2023

PHYSICS

PAPER-II

Time Allowed — 3 Hours *Full Marks — 200*

If the questions attempted are in excess of the prescribed number, only the questions attempted first up to the prescribed number shall be valued and the remaining ones ignored.

*Answer may be given either in **English** or in **Bengali** but all answers must be in one and same language.*

Group-A

Answer *any six* questions.

1. Consider three particles each of which can be in one of three quantum states of respective energies $0, \in$ and $3\in$. The system is at a temperature = $(k\beta)^{-1}$. Write the partition function Z if the particles obey classical *MB* statistics and are distinguishable. Find also Z if the particles obey *B-E* statistics. 5+5

2. Three containers, each of volume V, contain N particles of a classical, a Bose and a Fermi gas respectively at the same temperature T. State with reason which of the three containers will have the highest pressure. 10

3. The phase space of a one-dimensional single particle is described by its coordinate q and momentum p. Consider a rectangular phase space volume between $= q_1, q = q_2, p = p_1$ and $p = p_2$. Show that in the simple case of a free, non-interacting particle, the phase space volume remains invariant in time. 10

4. State the differences between depletion type and enhancement type MOSFET. Draw $I_D - V_{gs}$ transfer characteristics of depletion type MOSFET. 5+5

5. Differentiate between *n-type* and *p-type* semiconductor. Draw and explain the transfer characteristics of a BJT in common emitter mode. 5+5

6. (a) What is meant by 'cross-section' of a nuclear reaction? Calculate the threshold energy of the reaction $^{14}N(n, \alpha)^{11}B$.

   Relevant masses are: $M\left(^{14}N\right) = 14{\cdot}007550$ amu

   $M(n) = 1{\cdot}008983$ amu

   $M(\alpha) = 4{\cdot}003879$ amu

   $M\left(^{11}B\right) = 11{\cdot}012811$ amu

(b) Explain with reasons whether the following reactions are allowed or forbidden:

(i) $p \rightarrow \pi^+ + \pi^- + e^-$

(ii) $\pi^+ + n \rightarrow \pi^0 + k^+$

(iii) $p + \pi^- \rightarrow n + \pi^0$ (2+5)+3

7. (a) Determine the ground state spin parity of $^{19}_{9}F$ in the context of single particle shell model.

(b) Show that the conservation of angular momentum is not violated in β- decay if the intrinsic spin of the neutrino is $\frac{\hbar}{2}$. 5+5

8. (a) Use uncertainty principle to calculate the radius and energy of first Bohr Orbit.

(b) The exciting line in an experiment is 546 nm and the stokes line is at 552 nm, find the wavelength of the anti-Stokes line. 5+5

9. What is the physical significance of Fermi-level in semiconductor? Sketch the Fermi-Dirac distribution function and its derivative for $T = 0\ K$ and $T > 0\ K$ showing clearly the Fermi energy. 10

Group-B

Answer *any seven* questions.

10. (a) For a system of N one-dimensional harmonic oscillators, obtain the canonical partition function and calculate the average energy.

(b) Show that the average energy of a system in contact with a heat bath can be expressed as $\langle E \rangle = -\frac{\partial \ln z}{\partial \beta}$ where Z is the partition function and $= \frac{1}{K T}$. (5+5)+10

11. (a) The entropy of an ideal gas of N monoatomic molecules occupying a volume V at a temperature T is given by,

$$S(N,V,T) = Nk \log\frac{V}{N} + \frac{3}{2}Nk\left[\frac{5}{3} + \log\left(\frac{2\pi mkT}{h^2}\right)\right]$$

Two non-identical gases having N_1 and N_2 molecules, occupying volumes V_1 and V_2 respectively, are allowed to mix quasi-statically by removing the separating wall. Find the change in entropy in this mixing process. Assume that initially, the gases are at the same temperature T and have equal number densities, i.e., $\left(N_1/V_1\right) = \left(N_2/V_2\right)$.
Also assume the mass of all gas molecules to be equal.

(b) A particle in $1D$ has energy = $\frac{p^2}{2m} + \lambda q^4$, where q and p denote the generalized coordinate and momentum, respectively. Show that heat capacity of a gas comprising of N such particle is $C_V = \frac{3}{4}Nk$. 10+10

12. (a) (i) In how many ways can 5 identical balls be distributed among 3 identical boxes where each box can contain any number of balls?

(ii) Consider a free particle inside a $1D$ box of length L. Calculate the number of microstates between the energy values E and $+ dE$.

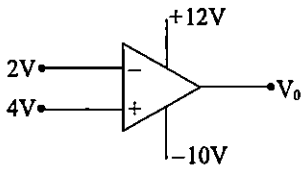
(b) (i) Derive Wein's displacement law from Plank's law.

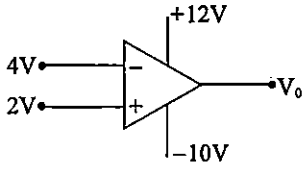
(ii) The entropy of blackbody radiation is given by, $S = \frac{4}{3}\sigma V^{\frac{1}{4}} E^{\frac{3}{4}}$. Show that PV = $\frac{E}{3}$.

(4+6)+(5+5)

13. (a) What should be the input resistance, output resistance and voltage gain of an ideal OP AMP? Calculate the voltage gain of an inverting OP AMP.

(b) Find out the output voltage of the following two circuits: (6+6)+8





14. (a) (i) Verify the Boolean identity: $AC + ABC = AC$

(ii) Verify the Boolean identity: $A + \overline{A}B = A + B$

(iii) Show that $\overline{AB} + \overline{A} + AB = 1$

(b) Implement the Boolean function $Y = AB + \overline{A}C$ using only NAND gates.

(c) Draw the circuit diagram of two input AND gate with the help of diodes and write the truth table of it. (3+3+3)+5+6

15. (a) What is basic difference between a nuclear reactor fission and a nuclear fission bomb? Explain with example the action of Moderator and control rods in a fission reactor.

(b) Use the semi empirical mass formula to construct the mass-parabola for isobars having same mass number A. Hence find an expression for the most stable isobar. Illustrate your answer by a suitable plot of $M(A, Z)$ against Z. (4+3+3)+(6+2+2)

16. (a) Consider the one-dimensional problem of a particle in a box, i.e., a particle placed in a potential:

$V(x) = 0$, for $0 < x < L$

$= \infty$, otherwise.

Evaluate the $x - p$ uncertainty product $(\Delta x)^2 (\Delta p)^2$, for the ground state.

(b) The initial (r = 0) wave function of a free particle is described by the Gaussian wave packet

$\psi_0 = Ae^{-\alpha x^2}$, where A and α are constants.

(i) Normalize the wave function $\psi_0(x)$.

(ii) Find the wave function $\psi(x, t)$ of the free particle at a later time t.

(iii) Calculate the probability density and hence show that the wave packet of the free particle broadens spatially with time.

(iv) Plot the probability density at time $t = 0$ and time $t > 0$ with x.

8+(3+3+3+3)

17. (a) Find the degeneracy of an energy level with principal quantum number n for a hydrogen atom.

(b) Define group velocity. Show that group velocity of a wave packet is equal to the velocity of a particle. Using the definition of expectation value of an observable, show that $\frac{d\langle x\rangle}{dt} = \frac{\langle P_x\rangle}{m}$, where the symbols have their usual meanings. 8+(2+4+6)

18. (a) What do you mean by *LS*– and *jj*-coupling? When do they occur? Irradiation of CCl_4 by 435·8 nm radiation yields Raman lines at 440·0, 441·9 and 444·7 nm. Calculate the Raman shift for line in the middle.

(b) What do you mean by 'population inversion'?

(c) Find the ratio of the rate of spontaneous and stimulated emission in terms of frequency and temperature.

(d) Draw the energy level diagram of ruby laser. (2+2+4)+4+4+4

19. (a) Consider a particular energy band, which is filled with electrons up to the value $k = k_1$. Show that the effective number of free electrons in the band is directly proportional to the slope of the E – k diagram $\left(\frac{dE}{dk}\right)_{k=k_1}$.

(b) Explain why the electronic specific heat associated with a free electron gas is negligibly small. What are the various contributions to the specific heat of a solid? Use Debye theory of specific heat to establish the famous Debye T^3 law. 6+(4+4+6)
