Total number of printed pages–8

3 (Sem–5 /CBCS) PHY HC 1

2021

(Held in 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 the following questions : 1×7=7

(a) Write down the quantum mechanical form of total energy operator of a particle moving in *x*-direction.

(b) Determine whether or not $\psi(x) = e^x$ is an acceptable wave function.

Contd.

(c) Show that $\left[x, \frac{\delta^2}{\delta x^2}\right] = -2\frac{\delta}{\delta x}$

(d) How does the number of superimposed waves, forming a wave packet, affect the localization of the particle ?

(e) What is Landé g-factor ?

(f) What is the total number of energy level (or degeneracy) for the nth state of hydrogen atom ?

(g) The splitting of a spectral line in the presence of external electric field is termed as

(i) Anomalous Zeeman effect

(ii) Paschen-Back effect

(iii) Normal Zeeman effect

(iv) Stark effect

2. Answer the following questions : $2\times4=8$

(a) What is the physical significance of the wave function $\psi(x, t)$?

(b) A particle with total energy E is influenced by a potential energy $V(x)$. Show that the one-dimensional Schrödinger equation can be written in the form

$$\left[\frac{d^2}{dx^2}+k^2-U(x)\right]\psi(x)=0$$

where,

$$k^2=\frac{2mE}{\hbar^2} \quad \text{and} \quad U(x)=\frac{2mV(x)}{\hbar^2}$$

(c) Show that $\hat{p}_x=-i\hbar\frac{d}{d\phi}$ is an Hermitian operator.

(d) A particle of mass m and moving in a potential $v(x)$ has the wave function

$$\psi(x,t)=A\exp\left(-ikt-\frac{km}{\hbar}x^2\right)$$

where both A and k are constants. Determine the explicit form of the potential.

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

(a) What do you mean by expectation value of a dynamical variable ? Find the expectation value $<p>$ and $<p^2>$ for the wave function

$$\psi(x) = \sqrt{2/L}\ \sin\left(\frac{\pi x}{L}\right) \quad \text{for } 0<|x|<L$$
$$\text{for } \quad |x|>L$$

1+(2+2)=5

(b) Show that if $\psi_1(\vec{r})$ and $\psi_2(\vec{r})$ are two independent solutions of the Schrödinger equation, then

$$\psi(\vec{r}) = a_1\psi_1(\vec{r}) + a_2\psi_2(\vec{r})$$

is also a solution of the Schrödinger equation. What does it imply ?

4+1=5

(c) What are momentum space wave functions ? Show that these wave functions can be obtained as Fourier transform of position space wave functions.

1+4=5

(d) Write down the radial wave function for $1s$ state of hydrogen atom. Also, compare the probabilities of a $1s$ electron in the hydrogen atom being at a distance a_0 from the nucleus than at a distance $a_0/2$. 1+4=5

(e) State Pauli's exclusion principle. An atomic state is denoted by $^4D_{5/2}$. Give the values of L, S and J. What should be the minimum number of electrons involved for the state ? 2+3=5

4. What is the need for normalization of a wave function ? Calculate the normalization constant of a wave function (at $t=0$) given by

$$\psi(x) = a e^{\left(-\alpha^2 x^2/2\right)} . e^{ikx}$$

known as the Gaussian wave packet.

Determine (a) the probability density, and (b) the probability current density of the wave function. 2+3+5=10

OR

A finite square potential well of depth V_0 is defined as

$$V(x)=\begin{cases} 0 & \text{for} \quad x<0 \\ -V_0 & \text{for} \quad 0 \le x \le L \\ 0 & \text{for} \quad x>L \end{cases}$$

Set up Schrödinger equation for the potential well. Also solve using appropriate boundary conditions and determine the energy eigenvalues. 2+8=10

5. (i) Write down Schrödinger equation for a linear harmonic oscillator. What are the eigen-values and eigen-functions of the Hamiltonian of a linear harmonic oscillator ? Explain the significance of zero-point energy of the oscillator. 1+2+2=5

(ii) 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 wave functions for the ground state and the first excited state respectively. 5

Or

Write down Schrödinger wave equation for hydrogen atom in spherical polar coordinates. Separate the equation into radial and two angular parts. Also, from the radial part of the Schrödinger equation, find the eigenvalues of energy E for the ground state of hydrogen atom.

1+2+7=10

6. *(i)* Describe and explain L-S coupling. Under what condition does it hold ?

(ii) Under what condition L-S coupling breaks down and what kind of new coupling takes place ?

(iii) Describe J-J coupling. Illustrate L-S and J-J coupling with the help of vector diagram.

3+3+4=10

Or

With a suitable diagram illustrate the Stern-Gerlach experiment. What is the significance of inhomogeneous magnetic field used in Stern-Gerlach experiment ? explain mathematically.

In a Stern-Gerlach type experiment, the magnetic field varies with distance in z-direction according to $dB_z/dz = 1 \cdot 4\ T/mm$. Silver atoms travel a distance $x = 3 \cdot 5\ cm$ through the magnet. The speed of atoms emerging from oven is $v = 750\ m/sec$. Find the separation of the two beams as they leave the magnet. Mass of silver atom $= 1 \cdot 8 \times 10^{-25}\ kg$ and its magnetic moment is 1 *Bohr* magneton.

3+3+4=10

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3 (Sem–5/CBCS) PHY HC 2

2021

(Held in 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: 1×7=7

   (a) The Miller indices of the plane parallel to x and z axes are

   (i) (1 0 0)

   (ii) (0 0 1)

   (iii) (0 1 0)

   (iv) (1 1 1)

Contd.

(b) The most unsymmetrical crystal system is

(i) cubic

(ii) orthorhombic

(iii) triclinic

(iv) trigonal

(c) Above Curie temperature, a ferromagnetic material becomes

(i) antiferromagnetic

(ii) paramagnetic

(iii) diamagnetic

(iv) ferrimagnetic

(d) Fermi level in n-type semiconductor lies

(i) in between the bottom of the conduction band and donor level

(ii) in between the top of valence band and acceptor level

(iii) midway between conduction band and valence band *(iv)* outside the gap between conduction band and valence band

(e) Superconductivity state is perfectly

(i) paramagnetic

(ii) diamagnetic

(iii) ferromagnetic

(iv) ferrimagnetic

(f) The number of different Bravais lattices in three dimensions is

(i) 3

(ii) 14

(iii) 167

(iv) unlimited

(g) Piezoelectric effect is the production of electricity by

(i) chemical effect

(ii) varying field

(iii) temperature

(iv) pressure

2. Give short answers of the following questions : 2×4=8

(a) What are primitive and non-primitive unit cells?

(b) State Wiedemann-Franz law.

(c) Define symmetry operation in crystalline solids. Mention different types of fold rotation axes that are permissible.

(d) What are ferroelectrics? Mention the chief characteristics of ferroelectric materials.

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

(a) Why are crystalline solids used for X-ray diffraction? Explain why visible light cannot be used for the determination of crystal structure.

An X-ray beam of frequency 10^{20} *Hz* undergoes diffraction from a set of plane with spacing 1·5 *Å*. What is the direction of first-order diffraction?

1+2+2=5

(b) Explain Meissner effect. What are type II superconductors? 3+2=5

(c) Define hysteresis. Draw hysteresis loop for ferromagnetic material and label different parts. What is ferromagnetic domain? 1+2+2=5

(d) What are phonons? Mention its characteristics. 2+3=5

(e) Discuss the important conclusions of Kronig-Penney model. 5

4. Answer the following questions: 10×3=30

(a) What are reciprocal lattice vectors? Obtain expressions for them. Show that the reciprocal lattice to a simple cubic is itself a simple cubic. 3+5+2=10

Or

Show that a monatomic linear lattice can be regarded as a low-pass filter. 10

(b) Explain polarisability of atoms. Derive Clausius-Mossotti equation between polarisability and dielectric constant of solid. 4+6=10

Or

Explain classical Langevin theory of diamagnetism. What is the essential condition for an atom to be diamagnetic? 8+2=10

(c) What is Hall effect? Find Hall coefficient in a metal where the carriers are only electrons. Why is Hall coefficient positive in some metals?

An *n*-type germanium strip, 1 *mm* wide and 1 *mm* thick, has a Hall coefficient of 10^{-2} *m/coulomb*. If for a current of 1 *mA* the Hall voltage produced inside the strip is 1 *mV*, calculate the strength of the magnetic field.

2+5+1+2=10

Or

Write short notes on : ***(any two)*** $5 \times 2 = 10$

(i) Plasma oscillations

(ii) Einstein's theory of specific heat

(iii) Bragg's law

(iv) Curie-Weiss law.