PHYSICS - II
(PHYS 2001)

Time Allotted: 3 hrs **Full Marks: 70**

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and <u>any 5 (five)</u> from Group B to E, taking <u>at least one</u> from each group.

Candidates are required to give answer in their own words as far as practicable.

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternative for the following: **10 × 1 = 10**

(i) Find the degrees of freedom of the system where two particles connected by a rigid rod moving freely in a space.
(a) 2 (b) 3 (c) 6 (d) 5.

(ii) Which one of the following is an acceptable wave function of a quantum particle?
(a) x (b) e^{-x^2} (c) x^2 (d) cos x.

(iii) The lagrangian of a system is a function of
(a) q_j, p_j, t (b) $q_j, \dot{q}_j, t$ (c) $\dot{p}_j, q_j, t$ (d) $p_j, \dot{q}_j, t$.

(iv) Which one of the following is boson?
(a) Photon (b) Electron (c) Phonon (d) Alpha particle.

(v) The number of ways in which 3 fermions can be arranged in 4 energy states is
(a) 4 (b) 2 (c) 3 (d) 6.

(vi) In a p-type semiconductor, the donor level
(a) lies near the valence band edge
(b) lies near the conduction band edge
(c) lies halfway between the valence band and conduction band edges
(d) does not exist.

(vii) The paramagnetic susceptibility of a material varies as
(a) T (b) $\frac{1}{T}$ (c) T^2 (d) $\frac{1}{T^2}$.

(viii) The average energy of an electron at T = 0K in a metal in terms of energy E_f at the Fermi level is
(a) $\frac{2}{3}E_f$ (b) $\frac{1}{3}E_f$ (c) $\frac{3}{5}E_f$ (d) $\frac{3}{4}E_f$

(ix) The density of states for fermions in 3 dimensions is proportional to

(a) E (b) E^2 (c) $E^{\frac{1}{2}}$ (d) $\frac{1}{E}$.

(x) If N is the number of atoms per unit volume in a dielectric, the relationship between the atomic polarizability α and the electric susceptibility χ is given by

(a) $\chi = \frac{N\alpha}{\varepsilon_o}$ (b) $\chi = N\alpha\varepsilon_0$ (c) $\alpha = \frac{N_\chi}{\varepsilon_0}$ (d) $\alpha = N_\chi \varepsilon_0$

Group- B

2. (a) State the nature of constraint and enumerate the degrees of freedom in each of the following cases:
   i) a simple pendulum with rigid support.
   ii) a particle sliding down an inclined plane under the influence of gravity.

   (b) Consider a simple pendulum with a mass m and string length l. Obtain Lagrange equations of motion for this system.

   (c) Show that the Hamiltonian remains conserved for a system where Lagrangian does not explicitly depend on time.

   (d) Under what conditions does the Hamiltonian represent the total energy of a system. Give an example of such a system.

(1.5 + 1.5) + 4 + 3 + (1 + 1) = 12

3. (a) The potential energy of a quantum particle confined within one-dimension is

$$V(x) = 0, for\ 0 < x < L$$
$$= \infty, for\ x \le 0; x \ge L.$$

   Show that the energy of this particle is quantized.

   (b) If a wave function of a quantum mechanical particle is given by

$\varphi(x,t) = A\ Sin\left(\frac{\pi x}{L}\right)$ for $0 \le x \le L$

$= 0$ for $0 \ge x \ge L$

   Find the value of A from normalization condition. Also find the value of x corresponding to maximum probability of finding the particle for the above system.

   (c) Write down the time-dependent Schrodinger equation in one dimension, and define all the terms. When can this equation be reduced to the time-independent Schrodinger equation?

3 + (3 + 3) + (2 + 1) = 12

Group - C

4. (a) Four distinguishable particles are to be distributed into three energy levels having energies 0, E, 3E so that the total energy is 4E . If the levels are degenerate with degeneracies 2, 1, 1 respectively, write down all the possible microstates and the corresponding macrostates.

   (b) (i) Write down the Fermi-Dirac distribution function. (ii) Plot it against energy for $T = 0\ K$ and for $T > 0\ K$ where T is the temperature. (iii) Evaluate the Fermi-

Dirac distribution function at an energy kT above the Fermi energy, where k is the Boltzmann constant.

(3 + 3) + (2 + 2 + 2) = 12

5. (a) Write down the Bose-Einstein distribution function. Develop an expression for the density of states of a photon gas in equilibrium. Hence derive Planck's radiation law for black bodies.
   (b) Using Fermi-Dirac distribution, Calculate the concentration of electron in the conduction band of an intrinsic semiconductor.
   (c) Find the Fermi energy in copper on the assumption that each copper atom contributes one free electron to electron gas. [Given that: density of copper 8.94 gm/cm^3, Atomic mass of copper 63.5].

(2 + 2 + 2) + 4 + 2 = 12

Group - D

6. (a) What are polar and non-polar dielectrics? Find the expression of induced charge in a dielectric material when it is kept within a parallel plate capacitor?
   (b) A capacitor uses a dielectric material of dielectric constant is 4. It has an effective surface area of 0.024 m^2 with a capacitance of 2μF. Calculate the field strength and dipole moment per unit volume if a potential difference of 10 V exists across the capacitor.
   (c) Calculate the induced dipole moment per unit volume of gas if it is placed in an electric field of 6000 V/cm. The atomic polarizability of He is $0.18 \times 10^{-40}\ Fm^2$ and gas density is 2.6×10^{25} atoms per m^3.

(2 + 3) + (2 + 2) + 3 = 12

7. (a) Define magnetic dipole moment. Write down the expression of the Bohr magneton. Estimate its value.
   ($e= 1.6\times10^{-19}$C, $m=9.1\times10^{-31}$kg, $h =6.63\times10^{-34}$Js)
   (b) Draw the B-H curve for ferromagnetic materials and identify the retentivity and the coercive field on the curve.
   (c) Write down the relation between magnetization $\vec{M}$, magnetic field intensity $\vec{H}$, and magnetic flux density $\vec{B}$ within a material and hence establish the relationship between relative permeability and magnetic susceptibility for a linear magnetic material.

(2 +1+1) + (2 + 2) + (2 + 2) = 12

Group - E

8. (a) Define the term 'effective mass of an electron'. The energy versus wave vector relationship for a conduction electron in a semiconductor is $E = \frac{5\hbar^2 k^2}{m_0}$. Determine the electron effective mass.
   (b) What are the basic features of the Kronig-Penney model? Mention at least two points.

(c) The so called E-k relation in a band structure is given by $E = \alpha + \beta k^2$. Find the group velocity of a carrier.

(2 +3) + (3 + 2) + 2 = 12

9. (a) Write the mathematical expression for the critical magnetic field for a superconductor at varying temperature. Draw the graph.

(b) Establish London equation of superconductivity in terms of magnetic field induction and hence describe Meissner effect?

(c) Calculate the number density of electrons in a material for which London penetration depth is $\lambda = 0.8 \times 10^{-8} m$. (take $\mu_0 = 4\pi \times 10^{-7}$ in SI unit)

(2 + 2) + (3 + 2) + 3 = 12