removing the partition between them, the change in the entropy is given by :

$$\Delta S = Nk \ln [(P_1 + P_2)^2 / (4 P_1 P_2)]$$

where N denotes the number of atoms in each container. Assume that the temperature remain the same after mixing of the ideal gases.

(c) The partition function, Z (V, T), for some physical system is given as:

$$Z(V, T) = \exp[(8\pi^5 k^3 V T^3) / (45 h^3 c^3)]$$

where the symbols have their usual meaning. Calculate the internal energy and pressure for such system. (6.75,6,6)

2. Consider an isolated system of N distinguishable particles. Each particle can occupy only one of two energy levels of energy ε_1 and ε_2 (where $\varepsilon_1 < \varepsilon_2$). Particles are distributed in such a way that n_2 particles resides in energy level ε_2 and n_1 particles are present in level of energy ε_1. (Assume N is very large and $N = n_1 + n_2$)

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(a) Find the entropy and energy of this system. Show that entropy of such system is maximum when n2 = N/2.

(b) Find the maximum and minimum value of the entropy.

(c) Obtain the general expression of temperature for the above mentioned isolated system and explain how is it possible to attain negative temperature in it. (6.75,6,6)

3. (a) Consider a spherical enclosure whose wall are moving outward with speed v (v << c) and are perfectly reflecting. Suppose that an electromagnetic wave of wavelength λ incident at an angle θ to the normal on the wall. Show that

change in the wavelength after one reflection during adiabatic expansion of blackbody radiation is $d\lambda = (2v\lambda/c)\cos\theta$.

(where c is velocity of light)

(b) Obtain the value of Wien's constant by using the Planck's radiation formula.

(c) A radiating cavity has the maximum of its radiating power per unit area at $(\lambda_1)_{max} = 24\ \mu m$ at temperature T_1. Now the temperature of the cavity is changed to T_2 such that total power radiated per unit area by the cavity is 81 times higher than its previous value. Calculate the wavelength $(\lambda_2)_{max}$ where the maximum emission of radiation occur. (6.75,6,6)

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4. (a) At what temperature would you expect a trapped gas of hydrogen atoms with peak density 1.8×10^{14} atoms/cm^3 to show the signs of Bose- Einstein Condensation.

(Given $m_H = 1.66 \times 10^{-27}$ kg)

If the number density of bosons become 8 times of its previous value, find the change in the condensation temperature.

(b) Consider a photon gas enclosed in a Volume V. The photons are in equilibrium at temperature T. The average number of photons in equilibrium is given as $N = \gamma V^{\alpha} T^{\beta}$. Obtain the value of constants α, β and γ.

(c) Plot the pressure of strongly degenerate bosons with temperature. Show explicitly the $T < Tc$ and $T > Tc$ regions in the graph. Compare it with classical gas. (6.75,6,6)

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5. (a) Calculate the internal energy possessed by the non-relativistic and strongly degenerate $(T < T_F)$ electrons moving in 3-dimensions.

(b) Derive an expression for Fermi velocity of electrons at T = 0 K and hence show that the de Broglie wavelength associated with the electrons is given by

$$\lambda_{dB} = 2 \, (\pi/3n)^{1/3}$$

where n is the number density (N/V) of the electron gas.

(c) Prove that for a system consisting of fermions at temperature T ($T \ll T_F$), the probability that a filled state ΔE lying above Fermi level is the same as the probability of an empty state ΔE lying below the Fermi level. (6.75,6,6)

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Useful constants and Integrals :

$h = 6.6 \times 10^{-23}$ Js

$k_B = 1.38 \times 10^{-23}$ J/K

$c = 3 \times 10^{8}$ m/s

$\int_0^\infty x^2/(e^x - 1)\, dx = 2.404$