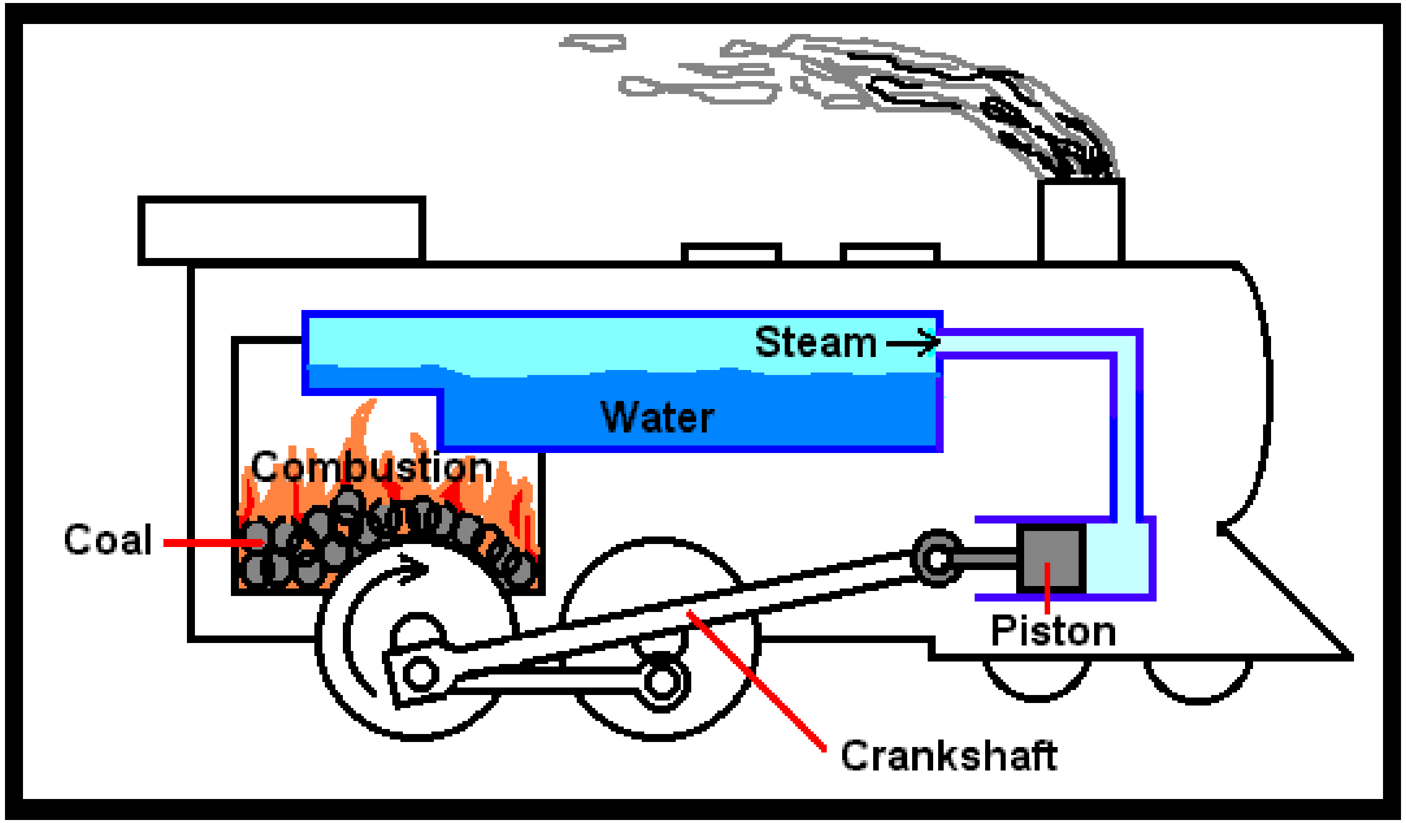
Steam Engine!

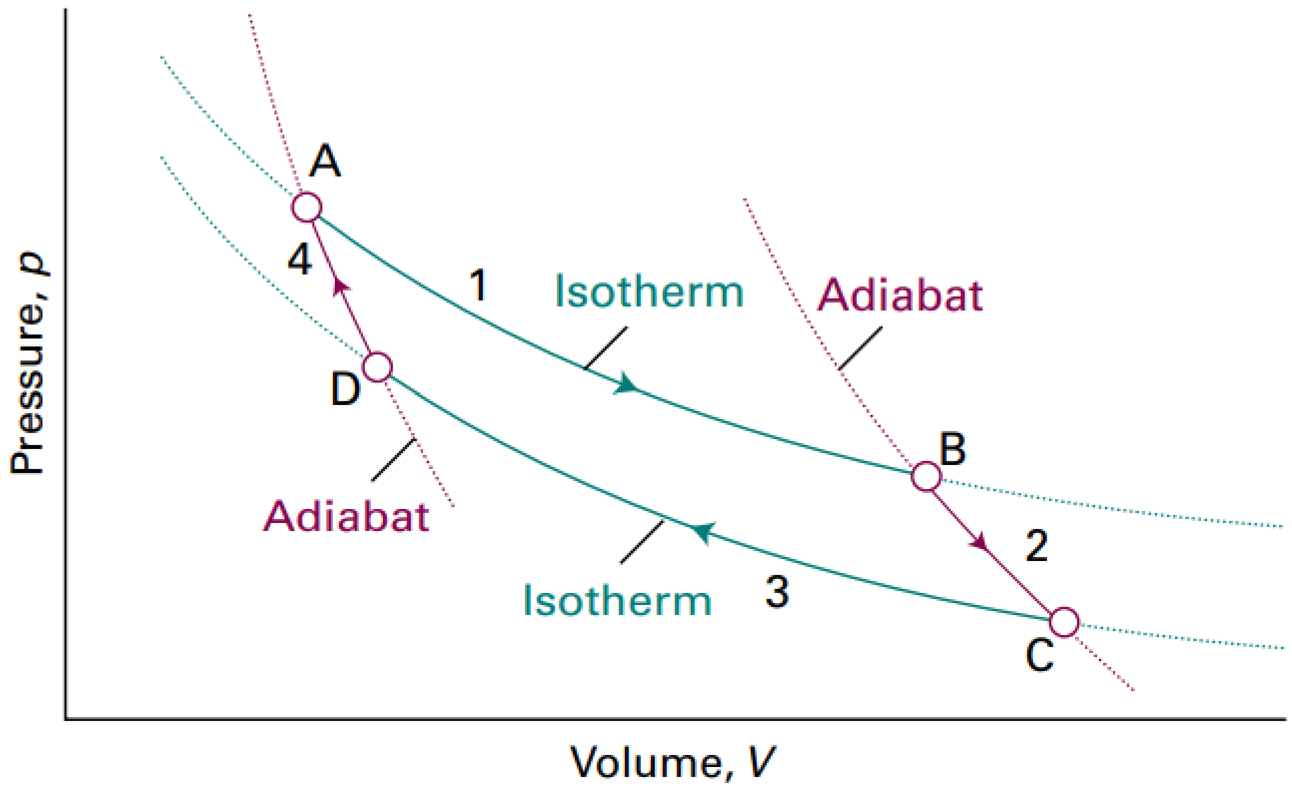
The steam engine is a heat engine that converts thermal energy from steam into mechanical work. It played a crucial role in the Industrial Revolution and transformed industries, transportation, and manufacturing.



https://www.youtube.com/watch?v=2WcmjLVyR4k

Carnot cycle

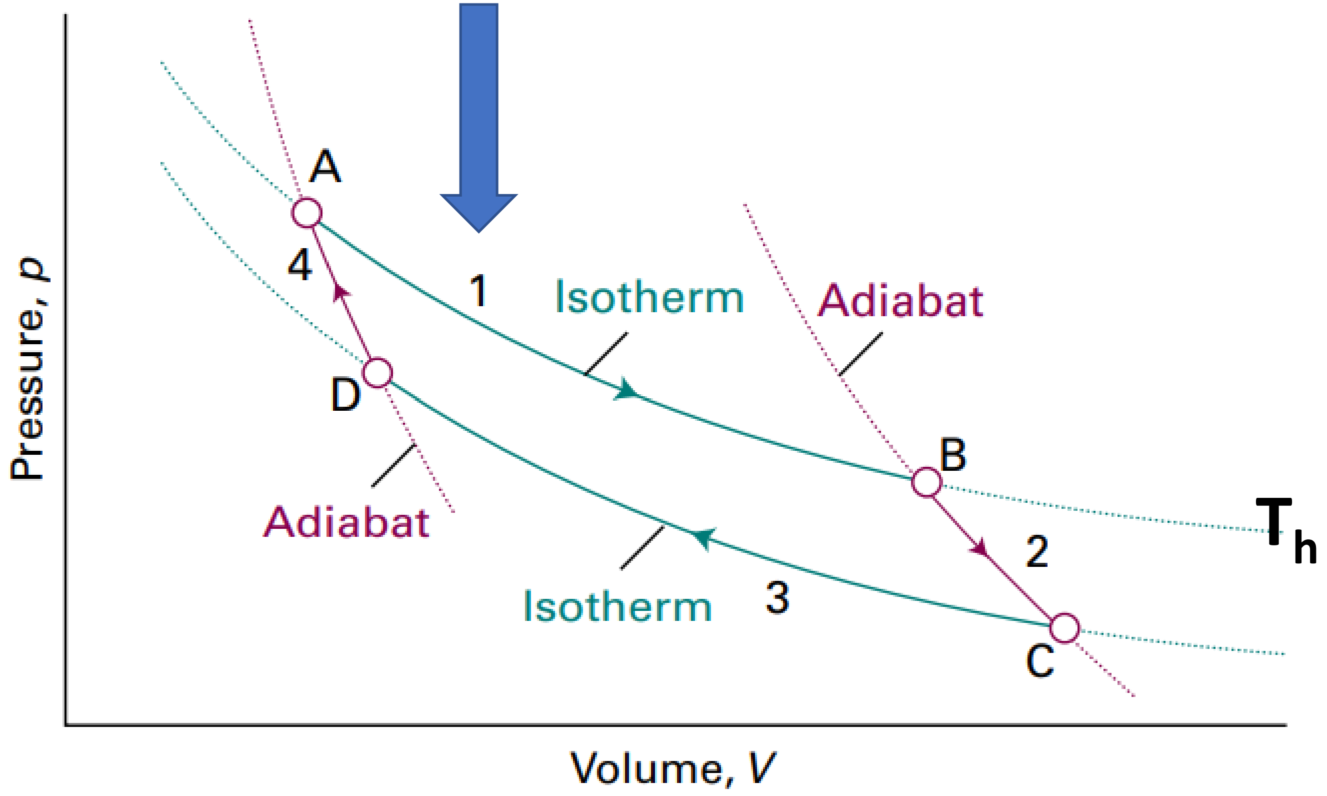
The Carnot cycle is an idealized thermodynamic cycle that describes the most efficient possible heat engine operating between two temperature reservoirs.
It consists of four reversible processes:



- Introduced by Sadi Carnot in 1824
- Carnot's goal was to determine the maximum efficiency that any heat engine could achieve
- Carnot showed that the efficiency of an engine depends **only** on the temperatures of the heat reservoirs, not on the working substance or specific engine design.

Carnot cycle

$$q_h / T_h$$



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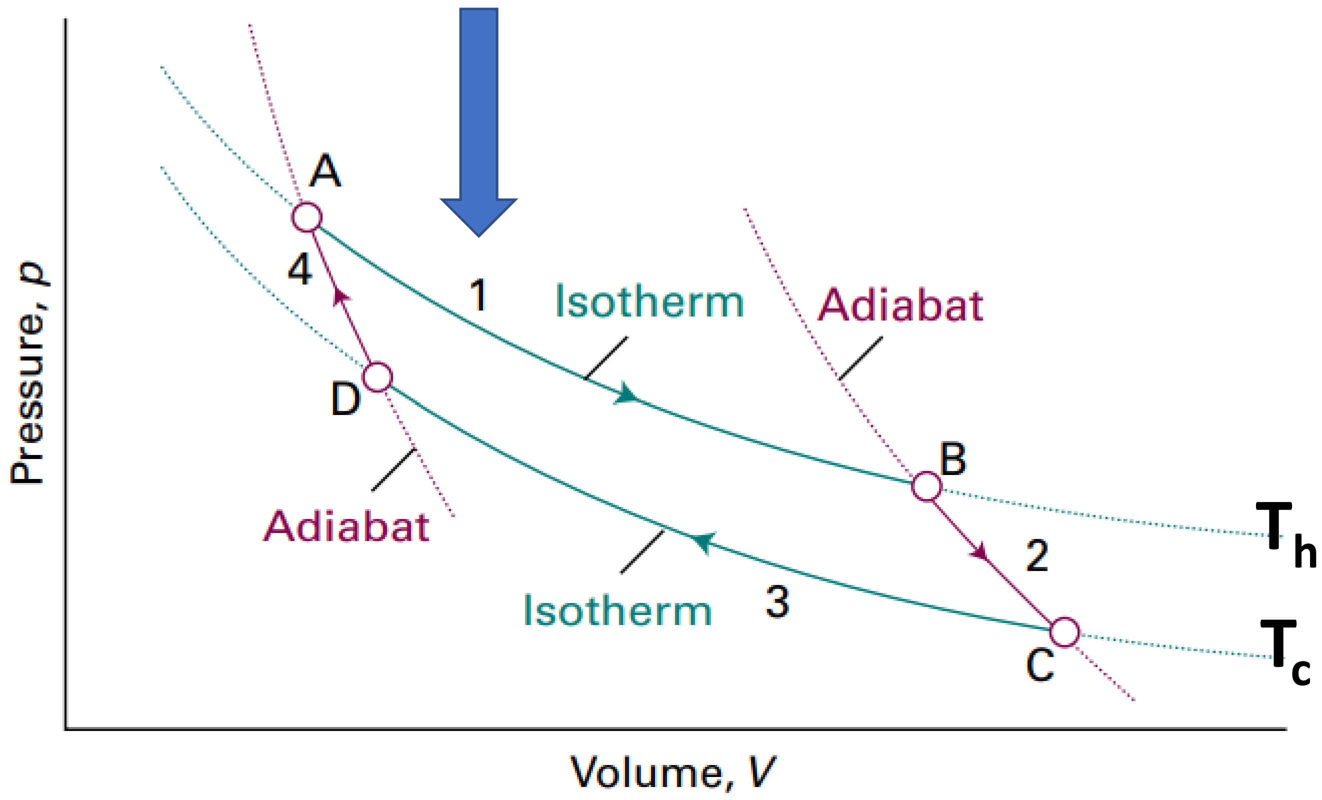

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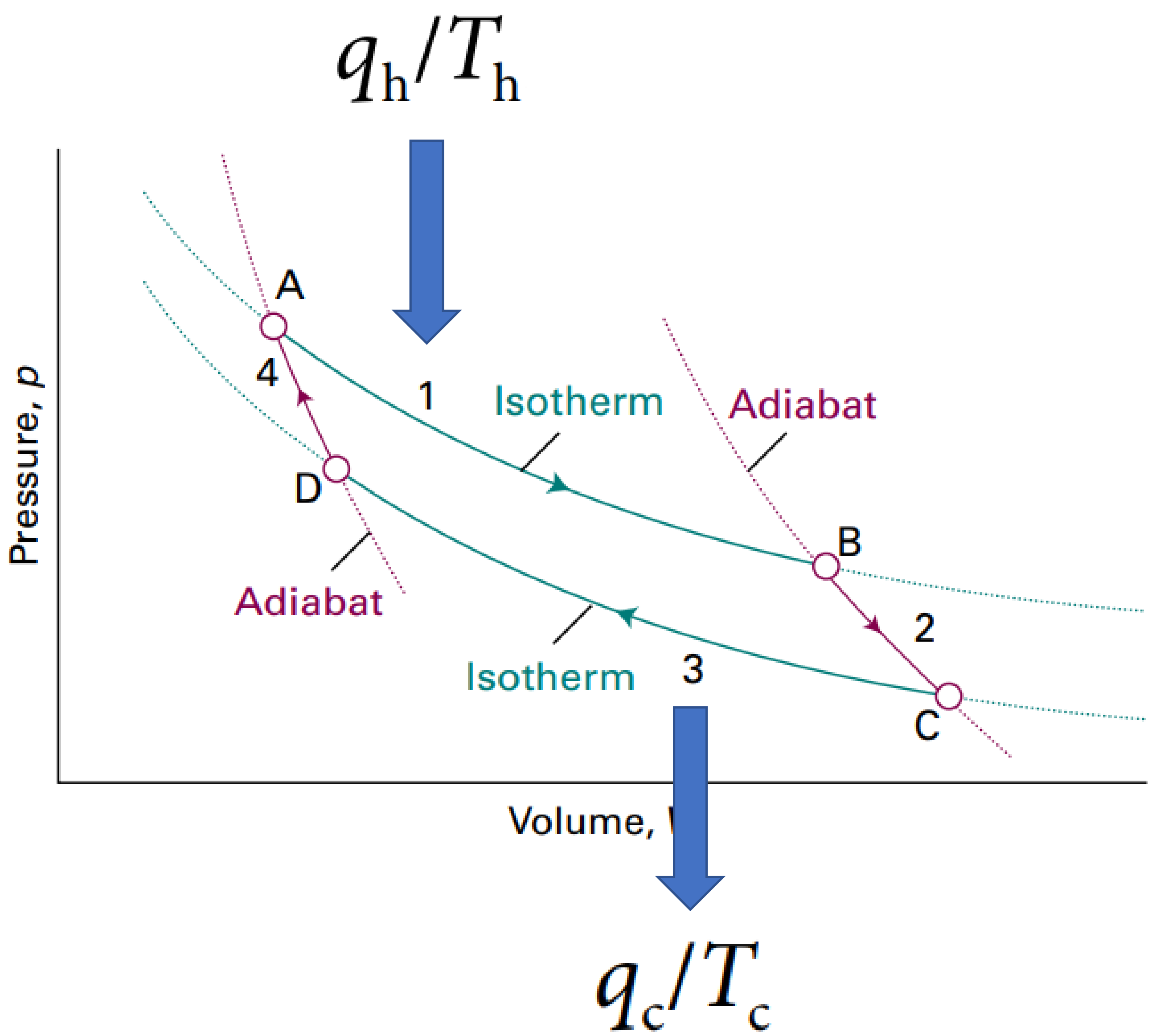

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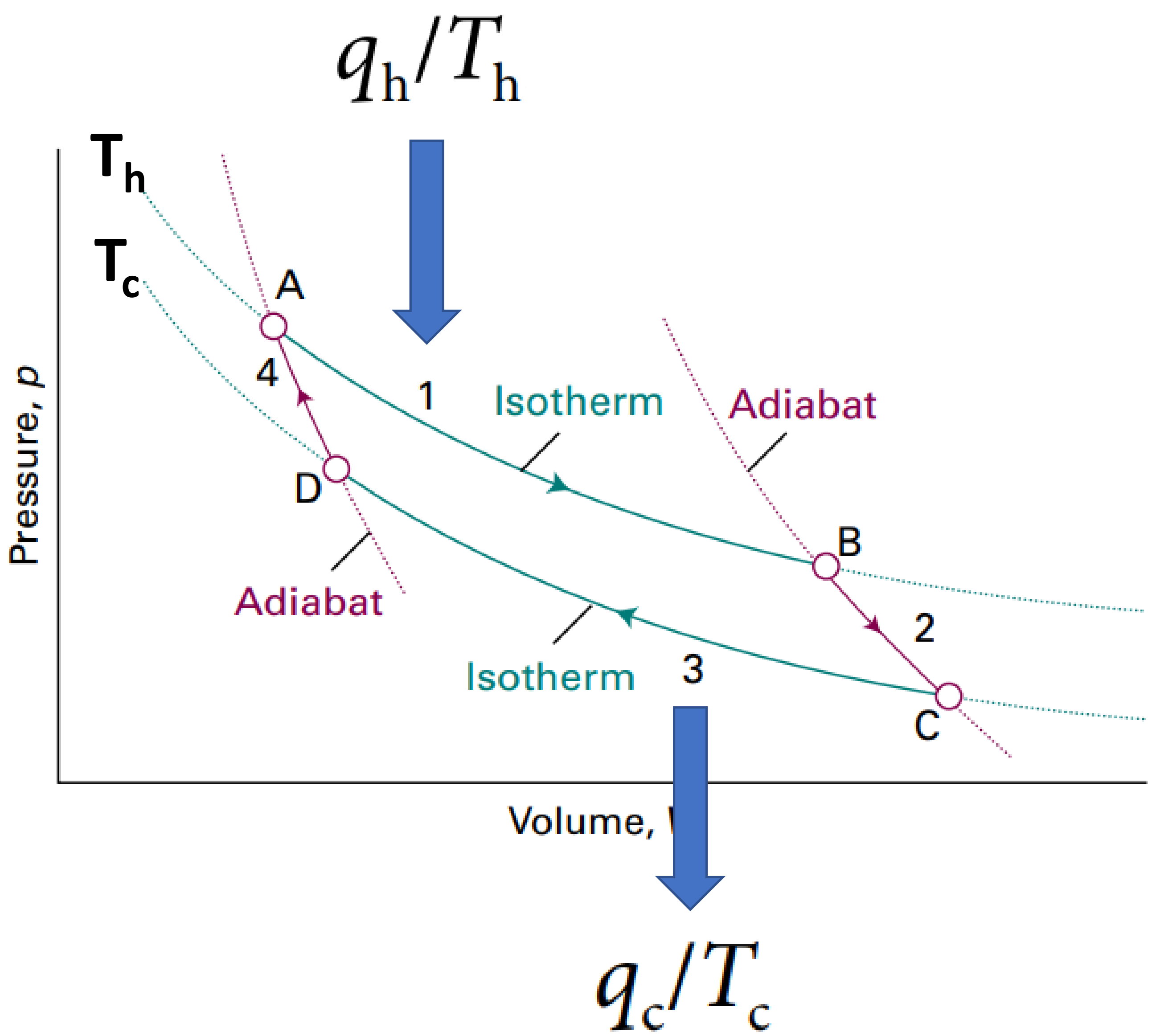

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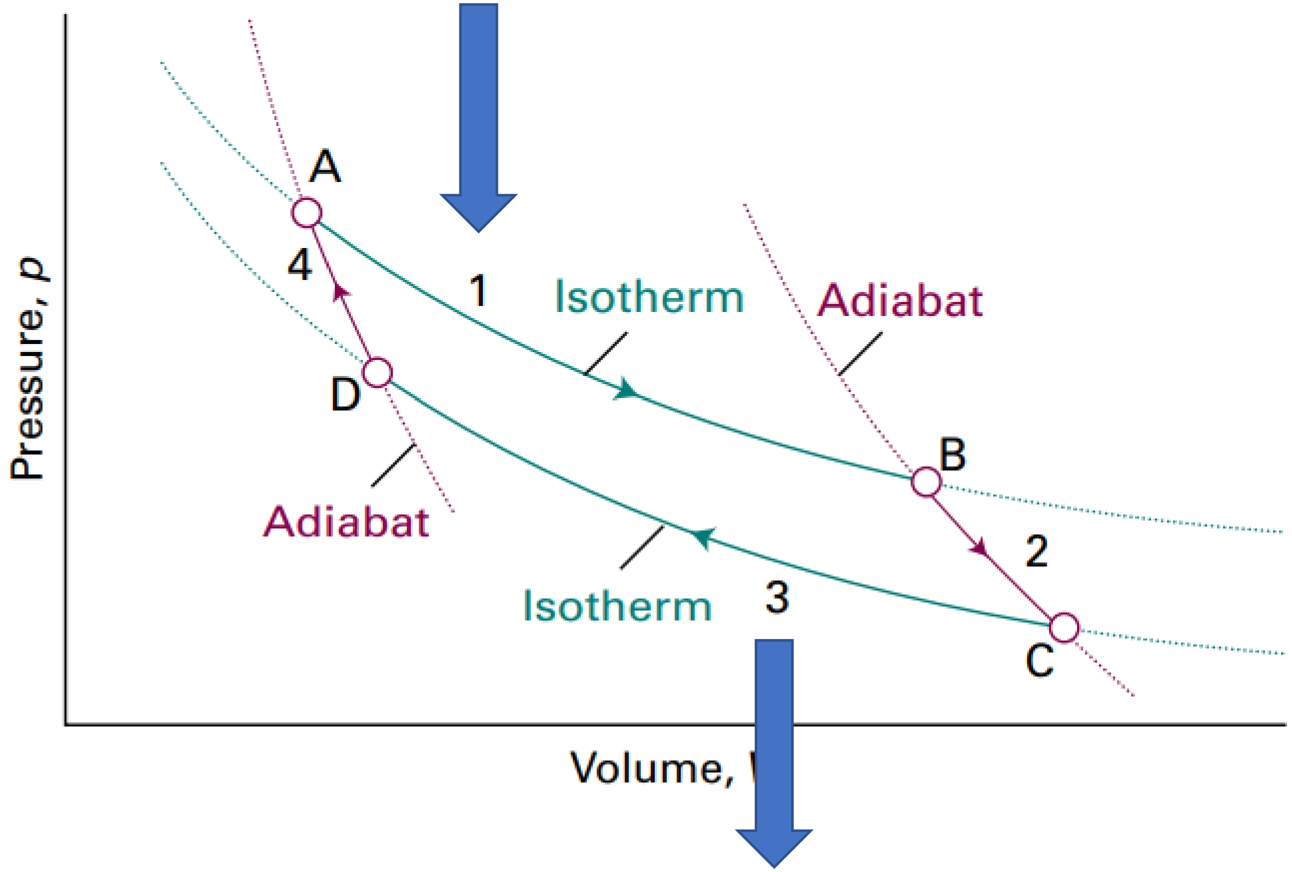
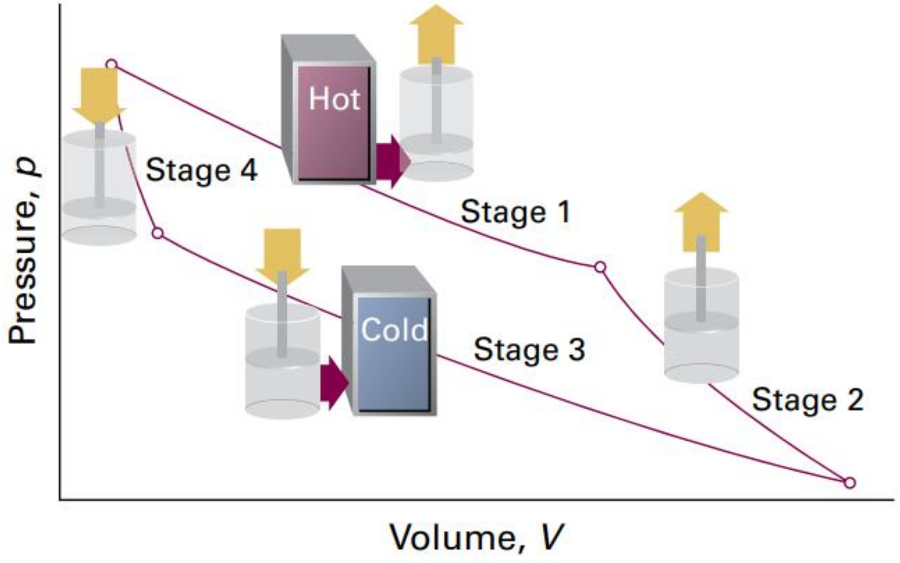


$$q_c/T_c$$



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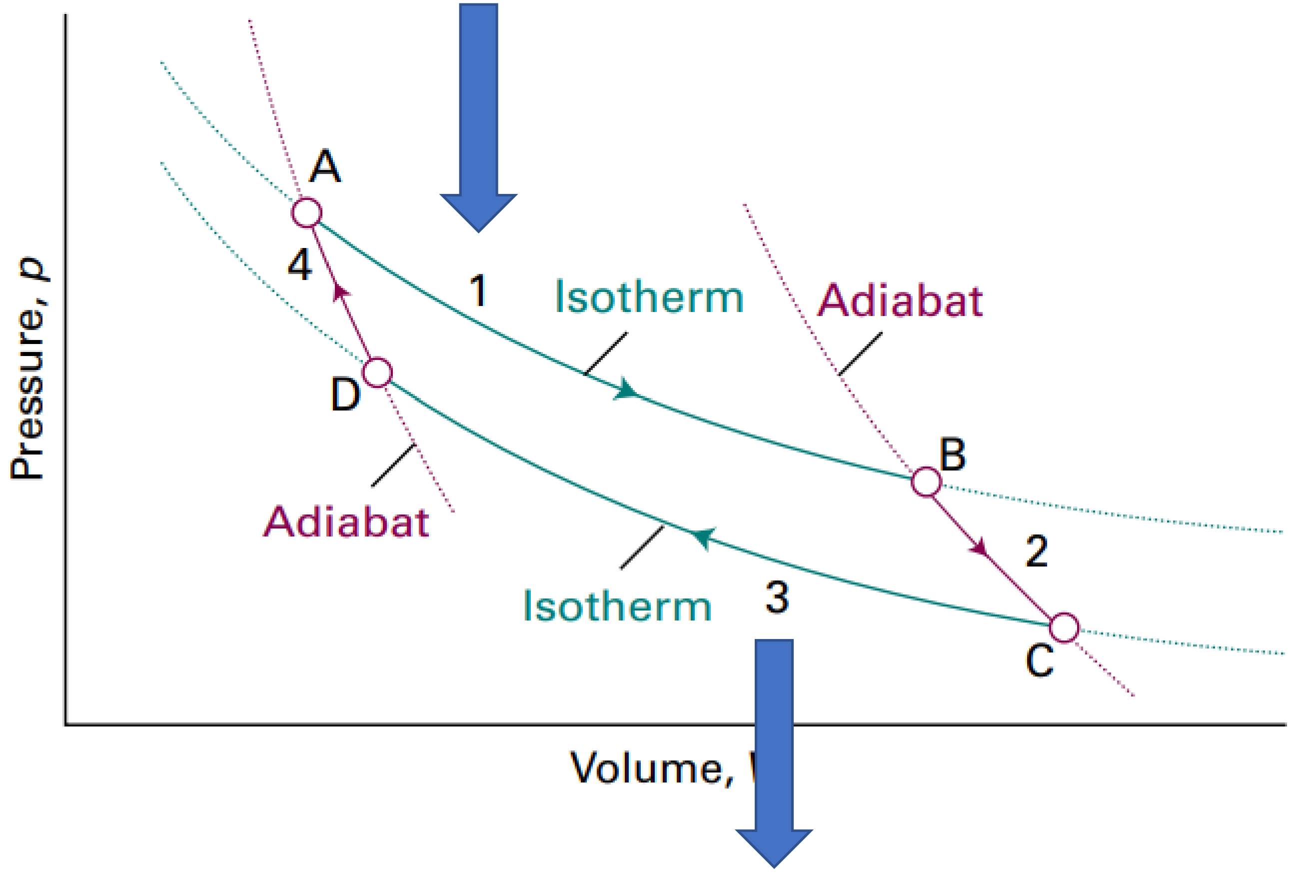

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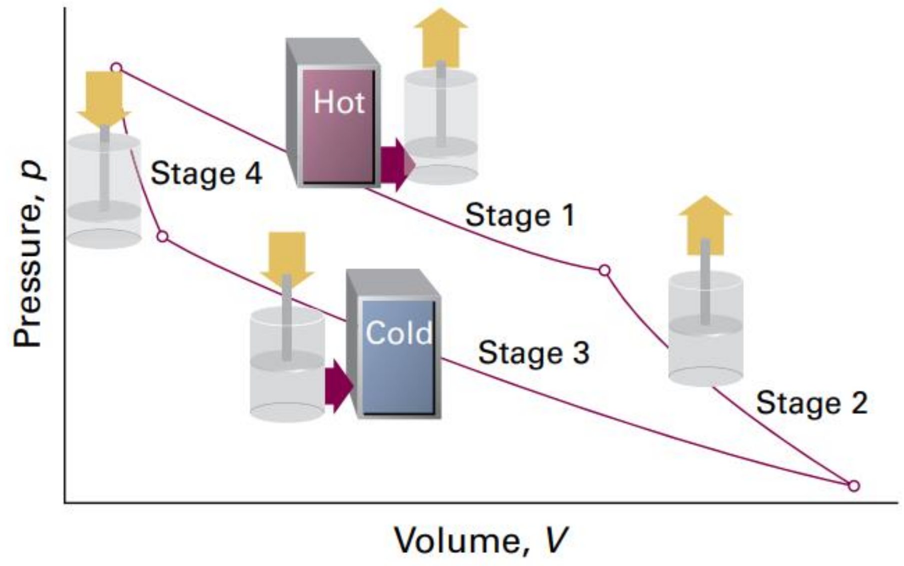
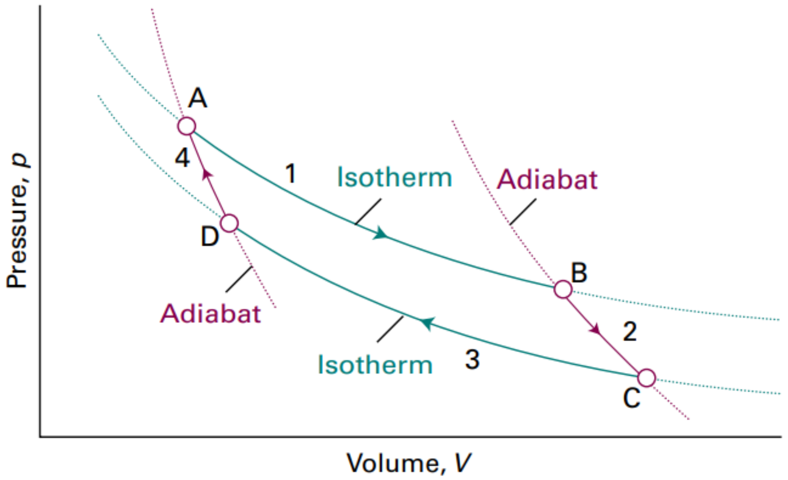


$$\oint dS = \frac{q_h}{T_h} + \frac{q_c}{T_c}$$

Carnot cycle – Show S is a state function

reversible isothermal processes

reversible adiabatic process



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$$\overbrace{q_h = nRT_h \ln\frac{V_B}{V_A}}^{stage\ 1}$$

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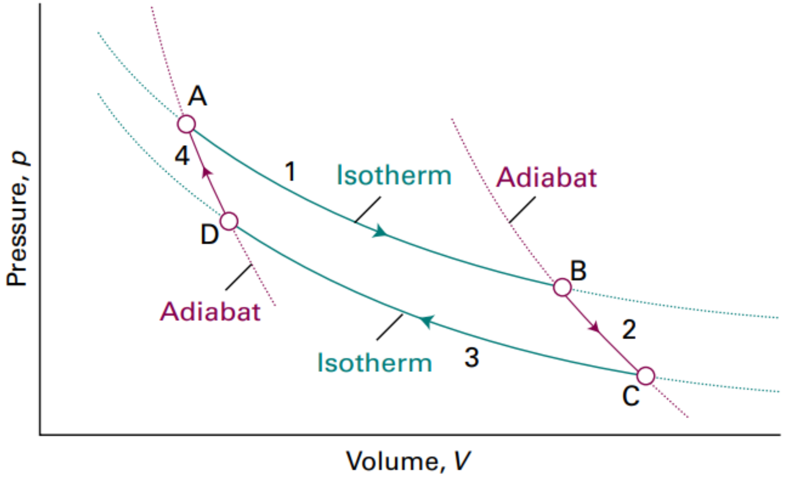

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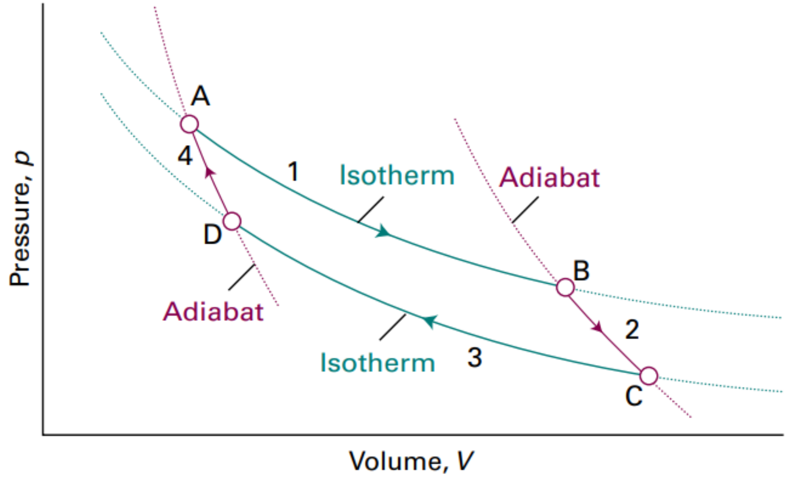
reversible adiabatic process

Stage 2

Stage 4

$$VT^c = \text{constant}$$



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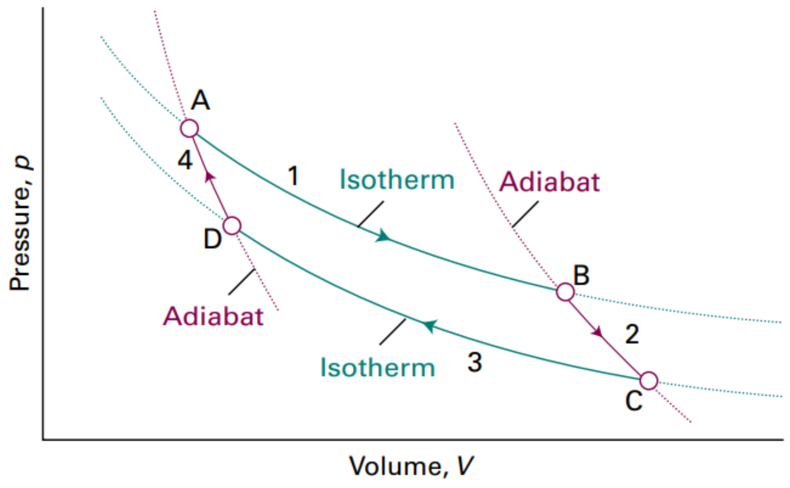

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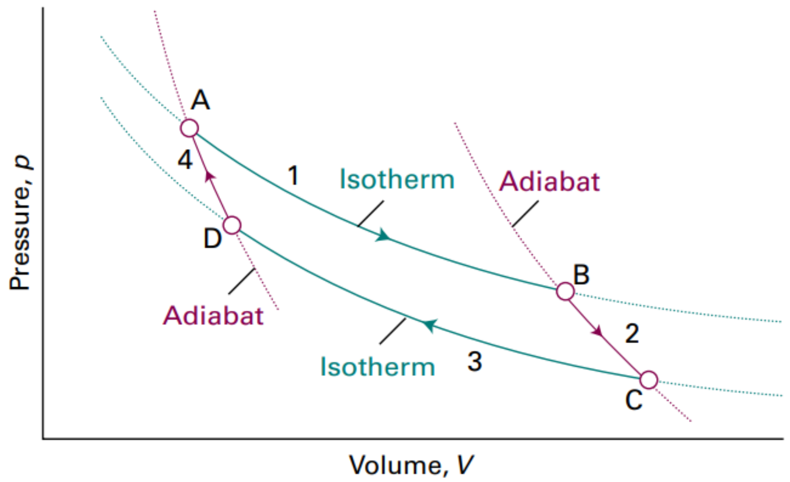

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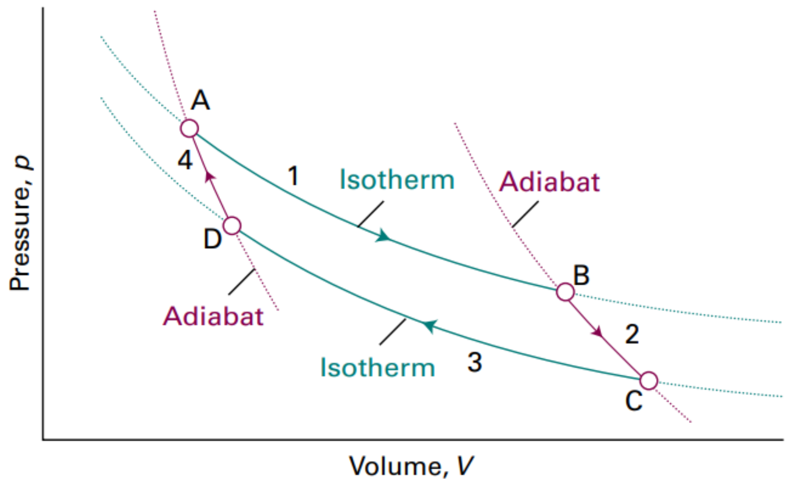

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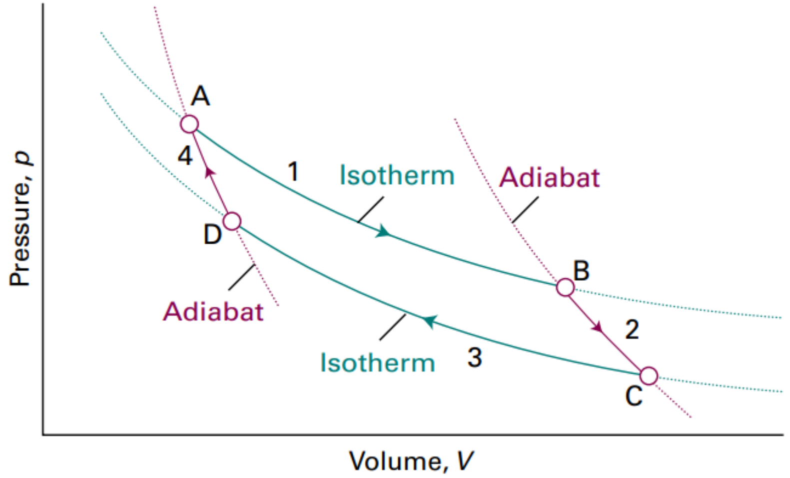

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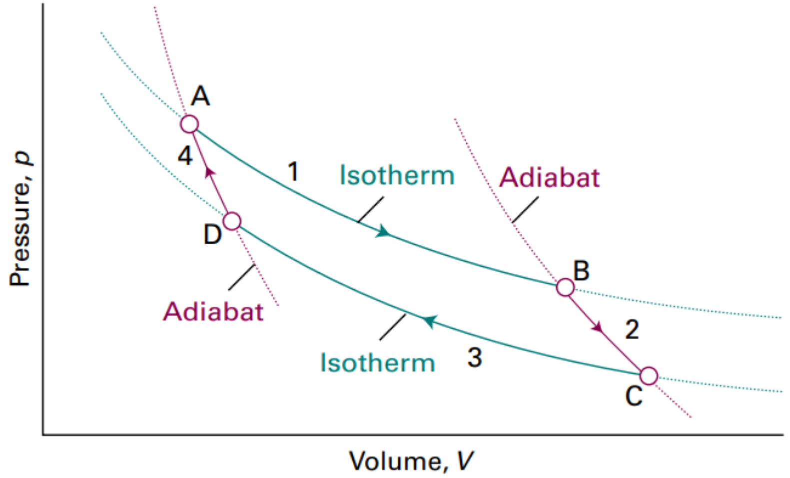

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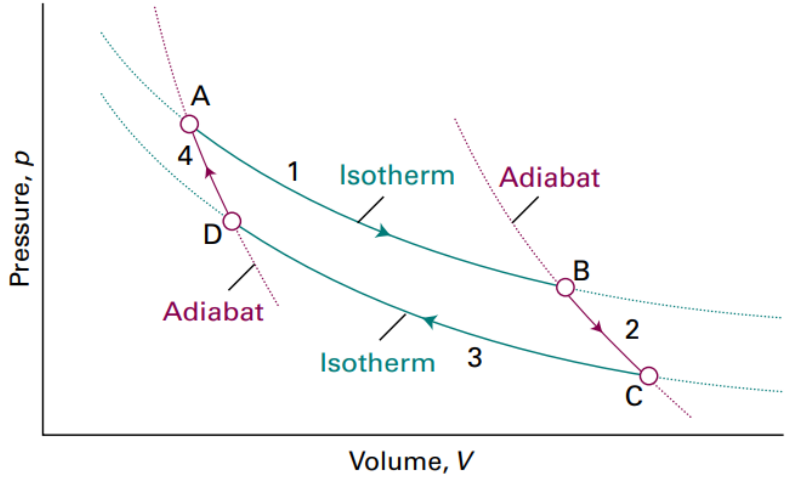

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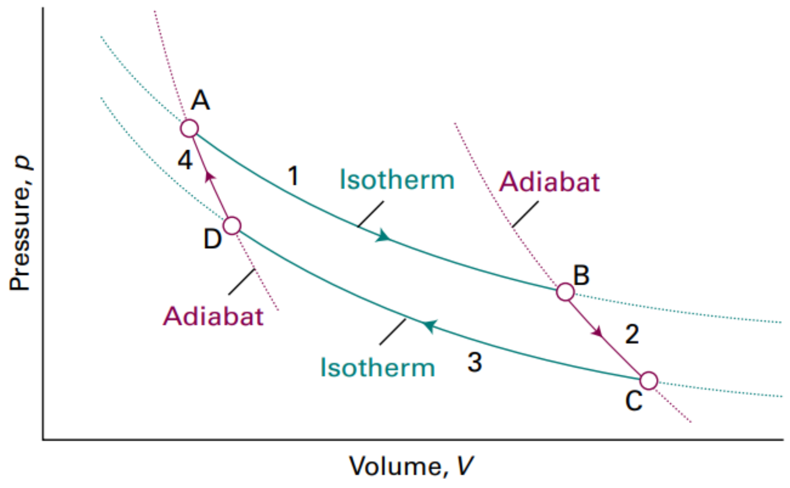

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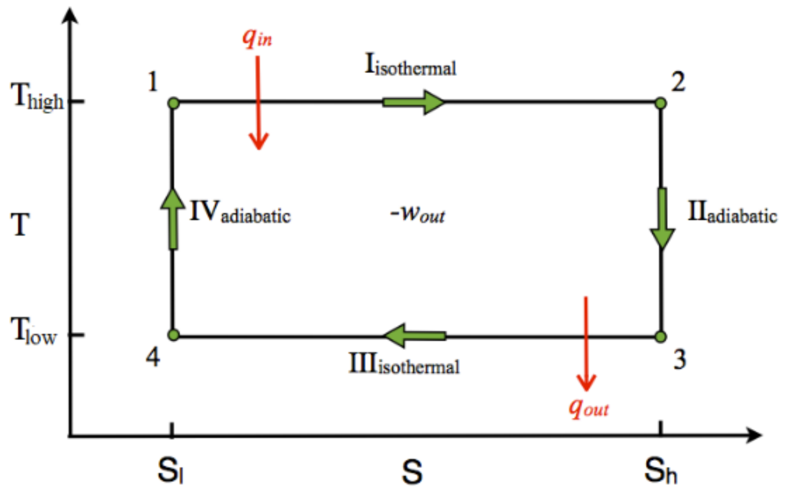
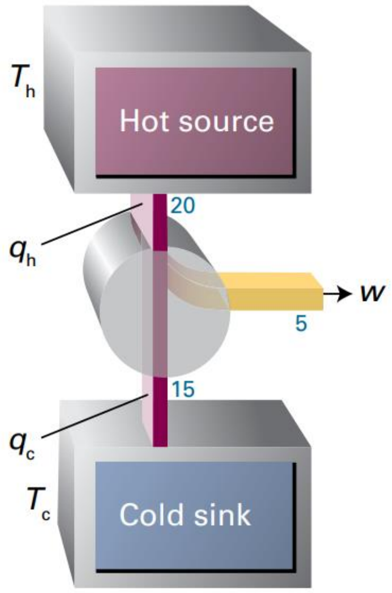
This proves that entropy (S) is a state function and that the net entropy change for a Carnot cycle (a reversible process) is zero.

Carnot engine





Carnot engine is a theoretical heat engine that operates on the Carnot cycle

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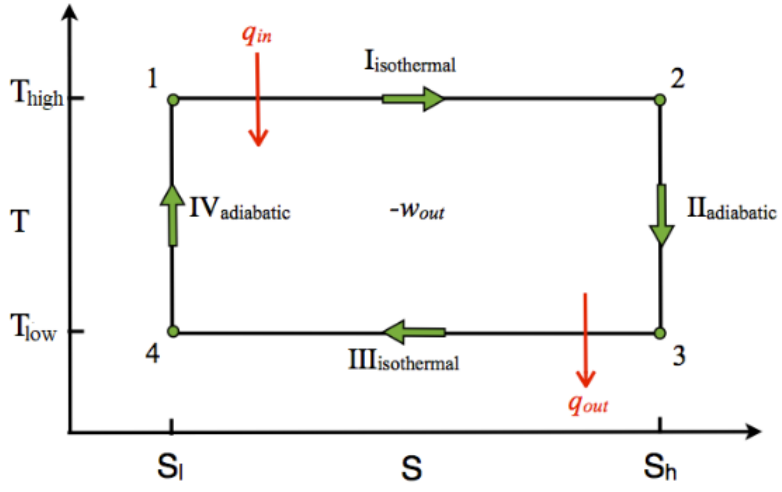
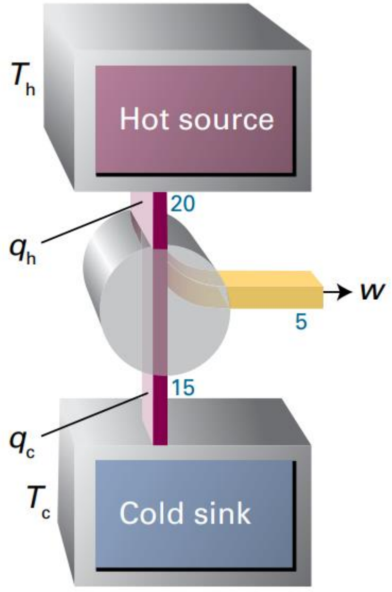
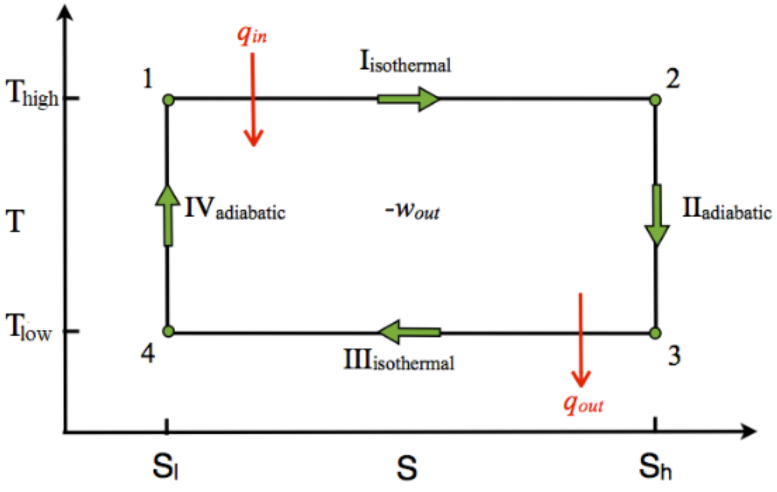


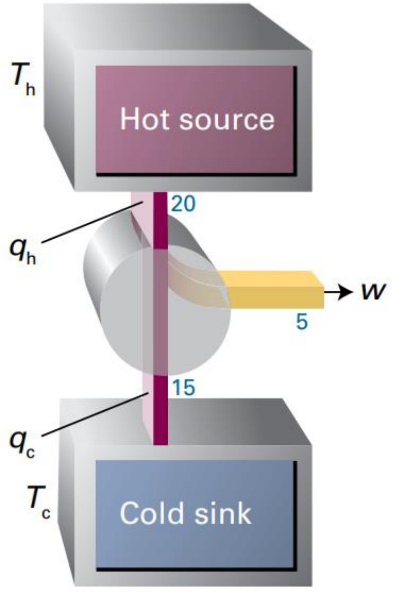


Carnot engine is a theoretical heat engine that operates on the Carnot cycle

A Carnot engine is the most efficient heat engine possible

Carnot engine - efficiency





The Carnot engine is the most efficient heat engine which is theoretically possible.

https://www.youtube.com/watch?v=2WcmjLVyR4k

$$\eta = \frac{\text{work performed}}{\text{heat absorbed from hot source}} = \frac{|w|}{|q_h|}$$

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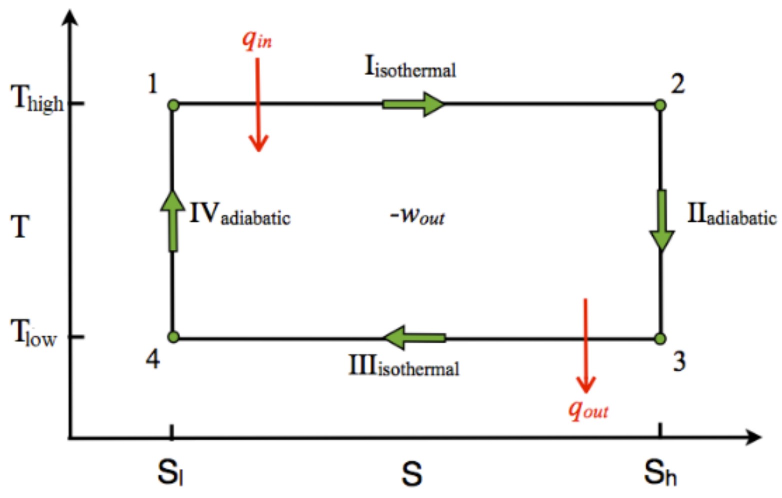

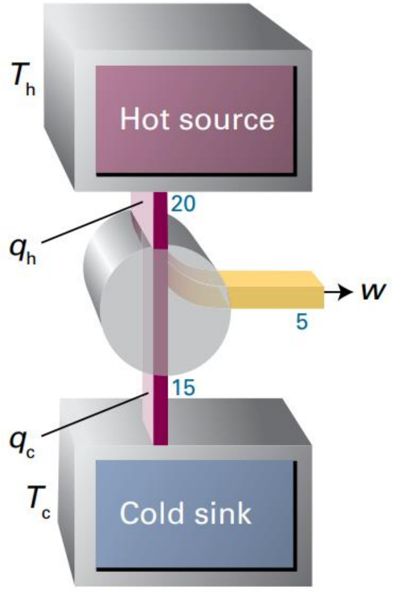

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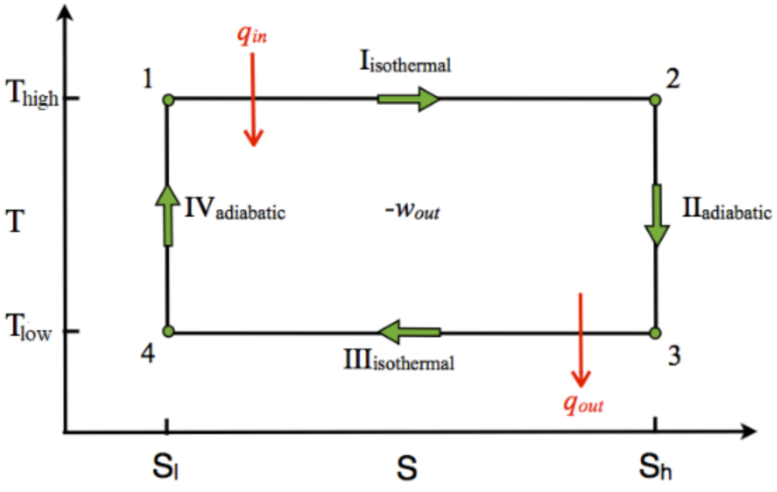

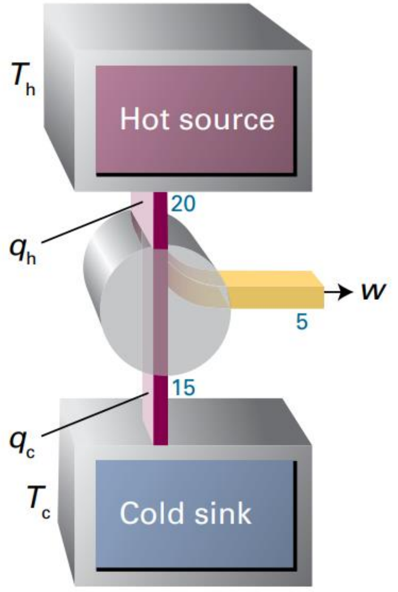

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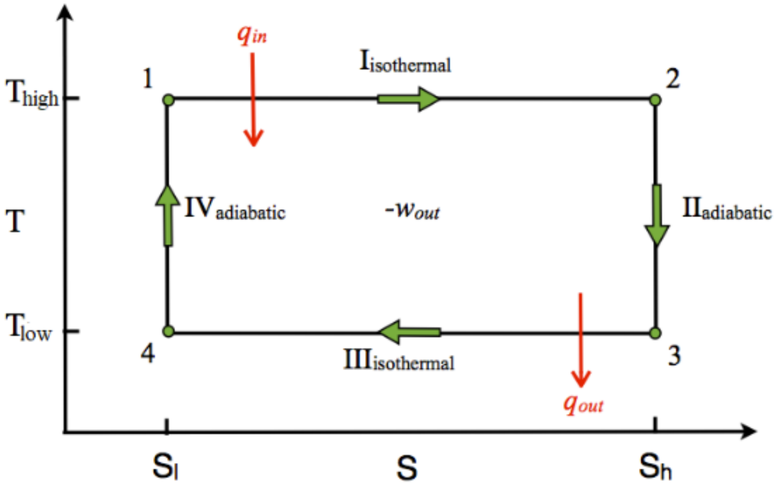

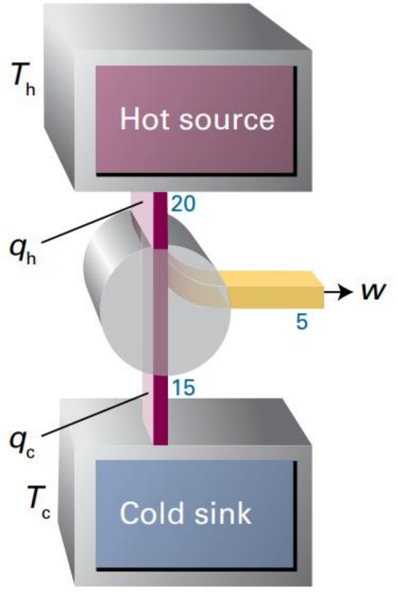

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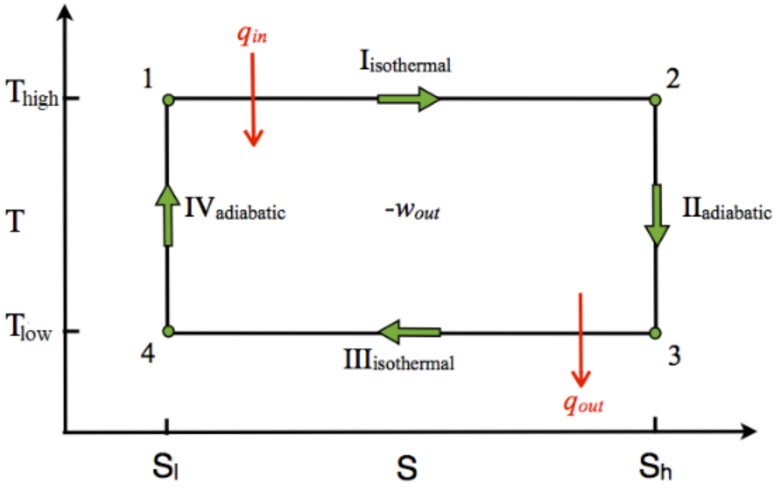
Carnot efficiency

Carnot engine - efficiency



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Carnot efficiency

Example

A certain power station operates with superheated steam at 300 °C (T_h = 573 K) and discharges the waste heat into the environment at 20 °C (T_c = 293 K). The theoretical efficiency is therefore

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$$\eta = 1 - \frac{T_c}{T_h}$$

Carnot efficiency

$$\eta = 1 - \frac{293\,\mathrm{K}}{573\,\mathrm{K}} = 0.489$$

Carnot cycle

All reversible engines working between the same thermal reservoirs have the same efficiency.

Carnot cycle

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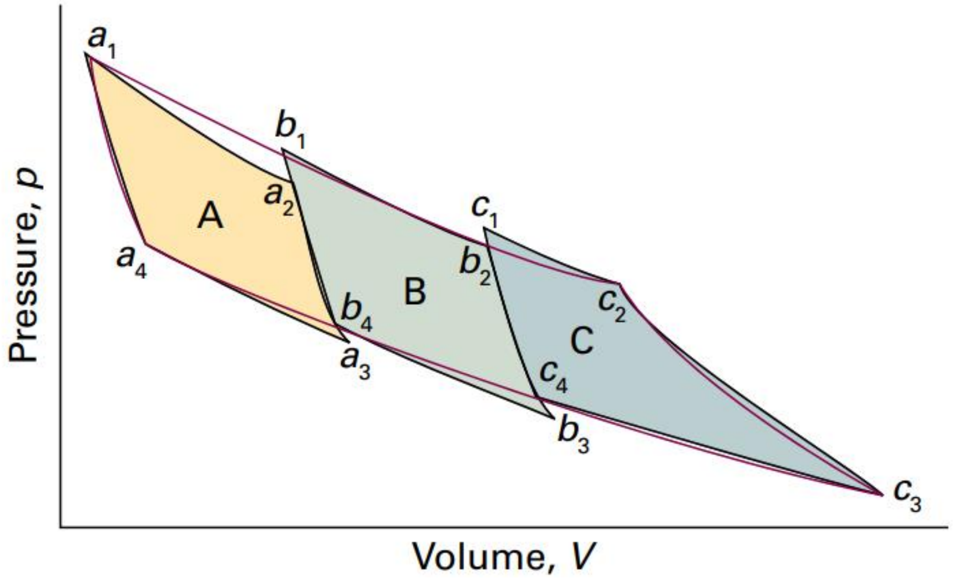

The sum q_{rev}/T around the perimeter is zero

The Clausius inequality

$$dS = \frac{dq_{rev}}{T}$$

Thermodynamic definition of entropy

The Clausius inequality

$$dS = \frac{dq_{rev}}{T}$$

Thermodynamic definition of entropy

$$dS > \frac{dq}{T}$$

For irreversible processes

- In any real (irreversible) cycle, there is always some entropy generation due to irreversibilities like friction, turbulence, or heat transfer with a finite temperature difference

- These factors generate additional entropy beyond the entropy change associated with heat transfer alone, making irreversible processes have a greater total entropy change than their reversible counterparts.

Focus 3: The Second and Third Laws

Entropy

Entropy changes in processes

Entropy measurement

Gibbs free energy

Combining 1st and 2nd law