B.TECH/ AEIE /CSE/ECE/4TH SEM/ PHYS 2001/2018

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 any 5 (five) from Group B to E, taking at least one 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) 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) $p_j, \dot{q}_j, t$.

(ii) The operator corresponding to the linear momentum in one dimension of a quantum mechanical particle is given by
(a) $i\hbar\frac{\partial}{\partial x}$ (b) $-i\hbar\frac{\partial}{\partial x}$ (c) $\frac{i}{\hbar}\frac{\partial}{\partial x}$ (d) none of these.

(iii) Planck's constant has the dimensions of
(a) energy (b) linear momentum
(c) angular momentum (d) torque.

(iv) The value of $[\hat{p}, \hat{x}]$ here $\hat{p}$ is the momentum operator along x-direction, is
(a) 1 (b) $i\hbar$ (c) $-i\hbar$ (d) 0.

(v) The density of charge carrier in a pure semiconductor is proportional to
(a) $e^{\frac{-E_g}{KT}}$ (b) $e^{\frac{-E_g}{2KT}}$
(c) $e^{\frac{-2E_g}{KT}}$ (d) $e^{\frac{-E_g}{T}}$, symbols have their usual.

(vi) The number of possible arrangements of two bosons in 3 cells are
(a) 6 (b) 5 (c) 4 (d) 3.

(vii) The density of states for fermions in 3 dimensions is proportional to
(a) E (b) E^2 (c) $E^{\frac{1}{2}}$ (d) $\frac{1}{E}$.

(viii) The electric displacement, $\vec{D}$ is expressed through the following relationship between the polarization vector $\vec{P}$, and the electric field $\vec{E}$.
(a) $\vec{D} = \varepsilon_0\vec{E} + \vec{P}$ (b) $\vec{D} = \varepsilon_0\vec{E} - \vec{P}$
(c) $\vec{P} = \varepsilon_0\vec{E} - \vec{D}$ (d) none of these.

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

(x) In an intrinsic semiconductor, the donor level
(a) lies near the valence band edge
(b) lies near the conduction band edge
(c) lies halfway between the valence and conduction band edges
(d) does not exist.

Group – B

2. (a) Two masses m and M (M > m) are attached to either of the ends of an inextensible massless string of length L . The string is further mounted over a fixed massless pulley so that the whole thing can execute a vertical motion in the X – Y plane under the influence of constant gravity. Write down the Lagrangian for this system and set up Lagrange's equation (you do not need to solve it).

(b) The Lagrangian of a system is given by
$L = \frac{1}{2}M\dot{x}^2 + \frac{1}{2}m(\dot{x}^2 + \dot{y}^2 + 2\dot{x}\dot{y}cos\alpha) + mgysin\alpha$
Where M, m, g, α are constants. Identify the cyclic coordinate and calculate the corresponding conjugate momentum.

(c) What are holonomic and nonholonomic constraints?

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

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

3. (a) Write down the time-dependent Schrodinger equation in one dimension, and define all the terms. Write down the normalization condition for the wave function. What does this physically mean?

(b) Write down the time independent Schrodinger equation in one dimension. Use this to find the wave function for a particle in a one-dimensional box (0 <x <a). Normalize the wavefunction.

(c) Given that $\hat{A}, \hat{B}, \hat{C}$ are three operators in quantum mechanics, show that
$[\hat{A}, \hat{B}\,\hat{C}] = [\hat{A}, \hat{B}]\hat{C} + \hat{B}[\hat{A}, \hat{C}]$

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

Group – C

4. (a) Compare Maxwell-Boltzmann (MB), Fermi-Dirac (FD), and Bose-Einstein (BE) statistics mentioning at least three characteristics.

(b) 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. What is the thermodynamic probability of the most probable macrostate?

(c) Apply BE statistics to photon gas and deduce Planck's law of spectral energy density of black body radiation.

2 + (3+2+1) + 4= 12

5. (a) Deduce equi-partition energy law and find out the expression of most probable speed of gas molecules.

Given that $N(E)dE = \left[\frac{2\pi N}{(\pi KT)^{\frac{3}{2}}}\right] e^{-\frac{E}{KT}} E^{\frac{1}{2}}\, dE$; where symbols have their meaning.

(b) Express the Fermi energy value in a metal in terms of free electron density at T=0K.

(c) Calculate the Fermi temperature and Fermi velocity for sodium ($E_F = 3.24\ eV$, Boltzmann constant = $1.38 \times 10^{-23}\ J/K$)

(3 + 4)+ 2 +(1.5+1.5) = 12

Group – D

6. (a) Using a simple spherical model for an atom, show that the electronic polarizability is proportional to atomic volume.

(b) 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.

(c) Show that in the case of a parallel plate capacitor both with and without a dielectric, the magnitude of the electric displacement vector becomes equal to the surface density of free charges on the positive capacitor plate.

5+ 3+ (2 + 2) = 12

7. (a) What is a magnetic dipole? Develop an expression for the magnetic dipole moment.

(b) Write down the expression of the Bohr magneton. Estimate its value. What is its physical significance?
(e= 1.6×10^{-19}C, m=9.1×10^{-31}kg,h =6.63×10^{-34}Js

(c) What is Curie temperature? State Weiss' hypotheses for ferromagnetic materials and obtain Curie-Weiss law.

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

Group – E

8. Consider an electron moving in a one dimensional periodic crystal of lattice constant 'a'.
   (a) Define the lattice translation operator T_a .
   (b) Write down the action of T_a on a potential of the form $V(x)=V_0 \cos(2nx/a)$ to show that it is a periodic potential.
   (c) Show that if $\Psi(x)$ is an eigenfunction of the Hamiltonian it also an eigenfunction of T_a.
   (d) Comment on the eigenvalue of T_a.
   (e) State Bloch's theorem and write down its mathematical form.

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

9. (a) What are the two basic properties of a superconductor? Explain the Meissner effect with suitable sketches.

(b) What is the effect of magnetic field on superconductor? Define critical magnetic field.

(c) The transition of Tin (Sn) to its superconducting state occurs at 3.6 K. If the critical magnetic field of Sn at 0 K is 6.6 A/m, calculate its critical magnetic field at 2 K.

(d) Calculate the number density of electrons in a material for which the London penetration depth (at 0 K) is 0.5×10^{-8}m
($\mu_0 = 4\pi \times 10^{-7}\ \frac{N}{A^2}$, $e = 1.6 \times 10^{-19} C$, $m = 9.1 \times 10^{-31} kg$)

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