Some General Features of Entropy

Raj Pala,
rpala@iitk.ac.in
Department of Chemical Engineering,
Associate faculty of the Materials Science Programme,
Indian Institute of Technology, Kanpur.

Last lecture: Irreversible-Less Work$_{HE}$→More Heat rejection

- Irreversible/Actual HE:

$$W_{ac} < W_{rev} \quad \Rightarrow \quad Q_{L\,ac} > Q_L$$

$$\oint \delta Q = Q_H - Q_L \geq 0$$

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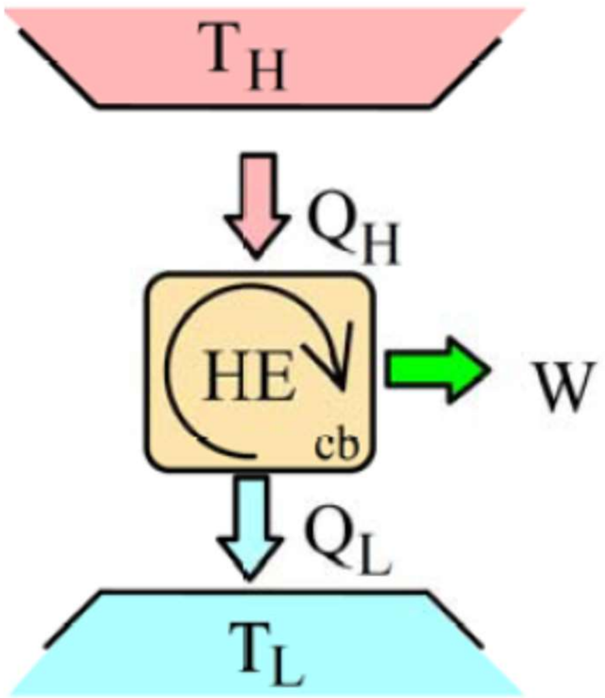
$$\oint (1/T)\,\delta Q = \frac{Q_H}{T_H} - \frac{Q_L}{T_L} = 0$$

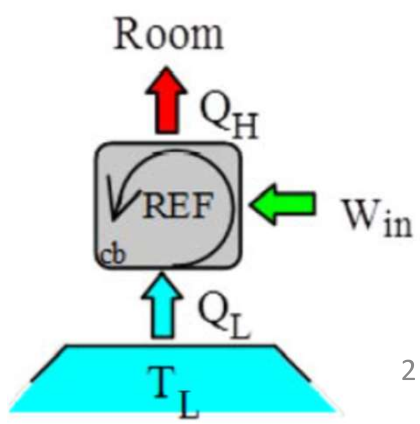
$$\oint (1/T)\,\delta Q = \frac{Q_H}{T_H} - \frac{Q_{L\,ac}}{T_L} < 0$$

All cycles: $\oint \frac{\delta Q}{T} \leq 0$

= reversible processes; < irreversible processes



Figs: TD-Borgnakke & Sonntag



Closed cyclic path & series of Carnot cycles

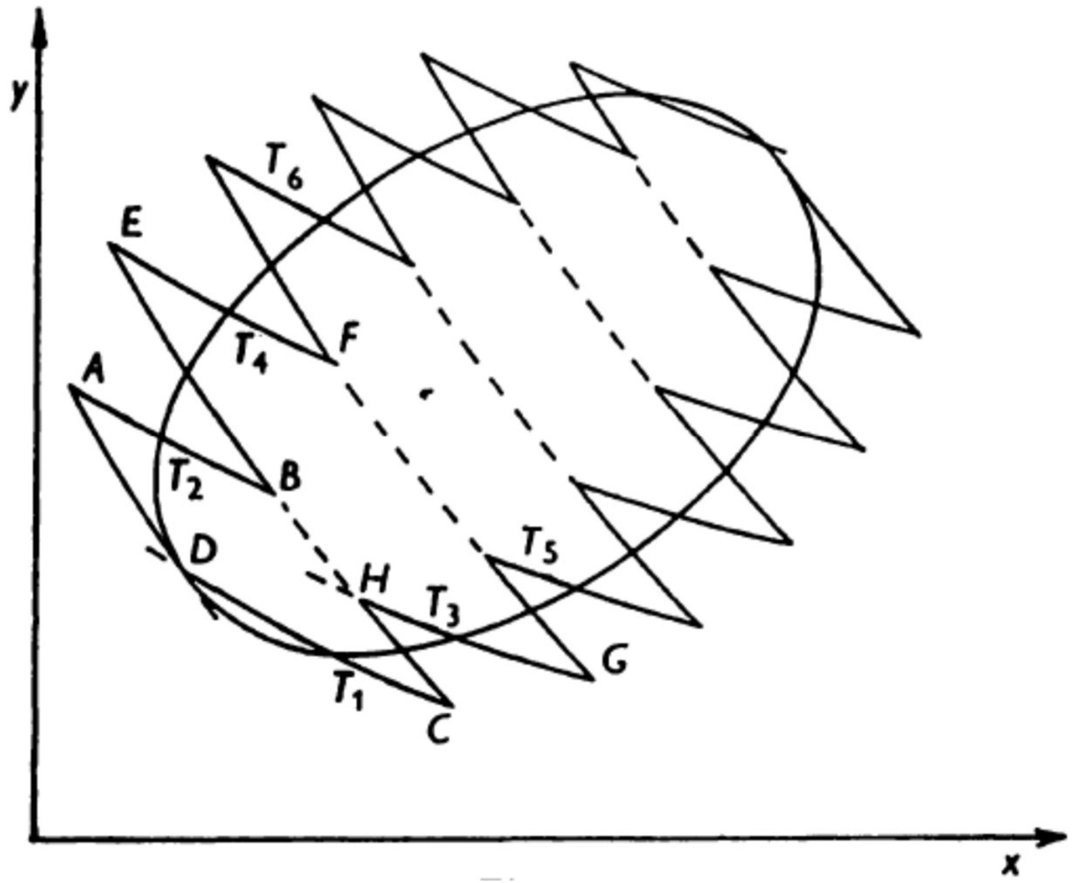
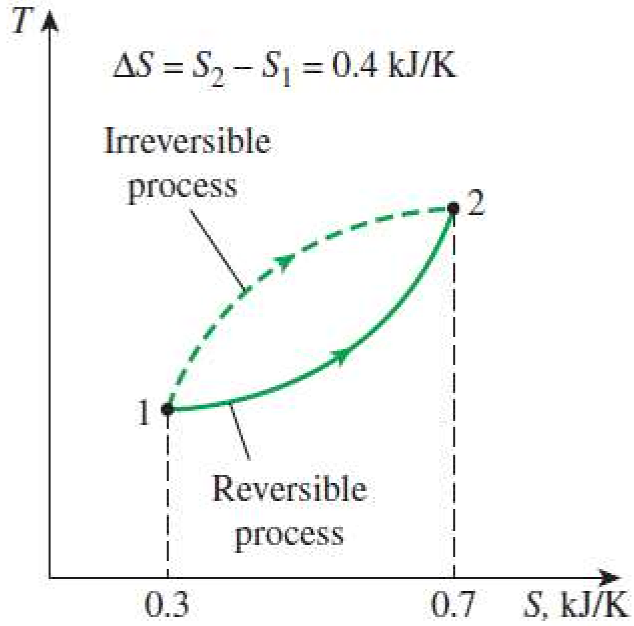


Fig: TD-Denbigh

Entropy of internally reversible processes

- T vs. S plot; Extensive S

$$\oint \left(\frac{\delta Q}{T}\right)_{\text{int rev}} = 0$$



- Internally reversible isothermal HT (e.g. phase change, HT from reservoir)

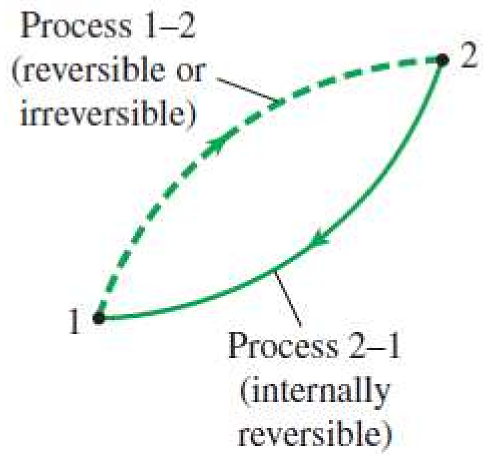
$$\Delta S = \int_1^2 \left(\frac{\delta Q}{T}\right)_{\text{int rev}} = \int_1^2 \left(\frac{\delta Q}{T_0}\right)_{\text{int rev}} = \frac{1}{T_0}\int_1^2 (\delta Q)_{\text{int rev}}$$

$$\Delta S = \frac{Q}{T_0}$$

"Entropy always increases"-when & why?!

$$\oint \frac{\delta Q}{T} \leq 0 \qquad \int_1^2 \frac{\delta Q}{T} + \int_2^1 \left(\frac{\delta Q}{T}\right)_{\text{int rev}} \leq 0$$

$$\int_1^2 \frac{\delta Q}{T} + S_1 - S_2 \leq 0 \qquad S_2 - S_1 \geq \int_1^2 \frac{\delta Q}{T}$$



- (In)equality for (Ir)reversible $dS \geq \frac{\delta Q}{T}$

$$\Delta S_{\text{sys}} = S_2 - S_1 = \int_1^2 \frac{\delta Q}{T} + S_{\text{gen}}$$

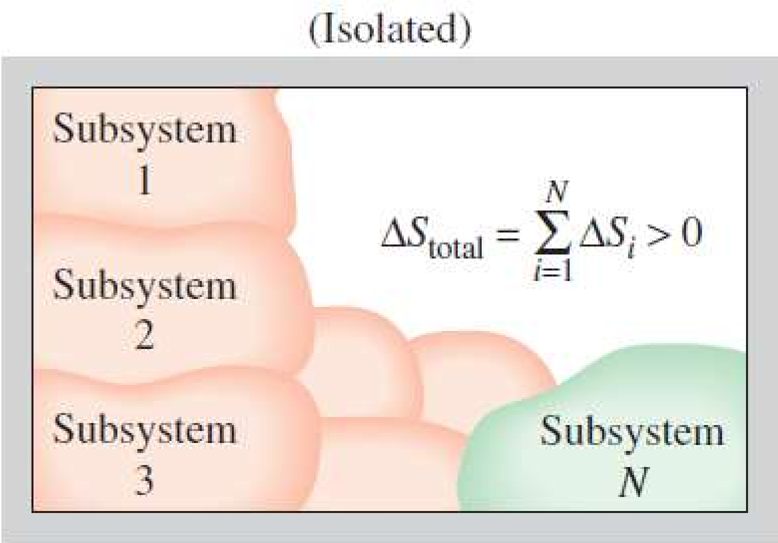
$$S_{\text{gen}} = \Delta S_{\text{total}} = \Delta S_{\text{sys}} + \Delta S_{\text{surr}} \geq 0$$

Figs: TD-Cengel & Boles

Entropy of an isolated system $\geq$ **0**

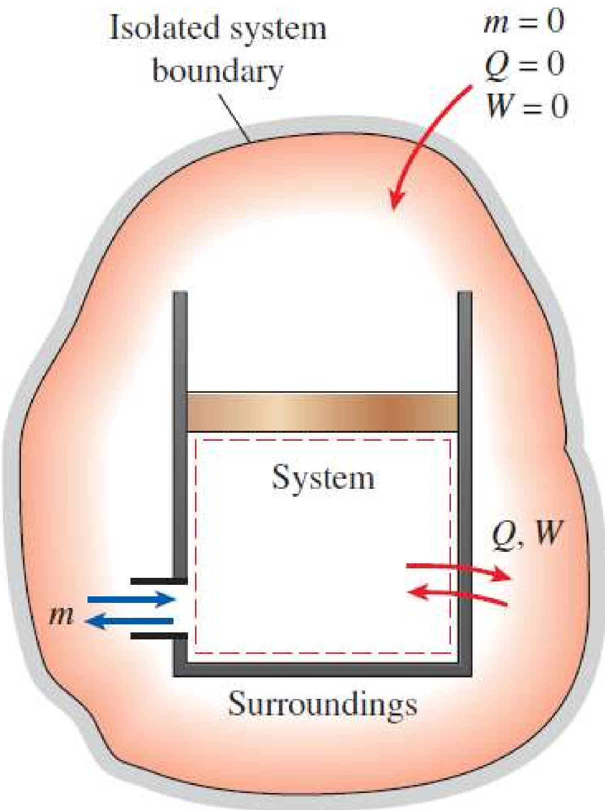
$$\int_1^2 \frac{\delta Q}{T} + S_1 - S_2 \leq 0 \quad S_2 - S_1 \geq \int_1^2 \frac{\delta Q}{T}$$

$$\Delta S_{\text{isolated}} \geq 0$$



$$S_{\text{gen}} = \Delta S_{\text{total}} = \Delta S_{\text{sys}} + \Delta S_{\text{surr}} \geq 0$$

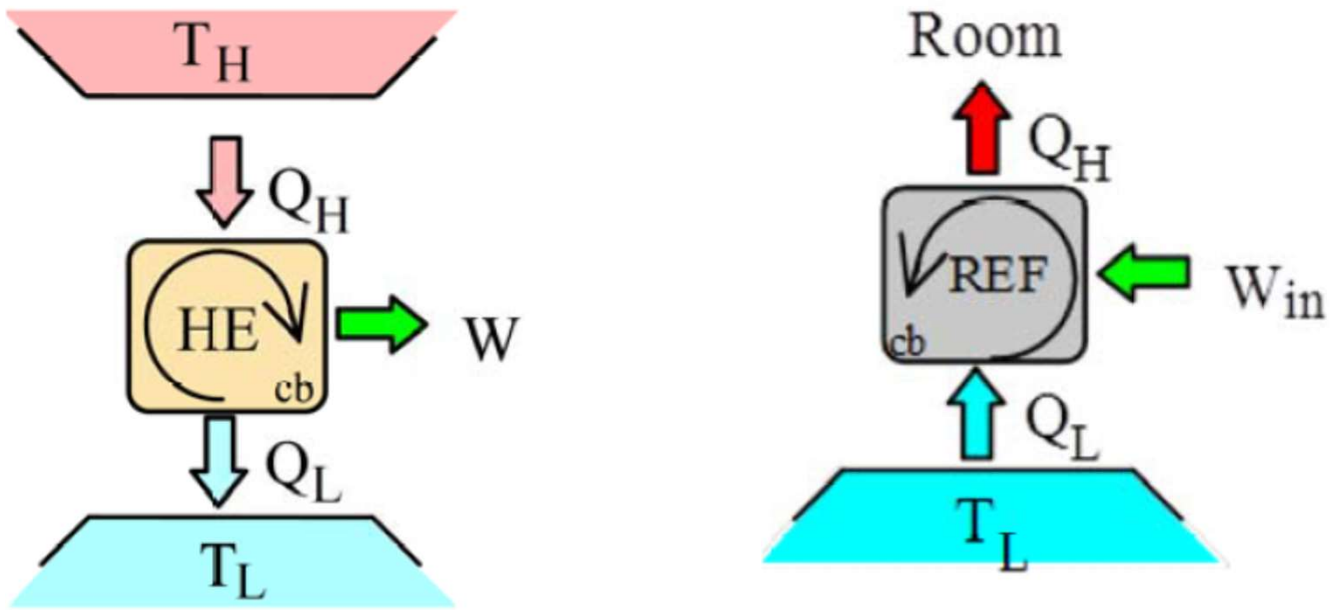
$$S_{\text{gen}} \begin{cases} > 0 & \text{Irreversible process} \\ = 0 & \text{Reversible process} \\ < 0 & \text{Impossible process} \end{cases}$$



Figs: TD-Cengel & Boles

Entropy of an isolated system vs. Clausius Inequality

$$\Delta S_{\text{isolated}} \geq 0$$



All cycles: $\oint \frac{\delta Q}{T} \leq 0$

= reversible processes; < irreversible processes

Figs: TD-Cengel & Boles

Conservation laws…Entropy is not a conserved quantity!

- Much of engineering is about conservation laws (Energy, Mass, Momentum…)
- Noether's theorem- "Every continuous symmetry of the dynamical behavior of a system implies a conservation law for that system"
- Entropy is not a conserved quantity!!!

$$S_{\text{gen}} \begin{cases} > 0 & \text{Irreversible process} \\ = 0 & \text{Reversible process} \\ < 0 & \text{Impossible process} \end{cases}$$

Noether's theorem - Wikipedia
en.wikipedia.org › wiki › Noether's_theorem
https://en.wikipedia.org/wiki/Emmy_Noether
https://en.wikipedia.org/wiki/Symmetry_(physics)

What's next?

- Entropy of substances & processes