

PHYSICS

Paper—II

Time : Three Hours

Full Marks : 300

Candidates should attempt Question No. 1 from Section-A and Question No. 5 from Section-B which are compulsory, and any THREE of the remaining questions, selecting at least ONE from each Section. All questions carry equal marks.

SECTION—A

1. Answer any **THREE** of the following :— $20 \times 3 = 60$

- (a) (i) The wave function of a particle confined in a box of length L is given by

$$\psi(x) = \sqrt{\frac{2}{L}} \sin \frac{\pi x}{L}$$

in the region $0 < x < L$ and zero elsewhere.

Calculate the probability of finding the particle in the region $0 < x < L/2$.

- (ii) Show that the de Broglie wavelength of a neutron of energy E electron volts is given by $\lambda = 0.287 E^{-1/2}$ angstroms.
- (b) (i) An eigenfunction of the operator $\frac{d^2}{dx^2}$ is $\psi = e^{2x}$. Find the corresponding eigenvalues.
- (ii) A wave function is given by
- $$\psi = A \exp\left[-\frac{x^2}{2a^2}\right],$$
- where a is a constant with dimensions of length. What value of A is needed to normalize its wave function ?
- (c) (i) A sample of certain element is placed in a magnetic field of 0.300 Tesla and suitably excited. How far apart are the Zeeman components of the 450 nm spectral line of this element ?
- (ii) Using uncertainty principle find the ground state energy of the linear harmonic oscillator.
- (d) (i) Calculate the values of L , S and J for a d-electron in one electron atomic system. The symbols L , S and J have their usual meanings.

- (ii) The force constant of HCl molecule is 4.5×10^5 dynes/cm. Find the energy required to increase the nuclear separation by 1 Å.
2. (a) Substitute the wave function $\psi = x e^{-m\omega x^2/2\hbar}$ in the Schrödinger equation
- $$\frac{d^2\psi}{dx^2} + \frac{2m}{\hbar^2}(E - V)\psi = 0 \quad \text{and show that}$$
- $$E = \frac{3}{2}\omega\hbar. \text{ Given that } V = \frac{1}{2}m\omega^2x^2. \quad 20$$
- (b) Show that at long wavelength, Planck's radiation law reduces to the Rayleigh-Jeans law. 20
- (c) Discuss the experimental evidence of the existence of electron spin. 20
3. (a) Describe and explain the Stern-Gerlach experiment. Show how it verifies the principal features of vector atom model. 30
- (b) Starting from commutation relation, derive the eigenvalues of operator J^2 and J_x . Where J^2 and J_x represent the square and the Z-component of the angular momentum operator. 30
4. (a) Discuss the main features of the vibrational and rotational Raman spectra of diatomic molecules. Also give the necessary theory. 30

- (b) Define the term NMR. Explain the applications of NMR in the fields of chemical structures and medicine. 30

SECTION—B

5. Answer any **THREE** out of questions (a), (b), (c) and (d) (Total marks 60) :— 20×3=60

(a) (i) On what factors does the stability of a nucleus depend ?

(ii) Why are the fission and fusion observed for only heavy and light nuclei respectively having less binding energy per nucleon ?

(iii) What is the size of a nucleus ? Determine the radii of a ^{16}O and ^{206}Pb nucleus given that $r_0 = 1.4 \text{ fm}$.

(iv) What are the properties of nuclear spin and magnetic moment ? Indicate the various factors on which they depend.

(b) What do you mean by nuclear chain reaction ? What is its role in a nuclear reactor ? Discuss the operational principle of a nuclear reactor.

(c) What led Pauli to put forward the neutrino hypothesis ? Give the elementary theory of

β -decay. Explain qualitatively how the hypothesis of a neutrino solves the apparent breakdown of conservation of spin angular momentum and energy in β -decay.

(d) What do you mean by 'quarks' ? How many possible quarks are there ? Give the charge and quantum numbers associated with each quark. How do the quarks combine to form baryons and mesons ?

6. Answer the following questions (Total Marks 60) :—

(a) Explain the salient features of the single-particle shell model and formation of discrete energy states and shells by the nucleons. What are magic numbers ? How far those can be explained in the light of the shell model ? 30

(b) What are the fundamental forces in nature ? Indicate their relative strength and ranges. What do you mean by unification of forces in nature ? Indicate the length and energy scales at which such an unification may be possible. 30

7. (a) Define the terms *lattice* and *crystal* and bring out the difference between them. Draw the diagram of a face centered cubic (fcc) lattice and show the three basis vectors. 10+10=20

(b) Discuss how energy bands arise in the electronic structure of a crystalline solid. Explain the existence of the three types of crystalline solids—metals, insulators and semiconductors—in terms of band structure. $12+8=20$

(c) Discuss the salient features of superconductivity. 20

8. (a) Draw the circuit diagram of a Hartley oscillator and explain its working. 20

(b) What is the difference between a JFET and a bipolar transistor ? Draw the schematic diagram of a n-channel FET and explain its working. What is the difference between a MOSFET and a JFET ? $5+10+5=20$

(c) Explain the exclusive-OR operation with the truth table. Derive an expression to show that the exclusive-OR operation can be implemented using the NAND gate. Also draw the logic-gate diagram for the same. $5+10+5=20$