



ME-251: Thermodynamics and energetics I Second Law III

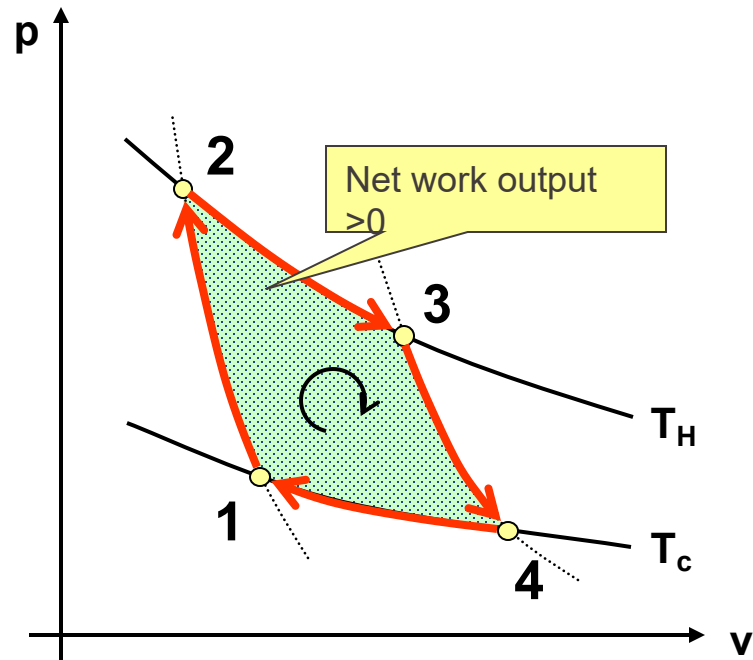
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Energy Transport Advances
Laboratory
EPFL Mechanical Engineering

2025 Fall Semester

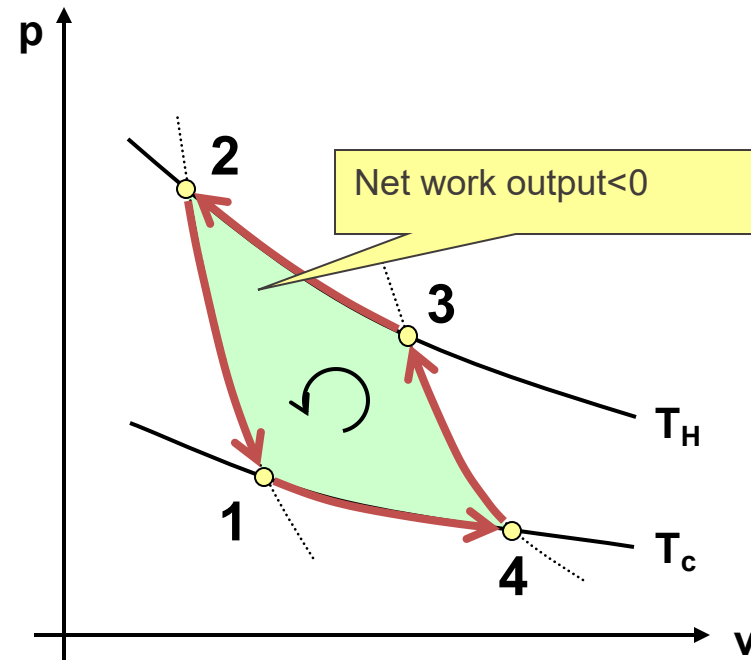
Photo Credit: Trougnouf

- Thermodynamic temperature scale
- Carnot efficiency
- Carnot cycle
- Clausius inequality and its relation to entropy
- Evaluation of entropy change

Power Cycle



Refrigeration cycle



For any thermodynamic cycle (reversible or not), $\oint \frac{\delta Q}{T} \leq 0$

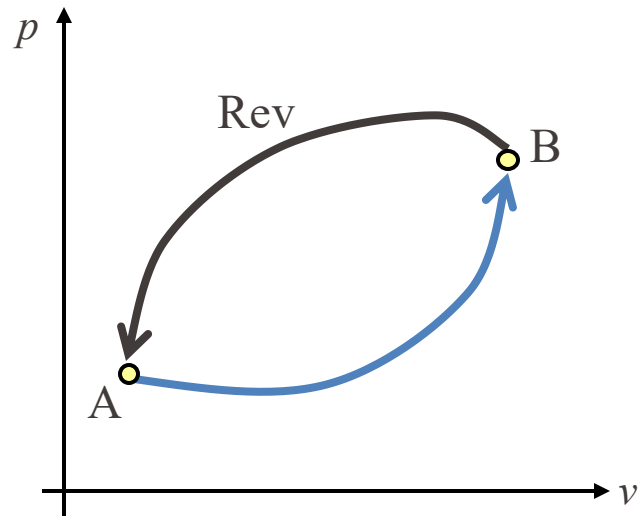
where δQ represent the heat increment supplied to the system at temperature T (negative value means heat discharge)

Construct a state function S

$$S(B) - S(A) = \int_A^B \frac{\delta Q_{rev}}{T}$$

This defines the entropy S up to a constant

$$S_A = S_{ref} + \int_{ref}^A \frac{\delta Q_{rev}}{T}$$



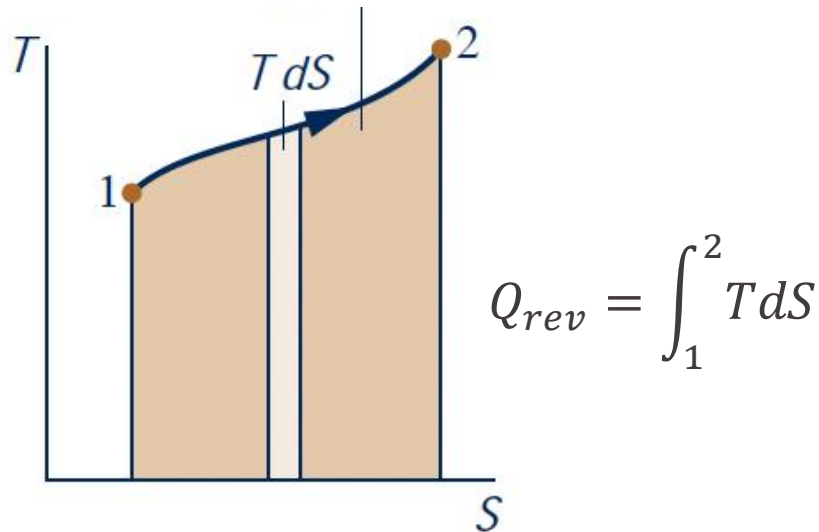
$$du = Tds - pdv \quad dh = Tds + vdp$$

For liquid-vapor phase change $h_{fg} = T\Delta s_{fg}$

Incompressible substance $s_2 - s_1 = \int_{T_1}^{T_2} \frac{c(T)}{T} dT$

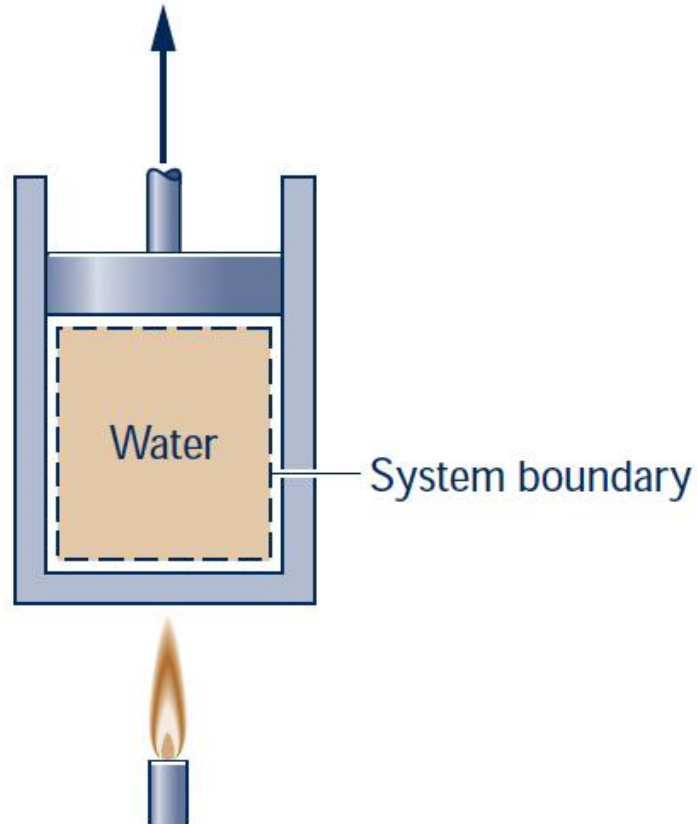
Ideal gas $s_2 - s_1 = \int_{T_1}^{T_2} \frac{c_v(T)}{T} dT + R \ln \frac{v_2}{v_1} = \int_{T_1}^{T_2} \frac{c_p(T)}{T} dT - R \ln \frac{p_2}{p_1}$

$$dS = \frac{\delta Q_{rev}}{T} \Rightarrow \delta Q_{rev} = T dS$$



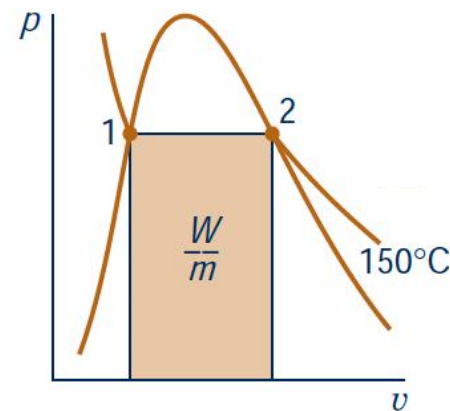
Temperature must be in Kelvin

Area only represents the **reversible** heat transfer



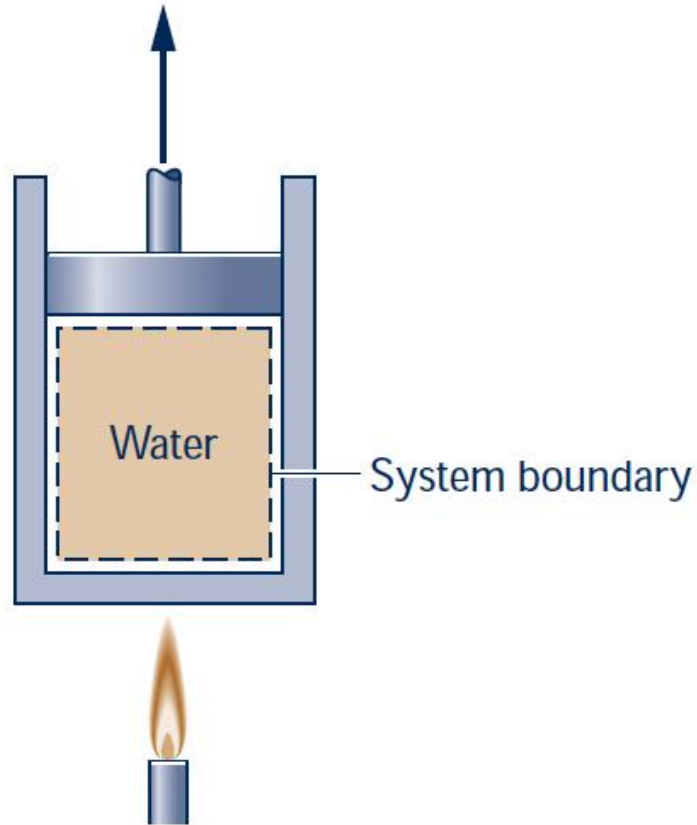
Water contained in a piston-cylinder assembly undergoes a reversible process at 150 °C from saturated liquid to vapor

Determine the work and heat transfer per unit mass.



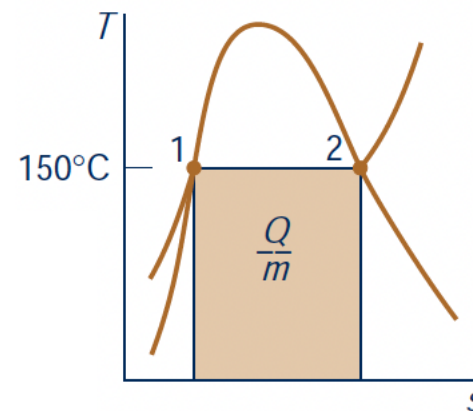
Pressure stays at the saturation pressure at 150 °C

$$\frac{W}{m} = \int_1^2 p dv = p(v_2 - v_1)$$



Water contained in a piston-cylinder assembly undergoes a reversible process at 150 °C from saturated liquid to vapor

Determine the work and heat transfer per unit mass.



$$\frac{Q_{rev}}{m} = \int_1^2 T ds = T(s_2 - s_1)$$



- Entropy balance for closed systems

- Reading: 6.7

Entropy Balance for Closed Systems

change in the amount of entropy contained within the system during some time interval

=

net amount of entropy transferred in across the system boundary during the time interval

+

amount of entropy produced within the system during the time interval

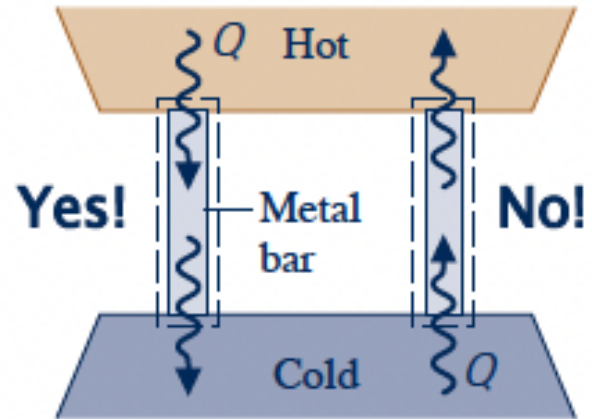
Interpreting Entropy Balance

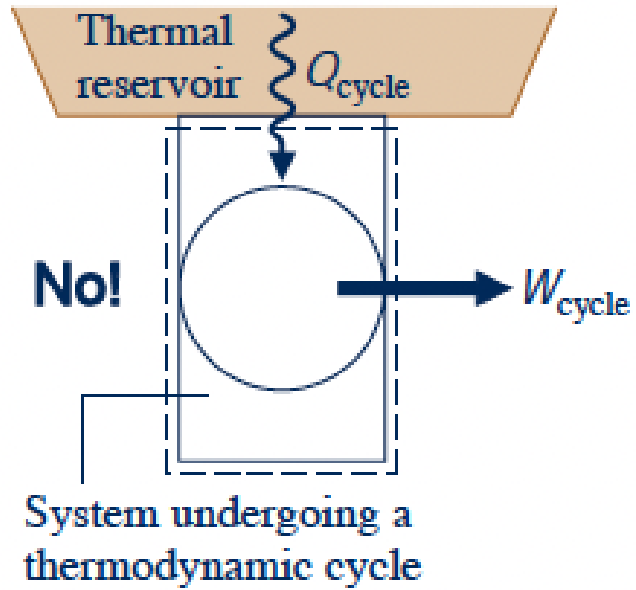


Entropy production is non-negative for any system

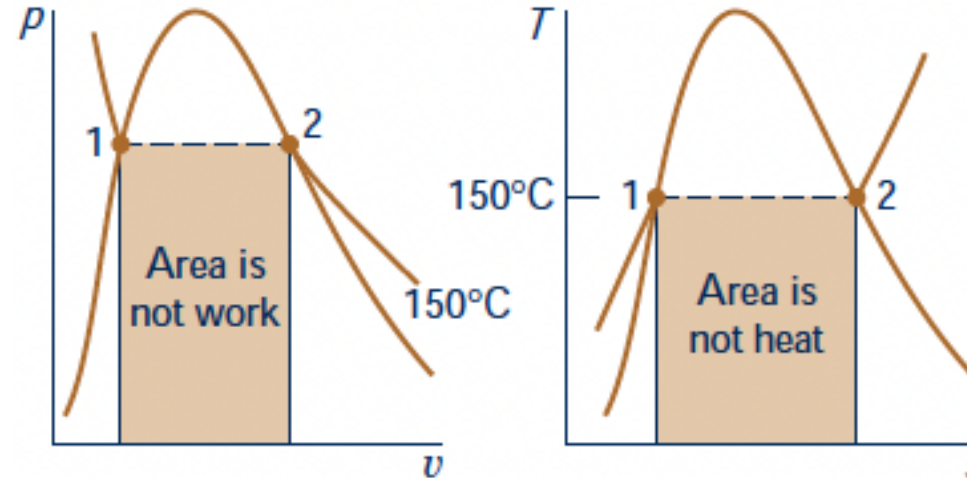
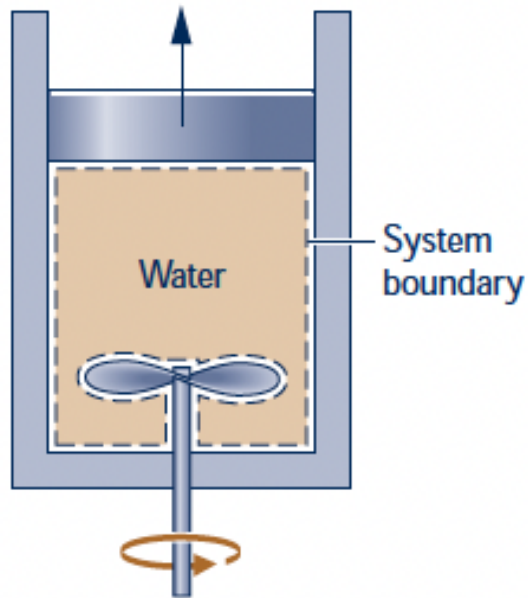
For an isolated system (closed system with no heat transfer), entropy can only go up or stay the same

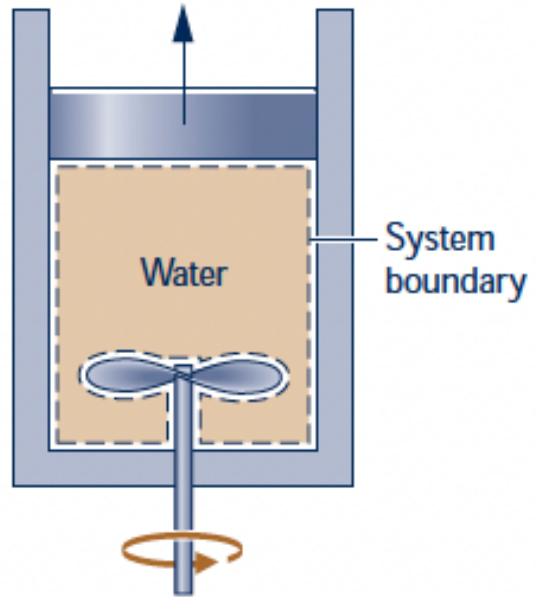
Internally reversible system: $\sigma = 0$





Water contained in a piston–cylinder assembly undergoes an adiabatic process from saturated liquid to saturated vapor at 150 °C. During the process, the piston moves freely, and the water is rapidly stirred by a paddle wheel. **Determine the net work per unit mass and the entropy production per unit mass.**





$$\frac{dS}{dt} = \sum_j \frac{\dot{Q}_j}{T_j} + \dot{\sigma}$$

dS/dt : rate of change of system entropy

$\frac{\dot{Q}_j}{T_j}$: entropy transfer rate through the part of boundary that has temperature T_j

$\dot{\sigma}$: entropy generation rate in the system