M. Sc. (Physics) 4th Semester Examination 2019
PHY 522 (Material Physics)

Answer in your own words as far as practicable. The marks on the right-hand margin indicate the full marks for the question.

F.M- 50

Time- 2hrs

Answer Q. 1 and any three from the rest

1. Answer any five of the followings: $5 \times 4 = 20$

(a) Estimate the fraction of electrons in 3d free electron gas at $T = 0$ between $E_F - \epsilon$ and E_F ($\epsilon \ll E_F$). What is the average level spacing at the Fermi energy of such a system?

2+2

(b) State two important properties of a carbon nanotube. How many individual calculations must be performed to analyze the movement of water molecule (dimension 0.14 nm) in a carbon nanotube with a radius of 30 nm and a length of 1mm?

2+2

(c) Define absorption coefficient $\alpha(\omega)$. Show that for direct band gap (E_g) 3d material with parabolic band edge, $\omega\alpha(\omega) \propto (\hbar\omega - E_g)^2$.

1+3

(d) Derive Scherrer's formula, $S = \frac{k\lambda}{\beta \cos(\theta)}$ where the symbols have their usual meaning. Discuss how the grain size of a poly-crystalline material affects the XRD pattern.

4

(e) Show that in a crystalline lattice the diffusion coefficient, D is given by $D = \alpha^2 p\tau$ where α is the inter planar spacing, p the jumping probability and τ is the jump frequency.

4

(f) Consider a trilayer (ferromagnetic-non magnetic-ferromagnetic) Giant Magneto-Resistive (GMR) system. If the resistance for the spin up and down electrons through the ferromagnetic layer and the scattering at the interface to the non-magnetic layer is $R_\uparrow$ and $R_\downarrow$, respectively, then show that

$$\Delta R = R_H - R_0 = -\frac{1}{2}\frac{(R_\uparrow - R_\downarrow)^2}{(R_\uparrow + R_\downarrow)}$$

where R_0 and R_H is the resistance in absence and in presence of magnetic field of strength H. 4

2. (a) Discuss the role of nucleation in artificial rain making.
(b) Subsitutional diffusion occurs between two atoms A and B. If D_A, D_B are the diffusion coefficients and x_A, x_B are the concentrations of A and B atoms respectively, then show that, the expression for mutual diffusion coefficient ($\bar{D}$) is given by:

$$\bar{D} = D_A x_B + D_B x_A.$$

(c) Consider Free Energy composition diagram for a binary alloy consisting of x_1, x_2 mole fractions of atoms '1' and '2', respectively. If ΔG_m is free energy change due to mixing and G_s is the free energy per mole of the solution, then derive and plot:
i) ΔG_m versus composition for the ideal solution
ii) G_s versus composition for the exothermic solution.

2+4+4

3. (a) Starting from the expression for the elastic scattering cross section, state why high voltages are used in the operation of Transmission Electron Microscope (TEM).
(b) Write down the concept of mass-thickness contrast mechanism in TEM image formation of non-crystalline specimen.
(c) State with an example the working principle of a Field Emission source used in an electron microscope.
(d) Discuss the origin of Secondary Electron (SE) and Back Scattering Electron (BSE) in a Scanning Electron Microscope (SEM). What is the advantage of BSE image over SE image in a SEM?

2+2+2+4

4. (a) Define permeability tensor μ_{ij} of a magnetic system. Show from thermodynamics that $\mu_{ij} = \mu_{ji}$.
(b) What are the basic assumptions in Drude model? Using this model, obtain the value of the optical sum rule $\int_0^\infty \omega\epsilon_2(\omega)d\omega$ where $\epsilon_2(\omega)$ is the imaginary part of the dielectric function. What is the implication of such a sum rule?

(c) A magnetic material EuO exhibits a straight line graph with a postive intercept when $C/T^{3/2}$ (C is the specific heat) is plotted against

$T^{3/2}$ at low temperature (T). Indicate the nature of the magnetic material and its dimensionality.

(1+2)+(2+2+1)+2

5. (a) Why graphene is called a semimetal? The low energy excitation in two-dimensional (2d) sheet of graphene is $E(k) = \hbar v k$, v is the velocity of excitaton. Obtain an expression of density of states (DOS) as a function of energy. In which way is this DOS different from a 2d conventional metal?

   (b) Consider the asymmetrical dependence of potential energy of atomic separation of the form

$$U(s) = \tfrac{1}{2}k_0 s^2 - \tfrac{1}{3}\mu s^3,\ s = r - r_0,\ \mu \ll k_0^2$$

   where r_0 is the equilibrium distance. Show that the thermal expansion coefficient is independent of temperature and is given by $\frac{\mu k_b}{r_o k_0^2}$.

   (c) Consider the Landau free energy $F(m, h, T)$ for ferromagnetic to paramagnetic phase transition

$$F(m, h, T) = F_0 + a_0(T - T_C)^x\ m^2 + a_4\ m^4 - hm$$

   where a_0, a_4 and $h > 0$. What could be the value of x from the experimental point of view and why? Obtain the specific heat critical exponent α.

(1+2+1)+3+3

6. (a) State and prove Hohenberg-Kohn theorem in density functional theory.

   (b) What is a quantum dot? What will be the minimum diameter of a quantum dot that can effectively confine an electron in Copper with a ground state energy equal to the Fermi energy of 7 eV?

   (c) The exchange energy of a homogeneous electron gas is given by:

$$E_X(n, V) = -\tfrac{1}{2} \times 2 \sum_{i,j} \int d^3r \int d^3r' \ \frac{\phi_i^*(r)\phi_i(r')\phi_j^*(r')\phi_j(r)}{|\vec{r} - \vec{r'}|}$$

   Show that $E_X(n, V)$ satisfies the following equation:

$$n\frac{\partial \log E_X}{\partial n} + V\frac{\partial \log E_X}{\partial V} = \frac{7}{3}$$

(1+3)+(1+2)+3