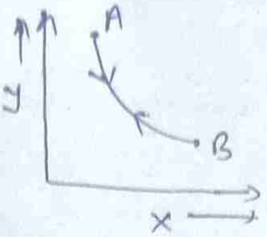
# Reversibility & Irreversibility

(a) Reversible or ideal process

(b) Irreversible or natural process.

Reversible process : ⟶ at conclusion of process.
⇓
System & Surrounding may be restored to initial states.




⟶ follow same path both the times.

reversible process (infinitesimal gradient) ⟶ infinitely slow
every state is an equilibrium state. (quasi-state)

Natural process ⟶ finite gradient

reversible & irreversible. ($f(t)$)

Cause of irreversibility.

* Lack of equilibrium during the process.
* Dissipative effect

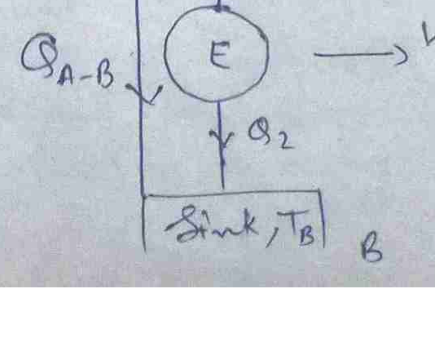
⟶ thermal, mechanical, chemical.

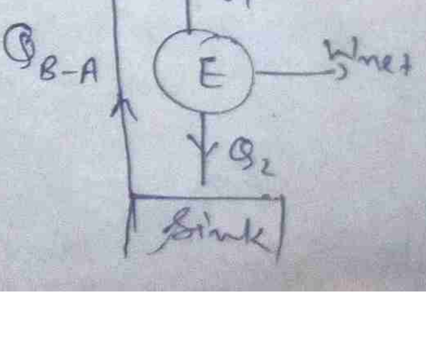
thermal ⟶ finite temp. gradient

mechanical ⟶ pressure

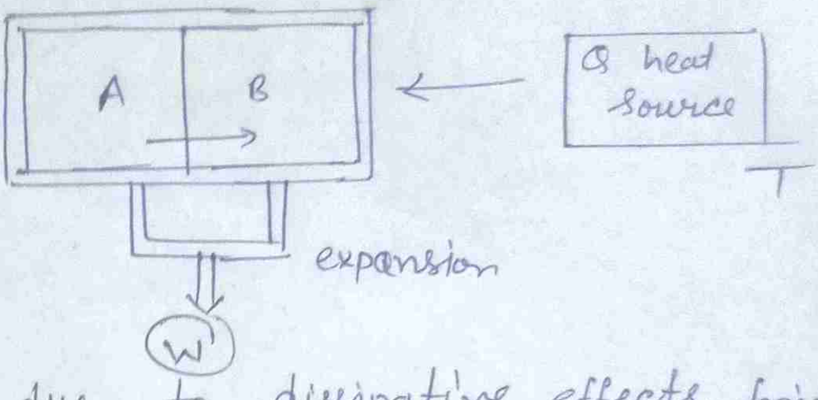
chemical ⟶ chemical potential

Proof.



$Q = W$




Irreversibility due to dissipative effects. friction.

↓

Work is done without increment equivalent P.E. & K.E.

⇓

heat ⟶ internal energy (or to surrounding).

via. friction, viscosity, inelasticity, electrical resistance, (dissipative effect).

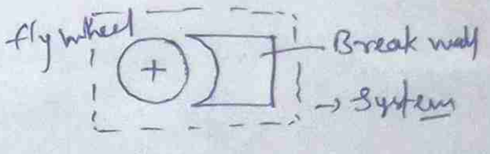
$Q_{1-2} = E_2 - E_1 + W_{1\to 2}$

if breaking is rapid ⟶ no heat transfer. $E_1 = E_2$

$$\Rightarrow U_2 + \frac{mv^2}{2} + mgz_2 = U_1 + \frac{mv_1^2}{2} + mgz_1$$

$$\Rightarrow U_2 = V_1 + \frac{mv_1^2}{2}$$ (dissipative effect)

(b) Paddle - wheel work.




(c) Transfer of electricity through a resister.

→ Reverse violate → K-P statement

(a) → heated wheel & break use U ⇒ K.E.
(b) K.E. ⇒ weight raise
(c) supply heat → to restore initial or I state

# Condition of reversibility

Natural process → irreversible

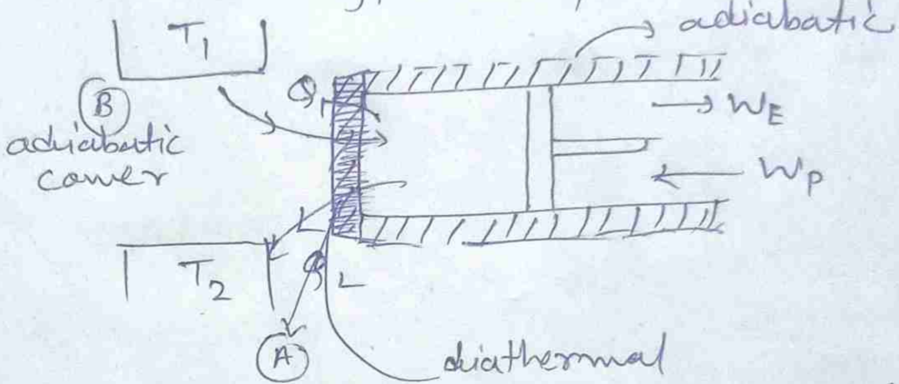
{ no equilibrium (quasi-static) process & dissipative }

→ for reversibility these are not allowed.

→ infinitesimally near equilibrium & without dissipation.

## CARNOT-CYCLE

→ hypothetically (reversible)




(a) Reversible isothermal Process (isothermal expansion)

$$Q_1 = \underbrace{U_2 - U_1}_{\text{for ideal gas}} + W_{1-2} \qquad \underline{U_2 = U_1}$$

(b) Reversible adiabatic process

(A) diathermal is replaced with (B) adiabatic wall.

work done $\underbrace{\text{reversibility}}$ ($T_1 \rightarrow T_2$) and System does $W_E$ work.

$$0 = U_3 - U_2 + W_{2-3}$$

(C) Reversible isothermal process.

(B) is replaced by (A).

$Q_2$ heat leave the system.

$$-Q_2 = U_4 - U_3 - W_{3-4}$$

(for ideal gas $U_4 = U_3$)

(d) Reversible adiabatic process.

(B) again replace by A.

$W_p$ done on system.

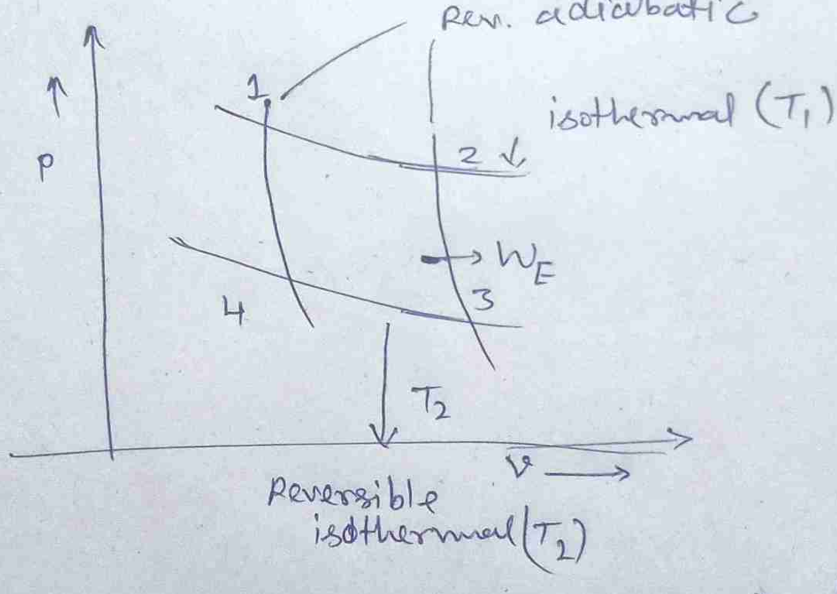
(reversibly & adiabatically)

internal energy increase

temp. rises from $T_2$ to $T_1$

1st law

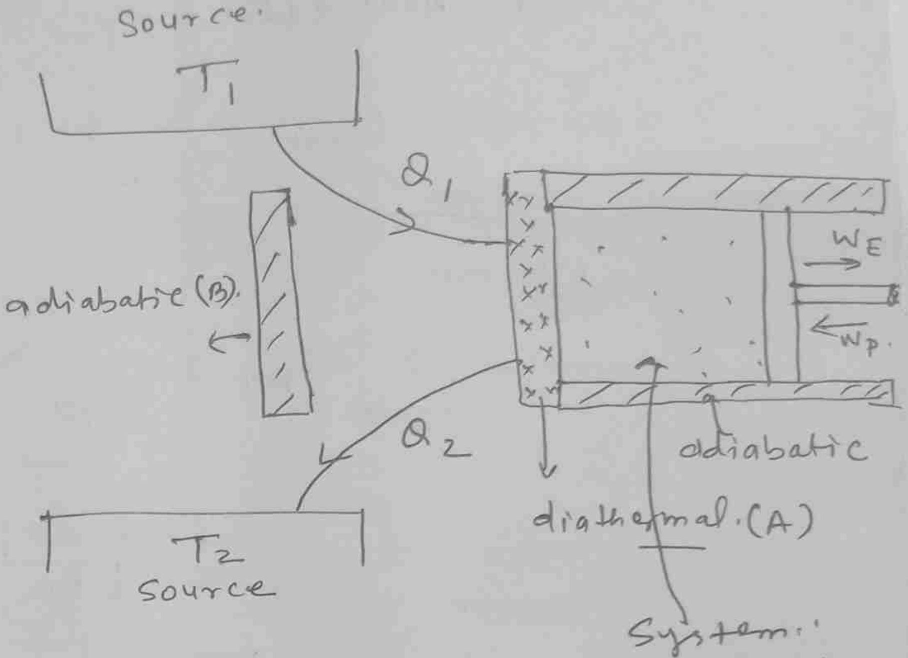
$$0 = U_1 - U_4 - W_{4-1}$$




$$Q_1 - Q_2 = (W_{1-2} + W_{2-3}) - (W_{3-4} + W_{4-1})$$

① Reversible $\longrightarrow$ slow & nondissipative.
(ideal process).

## CARNOT CYCLE




ⓐ Reversible isothermal. Process. (expansion).

1st Law:

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

or, Considering pdv work.

$$Q_1 = U_2 - U_1 + W_{1-2}$$

ⓑ Reversible adiabatic. (expansion).

1st Law.

$$0 = U_3 - U_2 + W_{3-2}.$$

ⓒ Reversible isothermal process (compression)

$$-Q_1 = U_4 - U_3 - W_{4-3}.$$

ⓓ Reversible adiabatic process (compression)

$$0 = U_1 - U_4 - W_{1-4}.$$

(2)

$Q =$

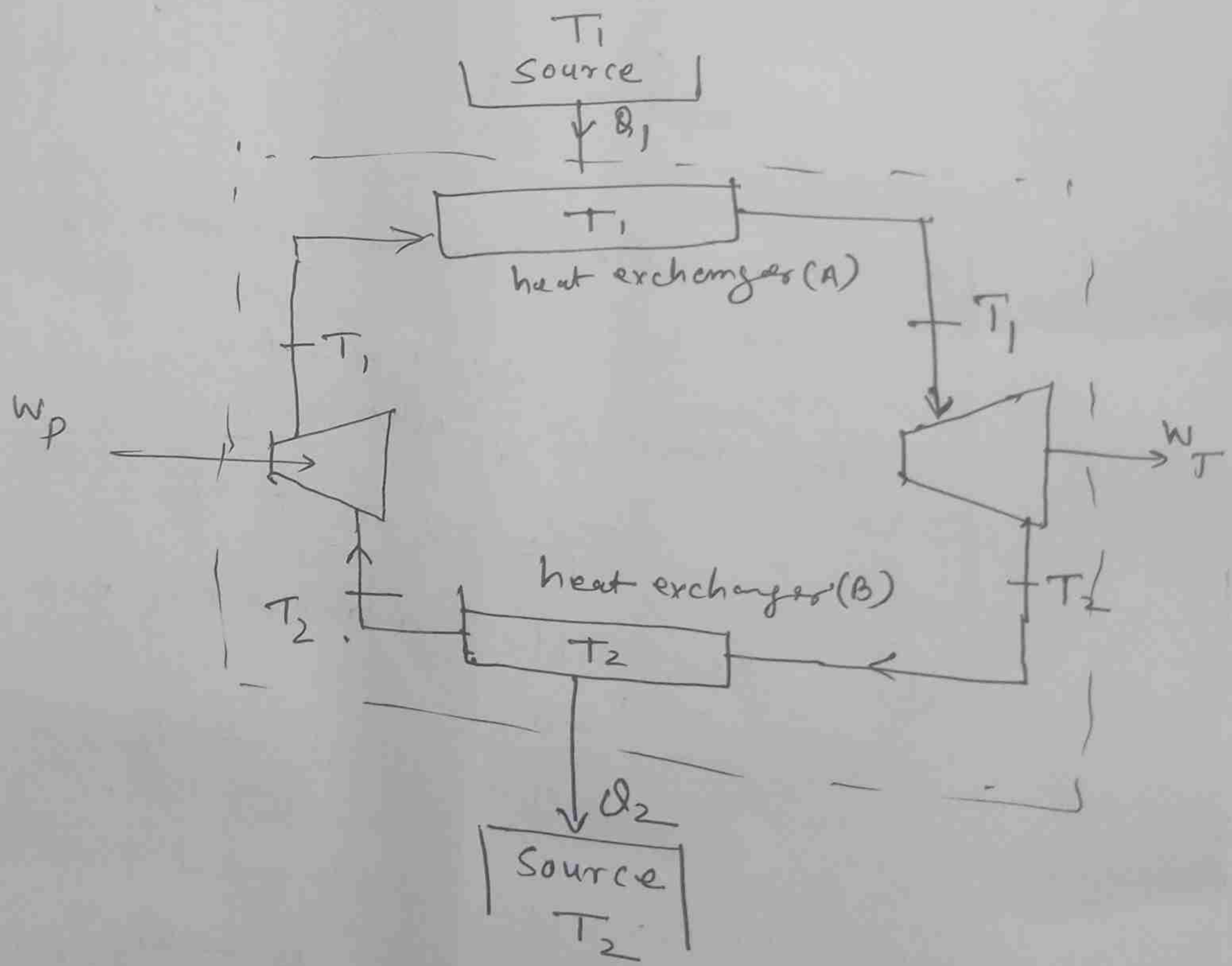
$$Q_1 - Q_2 = (W_{2-1} + W_{3-2}) - (W_{4-3} + W_{1-4}).$$

Net heat addition = Net work done.

$$\Rightarrow \sum_{cycle} Q_{net} = \sum_{cycle} W_{net} \rightarrow \text{when work by System is +ve}$$

otherwise:

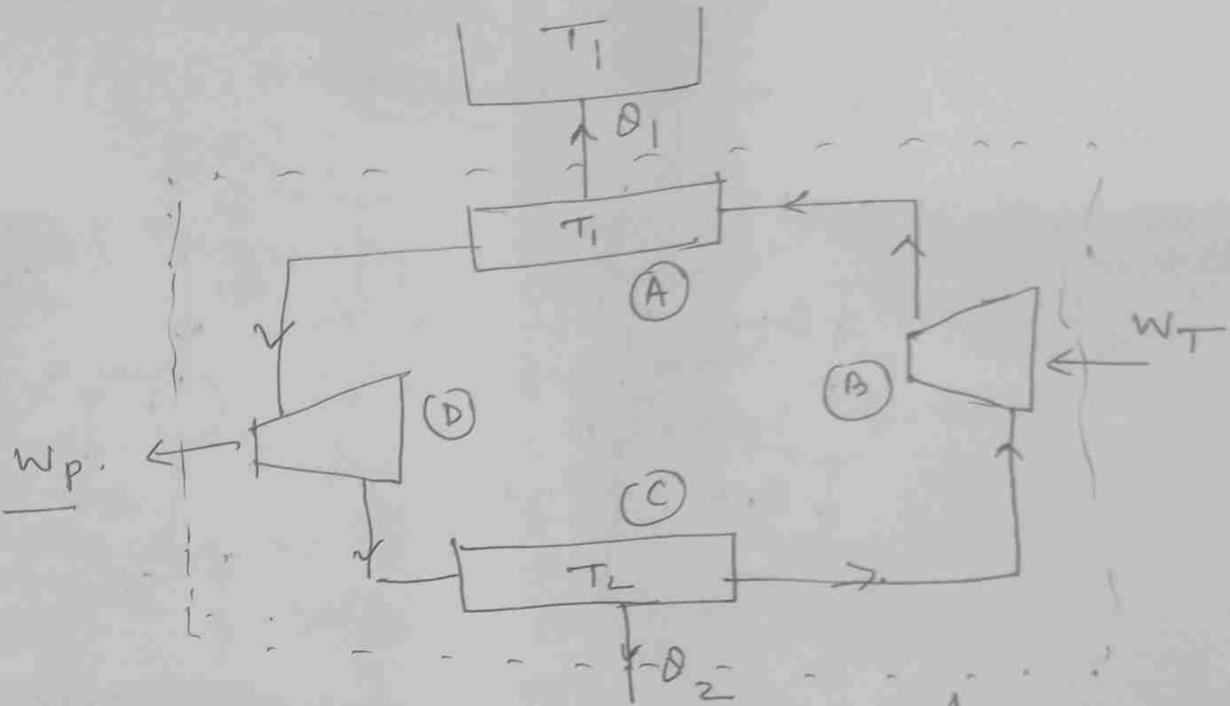
$$\sum_{cycle} Q_{net} = -\sum_{cycle} W_{net} \rightarrow \text{work by System is -ve}$$



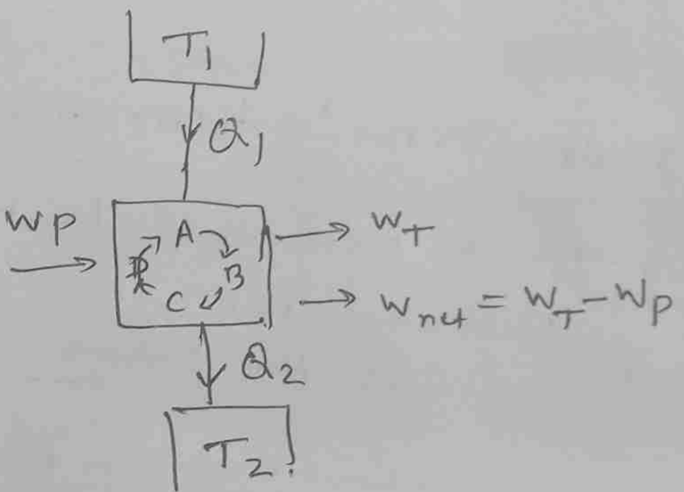
③ Reverse heat Engine.

Carnot cycle → reversible.

all processes are reversed.




↓
heat pump
or
refrigerator



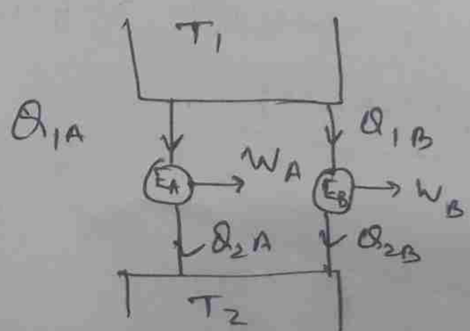

CARNOT theorem.

none has higher efficiency than reversible engine.

proof:

A → any heat Engine.

B → reversible heat Engine.

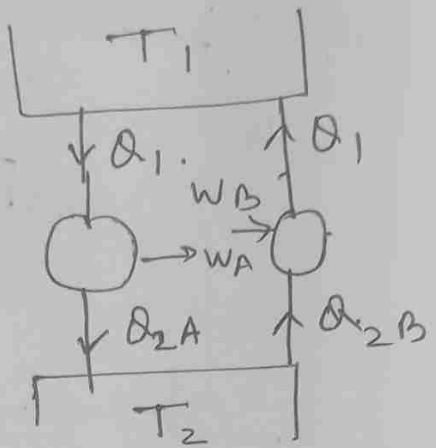


(ii) Assume → $\eta_A > \eta_B$ & take $Q_{1A} = Q_{1B} = Q_1$.

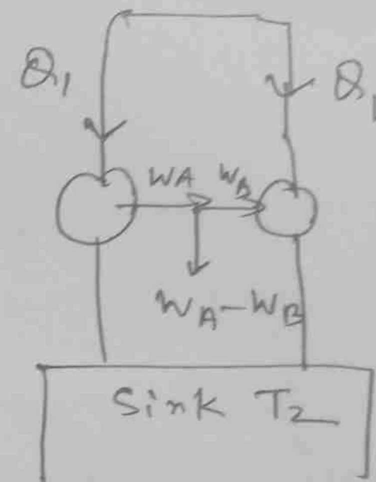
then. $\frac{W_A}{Q_1} > \frac{W_B}{Q_1} \Rightarrow W_A > W_B$.

~~No~~ if $W_A > W_B$ ~~Statement combine both (A) & (B)~~

Now B is reversible.




$\Rightarrow$




Violate K-P. Statement.

Corollary of Carnot's theorem.

efficiency of all reversible heat engine operating between the same tem. levels is the same.

Similar to above. we can prove $\eta_A = \eta_B$.

for reversible engine cycle amount or nature of substance doesn't influence efficiency.

## (5) Efficiency of the reversible heat Engine.

$$\eta_{rev.} = \eta_{max} = 1 - \left(\frac{Q_2}{Q_1}\right)_{rev.} = 1 - \frac{T_2}{T_1}$$

$$\eta_{rev.} = \frac{T_1 - T_2}{T_1}$$

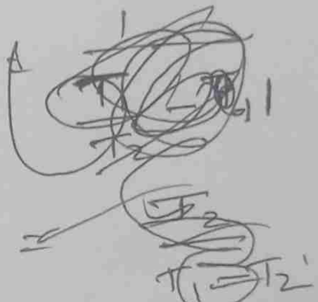
as: $T_2 \downarrow$ $\eta_{rev} \uparrow$.
& $T_1 \uparrow$ $\Rightarrow$

$\eta < 1$ as $T_2 > 0$ always.

$$(COP)_{refr.} = \frac{Q_2}{Q_1 - Q_2} = \frac{1}{\frac{Q_1 - Q_2}{Q_2}}$$

for reversible refrigerator: $\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$

$$= \frac{1}{\left(\frac{Q_1}{Q_2}\right) - 1}$$



$$(COP)_{H.P.} \left[(COP)_{refr.}\right]_{rev.} = \frac{T_2}{T_1 - T_2}.$$

Similarly,

$$\left[(COP)_{H.P}\right]_{rev.} = \frac{T_1}{T_1 - T_2}$$

(3) **Absolute thermodynamic temp. Scale.**

efficiency of heat engine cycle.
receiving $Q_1$ heat
rejecting $Q_2$ heat

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

2nd Law heat flow from high to low temp

$\Rightarrow (T_1 - T_2) = 0$ for to obtain work from cycle

for reversible cycle efficiency doesn't depent of Sub., amnt etc.

$$\Rightarrow \underline{\eta = f(t_1, t_2)}$$

$$1 - \frac{Q_2}{Q_1} = f(t_1, t_2).$$

$$\text{or} \quad \frac{Q_2}{Q_1} = F(T_1, T_2)$$

if some fn relationship is assigned between, $T_1, T_2$ & $\frac{Q_1}{Q_2}$.

then equation becomes temp. scale.

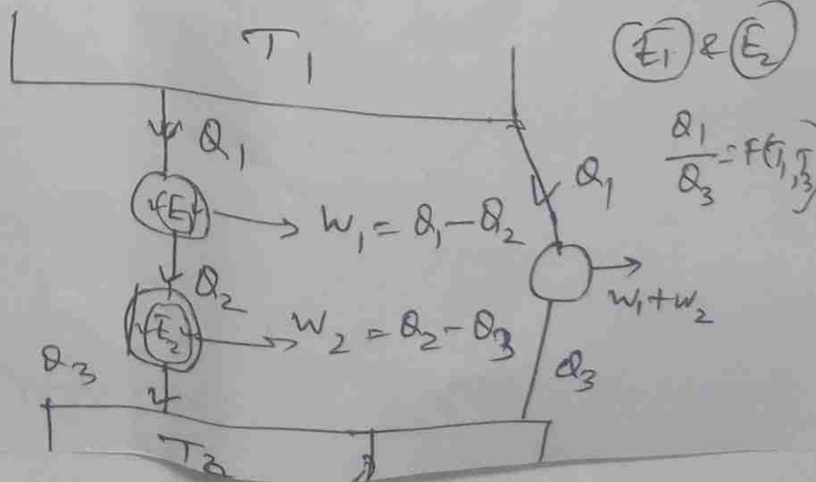
Assume. two Engine.

$E_1$ recieve heat from Source at $T_1$

$E_2$ recieve heat from Source at $T_2$

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

$$Q_2 / Q_3 = F(T_2, T_3)$$



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

$\Downarrow$

$T_3$ should be droped out.

$$\Rightarrow F(T_1, T_3) = \Phi(T_1)\,\psi(T_3).$$

$$\Rightarrow \frac{Q_1}{Q_2} = F(T_1, T_2) = \frac{\Phi(T_1)}{\Phi(T_2)}.$$

Since, $\Phi$ is any arbitrary fn

the simplest way to define is,

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

Absolute thermodynamic temp. Scale is defined as Kelvin Scale. having same relation as heat absorved & rejected in Carnot cycle.

hence, indep. of any characteristics of any Substance

In defining the kelvin temp. Scale also, the triple point of water is taken as the standard reference pt.

$Q$ carnot engine between $T$ & $T_t$.

$$\Rightarrow \frac{Q}{Q_t} = \frac{T}{T_t} \Rightarrow T = 273.16\,\frac{Q}{Q_t}$$

$\downarrow$

arbitrarily.

in Kelvin scale, $Q$ play the role of thermometric property.

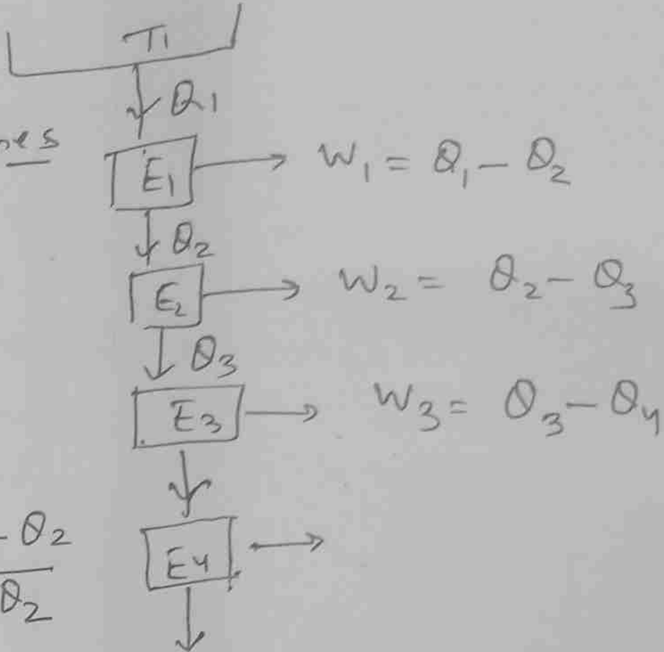
(8) here, amount of heat supply $\propto$ temp.

Just like, thermal emf in a thermocouple.

absolute thermodynamic ~~scale~~ temp. scale has a definite zero pt.

e.g.

a series of reversible engines extending from $T_1$ to lower temp.




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

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

$$\Rightarrow (T_1 - T_2) = (Q_1 - Q_2)\frac{T_2}{Q_2} = (\cdot$$

$$(T_2 - T_3) = (Q_2 - Q_3)\frac{T_3}{Q_3} = (Q_2 - Q_3)\frac{T_2}{Q_2}.$$

$$(T_3 - T_4) = (Q_3 - Q_4)\frac{T_2}{Q_2}.$$

$\vdots$

~~E3~~ Assume equal temp. interval.

i.e., $T_1 - T_2 = T_2 - T_3 = T_3 - T_4 = \cdots$

$\Rightarrow W_1 = W_2 = W_3 = \cdots$

Conversely, making equal work in a series we can make.

$T_1 - T_2 = T_2 - T_3 = \cdots$

i.e. equal temp. interval.

if we have 100 carnot cycle in between steam pt. & ice pt., we can measure hundred temp. interval

(9) Such scale would be indep. of substance.

if we make enough engine

then. total work can be equal to $Q_1$

$\Rightarrow$ heat rejected will be zero.

$\Downarrow$

violate K-P statement

(thus 2nd Law).

hence, heat rejection can't be zero

but approaching to zero.

then $T_{(sink)} \rightarrow 0$.

thus appear that definite zero exist but can't be reached without violating 2nd Law.

$\Downarrow$

3rd Law.

it is impossible to reduced any system to absolute zero temp. (even in the most idealized case) in finite step].

$\Downarrow$

Fowler – Guggenheim Statement

(concept of heat engine is not neccessary for realising of ~~attaindability~~ of abs. zero temp)

attainability