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3 (Sem–5/CBCS) PHY HC1

2024

PHYSICS

(Honours Core)

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 the following questions : 1×7=7

(a) Eigenvalue of Hamiltonian operator is

(i) kinetic energy

(ii) potential energy

(iii) both (i) and (ii)

(iv) total energy

(b) Why $\psi = e^x$ is not an acceptable wave function in quantum mechanics ?

Contd.

(c) What do you mean by space quantisation of an atom ?

(d) The value of $\left[\hat{x}, \frac{\partial}{\partial x}\right]$ is

(i) 1

(ii) −1

(iii) $i\hbar$

(iv) $-i$

(e) What is the value of spin-orbit interaction energy for the ground state of hydrogen atom ?

(f) When does the probability density of a quantum mechanical oscillator approach that of a classical oscillator ?

(g) Can the Stern-Gerlach experiment be performed with ions instead of neutral atoms ?

2. Answer the following questions : 2×4=8

(a) Is the wave function $\psi(x) = e^{ikx}$ an eigenfunction of the kinetic energy operator T ? If yes, what is its eigenvalue ?

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

(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) Calculate the Lande's g factor for the $^2p_{3/2}$ state.

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

(a) State the conditions of "acceptability of wave function" in quantum mechanics with explanation.

(b) Obtain time-independent Schrödinger wave equation for a free particle in one dimension. Give a physical interpretation of the wave function $\psi(x,t)$. 4+1=5

(c) Find the expectation value of energy when the state of harmonic oscillator is described by the following wave function :

$$\psi(x,t) = \frac{1}{\sqrt{2}}\left[\psi_0(x,t) + \psi_1(x,t)\right]$$

where $\psi_0(x,t)$ and $\psi_1(x,t)$ are the wave functions for the ground state and first excited state respectively.

(d) State Pauli's exclusion principle. An atomic state is denoted by $^3p_2$. Determine the values of L, S and J and mention whether the above state is admissible or not. 2+3=5

(e) Discuss the significance of zero-point energy with reference to a linear harmonic oscillator. The energy of a linear harmonic oscillator in the third excited state is 0.1 eV. Find the frequency of vibration. 2+3=5

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

(a) (i) What is the need for normalization of a wave function ? A wave function $\psi(x)$ is given by

$$\psi(x) = A_n \sin\frac{2n\pi x}{L}$$ in the region $0 \le x \le L$. Find the value of A_n using normalization condition. 1+4=5

(ii) Derive the continuity equation from the time-dependent Schrödinger equation of a particle moving in a real potential and give its physical significance. 4+1=5

(b) A particle of mass m is moving in a one-dimensional potential given by

$$v(x) = 0 \text{ for } 0 \le x \le L$$

$$v(x) = \infty \text{ for } x < 0 \text{ and } x > L$$

Using appropriate boundary conditions, solve the Schrödinger equation and find allowed energy values and normalized wave functions of the particle. Also plot the eigenfunctions corresponding to different eigenvalues. 8+2=10

Contd.

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

(d) What is anomalous Zeeman effect ? Discuss the quantum mechanical theory of anomalous Zeeman effect, with special reference to Zeeman pattern for D_1 and D_2 lines of sodium. 2+8=10

(e) (i) Describe and explain LS and JJ couplings. Illustrate them with vector diagram. 2+2+4=8

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

(f) (i) A beam of electrons enters a uniform magnetic field of flux density $1.2 Wb/m^2$ in the z-direction. Find the energy difference between the electrons whose spins are parallel and anti-parallel to the field. 5

(ii) Write short note on ***any one*** of the following : 5

(i) Paschen-Back effect

(ii) Stark effect

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3 (Sem–5/CBCS) PHY HC2

2024

PHYSICS

(Honours Core)

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 of the following questions from the given options : 1×7=7

   (a) Atomic packing factor of simple cubic structure is

   (i) π

   (ii) $\pi/2$

   (iii) $\pi/4$

   (iv) $\pi/6$

Contd.

(b) A phonon does not have momentum but a phonam with wave vector k when interacts with other particles and fields, behaves as if it has a momentum

(i) $\hbar k$

(ii) hk

(iii) $\frac{1}{2}\hbar k$

(iv) $\frac{1}{2}hk$

(c) Two paramagnetic substances have susceptibilities χ_1 and χ_2 at absolute temperatures T_1 and T_2 respectively, then the ratio of χ_1 and χ_2 equals to

(i) $\frac{T_2}{T_1}$

(ii) $\frac{T_1}{T_2}$

(iii) $\frac{T_2^2}{T_1^2}$

(iv) $\frac{T_1^2}{T_2^2}$

(d) The polarisation which is observed in all kinds of materials is

(i) ionic polarisation

(ii) dipolar polarisation

(iii) electronic polarisation

(iv) space charge polarisation

(e) Piezoelectric coefficients of ferroelectrics are

(i) very small

(ii) small

(iii) large

(iv) very large

(f) For a sample having $8\times10^{28}/m^3$ numbers of electrons per unit volume, the Hall coefficient will be

(i) $0.078\times10^{-9}\,m^3/C$

(ii) $0.128\times10^{-9}\,m^3/C$

(iii) $0.081\times10^{-9}\,m^3/C$

(iv) $0.016\times10^{-9}\,m^3/C$

(g) The critical temperature of mercury with isotropic mass 199.5 *amu* is 4.185*K*. When its isotropic mass changes to 203.4 *amu*, the critical temperature will be

(i) 4.198*K*

(ii) 4.169*K*

(iii) 4.146*K*

(iv) None of the above

2. Answer the following questions : 2×4=8

(a) What is complex dielectric constant ?

(b) Explain, what do you mean by first-order and second order phase transition in case of ferroelectric crystals.

(c) Describe the significance of Block function.

(d) Draw the unit cell of simple cubic lattice showing clearly the Miller indices of all its six faces.

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

(a) Show that the reciprocal lattice of a bcc lattice is a fcc lattice.

(b) How lattice vibrations are quantized ? Name the various vibrational modes of a linear monoatomic lattice. Differentiate between normal processes and umklapp processes. 2+1+2=5

(c) What do you mean by ferromagnetic domain ? Explain the role of Block wall in case of domain formation. What is magnetic energy and anisotropic energy ? 1+2+2=5

(d) What do you mean by Fermi level ? What is Fermi sphere ? Write down the Fermi distribution function at temperature *T*. Give a schematic representation of this function at temperatures T_1 and T_2, where $T = 0^\circ K$ and $T_2 > T_1$. 1+1+1+2=5

(e) Differentiate between Type I and Type II superconductors showing their magnetisation curves. What is intermediate state ? 3+2=5

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

(a) (i) Show that Bragg's law in vector form when obtained from Ewald construction in reciprocol lattice is given by

$$G^2 + 2\,\vec{k}.\vec{G} = 0$$

where $\vec{G}$ is reciprocal lattice vector. 7

(ii) When X-rays of wavelength 1.8 Å are used, the Bragg's angle corresponding to the first-order reflection from (1, 1, 1) planes in a crystal is 45°. Calculate the interatomic spacing for the crystal. 3

(b) (i) Obtain Debye's T^3 law of specific heat of solids. 7

(ii) Evaluate the Debye frequency of a crystal lattice corresponding to Debye temperature 350*K*. Given that Boltzmann constant is $1.38 \times 10^{-23}\ m^2 kg\, s^{-2} K^{-1}$ 3

(c) (i) Use Langevin's classical theory to show that the paramagnetic susceptibility is inversely proportional to temperature. 7

(ii) The magnetic field of 20 CGS units produces a flux of 2400 CGS units in an iron bar of cross-section $0.2\,cm^2$. Calculate the permeability and susceptibility of this bar. 3

(d) (i) Establish Clausius-Mossotti relation between polarisability and dielectric constant of a material. 7

(ii) Calculate the induced dipole moment per unit volume of *He* gas placed in an electric field of $6 \times 10^5\, volt/m$. The molecular polarisability of *He* is 2.33×10^{-41} farrad$-m^2$ and the density of *He* is 20.6×10^{25} molecules/m^3. 3

(e) (i) Use free electron theory of metals to show that at constant temperature the ratio of thermal to electrical conductivity of metals is a constant. 7

(ii) For a semiconductor, the intrinsic carrier density is $1.5 \times 10^{16} m^{-3}$. If the mobility of electrons and holes are 0.13 and $0.5 m^2 V^{-1} s^{-1}$ respectively, calculate the conductivity. 3

(f) (i) State the Curie-Weiss law. What do you mean by Ferroelecrtic Curie temperature ? Explain in brief the significance of P-E hysteresis loop in case of ferroelectricity.

2+1+2=5

(ii) Write down the London equations of superconductivity. Show that Meissner effect contradicts the Maxwell's equation. 2+3=5