Prof. D. B. Patel

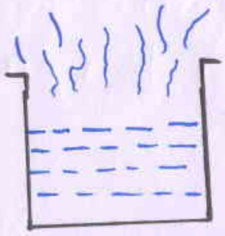
SECOND LAW OF THERMODYNAMICS:-

1) Limitation of the first law of thermodynamics

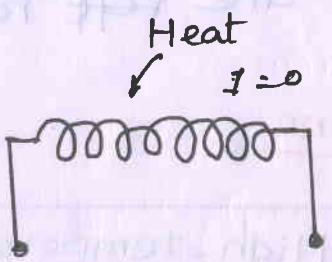
→ According to first law in cyclic process

1) Work is completely converted in to heat or heat is completely converted to work
2) Potential energy can be transfered in to K.E. or K.E. can be transfered in to P.E.
3) Heat flows from hot to cold or cold to hot
4) Gas expands from ~~hot to~~ high pressure to Low pressure or from low pressure to high pressure.

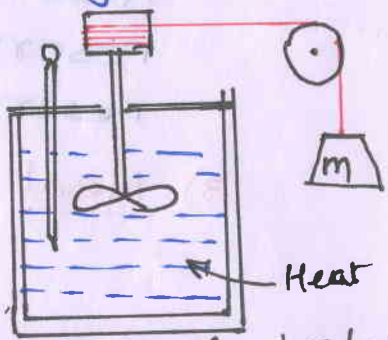
But from experience, we know that is not true. In natural way heat is not completely converted into work



→ A cup of hot coffee does not get hotter in room temp.



→ Transferring heat to wire will not generate electricity



→ Transferring heat to paddle wheel will not cause it to rotate

→ Limitation of first law of thermodynamics

1) First law does not help to predict whether the certain process is possible or not
2) A spontaneous process can proceed in a particular direction only but first law does not gives information about direction
3) First law not provides sufficient condition for a certain process to take place
4) First law established equivalence betn the amount of heat used and mechanical work but does not specify the condition under which conversion of heat in work is possible.

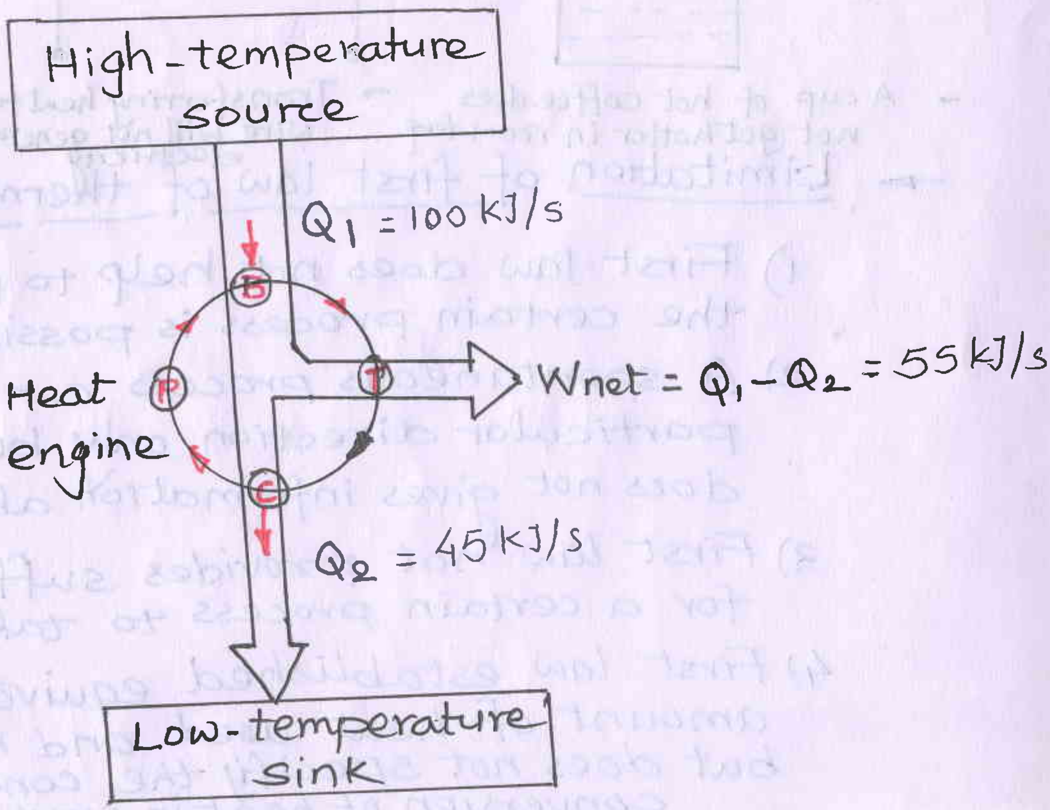
- The second law of thermodynamics light on Limitation of 1st law and may be defined as "Heat can not flow itself from colder body to a hotter body"

2) Thermal Energy Reservoirs (TER)

A thermal energy reservoir is defined as sufficiently large system in stable equilibrium that can supply or absorb finite amounts of heat without undergoing any change in temperature. such a body is called a thermal energy reservoir.

A reservoir that supplies energy in form of heat is called a source, and one that absorbs energy in the form of heat is called a sink. Thermal energy reservoirs are ~~refe~~ referred to as heat reservoirs

3) Heat Engine



Heat engines can be characterized by

1) They receive heat from a high temperature source (solar energy, oil furnace, nuclear reactor etc.)
2) They convert part of this heat to work (Usually in the form of a rotating shaft)
3) They reject the remaining waste heat to Low-temperature sink (the atmosphere, rivers)
4) They operate on a cycle.

$$\text{Thermal efficiency} = \frac{\text{New work output}}{\text{Total heat input}}$$

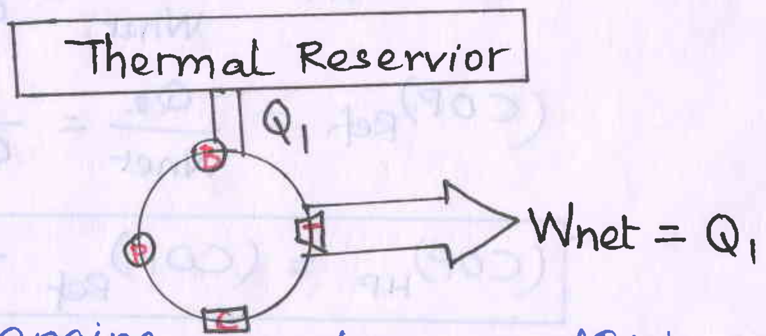
$$\eta_{th} = \frac{W_{net}}{Q_1}$$

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

The second Law of Thermodynamics

Kelvin - Plank statement

→ "It is impossible for any device that operates on a cycle to receive heat from a single reservior and produce a net amount of work"



No heat engine can have an efficiency of 100%.

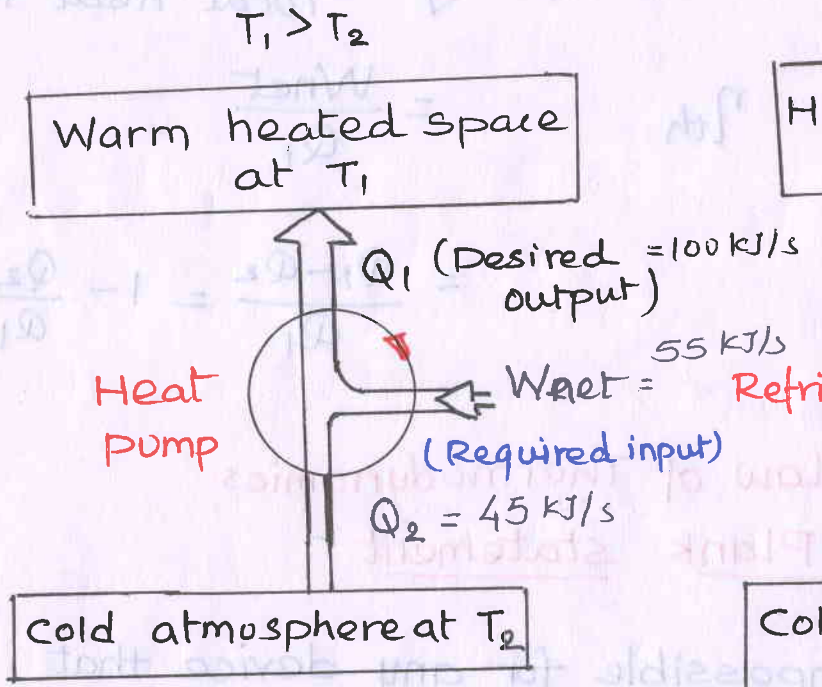
4) Heat pumps & refrigerators

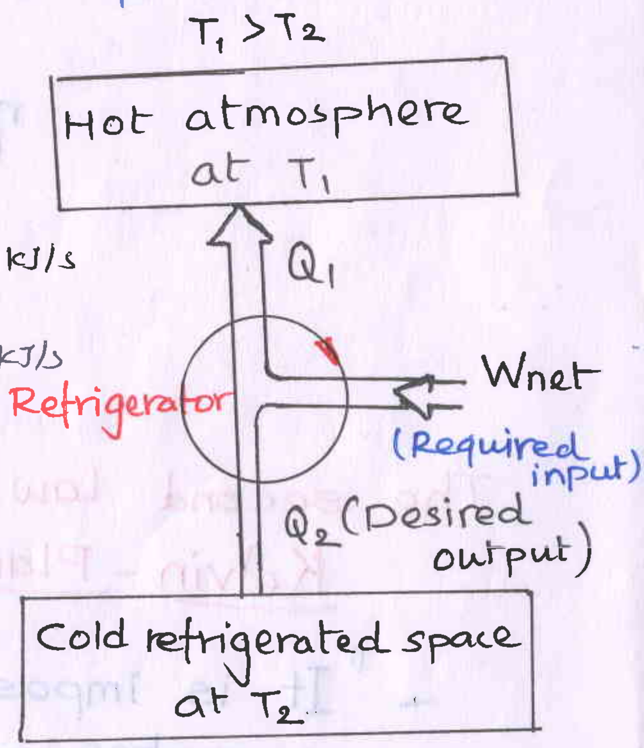
Heat pump & refrigerator are thermodynamic system operating in a cycle which absorb heat from a low temperature body and reject it to high temperature body

Objective of H.P. & refri.

Heat pump (H.P) → Maintain a heated space at high temp.

Refrigerator → Maintain a cooled space at low temp.





Co-efficient of performance (COP) $= \dfrac{\text{desired output}}{\text{required input}}$

$$(COP)_{H.P} = \frac{Q_1}{W_{net}} = \frac{Q_1}{Q_1 - Q_2}$$

$$(COP)_{Ref.} = \frac{Q_2}{W_{net}} = \frac{Q_2}{Q_1 - Q_2}$$

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

The Second Law of Thermodynamics:-

Clausius statement

" It is impossible to construct a device that operate in a cycle and produces no effect other than the transfer of heat from a lower temperature body to a higher-temperature body "

OR

" Heat can not itself flow from a colder body to a hotter body"

Conclusion:

Heat can not be converted to equal amount of work (kelvin plank) Heat engine)

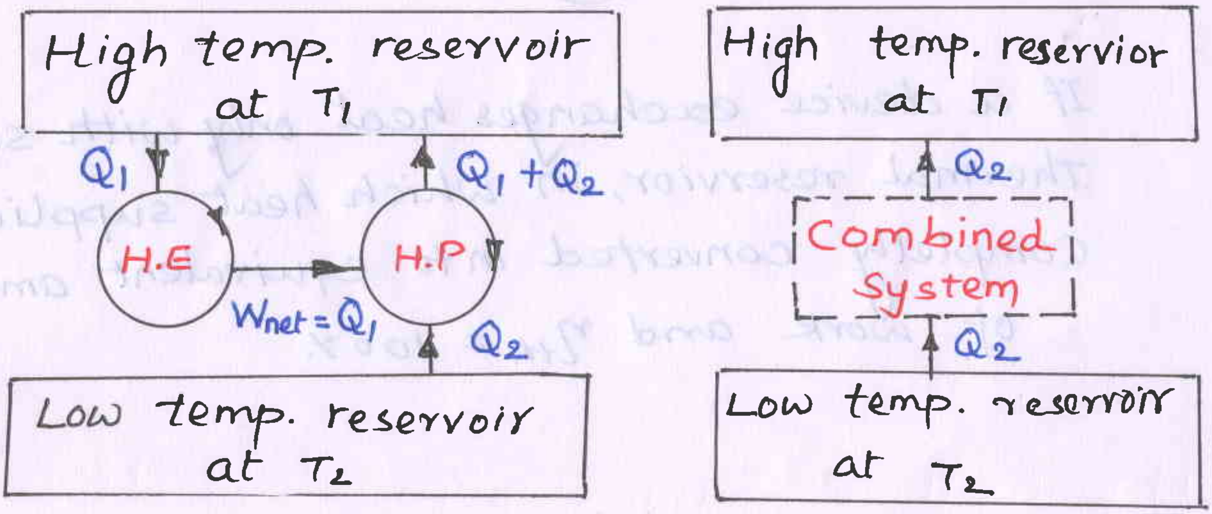
Work can be converted to equal amount of heat (clausius) Heat pump

→ Q heat is Low-grade energy

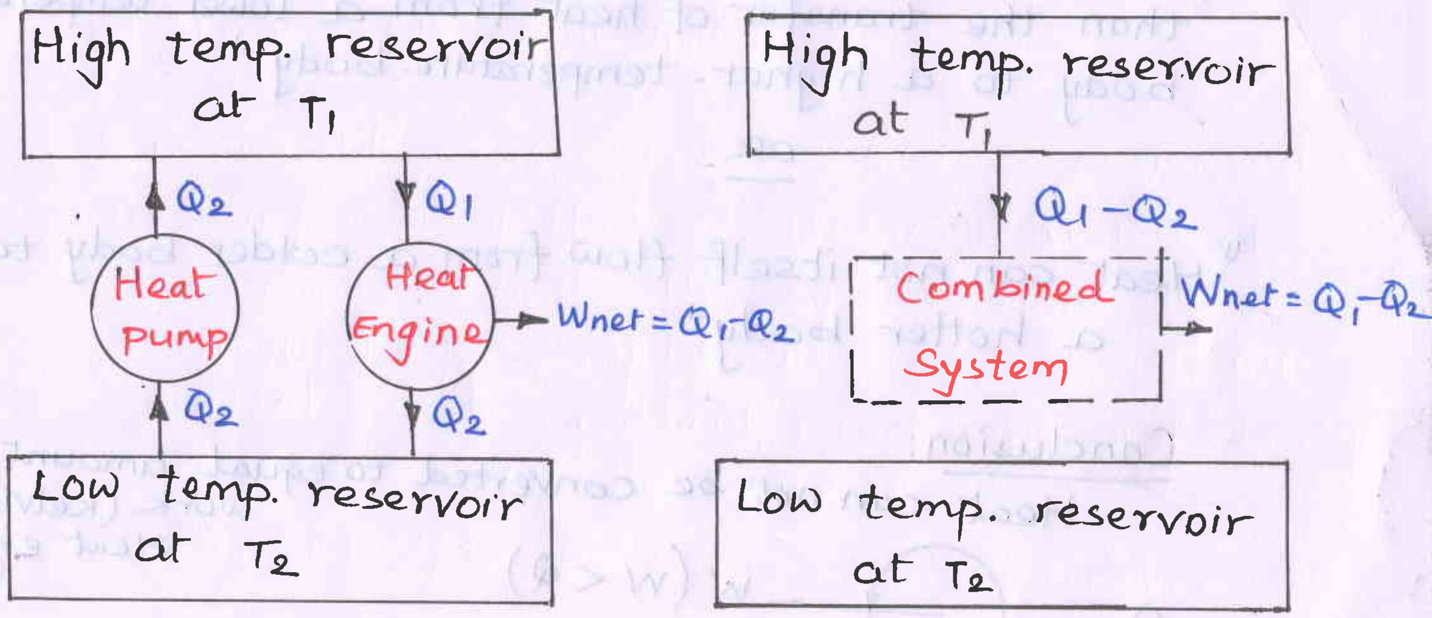
→ W work is high grade energy

5) Equivalence of the Kelvin plank & Clausius statement

i) Violation of kelvin-Plank statement leading to violation of clausius statement

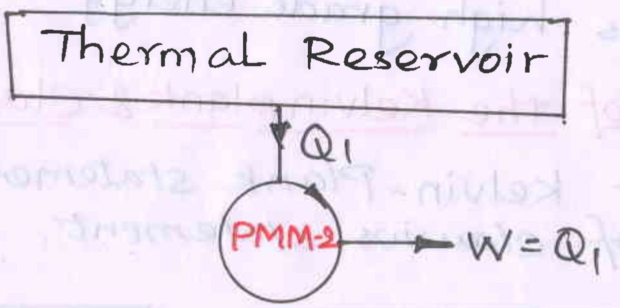


ii) Violation of Clausius statement leading to violation of Kelvin - Plank statement



6) Perpetual - Motion Machine of second kind (PMM-2)

A device that violates the second law of thermodynamics is called a PMM-2



If a device exchanges heat only with single thermal reservior, in which heat supplied is completly converted into equivalent amount of work and $\eta_{th} = 100\%$.

7) Causes of Irreversibility

There are two reason for irreversibility

i) Lack of thermodynamic equilibrium during the process

Thermodynamic equilibrium

Mechanical equilibrium	Thermal equilibrium	Chemical equilibrium
dp	dT	dC - Concentration $d\mu_c$ - Chemical potential
→ Lack of pressure equilibrium	→ Lack of temp. equilibrium	

ii) Dissipative effects

- → Mechanical friction
- → fluid viscosity
- → Magnetic hysteresis
- → Inelasticity
- → electrical resistance

* For perfectly reversible process

i)

Process	Perfectly reversible	Reversible in the limit
a) Mechanical work transfer	$\Delta P = 0$	$\Delta P \to 0$
b) Heat transfer	$\Delta T = 0$	$\Delta T \to 0$
c) Mass transfer	$\Delta c = 0$	$\Delta c \to 0$
d) chemical reaction	$\Delta \mu_c = 0$	$\Delta \mu_c \to 0$

ii) No dissipative effect

Reversibility & Irreversibility

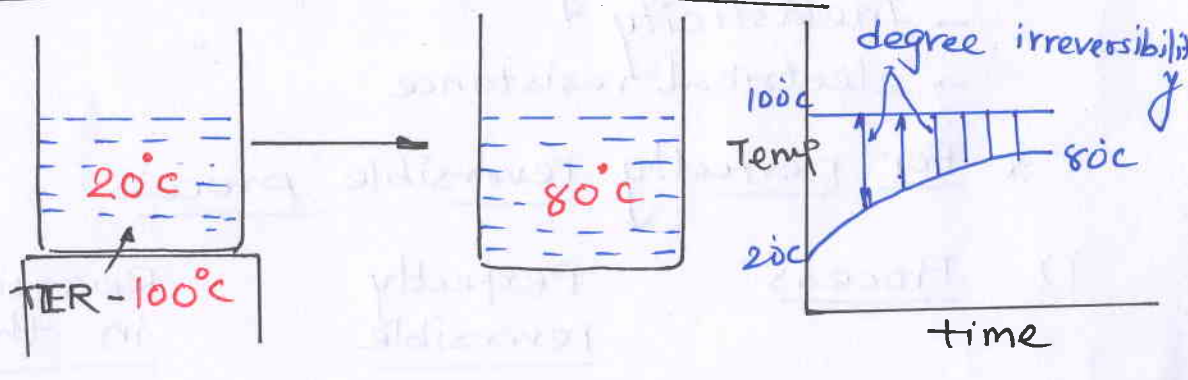
a) Reversible or ideal process
b) Irreversible or natural process

→ A reversible process is one which is performed in such a way that at the conclusion of the process, both the system and the surroundings may be restored to their initial states, without producing any changes in the rest of the universe.

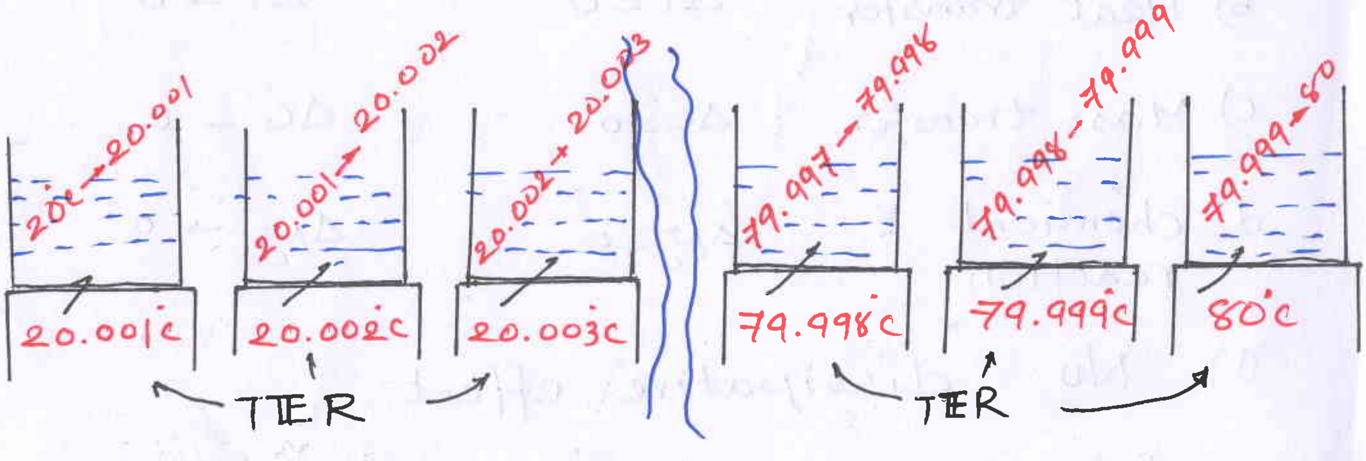
→ All spontaneous processes are irreversible

Example:

→ Irreversible heat transfer process



→ Reversible Heat transfer process ($\Delta T \to 0$)



→ Reversible cycle :- A reversible cycle is cycle where all the processes are reversible

→ Reversible Heat engine (HE_R) }
→ Reversible Heat pump (HP_R) } Both operating on a reversible cycle

8) Carnot theorem,

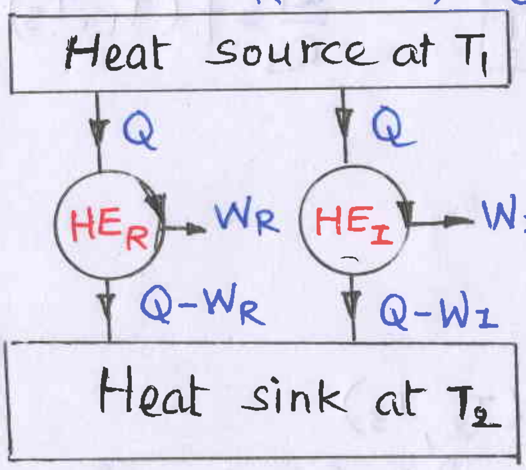
" It is impossible to construct an engine operating between two constant temperature reservoirs can be more efficient than a reversible engine operating between the same reservoirs, and all reversible heat engines operating between the same temperature reservoirs have the same efficiency "

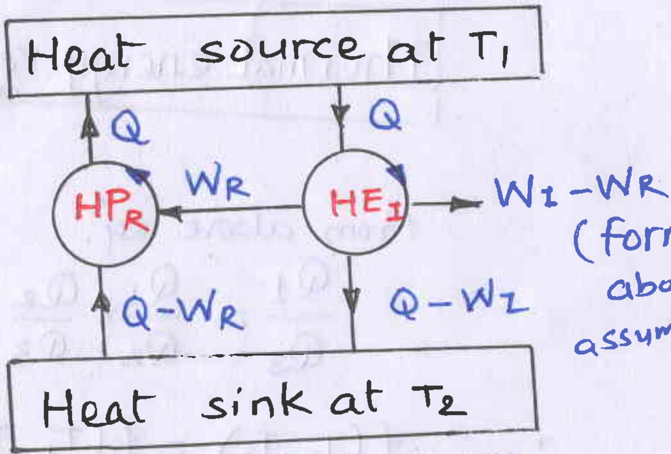
$$\eta_{Reversible} > \eta_{Irreversible} \, , \quad \eta_R = \eta_R$$

9) Corollary of Carnot theorem

We know $\eta_R > \eta_I$

Assume $\eta_R < \eta_I$, $\frac{W_R}{Q} < \frac{W_I}{Q} \Rightarrow W_R < W_I$

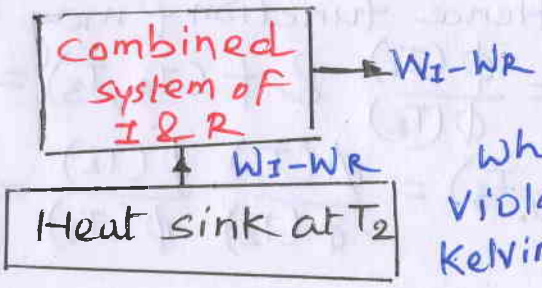




(form above assumption)

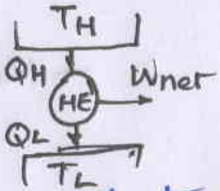
Reverse HE_R → acting as HP_R

$\eta_R < \eta_I$ → wrong
so only & only possible
$\eta_R > \eta_I$

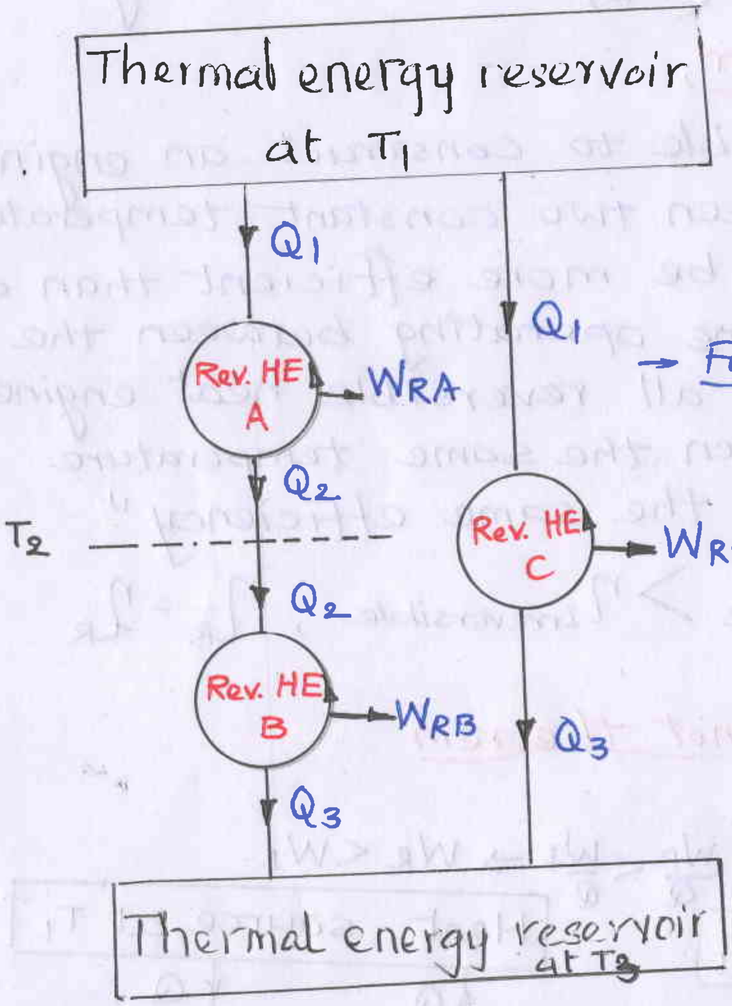


which is violation of Kelvin-Plank statement

9) The thermodynamic temperature scale



The thermodynamic temperature scale may be defined as that which is independent of the property of working substance



$$\eta_{Rev} = 1 - \frac{Q_L}{Q_H} \Rightarrow \eta_{Rev} = g(T_H, T_L)$$

$$\frac{Q_H}{Q_L} = f(T_H, T_L)$$

→ For H.E. → A

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

→ For - H.E - B

$$\frac{Q_2}{Q_3} = f(T_2, T_3)$$

→ For H.E. → C

$$\frac{Q_1}{Q_3} = f(T_1, T_3)$$

From above eq^n.

$$\frac{Q_1}{Q_3} = \frac{Q_1}{Q_2} \times \frac{Q_2}{Q_3}$$

$$f(T_1, T_3) = f(T_1, T_2) \times f(T_2, T_3)$$

Left Hand side of above eq^n. is function of T_1 and T_3 therefore, right hand side must be function of T_1 & T_3 and not T_2, Hence function f may be written

$$f(T_1, T_2) = \frac{\phi(T_1)}{\phi(T_2)} \quad \& \quad f(T_2, T_3) = \frac{\phi(T_2)}{\phi(T_3)}$$

$$f(T_1, T_3) = \frac{\phi(T_1)}{\phi(T_2)} \cdot \frac{\phi(T_2)}{\phi(T_3)} = \boxed{\frac{\phi(T_1)}{\phi(T_3)} = \frac{Q_1}{Q_3} = \frac{T_1}{T_3}}$$