2021

PHYSICS — HONOURS

Paper : CC-12

Full Marks : 50

The figures in the margin indicate full marks.

Candidates are required to give their answers in their own words as far as practicable.

[Syllabus : 2019-20]

(Statistical Physics)

Answer ***question no.*** **1** and ***any four*** questions from the rest.

1. Answer ***any five*** questions : 2×5

(a) Show that for a canonical system : $\overline{\left(E-\bar{E}\right)^2} = kT^2C_V$, where C_V is the heat capacity at constant volume.

(b) A particle of mass M is falling freely under gravity starting from rest. Draw its phase trajectory.

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

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

(e) Can $^{7}_{3}\text{Li}$ form BEC? Give reason.

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

(g) 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.

2. (a) What is the phase trajectory of a simple pendulum performing small oscillations? Show that the area enclosed by the trajectory is equal to the product of the total energy E and the time period T of the pendulum.

(b) Energy of a particle in 1D has the form $E = ap^2 + bq^5$ where p and q are the generalised momentum and coordinate and 'a' and 'b' are constants. Calculate the specific heat. (2+3)+5

3. A system of N classical particles in thermal equilibrium are distributed between two energy levels $\varepsilon = -\Delta/2$ and $\varepsilon = \Delta/2$.

(a) Write down the partition function for the system.

(b) Calculate the internal energy and entropy of the system.

(c) What is the specific heat of the system?

(d) Plot the specific heat and the entropy as a function of temperature and explain the high temperature and low temperature behaviour of the curves. 2+(1+1)+2+(2+2)

4. (a) Find the variation of the specific heat C_V as a function of the temperature T for photon gas confined in 1D box.

(b) Given the energy of a system at temperature T and volume V is

$$E = aT^4V$$

where 'a' is a constant . Calculate (i) entropy (ii) Helmholtz free energy and (iii) Gibb's free energy. 5+(1+2+2)

5. For a classical ideal gas, derive the equation of state separately using (a) Canonical partition function and (b) Grand canonical partition function. 5+5

6. (a) Consider a photon gas confined in a volume V at temperature T. Show that the number of photons in this volume is proportional to T^3.

(b) A photon gas is confined in volume V at temperature T. If the volume is increased adiabatically to $2V$, determine the final temperature.

(c) Derive Wein's displacement law from Planck's law. 3+2+5

7. (a) Sketch the Fermi–Dirac distribution function and its derivative for $T = 0$ K and $T > 0$ K showing clearly the Fermi energy.

(b) Explain physically how the electronic specific heat of a metal behaves as a function of temperature.

(c) Deduce the pressure-volume relationship for a free electron gas obeying Fermi-Dirac statistics at 0K. Hence find an expression for the bulk modulus of the gas. 3+3+4

[Syllabus : 2018-19]

(Solid State Physics)

Answer ***question no.*** **1** and ***any four*** questions from the rest.

1. Answer ***any five*** questions : 2×5

(a) Sketch (210) and ($\bar{1}\bar{1}\bar{1}$) planes of a cubic system.

(b) Determine the relationships between the lattice parameter 'a' and the atomic radius 'r' for monoatomic simple cubic, bcc and fcc structures.

(c) Show that the reciprocal lattice to a simple cubic lattice is also a simple cubic lattice with lattice constant $2\pi/a$.

(d) Explain hysterisis for ferroelectric materials.

(e) Give an indirect evidence for the existence of phonons.

(f) Consider two ferromagnets : one having a hysteresis curve with broad area and another with a narrow area. Which one can be used as electromagnet and why?

(g) The atomic polarizability of neon is 4.3×10^{-41} Fm^2. If a neon atom is placed in an electric field of 5×10^6 V/m, calculate its dipole moment and the displacement of the centroids of positive and negative charges in it.

2. (a) In a cubic crystal, show that the distance between the adjacent planes with Miller indices *hkl* is given by

$$d_{hkl} = \frac{a}{\sqrt{h^2 + k^2 + l^2}}.$$

(b) Considering the scattering of X-rays from individual atoms in a crystal followed by their recombination to obtain directions of diffraction maxima derive the Laue equations.

(c) An X-ray analysis of a crystal is made with monochromatic X-rays of wavelength 0.58 Å. Bragg's reflections are obtained at angles of (i) 6.45° (ii) 9.15° and (iii) 13°. Calculate the interplanar spacing of the crystal. 2+4+4

3. (a) Discuss the failure of classical theory in explaining the observed temperature dependence of specific heat of a solid.

(b) Calculate the Debye frequency for aluminium from the following data :

Density of atoms in Al = 6.02×10^{28}/m^3, v_l = 6374 m/s, v_t = 3111 m/s.

(c) What are phonons? What is the physical significance of Debye temperature? Consider the expression for internal energy of a lattice in Debye model :

$$U = 9R\frac{T^4}{\Theta_D^3}\int_0^{x_D}\frac{x^3 dx}{e^x - 1} \quad \text{(where the symbols have their usual meanings)}$$

Obtain an expression for the specific heat C_V at low temperature. What will happen to C_V at high temperature? 3+2+(1+2+2)

4. (a) Suppose a paramagnetic atom having permanent moment $\vec{\mu}$ with a given resultant quantum number $\vec{J}$ is placed in a uniform magnetic field $\vec{B}$. Obtain an expression of the magnetization as a function of $\vec{B}$ and temperature T. Hence, obtain Curie's law in the appropriate limit.

(b) Show that the force exerted by a field gradient on a specimen is proportional to its paramagnetic susceptibility.

(c) Explain why diamagnetism is an inherent property of an atom. (4+2)+3+1

5. (a) The dispersion relation of electrons in a 3d lattice is given by

$$\varepsilon(k) = \alpha\cos k_x a + \beta\cos k_y a + \gamma\cos k_z a$$

where a is the lattice constant and α, β, γ are constants. Find the effective mass tensor at the corner of the first Brillouin zone $\left(\frac{\pi}{a}, \frac{\pi}{a}, \frac{\pi}{a}\right)$.

(b) Calculate the Hall coefficient R_H in a solid where both electrons and holes contribute to the Hall effect.

(c) Schematically represent the variation of velocity, effective mass and acceleration as a function of wave vector. 4+3+3

6. (a) What do you mean by orientational polarization of molecules? Discuss the temperature dependence of such polarization.

(b) What do you mean by plasma frequency of free electrons? Using Lorentz model, derive Sellmeyer's equation for elastically bound electrons.

(c) What is the origin of piezoelectric effect? Mention one application of piezoelectric phenomenon. (1+2)+(1+3)+(2+1)

7. (a) What does the existence of energy gap in a superconductor imply?

(b) What is the relation between isotopic mass and transition temperature in a superconductor? Show the variation of energy gap with temperature.

(c) Write down the expression for penetration of external magnetic field inside a superconductor.

(d) In an experiment, a niobium (Nb) wire of radius 0.25 mm is immersed in liquid helium (T = 4.2 K) and required to carry a current of 300 A. It is given that $H_C(0)$ = 0.20T and the critical transition temperature T_C of Nb is 9.3 K. Will the wire remain superconducting? 2+(2+2)+1+3