3/9/19

Introduction to thermodynamics

Thermodynamics is the science of energy interaction & its affect on physical properties of matter (solid, liq. & gas).

Thermo → heat
dynamic → power.

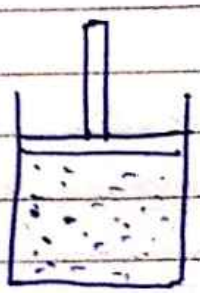
Thermodynamic system :
Defined as quantity of matter or region in space on which our study is followed.

- When we focus on finite quantity, then it is k/a controlled mass approach.

System:	Mass transfer	energy transfer.
① Closed	X	✓
② open	✓	✓
③ Isolated	X	X.

Examples:

①



- Characteristic of the system at one point is c/a state & when its characteristics changes from one state to another is c/a change of state.

- When the system goes from initial to final state by a continuous change of state is k/a process.

- A thermodynamic cycle is defined as a series of state changes such that the final state is identical to initial state.

- Mechanical eq^{bm}.
  $\Sigma F = 0$
- $A + B \rightleftharpoons C + D$
- Thermal eq^{bm}

⇒ If a body follows these 3 eq^{bm} cond^{n}, then it is said to be in thermodynamic eq^{bm}.

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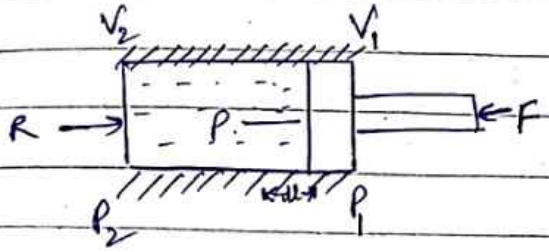
Specific property = $\frac{\text{extensive property}}{\text{mass.}}$



$R = F$

$R - F = 0$

$\Sigma F = 0.$

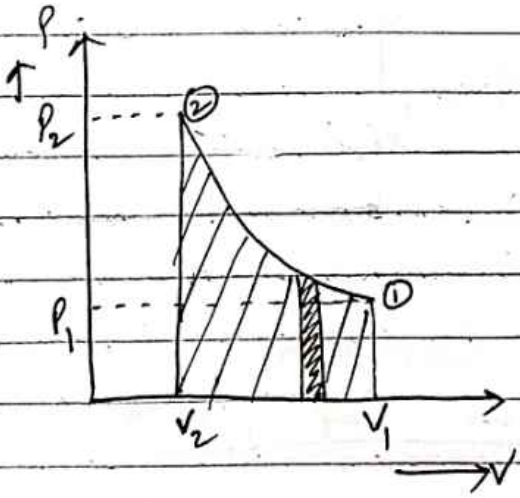
$\boxed{R = P \cdot a}$

$dW = F \cdot dl$

$dW = P \cdot a \cdot dl$

$dW = P \cdot dV$

$\boxed{a \cdot dl = dV}$



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

$$W = P[V_2 - V_1]$$

$$W = \int_{V_1}^{V_2} P\,dV$$

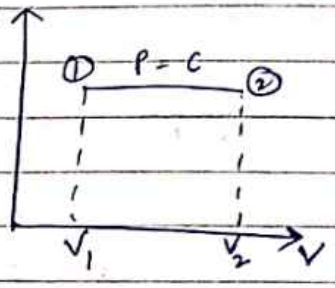
P.dV work for reversible process.

① Isobaric process or constt. pressure process.

$\boxed{P = C}$

$$W = \int P \cdot dV$$

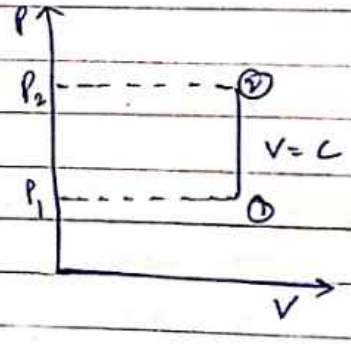
$$W = P[V_2 - V_1]$$



② Isochoric process or constt. vol. process

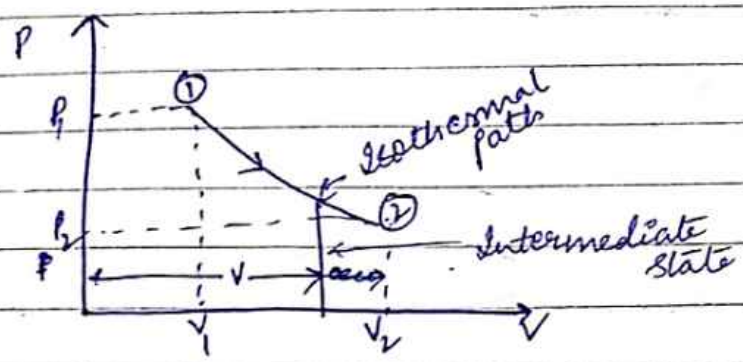
$$W = \int P \cdot dV$$

$\boxed{W = 0}$



③ Isothermal process or constt. temp. process

$\boxed{T = C}$



$P_1V_1 = P_2V_2$

$PV = P_1V_1$

$$P = \frac{P_1V_1}{V}$$

$$W = P_1V_1 (\ln V)_{V_1}^{V_2}$$

$$= P_1V_1 (\ln V_2 - \ln V_1)$$

$$W = P_1V_1 \ln \frac{V_2}{V_1}$$

$$W = P_1V_1 \ln \frac{P_1}{P_2}$$

④ Polytropic process:

$$PV^n = C \qquad 0 \le n \le \infty$$

$$P_1V_1^n = P_2V_2^n \qquad \frac{V_2}{V_1}$$

$$P = \frac{P_1V_1^n}{V^n}$$

$$W = \int_{V_1}^{V_2} P \cdot dV \Rightarrow P_1V_1^n \int_{V_1}^{V_2} V^{-n} dV$$

$$W = \frac{P_1V_1 - P_2V_2}{n-1}$$

Ques:

For adiabatic process :→ Heat will not be transferred.

$PV^\gamma = C$

$$W = \frac{P_1V_1 - P_2V_2}{\gamma - 1} \qquad \gamma = \frac{C_p}{C_v}$$

Q→ A mass of gas is compressed in a quasistatic process from 80 kPa, 0.1 m^3 to 0.4 MPa & 0.03 m^3. Assume pressure & vol. are related as $PV^n = C$. Find W.

~~80 × 0.1 =~~

$$n = \frac{\ln(P_1/P_2)}{\ln(V_2/V_1)}$$

Ques: Prove that

$$\left[\frac{dp}{dV}\right]_{\text{adiabatic process}} = \gamma \left[\frac{dp}{dV}\right]_{\text{isothermal process}}$$

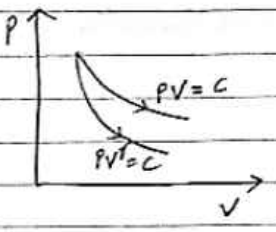
$\frac{dp}{dV}$ → is slope of PV-diagram.

$PV = K$

$p \times dV + \frac{dp}{dV} \times V = 0.$

$\frac{dp}{dV} V = -p$

$\frac{dp}{dV} = \frac{-p}{V}$



$PV^\gamma = C$

$\frac{dp}{dV} \times V^\gamma + p \times \gamma V^{\gamma-1} = 0$

$dp \times V^\gamma = -p \times \gamma V^{\gamma-1} \times dV$

$\frac{dp}{dV} = \frac{-p \times \gamma V^{\gamma-1}}{V^\gamma}$

$= \frac{-\gamma p}{V}$

- A form of energy which is transferred b/w 2 bodies of a system & surrounding by virtue of temp difference is k/a <u>heat</u>

Heat removed from system = −ve
" added to " = +ve.

$T_1 > T_2$

Heat removed, temp of the system will ↓ (−ve)

Heat transfer is (+ve).

$T_2 > T_1$

Heat added to system, temp. of system will ↑ (+ve).

⇒ Heat transfer is (+ve).

Ques-①

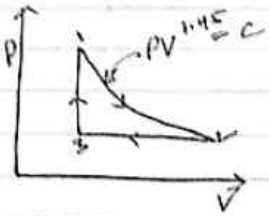
A piston cylinder device with air at an initial temp. of 30°C undergoes an expansion process for which P & V are related as

P (kPa)	100	37.9	14.4
V (m^3)	0.1	0.2	0.4

Calcate W by the systems.

② A piston cylinder device operates 1 kg of fuel at 20 atm pressure. The initial vol. is 0.04 m^3. The fuel is allowed to expand reversibly following a process

$PV^{1.45} = C$, so that the vol. becomes double. The fuel is then cooled at constt. pressure until the piston comes back to the original position. Keeping the piston unaltered, heat is added reversibly to restore it to the initial pressure. Calculate W in the cycle.



$PV^n = C$

$100 \times (0.1)^n = 14.4 \times (0.4)^n$

Heat (path func^n).

A form of energy which is transferred b/w 2 bodies or a system & surrounding by virtue of temp. differenc

(2) (4) Every path func^n is an inexact differential

Represented as → δW, δQ

$$\int_1^2 dW = W_2 - W_1 \; X$$

$$Q_2 - Q_1 \; X.$$

Specific heat → ('c')

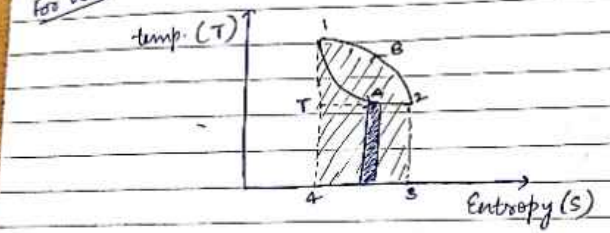
Amount of heat required to cause a unit change in temp. for a unit quantity of matter.

Unit → J/kg K or kJ/kg K

* For gases $(C_p > C_v)$

* for incompressible substances $(c_p = c_v)$

For heat:



Area under T-S diagram = heat transfer.

* Points to remember regarding heat transfer (H_t) & work transfer (W_t)

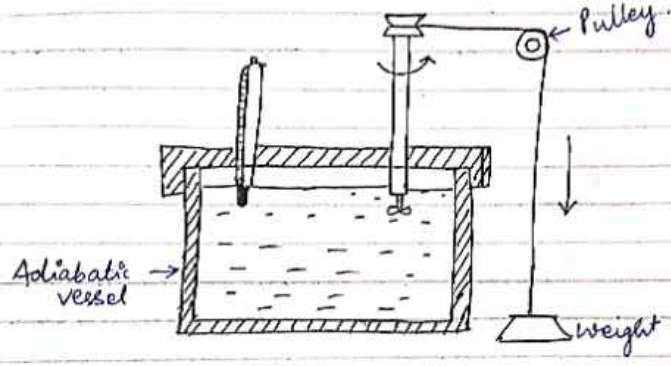
1. H_t & W_t are both are energy interactions.
2. The same effect in a close system can be brought about either by H_t or W_t.
3. Both H_t & W_t are boundary phenomenon. Both are observed at the boundary of the system & both represent energy crossing boundaries of the system.
4. H_t is the energy interaction due to temp. difference only. All other energy interactions may be termed as W_t.
5. Both, heat & work are path func^n & inexact differentials.

   The magnitude of H_t or W_t depends upon the path system followed during the change of state.

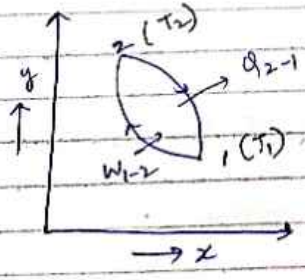
1/10/19

Thermodynamics

1st law for a closed system undergoing a cycle.



Adiabatic work



cycle completed by a system with 2 energy interactions.

→ Adiabatic work transfer W_{1-2} followed by heat transfer Q_{2-1}.

$$W_{1-2} \propto Q_{2-1}$$

$$W_{1-2} = J Q_{2-1}$$

$$(\Sigma W)_{cycle} = J (\Sigma Q)_{cycle}$$

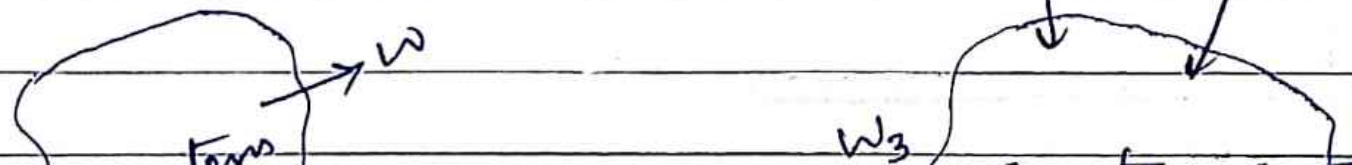
$$\oint dW = J \oint dQ$$

1st law for a closed system undergoing a change of state

$$Q - W = \Delta E$$

If Q is the amount of heat transferred to the system & W is the amt. of work transfer from the system, during the process, the net energy transferred will be stored in the system.

→ Energy in storage is neither heat nor work & given the name internal energy or energy of system.



Energy - a property of the system.

$Q_A = \Delta E_A + W_A$

$Q_B = \Delta E_B + W_B$

$(\Sigma W)_{cycle} = (\Sigma Q)_{cycle}$.

$W_A + W_B = Q_A + Q_B$

$Q_A - W_A = W_B - Q_B$

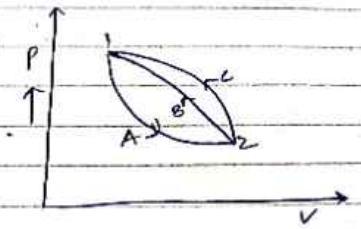
$$\boxed{\Delta E_A = -\Delta E_B} \quad \text{---(1)}$$

Similarly, $$\boxed{\Delta E_A = -\Delta E_C} \quad \text{---(2)}$$

From (1) & (2),

$$\boxed{\Delta E_B = \Delta E_C}$$

$\therefore$ the change in energy b/w 2 states of the system is same whatever path the system may follow in undergoing the change in state.



Energy - a property of the system.

Different form of stored energy

* 2 forms of energy:
  - ⇒ Energy in transit (Path func")
  - ⇒ Energy in storage (internal energy)
    - ↳ (Point / state func")

E = total energy stored in the system.

* 2 modes of energy:
  - Macroscopic
    - $KE = \frac{1}{2}mv^2$
    - $PE = mgz$
  - Microscopic
    - internal energy = U.
    - $E = E_{trans} + E_{rotn} + E_{vib} + E_{electronic} + E_{nuclear} + E_{chemical}$
    - no. of molecules $U = N\varepsilon$
    - $\boxed{U = f(T)}$ → for ideal gas.

In the case of magnetic, surface, ____ energy,

$E = E_k + E_p + U$

$\boxed{E = U}$

$q = \Delta E + W$

$q = \Delta U + W$

$$\boxed{q = \Delta U + P dV}$$

Enthalpy

Enthalpy of a substance, h,

$$h = U + PV$$

⇒ Intensive property (kJ/kg)

(*) For a unit mass of a pure substance,

$$dq = dU + PdV$$

At constt. pressure,

$$PdV = d(PV)$$

$$(dq)_P = dU + dPV$$
$$= d(U + PV)$$

$$\boxed{(dq)_P = dh}$$

$h = U + PV$, is the specific enthalpy, a property of the system.

(*) For an ideal gas,

$h = U + RT$

$h = f(T)$ → only for ideal gas

$PV = nRT$

$PV = RT$

$H = U + PV$

$h = H/m$ (J/kg).

Sp. heat at constt. vol X.
↳ Not done.

Specific heat at constt. pressure,
Rate of change of enthalpy w.r.t temp. at constt. pressure.

$$C_p = \left(\frac{dh}{dT}\right)_p$$

for constt. pressure,

$$(\Delta h)_p = \int_{T_1}^{T_2} C_p \, dT$$

$$dQ = dU + PdV$$
$$h = U + PV$$
$$dh = dU + PdV + Vdp$$
$$= dQ + Vdp$$
$$dQ = dh - Vdp$$
$$(dQ)_p = dh$$
$$(Q_p) = (\Delta h)_p$$

$$\boxed{(Q)_p = \int_{T_1}^{T_2} C_p \, dT}$$

Energy of an isolated system

↳ is always consett.

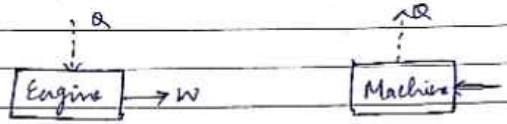
$dW = 0 \quad dQ = 0$

$dE = 0$

$\boxed{E = C}$

PMM1

(Perpetual Motion Machine of first kind).



PMM1 Converse of PMM1

Q→ A stationary mass of gas is compressed without friction from an initial state of $0.3 m^3$ & 0.105 MPa to a final state of 0.1

0.15

$W = \int P dV$

$W = 0.105 \cdot$

$Q = \Delta U + W$

$W = P dV$

$V_1 = 0.15$

$V_2 = 0.30$

$P = 0.105$

$Q_{1-2} = -37.6 \text{ kJ}$

Q→ A piston & cylinder ~~system~~ machine contains a fluid system which passes through a complete cycle of 4 process. During a cycle, the sum of all heat transfer is −170 kJ. The system completes 100 cycle per minute.

Complete the following table showing the method for each item & compute the net rate of work output in kWatt.

Process	Q(kJ/min)	W(kJ/min)	ΔE (kJ/min)
a−b	0	2170	−2170
	~~21000~~	~~0~~	
b−c	21000	0	21000
c−d	−2100	34,500	−36,600
d−a			

Q = ΔE + W.

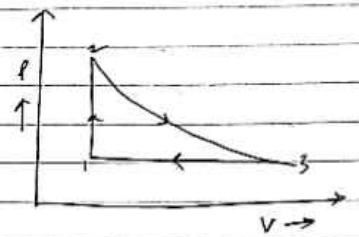
21000 = ΔE.

Q = ΔE + W

= 34500 − 36600

36600
34500
2100

Q→ A stationary fluid system goes through the cycle as shown in fig.



(i) Process 1-2 isochoric heat addⁿ of 235 kJ/kg.
(ii) Process 2-3 adiabatic expansion to its original process with loss of 70 kJ/kg in internal energy.
(iii) Process 3-1 isobaric compression to its original vol. with heat rejection of 200 kJ/kg.

Prepare a balance sheet of energy quantities & find the

Second law of thermodynamics:

$Q = \Delta U + W$

$W = Q$

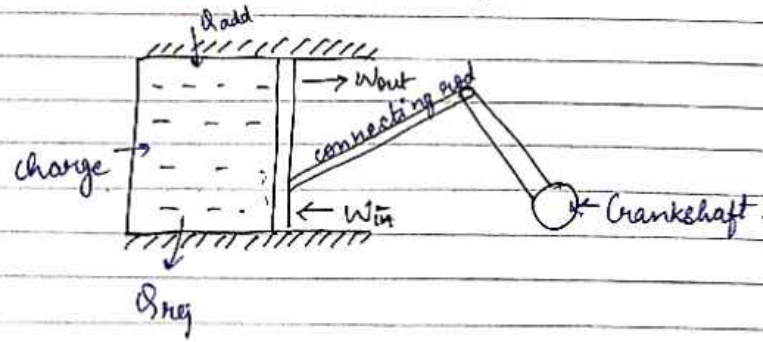
$Q \rightarrow W$

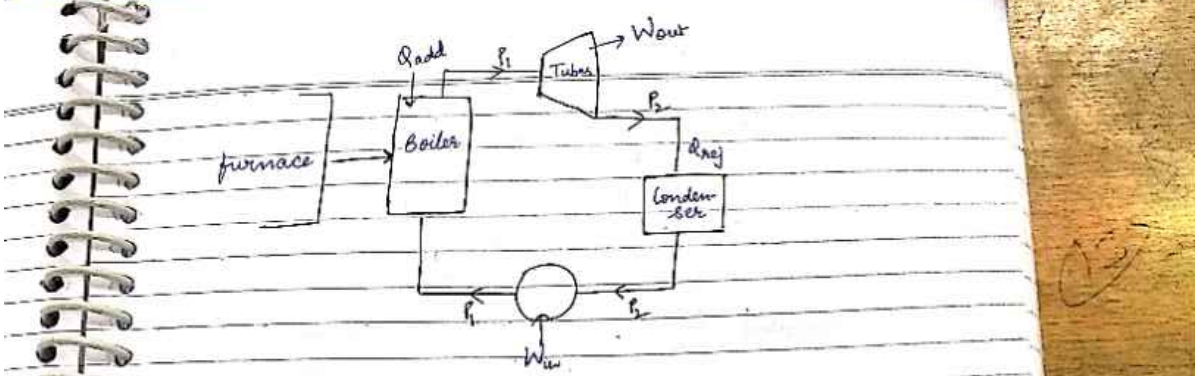
(*) Cyclic heat engine

- Reciprocating
- Rotatory or Rotodynamic

→ Cyclic heat engine is a thermodynamic cycle in which there is net heat transfer to the system & a net work transfer from the system.

→ They system which executes a heat engine cycle is c/a heat engine.





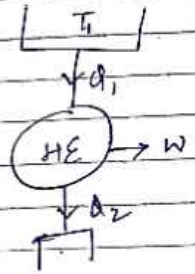
$$Q_{add} - Q_{rej} = W_{out} - W_{in}$$

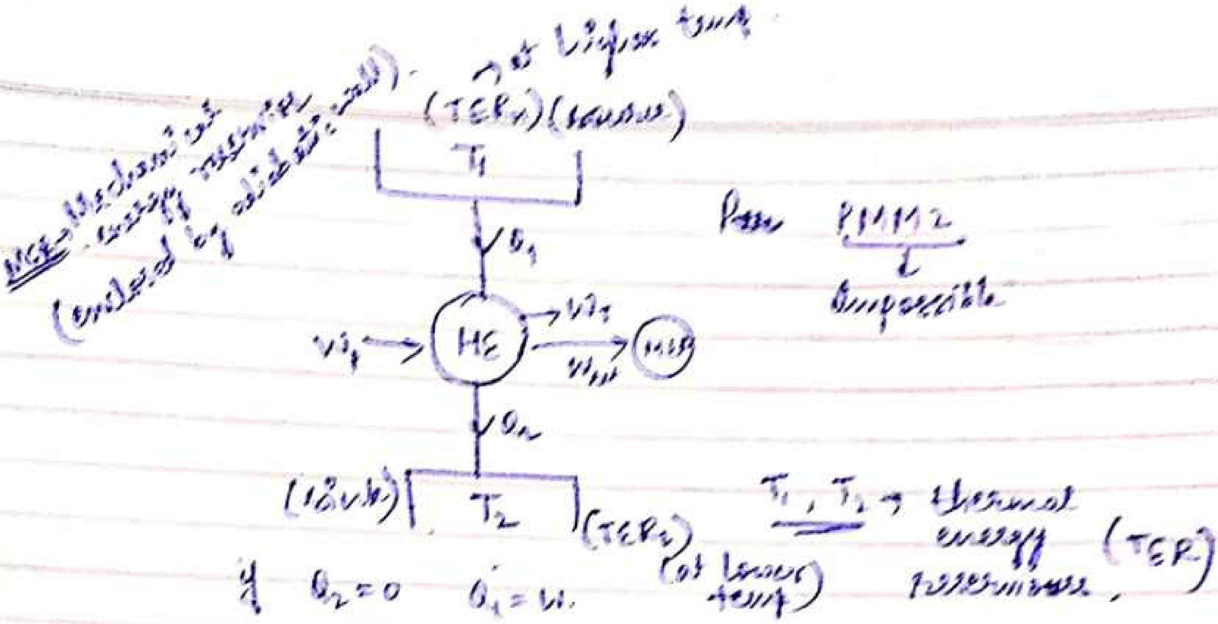
$$Q_{add} = Q_{rej} + W_{net}$$

$$\eta = \frac{W_{net}}{Q_{add}}$$ ← thermal efficiency.

$$\eta < 1$$

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





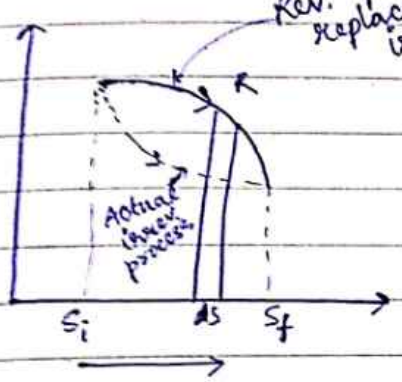
④ 2nd law
- → ① Kelvin Planck statement
- → ② Clausius statement.

→ It is impossible to construct a device which operating in cycle will produce no effect other than transfer of heat from a colder body to hotter body

→ Heat can't flow of itself from a body at a lower temp. to a body at higher temp. Some work must be expended to achieve it.

Temp Temperature - energy plot

$$\frac{dQ_R}{T} = \Delta S$$



Integration can be done on rev. path

$$dS = \frac{dQ_{rev}}{T}$$

$$dQ_{rev} = 0$$

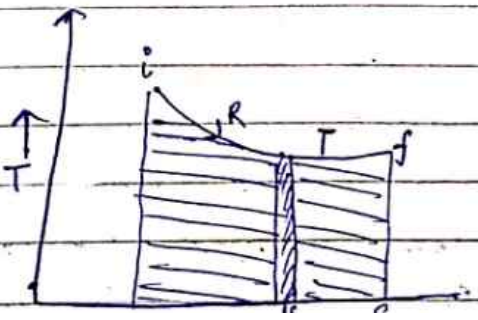
$$dS = 0$$

$$S = \text{constt.}$$

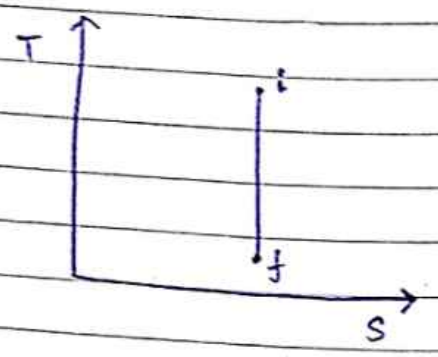
$$dQ_{rev} = T\,dS$$

$$Q_{rev} = \int_i^f T\,ds.$$

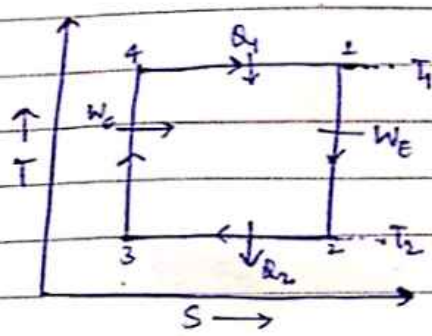
~~For rev. isothermal.~~
~~but heat too~~



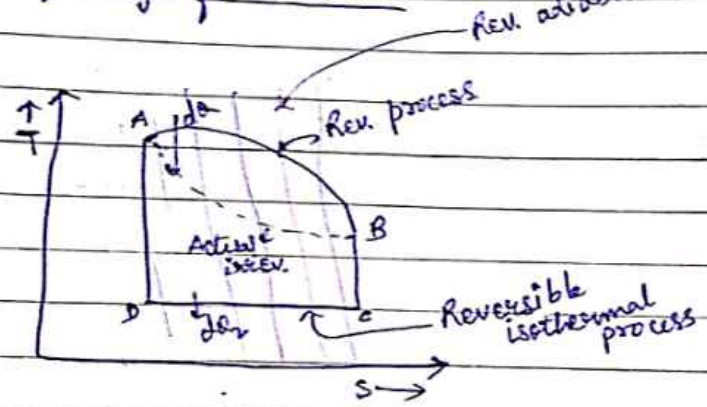
Isentropic process



Carnot cycle



Inequality of Clausius



For irrev. cycle,

$$\eta_{(thermal)} = \left(1 - \frac{dQ_2}{dQ}\right)$$

For rev. cycle

$$\eta_{(thermal)} = \left(1 - \frac{dQ_2}{dQ}\right)_{rev.}$$

From the Carnot theorem,

$$(\eta_{th})_{irrev.} \leq (\eta_{th})_{rev.}$$

$$\left(1 - \frac{dQ_2}{dQ_1}\right) \leq \left(1 - \frac{dQ_2}{dQ_1}\right)_{rev.}$$

$$\left(\frac{dQ_2}{dQ_1}\right) \geq \left(\frac{dQ_2}{dQ_1}\right)_{rev.} \Rightarrow \frac{dQ_2}{dQ_1} \geq \left(\frac{T_2}{T_1}\right)$$

$$\Rightarrow \left(\frac{dQ_2}{T_2}\right) \geq \left(\frac{dQ_1}{T_1}\right)$$

$$\eta_{carnot} = \frac{Q_1 - Q_2}{Q_1}$$

$$= \frac{T_1(\varepsilon_1 - \varepsilon_4) - T_2(\varepsilon_2 - \varepsilon_3)}{T_1(\varepsilon_1 - \varepsilon_4)}$$

$$= \frac{T_1 - T_2}{T_1} \Rightarrow 1 - \frac{T_2}{T_1} \quad \text{(for rev. cycle)}$$