

Thermodynamics

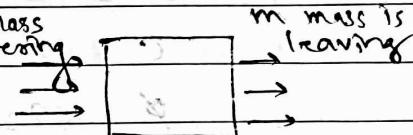
System: Part of universe that we take into consideration for doing experiments
is called system

Types of syst - i) Control mass system (closed system)

ii) Control volume system (open system)

- i. mass of system is fixed
- identify of syst is fixed.

ex: watch, egg



This doesn't maintain identity
hence not a system

- ii. Volume is fixed

ex: cup of tea, egg

Isolated syst:

No change in mass

No change in energy

ex: thermal flask, balloon

Extensive properties: Mass dependent

ex: energy, volume

Intensive properties: Mass independent

ex: temperature, pressure

We can define intensive properties even for a point

(having no mass)

* Thermodynamic state
 All thermodynamic properties are uniform throughout the system. They should be independent of time. These are conditions for a system to be in thermodynamic state.

* Gibbs's phase rule

$$f = C - \phi + 2$$

$C = \text{no. of components}$

$\phi = \text{no. of phases}$

$f = \text{no. of independent properties needed to be calculated}$
 $\text{to have enough to represent the system}$

$$C = 1, \phi = 1 \Rightarrow f = 2 \quad \text{water}$$

$$C = 1, \phi = 2 \Rightarrow f = 1 \quad \text{boiling water}$$

$$C = 1, \phi = 3 \Rightarrow f = 0 \quad \text{triple point}$$

* Dead state:

When there's no exchange of properties b/w system & surroundings & its properties are independent of time, the phenomenon is called as ^{dead} steady state

* Thermodynamic equilibrium:

1) Thermal eq.

2) Mechanical eq.

3) Chemical eq.

1) Thermal eq.: It is eq. state achieved by 2 sys. characterised by restricted values of thermodynamic properties

It is eq. state achieved by 2 sys. characterised by restricted values of thermodynamic properties

of the system after having communication with each other through diathermic wall

Temperature:

It is a thermodynamic property by the virtue of whose difference, heat flows from higher energy to lower one

It is a thermodynamic property which determines the existence of thermal equilibrium

Zeroth law:

When 2 bodies / systems are in thermal equilibrium with a third one, then they are in thermal equilibrium with each other (defines temp)

2) Mechanical equilibrium: (condition of static equilibrium)

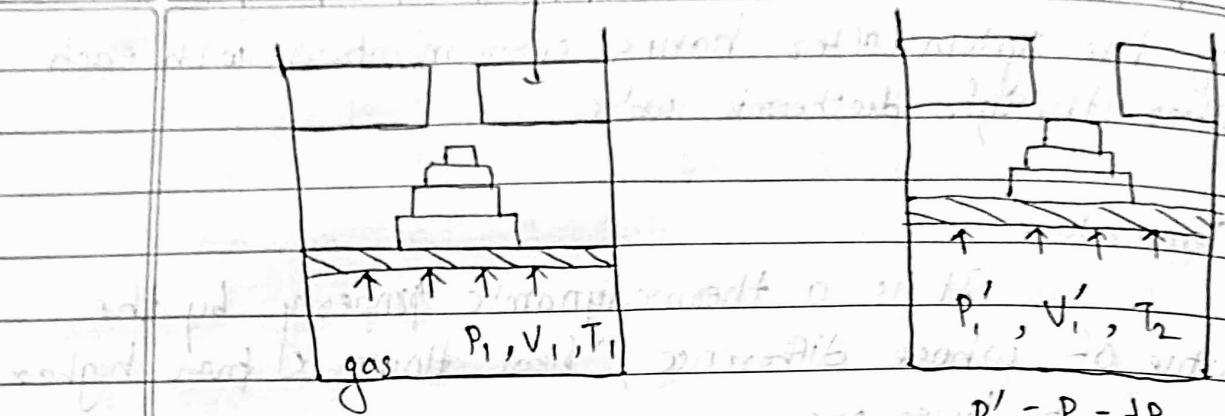
The condition for mechanical equilibrium is pressure gradient should be zero. Absence of unbalanced force

3) Chemical Equilibrium:

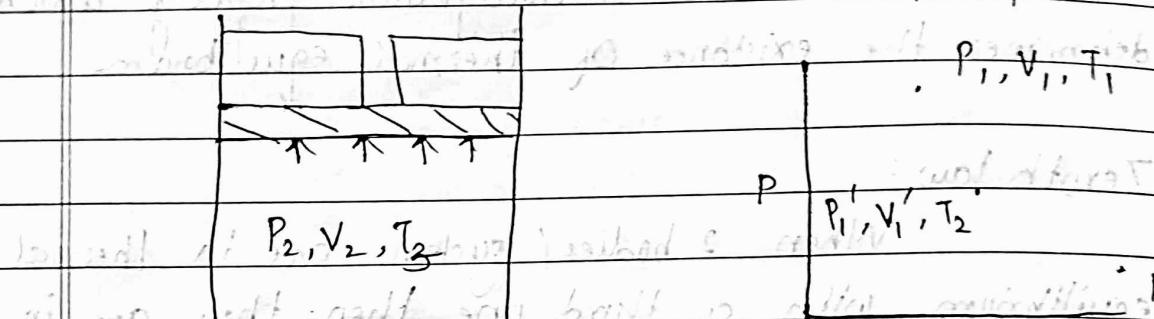
Condition for chemical equilibrium is concentration gradient should be zero.

When a system achieves all the three equilibrium, it is said to be in thermodynamic equilibrium

stoppers



During expansion $V' = V_1 + dV$



When we remove weight one by one, at every small step, system tries to achieve equilibrium

The process is called quasi-equilibrium / quasi-static or reversible process



Thermodynamic Concept of Energy

Energy stored in system and Energy in transfer

→ print form

→ heat transfer
→ work transfer

* Mechanical work Transfer

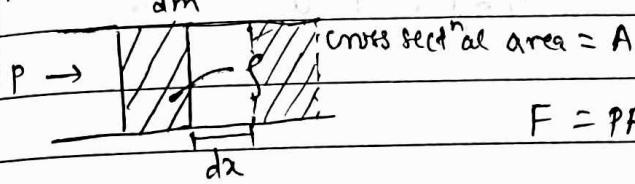
→ displacement work $W = \int pdV$ (only for reversible process)
non-dissipative work enclosed syst.

→ paddle wheel work, $W = \int \tau d\theta$ (closed syst) (irreversible process)
dissipative work

→ flow work, $W = PV$

→ shaft work, $W = \int \tau d\theta$

* Flow work



$$F = PA$$

$$W = PAdx$$

$$m = \rho Adx$$

$$\frac{W}{m} = \frac{PAdx}{\rho Adx} = \frac{P}{\rho}$$

$$V = \frac{1}{\rho} = \text{specific vol.}$$

= vol. per unit mass

* Shaft work

$$W = \int T d\theta$$

$$\dot{W} = \int \tau \frac{d\theta}{dt} = \tau \omega = \tau \cdot 2\pi N \quad \text{where } N \text{ is freq in rot^n per second}$$

work & heat are path fun?. They depend on path followed while state changes

conservation of energy

$U + Q = H$

* Sign Conventions

Workdone by the system : +ve

Workdone on the system : -ve

heat absorbed by the syst. : +ve

heat released by the syst. : -ve

{ W

Q

First Law of Thermodynamics

Joule's Experiment

$$\sum Q = \sum W$$

$$\oint (Q-W) = 0 \quad \text{if it is cyclic integral}$$

for infinitely many small processes,

$$\oint (\delta Q - \delta W) = 0$$

$\therefore \delta Q - \delta W = \delta U$... There must be a point fun if cyclic integral is 0.

$$\delta Q - \delta W = dU$$

$$Q - W = \Delta U$$

$$Q = W + \Delta U$$

for a system; $E = \text{internal energy} = \frac{1}{2}mv^2 + mgh + \Delta U + \text{d (other translational, vibrational energy)}$

$\Delta U = \Delta E$... therefore U is a point / state fun

$$\therefore [Q = \Delta U + W] \quad \text{--- FLTD}$$

(closed syst)

$$W = \int P dV$$

$$Q_{12} = U_2 - U_1 + \int P dV$$

* Exthalpy (H) keeps with each change in standard form

$$H = U + PV$$

H, U, V all are extensive prop

$$\frac{H}{m} = \frac{U}{m} + \frac{PV}{m}$$

$$h = U + PV$$

all are intensive prop

h - specific enthalpy

u - specific internal energy

v - specific vol. = vol/mass

closed syst.



Q_{12}

PdV

const pressure

$$P_1 = P_2 = P$$

$$Q_{12} = U_2 - U_1 + \int P dV$$

$$= U_2 - U_1 + P(U_2 - V_1)$$

$$= U_2 + P_2 V_2 - (U_1 + P_1 V_1)$$

$$= H_2 - H_1$$

∴ Enthalpy is heat exchanged during const. pressure

* Specific heat (C)

$$C_V = \lim_{\Delta T \rightarrow 0} \frac{\partial Q}{\partial T}$$

$$Q = U + \int P dV$$

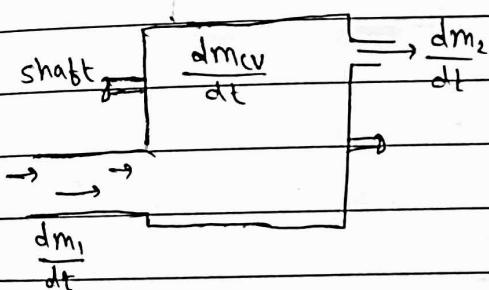
for closed syst., $dV = 0$

$$\therefore C_V = \frac{\partial U}{\partial T} \quad \text{--- vol. const.} \quad \therefore Q = U$$

$$\therefore \frac{\partial Q}{\partial T} = \frac{\partial U}{\partial T}$$

$$\text{Similarly, } C_P = \frac{\partial h}{\partial T} \quad \text{--- pressure const.}$$

* Open system



$$\text{conservn of mass: } \frac{dm_1}{dt} - \frac{dm_2}{dt} = \frac{dm_{CV}}{dt}$$

conservn of energy per mass

$$E = \frac{1}{2} mv^2 + mgz + PV + U$$

dividing all by mass,

$$e = \frac{v^2}{2} + gz + P_2 v + u = 0$$

$$= \frac{v^2}{2} + gz + h$$

When we provide $\frac{\delta Q}{\delta t}$ amount heat, suppose $\frac{\delta W}{\delta t}$ is performed

lets say input is $\frac{dm_1}{dt} e_1$, output is $\frac{dm_2}{dt} e_2$

energy per mass inside control vol. be e_{cv}

\therefore energy inside C.V. is $\frac{dm_{cv}}{dt} e_{cv}$

$$= \frac{dE_{cv}}{dt} \text{ --- say}$$

by conserv'n of energy,

$$\frac{dm_1}{dt} e_1 + \frac{\delta Q}{\delta t} - \frac{dm_2}{dt} e_2 - \frac{\delta W}{\delta t} = \frac{dE_{cv}}{dt} \quad \text{--- (2)}$$

for steady flow, $dE_{cv} = 0$

$$\therefore \text{RHS} = 0$$

$$\text{also, } \frac{dm_1}{dt} = \frac{dm_2}{dt} = \frac{dm}{dt}$$

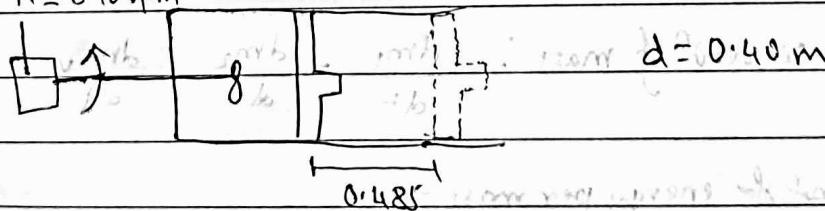
\therefore from (1) & (2), $\frac{dm}{dt} \left(h_1 + \frac{V_1^2}{2} + gz_1 \right) + \frac{\delta Q}{\delta t} - \frac{dm}{dt} \left(h_2 + \frac{V_2^2}{2} + gz_2 \right) - \frac{\delta W}{\delta t} = 0$ OR $\frac{dE_{cv}}{dt} = 0$

energy in :
$$h_1 + \frac{V_1^2}{2} + gz_1 + \frac{\delta Q}{\delta m} = h_2 + \frac{V_2^2}{2} + gz_2 + \frac{\delta W}{\delta m}$$

for generalization
flow

Assignment 01

11. $N = 840 \text{ rpm}$



$$W_{net} = W_{stirrer} + W_{piston}$$

$$W_{piston} = P_0 \Delta V$$

$$= 101.325 \times \frac{\pi d^2}{4} \times 0.485$$

$$P_0 = \text{atm pressure} \\ = 101.325 \text{ kPa}$$

$$= 6.175 \text{ kJ}$$

\therefore work is done by system. it'll be the

$$W_{net} = 2 \quad \therefore W_{stirrer} = 2 - 6.175 = -4.175 \text{ kJ}$$

$$\text{Power} = \frac{W_{stirrer}}{\text{Time}} = \frac{-4.175}{10 \times 60} = 6.95 \text{ kW}$$

$$\text{Power} = T \omega$$

$$T = \frac{P}{\omega} = \frac{6.95 \times 60}{2\pi N} = \frac{6.95 \times 60}{2\pi \times 840}$$

$$N = 840 \quad \therefore f = \frac{2\pi \times 840}{60}$$

$$T = 0.079 \text{ kJ}$$

13] Power
pressure = Force \times Velocity
= $P \times A \times V$ P - pressure
= $P \times Q$ Q is vol. flow rate

$$18 = P \times \frac{0.124}{60} \quad p = \frac{1080}{0.124} = 8709.6 \text{ kN/m}^2$$

14) ① ————— ②

$$Q_{1-2} = U_2 - U_1 + W_{1-2}$$

$$P_1 = 1000 \text{ kPa}$$

$$P_2 = 200 \text{ kPa}$$

$$V_1 = 0.2 \text{ m}^3$$

$$V_2 = 1.2 \text{ m}^3$$

$$P_1 = a+bV_1$$

$$P_2 = a+bV_2 \quad \left. \begin{array}{l} \text{calculate } a \& b \\ \end{array} \right.$$

from above value & find W_{12}

$$U = 1.5PV - 85 \quad Vm = 1.5$$

$$\therefore U = mu \quad V = mv$$

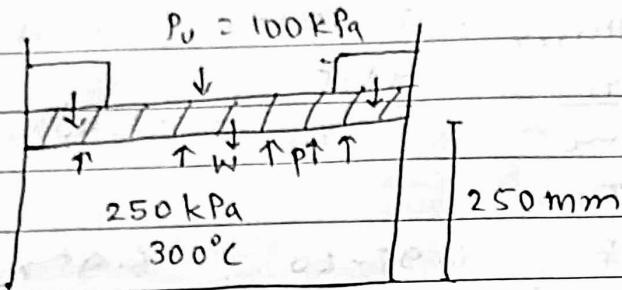
$$U = m(1.5V(a+bV) - 85)$$

$$U = 1.5V(a+bV) - 127.5$$

$\frac{dU}{dV} = 0$ will give some value of V

show $\frac{d^2U}{dV^2} < 0$ thereby U_{max} will hold for that V value

15)



\therefore Quasi-static it is isobaric process

a) balancing forces

$$P_A = W_{\text{piston}} + P_0 A + F_{\text{reactn}} \text{ forces due to stoppers}$$

$$F_{\text{reactn}} = 0 \text{ when it loses contact}$$

$$\therefore P \times \pi (0.1)^2 = 50 \times 9.81 + 101.325 \times 10^3 \times \pi (0.1)^2$$

$$\therefore P = 162.45 \text{ kPa}$$

when it just starts to move, $V_0 = \text{const!}$

~~for quasi-static process $\Delta V = 0$~~

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\frac{162.45}{300+273} = \frac{250}{T_1} \quad \therefore T_1 = 372.34 \text{ K}$$

b) for isobaric process,

$$V_1 = \frac{V_2}{T_2}$$

$$V_1 = \pi (0.1)^2 \times 2.50$$

$$V_2 = ?$$

$$T_1 = 372.34 \text{ K}$$

$$T_2 = 20 + 273 = 293 \text{ K}$$

V_2 will be calculated

$$V_1 = V_2 \quad \therefore V_2 = 1.17 \text{ m}^3$$

$$(2.3 - (V_0 + 0.2)V_2)^{1/3} = Y$$

$$(2.3 - (V_0 + 0.2)V_2)^{1/3} = V$$

$$V = 2.3 - (V_0 + 0.2)V_2^{1/3} \quad \therefore V_2 = 1.17 \text{ m}^3$$

$$V = 2.3 - (V_0 + 0.2)V_2^{1/3} \quad \therefore V_2 = 1.17 \text{ m}^3$$

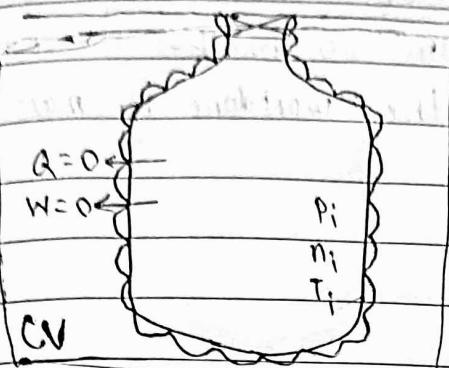
16)

valve

air 1 bar, 25°C

" if there is no output, the whole second term for output flow is 0

$$\frac{dQ}{dt} = \frac{dW}{dt} = 0$$



potential energy is significantly small than kinetic energy hence it can be ignored

∴ $\frac{dm}{dt} h_1 = \frac{dE_{cv}}{dt}$... This is unsteady flow ∵ mass is entering the bottle i.e. there are changes in properties with time

$$m_a h_a = m_f u_f - m_i u_i$$

$$m_a = m_f - m_i$$

$$(m_f - m_i) h_a = m_f u_f - m_i u_i \quad m_i = 0$$

$$\therefore h_a = u_f$$

$$\Delta H = nC_p T \quad U = nC_v T$$

$$h = C_p T$$

$$U = C_v T$$

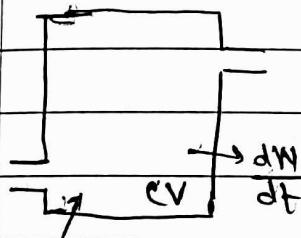
$$\therefore C_p T_a = C_v T_f$$

$$\frac{T_f}{T_a} = \frac{C_p T_a}{C_v T_f} = \frac{C_p}{C_v} \cdot \frac{T_a}{T_f}$$

$$T_f = \gamma T_a$$

$$-\frac{dW}{dt}$$

18)



$$\frac{dm_1}{dt} \left(h_1 + \frac{V_1^2}{2} + g z_1 \right) + \frac{dQ}{dt} = - \frac{dm_2}{dt} \left(h_2 + \frac{V_2^2}{2} + g z_2 \right) + \frac{dE_{cv}}{dt}$$

$$\frac{dm_1}{dt} = \frac{dm_2}{dt} = \dot{m}$$

$$\frac{dE_{cv}}{dt} = 0$$

∴ Steady flow

$$\therefore h_1 + \frac{V_1^2}{2} + g z_1 + \frac{dQ}{dt} = h_2 + \frac{V_2^2}{2} + g z_2 + \frac{dW}{dt}$$

∴ it is insulated; $dQ/dm = dW/dm = 0$

∴ horizontal ∴ $z_1 = z_2 = 0$

$$\therefore h_1 + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2}$$

$$10^3 \times 100 + \frac{100^2}{2} = h_2 + \frac{200^2}{2} \quad h_2 \approx ?$$

$$h_2 = 85000 \text{ J/kg}$$

$$\approx 85 \text{ kJ/kg}$$

* physical significance of enthalpies?

i. finding difference in enthalpies we can get velocity relation of flows fluids in venturi meter

ii. Change in enthalpy gives the workdone by mass by the turbine

(g)

mass flow rate = $\frac{dm}{dt}$

its unit is kg/s

Lagrangian and Euler

19) ~~$h_1 + \frac{V_1^2}{2} + gZ_1 + \frac{dQ}{dm} = h_2 + \frac{V_2^2}{2} + gZ_2 + \frac{dW}{dm}$~~

Ans

$\frac{dQ}{dm}$ is given to be 50 kJ/kg

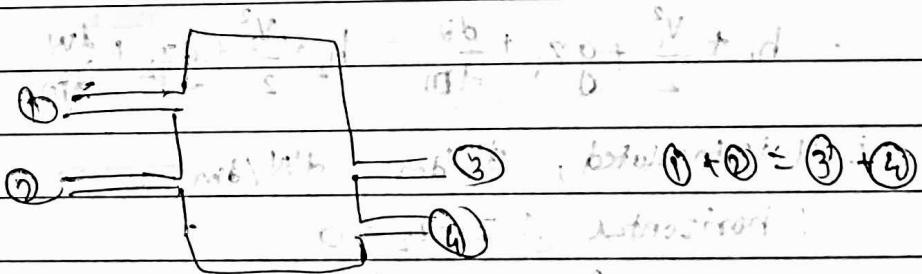
\therefore it is lost, it is -ve $\frac{dQ}{dm} = -50 \text{ kJ/kg}$

Velocity is significantly small

$$2993 - 50 = 226 + \frac{dW}{dm}$$

$$\frac{dW}{dm} = 2717 \text{ kJ/kg}$$

* When there are multiple inlets & outlets



$$\therefore m_1(h_1 + gZ_1 + \frac{V_1^2}{2}) + m_2(h_2 + gZ_2 + \frac{V_2^2}{2}) + \frac{dQ}{dt}$$

$$= m_3(h_3 + gZ_3 + \frac{V_3^2}{2}) + m_4(h_4 + gZ_4 + \frac{V_4^2}{2})$$

don't use per mass method here & use per time method

* Second law of thermodynamics

• Gives direct constraint of heat transfer & helps to decide nature of process (reversible or irreversible)

* Thermal reservoir /source

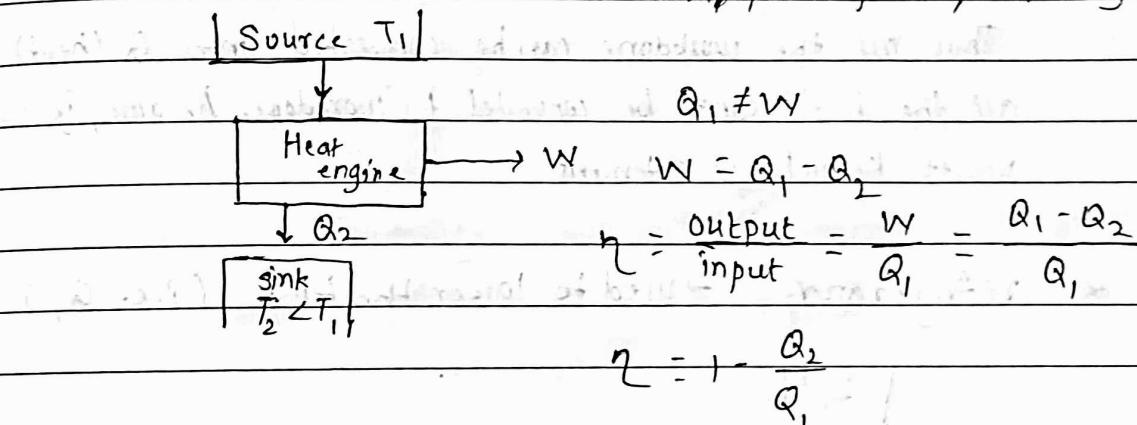
Body which has very high thermal capacity. The body provides heat to sink & hence called as source. The capacity is so high that there is no change in temp even after supplying heat

* Sink:

Sink is that which accepts heat from source /reservoir

* Heat engine:

It will extract heat from source & deliver work W
ex: Steam power plant, Rankine cycle



Imp The fictional machine which has efficiency of 100%. it is called as pmm of 2nd type

* Second law of Thermodynamics

Kelvin-Planck statement:

It is impossible for any device that operates on a cycle to exchange heat with single reservoir & produce net amount of work.

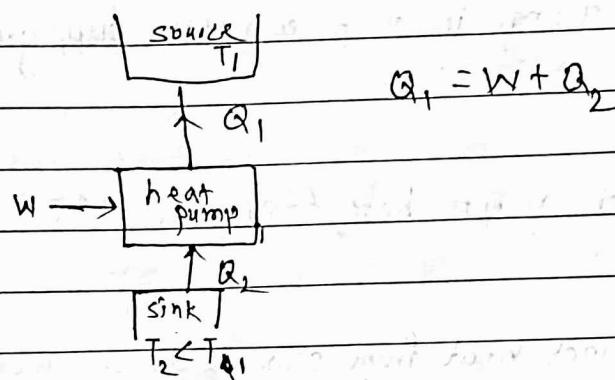
Work is high grade energy
heat is low grade energy

Date _____
Page _____

Clausius statement:

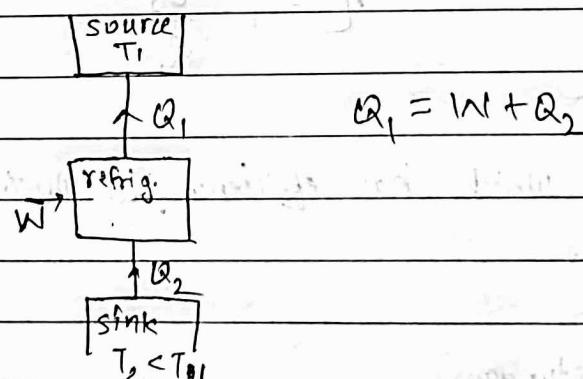
It is impossible to construct a device that operates in a cycle & produces no effect other than the transfer of heat from lower temp to higher temp body.

* Heat pump \rightarrow used to raise the temp (i.e. \Rightarrow source is desirable) (Q_1)



Thus all the workdone can be converted into Q (heat) but all the heat can't be converted to workdone. Because, if so, it'll violate Kelvin Planck statement

* refrigerator \rightarrow used to lower the temp (i.e. Q_2 is desirable)



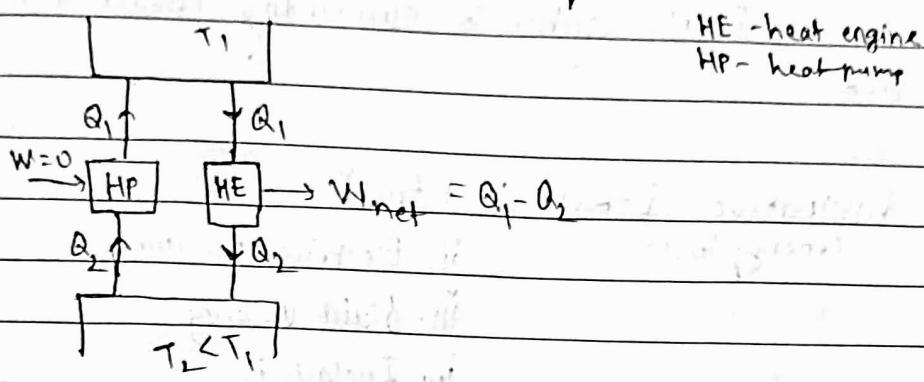
coefficient of pump $\Rightarrow \text{COP} = \frac{\text{desired effect}}{\text{Work input}}$

$$(\text{COP})_{HP} = \frac{Q_1}{W} = \frac{Q_1}{Q_1 - Q_2}$$

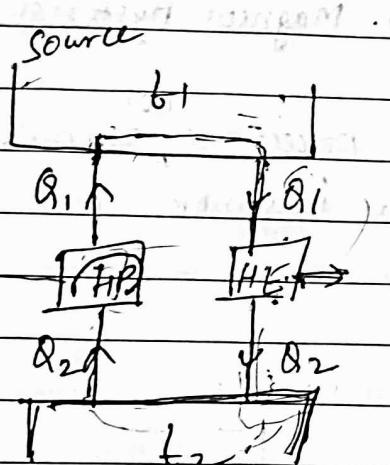
$$(\text{COP})_{RF} = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2}$$

$$\boxed{(\text{COP})_{HP} = 1 + (\text{COP})_{RF}}$$

Planck
Claussius & Kelvin statements are equivalent



HE - heat engine
 HP - heat pump

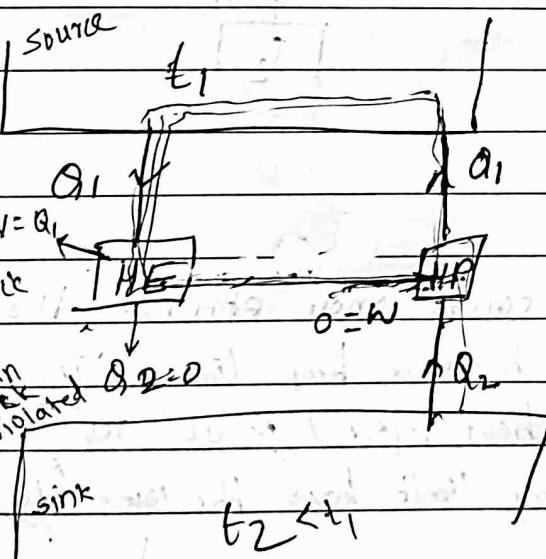


now when source is removed
 & the two are connected then

still there is heat flow & work even

$W_{net} = Q_1 - Q_2$ in presence of
 single reservoir
 that means Kelvin-
 Planck statement violated

Sink
 $t_2 < t_1$



here in heat pump, Q_2 is
 accepting & Q_1 is rejecting
 i.e. heat is flowing from
 lower Temp to higher
 temps without any work
 Supply that means $W \neq 0$

Thus Clausius statement

is violated

Thus both statements go hand in hand

* Reversible Process:

Both system & surrounding should reach the initial state

Dissipative Effect : i. friction
(energy loss)

ii. Electrical resistance

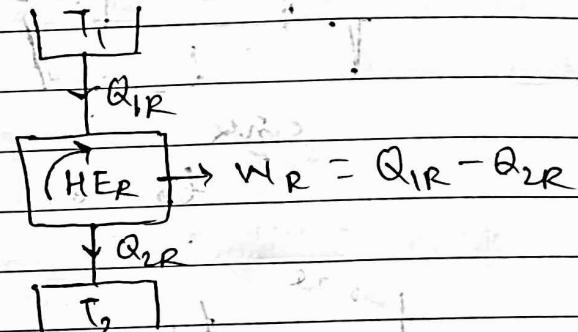
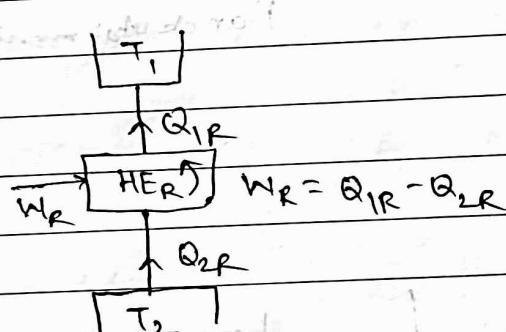
iii. fluid viscosity

iv. Inelasticity

v. Magnetic Hysteresis

If any of the above exist, process is ^{not} reversible i.e. irreversible.
In nature all processes are irreversible.

Reversible Heat engine



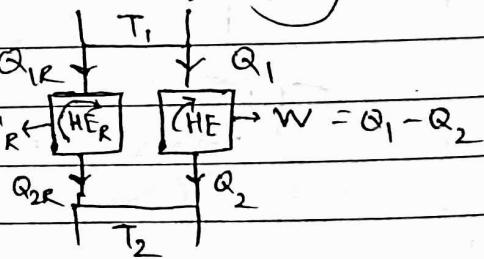
* Carnot Theorem

No heat engine can be more efficient than a rev. engine operating between the same temp limits. (Temp of heat addition & temp of heat rejection) & all rev. engines operating b/w the same temp limits have the same efficiency

$$\eta_R = \frac{W_R}{Q_{1R}}$$

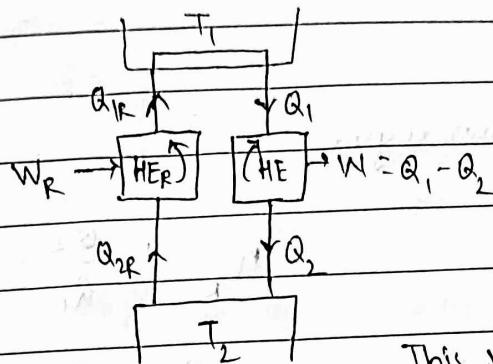
$$\eta_R > \eta$$

$$Q_{1R} - Q_{2R} = W_R$$



if we assume $\eta > \eta_R$

\therefore 1st engine is reversible, we'll reverse it



If we remove temp. source,
input Q_1 will be taken from

Q_{1R}

$$\text{then } W - W_R > 0$$

$$W > W_R$$

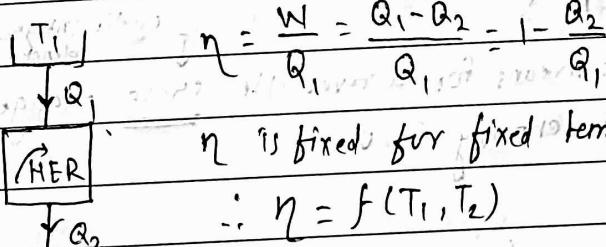
This violates Kelvin-Planck's statement

$\therefore \eta$ can't be greater than η_R

if we assume $\eta = \eta_R$

Then both will be reversible process & as we've assumed both
are different processes, $\eta \neq \eta_R$

* Absolute Thermodynamic Temperature Scale (only valid for rev. heat engine)



η is fixed for fixed temp range

$$\therefore \eta = f(T_1, T_2)$$

$$\therefore \frac{Q_1}{Q_2} = F(T_1, T_2)$$

T_1

$\downarrow Q_1$

$$Q_1 = F(T_1, T_2)$$

$$\frac{Q_1}{Q_3} = \frac{Q_1/Q_3}{Q_2/Q_3} = \frac{F(T_1, T_3)}{F(T_2, T_3)}$$

(HER)

$\downarrow Q_2$

$$Q_2 =$$

$$F(T_1, T_3) = \frac{F(T_1, T_3)}{F(T_2, T_3)}$$

T_2

$\downarrow Q_2$

$$Q_2 = F(T_2, T_3)$$

\therefore LHS is T_3 free, RHS must
be T_3 free

(HER)

$\downarrow Q_3$

$$Q_3 = F(T_1, T_3)$$

$$\therefore F(T_1, T_2) = \frac{F(T_1)}{F(T_2)}$$

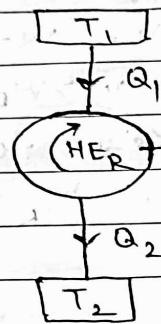
Kelvin
did some
experiments
to figure out
that

This is known as
absolute thermodynamic
temp scale

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

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

* Entropy for reversible heat engine,



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

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

$$\text{heat supplied} : \frac{Q_1}{T_1} + \left(-\frac{Q_2}{T_2} \right) = 0 \quad \text{heat ejected is -ve}$$

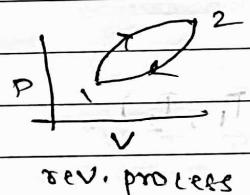
$$\sum_{\text{cycle}} \frac{\delta Q}{T} = 0$$

$$\therefore \oint \frac{\delta Q}{T} = 0$$

Cyclic integral is zero means it can be represented as a derivative of point fun"

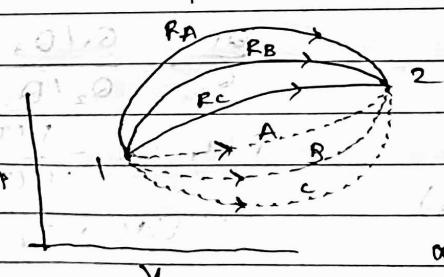
Clausius theorem $\oint \frac{\delta Q}{T} = 0$ cyclic integral is there to denote cycle

↳ This means for a reversible cycle change in entropy $\Rightarrow 0$.



for the cycle i.e. 1-2-1, $\oint \frac{\delta Q}{T} = 0$

$$\text{for path } 1-2, \oint \frac{\delta Q}{T} = \int_1^2 \frac{\delta Q}{T} = s_2 - s_1$$



R_A, R_B, R_C are rev. paths
 A, B, C are irrev. paths

$$\text{apparently, } \oint \frac{\delta Q}{T} = \int_{R_A} \frac{\delta Q}{T} = \int_{R_B} \frac{\delta Q}{T} = \int_{R_C} \frac{\delta Q}{T} = 0$$

$\therefore \frac{\delta Q}{T}$ i.e. s is a point/state fun", its value won't change for any reversible path followed.

* Clausius inequality

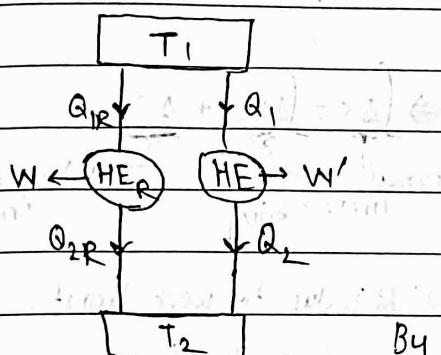
For any irreversible/natural process $\oint \frac{\delta Q}{T} < 0$, it is less than its counter path for a reversible process.

that means $\oint_A \frac{\delta Q}{T} < 0, \oint_B \frac{\delta Q}{T} < 0, \oint_C \frac{\delta Q}{T} < 0$
for a cycle.

for just a path (not a cycle) from 1-2, inequality will be like

$$\int \frac{\delta Q}{T} < \int \frac{\delta Q_R}{T} \quad \text{i.e. } \int \frac{\delta Q}{T} < \Delta S$$

↑ ↑
irrev path rev. path



Two heat engines, 1 rev & other irrev
are working betw fixed temp scale T_1 & T_2

$$\eta_R = 1 - \frac{Q_{2R}}{Q_{1R}} \quad \eta = 1 - \frac{Q_2}{Q_1}$$

By Carnot theorem, $\eta_R > \eta$

$$\frac{-Q_{2R}}{Q_{1R}} > \frac{-Q_2}{Q_1} \quad \therefore \frac{Q_{2R}}{Q_{1R}} < \frac{Q_2}{Q_1}$$

$$\therefore \frac{Q_{1R}}{Q_{2R}} > \frac{Q_1}{Q_2} \quad \text{we know, } \frac{Q_{1R}}{Q_{2R}} = \frac{T_1}{T_2}$$

$$\therefore \frac{T_1}{T_2} > \frac{Q_1}{Q_2} \quad \therefore \frac{Q_1}{T_1} + \left(-\frac{Q_2}{T_2} \right) < 0$$

$$\therefore \sum_{\text{cycle}} \frac{\delta Q}{T} < 0$$

$$\text{i.e. } \oint \frac{\delta Q}{T} < 0 \quad \text{but } \oint \frac{\delta Q_R}{T} = 0$$

$$\therefore \boxed{\oint \frac{\delta Q}{T} < \oint \frac{\delta Q_R}{T}}$$

... Clausius inequality for a cycle

$$\left. \begin{aligned} \int \frac{\delta Q}{T} &< \int \frac{\delta Q_R}{T} \\ \left[\int \frac{\delta Q}{T} < \Delta S \right] \end{aligned} \right\} \text{--- for a path}$$

ΔS is extensive prop.

That means we can write

$$\Delta S \geq \int \frac{\delta Q}{T}$$

for any process

for rev. adiabatic process,

$$\because \text{rev.} \therefore \Delta S = \int \frac{\delta Q}{T}$$

$$\oint \frac{\delta Q}{T} \leq 0$$

$$\because \text{adiabatic} \therefore \delta Q = 0 \quad \therefore \Delta S = 0$$

$$\therefore S = \text{constant}$$

$$\oint dS = 0$$

i.e. isentropic process

$$\oint \frac{\delta Q}{T} \leq \int \frac{\delta Q}{T}$$

$$\Delta S \geq \int \frac{\delta Q}{T}$$

$$\therefore \Delta S = \int \frac{\delta Q}{T} + X$$

$$\Rightarrow \Delta S = \underbrace{\int \delta S_e}_{\text{external irreversibility}} + \underbrace{\Delta S_i}_{\text{internal irreversibility}}$$

$$\Delta S \geq \int \frac{\delta Q}{T}$$

$$\Delta S \geq \int \frac{\delta Q}{T} + \Delta S_i$$

internal irreversibility (ΔS_i): It is due to work transfer

Ex. Raising the Temp of water due to stirrer



On stirring temp increases It is internal irrev.

because no external heat is applied

friction, viscosity, magnetic resistance

$$\oint \frac{\delta Q}{T} + \Delta S_i = \Delta S$$

$$\oint \frac{\delta Q}{T} \leq 0$$

rev. process (possible)

$$\oint \frac{\delta Q}{T} \geq 0$$

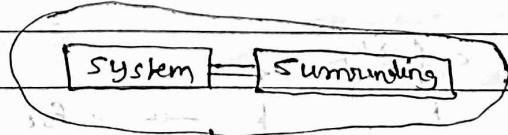
irrev process (possible)

$$\oint \frac{\delta Q}{T} \geq 0$$

never possible

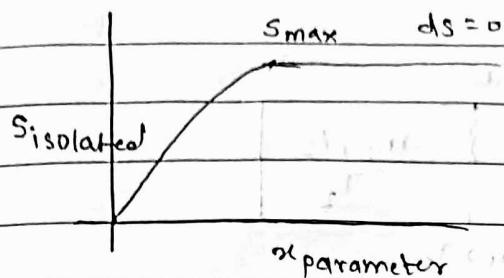
* Principle of increase in entropy

for an isolated system, $\Delta S > 0$



Universe

$$\Delta S_u = \Delta S_{\text{syst}} + \Delta S_{\text{surr}} > 0$$



Statement:

entropy of an isolated system always increases & becomes maximum at a state of equilibrium.

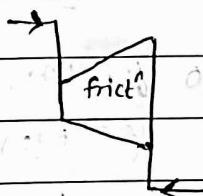
Rev. adiabatic process

$$\Delta S = \Delta S_e + \Delta S_i = \int \frac{dQ}{T} + \Delta S_i$$

\because no internal irrev. $\therefore \Delta S_i = 0$

\because adiabatic, $dQ = 0$

$\therefore \Delta S = 0 \quad \therefore S = \text{const} \Rightarrow$ isentropic



if the turbine is not isolated, there might be heat loss due to friction. Thus due to the process being irreversible,

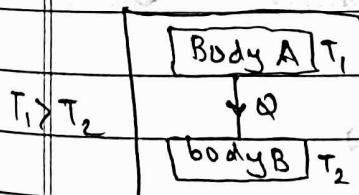
ΔS_i increases & thereby ΔS_e decreases here

i.e. $\Delta S_i > 0$ & $\Delta S_e < 0$. At some moment of time, $\Delta S_i + \Delta S_e = 0$, for that matter, the process

is isentropic $\Delta S = 0 \Rightarrow S = c$

Thus rev adiabatic process is isentropic for sure

But an isentropic process may not ensure the rev. nature of process, it might be irrev also



$$\Delta S = \Delta S_A + \Delta S_B$$

$$= -\frac{Q}{T_1} + \frac{Q}{T_2} = Q \left(\frac{T_1 - T_2}{T_1 T_2} \right)$$

rev

* fluid mixing

irrev



$$T_1 > T_2$$

To calculate entropy change when fluids are mixed, we've to find final temp both of them achieve

$$m_1 c_1 (T_1 - T_f) = m_2 c_2 (T_f - T_2) \dots \text{since adiabatic, } Q_1 = Q_2$$

$$T_f = \frac{m_1 c_1 T_1 + m_2 c_2 T_2}{m_1 c_1 + m_2 c_2}$$

$$\Delta S = \int_{T_1}^{T_f} m_1 c_1 dT + \int_{T_2}^{T_f} m_2 c_2 dT \quad T_1 > T_f > T_2$$

$$\Delta S = m_1 c_1 \ln \frac{T_f}{T_1} + m_2 c_2 \ln \frac{T_f}{T_2}$$

$$\text{If } m_1 = m_2 = m \quad c_1 = c_2 = c, \quad T_f = \frac{T_1 + T_2}{2}$$

$$\Delta S = mc \ln \frac{T_f^2}{T_1 T_2}$$

$\Delta S > 0$ for irrev since

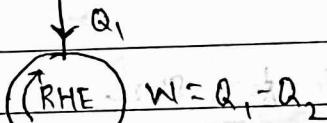
$$\left(\frac{T_1 + T_2}{2}\right)^2 > T_1 T_2$$

$$Am \geq Gm$$

$$m, c, T_1$$

$$\Delta S = \Delta S_A + \Delta S_{HE} + \Delta S_B$$

heat engine is reversible



$$W = Q_1 - Q_2$$

working in cycle, $\Delta S_{HE} = 0$

∴ the whole syst. is irrev, $\Delta S \geq 0$

we want to maximize the workdone

i.e. to decrease the measure of disorder

$$m, c, T_2$$

$$\therefore \Delta S = 0$$

$$\Delta S = mc \ln \frac{T_f^2}{T_1 T_2} = 0$$

$$\therefore T_f = \sqrt{T_1 T_2}$$

$$W = Q_1 - Q_2 = mc_c (T_1 - T_f) - mc_b (T_f - T_2)$$

$$= mc_c (T_1 + T_2 - 2\sqrt{T_1 T_2})$$

$$\delta Q = \delta E + \delta W \rightarrow \text{any process} \quad \text{--- (1)}$$

$$\delta Q = dU + SW \rightarrow \text{closed syst., any process} \quad \text{--- (2)}$$

$$\delta Q = dU + PdV \rightarrow \text{---, reversible} \quad \text{--- (3)}$$

$$\delta Q = TdS \rightarrow \text{reversible, closed syst.} \quad \text{--- (4)}$$

$$TdS = dU + PdV \rightarrow \text{any process} \quad \text{--- (5)}$$

(because all the terms in the eqn are point funⁿ)

$$H = U + PV$$

$$dH = dU + PdV + Vdp$$

$$dH = TdS + Vdp \rightarrow \text{any process (because this also contains the point funⁿ / state variables)} \quad \text{--- (6)}$$

Eqⁿ (5) & (6) are called as property relⁿ

Steady flow energy eqⁿ:

$$h_1 + \frac{V_1^2}{2} + gz_1 + q = h_2 + \frac{V_2^2}{2} + gz_2 + w$$

multiplying whole by mass & differentiating,

$$\delta Q = \delta W + \delta H + \underbrace{mVdV + qdz}_\text{neglecting them}$$

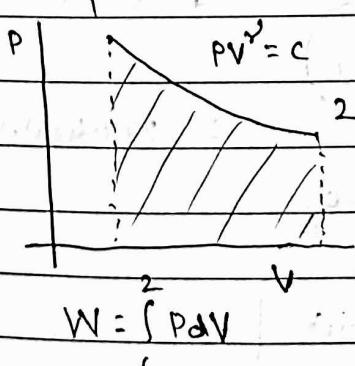
$$\delta Q = \delta W + \delta H$$

$$\text{also, } dH = Tds + Vdp \therefore \delta W = \delta Q - \delta H$$

for rev. adiabatic $\delta Q = 0$

$$\delta W = -\delta H \quad dH = Vdp$$

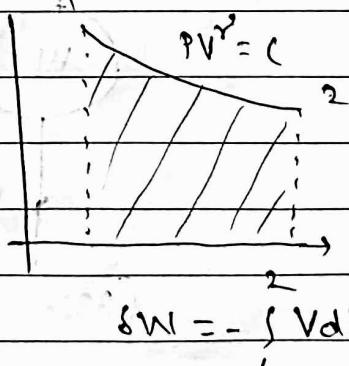
$$\delta W = -Vdp$$



closed syst

rev.

adiabatic



open syst

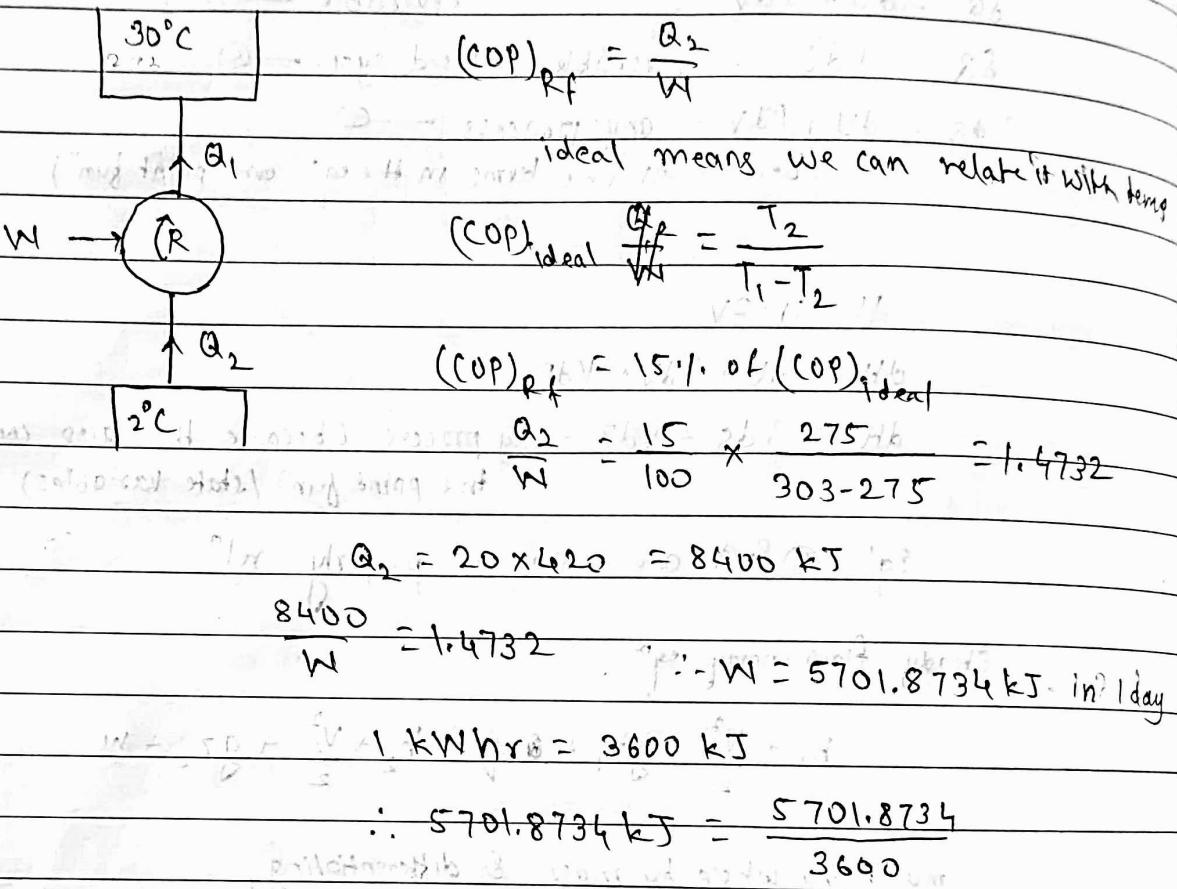
rev.

adiabatic

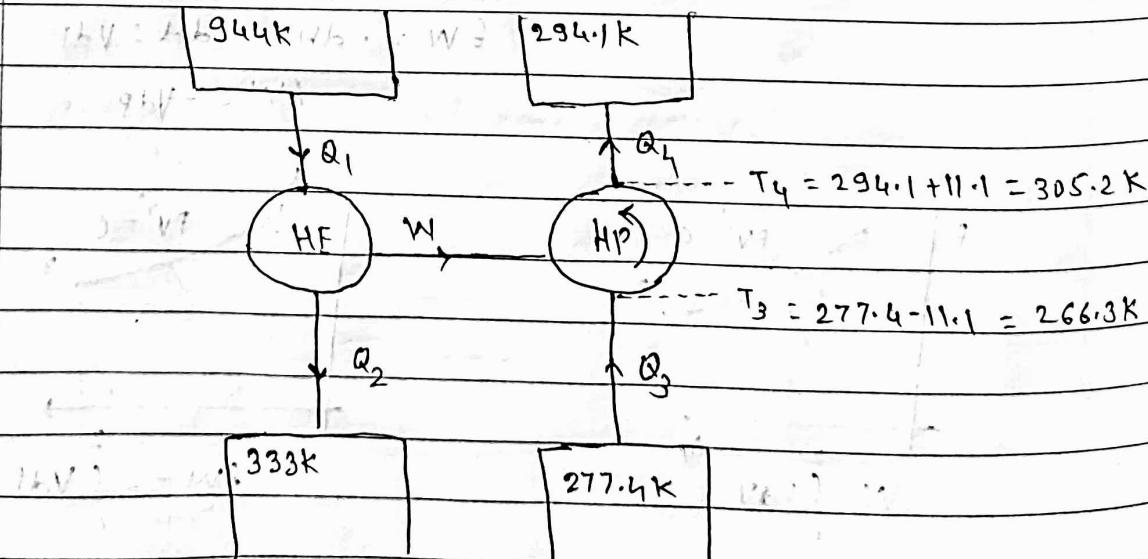
Assignment

3. It tells about irreversibility of system

17.



18.



$$\frac{Q_1}{Q_4} = ?$$

$$n_{HE} = \frac{W}{Q_1} = \frac{50}{100} \left(1 - \frac{333}{944} \right) \Rightarrow W = 0.3236 Q_1$$

$$(COP)_{HP} = \frac{Q_4}{W} = \frac{1}{2} \left(\frac{T_4}{T_4 - T_3} \right) = 3.9228$$

$$Q_4 = 3.9228 W$$

$$\text{now, } \frac{Q_1}{Q_4} = 0.7879$$

$$Q_1 = \frac{Q}{T} = \frac{333 \times 1}{273} = 1.2271 \text{ kJ/K}$$

$$b) AS_{ice} = \int_{T_1}^{T_2} \frac{mc dT}{T} = \int_{273}^{273} \frac{mc dT}{T} = 0$$

$$22. AS_u = AS_{syst} + AS_{atm}$$

c for water = 4.187 kJ/kg K

$$Q = mc\Delta T + mL + mc\Delta T$$

$$= \frac{1}{c \text{ for ice}} = 2.093 \text{ kJ/kg K}$$

$$= 2.093 \times 5 + 333.3 + 4.187 \times 20 = 264.73 \text{ kJ}$$

$$AS_{syst} = \int_{268}^{273} \frac{mc_{ice} dT}{T} + \frac{mL}{273} + \int_{273}^{293} \frac{mc_{water} dT}{T} \approx 1.5555$$

$$AS_{atm} = \frac{-Q}{T} = \frac{-Q}{293} \quad \dots \text{temp of atm. is 293}$$

$$= -2.448 \text{ kJ/K}$$

$$= -1.659 \text{ (ejected)}$$

$$\Delta S = 2.80038 \text{ kJ/kg}$$

~~429.8605~~

$$20. Q_1 = 420 \text{ kJ}$$

$$T_1 = 327^\circ C = 600 \text{ K}$$

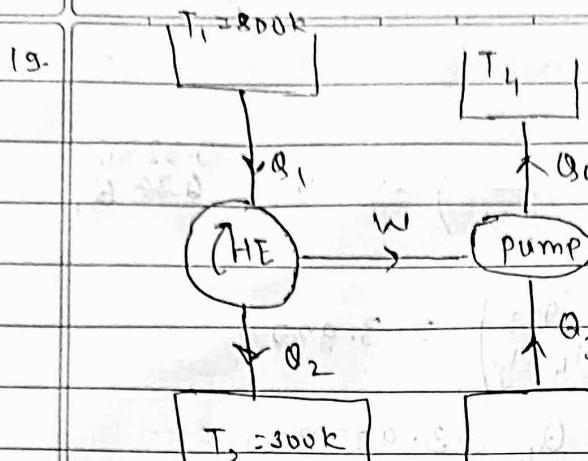
$$a) \Delta S = \frac{420}{600} - \frac{210}{300} = 0 \rightarrow \text{Reversible}$$

HER
↓

$$b) \Delta S = \frac{420 - 105}{600 - 300} > 0 \rightarrow \text{Not possible}$$

$$T_2 = 27^\circ C = 300 \text{ K}$$

$$c) \Delta S = \frac{420 - 315}{600 - 300} < 0 \rightarrow \text{irreversible}$$



It's given that $Q_3 = 2W$

$$\eta_{HE} = \frac{30}{100} \left(1 - \frac{300}{800}\right) = \frac{Q_1}{W} = 0.1875$$

$$COP = \frac{40}{100} \left(\frac{T_4}{T_4 - T_3}\right) = \frac{Q_4}{W} = 3 \quad \text{①}$$

$$T_3 = 300K$$

$$Q_4 - W + Q_3 = W + 2W = 3W$$

$$Q_4/W = 3$$

$$\text{from ①, } \frac{2}{5} \left(\frac{T_4}{T_4 - 300}\right) = 3 \Rightarrow T_4 = 346.15384K$$

$$Q_1/t = 40kW \quad Q_4/t = ?$$

$$\frac{Q_1/t}{Q_4/t} = \frac{0.1875}{40} = \frac{0.1875}{3}$$

$$\frac{Q_1/t}{Q_4/t} = \frac{3}{40} \Rightarrow Q_4/t = \frac{40}{3}$$

$$\therefore Q_4/t = 640kW$$

* Availability

from 1st law of thermodynamics,

→ point funⁿ (internal energy)

→ path funⁿ (heat, work)

from 2nd law of thermodynamics, (entropy)

→ directional constraints on mutual convertibility b/w heat & work in a continuous cyclic process

$$Q \xrightarrow{\text{(cycle)}} W \quad (W < Q) \quad \begin{matrix} \text{heat can't be converted into work} \\ \therefore \text{heat - low grade} \end{matrix}$$

$$W \xrightarrow{\text{(cycle)}} Q \quad (W = Q) \quad \begin{matrix} \text{Work can be converted fully into heat} \\ \therefore \text{Work - high grade} \end{matrix}$$

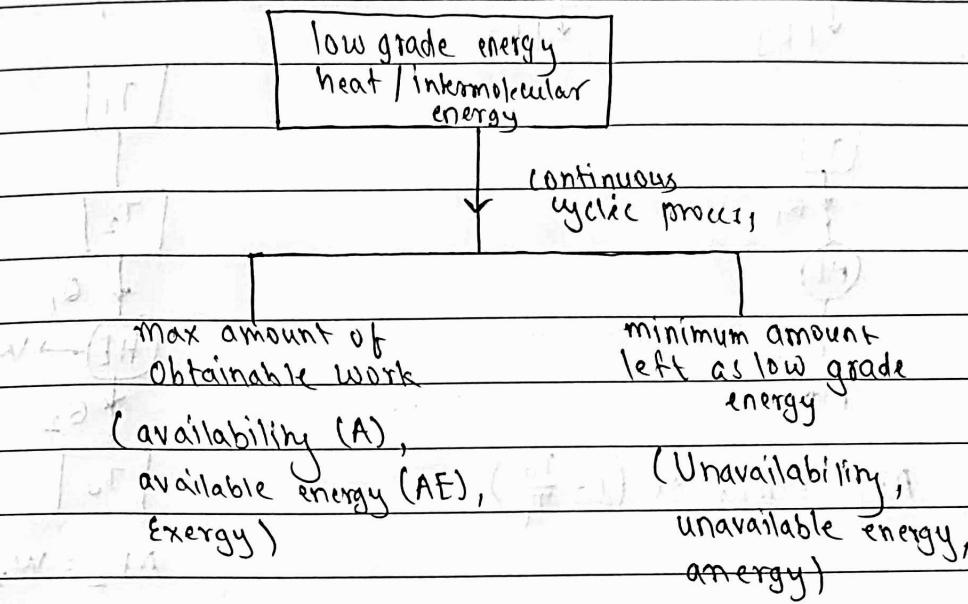
high grade energy

- Mechanical work
- Electric work
- Wind power

low grade energy

- heat
- intermolecular energy

high grade energy can't be converted into low grade energy but reverse is not possible.



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

$\text{HE} \rightarrow W = Q_1 - Q_2$ for η_{\max} , W should be W_{\max}

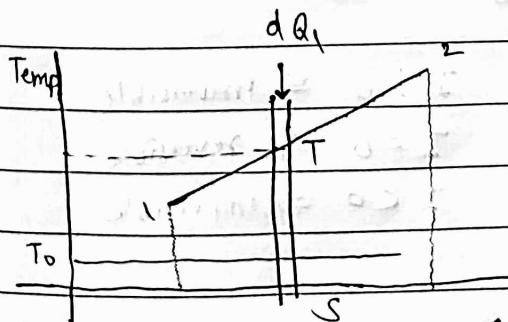
$$W_{\max} = Q_1 \left(1 - \frac{T_2}{T_1}\right)$$

T_2 should be as minimum as possible $\Rightarrow T_2$ should be room temp $\therefore T_2 = T_0$

$$\therefore W_{\max} = Q_1 \left(1 - \frac{T_0}{T_1}\right)$$

↓
A.E.

$$U.E. = Q_2 = Q_1 - W_{\max} = Q_1 \left(\frac{T_0}{T_1}\right)$$



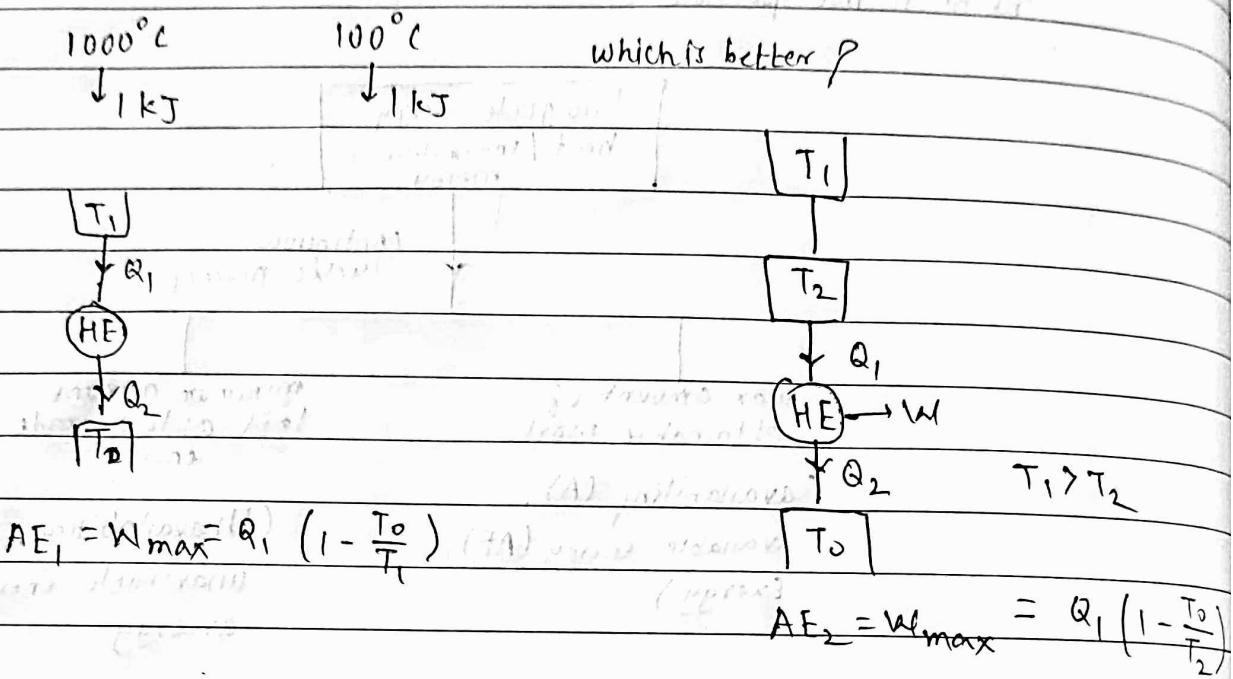
$$dW_{\max} = dQ_1 \left(1 - \frac{T_0}{T_1}\right)$$

$$\int_1^2 dW_{\max} = \int_1^2 dQ_1 - T_0 \int_1^2 \frac{dQ_1}{T}$$

$$AE = W_{\max, T_2} = Q_{1-2} - T_0 (S_2 - S_1)$$

$$UE = T_0 (S_2 - S_1)$$

law of degradation energy



$$AE_1 = W_{\max} - Q_1 \left(1 - \frac{T_0}{T_1}\right)$$

$$AE_2 = W_{\max} = Q_1 \left(1 - \frac{T_0}{T_2}\right)$$

that means greater temp. reservoir of same \Rightarrow heat extract will be easy / beneficial than compared to extracting same heat from lesser temps. reservoir

* Irreversibility (I)

$$I = W_{\max} - W$$

$$= T_0 \Delta S_{\text{universe}}$$

$$= T_0 (\Delta S_{\text{cyst}} + \Delta S_{\text{surv}})$$

$$\Delta S_{\text{uni}} > 0$$

$$\therefore I > 0$$

$I > 0 \Rightarrow$ irreversible

$I = 0 \Rightarrow$ reversible

$I < 0 \Rightarrow$ impossible

* Goodey - Stodola theorem

It states that the rate of laws of available energy or exergy in a process is proportional to the rate of entropy generation.

$$\Delta S_{\text{uni}} \geq 0$$

$$\therefore \Delta S_{\text{syst}} + \Delta S_{\text{univ}} \geq 0$$

$$\therefore S_2 - S_1 + S_{02} - S_{01} \geq 0$$

$$(S_2 + S_{02}) - (S_1 + S_{01}) \geq 0$$

$$I = T_0 \Delta S_{\text{generation}}$$

entropy final state entropy initial state

that means final state has always higher energy than initial i.e. entropy is always generated from state 1 to 2

$\therefore \Delta S_{\text{univ}}$ is sometimes referred to as $\Delta S_{\text{generation}}$

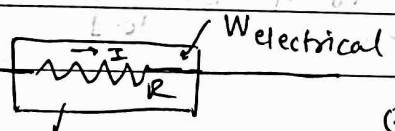
20 marks

1 - 1st law

2 - 2nd law

$$23) I = 10 \text{ A} \quad t = 1 \text{ sec} \quad R = 250 \Omega \quad T = 300 \text{ K}$$

$$\Delta S_R = \frac{Q}{T} = \frac{I^2 R t}{T} = \frac{(10)^2 \times 250 \times 1}{300} \text{ J/K}$$



$$Q = \Delta U + W$$

$$\Delta U = c \Delta T$$

$$\Delta T = 0 \dots T = \text{const}$$

$$\Delta U = 0$$

$$\Delta S_{\text{syst}} = \frac{\int mc dT}{T} = 0$$

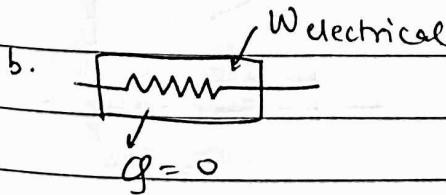
T is const.

$$Q = W_{\text{electrical}} = -I^2 R t = -100 \times 25 \times 1$$

... heat rejected is 0

$$\Delta S_{\text{syst}} = \Delta S_{\text{Resistor}} = \frac{-2500}{300} = 8.33 \text{ J/K}$$

$$\Delta S_{\text{uni}} = \Delta S_{\text{syst}} + \Delta S_{\text{univ}} = 8.33 \text{ J/K}$$



$$Q = \Delta U + W_{\text{electrical}}$$

$$\Delta U = -W_{\text{electrical}}$$

$$\Delta U = 2500 \text{ J}$$

$$\Delta U = mc \Delta T$$

$$T_f = 597.62 \text{ K}$$

$$2500 = 0.01 \times 840 (T_f - 300)$$

- adiabatic, $\Delta S_{\text{sum}} = 0$

$$\Delta S_{\text{syst}} = \int_{300}^{\text{597.62}} \frac{mc dT}{T} = mc \ln \frac{597.62}{300}$$

$$= 5.85 \text{ J/K}$$

$$\Delta S_{\text{uni}} = \Delta S_{\text{syst}} + \Delta S_{\text{sum}} = 5.85 \text{ J/K}$$

24. $\Delta S_{\text{uni}} = \Delta S_{\text{syst}} + \Delta S_{\text{sum}} \geq 0$

$$= \int_{T_1}^{T_0} \frac{cdT}{T} + \frac{Q-W}{T_0} \geq 0 \quad Q = C(T_0 - T_1)$$

$$= C \ln \frac{T_0}{T_1} + \frac{Q-W}{T_0} \geq 0$$

$$\therefore T_0 C \ln \frac{T_0}{T_1} + Q \geq W$$

$$W \leq C \left[(T_0 - T_1) + T_0 \ln \frac{T_1}{T_0} \right]$$

$$W \leq C \left[T_0 - T_1 - T_0 \ln \frac{T_1}{T_0} \right]$$

$$W = U_A - T_0 A = U_A$$

$$C = U_A$$

$$W = C - T_0 A = U_A - T_0 A$$

$$W = U_A - T_0 A = U_A - T_0 A$$

$$W = U_A - T_0 A$$