CMR INSTITUTE OF TECHNOLOGY

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Internal Assessment Test II

SUBJECT: BASIC THERMODYNAMICS								**Code:**	18ME33
Date:	**14/10/2019**	**Duration:**	**90 min**	**Max. Marks:**	**50**	**Sem:**	**03**	**Branch:**	MECH

Answer any **2** *FULL questions. Each question carries equal marks.*

Q. No.		**Question**	**Marks**	OBE MAP	
				CO	RBT
1	a	Write the vander walls equation and derive the vander walls constants	**[10]**	CO3	L1
	b	Mixture of gases comprises 30% CO, 15% CO_2, and 55% H_2. Find the gravimetric analysis specific gas constant and molecular weight of the mixture.	**[8]**	CO3	L2
	c	Determine the mass of nitrogen contained in a $35m^3$ vessel at 200 bar and 200 K by using i) the ideal gas equation ii) generalized compressibility chart.	**[7]**	CO3	L3
2	a	Write the short notes on the flowing. i) Law of corresponding states ii) compressibility factor ii) generalized compressibility chart.	**[8]**	CO3	L3
	b	10 kg of carbon dioxide is enclosed in a container at a temperature of 100^0 C and pressure of 1 bar calculate the volume of the container by i) ideal gas equation ii) vander walls equation iii) compressibility chart	**[10]**	CO3	L3
	c	I kg of co_2 has volume of 086 m^3 at 120^0C.compute the pressure using i) ideal gas equation ii) vander walls equation	**[7]**	CO4	L1
3	a	Define Entropy and prove the clausius theorem	**[9]**	CO3	L4
	b	A mixture of ideal gases contain 5 kg of N_2 and 8 kg of CO_2. The partial pressure of N_2 in the mixture is 120 kpa. Find i) mole fraction of N_2 and CO_2 ii) partial pressure of CO_2 iii) Molecular weight of the mixture.	**[9]**	CO4	L3
	c	Determine pressure exerted by CO_2 in a container $1.5m^3$ capacity, when it contains 5kg at 27^0 C, using i) ideal gas equation ii) vander walls equation.	**[7]**	CO4	L1

CI CCI HOD

Degree of saturation :-

It is defined as the mass of water vapour in a unit mass of dry Air, to L-mass of water vapour in a Air, when the Air is saturated at the same temperature.

Adiabatic saturation Temperature :-

It is the temperature at which the water (or) Ice can saturate by evaporating Adiabatically into it.

Enthalpy of Moist Air :-

It is the sum of enthalpy of dry Air and enthalpy of water vapour associated with dry Air.

1 (3) write the vanderwaals equation and Derive the constants a and b.

a

vanderwaal's equation is given by

$$\left(P + \frac{a}{V_c^2}\right)(V_c - b) = RT_c$$

$$\left(P + \frac{a}{V_c^2}\right) = \frac{RT_c}{V_c - b}$$

$$P = \frac{RT}{V-b} - \frac{a}{V^2} \rightarrow (1)$$

$$\frac{dp}{dv} = \frac{-RT_c}{(V_c-b)^2} + \frac{2a}{V_c^3} = 0 \rightarrow (2)$$

$$\frac{\partial^2 p}{dv^2} = \frac{2RT_c}{(V_c-b)^3} - \frac{6a}{V_c^4} = 0 \rightarrow (3)$$

$$\frac{RT_c}{(V_c-b)^2} = \frac{2a}{V_c^3} \rightarrow (4)$$

$$\frac{2RT_c}{(V_c-b)^3} = \frac{6a}{V_c^4} \rightarrow (5)$$

Divide ④ by ⑤

$$\frac{\frac{RT_c}{(V_c-b)^2}}{\frac{2RT_c}{(V_c-b)^3}} = \frac{\frac{2a}{V_c^3}}{\frac{6a}{V_c^4}}$$

$$\frac{\cancel{RT_c}}{\cancel{(V_c-b)^2}} \times \frac{(V_c-b)^{\cancel{3}}}{2\cancel{RT_c}} = \frac{\cancel{2}1\cancel{a}}{\cancel{V_c^3}} \times \frac{V_c^{\cancel{4}}}{\underset{3}{\cancel{6a}}}$$

$$\frac{V_c-b}{2} = \frac{V_c}{3}$$

$$3V_c - 3b = 2V_c$$

$$3V_c - 2V_c = 3b$$

$$V_c = 3b$$

$$\boxed{b = V_c/3}$$

substitute $b = V_c/3$ in eq ④

$$\Rightarrow \frac{RT_c}{(V_c-b)^2} = \frac{2a}{V_c^3}$$

$$\Rightarrow \frac{RT_c}{\left(V_c - \frac{V_c}{3}\right)^2} = \frac{2a}{V_c^3}$$

$$\Rightarrow \frac{RT_c}{\left(\frac{2V_c}{3}\right)^2} = \frac{2a}{V_c^3}$$

$$\Rightarrow \frac{RT_c}{\frac{4V_c^2}{9}} = \frac{2a}{V_c^3}$$

$$\Rightarrow RT_cV_c^3 = 2a\left[\frac{4V_c^2}{9}\right]$$

$$\Rightarrow RT_c V_c^3 = \frac{8aV_c^2}{9}$$

$$\Rightarrow R = \frac{8\cancel{V_c^2}\,a}{9T_c\,V_c^{\cancel{3}}}$$

$$\Rightarrow \boxed{R = \frac{8a}{9T_cV_c}}$$

substitute b and R values in vanderwaal's equation

$$\left(P_c + \frac{a}{V_c^2}\right)(V_c - b) = RT_c$$

$$\left(P_c + \frac{a}{V_c^2}\right)(V_c - V_c/3) = \frac{8a}{9\cancel{T_c}V_c} \cdot \cancel{T_c}$$

$$\left(P_c + \frac{a}{V_c^2}\right)\left(\frac{3V_c - V_c}{3}\right) = \frac{8a}{9V_c}$$

$$\Rightarrow \left(P_c + \frac{a}{V_c^2}\right)\left(\frac{2V_c}{3}\right) = \frac{8a}{9V_c}$$

$$\Rightarrow P_c + \frac{a}{V_c^2} = \frac{8a}{9V_c} \times \frac{3}{2V_c}$$

$$\Rightarrow P_c + \frac{a}{V_c^2} = \frac{\overset{4}{\cancel{24}}a}{\underset{3}{\cancel{18}}V_c^2}$$

$$\Rightarrow P_c + \frac{a}{V_c^2} = \frac{4a}{3V_c^2}$$

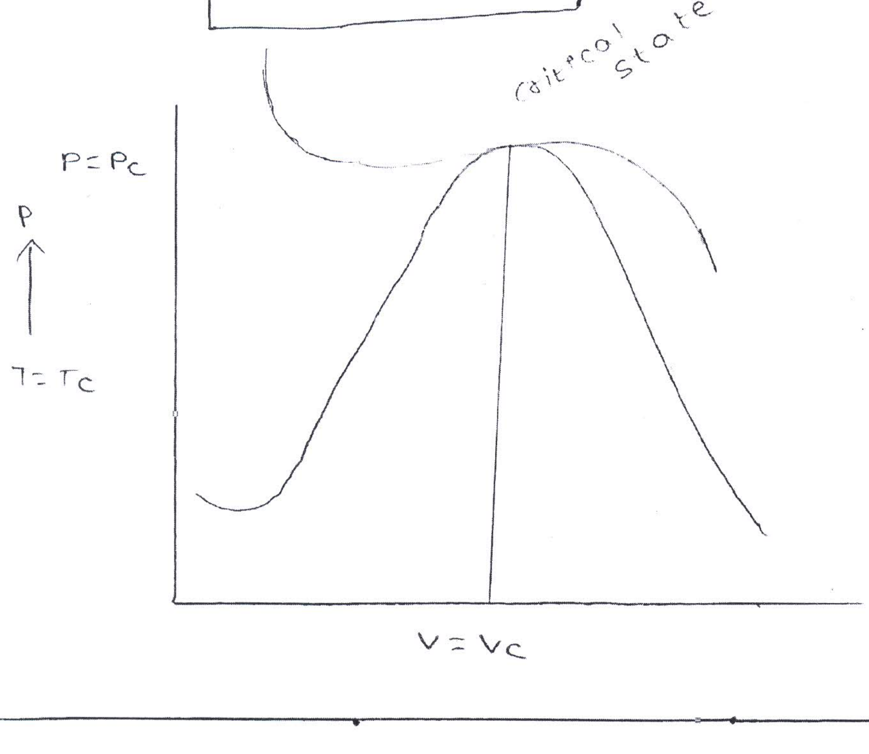
$$\Rightarrow P_c = \frac{4a}{3V_c^2} - \frac{a}{V_c^2}$$

$$\Rightarrow P_c = \frac{a}{V_c^2}\left[\frac{4}{3} - 1\right]$$

$$\Rightarrow P_c = \frac{a}{V_c^2}\left[\frac{4-3}{3}\right]$$

$$\Rightarrow P_c = \frac{a}{3V_c^2}$$

$$\Rightarrow \boxed{a = 3P_cV_c^2}$$



1> Given data

b. $x_{CO} = 0.3$ $\quad x_{CO_2} = 0.15$ $\quad x_{H_2} = 0.55$

$mf_{CO} = ?$ $\quad mf_{CO_2} = ?$ $\quad mf_{H_2} = ?$

$$M = x_{CO} M_{CO} + x_{CO_2} M_{CO_2} + x_{H_2} M_{H_2}$$

$$= 0.3 \times 28 + 0.15 \times 44 + 0.55 \times 2$$

$$= 16.1 \text{ kg/kg mol}$$

$$R = \frac{R_u}{M} = \frac{8.314}{16.1} = 0.516 \text{ kJ/kg.K.}$$

Gravimetric composition

$$mf_{CO} = x_{CO} \times \frac{M_{CO}}{M} = 0.3 \times \frac{28}{16.1} = 0.522$$

$$mf_{CO_2} = x_{CO_2} \times \frac{M_{CO_2}}{M} = 0.15 \times \frac{44}{16.1} = 0.409$$

$$mf_{H_2} = x_{H_2} \times \frac{M_{H_2}}{M} = 0.55 \times \frac{2}{16.1} = 0.068$$

1.c N_2, $V_2 = 35 M^3$ $P = 200 \times 100 kPa$.

i> ideal gas equation.

From Thermodynamic hand book, For N_2 We get

$M = 28$, $R_u = 8.314$ kJ/kg mol K.

$PV = mRT =$ $R = \frac{R_u}{M} = \frac{8.314}{28}$

$= 0.2969$ kJ/kg.K.

$200 \times 100 \times 35 = m \times 0.2969 \times 200$

$\underline{\underline{m = 11788.48 kg}}$

ii> Generalized compressibility. Chart.

$P_c = 33.94$ bar $T_c = 126.2°C$

$P_r = P/P_c = \frac{200}{33.94} = \underline{\underline{5.89}}$ $T_r = T/T_c = \frac{200}{126.2} = \underline{\underline{1.58}}$

$Z = 0.9$

$Z = \frac{PV_{act}}{RT} =$ $0.9 = \frac{200 \times 100 \times V_{act}}{0.2969 \times 200}$ $V_{ac} = 0.00266 M^3/kg$

$\underline{M} = 13098.312 kg$ $\underline{M} = \frac{35}{0.00266}$

and WBT.

This curve also possess WBT lines, enthalpy and specific volume lines.

Q) state the following

a. Law of corresponding states

If any two gases have equal values of reduced pressure and reduced temperature, Then they have same values of Reduced volume.

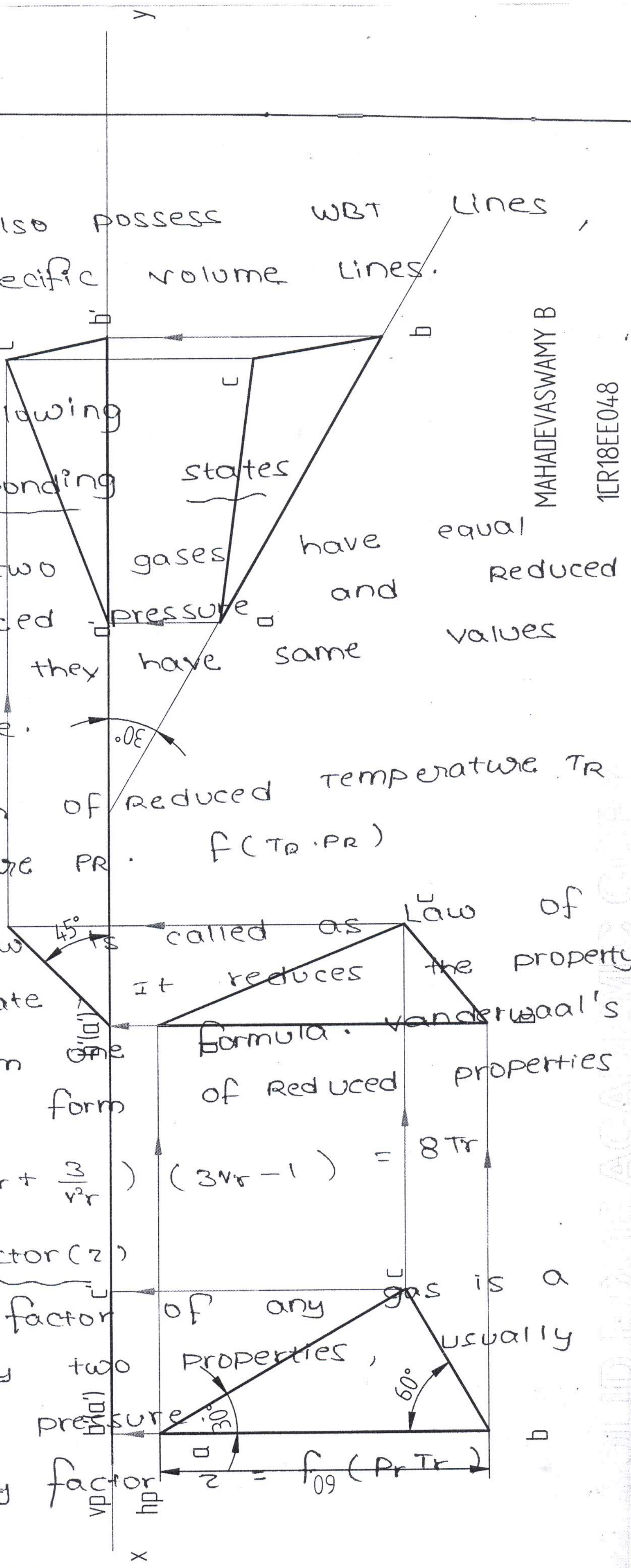
i.e V_R = function of reduced temperature T_R and reduced pressure P_R. $f(T_R \cdot P_R)$

The above law is called as Law of corresponding state. It reduces the property of all gases from one formula. vanderwaal's equation in the form of Reduced properties is given by $\left(P_r + \frac{3}{v_r^2}\right)(3v_r - 1) = 8T_r$

Compressibility Factor (z)

compressibility factor of any gas is a function of only two properties, usually temperature and pressure

i.e compressibility factor $z = f(P_r T_r)$



It also defined as the ratio of the actual volume to the, volume predected by the ideal gas law at a given pressure and Temperature.

$$Z = \frac{\text{actual volume}}{\text{Volume Predected by ideal gas law}}$$

$$Z = \frac{V_{act}}{\frac{RT}{P}} = \frac{P \cdot V_{act}}{RT}$$

If the gas behaves like an ideal gas, then $Z = 1$ at all temperatures and pressures. Thus to Quantify the deviation of Real gas behaviour from the ideal gas behaviour compressibility factor is used.

Generalized compressibility chart

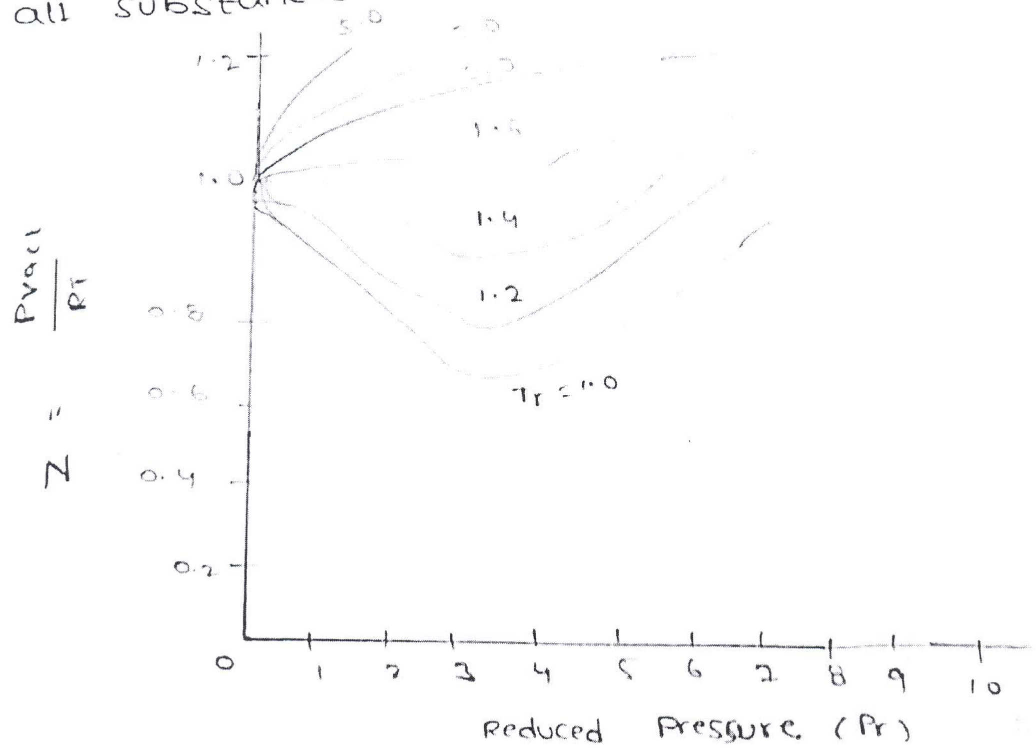
* The Generall compressibility chart is Plotted with Z versus Pr for values of Tr.
* This is constructed by plotting the known data of one or more gases and can be used for any gas.
* This chart provides one of the best means of expressing deviation from ideal behaviour and gives result with an accuracy of with in 5%.

The following observations can be made from the generalized chart

(1) At all temperatures $Z = 1$
$P_r = 0$

(2) At the temperature is equal to twice the critical temperature $(T_r = 2)$ and above $Z = 1$ over a wide range of pressure up to 5 times the critical pressure.

(3) The compressibility factor at the critical point $Z_c = \frac{P_cV_c}{RT}$ is called critical compressibility and is found to be equal to 0.275 for all substances.



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b. $m = 10\,kg$ $\quad T = 100 + 273 = 373\,K$ $\quad P = 1\,bar = 100\,kPa$

$V = ?$

From Thermodynamic data book for

$CO_2 = \quad M = 44.$

$a = 362850\ N/m^4 / (kgmol)^2 \quad b = 0.0423\ m^3/kgmol$

i ideal gas equation

$PV = mRT \qquad R = \frac{R_u}{m} = \frac{8.314}{44}$

$= 0.189\ kJ/kg.K.$

$$V = \frac{mRT}{P} = \frac{100 \times 0.189 \times 373}{1 \times 100} = 7.048\,m^3.$$

ii vanderwaal's equation.

$$\left(1 \times 10^5 + \frac{362850}{V_m^2}\right)(V_m - 0.0423) = 8.314 \times 373$$

$V_m = 30.75\ m^3/kgmol$

$n =$ ~~100~~ $\frac{m}{M} = \frac{10}{44} = 0.227\ mol$

Volume of $CO_2 = V = nV_m = 0.227 \times 30.75$

$= 6.98\,m3$

Compressibility factor

From Thermodynamic data book critical Properties. for CO_2

$T_c = 304.2°$ $P_c = 73.85$

$T_r = \frac{T}{T_c} = \frac{373}{304.2} = 1.23$ $P_r = \frac{P}{P_c} = \frac{1}{7385} = 0.0135$

From Compressibility Chart $T_r = 1.23$ & $P_r = 0.0135$

we get $Z = 0.98$

$Z = \frac{Pv}{RT} = 0.98 = \frac{100 \times v}{0.189 \times 373} = 0.701\ m^3/kg$

For mass is 10 kg

$V = 10 \times 0.701 = 7.01\ m3$

2 c. $a = 365.6 \frac{kNm^4}{(kgmol)^2}$ $b = 0.0423 \frac{m^3}{kgmol}$

$V = 1 M^3$ $T = 120 + 273 = 393 K$

CO_2 $n = \frac{m}{M} = 1/44$

i> using ideal gas equation

$P v_m = R_u T$. $R_u = 8.314$ kJ/kgmol

$P = \frac{R_u T}{V_m}$ $V_m = V/n$ $\frac{0.86}{\frac{1}{44}} = 37.84 m^3/kgmol$

$= \frac{8.314 \times 393}{37.84} = 86.35 kN/m^2$

ii> vander waal's equation

$$\left(P + \frac{a}{V_m^2}\right)(V_m - b) = R_u T$$

$$\left(P + \frac{365.6}{37.84^2}\right)(37.84 - 0.0423) = 8.314 \times 393$$

$P = 86.18 kN/m^2$.

3b.

$$x_{N_2} = \frac{n_{N_2}}{n_{N_2}+n_{CO_2}} = \frac{0.17}{0.17+0.182} = 0.483.$$

$$n_{N_2} = \frac{m_{N_2}}{M_{N_2}} = 5/28 = 0.17 \text{ kg mol}$$

$$n_{CO_2} = \frac{M_{CO_2}}{M_{CO_2}} = 8/44 = 0.182 \text{ kg mol}$$

$$x_{CO_2} = \frac{n_{CO_2}}{n_{N_2}+n_{CO_2}} = \frac{0.182}{0.17+0.182} = 0.517$$

ii) $$x_{CO_2} = \frac{P_{CO_2}}{P} = 0.517 = \frac{P_{CO_2}}{P}$$

$$P_{CO_2} = 0.517P.$$

$$x_{N_2} = \frac{P_{N_2}}{P_2} \quad P = \frac{P_{N_2}}{x_{N_2}} = \frac{120}{0.483}$$

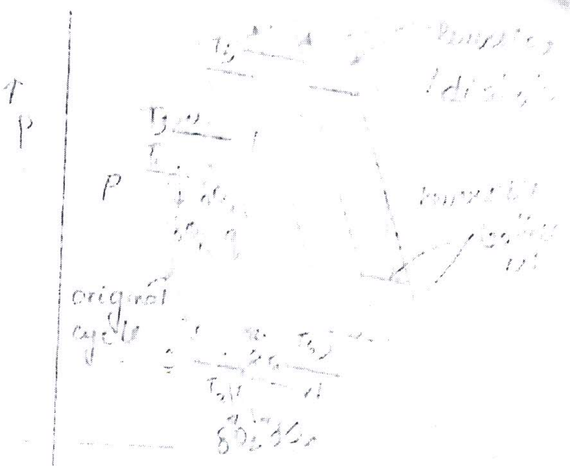
$$= 248.45 \text{ kpa.}$$

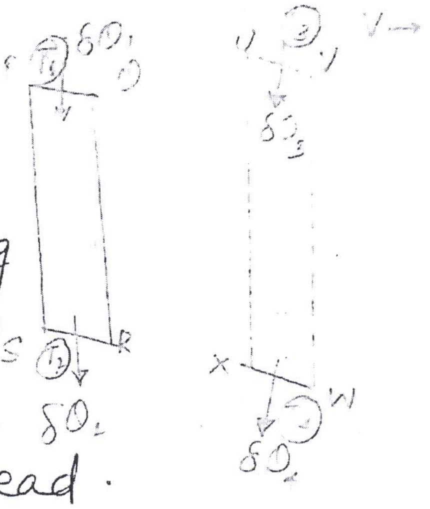
$$P_{CO_2} = 128.47 \text{ kPa.}$$

3 a

→ Clausius Theorem

- Consider a smooth, closed curve which represents a reversible cycle. A number of reversible adiabatic(s) can be drawn as shown in the above fig. so that the closed cycle can be split into large no. of small strips, each of which may be closed by drawing reversible isotherms at top & bottom so that the original cycle (circle) is replaced a no. of Carnot-Cycles instead.





- For the elemental cycle PQRS, 'δQ₁' is the heat absorbed reversibly at temp T_1 & 'δQ₂' is the heat rejected reversibly at temp T_2. WKT,

$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2} \Rightarrow \frac{\delta Q_1}{\delta Q_2} = \frac{T_1}{T_2}$$

i.e.,

$$\frac{\delta Q_1}{T_1} = \frac{\overset{\text{rejected}}{-\delta Q_2}}{T_2} \Rightarrow \frac{\delta Q_1}{T_1} + \frac{\delta Q_2}{T_2} = 0$$

We consider heat supplied to & rejected by the system is considered +ve & -ve respectively.

- Similarly, for elemental cycle UVWX, $\frac{\delta Q_3}{T_3} = \frac{\delta Q_4}{T_4}$

i.e.,

$$\frac{\delta Q_3}{T_3} + \frac{\delta Q_4}{T_4} = 0$$

3

a.

- Similarly, similar/identical equations can be written for all elemential Carnot Cycles.

∴ for the whole original cycle,

$$\frac{\delta Q_1}{T_1} + \frac{\delta Q_2}{T_2} + \frac{\delta Q_3}{T_3} + \cdots \frac{\delta Q_n}{T_n} = 0$$

$$\boxed{\left(\frac{\delta Q}{T}\right)_R = 0}$$

3

c. i ideal gas equation

$$R = \frac{R_u}{M} = \frac{8.314}{44} = 188.95 \text{ J/kg.K}$$

$$Pv = mRT \qquad P = \frac{mRT}{V} = \frac{5 \times 188.95 \times 300}{1.5}$$

188.95 kPa

1.88 bar

ii) using vander wall's equatn

$$\left(P + \frac{a}{V_m^2}\right)(V_m - b) = R_u T$$

$$V_m = \frac{V \times M}{m} = \frac{1.5 \times 44}{5} = 13.2 \text{ m}^3/\text{kg-mol}$$

$$\left(P + \frac{364.3}{13.2^2}\right)(13.2 - 0.0427) = 8.314 \times 300$$

$P = 188.9$ kPa

$= 1.88$ bar