3 (Sem–5/CBCS) PHY HC 1

2022

**PHYSICS**

(Honours)

Paper : PHY–HC–5016

***(Quantum Mechanics and Applications)***

*Full Marks : 60*

Time : Three hours

***The figures in the margin indicate full marks for the questions.***

1. Answer ***any seven*** of the following : 1×7=7

   *(a)* Write down the expression of wave function of matter wave associated with a free particle travelling along the $x$-axis having momentum $p$ and energy $E$.

   *(b)* Is the function $\psi = a\cos m\phi$ an eigen-function of $z$-component of angular momentum operator ? Give reason.

   *(c)* Why $\psi = ax^2$ is not an acceptable wave function in quantum mechanics ?

(d) Write down the condition of orthogonality of wave function.

(e) When does the quantum mechanical probability of oscillator become identical with the classical probability ?

(f) How do you represent dynamical variables in quantum mechanics ?

(g) The number of permitted eigenvalues in a finite potential well is :

(i) two

(ii) zero

(iii) fixed for well of any height

(iv) variable, depending on the height of the well

(h) What is the total number of energy level (or degeneracy) for the $n$th state of hydrogen atom ?

(i) Why does the normal Zeeman effect occur only in atoms with even number of electrons ?

(j) What is the need of an inhomogeneous magnetic field in Stern-Gerlach experiment ?

(k) The spin-orbit interaction has no effect on

(i) $f$-state

(ii) $\delta$-state

(iii) $d$-state

(iv) $p$-state



(l) What is Bohr magneton ?

2. Answer ***any four*** of the following : 2×4=8

(a) What are the conditions and limitations that the wave function must obey ?

(b) Show that $\left[\hat{x}^n, \hat{P}_x\right] = i\hbar n x^{n-1}$

(c) The one-dimensional wave function is given by $\psi(x) = \sqrt{a}\, e^{-ax}$. Find the probability of finding the particle between $x = \frac{1}{a}$ and $x = \frac{2}{a}$.

(d) What is a Gaussian wave packet ? Express its wave function.

(e) For a free particle, show that the group velocity of the wave packet is equal to the classical velocity of the particle.

(f) What do you mean by Larmor precession ? What is Larmor frequency ?

(g) Determine the value of spin magnetic momentum of free electron.

(h) Determine the possible values of resultant angular momentum for two electrons having $j_1 = \frac{3}{2}$ and $j_2 = -\frac{5}{2}$.

3. Answer ***any three*** of the following : 5×3=15

(a) In what respect does Schrödinger equation differ from classical wave equation ? Obtain the three-dimensional time independent Schrödinger equation from the time-dependent form. 1+4=5

(b) What do you understand by the wave function $\psi$ of a moving particle ? Give its physical significance. What does the square of wave function signify ? 1+2+2=5

(c) What is an operator ? Write the expression for position operator, momentum operator and energy operator. What is Hamiltonian operator ? 1+3+1=5

(d) Use the time independent Schrödinger equation to find $V(x)$ and energy $E$ for which the wave function is

$$\psi(x)=\left(\frac{x}{x_0}\right)^n e^{-x/x_0}$$

where $n$ and $x_0$ are constants.

Assume $V(x)\to 0$, as $x\to\infty$.



(e) What is the significance of zero point energy ? Calculate the zero point energy for an oscillating mass of 1$gm$ connected to a spring, which is stretched 1$cm$ by a force 0·1$N$. The particle is constrained to move along the $x$-axis. 2+3=5

(f) Derive an expression for orbital magnetic moment due to electron rotating arround the nucleus of an atom. What is Bohr magneton ? 4+1=5

(g) What is Lande's $g$-factor ? Calculate the Lande's $g$-factor for the $^3P_1$ state. Use the result to predict the splitting of the energy level when the atom is placed in an external magnetic field of 0.1 Tesla.
(Given Bohr magneton = $9.3\times10^{-24}Am^2$) 1+1+3=5

(h) The atomic number of Beryllium is 4. Determine its

(i) electronic configuration in ground state.

(ii) electronic configuration in first excited state.

(iii) spectroscopic terms in the ground state.

(iv) spectroscopic terms in the first excited state.

4. Answer ***any three*** of the following : 10×3=30

(a) (i) What is the need for differential wave equation ? Starting from the wave equation and introducing energy and momentum of the particle, obtain expression for one dimensional Schrödinger time dependent wave equation for waves associated with a moving particle in a potential field $V$. 1+4=5

(ii) What is the physical significance of $\int_{-\infty}^{+\infty} |\psi|^2 \, dx = 1$ ?

A particle is represented by the wave function $\psi(x) = Ae^{-|x|} \sin \alpha x$ Evaluate the normalization constant $A$, $\alpha$ being a constant. 1+4=5

(b) (i) Calculate the normalization constant for a wave function (at $t = 0$) given by $\psi(x) = ae^{-\left(\alpha^2 x^2\right)/2} e^{ikx}$ known as Gaussian wave packet. Determine.

(ii) the probability density and



(iii) probability current density for this function. 4+2+4=10

(c) Write the radial equation of Hydrogen atom and solve it for obtaining its energy eigenvalues. 2+8=10

(d) Discuss classical and quantum interpretations of square well potential of finite depth and determine allowed values of energy using graphical method. Also sketch the wave functions corresponding to three lowest energy levels.

(e) (i) What are symmetric and anti-symmetric wave functions ? 2

(ii) State and explain Pauli's exclusion principle. How does a knowledge of symmetric and anti-symmetric wave functions lead to this principle ? 5+3=8

(f) Describe and explain $LS$ and $JJ$ couplings. Illustrate them with vector diagram. Give the selection rules for $L$, $S$ and $J$. 2+2+4+2=10

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*Contd.*

(g) Elucidate anomalous Zeeman effect using concept of 'spin' of electrons. Illustrate the anomalous Zeeman effect for Sodium D-lines. 6+4=10

(h) Write short notes on *any two* of the following : 5×2=10

(i) Stern-Gerlach experiment

(ii) Paschen-Back effect

(iii) Stark effect

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**3 (Sem–5/CBCS) PHY HC 2**

**2022**

**PHYSICS**

( Honours )

Paper : PHY–HC– 5026

***( Solid State Physics )***

*Full Marks : 60*

Time : Three hours

***The figures in the margin indicate full marks for the questions.***

1. Choose the correct answer from the following : ***(any seven)*** 1×7=7

   *(a)* The number of atoms per unit cell of a body centred cubic lattice (bcc) is

   *(i)* 8

   *(ii)* 1

   *(iii)* 3

   *(iv)* 2

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   *(a)* The number of atoms per unit cell of a body centred cubic lattice (bcc) is

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(b) Classify the following unit cell into proper crystal system, $a = 1.08$ *nm*, $b = 1.947$ *nm*, $c = 0.52$ *nm* and $\alpha = 41^\circ$, $\beta = 82^\circ$, $\gamma = 95^\circ$

(i) Triclinic

(ii) Monoclinic

(iii) Orthorhombic

(iv) Hexagonal

(c) Because of which property of the crystals, X-rays can be defracted from the crystals ?

(i) Random arrangement of atoms

(ii) Colour of the crystals

(iii) Periodic array of atoms

(iv) None of the above

(d) The harmonic oscillator can have values of energy as

(i) $n\hbar w^2$

(ii) $n^2\hbar w$

(iii) $n\hbar w$

(iv) $2n\hbar w$



(e) The unit of magnetic susceptibility is

(i) $Wb/m^2$

(ii) $Wb/m$

(iii) $amp/m$

(iv) unitless ratio

(f) Diamagnetic materials possess

(i) permanent magnetic dipoles

(ii) no permanent magnetic dipoles

(iii) induced dipole moment

(iv) None of the above

(g) Most widely used conducting materials are

(i) germanium and silicon

(ii) copper and alumium

(iii) gold and silver

(iv) tungsten and platinum

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(h) Transition temperature $T_c$ and critical field $H_c$ for a superconductor are related to ( $H_0$ : critical field at $0K$, $T_0$ : Transition temperature at $0^\circ K$.)

(i) $H_c = H_0(T_c - 1)$

(ii) $H_c = H_0(T_c + 1)$

(iii) $T_c = T_0\left[1 - \left(\frac{H_0}{H_c}\right)^2\right]$

(iv) $H_c = H_0\left[1 - \left(\frac{T}{T_c}\right)^2\right]$

(i) The forbidden energy gap of carbon in diamond structure is

(i) 0.7 $eV$

(ii) 1 $eV$

(iii) 0.01 $eV$

(iv) None of the above



(j) Intrinsic germanium can be made P-type semiconductor by doping with

(i) phosphorous

(ii) aluminium

(iii) sulphur

(iv) carbon

(k) The polarization $P$ in a solid, dielectric field $E$ and the electric flux density $D$ can be related by the relation

(i) $E = \varepsilon_0 D + P$

(ii) $D = E + \varepsilon_0 P$

(iii) $D = E\varepsilon_0 + P$

(iv) $D = \varepsilon_0 (E + P)$

(l) The chemical formula for magnetite is

(i) $Fe_2O_3$

(ii) $FeO$

(iii) $Fe_3O_4$

(iv) $Fe(OH)_2$



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2. Give short answers of the following questions : ***(any four)*** 2×4=8

(a) Write the basic differences between crystal and amorphous solid.

(b) Show that for a simple cubic lattice $d_{100} : d_{110} : d_{111} = \sqrt{6} : \sqrt{3} : \sqrt{2}$

(c) (i) Define Fermi energy level.

(ii) Draw the Fermi function with respect to energy for the temperature at $T = 0K$ and $T = 300\,K$.

(d) What do you mean by magnetic permeability and magnetic susceptibility ?

(e) (i) Write the Dulong and Petit law related to specific heat of solid.

(ii) What do you understand by phonon ?

(f) How are the variation of resistance ($R$) with temperature ($T$) changes for normal conductor and super-conductor ? Draw a simple graph of $R$ vs $T$.

(g) Define dipole moment and polarization vector of dielectric.

(h) What do you mean by Atomic form factor and Geometrical structure factor ?



3. Answer ***any three*** from the following questions : 5×3=15

(a) (i) What do you mean by atomic packing factor of a crystal ? 1

(ii) Find out the packing factor of face centred cubic structure of a crystal. 4

(b) (i) Discuss the success and limitations of classical free electron theory of metal. 2

(ii) Why free electron theory is important in solid state physics ? 1

(iii) Write down basic differences of classical and quantum free electron theory of metals. 2

(c) (i) What is Hall effect ? 1

(ii) Find out the expression for Hall coefficient. 3

(iii) Write down the applications of phenomenon of Hall effect. 1

(d) What are differences between ferromagnetic, paramagnetic and diamagnetic materials ?

(e) Draw the band structure for intrinsic semiconductor, *p*-type and *n*-type semiconductor.

(f) (i) What do you mean by drift velocity, mobility of a conductor ? 2

(ii) Write the expression for conductivity of intrinsic and extrinsic semiconductor. 2

(iii) Why conductivity of a metal decreases with the increase of temperature ? 1

(g) (i) What is superconductivity ? 1

(ii) Explain type–I and type–II superconductor. 4

(h) Discuss Meissner effect of superconductor.

4. Answer the following questions : ***(any three)*** 10×3=30

(a) (i) Why X-rays are used for material characterization ? Can X-ray be defracted from a single slit of width 0.1 *mm* ? Justify your answer. 1+1=2



(ii) State the Bragg's law in X-ray diffraction of a crystalline solid. Derive its expression. 1+2=3

(iii) The spacing between successive plane in *NaCl* is 2.82 $\mathring{A}$ . X-rays incident on the surface of the crystal is found to give rise to 1st order Bragg's reflections at glancing angle $8.8^{\circ}$. Calculate the wavelength of X-rays.

(Given $\sin 8.8^{\circ} = 0.152$) 5

(b) (i) What is Miller indices in a crystal ? 1

(ii) How Miller indices are determined ? 2

(iii) Draw (100), (001), (010) and (111) plane of a simple cubic structure. 2

(iv) Miller indices of a plane is (326). Find out the point of intercept made by the plane along the three crystallographic areas $(x, y, z)$. 2

(v) The density of iron (having bcc structure) is 7900 $kg/m^3$ and its atomic weight is 56. Calculate lattice parameters. 3

(c) (i) State the Wiedemann-Franz law in solid. Discuss its physical significant. 2

(ii) Discuss the classical and quantum mechanical expression of Lorentz number. 5

(iii) For copper at 20 °C, the electrical and thermal conductivity are $1.7\times10^8\ \Omega m$ and 380 $Wm^{-1}K^{-1}$ respectively. Calculate Lorentz number. 3

(d) (i) Discuss the original concept of band theory of solid. 1

(ii) Discuss Kronig-Penney model related to band theory of solid. 8

(iii) What do you mean by Brillouin zones ? 1

(e) (i) What is specific heat of solid ? 2



(ii) Discuss Einstein theory of specific heat of solid. 8

(f) (i) Deduce the expression for Curie law using classical theory of paramagnetism. 8

(ii) What is ferromagnetic domain ? 1

(iii) How hysteresis curve is related to energy loss ? 1

(g) (i) Define Piezoelectric effect, Pyroelectric effect and Ferroelectric effect in solid. 3

(ii) Derive the Clausius-Mossotti equation for dielectric material. 7

(h) Write short notes on ***any two*** of the following : 5×2=10

(i) Bravais lattice

(ii) Reciprocal lattice

(iii) Symmetry in crystal

(iv) Plasma oscillations

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