

Thermodynamics

INTRODUCTION :

- * ZLOT : Concept of temperature
- * FLOT : Energy of conservation in thermo from of conservation of energy.
- * SLOT: (i) Heat always flow from higher temp to lower temperature

(ii) 100% efficiency of any heat engine not possible

- * Concept of heat engine : Converted of heat into mechanical work
- * At 1 atmospheric pressure boiling point of water is 100°C. In pressure cooker, pressure is 2.38 atm than boiling point is 137°C

FOUNDATION THERMO

Heat and mechanical work :



KEY POINTS :

- * Both are form of energy.
- * First conversion Practically given by Rumford.
- * Mathematical expression given by Joule.

 $W \propto H$ (heat)

$$W = JH$$

Where J is mechanical equivalent of Heat or conversion constant

* J = 4.18 Joule/cal ≈ 4.2 Joule/cal $= 4.18 \times 10^3$ Joule/Kcal

$$1 \text{ cal} = 4.2 \text{ J} \qquad 1 \text{ cal} > 1 \text{ joule} \qquad 1 \text{ J} = 0.24 \text{ cal}$$

Two conversion :-

(i) mechanical work $\xrightarrow{devide by J}$ $\xleftarrow{}_{Multiply by J}$ heat (cal or K cal)

(a) P. E. :
$$\frac{mgh}{J} = ms\Delta\theta$$

(b) K.E.:
$$\frac{1}{2}\frac{\mathrm{d} \mathbf{r}}{\mathrm{J}} = \mathrm{ms}\,\Delta\theta$$

(c) R.K.E.:
$$\frac{1}{2} \frac{I\omega^2}{J} = ms\Delta\theta$$

(ii) Heat $\xrightarrow{}$ mechanical energy

Solved Examples

Ex.1 If earth suddenly stop its spin rotation then what will be the rise in temperature.

Sol.
$$\frac{1}{2} \frac{I\omega^2}{J} = MS\Delta\theta$$
 For earth $I = 2/5 MR^2$
 $\frac{1}{2} \times \frac{2}{5} \frac{MR^2\omega^2}{J} = MS\Delta\theta \implies \Delta\theta = \frac{R^2\omega^2}{5SJ}$

Ex.2 Water fall from a height 50m, If one third of its mechanical energy converted into heat what will be the rise in temperature of water.

Sol.
$$\frac{1}{3} \frac{M \times 10 \times 50}{J} = M \times 10^{3} \times \Delta \theta$$

 $[\because S_{water} = 10^{3} \text{ cal/kg }^{\circ}\text{C}]$
 $\Delta \theta = \frac{500}{3 \times 4.2 \times 10^{3}} \implies \Delta \theta = 0.04^{\circ}\text{C}$ Ans.

Ex.3 A man got 100 K cal heat from its lunch. Its efficiency is only 25% and mass of man is 60 Kg. Calculate the height he can acquire.

Sol.
$$\frac{25}{100} \times 100 \times 10^3 = Mgh$$
 $\Rightarrow 25 \times 10^3$
= $\frac{60 \times 10 \times h}{4.2}$ $\Rightarrow h = \frac{25 \times 10 \times 4.2}{6}$
= 175 m. Ans.

Ex.4 A 63 gm bullet moving with velocity 200 m/s. Collides against a wall consequently two third of it's kinetic energy is converted into heat. Than what will be the heat developed by bullet in calorie. (Given : J = 4.2)

Sol. Q =
$$\frac{2}{3} \times \left(\frac{1}{2} \frac{mv^2}{J}\right) = \frac{2}{3} \times \frac{1}{2} \frac{(0.063)(200)^2}{4.2}$$

= 200 cal. Ans.

Calorie :– Heat required for 1° C rise in temperature (between 14.5° to 15.5°C) of 1 gm of water is called calories.

Anamolous expression of water :-



KEY POINTS :

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Heating Between 0°C to 4°C

(a) Mass M = const.

(b) Volume = decrease, Density (ρ) = increase

$$(c) C_v > C_p$$

* At 4°C %

(a) $V = \min . \& \rho = \max .$

(b) Sufrace Tension = max

(c) Capillary height is minimum.

- * Between 14.5°C to 15.5°C, density of water is constant so 1 calorie is defined between this range.
- * All specific constants of solids and liquid are taken at 20°C.

Phase conversion :-



Vapour	Condensation Liquid
Solid	Sublimation Vapour
Vapour	$\xrightarrow{\text{Vapour freezing}} \text{Solid}$

(1) All phase conversion are isothermal and isobaric process

Heat reject ∆Q = –ve

- (2) The heat given to system of 1 gm substance for phase conversion is called as latent heat of phase conversion
- (3) Required heat for phase conversion.

$$Q = ML$$

L = Latent heat of phase conversion.cal/gm or K.cal/ kg, Dimension $\rightarrow L^2T^{-2}$

Special results :

- (i) Heat absorbed by the system $\Delta Q = +ve$ Heat rejected by the system $\Delta Q = -ve$
- (ii) Ice \longrightarrow water

- (iii) Water \longrightarrow Vapour
 - (a) m = constant
 - (b) $V_{liquid} < V_{vapour}$ (always)
 - (c) 1 gm water = 1671 cm^3 vapour (imp.)
 - (d) $L_{vapour} = 536 \text{ cal./gm} = 2260 \text{ KJ/kg}$

Formula used in phase conversion

- Required heat $\Delta Q = mL$ (i)
- Work done $\Delta W = P \Delta V$ (ii)

(a)
$$\Delta W = P_{ext} \left(\frac{M}{\rho_{water}} - \frac{M}{\rho_{ice}} \right)$$

(b) $\Delta W = P_{ext} \left(V_{final} - V_{initial} \right)$

For ice melt

For vaporisation (iii) Change in internal energy

By FLOT (Apply energy conservation)

 $dU = \Delta Q - \Delta W$

Solved Examples

Ex.5 1 gm. of ice is melt against external pressure than find out

(a) total heat is given (b) external workdone (c) Change of internal energy

Sol. (a) total heat is given $\triangle Q = ML = 80$ cal.

(b) Workdone :
$$\Delta W = P \left[\frac{M}{\rho_w} - \frac{M}{\rho_{ice}} \right]$$

$$= 10^5 \times 10^{-3} \left(\frac{1}{10^3} - \frac{1}{900} \right)$$

$$= -\frac{1}{90} = -0.01 J = -0.01 \times .24 \text{ cal.} = -24 \times 10^{-4} \text{ cal}$$
(c) Internal energy : $\Delta Q = \Delta W + dU$
(+80) = (-24 × 10^{-4} \text{ cal}) + dU \Rightarrow dU
= 80+24 × 10^{-4} \text{ cal}

Ex.6 The amount of heat required to convert 10 gm. of ice at – 10°C to water at 10°C will be:–

Sol. S_{ice} = 0.5 cal/gm°C;
$$L_{xyu} = 80$$
 cal/gm.

$$\sum Q = (-10°C \rightarrow 0°C) + (0°C \rightarrow 0°C) + (0°C \rightarrow 10°C)$$

$$= MS_{ice} \Delta \theta + ML_{xyu} + Ms_{w} \Delta \theta = [10 \times 0.5 \times 10] + (10 \times 80) + (10 \times 1 \times 10) = cal$$

$$= (50) + (800) + (100)cal = 950 cal.$$

THERMAL CAPCITY OR **HEAT CAPACITY** (\mathbf{H}_c) : $\mathbf{H}_c = \mathbf{MS}$

The required heat for 1°C rise in temperature of given mass called its heat capacity

- (i) **Unit** : $Cal/^{0}C$ or Cal/K
- (ii) **Dimension :** $ML^2T^{-2}K^{-1}$
- (iii) **H** depends : (a) Property of material (b) Body (shape)

WATER EQUIVALENT **OF SUBSTANCE : (W)**

- It is equal to the unit of water whose thermal capacity is just equal to thermal capacity of given substance.
- * It is always expressed in mass quantity of water.
- * Simply water equivalent, numerically equal to heat capacity of substance.

HEATING OF A SOLID

Heating of solid can be represented on a graph plotted between heat v/s temperature





- If all three phase conversion curve plotted on a single P-T graph then they will intersect only and only at unique point i.e. called as triple point of substance.
- 5. At **triple point** all three phase of substance remain in conversion that mean contribution of each phase is identical for same volume, same mass, same density.
- 6. At triple point the temperature and pressure their values for water

 $T_{triple} = 0.0098^{\circ}C \approx 0.01^{\circ}C = 273.16 \text{ K}$

 $P_{triple} = 4.6$ mm. of Hg column = 605.26 N/m² = 0.00625 atm.

- * if volume V A and P A then result temperature T A (MP A or BP A)
- * if volume $\nabla \beta$ and $P \beta$ then result temperature $T \beta (MP \beta \text{ or } BP \beta)$
- * Slope concept $\frac{dP}{dT}$:

For a phase conversion curve its slope is

 $\frac{dP}{dT} (+Ve) \text{ if } P^{\uparrow} \text{ then } (MP \text{ and } BP)^{\uparrow}$ If $\frac{dP}{dT} (-ve) \& P^{\uparrow} \text{ then } (MP \& BP) \downarrow$

REGELATION PROCESS

When weights are suspended from a ice block with the help of a wire, then the wire cuts the ice block and moves down, but the block again gets intact above the wire this process is known as regelation process.

DIFFERENCE BETWEEN VAPORISATION AND EVAPORATION

Evaporation	Vapourisation
This is possible at	It is possible only at a
all temperature	perticular temperature
In this process a liquid	Liquid is required to be
need not be heated	heated.
The temperature of	Temperature increases
substance decreases	and cooling is produced.
Possible only at liquid	Whole of liquid takes
surface	part.
It is a slow process	It is a fast process.

THERMODYNAMIC SYSTEM

A system whose state is expressed in parameters like pressure (P), volume (V), Temperature (T) internal energy (U), Entropy (S) is called thermodynamic system.

(a) **Microscopic system :**- The system in which the number of particles is very less.

eg. A single atom, or single molecule, mass, velocity, angular velocity, kinetic energy etc.

(b) **Macroscopic system :**– In this system, the number of particles is very large.

eg. Pressure of gas, temperature, volume etc.

- (c) **Open system :** In this system, heat and matter both can be exchanged.
- (d) **Closed system :** In this system, only heat can be exchanged.
- (e) **Isolated system :** In this system neither heat can be exchanged nor work can be done so the change of internal energy in this system is zero.
- * Work done :-
- (I) Mathematical method :-
 - $\Delta \mathbf{W} = \mathbf{P} \Delta \mathbf{V} \quad \Rightarrow \quad \mathbf{W} = \int_{\mathbf{v}_1}^{\mathbf{v}_2} \mathbf{P} d\mathbf{v}$
 - (a) If P constant, $W = P(V_2 V_1)$
 - (b) If V constant, W = 0
 - (c) If T constant, $W = 2.303 \mu RT \log_{10} V_2 / V_1$
 - (d) If Q constant, $W = \mu R (T_1 T_2)/\gamma 1$
- (II) Graphical method :-

Workdone = Area enclosed between PV curve and V - axis



P-V indicator graph :-

Sign Concept :

(i) Sign. concept for workdone :-

(a) If $V \not A \Rightarrow dV = +ve \Rightarrow exp^n$ of gas $\Rightarrow \Delta W$ = (+ve) \Rightarrow workdone **by** the system.

(b) If $V \not b \Rightarrow dV = -ve \Rightarrow$ Compression of gas

 $\Rightarrow \Delta W = (-ve) \Rightarrow$ wordone **on** the system.

(ii) Sign concept for heat :-

(a) If heat given to system or heat absorbed by the system $\Delta Q = +ve$

(b) If heat rejected by system or Heat evolved by system $\Delta Q = -ve$

(iii) Sign concept for internal energy :-

Obtained by difference of $(\Delta Q - \Delta W)$

(a) If dU (+ve)
$$\Rightarrow$$
 then U

(b) If dU (-ve)
$$\Rightarrow$$
 then U

CYCLIC PROCESS

A cyclic process consists of a series of changes which returns the system back to its initial state.



- (i) **Internal energy :-** In cyclic process change in internal energy is zero. Because final and initial points are same.
- (ii) Work done : "Area enclosed by closed loop".

-Work done = (+)ve if cycle is clockwise

-Workd done = (-)ve if cycle is anticlockwise

Ans.:
$$W_{net} = (+)ve$$

Beacause area of clockwise cycle is greater than area of anticlockwise cycle.

(iii) **Heat :-** From FLOT $\delta Q = dU + \delta W$

 $\delta \mathbf{Q} = \delta \mathbf{W} \qquad \because \mathbf{dU} = \mathbf{0}$

In cyclic process heat supplied is totally converted into work done.

Ex. A cyclic process of ideal monoatomic gas is shown in figure the correct statement is -

- (i) Work done by the gas in process AB is more than that of the process BC
- (ii) net heat energy has been supplied to the system is equal to work done
- (iii) temperature of the gas in state B is more than C
- (iv) in process CA, heat energy is equal to work (Ans. ii)

ZEROTH LAW OF THERMODYNAMICS

- * ZLOT given by R.H. Fahular.
- * ZLOT gives Concept of temperature **Statement :** If two system (A & B) are seprately in thermal equilibrium with a third system C, then they must be in thermal equilibrium with each other.
- * Temperature indicates : Degree of hotness or Degree of coldness.
- * Measurement of temperature
 - \Rightarrow thermometric property
 - \Rightarrow temperature scale.
 - \Rightarrow thermometer.

THERMOMETRY

Branch of physics relating to the measurement of temperature (degree of hotness) of a body.



Thermometer :– An instrument used to measure temperature of a body

- * The highest possible temperature laboratory temperature is $\approx 10^8 \text{ K}$ (fusion test reactor)
- * The lowest = 10^{-8} K (achieved in 1990 through nuclear spin cooling)
- * Production and measurement of very low temperature is called cryogenic \rightarrow (below 77K)
- * Measurement of very high temperature (>800°C) is called pyrometer.

Type of Thermometers :-

1. Liquid thermometers :-

(a) Hg thermometer (b) Alcohol thermometer

Basic principle - Expansion of liquid on increasing their temperature.

In these thermal expansion of Hg/Alcohol in the bulb causes it to rise in the capillary tube.

$$\mathbf{T} = \left[\frac{\ell_{\mathrm{t}} - \ell_{\mathrm{0}}}{\ell_{\mathrm{100}} - \ell_{\mathrm{0}}} \right] \times 100$$

2. **Gas Thermometers :-** Basic principle – Change in pressure with temperature in a gas at constant volume. (Constant volume gas thermometers)

$$\mathbf{T} = \left(\frac{\mathbf{P}_{\mathrm{t}} - \mathbf{P}_{\mathrm{0}}}{\mathbf{P}_{\mathrm{100}} - \mathbf{P}_{\mathrm{0}}}\right) \times 100$$

- These are more sensitive than liquid thermometers
- These are most accurate and are used to calibrate other thermometer
- 3. **Resistance thermometers :-** Basic principle–Variation of resistance of metals with temperature.

Note :- Platinum is used in resistance thermometers because platinum has high melting point and the variation in resistance for pure platinum is quite large & is uniform throughout the range -200°C to 1200°C

$$T = \left(\frac{R_t - R_0}{R_{100} - R_0}\right) \times 100$$
$$T = \left(\frac{x_t - x_0}{x_{100} - x_0}\right) \times 100$$

In general

- *Note :* The platinum resistance thermometer works on the principle of wheatstone bridge to measure a resistance. Germanium (semiconductor) resistance thermometer used in the range 4K to 77 K (for Low temperature)
- 4. Thermocouple thermometer :- Basic principle : Seeback effect
 - It can be used to measure quickly changing temperature
 - and temperature of tin object.

- 5. **Radiation thermometers** (or Pyrometers)
 - are used to measure very high temperature



Pyrometer

(Based on $E = \sigma T^4$) (Based on $\lambda_m T = constant$)

6. Vapour Pressure Thermometers :-Basic principle :- Saturated vapour pressure P of a liquid depends on temperature is given by $\log P = a + bt + C/T$

Temperature range for different thermometers

Type of thermometer :	Range
Liquid thermometer	-30°C to 300°C
(a) Hg thermometer	
(b) Alcohal thermometer	-80° to 550°C
constant volume gas	–250°C to 1600°C
thermometer	
Resistance thermometer	–200°C to 1200°C
(Platinum)	
Thermocouple	–200°C to 1600°C
thermometer	
Pyrometer	+800° C to No limit
Vapour pressure	0.71 K to 1212 K
thermometer	

- **Bolometer & Thermopile :-** Instruments that are used to detect & measure the amount of thermal radiation

- Sp heat of metal = $\frac{6}{\text{Atomic weight}}$

Cal/gm°C order $S_{Hg} < S_{cu} < S_{Al}$ – Sp heat is minimum of radon and actinium = 0.022 cal/gm°C and maximum H₂ gas = 3.5 cal/ gm°C

Temperature scale : Any temperature scale defined by two fixed points

- (i) lower fixed point (LFP)- melting of ice at normal atm. pressure
- (ii) upper fixed point → Boiling of water at normal pressure = steam points.

Name of scale	Ice point (LFP)	Steam point (UFP)	No of division
Celcius (centigrade)	0°C	100°C	100
Farenheit (°F)	32°F212°F	180	
Reaumer (°R)	0°R	80°R	80
Ideal kalvin scale(K)	273K	373K	100
Rankine (°Ra)	460°Ra	672°Ra	212

Different temperature scales :-

KEY POINTS:

* Change of temperature :-

 $1^{0}R > 1^{0}C = 1 K > 1^{0}F > 1^{0} Ra (min^{m})$

- **Sp. heat :** $= S_{0_{R}} > S_{0_{C}} = S_{V} > S_{0_{R}} > S_{0_{R}}$ *
- * **Relation between different temperature scales** :- For any temperature scale.

 $\frac{\text{Reading} - \text{LFP}}{\text{LFP} - \text{LFP}} = \text{const}; \quad \frac{^{\circ}\text{C} - 0}{100 - 0} = \frac{^{\circ}\text{F} - 32}{212 - 32}$ $=\frac{{}^{\circ}\mathbf{R}-\mathbf{0}}{80-0}=\frac{\mathbf{K}-273}{373-273}=\frac{{}^{\circ}\mathbf{Ra}-460}{672-460}$ $\frac{{}^{\circ}C}{100} = \frac{{}^{\circ}F-32}{180} = \frac{{}^{\circ}R}{80} = \frac{K-273}{100} = \frac{{}^{\circ}Ra-460}{212}$ = constant $\frac{{}^{\circ}C}{5} = \frac{{}^{\circ}F-32}{9} = \frac{{}^{\circ}R}{4} = \frac{K-273}{5} = \frac{{}^{\circ}Ra-460}{106}$

= constant

- * For a pair of temperature If no. of divisions are same (Celcius & Kelvin) than they can not show same reading for any temperature
- * If temperature change on one scale, may easily related to other scale by using conversion scales.
- * Unit degree change $1^{\circ}C \equiv 1$ K, $1^{\circ} F = 9/5 {\circ} C$ \Rightarrow 1° C = 5/9 °F

FIRST LAW OF



Based on energy conservation 1.

 $\Delta \mathbf{Q} = \Delta \mathbf{W} + \mathbf{d} \mathbf{U}$

- All parameters must in same unit all Joule or all 2. calorie
- 3. Heat and work both are path dependent so they called unexact differential parameter(Δ)

- 4. Internal energy is a point function or state function, Internal energy only depends on initial and final state of system so it is called exact differential parameter (d)
- 5. Thermodynamic force is nonconservative force.



By Graph :

- (i) Order of work : $\Delta W_1 > \Delta W_2 > \Delta W_3$ [As per area enclosed]
- (ii) Order of heat : $\Delta Q_1 > \Delta Q_2 > \Delta Q_3$ [From FLOT]
- (iii) Change in internal energy $dU \rightarrow same$

Note : Isothermal process is not possible in practical

Thermo special :- Order of Slope : Slope_{IM} > Slope_{AD} > Slope_{IT} > Slope_{IB}









Solved Examples

Ex.7 At constant temperature, if vol. of gas decrease by 5% then what will be to change in pressure.

Sol. $P'V' = PV$	V' = 9	95% of \Rightarrow	V'= 0.95V
P'(.95V) = PV	\Rightarrow	$\mathbf{P'} = \frac{\mathbf{PV}}{.95 \mathrm{v}}$	$=\frac{P}{95}=\frac{100P}{95}$
% change $\frac{P_{f} - Pi}{Pi}$	×100 =	$\frac{\frac{100}{95}P - P}{P} \times \frac{100}{95}P + 10$	100
$= \left(\frac{100}{95} - 1\right) \times 100$	$=\frac{5}{95}\times$	$100 = \frac{100}{19} =$	= 5.26%

- **Ex.8** At const. temperature in order to increase 10% in volume. What will be required to change in pressure.
- **Sol.** V = V+10% of V = V+.1 V = 1.1V

P' × (1.1 V) = PV P' =
$$\frac{P}{1.1} = \frac{10}{11}$$
.P,
% change = $\left(1 - \frac{10}{11}\right)$ P = $\frac{1}{11}$ P × 100 = $\frac{100}{11}$ = P

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Therm	ndvng	amics
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							Heating	g effect	Cooling effect
	Adiabatic/Isoentropic (AD)	Heat or Entropy	Poisson's low $PV' = constant$, $TV'^{r^1} = constant$ $P^{1^{\gamma}}T' = constant$, $P\rho^{\gamma} = constant$	$\Delta W = \frac{\mu R(T_1 - T_2)}{\gamma - 1} = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$ $\Delta Q = 0, \ \Delta W = -dU = -\mu C_v \Delta T$	A A A A A A A A A A A A A A A A A A A	Slope _{AD} = dP/dV= \neg ?P/V	 (i) Non-Conductive vessel / Insulated vessel (ii) Rapidly/Fast/Sudden process (i) Sound propagation in gaseous medium (ii) Continuous hammering on metal body 	 (iii) Barrel(pipe) become hot during pumping of air in to tyre tube (iii) Suddan bructing of the tube 	(v) If CO ₂ gas cylinder is suddenly opened then conversion of CO ₂ into dry ice. (vi) Free exp ⁿ of real gas ADE $\Rightarrow \Delta W = +ve$, dU= $-ve \Rightarrow U\downarrow$, T $\downarrow \Rightarrow$ Cool ADC $\Rightarrow \Delta W = -ve$, dU= $+ve \Rightarrow U\uparrow$, T $\uparrow \Rightarrow$ Hot
DDYNAMIC PROCESS	Isothermal (IT)	Tempreture	Boyl's law PV = constant	$\Delta W = 2.303 \ \mu RT \ log_{10} \ \frac{V_2}{V_1}$ dU = 0, $\Delta Q = \Delta W$	A A A A A A A A A A A A A A A A A A A	Slope _{IT} = dP/dV= $-P/V$	(i) Conductive vessel.(ii) Slowly process(i) All phase conversion	(II) Changes occur in environment in any season	$\Delta W = 2.303 \ \mu RT \ log_{10} \ \frac{P_1}{P_2}$
THERMO	Isobaric (IB)	Pressure	Charle's Law . α T	$\Delta W = P\Delta V = \mu R\Delta T$ $\Delta Q \neq 0, \Delta W \neq 0, dU \neq 0$ $\Delta Q=, dU = \mu C_v \Delta T$	→ → → → → → → → → → → → →	Slope _{IB} = dP/ dV=0(min)	Constant pressure (Open container)	All phase conversion	$\Delta W = \mu R \Delta T$
	Isochoric (IM)	Volume	Gay Lussac's Law $P \propto T$	$\Delta W=zero$ $\Delta Q = dU = \mu C_v \Delta T$	∧ ▲ = 00°	Slope $_{IM}$ = dP/dV= ∞ (Max.)	Closed container	Heating of solid and liquid	$\Delta Q = dU = \mu \ C_v dT$
	Basic Point	Constant	Gas Law Eq ⁿ of state	Work done Applied to	FLOT P–V diagram	Slope of PV graph	Specific condition	Special example	Remarks

FREE EXPANSION OF GAS

(Expansion against vaccum)

Condition : $\Delta Q = 0$ (because non conducting vessel) and P = 0 (because vacuum)

so $\Delta W = P \Delta V = 0$ then what is dU = ?

For any gas $\Delta W = 0$, $\Delta Q = 0$ (always)

(i) For an **ideal gas** : no internal work against into molecular forces

(:: IMF = 0) so for ideal gas dU = 0, U = constant, T = constant, (isothermal)

 (ii) For real gas : real gas has to do work against IMF in order to increase, distance between gas molecules. Hence

U(KE) is decreases. So it gives only adiabatic cooling effect.

Main Conclusion :-

Free expansion of ideal gas-AD, IT

Free expansion of real gas – only AD.

DRAW BACKS OF FLOT

- * No information about what part of heat converted in to mech-work.
- * Does not gives proper direction of heat flow.

SECOND LAW OF

THERMODYNAMICS (SLOT)

Statement :

- 1. *Kelvin plank statement :* It state that in cyclic process total heat can not be converted into mechwork.
- 2. *Claussius statement :* It is impossible to have net heat flow from low temperature body to high temperature body.
- 3. *Carnot theorem :* This theorem states that efficiency of any irreversible heat engine can not be greater then or equal to efficiency of a reversible heat engine. Work between same heat source & sink.

Heat engine :-



Main elements of heat engine : three elements

- (i) Heat source at temperature $T_1 =$ Heat reservoir
- (ii) Wroking substance
- (iii) Sink at low temperature $T_2 = \text{Cold reservoir}(\text{out put})$

$$Q_1 = Q_2 + W \Rightarrow \text{efficiency } \eta = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = \frac{T_1 - T_2}{T_1}$$
$$\boxed{\eta = \left(1 - \frac{Q_2}{Q_1}\right) \times 100 \% = \left(1 - \frac{T_2}{T_1}\right) \times 100 \%}$$
carnot engine $\frac{Q_1}{Q_1} = \frac{T_1}{Q_1}$

carnot engine $\frac{Q_1}{Q_2} = \frac{I_1}{T_2}$

Carnot Heat engine :-



- (1) In cyclic process dU = 0
- (2) In cyclic process $Q_{net} = W_{net}$ $Q_{absorbed} - Q_{released} = W_{net} = Q_{in} - Q_{out}$

(3) % Efficiency in cyclic process η

$$= \frac{W_{net}}{Q_{in}} \times 100 \qquad W_{net} = Q_{net}$$

$$T_{1} \rightarrow \text{temperature of Heat source}$$

$$W_{net} = \mu R(T_{1} - T_{2}) \log_{e} \left| \frac{V_{f}}{V_{i}} \right| \qquad r \quad Q_{in} = \mu RT_{1} \log_{e} \frac{V_{f}}{V_{i}}$$

$$\eta_{1} = \frac{W_{net}}{Q_{in}} \times 100 = \frac{\mu R(T_{1} - T_{2}) \log_{e} \frac{V_{f}}{V_{i}} \times 100}{\mu RT_{1} \log_{e} \frac{V_{f}}{V_{i}}}$$

$$\Rightarrow \boxed{\eta = \frac{T_{1} - T_{2}}{T_{1}} \times 100}$$

Carnot refrigerator :-



 Q_2 - heat absorb

 $W \rightarrow Input$

$$Q_2 \alpha T_2, Q_1 \alpha T_1 \quad \frac{Q_1}{Q_2} = \frac{T_1}{T_2}$$
$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2} \qquad \qquad \boxed{Q_2 + W = Q_1}$$

KEY POINT

- * Refrigerator is just opposite to heat engine.
- * In carnot refrigerator, heat is absorbed from a cold body & some external work is to be done on refrigeratant and the total heat is given out at higher temperature source.

The co-efficient of performance is reciprocal of efficiency & for refrigerator it is better to work out its C.O.P.

C.O.P. (
$$\beta$$
) = $\frac{\text{Heat absorbed} Q_{\text{in}} \int}{W}$

*

$$= \frac{Q_2 \left[Heat absorbed from cold body \right]}{W \left[Mech work on refrigerator \right]}$$

C.O.P. =
$$\frac{Q_2}{Q_1 - Q_2} \implies C.O.P. = \frac{T_2}{T_1 - T_2}$$

Heat engine $\eta = \frac{T_1 - T_2}{T_1} \times 100$
Refrigerator C.O.P. = $\frac{T_2}{T_1 - T_2}$

THERMAL EXPANSION

Expansion of Solid :

All solids are found to expand on heating. This is called thermal expansion. According to atomic theory of matter, **unsymmetry in potential energy curve is responsible for thermal expansion.**



U = Potential energy

r = Average distance between molecules.

As temperature \uparrow ; energy \uparrow so that amplitude of vibrations of atoms increases and hence average distance between them increases. If potential energy curve is symmetrical, no thermal expansion will take place in spite of heating.

Thermal expansion of solids is of three types :-

- 1. Linear expansion
- 2. Superficial expansion or surface expansion
- Cubical expansion or volume expansion 3.
- The coefficient of linear expansion is defined as (i) fractional increase in length per°C rise in temperature

$$\alpha = \lim_{\Delta T \to 0} \frac{1}{L} \frac{\Delta L}{\Delta T}$$
; $\alpha = \frac{1}{L} \frac{dL}{dT}$

The coefficient of surface expansion $\left| \beta = \frac{1}{A} \frac{dA}{dT} \right|$ and coefficient of volume expansion $\gamma = \frac{1}{V} \frac{dV}{dT}$ are defined in similar way.

(ii) Due to rise in temperature ΔT change in length $\Delta L = L\alpha \Delta T$, change in area $\Delta A = A\beta \Delta T$ and change in volume $\Delta V = V \gamma \Delta T$

(iii)Final length $|L' = L(1 + \alpha \Delta T)|$ final area $A' = A(1 + \beta \Delta T)$ and final volume $\mathbf{V}' = \mathbf{V}(1 + \gamma \Delta \mathbf{T})$

$$\frac{A'}{A} = \left[\frac{L'}{L}\right]^2 \text{ and } \frac{V'}{V} = \left[\frac{L'}{L}\right]^3$$

Expansion of liquid :-

When a liquid in a vessel is heated then the observed **Sol.** :: $\Delta A = A\beta\Delta T$ expansion of the liquid is slightly less than it's real (or actual) expansion, because along with the liquid the vessel also expands.

Accordingly here we shell have two types of coefficients namely coefficient of apparent expansion (γ_{a}) and coefficient of real expansion (γ_{a})

observed (or apparent) increase in volume (a) $\gamma_a = \frac{11}{\text{original volume} \times \text{change temperature}}$

(b) $\gamma_r = \frac{\text{Real increase in volume}}{\text{original volume} \times \text{change in temperature}}$

(c) Relation between γ_a and γ_r in case of a liquid $\gamma_r = \gamma_a + \gamma_g$ (where $\gamma_g = \text{coefficient of volume}$ expansion of the vessel)

- **Expansion of gas :-**
- (a) Volume expansion coefficient γ_{y}

$$\Rightarrow V = V_0(1 + \gamma_v t)$$

(b) Pressure expansion coefficient $\gamma_{\rm p}$

$$\Rightarrow V = V_0(1 + \gamma_P t)$$

Solved Examples

Ex.9 A brass rod of length 50 cm and diameter 3.0 mm is joined to a steel rod of the same length and diameter. Calculate the change in length of the combined rod at 250°C, if the original lengths are at 40°? (Coefficient of linear expansion α_{brass}

= $2.10 \times 10^{-5} \ ^{\circ}C^{-1}$, $\alpha_{steel} = 1.2 \times 10^{-5} \ ^{\circ}C^{-1}$)

- **Sol.** $\Delta L_{\text{steel}} = L \alpha_{\text{steel}} \Delta T$(1) $\Delta L_{Brass} = L \alpha_{Brass} \Delta T$(2) Net change in length = $\Delta L_{steel} + \Delta L_{Brass}$ $= L (\alpha_{steel} + \alpha_{Brass}) \Delta T = 50$ $(1.2 \times 10^{-5} + 2.1 \times 10^{-5}) (250 - 40) = 0.346 \text{ cm}$
- Ex.10 A sheet of brass is 50 cm long and 10 cm broad at 0° C. The area of the surface increase by 1.9 cm² at 100°C. Find the coefficient of linear expansion of brass.

$$\beta = \frac{\Delta T}{A\Delta T} = \frac{1.9}{500 \times 100} = 3.8 \times 10^{-5} \text{ °C}^{-1}$$

$$\therefore \quad \alpha = \frac{\beta}{2} = \frac{3.8 \times 10^{-5}}{2} = 1.9 \times 10^{-15} \quad ^{\circ}C^{-1}$$

Ex.11 The volume of thin brass vessel and the volume of a solid cube are both equal to 1 litre. What will be the change in the volumes of the vessel and the cube upon being heated to 25° C? (Given α for brass $= 1.9 \times 10^{-5} \circ C^{-1}$

Sol.
$$\Delta V = V (3\alpha) \Delta T$$

 $= (10^{-3}) (3 \times 1.9 \times 10^{-5}) (25) \times 10^{6} \text{ cm}^{3}$ \therefore 1 litre = 10⁻³ m³ = 10³ cm³ $= 1.425 \text{ cm}^2$

HUMIDITY

Dew :- The water drops obtained by condensation of saturated vapours, are called dew.

Dew point :– The temperature at which the water vapours actually presents in air become saturated & start condensing as dew is called dew temperature.

Absolute Humidity :- The amount of water vapour present in a unit volume of air is called the absolute humidity of air unit \rightarrow gm/m³

RH = Relative Humidity

Amount of water vapour present

in a given volume of air at a given temp.

 \pm Amount of water vapour required to saturate

the same volume of air at the same temp.

RH is generally expressed as a percentage (%) if above ratio is 0.48 then R.H.=48%

For saturated air RH = 100%

Another definitions of RH

Vapour pressure of air

RH= Saturated Vapour Pressure (SVP) at the same temp.

or $RH = = \frac{SVP \text{ at the dew point}}{SVP \text{ at the air temp.}}$

 $(SVP \rightarrow saturated vapour pressure)$

Ex.: On rainy day – water vapours present in air are saturated

 \Rightarrow RH = 100% dew temperature = room temperature

Solved Examples

- **Ex.12.** Find the change in internal energy of a gas when (i) it absorbs 80 calorie of heat and performs work equal to 170 Joule (ii) it absorbs 20 calorie of heat and work equal to 55 Joule is performed on it.
- Sol. (i) Here, dQ = +80 cal $= 80 \times 4 \cdot 2 = 336$ J (Heat is absorbed) dW = 170 J (work is done by the gas) Now, dQ = dU + dW $\therefore dU = dQ - dW = 336 - 170 = 166$ J Ans. (ii) Here, dQ = +20 cal $= 20 \times 4 \cdot 2 = 84$ J (heat is absorbed) dW = -55 J (Work is done on the gas)
 - :. dU = dQ dW = 84 (-55) = 139 J. Ans.

- **Ex.13.** Difference between two specific heats of a gas is 5000 J kg⁻¹ K⁻¹ and the ratio of specific heats is 1.6. Find the specific heats.
- **Sol.** Let C_p and C_v be the specific heats of a gas at constant pressure and constant volume.

Again from (ii) $C_p = 1\cdot 6\times 8\cdot 33\times 10^3 = 1\cdot 33\times 10^4$ Jkg⁻¹ K⁻¹ Ans.

- **Ex.14.** Calculate the difference between two principal specific heats of 1 g of helium gas at normal temperature and pressure. Take universal gas constant as $8 \cdot 31 \text{ J}$ mole⁻¹ K⁻¹, J = 4 \cdot 186 joules/cal and molecular weight as 4.
- **Sol.** Here, $M_w = 4$, $R = 8.31 \text{ J} \text{ mole}^{-1} \text{ K}^{-1}$, $J = 4.186 \text{ Jcal}^{-1}$

Now, $C_P - C_V = r/J$, where C_P and C_V are principal specific heats and r is the gas constant or

 $C_{\rm P} - C_{\rm V} = R/M_{\rm W}J$ where R is the universal gas constant

:
$$C_{p} - C_{v} = \frac{8 \cdot 31}{4 \times 4 \cdot 186} = 0.496 \text{ cal } g^{-1} \text{ K}^{-1} \text{ Ans.}$$

Ex.15. Two engines A and B have their sources at 400 K and 350 K and sinks at 350 K and 300 K respectively. Which engine is more efficient and by how much ?

Sol. For A engine $T_1 = 400 \text{ K}$; $T_2 = 350 \text{ K}$

$$\therefore \eta_{A} = 1 - \frac{T_{2}}{T_{1}} = 1 - \frac{350}{400} = \frac{50}{400} = \frac{1}{8} \Rightarrow \% \eta_{A}$$
$$= \frac{1}{8} \times 100 = 12.5\%$$

For B engine $T_1 = 350 \text{ K}$; $T_2 = 300 \text{ K}$

$$\therefore \eta_{B} = 1 - \frac{T_{2}}{T_{1}} = 1 - \frac{300}{350} = \frac{1}{7} \implies \% \eta_{B}$$
$$= \frac{1}{7} \times 100 = 14.3\%$$

Since $\eta_B > \eta_A$, so engine B is more efficient than engine A by $14 \cdot 3 - 12 \cdot 5 = 1 \cdot 8\%$ **Ans.**

Ex.16. A carnot engine operates between 500 K and 400 K. If it absorbs 6×10^5 cal. heat at higher temperature, how much work per cycle can the engine perform ?

Sol.
$$T_1 = 500 \text{ K}$$
; $T_2 = 400 \text{ K}$; $Q_1 = 6 \times 10^5 \text{ cal}$
 $\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{400}{500} = \frac{1}{5}$, Now $\eta = \frac{W}{Q_1}$ or W
 $= \eta Q_1 = \frac{1}{5} \times 6 \times 10^5 \text{ cal} = 12 \times 10^4 \text{ cal}$
 $= 12 \times 10^4 \times 4.186 = 5.024 \times 10^5 \text{ J}$
Ans. ($\because 1 \text{ cal} = 4.186 \text{ J}$)

Ex.17. A carnot engine whose sink is at 290 K has an efficiency of 30%. By how much the temperature of the source be increased to have its efficiency equal to 50%, keeping sink temperature constant

Sol. Step. I
$$\eta = 30\% = \frac{30}{100} = \frac{3}{10}$$
, $T_2 = 290 \text{ K}$
Now, $\eta = 1 - \frac{T_2}{T_1}$ or $\frac{T_2}{T_1} = 1 - \eta = 1 - \frac{3}{10} = \frac{7}{10}$
or $T_1 = \frac{10}{7}$ $T_2 = \frac{10}{7} \times 290 = 414 \cdot 29 \text{ K}$
Step. II Here $\eta = 50\% = \frac{1}{2}$, $T_2 = 290 \text{ K}$
Now, $\eta = 1 - \frac{T_2}{T_1}$ or $\frac{T_2}{T_1} = 1 - \eta = 1 - \frac{1}{2} = \frac{1}{2}$ or
 $T_1 = 2T_2 = 2 \times 290 = 580 \text{ K}$
 \therefore Increase in source temperature = $580 - 414 \cdot 29$
 $= 165 \cdot 71 \text{ K}$

- **Ex.18.** A carnot engine whose source temperature is at 400 K takes 100 kcal of heat at this temperature in each cycle and gives 70 kcal to the sink. Calculate (i) the temperature of the sink and (ii) the efficiency of the engine.
- **Sol.** Here $T_1 = 400$ K, $Q_1 = 100$ kcal, $Q_2 = 70$ kcal

(i)
$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$$
 : $T_2 = \frac{Q_2}{Q_1} T_1 = \frac{70}{100} \times 400 = 280 \text{ K}$
(ii) $\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{280}{400} = 1 - 0.7 = 0.3 \text{ or } \%$
 $\eta = 0.3 \times 100 = 30\%$

- **Ex.19.** A refrigerator freezes 5 kg of water at 0°C into ice at 0°C in a time interval of 20 minutes. Assume that room temperature is 20°C. Calculate the minimum power needed to accomplish it ?
- **Sol.** Amount of heat required to convert water into ice at 0°C,

Q₂ = mL = (5 kg) × (80 kJ cal/kg) = 400 kcal
Now T₁ = 20°C = 273 + 20 = 293 K ;
T₂ = 0°C = 273 + 0 = 273 K
We know
$$\frac{Q_2}{W} = \frac{T_2}{T_1 - T_2}$$

∴ W (work done) = Q₂ × $\frac{T_1 - T_2}{T_2}$
= 400 × $\frac{293 - 273}{273}$ = 400 × $\frac{20}{273}$ = 29.3 kcal
= 29.3 × 4.2 × 10³ J or W = 123 × 10³ J
Time, t = 20 min = 20 × 60 = 1200 s.

$$\therefore \text{ Power needed, } \mathbf{P} = \frac{\mathbf{w}}{\mathbf{t}} = \frac{123 \times 10^3}{1200} = 102 \cdot 5 \text{ W}$$

Ex.20. Refrigerator A works between -10° C and 27° C while refrigerator B works between -20° C and 17° C, both removing heat equal to 2000 J from the freezer. Which of the two is better refrigerator.

[Ans. A is better than B]

Ex.21. How many metres can a 60 kg man climb by using the energy from a slice of bread which produces 100,000 cal heat ? Assuming that human body works at an efficiency of 28% ?

[Here work done in climbing is equal to increase in potential energy] [Ans. 200 m]

- **Ex.22.** In thermometery, triple point of water is taken as a standard fixed point. Explain, why the melting point of ice and boiling point of water are not considered fix as standard fixed point
- **Sol.** Since triple point of water is easily reproducible so it used as a standard temperature in the thermometry. Ice point and steam points of water are difficult to duplicate as they are very sensitive to the dissolved impurities.

- **Ex.23.** What is ice point on Kelvin scale. If the temperature of a body increases by 1°C, what will be the change in temperature on Kelvin scale ?
- Sol. 273.15 K is the ice point on Kelvin scale. The relation between Kelvin scale and the Celsius scale is given by T (K) = $0(^{\circ}C) + 273.15$. The increments in temperature on Kelvin scale are the same as those of the Celsius scale i.e. $1^{\circ}C = 1K$.
- **Ex.24.** A long cylinderical vessel having linear coefficient of expansion α is filled with a liquid upto a certain level. On heating, it is observed that the level of the liquid in the cylinder remains the same. What is the volume coefficient of expansion of the liquid ?
- **Sol.** As the level of the liquid remains the same, therefore the volume coefficient of the liquid is same as that of volume coefficient of expansion of the cylinder. Since the volume coefficient of expansion is 3 times the linear coefficient of expansion say α . Then volume coefficient of expansion of the liquid is 3 α .
- **Ex.25.** How the fishes can survive in the extreme winter when ponds and lakes are frozen ?
- **Sol.** Water contracts as its temperature increases from 0°C to 4°C. Above 4°C, the water expands with the increase in temperature. Hence water has maximum value of density at 4°C. This is the reason why the water in ponds and lakes freezes first at the surface. The ice formed on the surface remains floating because the water under it is at 4°C and is heavier. Since ice is a poor conductor of heat and hence prevents the water under it from the further freezing. That is why the fishes can survive in extreme winter.
- **Ex.26.** When two bodies having temperatures T_1 and T_2 are brought in contact, then the temperature of this $(T_1 + T_2)$

system may not be $\frac{(T_1 + T_2)}{2}$. Explain why?

Sol. If two bodies made of same material and have the same mass but different temperatures T_1 and T_2 , then their equilibrium temperature T when they are

brought in thermal contact will be $\frac{(T_1 + T_2)}{2}$

- [:: Heat lost = Heat gained]
- The equilibrium temperature T will not be necessarily $\frac{(T_1 + T_2)}{2}$ if two bodies in thermal equilibrium have
- $\frac{1}{2}$ if two bodies in thermal equilibrium have different heat capacities.

- **Ex.27.** Why is a small space left between two rails on a railway track ?
- **Sol.** If there is no space left between two rails then during summer due to the rise in temperature, the rails will expand and they will bend. Hence the train will be derailed. For this reason, a small gap is left between two iron rails.
- Ex.28. Why do telephone wires become taut in winter?
- **Sol.** They contract due to the fall in temperature, so they become taut.
- **Ex.29.** What are the various properties of a thermometric substance ?
- **Sol.** (i) They should have high boiling point and low freezing point to provide for the measurement of a wide range of temperature.

(ii) The coefficient of expansion of the substance be high so that the thermometer may be sensitive.

(iii) The substance should not stick to the sides of the glass tube.

- (iv) It should have good thermal conductivity.
- (v) It should not be volatile.
- (vi) It should be available in abundance.
- (vii) It should be available in pure state.
- **Ex.30.** It is generally very cold after the hail storm than during or before it. Why ?
- **Sol.** After hail storm, the ice balls melt by absorbing lot of heat energy from the atmosphere. This reduces the temperature of the atmosphere.
- **Ex.31.** If the door of the refrigerator is kept open in a room, will it make the room warm or cool ?
- **Sol.** A refrigerator is a heat engine that works in the backward direction i.e. it extracts heat from a low temperature reservoir and transfers it to a high temperature reservior. Thus it exhausts more heat into the room than it extracts from it. Hence the room will become warm.

- **Ex.32.** Does the internal energy of an ideal gas change in an isothermal process ? In an adiabatic process
- **Sol.** Internal energy of ideal gas changes when the temperature of the gas changes. Since in isothermal process, there is no change in temperature and hence internal energy of an ideal gas does not change. Since in adiabatic process, temperature of gas changes and hence internal energy also changes.
- **Ex.33.** Is it possible to increase the temperature of a gas without giving it heat ?
- Sol. Yes, when gas is compressed adiabatically.

MEMORY TIPS

Heat is a form of energy and has the capacity of doing work.

Temperature of a body is that physical quantity which determines the degree of hotness or coldness of a body and the direction of flow of heat.

Heat is the cause while temperature is the effect.

When heat is supplied to a body without changing its state, the temperature of body increases and the rise in temperature is directly proportional to the quantity of heat supplied.

Equality of the temperature of two bodies does not imply that heat contents of both are the same, Two bodies having the same heat contents need not be at the same temperature.

The branch of physics dealing with the measurement of temperature is called Thermometry.

If temperature on celsius scale is C, that on fahrenheit scale is F, on kelvin scale is K and on Reaumer scale

is R, then $\frac{C}{5} = \frac{F-32}{9} = \frac{K-273}{5} = \frac{R}{4}$

If mechanical work W produces the same temperature change as heat H, then we can write W = JH where J is the called mechanical equivalent of heat.

The heat absorbed or given out by a body of mass m, when its temperature changes by ΔT is $\Delta Q = mc \Delta T$ where c is a constant for the substance. It is called specific heat.

Heat capacity of a body of mass m is defined as ΔQ = mc

Water equivalent of a body is numerically equal to the product of its mass and specific heat i.e. w = mc

When the state of matter changes , the heat absorbed or evolved is given by Q = mL where L is called latent heat.

Principle of calorimetry states that the heat lost = heat gained. It is in accordance with the law of conservation of energy.

In case of gases, there are two type of specific heats i.e., $C_p \& C_v (C_p = \text{specific heat at constant pressure}$ and $C_v = \text{specific heat at constant volume.})$

Molar specific heats of a gas are :-

 $C_p = M_w c_p$ and $C_v = M_w c_v$, where $M_w =$ molecular weight of the gas

 $C_p > C_v$. The difference between the two specific heats is equal to the amount of heat equivalent to the work performed by the gas during expansion at constant pressure.

Mayer's formula : $C_p - C_v = R$

where R is the universal gas constant.

Thermodynamics is the branch of science that deals with the relation between heat & mechanical energy.

Work done by a system is numerically equal to area under the PV- diagram. During expansion the work is done by the system and is taken as positive. During compression, the work is done on the system and is takes as negative.

If the tracing of curve in a cyclic process is in clockwise direction, the work is done by the system is equal to area of closed curve.

Internal energy of a gas is defined as the sum of kinetic energy and the intermolecular potential energy of the molecules of the gas.

Internal energy of an ideal gas is wholly kinetic in nature and is a function of temperature only.

According to the first law of thermodynamics,

 $\Delta Q = dU + \Delta W$

where ΔQ = The heat absorbed by the system.

dU = The increase in internal energy $\Delta W =$ The work done.

Work done during isothermal process :-

$$W_{rr} = 2.303 \,\mu RT \log_{10} \frac{V_F}{V_i} = 2.303 \,\mu RT \log_{10} \frac{P_i}{P_F}$$

An adiabatic process is one in which pressure, volume and temperature of the system change but there is no exchange of heat between the system and the surroundings.

An adiabatic process may be achieved (a) If a gas is enclosed in a vessel whose walls are made of a highly insulating material and (b) the gas is compressed or allowed to expand very quickly.

Relation between P,V & T in an adiabatic process :-

(a) PV γ = constant

(b) TV $^{\gamma}$ -1 = constant

(c) $P^{1-\gamma} T^{\gamma} = constant$

Work done during adiabatic process :-

(a)
$$W_{AD} = \frac{1}{\gamma - 1} [P_i V_i - P_f V_f]$$

(b)
$$W_{AD} = \frac{\mu \kappa}{\gamma - 1} [T_i - T_f]$$
 (c) $W_{AD} = \mu C_v (T_i - T_f)$

For monoatomic gas :-

$$C_{v} = \frac{1}{\mu} \left(\frac{dU}{dT} \right) = \frac{3}{2} R$$

$$U = \mu \left| \frac{3}{2} RT \right|$$

$$C_{p} = C_{v} + R = \frac{5}{2} R \text{ and } \gamma = \frac{C_{p}}{C_{v}} = \frac{5}{3} = 1.67$$
for diatomic gas
$$C_{v} = \frac{1}{\mu} \left(\frac{dU}{dT} \right) = \frac{5}{2} R$$

$$U = \mu \left| \frac{5}{2} RT \right|$$

$$C_{p} = C_{v} + R = \frac{7}{2} R \text{ and } \gamma = \frac{C_{p}}{C_{v}} = \frac{7}{5} = 1.40$$
Efficiency of carnot heat engine is given by :-
$$n = \frac{Q_{1} - Q_{2}}{Q_{1} - Q_{2}} = \frac{T_{1} - T_{2}}{Q_{1} - Q_{2}}$$
where T is the temperature

 $\eta = \frac{Q_1 - Q_2}{Q_1} = \frac{T_1 - T_2}{T_1}$ where T_1 is the temperature of source and T_2 is that of sink.