2025

PHYSICS — HONOURS

Paper : DSCC-12

(Thermal Physics and Statistical Mechanics)

Full Marks : 75

The figures in the margin indicate full marks.

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

Answer ***question no.*** **1** and ***any five*** questions, taking at least ***one*** question from each **Group.**

1. Answer ***any five*** questions : 3×5

(a) Define thermal conductivity. What is its unit in SI system?

(b) Write down Wien's displacement law. A blackbody at a temperature of 1646K has the wavelength corresponding to maximum emission (λ_m) equal to 1.78 micron. Assuming the moon to be a perfect blackbody find the temperature of moon if λ_m for the moon is 14 micron.

(c) Under what conditions the equilibrium of a system is determined by the minimum of the Gibbs free energy?

(d) What is Brownian motion? Give some of its essential features.

(e) Define first and second order phase transitions.

(f) Distinguish between cooling produced by Joule-Thomson expansion and adiabatic expansion.

(g) Write down the postulate of equal a priori probabilities in classical statistical mechanics.

(h) Find the phase space trajectory of a simple harmonic oscillator. How the trajectory will be modified in presence of damping?

Group - A

2. (a) From the kinetic theory of gases obtain the expression for the coefficient of viscosity

$$\eta = \frac{1}{3} mn\lambda \bar{c},$$

where m is the mass of a molecule, n is the number of molecules per unit volume, λ is the mean free path and $\bar{c}$ is the average molecular speed.

(b) How does η vary with temperature and pressure?

(c) Calculate the mean free path and diameter of a molecule in a gas, given $\eta = 1.66 \times 10^{-5}$ Nm^{-2}s, the average molecular speed $\bar{c} = 450$ ms^{-1} and the density of the gas $\rho = 1.25$ Kg m^{-3}. 6+(2+2)+2

Please Turn Over

3. (a) Set up the differential equation for one-dimensional flow of heat in a metal bar taking into account radiation loss.

(b) Solve it for the temperature at the steady state. How will the solution be modified if radiation loss is prevented?

(c) What are critical temperature and critical pressure of a gas? 3+(3+2)+(2+2)

Group - B

4. (a) Write the four Maxwell's thermodynamic relations.

(b) Derive (using Maxwell's relations only) the following relations where the symbols have their usual meaning :

(i) $\left(\frac{\partial U}{\partial V}\right)_T = T\left(\frac{\partial P}{\partial T}\right)_V - P$

(ii) $C_P - C_V = \left[\left(\frac{\partial U}{\partial V}\right)_T + P\right]\left(\frac{\partial V}{\partial T}\right)_P$.

(c) Evaluate $\left(\frac{\partial U}{\partial V}\right)_T$ and $C_P - C_V$ for an ideal gas. 2+(3+3)+(2+2)

5. (a) Use a Legendre transformation to obtain the Gibbs free energy $G(T, P)$ from the internal energy $U(S, V)$ of a gaseous system.

(b) Show that the Helmholtz free energy $F = \frac{\partial\left(\frac{G}{P}\right)}{\partial\left(\frac{1}{P}\right)}$.

(c) Prove that the initial and the final values of the enthalpy for a gas undergoing a Joule-Thomson throttling process are equal where the enthalpy is defined by $H = U + PV$. 4+4+4

6. Consider the liquid-vapour coexistence curve in a P-T phase diagram of a system.

(a) Show that $g_1(T, P) = g_2(T, P)$ where g_1 and g_2 are the specific Gibbs free energies on the two sides of the coexistence curve.

(b) Using the result of (a), deduce the Clausius-Clapeyron equation

$$\frac{dP}{dT} = \frac{L}{T(v_2 - v_1)}$$

(The symbols have their usual meaning)

(c) Calculate the change in melting point of ice when the pressure on it is increased by 1 atmosphere. Given, 1 *atmosphere* = 1.01×10^5 N m^{-2}, latent heat of ice $L = 3.34 \times 10^5$ J Kg^{-1} and specific volume of ice is 1.09×10^{-3} m^3 Kg^{-1}. 3+5+4

7. (a) Draw the blackbody radiation curve at two different temperatures ($T_1 > T_2$).

(b) What do you mean by ultraviolet catastrophe?

(c) What is Planck's hypothesis? By using the hypothesis how blackbody radiation is explained?

(d) Assume the sun to be a blackbody at temperature 5800K. Find the rate at which energy is reaching the top of the earth's atmosphere. Given : Radius of the sun = 7×10^8 m. Distance of the earth's atmosphere from the sun = 1.5×10^{11} m, Stefan's constant : 5.672×10^{-8} $Wm^{-2}K^{-4}$. 2+2+4+4

Group - C

8. (a) Define canonical ensemble.

(b) Show that the canonical partition function of an ideal classical monatomic gas having N molecules can be expressed as

$$Z(N,V,T) = \frac{1}{N!}\left[\frac{V}{h^3}(2\pi mkT)^{3/2}\right]^N,$$

where the symbols have their usual meaning.

(c) Hence derive the Sackur-Tetrode equation representing the entropy expression for classical ideal gas. 2+5+5

9. (a) Write the condition for which negative absolute temperature can be achieved.

(b) Show that the mean energy, $\overline{E} = -\left(\frac{\partial \ln Z}{\partial \beta}\right)_{N,V}$ where $Z(N, V, T)$ is the canonical partition function and $\beta = \frac{1}{kT}$.

(c) The partition function for a two-state system of N dipoles in the presence of an external magnetic field H is given by

$$Z = \left(e^{\beta\epsilon} + e^{-\beta\epsilon}\right)^N,$$

where $\epsilon = \mu H$, μ being the dipole moment.

Find the Helmholtz free energy and entropy of the system. 2+4+(3+3)