

EQUIVALENCE of 1st & 3rd Forms of 2nd LAW

PHYSICS 117
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3rd Form: $\Delta S \geq 0$

3rd Form: ENTROPY of closed system always INCREASES

1st Form: $\eta_{\text{actual}} \leq 1$, $\eta_{\text{actual}} = \frac{W_{\text{out}}}{Q_{\text{in}}}$

1st Form: That engine cannot produce WORK without exhausting heat energy; in short $Q_{\text{out}} > 0$.

Consider DEFINITIONS of η_{actual} & ΔS :

$$\eta_{\text{actual}} = \frac{W_{\text{out}}}{Q_{\text{in}}} = \frac{Q_{\text{in}} - Q_{\text{out}}}{Q_{\text{in}}} = 1 - \frac{Q_{\text{out}}}{Q_{\text{in}}} = \text{efficiency of an actual heat engine}$$

$$\text{and } \Delta S = -\frac{Q_{\text{in}}}{T_H} + \frac{Q_{\text{out}}}{T_C}$$

Considering the whole universe as an closed system.

THEN 3rd Form yields $\Delta S > 0 \Rightarrow$

$$\frac{Q_{\text{out}}}{T_C} > \frac{Q_{\text{in}}}{T_H} \Rightarrow \frac{Q_{\text{out}}}{Q_{\text{in}}} > \frac{T_C}{T_H} \dots \text{RESULT (A)}$$

Then consider CARNOT'S ideal engine, with efficiency

$$\eta_{\text{CARNOT}} = 1 - \frac{T_C}{T_H} > 1 - \frac{Q_{\text{out}}}{Q_{\text{in}}} = \eta_{\text{actual}}, \text{ by (A) above.}$$

Conclude that $\Delta S > 0$ implies $\eta_{\text{CARNOT}} = 1 - \frac{T_C}{T_H} > \eta_{\text{actual}}$

Independently $\eta_{\text{CARNOT}} = (1 - T_C/T_H) < 1$, unless $T_C \equiv 0$.
But $T_C \equiv 0$ is impossible, by 3rd LAW.

Therefore $\Delta S > 0 \Rightarrow \eta_{\text{actual}} < 1$ Q.E.D.
i.e. 3rd form implies 1st form of 2nd LAW

{ N.B. Q.E.D = "Quod Erat Demonstrandum" in Latin
means what was set forth to be proved.

& N.B = "Nota Bene" in Latin: Note Well. }