CARNOT'S MAXIMALLY EFFICIENT 
CYCLIC HEAT ENGINE \( \Rightarrow \) 2nd LAW 

\[
\text{Actual Efficiency} \quad \eta_{\text{actual}} = \frac{\text{Net Work}}{\text{Qin}} = \frac{\text{Qin} - \text{Qout}}{\text{Qin}} = 1 - \frac{\text{Qout}}{\text{Qin}}
\]

for any actual heat engine

\& CARNOT proved that

\[
\eta_{\text{CARNOT}} = 1 - \frac{T_c}{T_h}
\]

for CARNOT'S IDEALIZED HEAT ENGINE

AND also, by design of CARNOT ENGINE, that

\[
\eta_{\text{CARNOT}} > \eta_{\text{actual}}
\]

for any engine operating between \( T_h \) \& \( T_c \)

therefore

\[
\frac{\text{Qout}}{\text{Qin}} > \frac{T_c}{T_h}
\]

AND \( \text{Qout} > 0 \), since \( T_c > 0 \)

(by 3rd LAW)
(Equivalent!) Versions of 2nd Law of Thermodynamics

1) A heat engine **must** exhaust heat.
2) A refrigerator **must** consume work

Entropy of a closed system **must** increase.
CHANGE IN ENTROPY

\[ \Delta S = \sum \frac{Q_i}{T_i} \]  ← Definition of \( \Delta S \).

\[ \text{For } Q \text{ transferred from } T_H \text{ to } T_c \]

\[ \Delta S = \frac{Q}{T_c} - \frac{Q}{T_H} \]

Clearly, \( \Delta S > 0 \) iff \( T_H > T_c \)

\( \Delta S > 0 \) \( \iff \{ Q \text{ flows from } \text{Higher to Lower } T_i \} \)
For heat engine + surroundings:

\[ \Delta S_{\text{univ.}} = \Delta S_{\text{surr}} + \Delta S_{\text{engine}} \]

\[ = \frac{Q_{\text{in}}}{T_H} + \frac{Q_{\text{out}}}{T_C} + 0 \]

Because engine is same at end of cycle as at beginning,

\[ \Delta S_{\text{univ.}} > 0 \implies \frac{Q_{\text{out}}}{T_C} > \frac{Q_{\text{in}}}{T_H} \]

\[ \iff \frac{Q_{\text{out}}}{Q_{\text{in}}} > \frac{T_C}{T_H} : \text{Carnot's 2nd Law} \]

\[ \Delta S_{\text{univ.}} > 0 \iff Q_{\text{out}} > 0 \]

Third form of 2nd Law

Is equivalent to 1st form!
**Entropy & Probability**

\[
S = k (\ln W)
\]

\( k = \) 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.