RAMAKRISHNA MISSION VIDYAMANDIRA

(Residential Autonomous College affiliated to University of Calcutta)

B.A./B.Sc. THIRD SEMESTER EXAMINATION, MARCH 2022

SECOND YEAR [BATCH 2020-23]

Date : 07/03/2022

PHYSICS (HONOURS)

Time : 11 am – 1 pm

PAPER : VII [CC7]

Full Marks : 50

Answer **any five** questions of the following: [5×10]

1. a) Calculate the critical temperature and critical pressure of He. Given, a = $6.15\text{x}10^{-5}$, b= $9.95\text{X}10^{-4}$ per gm-molecule, where the units of pressure is the atmosphere and the unit of volume is the volume of the gas at N.T.P.

   b) If η= $166\text{x}10^{-6}$ dynes per sq-cm. per unit velocity gradient, $\bar{c}$ = $4.5\text{X}10^{4}$ cm/s, ρ = 1.25 X 10^{-3} g/c.c. n = 2.7X 10^{19} molecules/c.c. for N_2, calculate the mean free path, collision frequency and the diameter of N_2 molecules.

   c) For the formation of ice, find out the time required to increase in thickness of ice-layer from x_1 to x_2, where the density of water is ρ.

   d) A cubically shaped vessel 20 cm on a side constains diatomic H_2 gas at a temperature of 300 K. Each H_2 molecule consists of two hydrogen atoms with mass of 1.66 x 1 0^{-24} **g** each, separated by 10^{-8} cm. Assume that the gas behaves like an ideal gas. Ignore the vibrational degree of freedom.

   i) What is the average velocity of the molecules?

   ii) What is the average velocity of rotation of the molecules. [2+2+2(2+2)]

2. a) Suppose that there are n independent random variables, Xi, each with the same mean <X> and variance σ^2_X. Let Y be the sum of the random variables, so that Y = X1 +X2 +· · ·+Xn. Find the mean and variance of Y.

   b) Consider **a** gas at temperature T and pressure **p** escaping into vacuum through a hole of area ***A*** which is in the wall of its container. Assume the radius of the hole is much less than the mean free path for the gas in the container. Roughly, what is the mass-rate of escape of the gas?

   c) A circular cylinder of height L, cross-sectional area ***A,*** is filled with a gas of classical point particles whose mutual interactions can be ignored. The particles, all of mass **m,**are acted on by gravity (let g denote the gravitational acceleration, assumed constant). The system is maintained in thermal equilibrium at temperature T. Let $\mathbf{c_v}$**,** be the constant volume specific heat (per particle). Compute $\mathbf{c_v}$**,** as a function of T, the other parameters given, and universal parameters. Also, note especially the result for the limiting cases, T→ 0, T→∞**.** [3+3+4]

3. a) Assume the earth's atmosphere is pure N_2 in thermodynamic equilibrium at a temperature of 300 K. Calculate the height above sea-level at which the density of the atmosphere is one half its sea-level value.

   b) A container is divided into two parts by a partition containing a small hole of diameter D. Helium gas in the two parts is held at temperature T_1= 150 K and T_2 = 300 K respectively through heating of the walls.

   i) How does the diameter D determine the physical process by which the gases come into a steady state?

ii) What is the ratio of the mean free paths l_1/l_2 between the two parts when $D << l_1$, $D << l_2$, and the system has reached a steady state?

iii) What is the ratio l_1/l_2 when $D >> l_1$, $D >> l_2$?

c) A quantity of argon gas (molecular weight 40) is contained in a chamber at T_o = 300 K. **A** small hole is drilled in the wall of the chamber and the gas is allowed to effuse into a region of lower pressure. Calculate the most probable velocity of the molecules which escape through the hole.

[2+(2+2+2)+2]

4. a) A metallic bar of length L with both ends maintained at $T = T_0$ passes a current which generates heat H per unit length of the bar per second. Find the temperature at the centre of the bar in steady state.

b) Determine the ratio *(pV/RT)* at the critical point for a gas which obeys the equation of state:

$p(V - b) = RT\exp(-a/RTV)$. Give the numerical answer accurately to two significant figures.

c) One mole of gas obeys Van der Waals equation of state. If its molar internal energy is given by $\mathbf{u} = cT - a/V$ (in which ***V*** is the molar volume, ***a*** is one of the constants in the equation of state, and ***c*** is a constant), calculate the molar heat capacities C_p, and C_v.

d) What fraction of H_2 gas at sea level and T = 300 K has sufficient speed to escape from the earth's gravitational field? (You may assume an ideal gas. Leave your answer in integral form.)

[2+3+2+3]

5. a) With reference to a thermodynamic system define a state function. What is its mathematical characteristic?

b) Show that for a hydrostatic system $\frac{dV}{V} = \beta_P dT - \frac{dP}{B_T}$

where, β_P = volume co-efficient of expansion at constant P

B_T = isothermal bulk modulus.

For a hypothetical substance, $\beta_P = \frac{bT^2}{P}$, and $B_T = \frac{P^2}{aT^3}$, where *a* and b are constants. Utilising the properties of state function, find the relationship between *a* and b.

c) Give the mathematical formulation of the first law of thermodynamics for an open hydrostatic system and explain each term. Define chemical potential of a single component system. [(1+1)+2+3+3]

6. a) Derive a relation between T and V of an ideal gas undergoing reversible adiabatic transformation.

b) An ideal gas having initial pressure P, volume V and temperature T is allowed to expand adiabatically until its volume becomes 5.66 V while its temperature falls to T/2 . How many degrees of freedom do the gas molecules have?

c) Show that in any irreversible process entropy change of the universe is always positive. [3+4+3]

7. a) Use Legendre transformation to obtain the expression of Helmholtz free energy F(T,V) starting from enthalpy function H(S,P). Using the expression of F(T,V), show that

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

b) Find the expression of $\left(\frac{\partial U}{\partial V}\right)_T$ and show that for van der Waals' gas $\left(\frac{\partial U}{\partial V}\right)_T = \frac{a}{V^2}$.

c) Starting from $\left(\frac{\partial S}{\partial V}\right)_T = \left(\frac{\partial P}{\partial T}\right)_V$., show that $\left(\frac{\partial C_V}{\partial V}\right)_T = T\left(\frac{\partial^2 P}{\partial T^2}\right)_V$. Hence find out the value of $\left(\frac{\partial C_V}{\partial V}\right)_T$ for van der Waals' gas. [3+(2+2)+3]

8. a) What are the basic differences between free expansion and Joule-Thomson expansion? Show that for a gas undergoing Joule-Thomson expansion, final enthalpy is same as initial enthalpy.

b) Define emissive power and absorptive power of a body associated with thermal radiation.

c) Assume that pressure due to diffuse radiation is P=u/3, where u is the energy density of the radiation field. Hence show that energy density of black body radiation is u = aT^4, where a is a constant. [(2+3)+2+3]

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