CARNOT'S MAXIMALLY Efficient CYCLIC HEAT ENGINE ⇒ 2nd LAW

ACTUAL Efficiency

$$\eta_{ACTUAL} = \frac{W_{out}^{NET}}{Q_{IN}} = \frac{Q_{IN} - Q_{out}}{Q_{IN}} = 1 - \frac{Q_{out}}{Q_{IN}}$$

for any ACTUAL Heat Engine

& CARNOT proved that

CARNOT EFFICIENCY,

$$\eta_{CARNOT} = 1 - \frac{T_C}{T_H}$$

for CARNOT'S IDEALIZED Heat Engine

AND ALSO, by design of CARNOT ENGINE, that

$$\eta_{CARNOT} > \eta_{ACTUAL}$$

for any engine operating between T_H & T_C

THEREFORE

$$\frac{Q_{out}}{Q_{IN}} > \frac{T_C}{T_H}$$

AND $Q_{out} > 0$, since $T_C > 0$

(by 3rd LAW)

3 (EQUIVALENT!) VERSIONS
of 2nd LAW of ThermoDynamics

1) A HEAT ENGINE MUST EXHAUST HEAT.

2) A REFRIGERATOR MUST CONSUME WORK.

3) ENTROPY of a closed system
MUST INCREASE.

CHANGE IN ENTROPY

$$\Delta S = \sum \frac{Q_i^{IN}}{T_i} \leftarrow \text{Definition of } \Delta S.$$

EG FOR Q transferred from T_H to T_c

$$\Delta S = \frac{Q}{T_c} - \frac{Q}{T_H}$$

Clearly $\Delta S > 0$ iff $T_H > T_c$

ie $\Delta S > 0 \iff \{ Q$ flows from Higher to Lower $T.\}$

FOR HEAT ENGINE + SURROUNDINGS

$$\Delta S_{univ.} = \Delta S_{surr} + \Delta S_{engine}$$

$$= -\frac{Q_{IN}}{T_H} + \frac{Q_{out}}{T_C} + 0$$

because engine is same at end of cycle as at beginning.

$$\Delta S_{univ.} > 0 \Rightarrow \frac{Q_{OUT}}{T_C} > \frac{Q_{IN}}{T_H}$$

$$\Longleftrightarrow \frac{Q_{OUT}}{Q_{IN}} > \frac{T_C}{T_H} : \text{ CARNOT'S } 2^{nd} \text{ LAW}$$

$$\Delta S_{univ} > 0 \Longleftrightarrow Q_{out} > 0$$

THIRD FORM of $\boxed{2^{nd} \text{ LAW}}$ is equivalent to 1^{st} FORM!

ENTROPY & PROBABILITY

ENTROPY $S = k(\ln W)$

k = Boltzmann's constant per molecule

=

& W = probability of microscopic state of system

THUS

INCREASE of ENTROPY in a process

$\iff$ movement towards a state of higher probability.