PHYSICS

PAPER—II

Time Allowed : Three Hours	Maximum Marks : 200

QUESTION PAPER SPECIFIC INSTRUCTIONS

Please read each of the following instructions carefully before attempting questions

There are EIGHT questions in all, out of which FIVE are to be attempted.

Question Nos. **1** and **5** are compulsory. Out of the remaining SIX questions, THREE are to be attempted selecting at least ONE question from each of the two Sections A and B.

Attempts of questions shall be counted in sequential order. Unless struck off, attempt of a question shall be counted even if attempted partly. Any page or portion of the page left blank in the Question-cum-Answer Booklet must be clearly struck off.

All questions carry equal marks. The number of marks carried by a question/part is indicated against it.

Answers must be written in ENGLISH only.

Unless otherwise mentioned, symbols and notations have their usual standard meanings.

Assume suitable data, if necessary, and indicate the same clearly.

Neat sketches may be drawn, wherever required.

List of Useful Constants

Mass of proton	$= 1\cdot673 \times 10^{-27}$ kg
Mass of neutron	$= 1\cdot675 \times 10^{-27}$ kg
Mass of electron	$= 9\cdot11 \times 10^{-31}$ kg
Planck constant	$= 6\cdot626 \times 10^{-34}$ J s
Boltzmann constant	$= 1\cdot380 \times 10^{-23}$ J K^{-1}
Bohr magneton (μ_B)	$= 9\cdot273 \times 10^{-24}$ A m^2
Nuclear magneton (μ_N)	$= 5\cdot051 \times 10^{-27}$ J T^{-1} (A m^2)
Electronic charge	$= 1\cdot602 \times 10^{-19}$ C
Atomic mass unit (u)	$= 1\cdot660 \times 10^{-27}$ kg
	$= 931$ MeV

$g_s^p = 5\cdot5855\ \mu_N$ $\qquad$ $m(p) = 1\cdot00727$ u

$m(n) = 1\cdot00866$ u $\qquad$ $m({}^4_2\text{He}) = 4\cdot002603$ u

$m({}^{12}_{6}\text{C}) = 12\cdot00000$ u $\qquad$ $m({}^{87}_{38}\text{Sr}) = 86\cdot908893$ u

$m({}^2_1\text{H}) = 2\cdot014022$ u $\qquad$ $m({}^3_1\text{H}) = 3\cdot0160500$ u

SECTION—A

1. Answer **all** of the following questions : 8×5=40

(a) In a nuclear experiment, beams of electrons and protons are moving with velocities $c/10$ and $c/20$ respectively. Calculate the de Broglie wavelengths of both the particles in metre (c is the speed of light $= 3 \times 10^8$ m / s).

(b) Recall the Pauli matrix representation of two-state system of electron, $\sigma_x, \sigma_y, \sigma_z$, and show that they do not commute.

(c) What does the uncertainty principle signify? Consider an electron in a box of size 10^{-10} m. What will be its maximum uncertainty in momentum?

(d) Consider a two-electron system in ground state with orbital quantum number zero $(l = 0)$. Use Pauli's exclusion principle to obtain orientations of the two electrons.

(e) Explain the phenomenon of Zeeman effect of atomic physics.

2. *(a)* Obtain the solution of one-dimensional free particle Schrödinger equation. Show that it corresponds to plane monochromatic (constant angular frequency) wave. 10

(b) Consider a one-dimensional harmonic oscillator potential

$$V(x) = \frac{1}{2} m \omega_0^2 x^2$$

where m represents the mass of a particle, ω_0 is the classical frequency of the oscillator and x is the displacement from equilibrium position. Obtain the solution of the corresponding Schrödinger equation. Using the normalization condition on the solution, show that the ground-state wave function has the form

$$\psi_0(x) = \left(\frac{\alpha}{\pi}\right)^{1/2} e^{-\frac{1}{2}\alpha^2 x^2}$$

$$\alpha = \left(\frac{m\omega_0}{\hbar}\right)^{1/2}$$

30

3. (a) Consider a hydrogen atom in Bohr atomic model. Outline its importance in the context of spatial quantization and the spin of the electron. 15

(b) Outline the Stern-Gerlach experiment and discuss its importance in the context of quantum nature of atom. 25

4. (a) Obtain the frequency ν_r of the spectral line of rotation spectra of a diatomic molecule and discuss the characteristics of its spectrum. 20

(b) Outline elementary theory of Nuclear Magnetic Resonance (NMR) and discuss its applications. 20

SECTION—B

5. Answer **all** of the following questions : $8 \times 5 = 40$

(a) In a nuclear fusion process, four hydrogen nuclei combine to form a helium nucleus. Obtain the energy released in such a process. If the same process is responsible for energy of a star of mass 2×10^{30} kg, each kilogram having 6×10^{26} protons, what could be the magnitude of energy released in it?

(b) Obtain the *Q*-values for the following four nuclear reactions :

(i) ${}^{14}_{7}\mathrm{N} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{17}_{8}\mathrm{O} + {}^{1}_{1}\mathrm{H}$

(ii) ${}^{7}_{3}\mathrm{Li} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{10}_{5}\mathrm{B} + {}^{1}_{0}n$

(iii) ${}^{6}_{3}\mathrm{Li} + {}^{1}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + {}^{4}_{2}\mathrm{He}$

(iv) ${}^{23}_{11}\mathrm{Na} + {}^{1}_{1}\mathrm{H} \rightarrow {}^{20}_{10}\mathrm{Ne} + {}^{4}_{2}\mathrm{He}$

(c) What are the quantum numbers of u, d and s quarks and of the corresponding antiquarks $(\overline{u}, \overline{d}, \overline{s})$? Obtain the quark contents of proton (p), neutron (n), positively charged pion (π^+) and negatively charged omega minus (Ω^-) particle.

(d) Distinguish between a normal conductor, a superconductor and a semiconductor. How a p-type semiconductor differs from an n-type?

(e) What are logic gates and truth tables? Obtain the truth table of a two-input OR gate.

6. (a) Give an outline of meson theory of nuclear forces. Describe the physical basis of short-range nuclear repulsion between like nucleons : proton-proton (p-p) or neutron-neutron (n-n). Consider the following two three-nucleon systems : (p-p-p) and (n-n-n). Which one is more likely to form a bound state? 20

(b) What is parity transformation? Discuss the experiment that confirms the violation of parity in beta decay. 20

7. (a) What are leptons? How are they different from other baryons? Define their quantum numbers and identify the forbidden ones in the following scattering or decay processes, justifying your conclusions : 20

(i) $\pi^0 \rightarrow \gamma + \gamma$

(ii) $\pi^0 \rightarrow \gamma + \gamma \rightarrow (e^+ + e^-) + (\mu^- + \mu^+)$

(iii) $n \rightarrow p + e^- + \bar{\nu}_\mu$

(iv) $\pi^+ + p \rightarrow p + p + \nu_\tau + \bar{\nu}_e$

(v) $\nu_e + p \rightarrow \nu_\mu + p + \pi^0$

(b) Describe the properties of field quanta of electro-weak and strong interactions of particles. 5

(c) Describe the phenomenon of Meissner effect and its importance in the study of superconductors. 15

8. (a) Give an elementary outline of high-temperature superconductors and their experimental status. 10

(b) Give schematic diagrams to distinguish between *n-p-n* and *p-n-p* transistors. 10

(c) Describe the following laws of Boolean algebra with one application each to logic circuit : 5×4=20

(i) Commutative law of addition

(ii) Associative law of addition

(iii) Associative law of multiplication

(iv) Distributive law

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