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) The span of first Brillouin zone of a crystal vibration with diatomic lattice having lattice constant 'a' is

(a) $-\pi a \leq k \leq \pi a$ (b) $-\frac{\pi}{a} \leq k \leq \frac{\pi}{a}$

(c) $-\frac{2\pi}{a} \leq k \leq \frac{2\pi}{a}$ (d) $-\frac{\pi}{2a} \leq k \leq \frac{\pi}{2a}$

(ii) Expression of kinetic energy operator is

(a) $\frac{\hbar^2}{2m}\nabla^2$ (b) $\frac{\hbar}{2m}\nabla^2$ (c) $-\frac{\hbar^2}{2m}\nabla^2$ (d) $-i\hbar\vec{\nabla}$

(iii) Potential energy of a magnetic dipole in a magnetic field is given by

(a) $-\vec{\mu}_m^0.\vec{B}$ (b) $|\vec{\mu}_m^0 \times \vec{B}|$ (c) $\vec{\mu}_m^0.\vec{B}$ (d) $-|\vec{\mu}_m^0 \times \vec{B}|$

(iv) Dimension of a reciprocal lattice vector is

(a) [L] (b) $[L]^0$ (c) $[L]^{-1}$ (d) $[L]^{-2}$

(v) Number of lattice points in an fcc copper unit cell is

(a) 1 (b)2 (c) 3 (d) 4.

(vi) A superconducting material becomes

(a) ferromagnetic (b) diamagnetic

(c) paramagnetic (d) anti-ferromagnetic.

(vii) Which of the following cannot be a wave function representing a quantum particle?

(a) $e^{-|x|}$ (b) $e^{-|x^2|}$ (c) e^x (d) $\sin x$ for two boundaries.

(viii) The essential condition for scattering is

(a) E < V (b) E = V (c) E > V (d) E = 0

Where E and V stands for total energy of the quantum particle and potential energy of the field respectively.

(ix) Which one is not a primitive translation vector of fcc lattice?
(a) $\frac{a}{2}\hat{\imath}+\frac{a}{2}\hat{\jmath}$ (b) $\frac{a}{2}\hat{\imath}-\frac{a}{2}\hat{\jmath}$ (c) $\frac{a}{2}\hat{\jmath}+\frac{a}{2}\hat{k}$ (d) $\frac{a}{2}\hat{k}+\frac{a}{2}\hat{\imath}$

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

Group – B

2. (a) What do you mean by wave packet with reference to quantum particle? Show that the particle velocity of a quantum particle is equal to the group velocity of the associated wave packet.

(b) Eigen function of a particle in 1-D infinite potential well of width L is given by,
$\emptyset_n(x) = \sqrt{\frac{2}{L}}\sin(\frac{n\pi x}{L})$
For the ground state eigen function (n=1) obtain $\langle x\rangle$ and $\langle E\rangle$

(c) Prove the following commutation relations,
$[\widehat{x},\widehat{p_x}] = i\hbar$ and $[\widehat{L_x},\widehat{L^2}] = 0$

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

3. (a) Write down the 1-dimensional time dependent Schrodinger equation for a quantum particle. Using the method of separation of variables establish time independent Schrodinger equation from the time dependent one.

(b) Normalize the standard free particle wave function.

(c) Find the eigen function of the momentum operator $\widehat{p_x} = -i\hbar\partial/\partial x$ corresponding to the eigen value p_x.

(d) What do you mean by the process of quantum tunneling?

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

Group – C

4. (a) Consider an electron moving in a circular Bohr orbit of radius r. Find out an expression of its orbital magnetic moment. Show that its direction is opposite to the orbital angular momentum of the electron.

(b) In terms of atomic magnetic dipole moment and susceptibility, differentiate dia-, para-, ferro- and ferrimagnetic materials.

(c) Graphically show the variation of susceptibility inverse with temperature for ferromagnetic and anti-ferromagnetic materials, qualitatively explaining the plots.

(d) Applying Hund's rule and Pauli's exclusion principle show that the Cr^{2+} ion does not have permanent magnetic dipole moment (atomic number of Cr is 24).

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

5. (a) Establish London equation of superconductivity in terms of magnetic field induction. Define London penetration depth.

   (b) Write down the differences between a perfect conductor and a superconductor and hence explain Meissner effect.

   (c) Define critical magnetic field for a superconductor and explain how it varies with sample temperature.

   (d) Write down three differences between type-I and type –II superconductors.

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

Group – D

6. (a) Draw a cubic unit cell and show [111] and $[11\bar{2}]$ directions. Find out the angle between these two directions in a cubic lattice in degrees.

   (b) Find out the distance of nearest neighbors along [110] of a fcc Cu having atomic volume 7.1×10^{-6} m^3/mole.

   (c) What is the lattice type and the atom positions in a basis (motif) of a diamond crystal?

   (d) Find out h, k, l values for (hkl) planes with an interplanar spacing of 0.1576 nm in cubic Ni, having cell length a = 0.3524 nm.

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

7. (a) Prove that the reciprocal lattice vector $\mathbf{G} = h\mathbf{b_1} + k\mathbf{b_2} + l\mathbf{b_3}$ is perpendicular to (hkl) plane, where $\mathbf{b_1}$, $\mathbf{b_2}$ and $\mathbf{b_3}$ are three reciprocal primitive vectors. Show that the distance between two adjacent parallel planes of the lattice is $2\pi/|\mathbf{G}|$.

   (b) The edge length of the Ag fcc unit cell, $a = 0.4086$ nm. An X-ray beam produces a strong interference from the (111) planes at 2θ = 38.12°. What is the X- ray wavelength?

   (c) "The diffraction pattern does not contain lines such as (100), (300), (111) or (210) for bcc lattice" - justify from the concept of structure factor.

   (d) Write down Bragg condition in terms of wave vector and reciprocal lattice vector. Obtain $2d \sin\theta = n\lambda$ relation from it.

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

Group – E

8. (a) What is phonon? How is the mean square phonon amplitude quantized?

   (b) Write down the expression for group velocity in a diatomic lattice vibration and find its values at $k = 0$ and at the boundaries of the first Brillouin zone for optical and acoustic branches. Justify the name 'optical' of optical branch.

(c) Show graphically the expression of the total energy of interaction in an ionic crystal as a function of interatomic distance.

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

9. (a) Explain the failures of Drude Sommerfeld model. State Bloch theorem in 1-d.

(b) An operator $\hat{T}$ is defined as $\hat{T}f(x) = f(x + a)$, prove that $\hat{H}\{\hat{T}g(x)\} = E\{\hat{T}g(x)\}$ (Symbols have their usual meanings).

(c) The energy-wave vector dispersion relation for a one dimensional crystal of lattice constant a is given by $E(k) = E_0 - \alpha k - 2\beta\cos ka$, where E_0, α, β are constants. Find the value of k at which the group velocity of an electron is maximum. Find the difference between the top and the bottom of the energy band. Find the effective mass of the electron and that of the hole.

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

Department & Section	Submission Link
CHE	https://classroom.google.com/c/MTIyOTUwMjc5NDAz/a/Mjc0NDE0NjU1ODU0/details