

PHYSICS

(Paper II)

Time Allowed : Three Hours
Maximum Marks : 300

QUESTION PAPER SPECIFIC INSTRUCTIONS

(Please read each of the following instructions carefully before attempting questions)

There are EIGHT questions divided in two Sections.

Candidate has to attempt FIVE questions in all.

Question Nos. 1 and 5 are compulsory and out of the remaining, any THREE are to be attempted choosing at least ONE question from each Section.

The number of marks carried by a question/part is indicated against it.

Wherever any assumptions are made for answering a question, they must be clearly indicated.

Word limit in questions, wherever specified, should be adhered to.

SECTION 'A'

1. Answer any three of the following
 - (a)(i) State and explain Heisenberg's uncertainty principle. Experimental data reveal that no electron in an atom has energy greater than 4 MeV. Assuming that the radius of a nucleus is 10^{-14} m, show using Heisenberg's uncertainty principle that an electron cannot exist inside the nucleus. 10
 - (a)(ii) Calculate the de Broglie wavelength of thermal neutrons at 300 K. 10
 - (b)(i) Define angular momentum, Express it in operator form and show that $\mathbf{L} \times \mathbf{L} = i\hbar \mathbf{L}$. Explain the physical significance of this relation. 10
 - (b)(ii) Let Y_{lm} be an eigenstate of L^2 and L_z with eigenvalues $l(l+1)\hbar^2$ and $m\hbar$, respectively. Show that

$$\phi = (L_x + iL_y) Y_{lm}$$
 is likewise an eigenstate of L^2 and L_z , and determine the eigenvalues. 10
 - (c)(i) State and explain Franck-Condon principle. 5
 - (c)(ii) In three separate pairs of electronic states (one ground and another upper state) of diatomic molecules, the average internuclear distances are – 1. equal; 2. slightly greater; 3. appreciably greater. In accordance with Franck-Condon principle, obtain most favorable transitions from the ground state vibrational levels in each of the above situations. Illustrate the transitions by drawing suitable energy-level diagrams. 15
 - (d)(i) What is Lamb shift? Has it been observed in any atom other than hydrogen? 10
 - (d)(ii) How does the 21 cm hydrogen line originate? Comment on its astronomical applications. 10
2. (a) Solve the Schrodinger equation for a linear harmonic oscillator. Obtain the eigenvalues and the corresponding eigenfunctions. 40
 - (b) A one-dimensional potential barrier is represented by the function

$$V(x) = 0 \text{ for } x < 0$$

$$= V_0 \text{ for } x > 0$$
 Where V_0 is positive. Find the transmission coefficient for particles of mass m incident from the left on the barrier. 20
3. (a) Determine the discrete energy levels and the corresponding eigenfunctions for a particle in an infinitely deep potential well inside a cube of dimension L , i.e., assume

$$V(x,y,z) = 0 \text{ for } 0 < x < L; 0 < y < L; 0 < z < L = \infty \text{ elsewhere}$$
20

- (b) In the free electron theory of metals, a conductor is regarded as consisting of free electrons in a three-dimensional box. Using the results of (a), obtain an expression for the density of states, 25
- (c) Describe Stern-Gerlach experiment. Explain how it demonstrates the discrete nature of the magnetic moment of an atom. 15
4. (a) Write an expression for the energy of a diatomic molecule executing both rotation and vibration in a given electronic state. Explain the observed spectra giving a schematic diagram. What are O, P, Q, R and S branches? 20
- (b) Why does a spinning nucleus precess in a magnetic field? Explain the underlying principle of nuclear magnetic resonance (NMR) spectroscopy. Calculate the radio frequency at which NMR occurs in water kept in a uniform magnetic field of 2.4 T, the magnetic moment of proton being $2.793 \mu_N$. 40

SECTION 'B'

5. Answer any three of the following:
- (a)(i) Calculate the Q-value of the reaction

$${}^9_4\text{Be}({}^4_2\text{He}, n){}^{12}_6\text{C}$$
 Given Mass (${}^9\text{Be}$) = 9.012183 u Mass (${}^4\text{He}$) = 4.002603 u Mass (${}^{12}\text{C}$) = 12.000 u 10
- (a)(ii) Write down the nucleonic configuration of ${}^7\text{Li}$, ${}^{12}\text{C}$, ${}^{17}\text{O}$ and ${}^{27}\text{Al}$ in the ground state of the nuclear shell model and hence calculate the corresponding ground state angular momenta and parities. How do the observed ground state angular momenta and parities agree with those predicted on the basis of the shell model? 10
- (b)(i) Show that a lattice cannot have a five-fold rotational symmetry. However, some solids appear to exhibit this rotational symmetry. Explain briefly how this can be done. 10
- (b)(ii) State the quantum numbers I_z , Y and S for the uds quarks and antiquarks. Which combination of these leads to the formation of (1) proton and (2) neutron? 10
- (c)(i) Simplify the equation:

$$Y = [AB\bar{C} + BD + \bar{(AB)}C]$$
 using Boolean algebra Give the logic circuit for the equation before and after the simplification. 10
- (c)(ii) Explain the difference between n-p-n and p-n-p transistors. Give their device structure and biasing circuits. Draw a circuit for a single-stage common-emitter amplifier. 10
- (d)(i) Discuss briefly the concept of effective mass in semiconductors and explain the significance of negative effective mass. 10
- (d)(ii) A star converts all its hydrogen to helium, achieving 100% helium composition. It then converts the helium to carbon via the reaction

$$4{}^4_2\text{He} + \text{He} \rightarrow {}^{12}_6\text{C} + 7.27 \text{ MeV}$$
 The mass of the star is 5×10^{32} kg and it generates energy at the rate of 5×10^{30} W. How long will it take to convert all helium to carbon at this rate? 10
6. (a) Write down the Bethe-Weizsacker semi-empirical mass formula for a nucleus. Explain the significance of each term occurring in it. Discuss the stability of a nucleus against β -decay. What is the effect of pairing term on stability? 40
- (b) What are mirror nuclei? How does the charge independence of nuclear force emerge from this concept? 20
7. (a) Give some characteristic properties of strange particles which distinguish them from non-strange ones. Write the Gell-Mann-Nishijima relation. How is it used for the classification of elementary particles? 30

	(b)	What is Josephson effect? Discuss briefly DC and AC effects. Give some practical applications of Josephson junctions.	30
8.	(a)	Explain the working of a phase-shift oscillator. Draw the circuit diagram of a phase-shift oscillator using either a transistor or an op-amp. What are the conditions which must be satisfied to achieve stable oscillations? Calculate the frequency of oscillations for $R=1\ \Omega$ and $C=0.01\ \mu\text{F}$.	25
	(b)	Give the Boolean expression and the truth table for an XOR gate. Why are NAND gates called universal gates? Realise OR and XOR gates employing only NAND gates.	15
	(c)	Draw the device structure of a p-n junction solar cell and explain how the light energy is converted into electrical energy. Define the 'short-circuit current', 'open-circuit voltage' and 'efficiency' of a solar cell.	20