Exam. Code : 209002
Subject Code : 4771

M.Sc. Physics Semester—II

PHY–452 : ELECTRODYNAMICS–I

Time Allowed—3 Hours] [Maximum Marks—100

Note :— Section A is compulsory. Attempt at least **one** question each from Sections B, C, D and E.

SECTION–A

1. (i) The electric displacement vector $\vec{D}$ and the magnetic field $\vec{H}$ satisfy the Maxwell equations $\vec{\nabla}.\vec{D} = \rho$, $\vec{\nabla} \times \vec{H} = \vec{J}$, where ρ and $\vec{J}$ are, respectively, the charge and current density. At the boundary between two media there are, respectively, the surface charge and current densities σ and $\vec{K}$. What are the appropriate boundary conditions for $\vec{D}$ and $\vec{H}$, respectively ?

(ii) A magnetic vector potential is given by :

$$\vec{A} = \frac{\mu_0}{4\pi}\frac{\vec{m} \times \vec{r}}{r^3}$$

Find magnetic induction $\vec{B}$ of a point magnetic dipole with dipole moment $\vec{m} = m\hat{e}_z$.

(iii) A charged particle is released from rest in a region where there is a constant electric field and a constant magnetic field. If the two fields are parallel to each other, what will be the path of the particle ?

(iv) A negative test charge is moving near a long straight wire in which there is a current. A force will act on the test charge in a direction parallel to the direction of the current if the motion of the charge is in a direction, say $\hat{n}$. What will be that direction ?

(v) A cube has a constant electric potential V on its surface. If there are no charges inside the cube, what will be the potential at the center of the cube ? Give explanation.

(vi) Listed below are Maxwell's equations of electromagnetism. If magnetic monopole exist, which of these equations would be INCORRECT ?

$$\vec{\nabla} \times \vec{H} = \frac{\partial \vec{D}}{\partial t} + \vec{J}$$

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t};$$

$$\vec{\nabla}.\vec{B} = 0$$

$$\vec{\nabla}.\vec{D} = \rho$$

(vii) The dispersion law for a certain type of wave motion is $\omega = \sqrt{c^2k^2 + m^2}$, where ω is the angular frequency, k is the magnitude of the propagation vector, and c and m are constants. Find the group velocity of these waves and how does it behave as k approaches 0.

(viii) The capacitor was initially charged in a RC circuit. In this circuit resistance and capacitor are connected in series. After closing the switch, how much time elapses until one-half of the capacitor's initial stored energy is dissipated ?

(ix) In the LCR circuit, in which three are connected in series across the applied voltage $\varepsilon(t) = \varepsilon_m \cos \omega t$. For a constant ε_m, at what angular frequency does the current have its maximum steady-state amplitude after the transients have died out ?

(x) Two capacitors of capacitances 1.0 microfarad and 2.0 microfarad are each charged by being connected across a 5 volt battery. They are disconnected from the battery and then connected to each other with resistive wires so that plates of opposite charge are connected together. What will be the magnitude of final voltage across the 2.0 microfarad capacitor ?

2×10=20

SECTION–B

2. (a) State and prove uniqueness theorem under both Dirichlet and Neumann boundary conditions and give their physical significances. 7

(b) A spherically symmetric charge distribution of radius R has a charge density given by $\rho = a/r^2$, where a is constant. Find the electric field both inside and outside the sphere. 7

(c) An electric potential is given by $\varphi(r) = \frac{z}{4\pi \epsilon_0} \frac{e^{-\alpha r}}{r}$. Reconstruct the electrical charge distribution that will produce this potential. Note that $\varphi(r)$ vanishes exponentially for large (r), showing that the net charge is zero. 6

3. (a) An electric dipole consists of two equal and opposite charges $\pm q$ separated by a distance d. Find the approximate potential at points far from the dipole. 5

(b) Under what condition is Gauss's law especially useful in determining the electric field intensity of a charge distribution. Justify your answer by taking one example. 5

(c) What is the potential in the region between two grounded concentric conducting spheres of radii a and b such that b > a, when a unit point charge is placed at an arbitrary point r between them. 10

SECTION–C

4. Show that the magnetic field is given by the curl of a vector potential. Expand this potential in terms of multi-pole potential and show that the leading term is a dipole term. 5,5,10

5. A circular loop of radius R in x-y plane carries a steady current I :

(a) What is the magnetic field at point P on the axis of the loop at a distance z from its center ?

(b) If we place a magnetic dipole $\mu = \mu_z k$ at P, find the magnetic force experienced by the dipole. Is this force attractive or repulsive ? What happens if the direction of the dipole is reversed $\mu = -\mu_z k$. 7,7,3,3

SECTION–D

6. Establish the law of conservation of energy and momentum for electromagnetic fields. Identify the various terms involved and write down the dimensional formula of Poynting vector. 17,3

7. (a) A thick wire of radius a, carries a constant current I, uniformly distributed over its cross-section. A narrow gap in the wire, of width w << a, forms a parallel plate capacitor. Find the magnetic field in the gap, at a distance s < a from the axis. 6

(b) In a certain region of the inertial reference frame there is magnetic field with induction B rotating with angular velocity ω. Find the curl of an electric field vector in the regions as a function of vectors ω and B. 14

SECTON–E

8. (a) What is the polarization of electromagnetic wave whose electric field components are given as :

$$E_x = 4E_0 \cos(3x + 4y - 500t)$$
$$E_y = 3E_0 \cos(3x + 4y - 500t + \pi)$$
$$E_z = 0$$

(b) Given two media having permeabilities μ_1 and μ_2, prove that

$$\frac{\tan\theta_1}{\tan\theta_2} = \frac{\mu_1}{\mu_2}$$

where θ_1 and θ_2 represent the angles that the magnetic fields with the normal to the interface in the two media.

(c) Starting from the equation of continuity and Gauss's law, show that for a conducting medium obeying ohm's law, $\vec{J} = \sigma\vec{E}$, with $\frac{\partial\rho}{\partial t} + \frac{\sigma}{\varepsilon}\rho = 0$. If an initial charge density ρ_0 is given, How does it vary with time. What is the physical significance of $\frac{\sigma}{\varepsilon}$, where σ is the conductivity of the medium. 7,7,6

9. (a) Differentiate between linear and circular polarization of an electromagnetic wave with expressions.

(b) A system of three polarizing sheets is placed in the x-y plane in the path of initially unpolarized light. The polarizing direction of the first sheet is parallel to the y-axis, that of the second sheet is 60° counterclockwise from the y-axis, and that of the third sheet is parallel to the x-axis. What fraction of the initial intensity I_0 of the light emerges from the system ?

(c) What do you mean by skin depth and obtain an expression for it ? 7,6,7

5. A system of N magnetic dipoles each having magnetic moment μ is placed in external magnetic field H. Obtain an expression for the partition function and magnetization in the system in quantum mechanical treatment, i.e., μ cannot have any arbitrary value. 10+10

SECTION—D

6. Show that the zero-point energy of a simple harmonic oscillator does not contribute to its entropy or heat capacity, but does contribute to its energy and Helmholtz function. 20

7. (a) Consider an ideal classical gas, an ideal Fermi gas and an ideal Bose gas. Which of these gases will exert the maximum and the minimum pressure and why ?

   (b) Show that the energy density of photons inside a cavity with fixed volume is proportional to T^4. 5+15

SECTION—E

8. Discuss the phenomena of Bose-Einstein condensation. Is it similar to the condensation of vapours into a liquid in ordinary space ? Show that for $T < T_C$ (T_C is the critical temperature) the pressure exerted by a bose condensate is proportional to $T^{5/2}$. 2.5+2.5+15

9. The restoring force of a harmonic oscillator is proportional to its displacement. Show that mean kinetic energy and mean potential energy are same and hence mean energy per oscillator is kT. Where k is Boltzman constant and T is absolute temperature. 10+10

Exam. Code : 209002
Subject Code : 4772

M.Sc. Physics Semester—II

STATISTICAL MECHANICS

Paper—Phy-453

Time Allowed—3 Hours] [Maximum Marks—100

Note :— Section—A is compulsory. Attempt **One** question from each of Section B, C, D and E.

SECTION—A

1. (a) State the law of "Equipartition of energy". Under what conditions it is valid ?

   (b) The motion of a mosquito moving freely in a room can be considered equivalent to motion of a gas molecule. What are the dimensions of its phase space ? What is the average energy of mosquito ?

   (c) Give Boltzman's statistical definition of entropy and explain its meaning clearly. Under what conditions the entropy of a given system is maximum and minimum ?

   (d) For a physical system with N-distinguishable particles the numbers of accessible microstates are $\Omega(N, V, E)$. How does the number $\Omega(N, V, E)$ change when particles are treated as indistinguishable ?

   (e) Determine the number of ways in which N-Bosons can be distributed in 3 phase space cells.

(f) Consider a two level system with energy levels $E_1 = 0$ and $E_2 = E$. Write expression for the partition function and hence evaluate the mean energy of the system.

(g) The Helmholtz free energy in a Canonical ensemble is given by $A = -kT \ln Q(N, V, T)$, where terms have their usual meaning. Write similar expression in Grand Canonical ensemble and explain the terms in the expression.

(h) Consider black body radiation in a cavity maintained at 2000 K. If the volume of the cavity is reversibly and adiabatically increased from 10 cm^3 to 640 cm^3, then calculate the new temperature of the cavity.

(i) Write an expression for occupation number in different statistics. Discuss its behaviour with temperature and under what conditions of temperature the results of quantum statistic matches with classical statistics.

(j) Write an expression for Fermi energy EF of a degenerate electron gas in terms of number density of electrons. 10×2=20

SECTION—B

2. A classical ideal gas with N non-interacting particles is confined to a volume V. Show that the partition function can be written as :

$$Q_N(V,T) = \frac{1}{N!}\left[\frac{V}{\lambda_T^3}\right]^N,$$

where $\lambda_T = \frac{h}{\sqrt{2\Pi mkT}}$ is called thermal wavelength, m is mass of each particle and other symbols have their usual meaning. Further obtain an expression for Helmholtz free energy for this system and show that internal energy per atom, i.e.,

$$\frac{E}{N} = \frac{3}{2}kT.$$

10+5+5

3. Show that for a classical ideal gas

$$\frac{s}{Nk} = \left(\ln\frac{Q_1}{N}\right) + T\left(\frac{\partial \ln Q_1}{\partial T}\right)_P,$$

where S, N, k and Q_1 are entropy, number of particles, Boltzman constant and partition function respectively. 20

SECTION—C

4. For a classical ideal gas, the expression for entropy after Gibbs correction becomes

$$S(N,V,E) = Nk \ln\left[\frac{V}{Nh^3}\left(\frac{4\Pi mE}{3N}\right)^{3/2}\right] + \frac{5}{2}Nk$$

Now, consider the mixing of :

(a) two identical gases at common temperature T and with equal particle densities.

(b) two different gases at common temperature and with different particle densities.

(c) two different gases at common temperature and with equal particle densities.

Show that for these cases the given expression for entropy is extensive. 10+5+5

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Subject Code : 4773

M.Sc. Physics Semester—II

PHY-454 : ATOMIC & MOLECULAR SPECTROSCOPY

Time Allowed—3 Hours] [Maximum Marks—100

Note :— Question No. 1 is compulsory. Attempt any **FOUR** questions from Sections B, C, D and E with at least **ONE** question from each Section. All questions carry equal marks.

SECTION–A

1. Attempt all the **ten** parts :

(a) Explain in brief Hyperfine splitting of states.

(b) Why nitrogen molecules do not show IR absorption or emission spectra ?

(c) Explain Larmor's theorem.

(d) Explain briefly j-j coupling of states.

(e) What is Paschen Back effect ?

(f) What are P, Q and R branches ? Why is Q branch absent in diatomic molecules ?

(g) Describe briefly Doppler effect.

(h) Write selection rule for a triplet.

(i) Define magnetic dipole moments.

(j) What is natural breadth of a line ?

SECTION–B

2. Explain the spectra of alkaline earth metals with example. Derive the expression for interaction energy in L-S coupling for two electron systems.

3. What is Lamb shift ? Explain the spin-orbit interaction and fine structure of hydrogen.

SECTION–C

4. What is stark broadening ? Explain the contribution of external effects on the breadth of spectral lines.

5. Explain intensity rules for the Zeeman effect. How natural width of a line be defined using classical and quantum theory ?

SECTION–D

6. Derive the expression for the rotational energy levels of diatomic molecule considering it as a rigid rotator. Discuss their spectrum and its selection rules.

7. Discuss and explain the principle of Fourier Transform spectroscopy and instrumentation involved in it.

SECTION–E

8. Give the classical and quantum mechanical view of Raman effect and explain the existence of stoke and anti-stoke lines.

9. Explain any **two** of the following :

   (i) Born-Oppenheimer Approximation

   (ii) Franck-Condon principle

   (iii) Fortrat Diagram.