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saathi

Unit-8

Chapter-12

Thermodynamics

Laws of Thermodynamics

Adiabatic process with work done

Isothermal process with work done

Mayer's formula
 $C_p - C_v = R$

Diff. b/w Isothermal & Adiabatic

Q Explain Thermodynamics with zeroth law.

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According to the first Law of Thermodynamics the energy dQ supplied to a system increase partly the internal energy of the system dU the rest is spent in doing work done on the environment dW

$$\boxed{dQ = dU + dW}$$

Some important applications of first law of Thermodynamics

1. Isothermal process $\Rightarrow T = T_0$
2. Adiabatic process
3. Isochoric process
4. Isobaric process

\Rightarrow Isothermal process:- Temp. Remain Constant
 $\Delta T = 0, dU = 0$
 $dQ = 0 + dW \Rightarrow dW = dQ$

\Rightarrow Adiabatic process:- No change in Heat energy
 $dQ = 0$
 $dU + dW = 0 \Rightarrow dU = -dW$

\Rightarrow Isochoric process:- Volume Remain Constant
 $\Delta V = 0, dW = 0$
 $dQ = dU$

\Rightarrow Isobaric process:- Pressure Remains Constant
 $dQ = dU + dW$
 $dU = dQ - dW$
 $= dQ - P\Delta V$
 $= dQ - P(V_F - V_i)$
 $= dQ - P(V_F - V_i)$

Note: 1. The general equation for an Isothermal process is

$$PV = \text{Constant}$$

$$P_1 V_1 = P_2 V_2$$

2. The general equation for an Adiabatic process is

$$PV^\gamma = \text{Constant}$$

$$\gamma = \frac{C_p}{C_v}$$

$$\boxed{P_1 V_1^\gamma = P_2 V_2^\gamma}$$

3. # $PV = nRT$

$$n = 1 \text{ gram mole}$$

$$PV = RT \Rightarrow V \propto \frac{T}{P}$$

$$P \propto \frac{T}{V}$$

$PV^\gamma = \text{Constant}$

$$P \frac{T^\gamma}{P^\gamma} = \text{Constant}$$

$$P^{1-\gamma} T^\gamma = \text{Constant}$$

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

$PV^\gamma = \text{Constant}$

$$\frac{T}{V} V^\gamma = \text{Constant}$$

$$TV^{\gamma-1} = \text{Constant}$$

$$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

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⇒ Define Adiabatic process with essential condition
 Derive a formula for work done for Adiabatic process

A change in pressure ~~and~~ ^{and} volume of a gas when no heat is allowed to enter into or escape from the gas is called an Adiabatic change or Adiabatic process

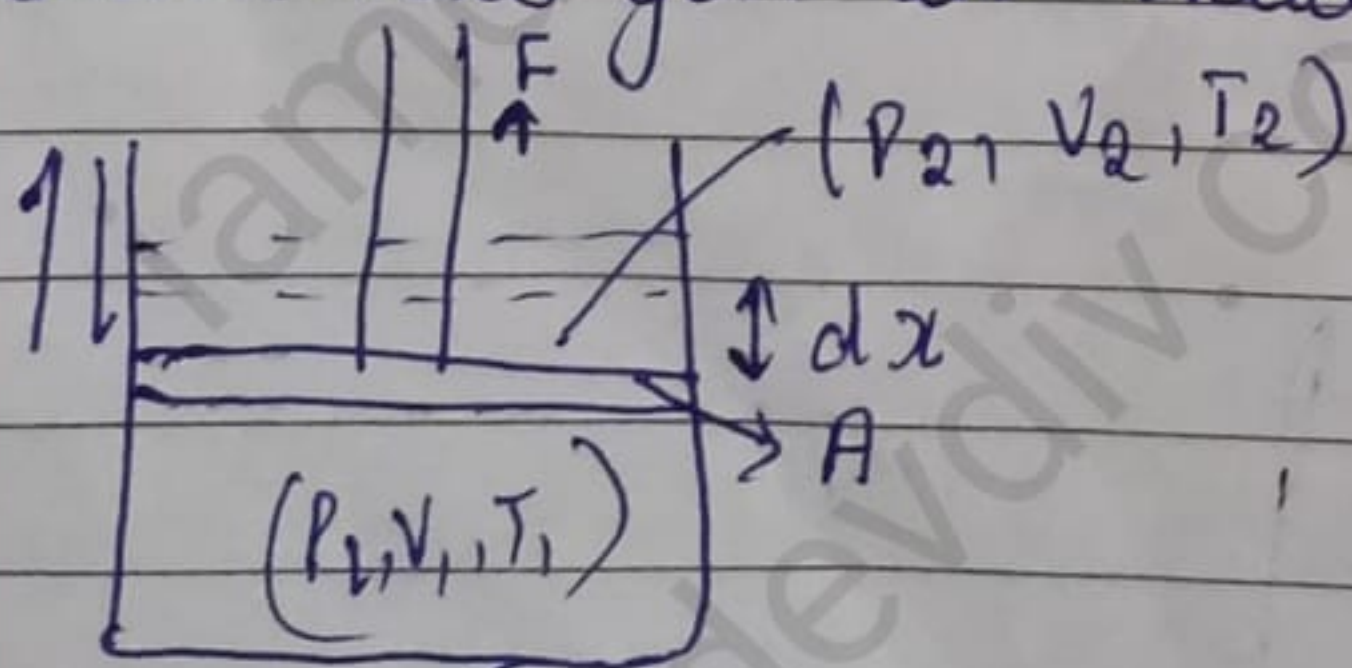
⇒ The two essential condition for a perfectly Adiabatic Change or process are:-

- The walls of the container must be perfectly non-conductive
- The process of compression or expansion should be suddenly so that there is no time for the exchange of heat

Examples of Adiabatic change:-

1. Suddenly bursting of the tube of a bicycle tyre.
2. Propagation of sound wave in air or other gases.

⇒ Work done for an Adiabatic process



$$F = P \times A \quad \text{--- (i)}$$

Required work done $dW = F dx$

$$dW = P A dx$$

$$\boxed{dW = P dv} \quad \text{--- (ii)}$$

$$\int dW = \int_{V_1}^{V_2} P dv$$

But for Adiabatic process $PV^\gamma = K$
 $P = KV^{-\gamma}$ — (iii)

$$\int_0^w dw = \int_{V_1}^{V_2} KV^{-\gamma} dV$$

$$W = K \int_{V_1}^{V_2} V^{-\gamma} dV$$

$$\int V^n dV = \frac{V^{n+1}}{n+1}$$

$$W = K \left[\frac{V^{-\gamma+1}}{-\gamma+1} \right]_{V_1}^{V_2}$$

$$= \frac{K}{1-\gamma} \left[V^{1-\gamma} \right]_{V_1}^{V_2}$$

$$= \frac{K}{1-\gamma} \left[V_2^{1-\gamma} - V_1^{1-\gamma} \right]$$

$$W = \left[\frac{KV_2^{1-\gamma} - KV_1^{1-\gamma}}{1-\gamma} \right] \text{ — (iv) in terms of volume}$$

Now putting value of K

$$W = \left[\frac{P_2 V_2^\gamma \cdot V_2^{1-\gamma} - P_1 V_1^\gamma \cdot V_1^{1-\gamma}}{1-\gamma} \right]$$

$$W = \left[\frac{P_2 V_2 - P_1 V_1}{1-\gamma} \right] \text{ — (v) in terms of Pressure & Volume}$$

So Again from eqⁿ (i)

$$[\because PV = RT]$$

$$W = \frac{R(T_2 - T_1)}{1-\gamma} \text{ — (vi)}$$

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Ques - A sample of gas ($\gamma = 1.5$) is taken through an Adiabatic process in which the volume is compressed from 1600 C.C. - 400 C.C. if the initial pressure is 150 k Pa = 150×10^3 Pa. What is the final pressure and how much work is done on the gas in this process.

$$P_2 = ? \quad \gamma = 1.5$$

$$\begin{aligned}
 P_1 V_1^\gamma &= P_2 V_2^\gamma \\
 150 \times (1600)^{3/2} &= P_2 (400)^{3/2} \\
 150 \times (400)^{3/2} &= P_2 (20^2)^{3/2} \\
 150 \times 64000 &= P_2 (8000) \\
 \frac{150 \times 64000}{18000} &= P_2
 \end{aligned}$$

$$\begin{aligned}
 1200 \text{ kPa} &= P_2 \\
 W &= \left[\frac{P_2 V_2 - P_1 V_1}{1 - \gamma} \right] \Rightarrow \left[\frac{1200 \times 400 - 150 \times 1600}{1 - 1.5} \right]
 \end{aligned}$$

$$\Rightarrow \left[\frac{48 \times 10^4 - 24 \times 10^4}{0.5} \right]$$

$$\Rightarrow 10^4 \left[\frac{48 - 24}{0.5} \right] \Rightarrow \frac{24 \times 10^4}{0.5}$$

$$\Rightarrow 48 \times 10^4 \text{ J (Ans)}$$

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Relation between two specific principle heat of gas or establish a relation between ~~CP & CV~~ CP & CV or Mayer's formula

$$C_p - C_v = R$$

↓

Molar specific heat at constant pressure

C_v = Molar specific heat at constant volume

R = Gas constant

$$\# dQ = du + dw$$

$$\# dw = P \Delta V$$

$$\# Q = mS \Delta T$$

$$\# m = 1, S = C_p, C_v$$

$$dQ = C_v \Delta T$$

$$dQ = C_p \Delta T$$

Let us consider 1 gm mole of a gas is enclosed in a cylinder with fitted piston and its initial thermodynamical parameters are:-

P, V, T respectively pressure, volume & temperature the gas is heated with two different specific heat capacity C_p & C_v , it given the following process/Two cases

Case I

When gas is heated at constant volume

$$\rightarrow C_v$$

$$\Delta V = 0$$

$$dw = P \Delta V = 0$$

$$dQ = C_v dT$$

from 1st law of thermodynamics

$$dQ = du + dw$$

$$C_v dT = du + 0$$

$$dw = C_v dT \quad \text{--- (1)}$$

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Case 2

When gas is heated at constant pressure

→ C_p

$\Delta V \neq 0$

$dW = P \Delta V$

$dQ = C_p \Delta T$

Again from 1st law of thermodynamics

$dQ = du + dW$

$C_p \Delta T = du' + P \Delta V$

$du' = C_p \Delta T - P \Delta V$ - (2)

from the equation (1) & (2) represent internal energy for both cases but we know that in both case change in temperature or rising temp. ΔT is same, internal energy depend only temp. so $du = du'$

(1) = (2)

$C_v \Delta T = C_p \Delta T - P \Delta V$

$C_v \Delta T = C_p \Delta T - P \Delta V$

~~$C_p \Delta T - C_v$~~

$C_p \Delta T - C_v \Delta T = P \Delta V$

$(C_p - C_v) \Delta T = P \Delta V$

$(C_p - C_v) \Delta T = R \Delta T$

$C_p - C_v = R$

$P V = R T$

$P \Delta V = R \Delta T$

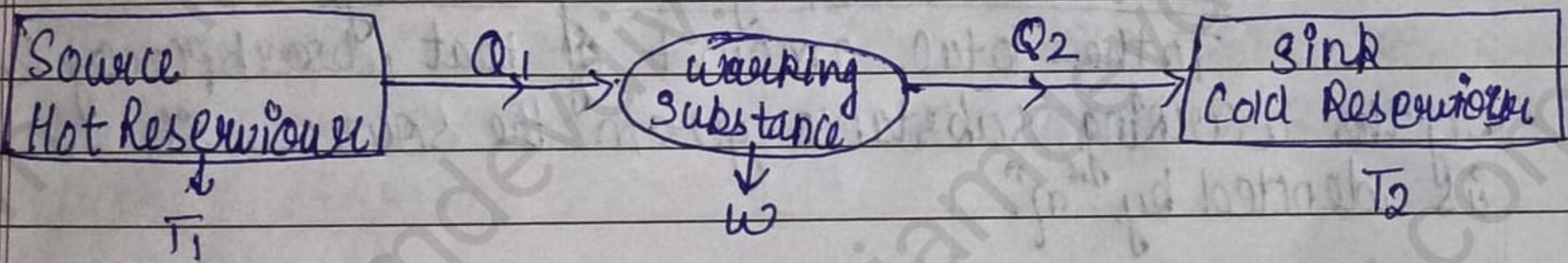
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★ Heat Engine

A heat engine is a device which convert heat energy into mechanical energy. This process made two undergo a cyclic process. A cyclic process consist of a series of change which return to the system back to its initial state.

Essential part of heat engine

Source of heat at higher temp. working substance sink of heat at lower temperature



- ★ Amount of heat absorb Q_1 by ~~heat~~ the working substance from source at T_1 in ^{one} complete cycle
- ★ W = Net amount of work done by the working substance on the environment in the cycle.
- ★ Q_2 = Amount of heat rejected to the sink at T_2 temp. in one cycle.

Net amount of heat absorbed in one cycle $dQ = Q_1 - Q_2$
 returns to its initial state the change in internal energy is $dQ = 0$

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- According to the first law $dQ = du + dw$
 $\therefore dQ = dw$

- That equal to So now net amount of heat absorb equal to external work done by the engine

Thermal efficiency

Thermal efficiency of an engine is defined as the ratio of net work done/cycle by the engine to the total amount

Net work done/cycle by the engine

To the total amount of heat absorb per cycle by the working substance from the source, it is denoted by " η ".

$$\eta = \frac{Q_1 - Q_2}{Q_1}$$

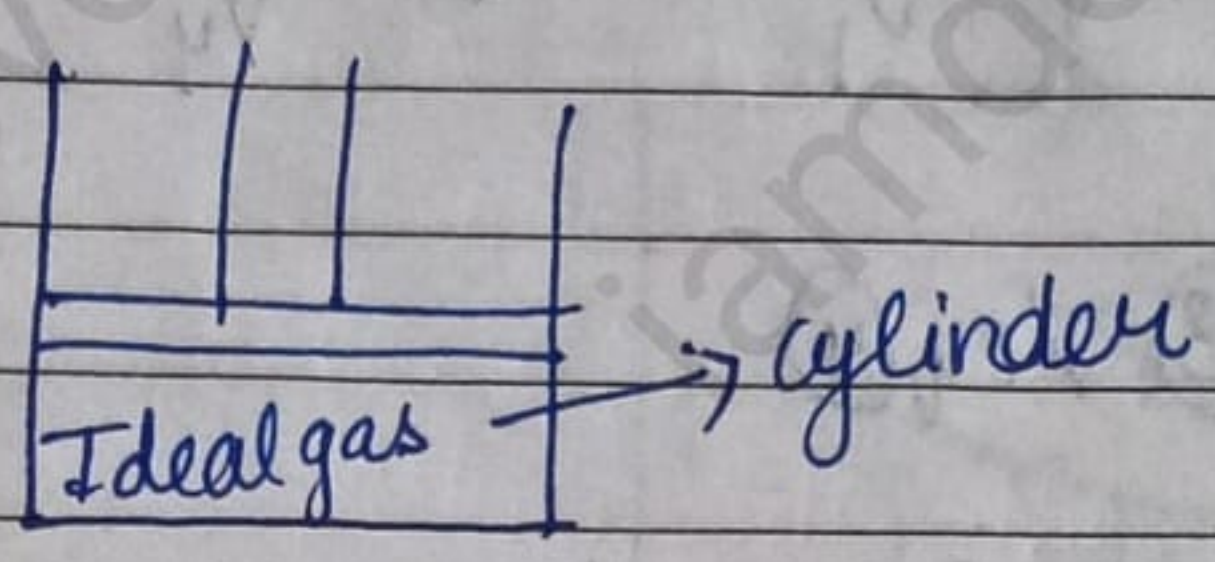
$$\eta = 1 - \frac{Q_2}{Q_1}$$

Carnot Cycle

It is a device, which work as ideal cycle of operation for a heat engine & it used for realising this ideal cycle of operation it always based on three essential part: source of heat, sink of heat & working substance. A Carnot Cycle or Carnot Heat Engine consist of the four main stage Isothermal Expansion, Adiabatic Expansion, Isothermal Compression & Adiabatic

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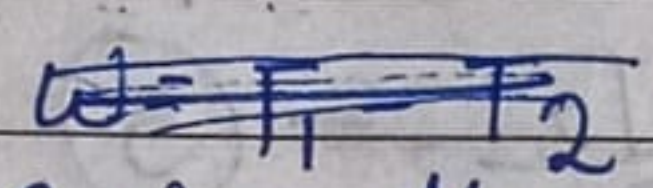
Compression.



Source of heat T_1

Insulated pad

Sink of heat T_2



In Carnot heat Engine the efficiency can be defined as following:-

The ratio of net mechanical work done per cycle by the gas w to the amount of heat energy absorbed per cycle from the source Q_1

$$\eta = \frac{w}{Q_1} = \frac{Q_1 - Q_2}{Q_1}$$

$$\eta = 1 - \frac{Q_2}{Q_1} \quad \text{--- (1)}$$

In Carnot cycle during the isothermal expansion, heat amount of heat energy

$$Q_1 = w = RT_1 \log_e \frac{V_2}{V_1} \quad \text{--- (2)}$$

Similarly amount of heat energy during the Isothermal Compression

$$Q_2 = w = RT_2 \log_e \frac{V_3}{V_4} \quad \text{--- (3)}$$

And all four state of Carnot cycle it is found that ratio of V_2 & V_1 always equal to V_3 & V_4

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~~Also~~
$$\log_e \frac{v_2}{v_1} = \log_e \frac{v_3}{v_4} \quad \text{--- (4)}$$

Now eq. (3) / eq. (4)

$$\frac{Q_2}{Q_1} = \frac{RT_2 \log_e \frac{v_2}{v_4}}{RT_1 \log_e \frac{v_2}{v_1}}$$

$$\frac{Q_2}{Q_1} = \frac{T_2}{T_1} \quad \text{--- (5)}$$

From eq. (5) & (1)

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

★ Second Law of Thermodynamics

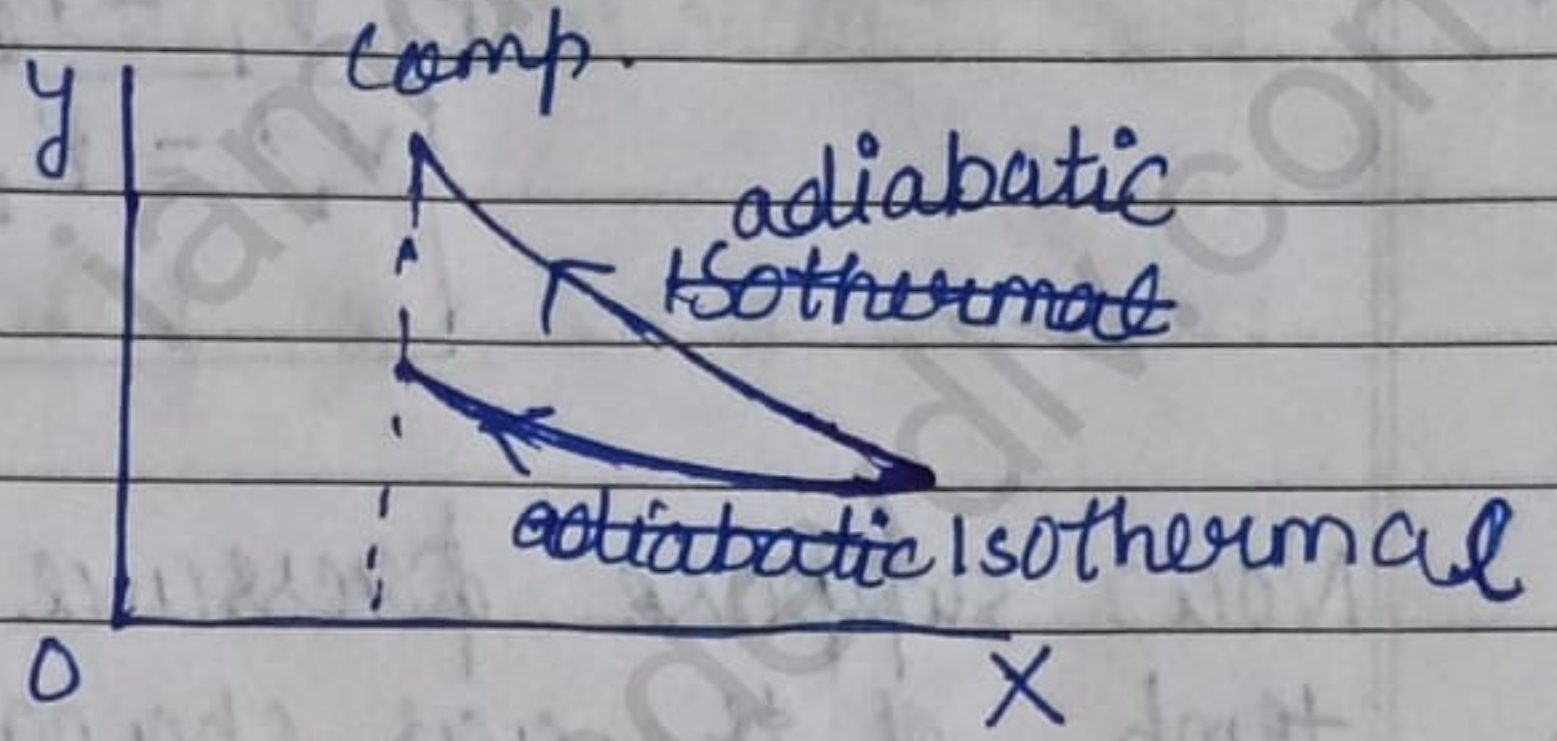
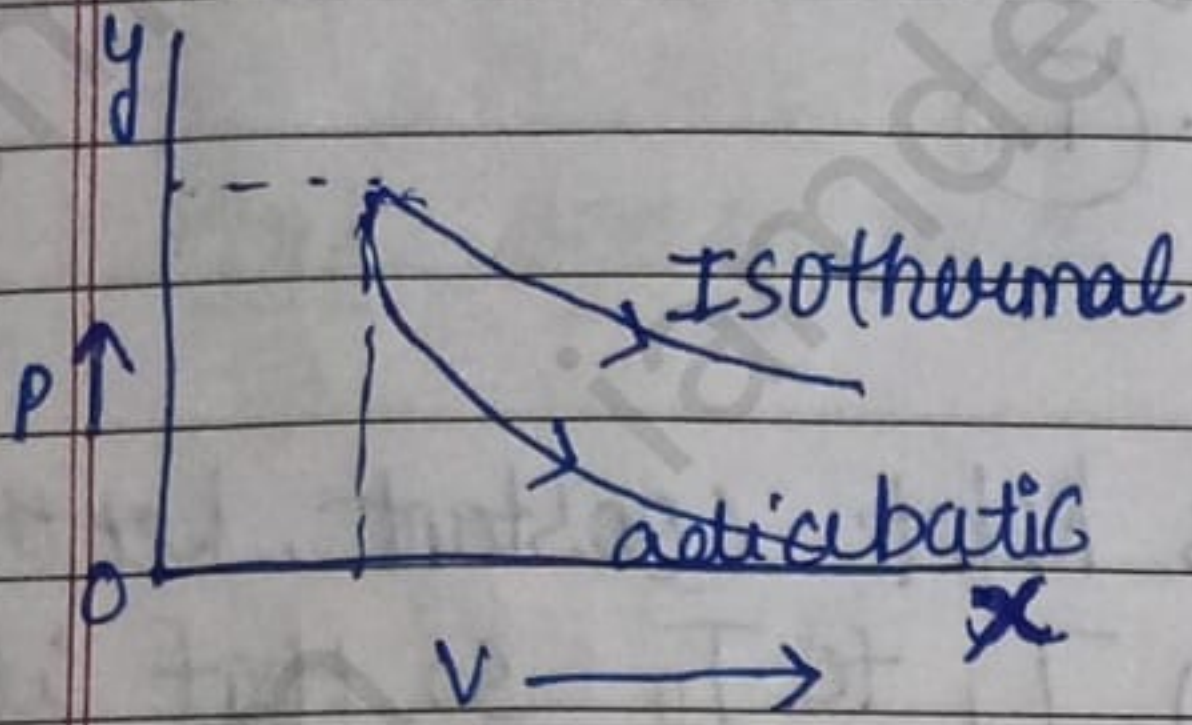
According to this law heat flows spontaneously from a substance at higher temp. to another at lower temp. heat does not flow spontaneously in the reverse direction.

Or

According to the Kelvin plank statement it is impossible to construct a heat engine which would absorb heat from a reservoir & convert 100% of heat absorbed into work done.

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Slopes of Isothermal and Adiabatic curve.



$$Pv = K$$

$$Pdv = v dP = 0$$

$$v dP = -Pdv$$

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