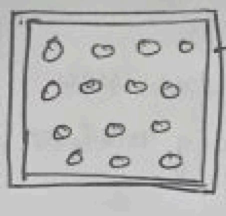
Thermodynamics

Thermal Equilibrium:-

→ When all macroscopic properties like P, V, T, m, n are constant & do not change with time.

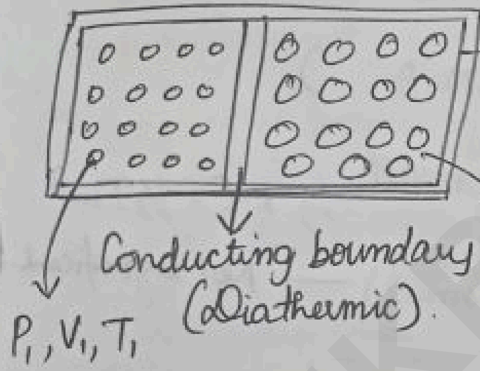
→ A body is said to be in thermal equilibrium with its surrounding if it's insulated completly.



→ Insulated boundary (isolated). → Adiabatic (No heat change) $\Delta Q = 0$.

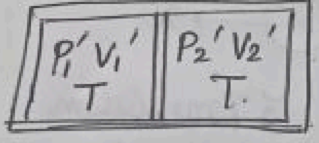
No exchange of energy. & heat

Two bodies in contact in Thermal Equim:

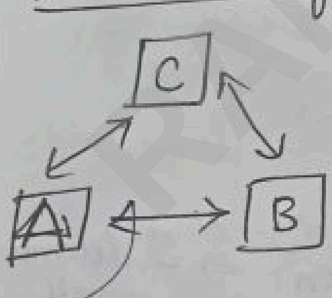


→ Insulated boundary (Adiabatic). → Heat flows from high temp to low temp. until $T_1 = T_2$.

→ Final state (thermal equi)



Zeroth Law of Thermodynamics:-



⟹ A & C in contact → T.E ($T_A = T_C$).

⟹ B & C in contact → T.E ($T_B = T_C$).

⟹ A & B are in Thermal Equi. $T_A = T_B$.

$$\boxed{T_A = T_C \text{ and } T_B = T_C \Rightarrow T_A = T_B}$$

Internal Energy:-

U = Potential energy of Molecules (Due to intermolecular force of attraction) + Kinetic energy of molecules (Due to motion of molecules).

For an Ideal gas at Rest :- → No external energy.

Total energy of gas = Internal energy of molecules = K.E of molecules.

$\boxed{T.E = K.E = U}$ → No intermolecular force of attraction in ideal gas (⇒ No P.E.).

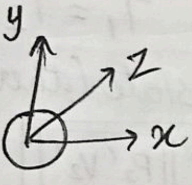
Degree of Freedom :-

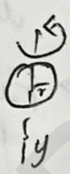
No. of independent ways in which a molecule possesses translational, rotational and vibratory motion.

[OR]

No. of independent terms in the expression for kinetic energy. (not dependent on each other).

Monoatomic gas : (Eg: Noble gases – He, Ne, Ar ...)





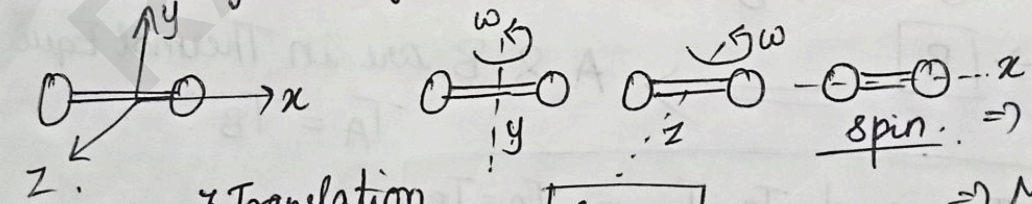
→ Radius – very small. ⇒ $K.E = \frac{1}{2}I\omega^2$.

$I = mr^2$ (very small) → Not significant.

3 Translation
0 Rotation ⇒ $\boxed{f = 3}$

$\boxed{\text{2 Vibration (at high temps).}}$

Diatomic gas : (Eg: O_2, N_2, H_2, ...).



⇒ I becomes small ⇒ NO K.E.

3 Translation
2 Rotation ⇒ $\boxed{f = 5}$

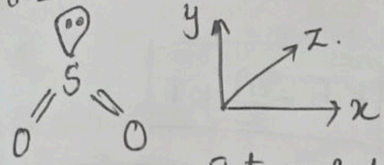
$\boxed{\text{2 Vibration (at high temps)}}$

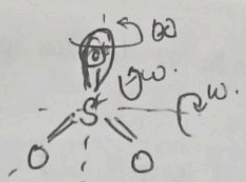
Polyatomic gas : (Eg: SO_2, CO_2, CH_4, NH_3)

(i) Non - Linear

(ii) Linear.

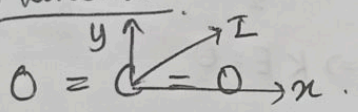
(i) Non-Linear :-

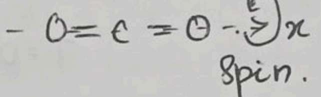


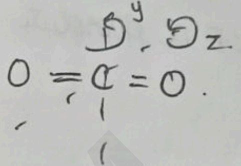


3 translation
3 Rotation $\Rightarrow \boxed{f = 6}$ (2 Vibration) (at high temps.)

(ii) Linear :-







3 translation
2 rotation $\Rightarrow \boxed{f = 5}$ (2 Vibration at high temps)

Ⓠ No. of translational degrees of freedom for a diatomic gas is :

For diatomic gas $f = 5$ (3T, 2R) $\Rightarrow \boxed{f_{translational} = 3}$

Ⓠ Degrees of freedom of a triatomic gas:

$\boxed{f = 6}$ (3T, 3R).

Law of Equipartition of Energy :-

The average K.E associated with each degree of freedom of a molecule is $\frac{1}{2} KT$.

K → Boltzman constant. $\boxed{K = \frac{R}{N}}$ R → Gas constant, N → Avogadro no.

1 molecule → f degrees of freedom.

$R = 8.314 \ J/mol K$
$= 2 \ cal/mol K$.
$N_A = 6.02 \times 10^{23}$.

K.E of each DOF $= \frac{1}{2} KT$

$$\boxed{\therefore \text{K.E of molecule} = \frac{f}{2} KT}$$

K.E of 1 mole of molecules $= N_A \times$ K.E of 1 molecule

$= N_A \times \frac{f}{2} KT = \boxed{\frac{f}{2} RT}$

K.E of n moles of molecules $= \boxed{n \frac{f}{2} RT}$

Ⓠ A polyatomic gas with n degrees of freedom has a mean energy per molecule given by :

K.E of 1 molecule = $\frac{f}{2}KT$ $\quad f = n \Rightarrow \boxed{K.E = \frac{n}{2}KT}$

Ⓠ At 0K, Which property of gas will be zero? $\boxed{\text{Kinetic Energy}}$

K.E ∝ Absolute temperature $\quad T.E = U = K.E = \frac{f}{2}KT.$

$T = 0 \Rightarrow K.E = 0$

Ⓠ Find the K.E of 4 moles of $\underline{N_2}$ at 27°C.

K.E of n moles = $n\frac{f}{2}RT.$ Diatomic gas → $f = 5.$

$= \overset{2}{\cancel{4}} \times \frac{5}{\cancel{2}} \times R \times 300.$ $\quad T = 27 + 273 = 300\ K.$

$= \boxed{3000\,R.}$

Ⓠ Find the K.E of $\underline{3.2\ g}$ of O_2 at temp T K.

$n = \frac{3.2}{32} = \frac{1}{10}.$ Diatomic gas → $f = 5.$

K.E of n moles $= n\frac{f}{2}RT = \frac{1}{\cancel{10}_2} \times \frac{\cancel{5}}{2} \times RT = \boxed{\frac{1}{4}RT}.$

Ⓠ A gas mixture consists of 2 moles of O_2 and 4 moles of Ar at temp T. Neglecting all vibrational modes, the total internal energy of the system is :

$O_2 \rightarrow f = 5 \quad n = 2$

$Ar \rightarrow f = 3 \quad n = 4.$

U of system = K.E of O_2 ② + K.E of Ar ①

$= 2 \times \frac{5}{\cancel{2}}RT + \overset{2}{\cancel{4}} \times \frac{3}{\cancel{2}}RT$

$= 5 + 6 = \boxed{11\,RT}.$

Ⓠ Find the change in U of 1.4 g of N_2 gas when it is heated from 27° to 127° C.

$\Delta U = \Delta K.E.$ $\quad K.E_i = n\frac{f}{2}RT_1 \Rightarrow \Delta K.E = n\frac{f}{2}R(T_2 - T_1) = \Delta U.$

$N_2 \rightarrow f = 5$ $\quad K.E_f = n\frac{f}{2}RT_2 \Rightarrow \Delta U = \frac{\cancel{1.4}}{\cancel{28}\,\cancel{20}\,4} \times \frac{\cancel{5}}{2} R\,(400 - 300)$

$27°C = 300\,K$

$127°C = 400\,K.$

$= \frac{R}{8} \times 100 = \boxed{12.5\,R}.$

Ⓠ The amount of heat energy required to raise the temp of 1g of Helium at NTP from $T_1 K$ to $T_2 K$ is: (at constant volume).

Monoatomic gas $\Delta U = \Delta K.E = n\frac{f}{2}R(T_2 - T_1)$.

$f = 3$.

$n = \frac{1}{4}$.

$= \frac{1}{4} \times \frac{3}{2} N_A k_B (T_2 - T_1)$

$$\Delta U = \boxed{\frac{3}{8} N_A k_B (T_2 - T_1)}$$

DPP-1.

④ $n = 1$ N_2 $T = 27^\circ C$ Total K.E = ?

K.E of n moles $= n \times \frac{f}{2} RT = 1 \times \frac{5}{\cancel{2}} \times \cancel{2}$ cal/molK $\times 300$

$= \boxed{1500 \text{ cal}}$

⑤ Mean K.E (Average Energy) per gm molecule of a monoatomic gas is given by:

per gm molecule $\rightarrow n = 1$. K.E $= n \times \frac{f}{2} RT = 1 \times \frac{3}{2} RT$.

Monoatomic $\rightarrow f = 3$.

$$\boxed{K.E = \frac{3}{2} RT}$$

⑥ Relation b/w specific heats ratio (γ) and degree of freedom (f):

$$\boxed{f = \frac{2}{\gamma - 1}}$$

⑦ 1g ~~of~~ mole of monoatomic gas + 1 g mole of a diatomic gas.

Specific heat of mixture at constant vol = ?

$n_1 = 1$ mole $\quad f_1 = \frac{2}{\gamma_1 - 1} \quad 3 = \frac{2}{\gamma - 1} \Rightarrow \gamma - 1 = \frac{2}{3} \Rightarrow \gamma_1 = \frac{5}{3}$.

$n_2 = 1$ mole

$$C_{V_1} = \frac{R}{\gamma - 1} = \frac{R}{5/3 - 1} = \frac{3R}{2}.$$

$$f_2 = \frac{2}{\gamma_2 - 1} = \frac{2}{\cancel{\gamma_2} - 1} = 5 \Rightarrow \gamma_2 - 1 = \frac{2}{5} \Rightarrow \gamma_2 = 7/5.$$

$$C_{V_2} = \frac{R}{\gamma - 1} = \frac{R}{7/5 - 1} = R/2/5 \Rightarrow C_{V_2} = \frac{5R}{2}.$$

$$\boxed{C_{V mix} = \frac{n_1}{n_1+n_2} C_{V_1} + \frac{n_2}{n_1+n_2} C_{V_2}}$$

$$= \frac{1}{1+1} \times \frac{3R}{2} + \frac{1}{1+1} \times \frac{5R}{2} = \frac{1}{\cancel{4}} (\overset{2}{\cancel{8}}R) = \boxed{2R}.$$

⑧ $n_{H_2} = 2n_{O_2}$, $K.E_{H_2} : K.E.O_2 = ?$ $T = 300\,k$.

$K.E \text{ of } H_2 = 2n \frac{f}{2} RT.$ $\frac{K.E H_2}{K.E O_2} = \frac{2n}{n} = \boxed{2:1}.$

$K.E \text{ of } O_2 = n \frac{f}{2} RT.$

⑨ $T_1 = 0°C$ $T_2 = 273°C$ $K.E f / K.E i = ?$

$= 273\,K$ $= 546\,K.$

$$K.E f / K.E i = \frac{n \frac{f}{2} RT_2}{n \frac{f}{2} RT_1} = \frac{T_2}{T_1} = \cancel{\frac{273}{546}} = \frac{546}{273} = \boxed{2}.$$

⑩ K.E associated per degree of freedom of a molecule:

$$\boxed{K.E = \frac{1}{2} kT}$$

⑪ $T_{O_2} = T_{H_2}$ $K.E O_2 = x\, K.E_{H_2}$ $x = ?$

$K.E_{O_2} = n \frac{f}{2} RT = n \frac{5}{2} RT.$ $K.E O_2 = K.E_{H_2}.$

$K.E_{H_2} = n \frac{f}{2} RT = n\, 5/2\, RT.$ (Equal). $\boxed{x = 1}.$

⑫ Avg energy of molecules of monoatomic gas at temp T:

$$K.E = \frac{f}{2} kT = \boxed{\frac{3}{2} kT}.$$

⑬ Specific heat of an ideal gas does not depend on T

⑭ Specific heat of a gas: can have any value

b/w 0 and ∞

Depends on the process.

⑮ Degrees of freedom of a non-linear triatomic gas is:

$\boxed{f = 6}$ (3T, 3R).

⑯ Mean K.E of one mole of gas per degree of freedom:

$$\boxed{K.E = \frac{1}{2}RT}$$

⑥ $C_V = \frac{f}{2}R$ $\quad C_P = C_V + R$

$$= \frac{f}{2}R + R.$$

$$\gamma = \frac{C_P}{C_V} = \frac{\frac{f}{2}R + R}{\frac{f}{2}R} = \frac{\frac{f}{2}+1}{f/2} = \frac{f+2}{f} = 1 + \frac{2}{f}.$$

$$\gamma = 1 + \frac{2}{f} \Rightarrow \frac{2}{f} = \gamma - 1 \Rightarrow \boxed{f = \frac{2}{\gamma - 1}}$$

Specific Heat :-

Amount of heat required to raise temperature of unit mass of a substance by unit °C / K. $\boxed{c = \frac{Q}{m\Delta T}}$

Molar Specific Heat :-

Amount of heat required to raise the temperature of 1 mole of substance by unit °C/K. $\boxed{C = \frac{Q}{n\Delta T}}$

Relation b/w S.H & M.S.H :-

$$C = \frac{Q}{n\Delta T} \quad c = \frac{Q}{m\Delta T}. \Rightarrow C = \frac{Q}{\frac{m}{M}\Delta T} = \frac{MQ}{m\Delta T}.$$

$$\Rightarrow \boxed{C = Mc}$$

Ⓠ For N_2 gas, S.H.C is c. Find molar S.H.C of the gas.

$C = Mc = \boxed{28c}$

C_V and C_P :-

C_V – Molar specific heat at constant volume. (Isochoric process). $\boxed{C_V = \frac{Q_V}{n\Delta T}}$

C_p - Molar specific heat at constant pressure (Isobaric process)

$$\boxed{C_p = \frac{Q_P}{n\Delta T}}$$

C_v and C_p in terms of f:-

$$\boxed{C_v = \frac{f}{2}R} \qquad \boxed{C_p = \left(\frac{f}{2}+1\right)R}$$

Monoatomic : $f = 3$

Diatomic : $f = 5$

Polyatomic

- ↳ Linear : $f = 5$
- ↳ Non-linear : $f = 6$.

$$C_p - C_v = \left(\frac{f}{2}+1\right)R - \left(\frac{f}{2}\right)R.$$

$$\boxed{C_p - C_v = R}$$

Ⓠ Find C_v, C_p and $C_p - C_v$ for (i) He (ii) O_2 (iii) SO_2.

(i) He $\boxed{f = 3}$ $C_v = \frac{f}{2}R = \boxed{\frac{3}{2}R}$ $C_v = \frac{3}{2}R + R = \boxed{\frac{5}{2}R.}$

(ii) O_2 $\boxed{f = 5}$ $C_v = \boxed{\frac{5}{2}R}$ $C_v = \frac{5}{2}R + R = \boxed{\frac{7}{2}R.}$

(iii) SO_2 $\boxed{f = 6}$ $C_v = \frac{6}{2}R = \boxed{3R}$ $C_p = 3R + R = \boxed{4R.}$

Ⓠ For hydrogen gas, $C_p - C_v = a$ and for oxygen gas, $C_p - C_v = b$. Relation b/w a and b is given by:

$$C_p - C_v = R \longrightarrow \text{Gas constant.}$$

$= 8.314$ J/mol K $= 2$ cal/mol K.

$= 0.0821$ atm l/mol K.

Ⓠ If C_p and C_v denote the specific heats of an ideal gas of molecular weight M, then: ~~C_p~~.

$$C_p - C_v = R \Rightarrow M c_p - M c_v = R$$

$$M(c_p - c_v) = R \Rightarrow \boxed{c_p - c_v = \frac{R}{M}}$$

Ratio of Specific Heats:-

$$\boxed{\frac{C_p}{C_v} = \gamma} \qquad \gamma = \frac{\left(\frac{f}{2}+1\right)\cancel{R}}{\left(\frac{f}{2}\right)\cancel{R}} = \frac{f+2}{f} = \boxed{1 + \frac{2}{f} = \gamma}$$

$$\boxed{\gamma_{mono} > \gamma_{dia} > \gamma_{tri}}$$

$$\boxed{\gamma = \frac{C_p}{C_v} = 1 + \frac{2}{f}}$$

(i) Monoatomic $\gamma = 1 + \frac{2}{3} = \frac{3+2}{3}$

$$\boxed{\gamma = \frac{5}{3} = 1.67}$$

$n = \frac{m}{M}$

(ii) Diatomic $\gamma = 1 + \frac{2}{5} = \frac{5+2}{5}$

$$\boxed{\gamma = \frac{7}{5} = 1.40}$$

(iii) Triatomic $\gamma = 1 + \frac{\cancel{2}^{1}}{\cancel{6}_{3}} = \frac{3+1}{3}$

$$\boxed{\gamma = \frac{4}{3} = 1.33}$$

$\frac{C_p}{C_v} = \gamma \quad C_p - C_v = R.$

$\gamma C_v - C_v = R$

$C_v(\gamma - 1) = R \Rightarrow \boxed{C_v = \frac{R}{\gamma - 1}}$

$C_p = \gamma C_v \Rightarrow \boxed{C_p = \frac{\gamma R}{\gamma - 1}}$

Ⓠ The ratio of specific heats $\frac{C_p}{C_v} = \gamma$ in terms of degrees of freedom (n) is:

$$\boxed{\gamma = 1 + \frac{2}{f}}$$

Ⓠ To find out degree of freedom, the expression is:

$\gamma = 1 + \frac{2}{f} \Rightarrow \gamma - 1 = \frac{2}{f} \Rightarrow \boxed{f = \frac{2}{\gamma - 1}}$

Ⓠ The value of γ for hydrogen, helium and other ideal diatomic gas X (whose molecules are not rigid but have an additional vibrational mode) are respectively equal to:

$H_2 \rightarrow f = 5 \Rightarrow \gamma = 1 + \frac{2}{5} = \frac{7}{5}.$

$He \rightarrow f = 3 \Rightarrow \gamma = 1 + \frac{2}{3} = \frac{5}{3}.$

$X_2 \rightarrow f = 5 + \underset{\text{(Vibrational)}}{2} = 7 \Rightarrow \gamma = 1 + \frac{2}{7} = \frac{9}{7}.$

$$\boxed{\frac{7}{5}, \frac{5}{3}, \frac{9}{7}}$$

Ⓠ For a certain gas, the ratio of specific heats $\gamma = 1.5$, for this gas C_p & C_v = ?

$$C_v = \frac{f}{2}R \qquad \gamma = 1 + \frac{2}{f} \Rightarrow 1.5 = 1 + \frac{2}{f}$$

$$C_p = \left(\frac{f}{2}+1\right)R \qquad f = \frac{2}{0.5} = \frac{2}{1/2} = 4.$$

$$C_v = \frac{f}{2}R = \frac{4}{2}R = \boxed{2R}. \qquad C_p = \left(\frac{f}{2}+1\right)R = \left(\frac{4}{2}+1\right)R = \boxed{3R}$$

Ⓠ C_p of ideal gas $= \frac{7}{2}R$. γ = ?

$$C_p = \left(\frac{f}{2}+1\right)\cancel{R} = \frac{7}{2}\cancel{R} \Rightarrow \frac{f}{\cancel{2}} = \frac{7}{2} - 1 = \frac{5}{\cancel{2}} \Rightarrow f = 5.$$

$$C_v = \frac{f}{2}R = \frac{5R}{2}. \qquad \gamma = \frac{C_p}{C_v} = \frac{7/2\,R}{5/2\,R} \Rightarrow \boxed{\frac{7}{5}}$$

Ⓠ If for a gas, $R/C_v = 0.67$, this gas is made up of molecules which are:

$$C_v = \frac{f}{2}R \Rightarrow \frac{C_v}{R} = \frac{f}{2} = \frac{\overset{1}{\cancel{0.67}}}{0.67} \Rightarrow \frac{R}{C_v} = \frac{2}{0.67} = 3.$$

$$f = 3 \Rightarrow \boxed{\text{monoatomic}}$$

Ⓠ The molar specific heats are C_p and C_v. If R is gas constant, then C_v is equal to:

$$\frac{C_p}{C_v} = \gamma \qquad C_p - C_v = R. \qquad \gamma C_v - C_v = R$$

$$C_v(\gamma - 1) = R \Rightarrow \boxed{C_v = \frac{R}{\gamma - 1}}$$

Molar Specific Heat Capacity of Mixture :-

$$\boxed{C_{mix} = \frac{n_1 C_1 + n_2 C_2}{n_1 + n_2}}$$

$n_1, n_2 \rightarrow$ no of moles of gases 1 and 2.

$C_1, C_2 \rightarrow$ SHCs of 1 & 2.

Work in Thermodynamics :-

$$\boxed{W = \int_{V_i}^{V_f} P\,dV}$$

If P is constant, (isobaric process)

$$W = P\int_{V_i}^{V_f} dV = P\,[V]_{V_i}^{V_f} \Rightarrow \boxed{W = P\Delta V = P(V_f - V_i)}$$

Sign of Work Done :-

$\boxed{W = P\,\Delta V}$

(i) If gas expands $(V_2 > V_1)$ ΔV = positive
Work is done by the gas → +ve work.

(ii) If gas compress $(V_2 < V_1)$ ΔV = negative.
Work is done on the gas → −ve work.

Ⓠ A gas expands 0.25 m^3 at constant pressure, $10^3\ N/m^2$. The work done is :

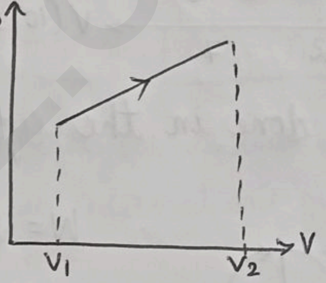
Expands → $\Delta V = +0.25\,m^3$
$P = 10^3\ N/m^2$

$W = P\Delta V = 10^3 \times 0.25$
$= \boxed{250\ J}$

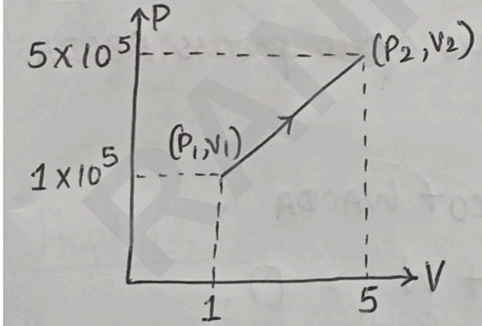
Work done by P-V curve :

$$W = \int_{V_1}^{V_2} P\,dV = \text{Area under P-V curve.}$$

If $V_2 > V_1$ → +ve work done
$V_1 > V_2$ → −ve work done.



Ⓠ A system changes from the state (P_1, V_1) to (P_2, V_2). What is the work done by the system?

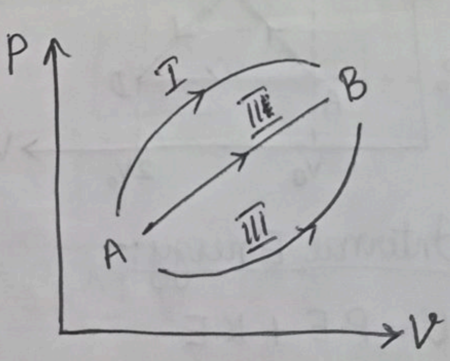


W = Area under P-V curve.
= Area of trapezium = $\frac{1}{2}$ × Sum of ∥ sides × dist b/w them.

$= \frac{1}{\cancel{2}} \times 6\times10^5 \times \overset{2}{\cancel{4}} = \boxed{12\times10^5\ J}$

Work is Path dependent :-

Work done depends on the path followed to reach the final state from initial state.



$A_{I} > A_{II} > A_{III}$

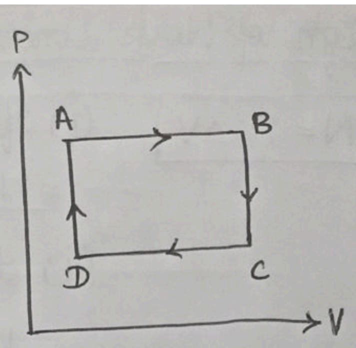
$\Rightarrow \boxed{W_{I} > W_{II} > W_{III}}$

Work done in Cyclic Process :-

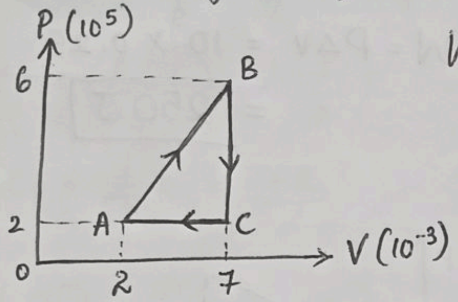
$\boxed{W_{cyclic} \neq 0}$ (Path dependent).

(i) clockwise cycle → Positive work

(ii) Anticlockwise cycle → Negative work.



Ⓠ A gas is taken through the cycle $A \rightarrow B \rightarrow C \rightarrow A$. What is work done by the gas?

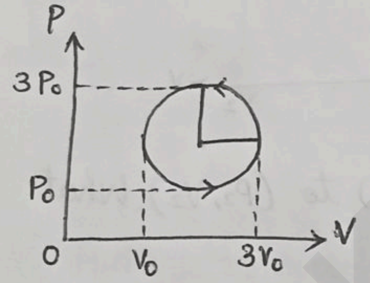


W = Area of Δle $= \frac{1}{\cancel{2}} \times 5 \times 10^{-3} \times {}^{2}\cancel{4} \times 10^{5}$

$= 10^{3} = 1000.$

W. D by gas (clockwise) $= \boxed{+1000\ J}$

Ⓠ Work done in the cyclic process shown is :

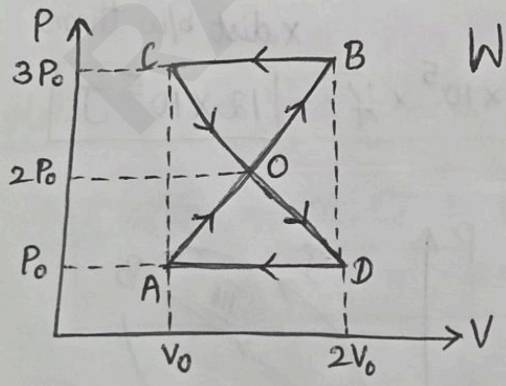


W = Area of circle $= \pi R^{2} = \pi R_1^{\cancel{2}} R_2.$

$= \pi P_0 V_0$

Anticlockwise cycle $\rightarrow \boxed{W = -\frac{22}{7} P_0 V_0}$

Ⓠ A thermodynamic system undergoes cyclic process ABCDA. The work done by the system is :



$W_{net} = W_{OBCO} + W_{AODA}.$

$= \underset{(A.CW)}{-W} + \underset{(C.W)}{W} = 0.$

Internal Energy :-

1) $U = P.E + K.E$

2) For ideal gas :

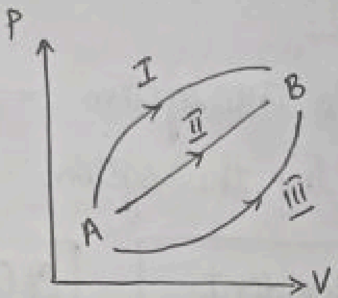
$\boxed{U = K.E = n \frac{f}{2} R T}$

3) For n moles of a gas : $\Delta U = n \frac{f}{2} R \Delta T.$

→ Internal Energy & kinetic energy depend only on temperature.

For gases :-

1) U is a state function.
2) U depends only on temp.
3) ΔU depends only on ΔT.
4) ΔU is path independent.
5) ΔU in closed cycle is zero.



$$\Delta U_{I} = \Delta U_{II} = \Delta U_{III}$$

$$\Delta U \propto (T_2 - T_1)$$

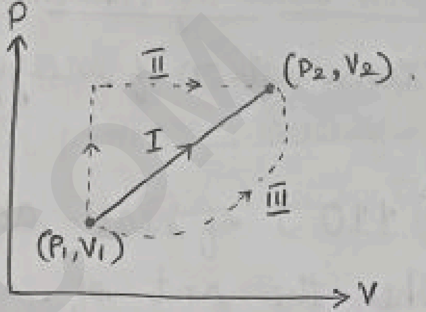
$$\Delta U = n\frac{f}{2}R\Delta T$$

ΔU from P–V curve :-

$$\Delta U = n\frac{f}{2}R\Delta T = n\frac{f}{2}R(T_2 - T_1)$$

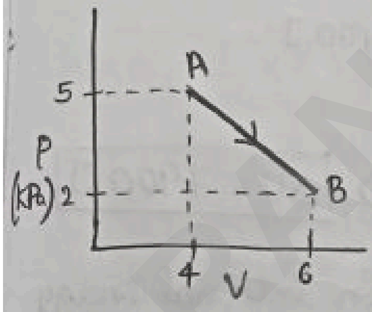
Ideal gas equation $PV = nRT$.

$$\boxed{\Delta U = n\frac{f}{2}(P_2V_2 - P_1V_1)}$$



For any process: $\boxed{\Delta U = nC_V\Delta T}$

Ⓠ 1 mole of an ideal diatomic gas undergoes a transition from A to B along a path AB. The change in internal energy of the gas during the transition is :



$$\Delta U = n \times \frac{f}{2}(P_2V_2 - P_1V_1)$$

$$= 1 \times \frac{5}{2}(2\times6\times10^3 - 5\times4\times10^3) = \frac{5}{2}\times10^3(12-20)$$

$$= \frac{5}{\cancel{2}}\times10^3\times-\cancel{8}^{4} = -20\times10^3\ J$$

$$= \boxed{-20\ kJ}$$

Heat (ΔQ) :-

(i) In terms of specific heat (c) $\Rightarrow$ $\boxed{\Delta Q = mc\Delta T}$

(ii) In terms of Molar specific heat (C) $\Rightarrow$ $\boxed{\Delta Q = nC\Delta T}$

(iii) At constant volume $\Rightarrow$ $\boxed{\Delta Q = nC_V\Delta T}$

(iv) At constant pressure $\Rightarrow$ $\boxed{\Delta Q = nC_P\Delta T}$

Sign of Heat (Q) :-

(i) Heat given to the system → Positive.

(ii) Heat given by the system → Negative.

$\boxed{Q \rightarrow \text{Path dependent}}$ $\boxed{Q_{\text{Cyclic}} \neq 0}$

First Law of Thermodynamics :-

(Conservation of energy). $\boxed{\Delta Q = W + \Delta U}$

Ⓠ 110 J of heat - added to a gas system whose $\Delta U = 40\,J$. Then the amt of external work done is :

$\Delta Q = +110\,J$ $\quad \Delta Q = W + \Delta U$

$\Delta U = 40\,J$ $\quad 110 = W + 40 \Rightarrow \boxed{W = 70\,J}$

Ⓠ $\Delta U = ?$ system absorbed 2 KCal of heat and done 500 J work.

$\Delta Q = 2\,\text{Kcal} = 2 \times 10^3\,\text{cal} = 2 \times 10^3 \times 4.2\,J$

$= 8.4 \times 10^3\,J. = 8400\,J.$

$W = +500\,J.$

$\Delta Q = W + \Delta U$

$8400 = 500 + \Delta U \Rightarrow \boxed{\Delta U = 7900\,J}$

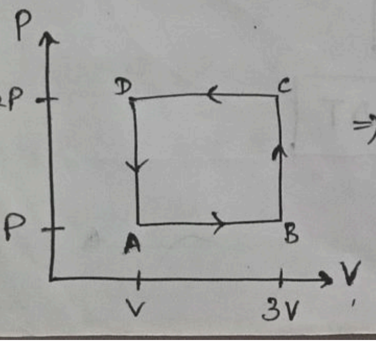
Ⓠ If Q, E and W are heat added, change in internal energy and work done in a closed cyclic process, then:

$\boxed{W_{\text{cyclic}} \neq 0}$ (Path dependent)

$\boxed{Q_{\text{cyclic}} \neq 0}$ (Path dependent)

$\boxed{\Delta U_{\text{cyclic}} = 0}$ (Path independent).

Ⓠ Heat rejected by the gas during the cycle is :



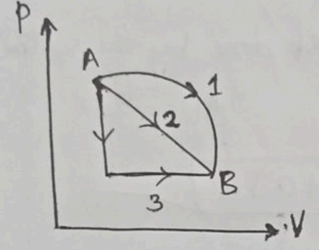
$\Delta Q = W + \Delta U \qquad \Delta U_{\text{cyclic}} = 0.$

$\Rightarrow \Delta Q = W = \text{Area under PV curve.}$

$= (2P - P)(3V - V) = 2PV.$

Anticlockwise cycle $\Rightarrow \boxed{\Delta Q = -2PV}$

Ⓠ An ideal gas goes from state A to B via three diff processes. If Q_1, Q_2, Q_3 indicate heat absorbed and ΔU_1, ΔU_2 and ΔU_3 indicate change in internal energy along the three processes, then:

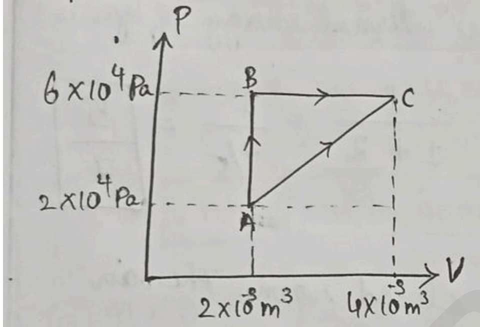


U → Path indepent. $\boxed{\Delta U_1 = \Delta U_2 = \Delta U_3}$

$W \propto Q$. $W_1 > W_2 > W_3$

$\Rightarrow \boxed{Q_1 > Q_2 > Q_3}$

Ⓠ A gas takes two paths to go from state A to C. In process AB, 400 J of heat is added to the system and in process BC, 100 J of heat is added to the system. The heat absorbed by the system in the process AC is:



$Q_{ABC} = Q_{AB} + Q_{BC} = 500$ J.

W_{ABC} = Area under curve ABC.

$= 6\times10^4 \times 2\times10^{-3} = 120$ J.

ΔU_{ABC}: $Q = W + \Delta U$

$500 = 120 + \Delta U \Rightarrow \Delta U = 380$J.

$W_{AC} = \frac{1}{\cancel{2}} \times \cancel{2}\times10^{-3} \times 4\times10^4$

$+ 2\times10^{-3}\times2\times10^4$.

$= 40 + 40 = 80$J.

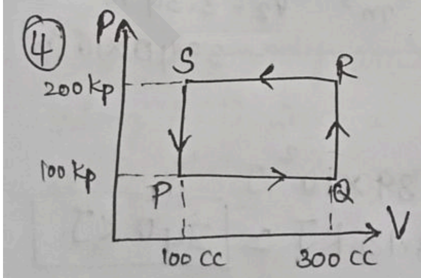
$\Delta U_{ABC} = \Delta U_{AC} = 380$ J.

$Q_{AC} = W_{AC} + \Delta U_{AC}$

$= 80 + 380 = \boxed{460J}$

DPP - 02

④



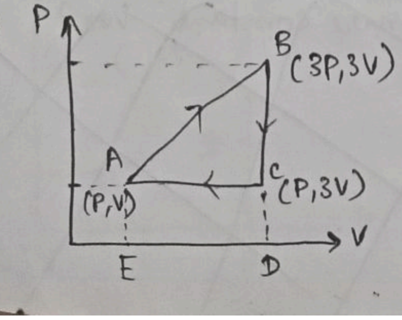
Net work done = Area under curve.

$= (200-100)\times10^3 \times (300-100)\times10^{-6}$

$= 10^5 \times 2\times10^{-4}$. $= 20$ J.

Anticlockwise cycle → $\boxed{W = -20J}$

⑤



Work done = Area under curve

$= \frac{1}{2} \times (3V - V) \times (3P - P)$

$= \frac{1}{\cancel{2}} \times \cancel{2}V \times 2P = 2PV$.

Clockwise cycle → $\boxed{W = +2PV}$

⑥ Ideal gas T- constant Expands. - Gas does external work.

$\Delta U = ?$

$\Delta U = n C_v \Delta T \qquad \Delta U \propto \Delta T$

↳ remain constant.

⑦ 150 J - heat added to system 110 J - Work done by the system

$\Delta U = ?$

$\Delta Q = W + \Delta U$

$150 = 110 + \Delta U \Rightarrow \boxed{\Delta U = 40 J}$

⑧ 110 J - heat added to system $\Delta U \rightarrow 40 J$ External $W = ?$

$\Delta Q = W + \Delta U \qquad 110 = W + 40 \Rightarrow W = 110 - 40 \ \boxed{W = 70 J}$

⑨ Ideal diatomic gas - heat at constant pressure. The fraction of heat energy supplied which increases the internal energy of gas is:

$$\frac{\Delta U}{\Delta Q} = \frac{n C_v \Delta T}{n C_p \Delta T} = \frac{C_v}{C_p} = \frac{1}{\gamma} = \frac{1}{1+\frac{2}{f}} = \frac{1}{1+\frac{2}{5}} = \frac{1}{7/5} = \boxed{\frac{5}{7}}$$

$f = 5$ (diatomic)

⑩ An electric fan is switched on in a closed room. The air in the room is: $\boxed{\text{heated}}$.

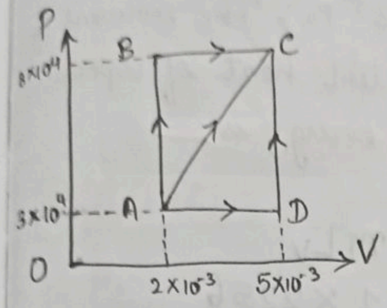
The motion of fan will do some work on the air in room $\Rightarrow$ ΔU of air increases $\Rightarrow$ Temperature increases.

⑪ Two kg of H_2O is converted into steam by boiling at atm pressure. The vol changes from 2×10^{-3} m³ to 3.34 m³. The work done by the system is:

$P_a = 1 \text{ atm} = 1.013 \times 10^5$ pa. $\quad V_1 = 2 \times 10^{-3} m^3 \quad V_2 = 3.34 m^3$
$= 3340 \times 10^{-3} m^3$

$W = P \Delta V = 1.013 \times 10^5 (3340 - 2) \times 10^{-3}$
$= 1.013 \times 3338 \times 10^2 = 3381.39 \times 10^2 J$
$= 338.13 kJ \simeq \boxed{340 kJ}$

⑮ $P_A = 3\times10^4$ Pa , $P_B = 8\times10^4$ Pa , $V_A = 2\times10^{-3}\ m^3$, $V_D = 5\times10^{-3} m^3$
In process AB, 600 J of heat is added to the system and in process BC, 200 J of heat is added to the system. The ΔU of the system in process AC would be :



$\Delta U_{AC} = \Delta U_{ABC}$.

$\Delta Q_{ABC} = 600 + 200 = 800$ J.

W_{ABC} = Area under ABC $= 8\times10^4 \times 3\times10^{-3}$
$= 240$ J.

$\Delta U_{ABC} = \Delta Q - W = 800 - 240 = 560$ J.

$\boxed{\Delta U_{AC} = 560 J}$

⑫ A gas is compressed at a constant pressure of 50 N/m² from 10 m³ to 4 m³. Energy of 100 J is then added to gas by heating. ΔU = ?

$\Delta Q = W + \Delta U \Rightarrow \Delta U = \Delta Q - W = 100 - 50(4-10)$
$= 100 - 50(-6) = 100 + 300$
$= 400$ J.

$\boxed{\Delta U - \uparrow\text{sed by } 400 J}$

⑬ $n = 0.1$ $T = 27°C$ $R = 2$ Cal/mol°C P constant W = ?
$V \to 2V$.

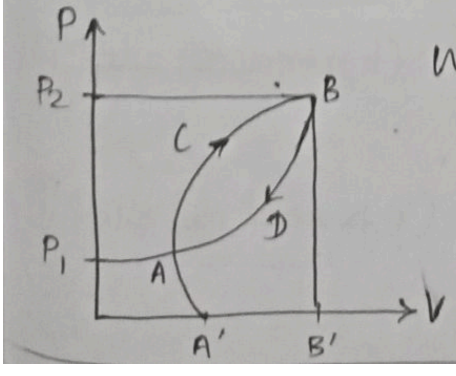
Isobaric process → $W = P\Delta V = nR\Delta T$.

$V \propto T \Rightarrow \frac{V}{T} = \text{constant} \Rightarrow \frac{V_1}{T_1} = \frac{V_2}{T_2}$.

$\frac{\cancel{V}}{300} = \frac{2\cancel{V}}{T_2} \Rightarrow T_2 = 600 K$.

$W = 0.1 \times 2 \times (600-300)$
$= 0.2(300) = \boxed{60 cal}$

⑭ A thermodynamic system is taken from state A and B along ACB and is brought back to A along BDA. The net work done during the complete cycle is given by area:



Work done = Area under the curve.
$= W_{ACB} + W_{BDA}$.
$= \boxed{W_{ACBDA}}$.

1) $\Delta U = K.E$ of molecules $= n\frac{f}{2}RT = n \cdot C_V \Delta T$.
2) ΔU depends on ΔT

} Only for ideal gases.

Ⓠ 1 g of H_2O of vol 1 cm^3 at 100°C is converted into steam at same temp under normal atm pressure ($= 1 \times 10^5$ Pa). The volume of steam formed equals 1671 cm^3. If the specific latent heat of vapourisn of H_2O is 2256 J/g, the change in internal energy is:

$$\begin{matrix}\text{Water}\\ 1g\\ 100^\circ C\\ 1\,cm^3\end{matrix} \xrightarrow[P = 1\times10^5\,Pa]{Q = mL_V} \begin{matrix}\text{Steam}\\ 100^\circ C\\ 1671\,cm^3\end{matrix}$$

$$\Delta Q = mL_V = 1 \times 2256 = 2256\,J.$$

$$W = P\Delta V = 1\times10^5 \times (1671 - 1) = 1670 \times 10^5\ Pa\,cm^{-3} = 1670 \times 10^5 \times 10^{-6} = 167\,J.$$

$$\Delta Q = W + \Delta U$$

$$\Delta U = 2256 - 167 = \boxed{2089\,J}$$

Ⓠ A sample of 0.1 g of H_2O at 100°C and normal pressure ($1.013 \times 10^5\ Nm^{-2}$) requires 54 cal of heat energy to convert to steam at 100°C. If the volume of steam produced is 167.1 cm^3, the ΔU of sample is:

$$\begin{matrix}\text{Water}\\ 0.1g\\ 100^\circ C\end{matrix} \xrightarrow[1.013\times10^5\,Pa]{54\,cal} \begin{matrix}\text{Steam}\\ 100^\circ C\\ 167.1\,cc\end{matrix}$$

$$\Delta Q = 54\,cal = 54 \times 4.2\,J = 226.8\,J.$$

$$W = P\Delta V = 1.013\times10^5 \times 167 \times 10^{-6} = 16.9\,J.$$

$$\Delta U = \Delta Q - W = 226.8 - 16.9 = \boxed{208.7\,J}$$

Types of Processes in Thermodynamics :-

① Isobaric (P-constant)

② Isochoric (V-constant)

③ Isothermal (T-constant)

④ Adiabatic ($\Delta Q = 0$).

Isobaric Process :-

① P constant.

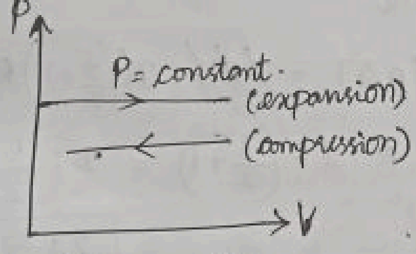
② Charle's Law valid. ⟶ Volume of a given mass of gas is directly proportional to Temperature.

$V \propto T \Rightarrow V = kT$

$\Rightarrow \frac{V}{T} = \text{constant}.$ $\boxed{\frac{V_1}{T_1} = \frac{V_2}{T_2}}$

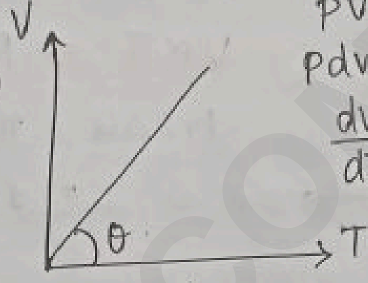
③ Graphs:

(i)



Slope $= \frac{dP}{dV} = 0.$

(ii)



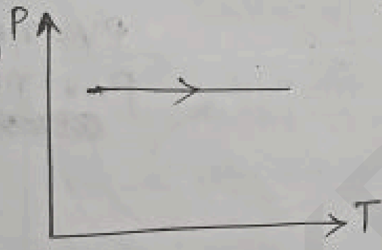
$PV = nRT$

$Pdv = nRdT$

$\frac{dv}{dT} = \frac{nR}{P}.$

Slope $= \frac{dV}{dT} = \tan\theta = \frac{nR}{P}.$
$= \text{constant}.$

(iii)



Slope $= \frac{dP}{dT} = 0.$

④ Molar SHC:

At constant pressure → $\boxed{C_p = \left(\frac{f}{2}+1\right)R = \frac{\gamma R}{\gamma - 1}}$

⑤ Heat : $\Delta Q = nC_p\Delta T = n\left(\frac{f}{2}+1\right)R\Delta T = \frac{n\gamma R\Delta T}{\gamma - 1}.$

⑥ Internal energy : $\Delta U = nC_v\Delta T = n\frac{f}{2}R\Delta T = \frac{nR\Delta T}{\gamma - 1}.$

⑦ Work done : $W = P\Delta V = nR\Delta T.$

⑧ Ratio (in terms of f) : $W : \Delta Q : \Delta U = nR\Delta T : n\left(\frac{f}{2}+1\right)R\Delta T : n\frac{f}{2}R\Delta T$

$= 1 : \frac{f}{2}+1 : \frac{f}{2}.$

⑨ Ratio (in terms of γ) : $W : \Delta Q : \Delta U = nR\Delta T : n\frac{\gamma R}{\gamma-1}\Delta T : \frac{nR\Delta T}{\gamma - 1}$

$= 1 : \frac{\gamma}{\gamma-1} : \frac{1}{\gamma-1}.$

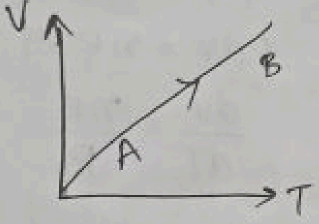
Ⓠ Heat is supplied to a diatomic gas at constant pressure. $\Delta Q : \Delta U : W = ?$

$\underline{f = 5}$

$\Delta Q : \Delta U : W = \frac{f}{2}+1 : \frac{f}{2} : 1$

$= \frac{5}{2}+1 : \frac{5}{2} : 1 = \frac{7}{2} : \frac{5}{2} : 1 = \boxed{7:5:2}$

Ⓠ The vol of a monoatomic gas varies with temp as shown. The ratio of work done by the gas, to the heat absorbed by it, when it undergoes a change from state A to state B is:



$V \propto T \Rightarrow P\text{-constant}.$

$W : \Delta Q = nRT : nC_p\Delta T = \cancel{n}\cancel{R}\cancel{T} : \cancel{n}\left(\frac{f}{2}+1\right)\cancel{R}\cancel{\Delta T}$

$= 1 : \frac{f}{2}+1 = 1 : \left(\frac{3}{2}+1\right) = 1 : \frac{5}{2}$

$= \boxed{2:5}$

Ⓠ $\frac{C_P}{C_V} = \gamma$, Vol $V \longrightarrow 2V$, constant pressure, ΔU of given mass is:

$\Delta U = nC_V\Delta T = \frac{nR}{\gamma-1}\Delta T = \frac{P\Delta V}{\gamma-1}$

$= \frac{P(2V-V)}{\gamma-1} = \boxed{\frac{PV}{\gamma-1}}$

$PV = nRT.$

$P\Delta V = nR\Delta T.$

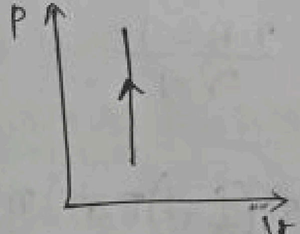
Isochoric Process:-

① V constant.

② $P \propto T \Rightarrow P = KT \Rightarrow \frac{P}{T} = \text{constant} \Rightarrow \boxed{\frac{P_1}{T_1} = \frac{P_2}{T_2}}$

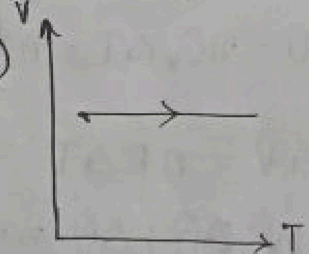
③ Graphs:

(i)



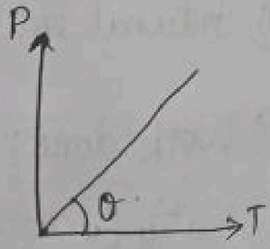
Slope $= \frac{dP}{dV} = \tan 90^\circ \rightarrow \infty.$

(ii)



Slope $= \frac{dV}{dT} = 0.$

(iii)



Slope $= \frac{dP}{dT} = \frac{nR}{V}$ = constant

④ Molar SHC:

At constant volume → $\boxed{C_V = \frac{f}{2}R = \frac{R}{\gamma-1}}$

⑤ Heat: $\Delta Q = nC_V\Delta T = n\frac{f}{2}R\Delta T = \frac{nR\Delta T}{\gamma-1} = \frac{V\Delta P}{\gamma-1}$.

⑥ Internal Energy: $\Delta U = nC_V\Delta T = n\frac{f}{2}R\Delta T = \frac{nR\Delta T}{\gamma-1} = \frac{V\Delta P}{\gamma-1}$.

⑦ Work $= \int_{V_1}^{V_2} P\,dV = 0$.

Isothermal Process:-

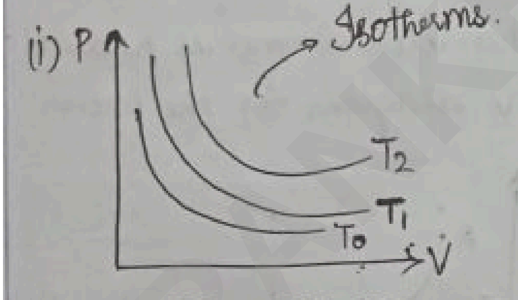
① T constant. → very slow process. (occurs in perfectly conducting boundary)

② Boyle's Law valid → $P \propto \frac{1}{V}$. ⇒ PV = constant

$\boxed{P_1V_1 = P_2V_2}$

③ Graphs:

(i)



$T_2 > T_1 > T_0$.

No 2 isotherms intersects each other.

$\text{Slope} = \frac{dP}{dV} = \frac{-P}{V}$

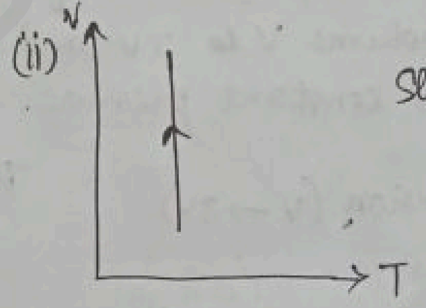
$PV = nRT = k$.

$PdV + VdP = 0$.

$PdV = -VdP$.

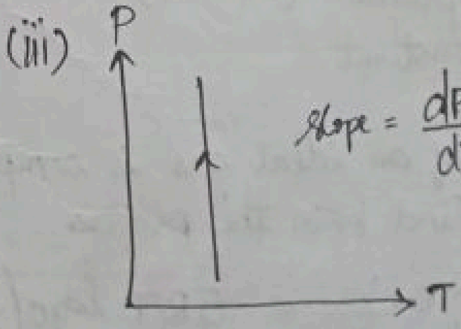
$\frac{dP}{dV} = \frac{-P}{V}$.

(ii)



$\text{Slope} = \frac{dV}{dT} = \tan 90° \to \infty$.

(iii)



$\text{Slope} = \frac{dP}{dT} = \tan 90° \to \infty$.

④ Molar SHC : Constant temp → $\Delta T = 0$.

$$C = \frac{\Delta Q}{n \Delta T} = \frac{\Delta Q}{0} \Rightarrow \boxed{C = \infty}$$

⑤ Heat : $\Delta Q = W + \Delta U = W \quad (\Delta U = 0)$.

$$\boxed{\Delta Q = nRT \log_e \frac{V_2}{V_1} = nRT \log_e \frac{P_1}{P_2}}$$

⑥ Internal energy : $\Delta U = n C_v \Delta T = 0 \quad (\Delta T = 0)$.

⑦ Work : $W = \int_{V_1}^{V_2} P\,dV = nRT \log_e \frac{V_2}{V_1} = nRT \log_e \frac{P_1}{P_2}$

~~$W = 2.303 \log_{10} V_2$~~

$$\boxed{W = 2.303\, nRT \log_{10} \frac{V_2}{V_1} = 2.303\, nRT \log_{10} \frac{P_1}{P_2}}$$

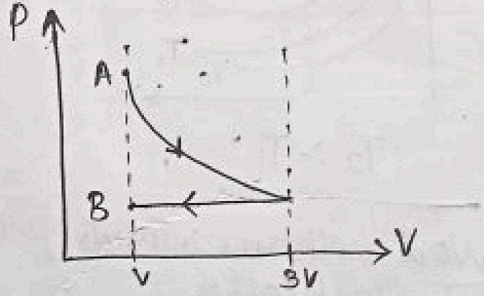
Ⓠ One mole of an ideal gas goes from an initial state A to final state B via two processes. It first undergoes isothermal expansion from volume V to 3V and then its volume is reduced from 3V to V at constant pressure. PV diagram for the processes:

Isothermal expansion ($V \rightarrow 3V$)

$P \propto 1/V$.

Isobaric compression ($3V \rightarrow V$).

$P = \text{constant}$.



Ⓠ Five moles of an ideal gas is compressed from 2V to V isothermally at T kelvin. Find W in the process.

$$W = nRT \log_e \frac{V_2}{V_1} = 5RT \log_e\left(\frac{\cancel{V}}{2\cancel{V}}\right) = 5RT \log_e (2)^{-1}.$$

$$= \boxed{-5RT \log_e 2}$$

Adiabatic Process :-

① $\Delta Q = 0$ → Very rapid process → Occurs in perfectly insulating boundary.

② $PV^{\gamma} = \text{constant}$. $\boxed{P_1 V_1^{\gamma} = P_2 V_2^{\gamma}}$

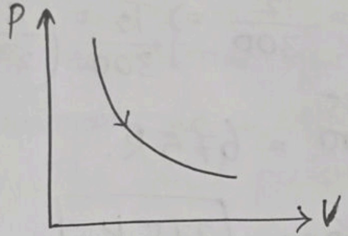
$\frac{nRT}{V} V^{\gamma} = \text{constant} \Rightarrow \boxed{T_1 V_1^{\gamma - 1} = T_2 V_2^{\gamma - 1}}$

$PV^{\gamma} = \text{constant} \rightarrow P\left(\frac{nRT}{P}\right)^{\gamma} = \text{constant} \Rightarrow P^{1-\gamma}T^{\gamma} = \text{constant}.$

$$\boxed{T_1^{\gamma} P_1^{1-\gamma} = T_2^{\gamma} P_2^{1-\gamma}}$$

③ Graphs:

(i)



$PV^{\gamma} = \text{constant}.$

$P \propto \frac{1}{V^{\gamma}}$

$\gamma_{mono} = 1.67$

$\gamma_{dia} = 1.40$

$\gamma_{tria} = 1.33$

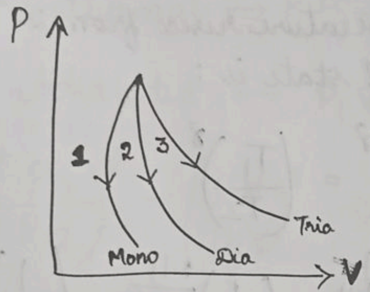
$\gamma > 1.$

$\text{Slope}_{adiabatic} = \frac{-\gamma P}{V}.$

$\text{Slope}_{isothermal} = \frac{-P}{V}.$

$$\boxed{\text{Slope}_{(adia)} > \text{Slope}_{(isotherm)}}$$

$\text{Slope} = \frac{dP}{dV} = \frac{-\gamma P}{V}.$

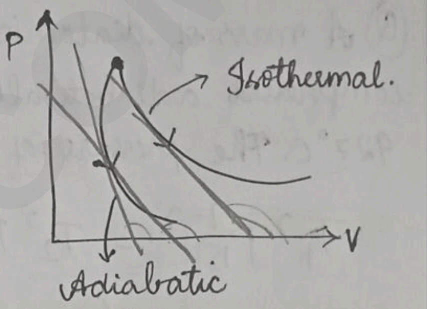


$$\boxed{PV^{\gamma} > PV}$$

Adiabatic ↓ Isothermal ↓

$\text{Slope} \propto \gamma.$

$$\boxed{\text{Mono} > \text{Dia} > \text{Tri}}$$



④ Molar SHC: $C = \frac{\Delta Q}{n\Delta T} = 0.$

⑤ Heat : $\Delta Q = 0.$

⑥ Internal Energy : $nC_V\Delta T = n\frac{f}{2}R\Delta T = \frac{nR\Delta T}{\gamma - 1}$

$$= \frac{nRT_2 - nRT_1}{\gamma - 1} = \frac{P_2V_2 - P_1V_1}{\gamma - 1}.$$

⑦ Work : $W = \underset{\substack{\downarrow \\ 0.}}{\Delta Q} - \Delta U \Rightarrow \boxed{W = -\Delta U}$

Ⓠ A monoatomic gas at pressure P_1 and volume V_1 is compressed adiabatically to 1/8 th of its original volume. What is the final pressure of the gas?

$P_1V_1^{\gamma} = P_2V_2^{\gamma}. \Rightarrow \left(\frac{V_1}{V_2}\right)^{\gamma} = \frac{P_2}{P_1} \Rightarrow (8)^{5/3} = \frac{P_2}{P_1} \Rightarrow P_2 = (8)^{5/3}P_1$

Monoatomic $\rightarrow \gamma = 5/3.$

$= (2^{\cancel{3}})^{5/\cancel{3}}P_1 = \boxed{32\ P_1}$

Ⓠ An ideal gas at 27°C is compressed adiabatically to 8/27 of its original volume. Rise in temperature is : ($\gamma = 5/3$).

$\cancel{T_1 V_1^{1-\gamma}}$ $\quad T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1} \Rightarrow \left(\frac{V_1}{V_2}\right)^{\gamma-1} = \frac{T_2}{T_1} \Rightarrow \left(\frac{V_1}{\frac{8V_1}{27}}\right)^{\gamma-1} = \frac{T_2}{300}$

$T_1 = 300K.$

$V_2 = \frac{8}{27} V_1$

$$\left(\frac{27}{8}\right)^{(5/3-1)} = \frac{T_2}{300} \Rightarrow \left(\frac{27}{8}\right)^{2/3} = \frac{T_2}{300} \Rightarrow \frac{T_2}{300} = \left(\frac{3^{\cancel{3}}}{2^{\cancel{3}}}\right)^{2/\cancel{3}}$$

$$\frac{T_2}{300} = \left(\frac{3}{2}\right)^2 = \frac{9}{4} \Rightarrow T_2 = \frac{9}{\cancel{4}} \times \overset{75}{\cancel{300}} = 675K.$$

$$\text{Rise in temperature} = T_2 - T_1 = 675 - 300 = \boxed{375K}$$

Ⓠ A mass of diatomic gas ($\gamma = 1.4$) at a pressure of 2 atm is compressed adiabatically so that its temperature rises from 27°C to 927°C. The pressure of the gas in the final state is :

$$T_1^{\gamma} P_1^{1-\gamma} = T_2^{\gamma} P_2^{1-\gamma}. \Rightarrow \left(\frac{P_2}{P_1}\right)^{1-\gamma} = \left(\frac{T_1}{T_2}\right)^{\gamma}.$$

$$\frac{P_2}{P_1} = \left(\frac{T_1}{T_2}\right)^{\gamma/1-\gamma}. \Rightarrow \frac{P_2}{2} = \left(\frac{\cancel{300}}{\underset{4}{\cancel{1200}}}\right)^{\frac{1.4}{1-1.4}} = \left(\frac{1}{4}\right)^{\frac{1.4}{-0.4}} = \left(\frac{1}{4}\right)^{\frac{-7}{2}}$$

$$\frac{P_2}{2} = (4)^{7/2} = (2^{\cancel{2}})^{7/\cancel{2}} = 2^7 = 128 \Rightarrow P_2 = 128 \times 2$$

$$= \boxed{256\,\text{atm}}$$

Ⓠ In an adiabatic change, Pressure & Temp of a monoatomic gas are related as $P \propto T^C$. $C = ?$ $\qquad \gamma_{mono} = 5/3.$

$$T^{\gamma} P^{1-\gamma} = \text{constant.} \Rightarrow P^{1-\gamma} = \frac{k}{T^{\gamma}} = kT^{-\gamma}.$$

$$P = (kT^{-\gamma})^{1/1-\gamma} \Rightarrow P \propto T^{-\gamma/1-\gamma}.$$

$$\Rightarrow C = \frac{-\gamma}{1-\gamma} = \frac{-5/3}{1-5/3} = \frac{-5}{-2} = \boxed{\frac{5}{2}}$$

Ⓠ During an adiabatic process, the pressure of a gas is found to be proportional to the cube of its temperature. The ratio of C_P/C_V of the gas is :

$p \propto T^3$. PV^γ = constant $\Rightarrow T^\gamma p^{1-\gamma}$ = constant.

$p^{1-\gamma} \propto T^{-\gamma} \Rightarrow P \propto T^{-\gamma/1-\gamma}$.

$$\frac{-\gamma}{1-\gamma} = 3 \Rightarrow -\gamma = 3-3\gamma \Rightarrow 2\gamma = 3 \Rightarrow \boxed{\gamma = \frac{3}{2}}$$

② A monoatomic gas at pressure P having a volume V expands isothermally to a volume 2V and then adiabatically to a volume 16 V. The final pressure of the gas is : ($\gamma = 5/3$).

$$P, V \xrightarrow[\text{expansion}]{\text{isothermal}} 2V \xrightarrow[\text{expansion}]{\text{Adiabatic}} 16V\,(P?)$$

(monoatomic)

Isothermal $\rightarrow P \propto \frac{1}{V}$ $V' = 2V$ $P' = \frac{P}{2}$

Adiabatic $\rightarrow P_1V_1^\gamma = P_2V_2^\gamma \Rightarrow \frac{P}{2}(2V)^\gamma = P_2(16V)^\gamma$

$$\left(\frac{P_2}{P/2}\right)^{\cancel{\gamma}} = \left(\frac{\cancel{2V}}{\underset{8}{\cancel{16V}}}\right)^\gamma \Rightarrow \frac{P_2}{P/2} = \left(\frac{1}{2^{\cancel{3}}}\right)^{5/\cancel{3}} = \frac{1}{32} \Rightarrow \boxed{P_2 = \frac{P}{64}}$$

DPP – 03

④ Ideal gas – compressed isothermally $\Longrightarrow \Delta T = 0 \Rightarrow \Delta U = 0$.

$\Delta Q = \underset{0}{\cancel{\Delta U}} + W \Rightarrow \Delta Q = -W$. (-ve → compression).

$\Rightarrow$ $\boxed{\text{Heat is released by the gas.}}$

⑤ The work done in an adiabatic expansion from temp T to T_1 is:

$$\underset{0}{\cancel{\Delta Q}} = \Delta U + W \Rightarrow W = -\Delta U = \frac{nR(T_i - T_f)}{\gamma - 1} = \boxed{\frac{R(T-T_1)}{\gamma-1}}$$

⑥ If a cylinder containing a gas at high pressure explodes, the gas undergoes:

Explosion → sudden change → (ADIABATIC) → Irreversible.

⇓

V↑↑ ⇒ Work → Positive $\underset{0}{\cancel{\Delta Q}} = \Delta U + W \Rightarrow \Delta U = -W$

$\Delta U \downarrow\downarrow \rightarrow T\downarrow\downarrow$.

$\boxed{\text{Irreversible Adiabatic change \& fall of temperature}}$

⑦ The work done in an adiabatic change in a gas depends only on:

$$W = \frac{P_iV_i - P_fV_f}{\gamma - 1} = \frac{nR(T_i - T_f)}{\gamma - 1} \rightarrow \boxed{\text{Change in temp}}$$

⑧ For adiabatic process $\left(\gamma = \frac{C_P}{C_V}\right)$:

$$\boxed{\begin{aligned} PV^{\gamma} &= \text{constant} \\ TV^{\gamma-1} &= \text{constant} \\ T^{\gamma}P^{1-\gamma} &= \text{constant} \end{aligned}}$$

⑨ 1 gm mol of a diatomic gas ($\gamma = 1.4$) is compressed adiabatically so that its temperature rises from 27°C to 127°C. The work done is: ($R = 8.310$).

$$W = \frac{nR(T_i - T_f)}{\gamma - 1} = \frac{1 \times 8.310 \times (100)}{1.4 - 1} = \frac{831.0}{0.4} = \frac{8310}{4}$$

$$= \boxed{2077.5\,J}$$

⑩ During an adiabatic process, the pressure of a gas is found to be proportional to the cube of its Absolute temp. The ratio C_P/C_V:

$P \propto T^{-3} \Rightarrow PT^{-3} = \text{constant}$. ~~PV~~

For adiabatic, $P^{1-\gamma}T^{\gamma} = \text{constant} \Rightarrow PT^{\gamma/1-\gamma} = \text{constant}$.

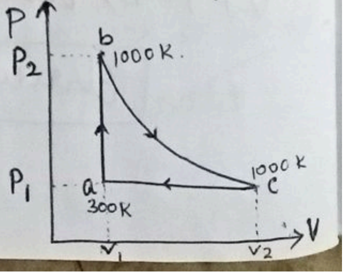
$$\frac{\gamma}{1-\gamma} = -3 \Rightarrow \gamma = -3 + 3\gamma \Rightarrow 2\gamma = 3 \Rightarrow \boxed{\gamma = \frac{3}{2}}$$

⑪ For a reversible process, necessary condition is: The loss of energy should be zero and it should be quasistatic.

⑫ A gas for which $\gamma = 1.5$ is suddenly compressed to 1/4 th of the initial ~~for~~ volume. Then the ratio of final to initial pressure is:

$PV^{\gamma} = \text{constant}$.
$$\frac{P_f}{P_i} = \left(\frac{V_i}{V_f}\right)^{\gamma} = \left(\frac{\cancel{V}}{\cancel{V}/4}\right)^{1.5} = (4)^{3/2} = 2^3 = \boxed{\frac{8}{1}}$$

⑬ CO gas absorbs 7000 J of heat as its temperature increases from 300K to 1000 K in going from a to b. The quantity of heat ~~increased~~ rejected by the gas during the process ca is:



ab: $\Delta Q = \Delta U + \cancel{W}^{\,0}$
$7000 = \Delta U = nC_V\Delta T$

$n\left(\frac{5}{2}R\right)(\cancel{700}) = \cancel{7000}$

$nR = \frac{20}{5} = 4.$

Ca: $Q = nC_p\Delta T = n\left(\frac{7}{2}R\right)(300-1000) = -(nR)\,\frac{7}{2}\times 700 = -\overset{2}{\cancel{4}}\times\frac{7}{\cancel{2}}\times 700.$

$$= \boxed{-9800\,\text{J}.}$$

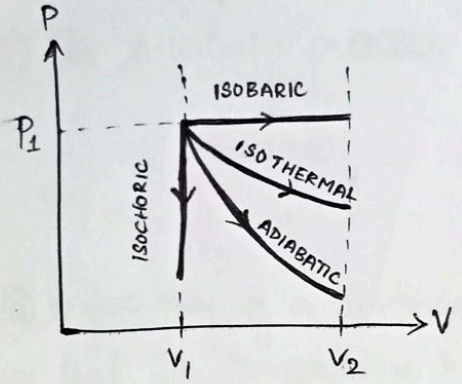
(ii) For an ideal gas, in an isothermal procces,

$T = \text{constant}\ (\Delta T = 0)$

$$\Delta U = nC_v\Delta T$$

Comparision of Different Processes :-

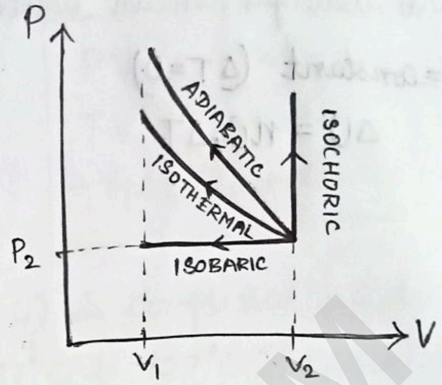
① Expansion :



For same expansion,

$W_{isobaric} > W_{isothermal} > W_{adiabatic} > W_{isochoric}$.

② Compression :

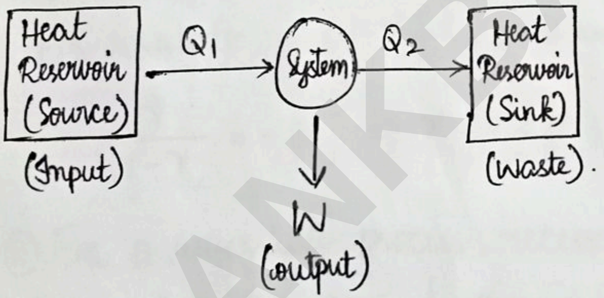


For same compression,

$W_{adiabatic} > W_{isothermal} > W_{isobaric} > W_{isochoric}$

Heat Engine :-

→ Device which converts heat into work.



Heat reservoirs → Heat capacity $= \infty$.

Second Law of Thermodynamics :-

All heat can never be converted into work.

From 1st law, If $\Delta U = 0$, $\Delta Q = W$.

It is impossible

(Drawback of 1st law).

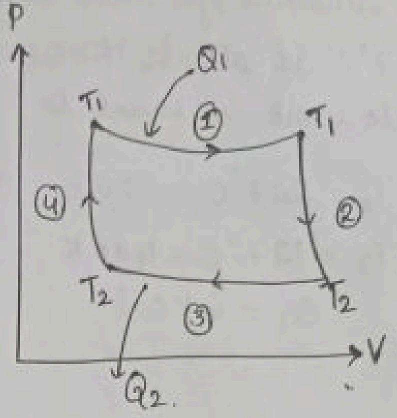
Work done = Input − Lost ⇒ $\boxed{W = Q_1 - Q_2}$

Efficiency : $\eta = \frac{Output}{Input}$ ⇒ $\boxed{\eta = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}}$

Carnot's Heat Engine :-

→ No heat engine operating b/w same temps T_1 & T_2 can have efficiency more than carnot engine.

→ Four processes : ① Isothermal expansion ② Adiabatic expansion ③ Isothermal compression ④ Adiabatic compression.



① Isothermal Expansion.

$\Rightarrow \Delta U = 0$ ($\because$ T-constant)

Heat is given to the system $\Rightarrow Q_1$

② Adiabatic Expansion.

$\Rightarrow \Delta Q = 0$.

③ Isothermal Compression.

$\Rightarrow \Delta U = 0$ (T-constant).

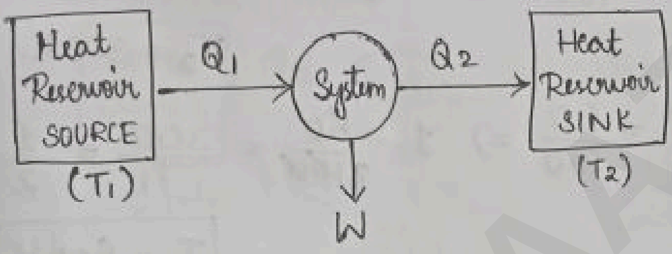
Heat is released by the system $\Rightarrow Q_2$.

④ Adiabatic Compression.

$\Rightarrow \Delta Q = 0$.

$\Rightarrow$ Maximum Efficiency

$$\boxed{\frac{Q_2}{Q_1} = \frac{T_2}{T_1}}$$



$$\boxed{W = Q_1 - Q_2} \quad (T_1 > T_2)$$

$$\boxed{\eta = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}}$$

Ⓠ The efficiency of an ideal heat engine working b/w the freezing point and boiling water is:

$T_1 = 373\,K$

$T_2 = 273\,K$.

$$\eta = \left(1 - \frac{T_2}{T_1}\right) \times 100 = 1 - \frac{273}{373} \times 100 = \frac{100 \times 100}{373}$$

$$= \boxed{26.8\%}$$

Ⓠ A scientist says that the efficiency of his heat engine which operates at source temperature 127°C and sink temp 27°C is 26%.

$T_1 = 127°C = 400\,K$

$T_2 = 27°C = 300\,K$.

$$\eta = 1 - \frac{T_2}{T_1} \times 100 = 1 - \frac{300}{400} \times 100$$

$$= \frac{100}{400} \times 100 = 25\%.$$

More than 25% efficiency is impossible

Ⓠ The efficiency of Carnot engine operating with reservoir temp of 100°C and −23°C will be:

$T_1 = 100°C = 373\,K$

$T_2 = -23°C = 250\,K$.

$$\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{250}{373} = \boxed{\frac{373-250}{373}}$$

Ⓠ An ideal gas heat engine operates in a Carnot cycle b/w 227°C and 127°C. It absorbs 6 Kcal at higher temp. The amount of heat converted into work is equal to :

$T_1 = 227°C = 500\,K.$

$T_2 = 127°C = 400\,K.$

$Q_1 = 6\,K\,cal.$

$$\frac{Q_2}{Q_1} = \frac{T_2}{T_1} \Rightarrow \cancel{\frac{Q}{Q_2}} \quad \frac{Q_2}{6} = \frac{4\cancel{00}}{5\cancel{00}}$$

$$Q_2 = \frac{24}{5} = 4.8$$

$$W = Q_1 - Q_2 = 6 - 4.8 = \boxed{1.2\,Kcal}$$

Ⓠ An ideal Carnot engine, whose efficiency is 40% receives heat at 500K. If its efficiency is 50%, then the intake temperature for the same exhaust temperature is :

$$\eta_1 = 1 - \frac{T_2}{T_1} = 1 - \frac{T_2}{500} = \frac{40}{100} \Rightarrow 1 - \frac{\cancel{4}\cancel{0}^{2}}{\cancel{10}\cancel{0}_{5}} = \frac{T_2}{\cancel{5}00} = \frac{3}{\cancel{5}}$$

$$T_2 = 300\,K.$$

$$\eta_2 = 1 - \frac{T_2}{T_1} = 1 - \frac{300}{T_1} = \frac{50}{100} \Rightarrow 1 - \frac{\cancel{5}\cancel{0}^{1}}{\cancel{10}\cancel{0}_{2}} = \frac{300}{T_1} = \frac{1}{2}$$

$$\boxed{T_1 = 600\,K}$$

Ⓠ An egine has an efficiency of 1/6. When the temp of sink is reduced by 62°C, its efficiency is doubled. Temp of source is:

$$\eta_1 = \frac{1}{6}. \quad \eta_2 = \frac{1}{3}. \qquad 1 - \frac{T_2}{T_1} = \frac{1}{6} \qquad 1 - \frac{(T_2 - 62)}{T_1} = \frac{1}{3}.$$

$$\frac{T_2}{T_1} = 1 - \frac{1}{6} = \frac{5}{6}. \qquad \frac{T_1 - T_2 + 62}{T_1} = \frac{1}{3}$$

$$T_2 = \frac{5}{6} T_1. \qquad 3T_1 - 3T_2 + 62\times 3 = \cancel{3}T_1$$

$$3T_2 = 2T_1 + 186.$$

$$\cancel{3} \times \frac{5}{\cancel{6}_2} T_1 = 2T_1 + 186.$$

$$5T_1 = 4T_1 + 372$$

$$\boxed{T_1 = 372\,K = 99°C}$$

$$= \frac{5}{\cancel{6}} \times 3\cancel{72}^{62}$$

$$\boxed{T_2 = 310\,K = 37°C}$$

Ⓠ The efficiency of Carnot engine is 50% and temp of sink is 500K. If temp of source is kept constant & its efficiency raised to 60%, then the required temp of sink will be:

$$\eta_1 = \frac{\cancel{50}^{1}}{\cancel{100}_{2}} = 1 - \frac{500}{T_1} \qquad \eta_2 = \frac{\cancel{60}^{3}}{\cancel{100}_{5}} = 1 - \frac{T_2}{1000}$$

$$\frac{500}{T_1} = \frac{1}{2} \Rightarrow T_1 = 1000\,K \qquad \frac{T_2}{\cancel{1000}_{200}} = 1 - \frac{3}{5} = \frac{2}{\cancel{5}} \Rightarrow \boxed{T_2 = 400\,K}$$

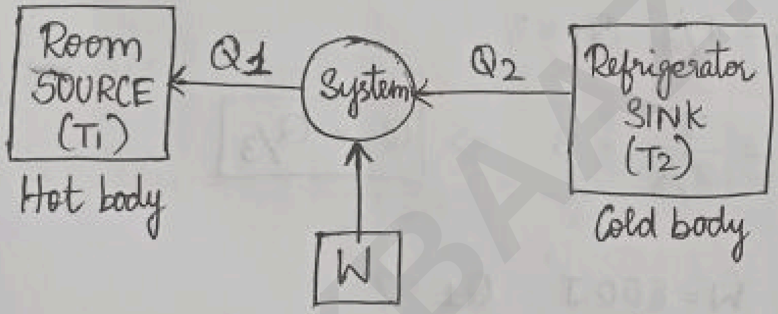
Ⓠ A carnot engine whose sink is at 300 K has an efficiency of 40%. By how much should the temp of source be increased so as to increase its efficiency by 50% of original efficiency?

$$\eta_1 = 1 - \frac{T_2}{T_1} \Rightarrow \frac{\overset{2}{\cancel{40}}}{\underset{5}{\cancel{100}}} = 1 - \frac{300}{T_1} \Rightarrow \frac{\overset{100}{\cancel{300}}}{T_1} = 1 - \frac{2}{5} = \frac{\cancel{3}}{5} \Rightarrow T_1 = 500\text{K}$$

$$\eta_2 = 1 - \frac{T_2}{T_1} \Rightarrow \frac{\overset{3}{\cancel{60}}}{\underset{5}{\cancel{100}}} = 1 - \frac{300}{T_1} \Rightarrow \frac{\overset{150}{\cancel{300}}}{T_1} = 1 - \frac{3}{5} = \frac{\cancel{2}}{5} \Rightarrow T_1' = 750\text{K}$$

Increase in temp $= T_1' - T_1 = 750 - 500 = \boxed{250\text{K}}$

Refrigerator :- (Reverse Carnot's Engine).



$Q_2 \rightarrow$ extracted from refrigerator

$Q_1 \rightarrow$ released out.

$W \rightarrow$ electrical work.

$$Q_1 = W + Q_2 \Rightarrow \boxed{W = Q_1 - Q_2}$$

For ideal refrigerator,

$$\boxed{\frac{Q_2}{Q_1} = \frac{T_2}{T_1}}$$

Coefficient of performane (K/β).

$$K = \frac{\text{Heat extracted}}{\text{Work done}} = \boxed{\frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2}} \boxed{= \frac{T_2}{T_1 - T_2}}$$

Ⓠ The coefficient of performance of a refrigerator is 5. If the temp inside freezer is −20°C, the temp of surroundings to which it rejects heat is:

$K = 5$

$T_2 = -20^\circ C = 253\text{K}.$

$$K = \frac{T_2}{T_1 - T_2} \Rightarrow 5 = \frac{253}{T_1 - 253}$$

$$5T_1 - 1265 = 253 \Rightarrow 5T_1 = 1518 \Rightarrow T_1 = \frac{1518}{5}$$

$$\boxed{T_1 = 303.6 \simeq 31^\circ C}$$

DPP-04:

④ A carnot's engine used first an ideal monoatomic gas then an diatomic gas. If the source and sink temp are 411°C and 69°C respectively and the engine extracts 1000 J of heat in each cycle, then area enclosed by the PV diagram is:

Efficiency does not depend upon the type of gas.

$$\eta = 1 - \frac{Q_2}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = \frac{W}{Q_1} \Rightarrow W = \eta Q_1 . = \left(1 - \frac{T_2}{T_1}\right) Q_1 .$$

$$W = 1 - \frac{(69+273)}{(411+273)} \times 1000 = \left(1 - \frac{\cancel{342}}{\underset{2}{\cancel{684}}}\right) \times 1000 = 0.5 \times 1000 = \boxed{500\ J}$$

⑤ $Q_2 = Q \quad T_2 = T \quad T_1 = T/3 \quad Q_1 = ?$

$$\frac{Q_2}{Q_1} = \frac{T_2}{T_1} \Rightarrow \frac{Q}{Q_1} = \frac{\cancel{T}}{\cancel{T}/3} = 3 \Rightarrow \boxed{Q_1 = Q/3}$$

⑥ $T_2 = 300K \quad T_1 = 600K \quad W = 800J \quad Q_1 = ?$

$$\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{300}{600} = \frac{3}{6} = \frac{1}{2} . \quad \eta = \frac{W}{Q_1} \Rightarrow \frac{1}{2} = \frac{800}{Q_1}$$

$$\boxed{Q_1 = 1600 J}$$

$$\cancel{\frac{Q_2}{Q_1} = \frac{T_2}{T_1} \Rightarrow \frac{Q_2}{\underset{800}{1600}} = \frac{300}{2600}}$$

⑦ $T_1 = 30°C = 303 k \quad T_2 = 0°C = 273 K. \quad K = ?$

$$K = \frac{T_2}{T_1 - T_2} = \frac{273}{303 - 273} = \frac{273}{30} = \frac{27.3}{3} = 9.1 \simeq \boxed{9.}$$

⑧ $T_2 = -23°C \quad T_1 = 27°C \quad K = ?$
$= 250 k \quad = 300 k.$

$$K = \frac{T_2}{T_1 - T_2} = \frac{250}{300 - 250} = \frac{25\cancel{0}}{5\cancel{0}} = \boxed{5}$$

⑨ For which combination of working temperatures, the efficiency of Carnot's engine is highest?

(A) 80K, 60K (B) 100K, 80K (C) 60K, 40K (D) 40K, 20K.

(A) $\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{60}{80} = \frac{80-60}{80} = \frac{20}{80} = \frac{1}{4}$.

(B) $\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{80}{100} = \frac{100-80}{100} = \frac{20}{100} = \frac{1}{5}$.

(C) $\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{40}{60} = \frac{60-40}{60} = \frac{20}{60} = \frac{1}{3}$.

(D) $\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{20}{40} = \frac{40-20}{40} = \frac{20}{40} = \boxed{\frac{1}{2}}$ (Highest).

⑩ Efficiency of Carnot's Engine : $\eta = 1 - \frac{T_2}{T_1} = \boxed{\frac{T_1 - T_2}{T_1}}$

⑪ $(T_1, T_2) \rightarrow \eta \quad (2T_1, 2T_2) \rightarrow \eta' = ?$

$\eta = 1 - \frac{T_2}{T_1} \qquad \eta' = 1 - \frac{\cancel{2}T_2}{\cancel{2}T_1} = 1 - \frac{T_2}{T_1} \Rightarrow \boxed{\eta' = \eta}$

⑫ $T_1 = 227^\circ C = 500 K \quad T_2 = 127^\circ C = 400 K. \quad Q_1 = 6 \times 10^4 J \quad W = ?$

$\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{400}{500} = \frac{1}{5}. \quad W = \eta Q_1 = \frac{1}{5} \times 6 \times 10^4$

$= \boxed{1.2 \times 10^4 J}$

⑬ $T_2 = 77^\circ C = 350 K \quad \eta = 30\% \quad T_1 = ?$

$\eta = 1 - \frac{T_2}{T_1} \Rightarrow \frac{3\cancel{0}}{10\cancel{0}} = 1 - \frac{350}{T_1} \Rightarrow \frac{\overset{50}{\cancel{350}}}{T_1} = \frac{\cancel{7}}{10} \Rightarrow \boxed{\begin{aligned} T_1 &= 500K \\ &= 227^\circ C \end{aligned}}$

⑭ $\eta = 70\% \quad T_1 = 1000K \quad T_2 = ?$

$\eta = 1 - \frac{T_2}{T_1} \Rightarrow \frac{7\cancel{0}}{10\cancel{0}} = 1 - \frac{T_2}{1000} \Rightarrow \frac{T_2}{100\cancel{0}} = \frac{3}{1\cancel{0}} \Rightarrow \boxed{T_2 = 300K}$

⑮ $T_2 = 0^\circ C \quad T_1 = 200^\circ C \rightarrow \eta_1 \quad T_1 = 0^\circ C \quad T_2 = -200^\circ C \rightarrow \eta_2$

$\frac{\eta_1}{\eta_2} = ?$

$\eta_1 = 1 - \frac{T_2}{T_1} = 1 - \frac{273}{473} = \frac{200}{473}$

$\frac{\eta_1}{\eta_2} = \frac{273}{473} = \boxed{0.577}$

$\eta_2 = 1 - \frac{73}{273} = \frac{273-73}{273} = \frac{200}{273}$

⑯ $T_1 = 200^\circ C \quad T_2 = 0^\circ C \rightarrow \eta_1 \quad T_1 = 0^\circ C \quad T_2 = -200^\circ C \rightarrow \eta_2 \quad \frac{\eta_1}{\eta_2} = ?$

$\frac{\eta_1}{\eta_2} = \frac{273}{473} \qquad \eta_1 : \eta_2 = \frac{273}{273} : \frac{473}{273}$

$= \boxed{1 : 1.73}$

Refrigerator as Heat Engine (or Vice-Versa) :-

$\eta = \frac{W}{Q_1}$ (heat engine) $K = \frac{Q_2}{W}$ (Refrigerator) $\boxed{K = \frac{1-\eta}{\eta}}$

Ⓠ A refrigerator works between 4°C and 30°C. It is required to remove 600 calories of heat every second in order to keep the temp of refrigerated space constant. The power required is:

$T_2 = 4^\circ C = 277\,K$

$T_1 = 30^\circ C = 303\,K$

$Q_2 = 600\,cal = 600 \times 4.2$
$= 2520\,J.$

$K = \frac{T_2}{T_1 - T_2} = \frac{Q_2}{W} \Rightarrow \frac{277}{303-277} = \frac{2520}{W}$

$W = \frac{2520 \times 26}{277} = \boxed{236.5\,W = P}$

Ⓠ The temp inside a refrigerator is $t_2^\circ C$ and the room temp is $t_1^\circ C$. The amt of heat delivered to the room for each joule of electrical energy consumed ideally will be:

$W = 1\,J \qquad W = Q_1 - Q_2 \Rightarrow Q_1 = Q_2 + 1.$

$K = \frac{T_2}{T_1 - T_2} = \frac{Q_2}{W} \Rightarrow \frac{t_2 + 273}{t_1 - t_2} = \frac{Q_2}{1}$

$Q_1 = \frac{t_2 + 273}{t_1 - t_2} + 1 = \frac{t_2 + 273 + t_1 - t_2}{t_1 - t_2} = \boxed{\frac{t_1 + 273}{t_1 - t_2}}$

Ⓠ A carnot engine having an efficiency of 1/10 as heat engine, is used as a refrigerator. If the work done on the system is 10 J, the amount of energy absorbed from the reservoir at low temp is:

$K = \frac{1-\eta}{\eta} = \frac{Q_2}{W} \Rightarrow \frac{1-0.1}{0.1} = \frac{Q_2}{10} \Rightarrow \boxed{Q_2 = 90\,J}$