PHYSICS - II
(PHYS 2111)

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) If a system is initially at $|\psi\rangle = \sum_i c_i\, |\Phi_i\rangle$ and outcome of a measurement is λ_j, then the system immediately after measurement is
(a) $|\Phi_j\rangle$ (b) Any possible i[th] state (c) $|\psi\rangle$ (d) None of the above

(ii) Dimension of an axis of a reciprocal lattice vector
(a) [L] (b) dimensionless (c) $[L]^{-1}$ (d) $[L]^{-2}$

(iii) Momentum operator in one dimension is given by
(a) $\frac{i}{\hbar}\frac{\partial}{\partial x}$ (b) $-\frac{\hbar}{i}\frac{\partial}{\partial x}$ (c) $i\hbar\frac{\partial}{\partial x}$ (d) $\frac{\hbar}{i}\frac{\partial}{\partial x}$

(iv) $[\hat{p}_x, \hat{x}]$ is equal to
(a) $i\hbar$ (b) $i\hbar^2$ (c) 0 (d) $-i\hbar$

(v) The relation between phase velocity and group velocity is given by
(a) $v_g = v_{ph}$ (b) $v_g = v_{ph} - \lambda^2 \frac{dv_{ph}}{d\lambda}$
(c) $v_g = v_{ph} + \lambda \frac{dv_{ph}}{d\lambda}$ (d) $v_g = v_{ph} - \lambda \frac{dv_{ph}}{d\lambda}$

(vi) Which of the following materials do not have a permanent magnetic moment of the individual atoms?
(a) Ferromagnetic (b) Paramagnetic
(c) Diamagnetic (d) Ferrimagnetic.

(vii) Ferrimagnetic materials can also be called as imperfect-
(a) aniferromagnets (b) ferromagnets (c) diamagnets (d) parramagnets.

(viii) Critical magnetic field of a superconductor varies with temperature as: $B_C \approx B_C(0)\left[1 - \left(\frac{T}{T_C}\right)^n\right]$. Here, n is:
(a) 1 (b) 2 (c) -1 (d) -2

(ix) Which of the following rotational symmetry is not possible in a crystal
(a) 2 fold (b) 3 fold (c) 4 fold (d) 5 fold

(x) Distance between two neighbouring atoms along [111] direction of an fcc crystal unit cell

(a) $a/\sqrt{3}$ (b) $a/2$ (c) $a\sqrt{3}$d) (d) $a\sqrt{3}/2$.

Group- B

2. (a) Write the statement of Heisenberg's uncertainty principle along with the mathematical relation for two conjugate variables. [(CO1)(Analyze/IOCQ)]

(b) Establish mathematically the relation between group velocity and the phase velocity with respect to plane wave. [(CO1)(Create/HOCQ)]

(c) Show that $\frac{d}{dt}\langle A\rangle = \frac{1}{i\hbar}[A,H]$ where A and H are any operator and H is the Hamiltonian operator of a quantum system. [(CO1)(Analyze/IOCQ)]

(d) Normalise the wave function $\psi_n = sin\frac{n\pi x}{L}$ for a particle confined within a one dimensional infinite potential wave. [(CO1)(Apply/IOCQ)]

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

3. (a) Write down the restrictions on potential energy for a 1D infinite potential well. Solve the Schrodinger equation to obtain the wave function representing the confined particle. [(CO1)(Analyze/IOCQ)]

(b) If an operator A commutes with the Hamiltonian H of a system and $|\psi\rangle$ is an eigenvector of H corresponding to the eigenvalue E then show that $A|\psi\rangle$ is also an eigenvector of H with the same eigenvalue. [(CO1)(Remember/LOCQ)]

(c) Obtain the commutation relation between the operators $[L^2, L_z]$.
[(CO1)(Analyze/IOCQ]

(d) Show that Hermitian operators have real Eigen value. [(CO1)(Analyze/IOCQ]

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

Group - C

4 (a) Suppose $\overrightarrow{\mu_m^0}$ is the magnetic dipole moment of an individual atom in a paramagnetic sample kept in an absolute temperature T. If we keep that sample inside an external magnetic field $\vec{B}$ what will be the probability of this magnetic dipole to make an angle between θ and $\theta + d\theta$ with the external magnetic field? [(CO2)(Evaluate/HOCQ)]

(b) Langevin function for paramagnetic materials is $a = \frac{e^a+e^{-a}}{e^a-e^{-a}} - \frac{1}{a}$ where $a = \frac{\mu_m^0 B}{KT}$. Show if the magnetic field is not too high and temperature is not too low, i.e. $a \ll 1$, then the Langevin function takes an approximate value of $\frac{a}{3}$.
[(CO2)(Evaluate/HOCQ)]

(c) Graphically show the variation of susceptibility is inverse with temperature for ferromagnetic and anti-ferromagnetic materials, qualitatively explaining the plots.
[(CO2)(Understanding/LOCQ)]

4 + 4 + 4 = 12

5. (a) Write down the differences between a perfect conductor and a superconductor and hence explain Meissner effect. [(CO3)(Analyze/IOCQ)]

(b) Establish London equation of superconductivity in terms of magnetic field induction. Define London penetration depth. [(CO3)(Apply/IOCQ)]

(c) Write down two fundamental differences between type-I and type –II superconductors [(CO3)(Remember/LOCQ)]

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

Group - D

6. (a) Describe an inversion centre in crystal lattice? Recognise that a 2-fold rotation plus a mirror plane is equivalent to an inversion. [(CO4)(Analyze/IOCQ)]

(b) Find out the angle between two primitive basis vectors of a bcc lattice. [(CO4)(Evaluate/HOCQ]

(c) Draw a cubic unit cell in each case and illustrate $(2\bar{2}0)$ and $(1\bar{1}0)$ planes. [(CO4)(Analyze/IOCQ]

(d) Atomic volume of fcc copper is 7.1×10^{-6} m^3/mole. Find out the interplanar spacing of (110) planes. [(CO4)(Evaluate/HOCQ]

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

7. (a) Obtain Bragg condition from $2\,\vec{k}.\vec{G} = G^2$, the symbols have their usual meanings. [(CO4)(Create/HOCQ)]

(b) A beam of X-rays of wavelength 0.154 nm is diffracted by (110) plane of fcc rock salt with lattice constant of 0.28 nm. Find the glancing angle for the second-order diffraction. [(CO4)(Evaluate/HOCQ)]

(c) Show that the reciprocal lattice for a simple cubic structure is another simple cubic. [(CO4)(Analyze/IOCQ)]

(d) Explain Ewald construction with diagram. [(CO4)(Understand/LOCQ)]

(e) If energy required for taking an atom from lattice site inside the crystal to lattice site on surface is 1 eV at temperature 1000 K, find out the ratio of number of vacancies to that of atoms. [(CO4)(Apply/IOCQ)]

3 + 2 + 2 + 3 + 2 = 12

Group – E

8. (a) Graphically illustrate the total energy of interaction in an ionic crystal as a function of interatomic distance. At which distance the energy will be minimum. [(CO5)(Remember/LOCQ)]

(b) Explain the importance of Brillouin zone. Sketch approximately the phonon dispersion curves for a NaCl crystal in the 1^{st} Brillouin zone. [(CO5)(Understand/LOCQ)]

(c) The group velocity in a certain linear monatomic chain at small k is 1.05×10^4 m/s. If the mass of each atom is 6.31×10^{-26} kg and the atomic separation at equilibrium is 0.48 nm, find the effective spring constant and the maximum normal mode angular frequency. [(CO5)(Analyse/IOCQ)]

(d) Describe the phonon dispersion relations from the inelastic scattering of neutrons with emission or absorption of phonon. [(CO5)(Analyse/IOCQ)]

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

9. (a) The energy of a free electron in a crystal is a function of wave number given by $E(k) = A - 2B \cos ka$, where A, B are constants and a is distance between adjacent atoms. Figure out the effective mass of electron. Explain why the mass of a hole in a partially filled band is negative. [(CO6)(Understand/LOCQ)]
(b) Explain the importance of Kronig-Penney model over free electron theory. Explain Bloch theorem in 1 dimension. [(CO6)(Understand/LOCQ)]
(c) If $V(x)$ is periodic, prove that for $Tf(x) = f(x+a)$, $H\{T\phi(x)\} = E\{T\phi(x)\}$. [(CO6)(Evaluate/IOCQ)]

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

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	29.2	49	21.8

Course Outcome (CO):

After the completion of the course students will be able to

1. To understand the concept of mechanics of Quantum Particles and hence their strange behavior which ultimately imparting the knowledge of nano – science and its applications in nanotechnology.
2. To understand magnetic properties and magnetic behaviour of materials which will enrich the industrial use of different materials for various purposes.
3. To understand the physics behind the superconducting properties of materials and their industrial and medical usefulness.
4. Understand the physics behind X-ray diffraction in crystalline structure of a material, and the different imperfection in it.
5. To understand the basic difference between the atomic structure of an isolated atom and atoms in solids differ and accordingly assures the electrical and thermal properties of solids.
6. To study the energy band formation in solids and the behavior of electron and hole in the bands.

*LOCQ: Lower Order Cognitive Question; IOCQ: Intermediate Order Cognitive Question; HOCQ: Higher Order Cognitive Question.