Name of Paper : Thermal Physics & Statistical Mechanics
Name of the Course : B.Sc. (Prog.) II Year (CBCS)
Semester : III
Duration : 3 Hours
Maximum Marks : 75

Nov. / Dec. 2019

Attempt give questions in all. Question No. 1 is compulsory.
All questions carry equal marks.

Q. 1. Attempt any five :

(*a*) Using third law of thermodynamics explain why it is not possible to attain absolute zero.

Ans. We will shaw that unattainability of absolute zero is equivalent to enerapy tending to zero as $T \to 0$.

Let us assume the contrary so that we can sperate a carnot engine between two referurly, one maintained at absolute zero and other at some finite temperature T, as shown in fig. 1.

For a cyclic process

We can write,

$$\Delta S = \oint \frac{\partial Q}{T} = 0$$

But we can write

$$\Delta S = \Delta S_{12} + \Delta S_{23} + \Delta S_{34} + \Delta S_{41}$$

With $$\Delta S_{12} = \frac{Q}{T}$$

Where Q is heat absorbed at temperature T. For an an adiabatic process, $\Delta S_{23} = \Delta S_{41} = 0$ and by third law, $\Delta S_{34} = 0$, hence

$$dS = \oint \frac{\partial Q}{T} = \Delta S_{12} \neq 0$$

But, this contraducts the second law of thermodynamics, S_Q, I + is not possible to attain absolute zero.

(*b*) **Distinguish between reversible and irreversible processes.**

Ans.

Reversible Process	Irreversible Processes
(*i*) This process is carried out infinitesimally slowly.	(*i*) It is carried out rapidly.
(*ii*) At any stage the equilibriumis not disturbed.	(*ii*) Equilibrium may exist only after completion of process.
(*iii*) It takes infinite time for compution.	(*iii*) It takes a finite time for completion.
(*iv*) Work sbtained in this process is maximum.	(*iv*) Work obtained in this is not maximum.

(*c*) **Calculate mean free path of a gas molecule whose diameter is 3 Å and number of molecules/cc is 3×10^{19}.**

Ans. $d = 3\,\text{Å}, \quad n = 3 \times 10^{19}$ mol/cc

$$\text{Mean free path} = \lambda = \frac{1}{\pi d^2 n}$$

$$\lambda = \frac{1}{3.14 \times 9 \times 10^{-20} \times 3 \times 10^{19}}$$

$$= 0.011795 \times 10^{-1} \text{ m}$$

$$\lambda = 1.179 \times 10^{-3} \text{ m}$$

(*d*) **What is the wavelength at maximum intensity of radiation emitted by a body maintained at temperature 3000°C. Given Wien's constant = 2.898×10^{-3}mK.**

Ans. $T = 3000°C, \quad \text{Constant} = 2.898 \times 10^{-3}\text{mK}$

$$\lambda T = \text{Constant}$$

$$\lambda \times 3000 = 2.898 \times 10–3$$

$$\lambda = \frac{2.898}{3000} \times 10^{-3}$$

$$\lambda = 9.66 \times 10^{-7} \text{ m}$$

(*e*) **Describe all the possible microstates for a system obeying B – E statistics and having two particles and two quantum states.**

Ans. Two particles following B – E statistics means they are indistinguishable we label them as A, A

Now, since there are two quantuum states so, possible microstates are :

(i) Two particles in I^{St} (2, 0)

(ii) Two particles in II^{nd} (0, 2)

(iii) One particles in each (1, 1)

Since the particles are in distinguishable, all microstates give rise to one microstates.

So, there are three microstates

In table form :

I	II
A A	O
O	A A
A	A

(f) Establish the T-dS equation : $TdS = C_V\, dT + T\left(\frac{\partial P}{\partial T}\right)_V dV$.

Ans. Let us take T and V as independent variables

So,
$$S = S(T, V)$$

$$dS = T\left(\frac{\partial S}{\partial T}\right)_V dT + T\left(\frac{\partial S}{\partial V}\right)_V dV$$

Now,
$$C_V = T\left(\frac{\partial S}{\partial T}\right)_V$$

$$TdS = C_V\, dT + T\left(\frac{\partial S}{\partial T}\right)_T dV$$

Now, using first maxwell relation

$$\left(\frac{dS}{dV}\right)_T = \left(\frac{dP}{dT}\right)_V$$

So,
$$TdS = C_V dT + T\left(\frac{\partial P}{\partial T}\right)_V dV$$

(g) Using Clausius-Clapeyron equation discuss the effect of pressure on boiling point of a liquid. **(5 × 3)**

Ans. Clausis-Clapeyron equation is given by:

$$\left(\frac{\partial P}{\partial T}\right)_{Sat} = \frac{L}{T(V_{vap} - V_{liq})}$$

This is one of the most important formulae in thermadynamic and gives the rate at which vapour pressure must change with temperature for two phases to in equilibrium.

Since, $V_{vap} > V_{liq}$, $\left(\frac{\partial P}{\partial T}\right)_{Sat}$ will always be positive. This implies that increase in pressure raising boiling point and in preassure lawers the boiling point.

So, this is the reason why it is difficult to make boiled potatoes and cook food at high altitudes.

Q. 2. (*a*) Show that the work done in a Cannot cycle is the area enclosed by the two isotherms and two adiabatics in P – V diagram and hence derive the expression for efficiency.

Ans. The solution to this question is in your textbook.

(*b*) A Carnot engine has an efficiency of 50% when the temperature of the sink is 27°C. Calculate the temperature of the source so that the efficiency becomes 60%. (10, 5)

Ans.
$$\text{Efficiency} = n = \frac{T_1 - T_2}{T_1} = 1 - \frac{T_2}{T_1}$$

T_1 = temperature of source

T_2 = temperature of sink

$$n = 50\% = \frac{50}{100} = \frac{1}{2} \qquad T_2 = 27°C = 300\text{ K}$$

So,
$$\frac{50}{100} = \frac{1 - 300}{T_1}$$

$$\frac{300}{T_1} = \frac{1-1}{2} = \frac{1}{2}$$

So,
$$T_1 = 600\text{ K}$$

now, for
$$n = 60\% = \frac{60}{100} = \frac{3}{5}$$

$$\frac{3}{5} = 1 - \frac{300}{T_1}$$

$$\frac{300}{T_1} = \frac{1-3}{5} = \frac{2}{5}$$

$$T_1 = 300 \times \frac{5}{2}$$

$$T_1 = 750 \text{ K}$$

So, temperature source should be 750 K so that efficiency as ingine is 60%.

Q. 3. (*a*) State first law of thermodynamics. What is its physical significance and discuss its limitations ?

Ans. The solution to this question is in your textbook.

(*b*) One mole of an ideal gas (γ = 1.4) initially kept at 17°C is adiabatically compressed so that its pressure become 10 times its original value. Calculate

(*i*) its temperature after compression.

(*ii*) work done on the gas.

Ans. $r = 1.4, \quad P_1 = P, \quad P_2 = 10P$

$$T_1 = 17°C = 290 \text{ K}$$

According to adiobatic equation

$$PV^r = \text{Const}$$

So, $$P_1V_1^{\,r} = P_2V_2^{\,r}$$

In terms of T and P

$$T^rP^{r-1} = \text{Const}$$

So, $$T_1^r P_1^{r-1} = T_2^r P_2^{r-1}$$

$$(290)^{1.4} (P)^{1.4-1} = (T_2)^{1.4} (10P)1^{.4-1}$$

$$(T_2)^{1.4} = (290)^{1.4} \left(\frac{P}{10P}\right)^{0.4}$$

$$(T_2)^{1.4} = (290)^{1.4} \frac{1}{(10)^{0.4}}$$

$$T_2 = (290)^{1.4/1.4} \frac{1}{(10)^{0.4/1.4}}$$

$$T_2 = 290 \frac{1}{(10)^{2/7}}$$

$$\text{work done} = w = \frac{R}{r-1}[T_1 - T_2]$$

$$w = \frac{R}{1.4-1}\left[290 - \frac{290}{10^{2/7}}\right]$$

$$w = \frac{290\ R \times 10}{0.4}\left[\frac{10^{2/7} - 1}{10^{2/7}}\right]$$

$$w = 725\ R\left[\frac{10^{2/7} - 1}{10^{2/7}}\right]$$

(*c*) Calculate the change in entropy of a perfect gas in terms of temperature and pressure. **(5, 5, 5)**

Ans. The solution to this question in your textbook.

Q. 4. (*a*) Using thermodynamic potentials derive Maxwell's four thermodynamical relations.

Ans. The solution to this question in your textbook.

(*b*) Using appropriate Maxwell's relations prove

$$C_P - C_V = T\left(\frac{\partial P}{\partial T}\right)_V\left(\frac{\partial V}{\partial T}\right)_P$$

and hence show that for an ideal gas $C_P - C_V = R$. **(10, 5)**

Ans. The solution to this question in your textbook.

Q. 5. (*a*) What is transport phenomenon? Derive the expression for coefficient of viscosity of a gas using Kinetic Theory.

Ans. The solution to this question in your textbook.

(*b*) Explain the porous plug experiment and discuss its results. Prove that enthalpy remains constant in Joule-Thomson expansion. **(9, 6)**

Ans. The solution to this question in your textbook.

Q. 6. (*a*) Starting from the Maxwell's law of velocity distribution obtain expressions for root mean square velocity, average velocity and most probable velocity.

Ans. The solution to this question in your textbook.

(*b*) Calculate the root mean square velocity of hydrogen molecule at 27°c. Given mass of hydrogen molecule = 3.34×10^{-27} Kg and $k = 1.38 \times 10^{-23}$ J/°K.

Ans. V_{rms} = Root mean square velocity

$$= \sqrt{\frac{3K_BT}{m}}$$

$$T = 27°C = 300K$$

$$m = 3.34 \times 10^{-27} kg$$

$$K_B = 1.38 \times 10^{-23}\ J/K$$

$$V_{rms} = \sqrt{\frac{3 \times 1.38 \times 10^{-23} \times 300}{3.34 \times 10^{-27}}}$$

$$= \sqrt{\frac{3 \times 1.38 \times 3}{3.34} \times 10^{6}}$$

$$= \sqrt{\frac{9 \times 1.38}{3.34}} \times 10^{3}$$

$$= 1.928 \times 10^{3} \text{ m/s}$$

$$V_{erms} = 1928.357 \text{ m/sec}$$

(*c*) State the law of equipartition of energy and hence determine the ratio of specific heat capacities (γ) for a monoatomic and diatomic gas. **(6, 3, 6)**

Ans. The solution to this question in your textbook.

Q. 7. Explain the spectral distribution of radiation emitted by a black body and its variation with temperature.

Ans. The solution to this question in your textbook.

(*b*) Derive Planck's law of black body radiation and hence derive Rayleigh-Jean's law and Wien's law. **(3, 12)**

Ans. The solution to this question in your textbook.

Q. 8. (*a*) Differentiate between MB, BE and FD statistics.

Ans. The solution to this question in your textbook.

(*b*) Derive Maxwell-Boltzmann distribution law for an ideal gas having N particles and energy E.

Ans. The solution to this question in your textbook.