2020

PHYSICS — HONOURS

Paper : CC-6

(Thermal Physics)

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.

Symbols have the usual meanings everywhere.

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

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

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

(b) Calculate the RMS velocity of Argon gas molecule at 200K (molecular weight of Argon = 40).

(c) Find the change in entropy in an adiabatic process when the temperature of an ideal gas is increased from T_1 to T_2.

(d) Define enthalpy and cite an example of an iso-enthalpic process.

(e) What is the order of the phase transition in ferromagnetic to paramagnetic transition of a metal and why?

(f) Find the ratio of the coefficient of viscosity of two gas molecules A and B if the diameter of A is twice that of B while the molecular weight is thrice.

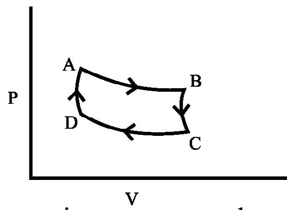
(g) A certain system has Gibbs free energy given by

$$G(p,T) = RT \ln\left[\frac{ap}{(RT)^{5/2}}\right]$$

where a and R are constants. Find out C_P, the specific heat at constant pressure.

2. (a) Prove that for an ideal gas, in an adiabatic process, PV^{γ} is constant. Is this relation valid in an irreversible process?

(b) A Carnot engine is shown below :



State the nature of the thermodynamic processes along AB, BC, CD and DA.

Where is work put in and where is it extracted?

If the above is a steam engine with $T_{in} = 500$ K operating at room temperature, calculate the efficiency of the engine. (3+1)+(2+2+2)

3. (a) Show that if average velocity is taken as the unit of speed of gas molecules, the probability of speed between v and $v + dv$ is independent of temperature.

(b) Find the fraction of gas molecules whose velocities are greater than the r.m.s. value by at least 2%.

(c) The speed of longitudinal waves of small amplitude in an ideal gas is $v = \sqrt{\frac{\partial p}{\partial \rho}}$

Show that for an adiabatic process $v = \sqrt{\frac{\gamma RT}{M}}$ where ρ is the density and M is the mass of the gas molecule.

(d) Justify that for a very dilute van der Waals gas, $C_P - C_V = R$. 3+3+2+2

4. (a) Calculate the probability that the speed of an O_2 molecule will lie between 200 and 201 ms^{-1} at 300 K (mass of oxygen molecule is 32 units).

(b) Using Maxwell's distribution for speed of molecules in a gas, establish that $v_{rms} > \bar{v} > v_p$, where $\bar{v}$ and v_p are the average and most probable speeds respectively. Why do the velocities increase with temperature? Is the distribution symmetric about v_p? 3+(4+2+1)

5. (a) For the equation of state

$$V = \frac{RT}{p} - \frac{C}{T^3}$$

show that

$$\left(\frac{\partial C_P}{\partial p}\right)_p = \frac{12C}{T^4}$$

(b) The Helmholtz free energy function A can be obtained from the internal energy U by a Legendre transformation. Show that it is a function of T and V.

(c) Liquid helium has a normal boiling point = 4.2 K. However, at a pressure of 1 mm of mercury, it boils at 1.2 K. Estimate the average latent heat of vaporization of helium in this temperature range (Take the volume in the liquid state $\ll$ volume in gaseous phase). 3+3+4

6. (a) Establish the relation for the rate of change of temperature with pressure in a Joule-Thomson process :

$$\mu_{JT} = \left(\frac{\partial T}{\partial P}\right)_H = \frac{V}{C_P}(\alpha T - 1)$$

What is the value of μ_{JT} for an ideal gas? What do you mean by the inversion temperature?

(b) Indicate the coexistence curves and the critical point in a solid-liquid-gas phase diagram.

(c) Show schematically the variation of the order parameter with temperature in a (i) first-order and (ii) a continuous phase transition. (4+1+1)+2+2

7. (a) Using the fact that dS is an exact differential, derive the following relation :

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

Hence show that for a van der Waals gas, the internal energy is not a function of temperature alone.

(b) Establish the relation

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

(c) The pressure p from an isotropic radiation field is 1/3 of its energy density :

$$p = u(T)/3 = U(T)/3V$$

Show that u obeys $u = \frac{1}{3}T\frac{du}{dT} - \frac{1}{3}u$

(You have to use the result of (b)). 4+2+4