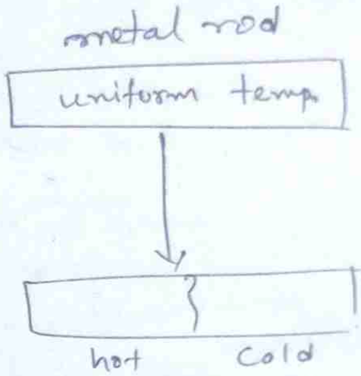
Second law of thermodynamic

Qualitative difference between heat & work

1^{st} law $\longrightarrow$ System undergoes change $\Rightarrow$ energy must be balanced.

but does not tell if such change is feasible or not



1st law ok.

how to know is a process is feasible or not (2nd law)

Spontaneous process in nature

$\Downarrow$

Only in one direction (require driving force)

$\Downarrow$

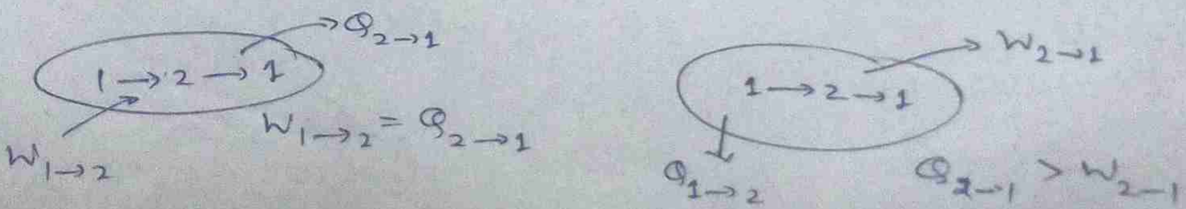
what happens (flux, current, effect)

Joule's exp. $\longrightarrow$ work $\xrightarrow{\text{Completely}}$ convert into heat

but Complete conversion of heat to work is not possible.

hence, work & heat are not equivalent

$$W \Rightarrow Q \quad , \quad Q \not\Rightarrow W$$



Cycle heat Engine

Engineering purpose $\longrightarrow$ 2^{nd} Law

$\downarrow$

Condition which govern the production of work by a thermodynamic System operating in a cycle.

heat engine cycle

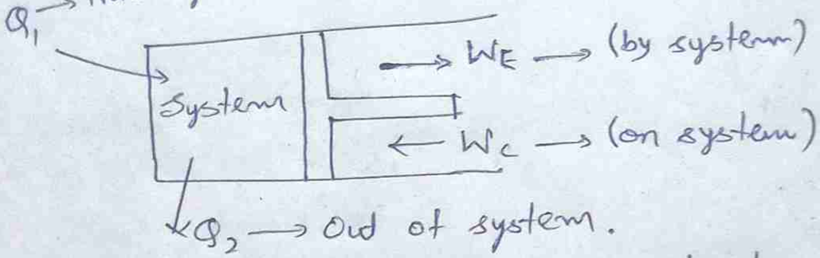
$\downarrow$

net heat in the system  net work out of system.

$\uparrow$

system executes. called heat engine.

Example of heat engine.



heat Engine Cycle performed by a closed. System undergoing four successive energy interaction with surrounding.

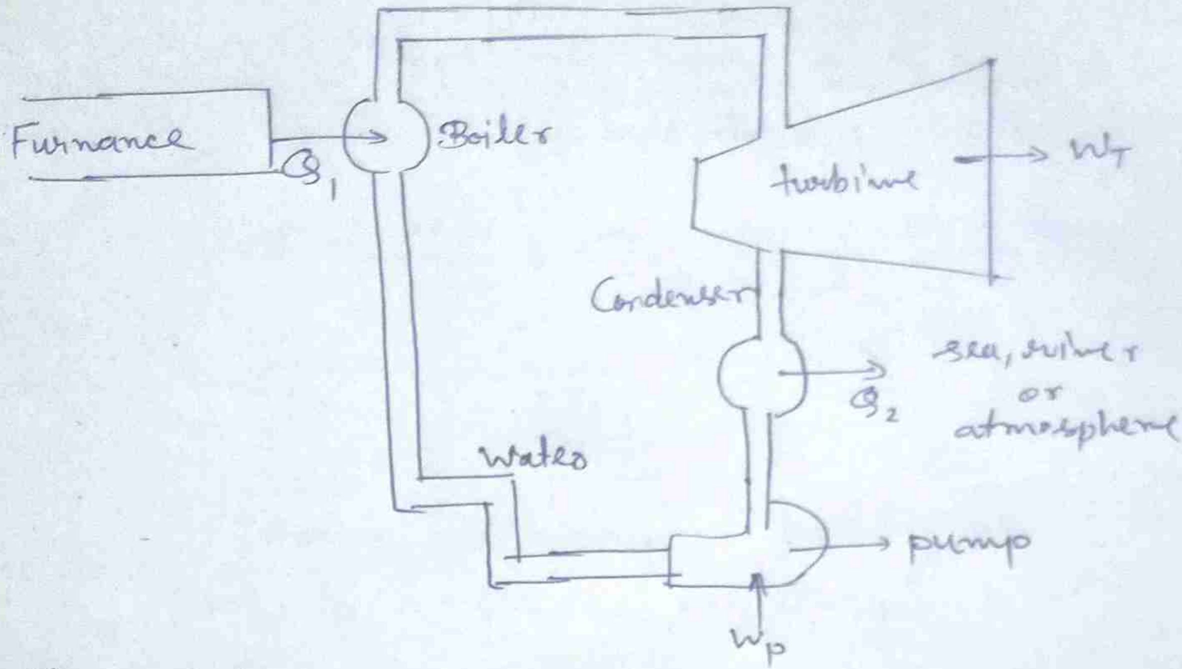
$Q_1 \rightarrow$ added $\rightarrow W_E \rightarrow$ by system $\rightarrow W_c$ on System

$\downarrow$

$Q_2 \rightarrow$ rejected to Surrounding

$\Downarrow$

Come to original state (Complete cycle).



Flow - cycle

Net heat transfer

$$Q_{net} = Q_1 - Q_2$$

net work transfer,

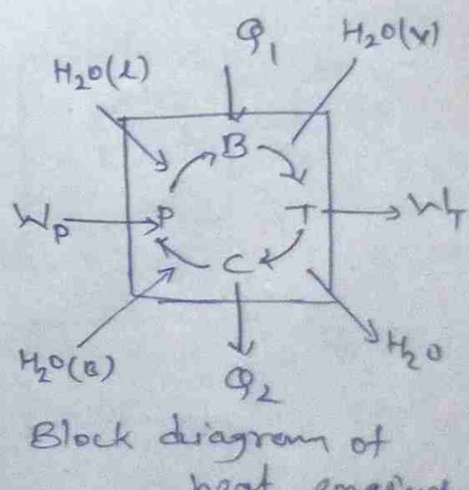
$$W_{net} = W_T - W_p \quad (\text{or } W_{net} = W_E - W_c)$$

by 1^{st} law of thermodynamics.

$$\sum_{cycle} Q = \sum_{cycle} W$$

$$Q_{net} = W_{net}$$

$$\Rightarrow \quad Q_1 - Q_2 = W_T - W_p$$



Block diagram of heat engine.

purpose of heat engine.

to produce work continously from heat

hence W_T & Q_1 are of primary interest.

Efficiency of heat engine.

$$\eta = \frac{\text{Net work output in a cycle}}{\text{total heat input in cycle}}$$

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

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

↓

thermal efficiency of heat engine.

(how to maximize efficiency)

Energy Reservoir

↓

large body with infinite heat capacity.

↓

Capable of absorbing or rejecting unlimited heat without suffering noticable changes in thermodynamic co-ordinates.

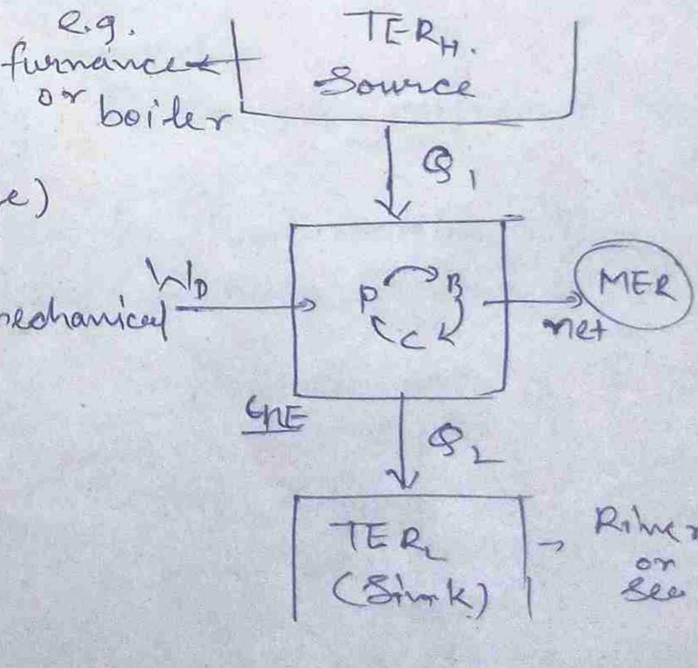
MER

↓

Mechanical energy reservoir (adiabatic, mechanical energy storage)

e.g. raising weight K.E.

(MER recieve and delivers mechanical energy quasi-statically).



Kelvin - Plank Statement of second law

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

$W_{net} < Q_1$

=> Q_1 transferred to a System can not be Completely converted to work. in a Cycle.

=> $\eta < 1$ => $Q_2 > 0$ => some heat will always be rejected.

=> two - reservior or heat exchanges bodies.

Kelvin - plank

↳ impossible for a heat engine to produce net work in a complete cycle if it exchange heat with only one body at a fixed temperature.

$Q_2 = 0$ => $\eta = 1$

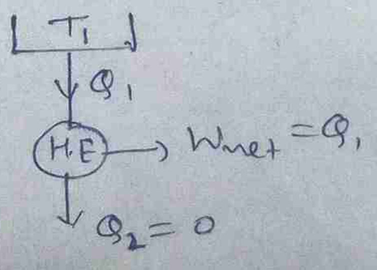
=> heat - engine with one exchanging body

violating K-P Rule

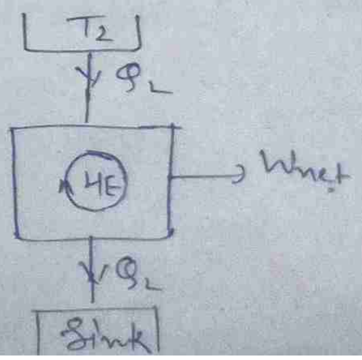
=> PMM2 ⟶ impossible

→ two heat exchanging bodies at different temp. are

→ Work will be produced by heat engine till temp. of two heat exchanging bodies become equal.



PMM2



Clausius's statement of the second law

heat flow from high T $\xrightarrow{\text{to}}$ low temp.

Reverse can not be occur spontaneously.

Not possible { No effect other than heat transfer from hoter to colder bodies.

how to do? via work.

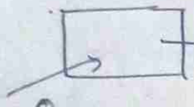
Refrigerator and heat-pump

a refrigerator is a device, → cycle
→ maintain $T_{body} < T_{surrounding}$

$T_2 < T_1$

↕

A → some leakage (Q_2)



$\rightarrow Q_2 \longrightarrow$ heat adsorbed by working fluid called refrigerant

Q_2 T_2 = Constant

↓

evaporates (E_1)
at $T < T_2$

by evaporting refrigerant body A losses. heat (Q_2) & maintain temp. T_2.

Vapour compressed in Compressor (C_1) by work W_c

than condense in condenser C_2
rejecting heat of condensation Q_1
at $T_1 > T_2$

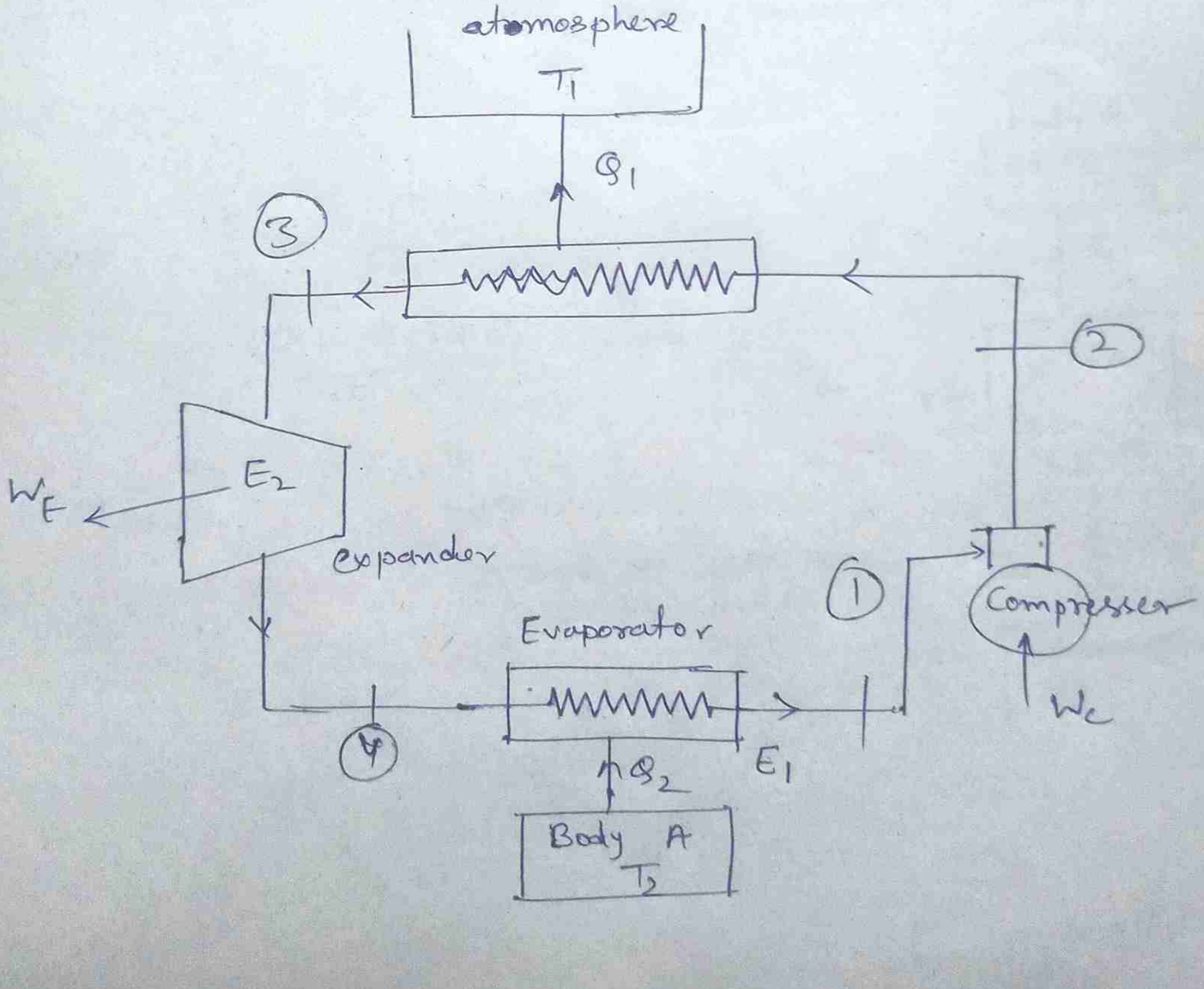
then condensate expands adiabatically
through an expander (an engine or turbine)

Producing work W_E

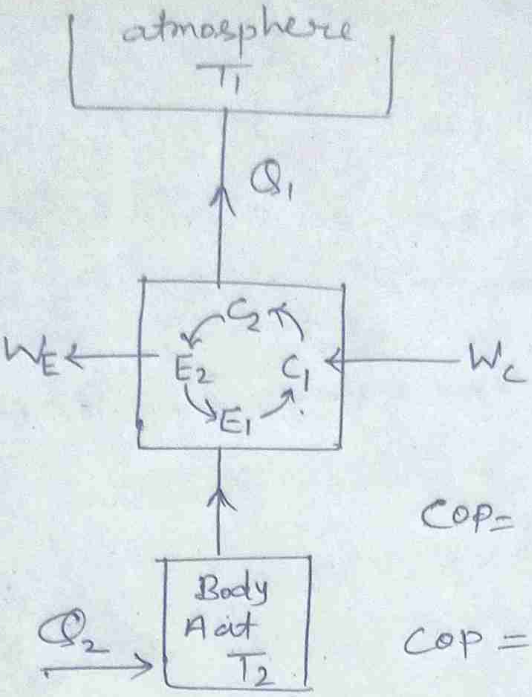
<u>when</u>, Temp. $T < T_2$

$\Rightarrow$ heat transfer from A to refrigerator

$E_1 - C_1 - C_2 - E_2$



COP
(Coefficient of performance)

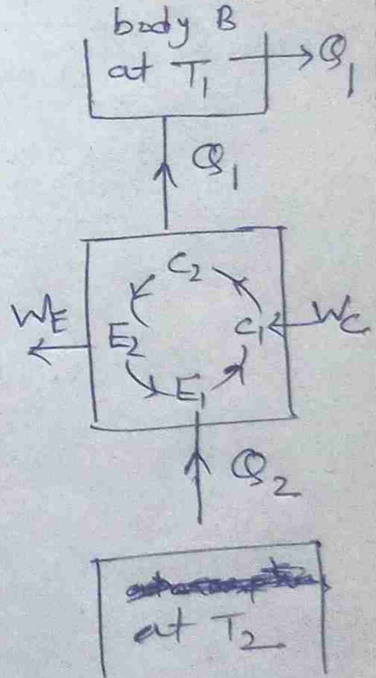


$$COP = \frac{Q_2 \text{ (desired effect)}}{W \text{ (work input)}}$$

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

<u>heat pump</u> :- → maintain Temp. lighter than surrounding temp.

$T_1 > T_2$



$$COP = \frac{Q_1}{W} = \frac{Q_1}{Q_1 - Q_2}$$

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

$$\Rightarrow (COP)_{H.P.} = [COP]_{ref.} + 1$$

COP of heat pump > COP of refrigerator by unit

$$Q_1 = [COP]_{H.P.}\, W$$
$$= [(COP)_{ref.} + 1]\, W$$

Electrical heater ?? $\Rightarrow$ work = heat

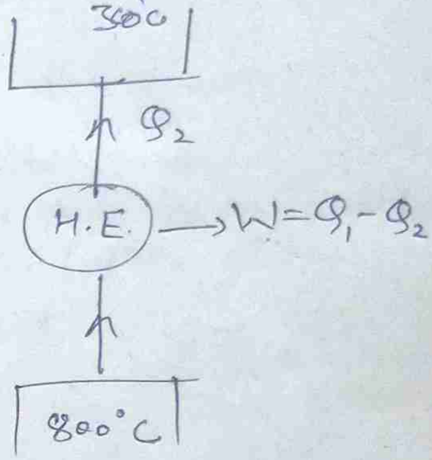
↳ heat $\nearrow$

Current

However current $\longrightarrow$ compressor $\longrightarrow$ work < heat

<u>Ex.</u>

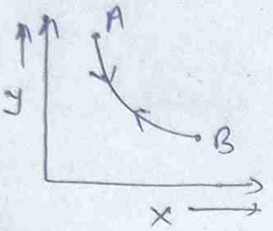
$$\eta = \eta_{ex} = 1 - \frac{T_2}{T_1}$$



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 & irrversible. (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.