# ME 209
# Basic Thermodynamics (Lecture-12)

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## Review of Lecture 11

- Analysed a Carnot engine and showed that the Thermodynamic scale and Ideal Gas Kelvin scale are identical
- Derived the Clausius Inequality, defined entropy and entropy production
- Derived the Second law in terms of change of entropy for an infinitesimal process
- Stated the principle of increase in entropy of the universe.



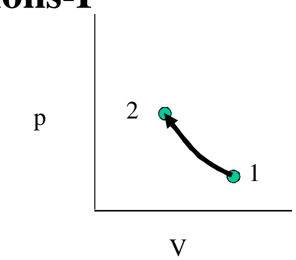
## Agenda for Today

- Understand property relations
- Understand h-s and T-s diagrams



## TdS Relations-I

- Consider two states 1 and 2 as shown
- The entropy change $S_2$-$S_1$ shall not depend on path
- Let us identify the reversible path 1-2




- First law for the closed system can be written as

$$dQ = dU + dW$$

$$\Rightarrow TdS = dU + pdV$$

Note that the above relation involves only properties and hence shall be independent of path

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## TdS Relations-II

- We can also modify the relation derived as follows

$$TdS = dU + pdV$$

$$\Rightarrow TdS = dU + d(pV) - Vdp$$

$$\Rightarrow TdS = dH - Vdp$$

- The above two property relations are the working equations for the evaluation of entropy change and are known as TdS relations

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## T-S Diagram-I

- For adiabatic and reversible process ds = 0
- Further, for a reversible process, the heat transferred per unit mass of the substance can be written as

$$\Rightarrow Q_R = \int_1^2 Tds$$

- The above has motivated construction of T-s diagram. Its usefulness is established by considering analysis of Carnot Cycle

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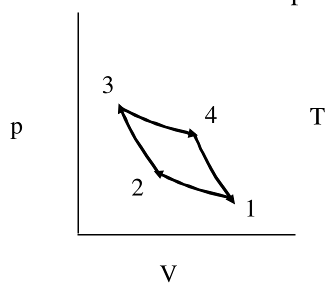
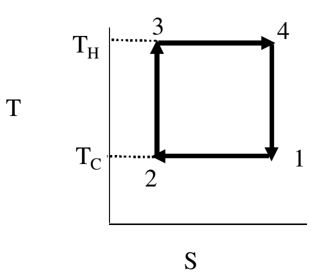
## T-S Diagram-II

1. Isothermal Compression (1-2)
2. Adiabatic Compression (2-3)
3. Isothermal Expansion (3-4)
4. Adiabatic Expansion (4-1)

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## T-S Diagram-III

- Heat rejected in process 1-2

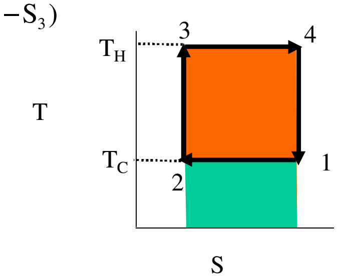
$$\Rightarrow Q_C = -Q_{12} = -\int_1^2 Tds = -T_C(S_2 - S_1)$$

- Heat added in process 3-4

$$\Rightarrow Q_H = Q_{34} = \int_3^4 Tds = T_H(S_4 - S_3)$$

$$\Rightarrow \eta = 1 - \frac{Q_C}{Q_H}$$

$$= 1 - \frac{T_C(S_1 - S_2)}{T_H(S_4 - S_3)} = 1 - \frac{T_C}{T_H}$$



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# h-s diagram

- For open systems, with kinetic and potential effects neglected, we saw that for turbines, pumps/compressor and heat exchangers the heat/work per unit mass of the substance was directly related to change of enthalpy
- This motivated inventions of h-s diagrams, particularly for water substance
- These are called Mollier Diagrams

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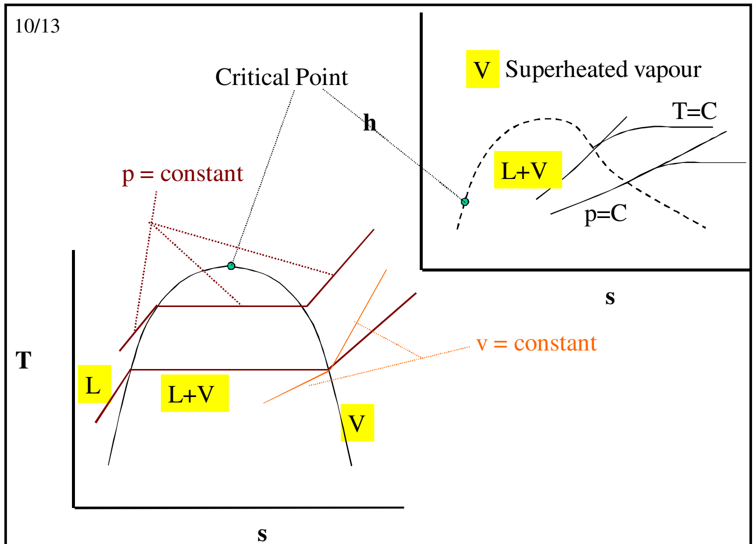


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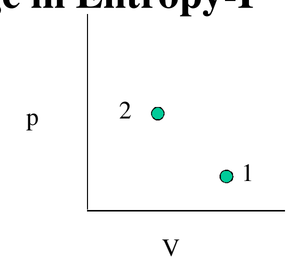
# Evaluation of Change in Entropy-I

**For the system with ideal gas**

- Once the two states are known we can use the TdS relations to evaluate the entropy change




$$TdS = dU + pdV$$

$$\Rightarrow TdS = mc_v dT + \frac{mRT}{V} dV$$

$$\Rightarrow dS = mc_v \frac{dT}{T} + mR \frac{dV}{V}$$

$$\Rightarrow \int_1^2 dS = mc_v \int_1^2 \frac{dT}{T} + mR \int_1^2 \frac{dV}{V}$$

$$\Rightarrow S_2 - S_1 = mc_v \ln\frac{T_2}{T_1} + mR \ln\frac{V_2}{V_1}$$

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# Evaluation of Change in Entropy-II

- Proceeding on similar lines, we can use the second TdS relation

$TdS = dH - Vdp$ and show

$$\Rightarrow S_2 - S_1 = mc_p \ln\frac{T_2}{T_1} - mR \ln\frac{p_2}{p_1}$$

# Evaluation of Change in Entropy-III

**For the system with incompressible substance**

- For incompressible substances the expansion work is absent that makes $c_p = c_v = c$

$$TdS = dU + pdV$$
$$\Rightarrow TdS = dU + \cancel{pdV}$$
$$\Rightarrow TdS = mcdT$$
$$\Rightarrow dS = mc\frac{dT}{T}$$
$$\Rightarrow \int_1^2 dS = mc\int_1^2 \frac{dT}{T}$$
$$\Rightarrow S_2 - S_1 = mc\ln\frac{T_2}{T_1}$$