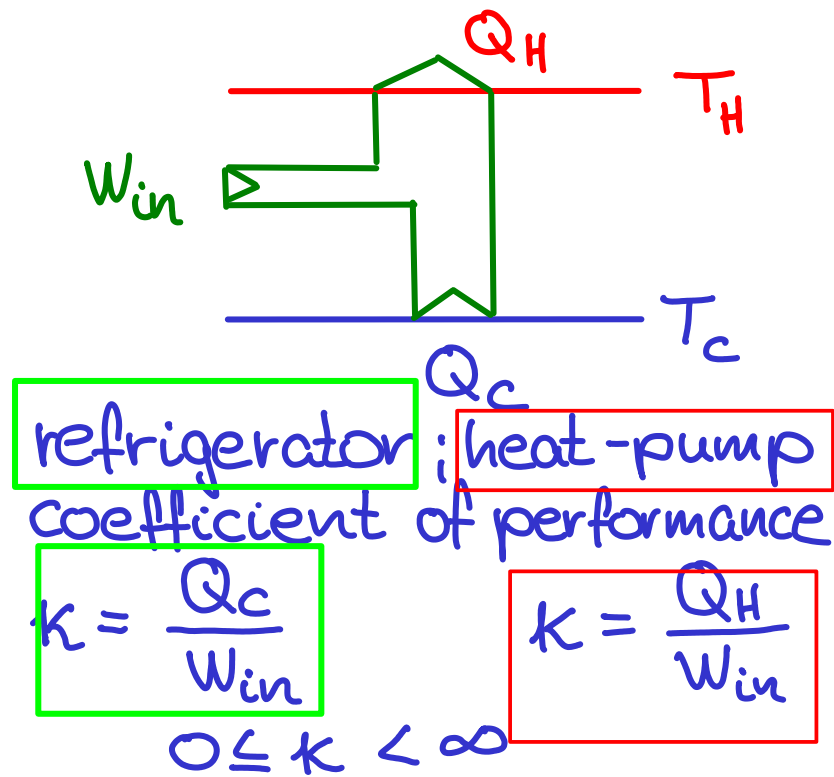
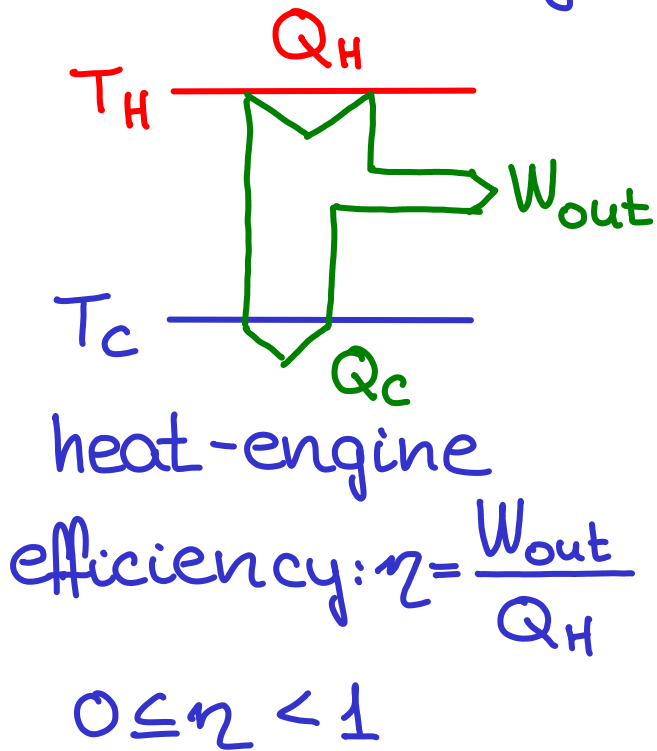
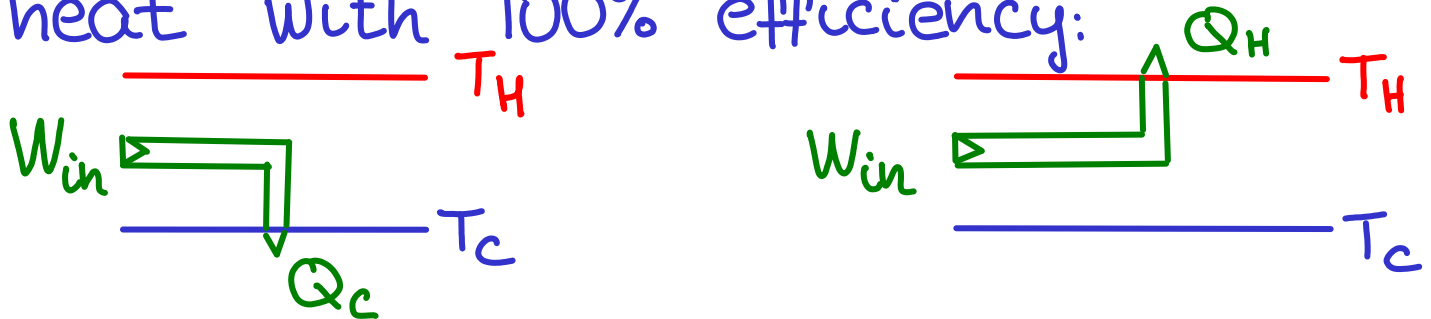


Heat-engines, heat-pumps

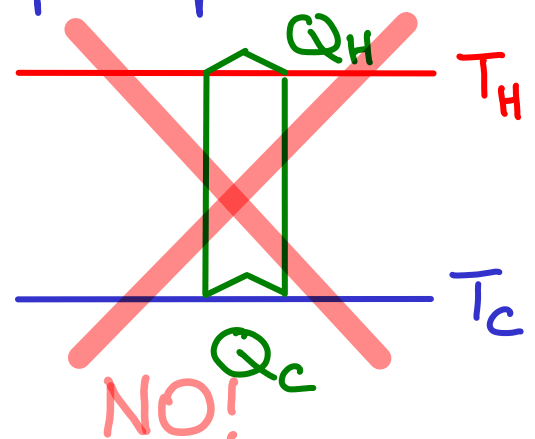
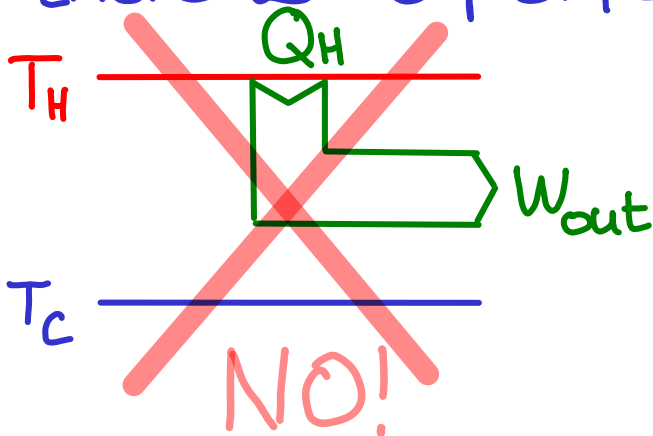


Mechanical work can be converted to heat with 100% efficiency:

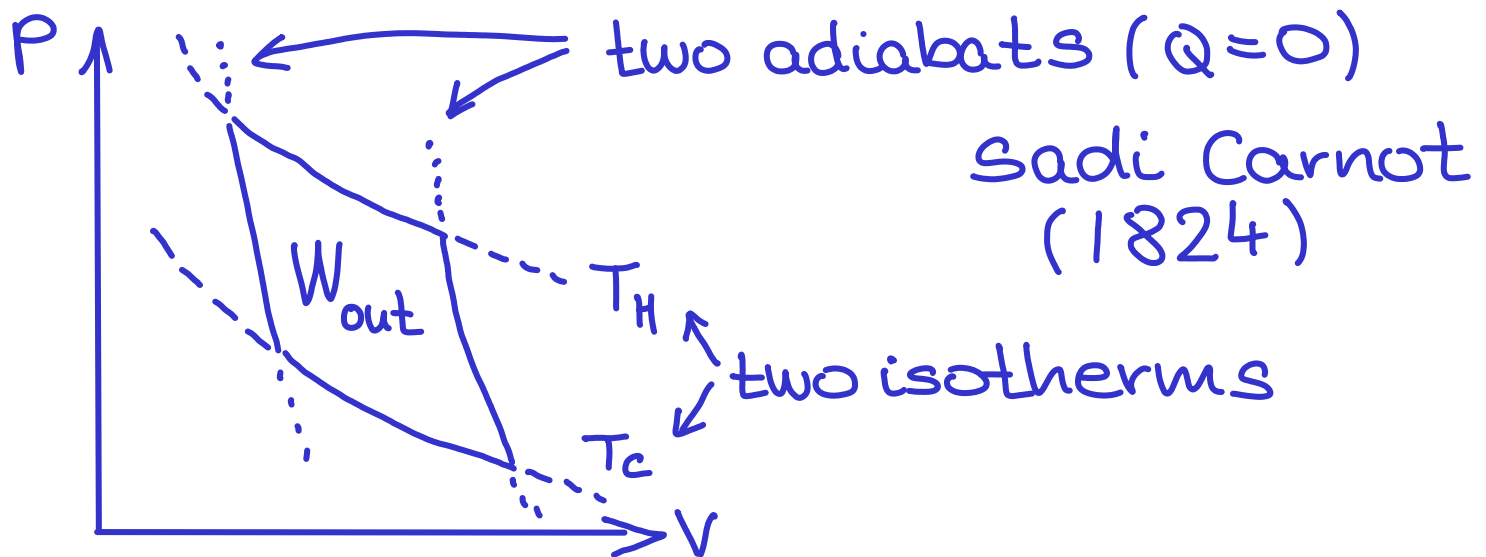


2nd law with engines/pumps:

- there is no perfect heat engine with $\eta = 1$
- there is no perfect heat pump with $k = \infty$



The Carnot-cycle



Definition: $\eta = \frac{W_{out}}{Q_H} = \frac{Q_H - Q_C}{Q_H}$

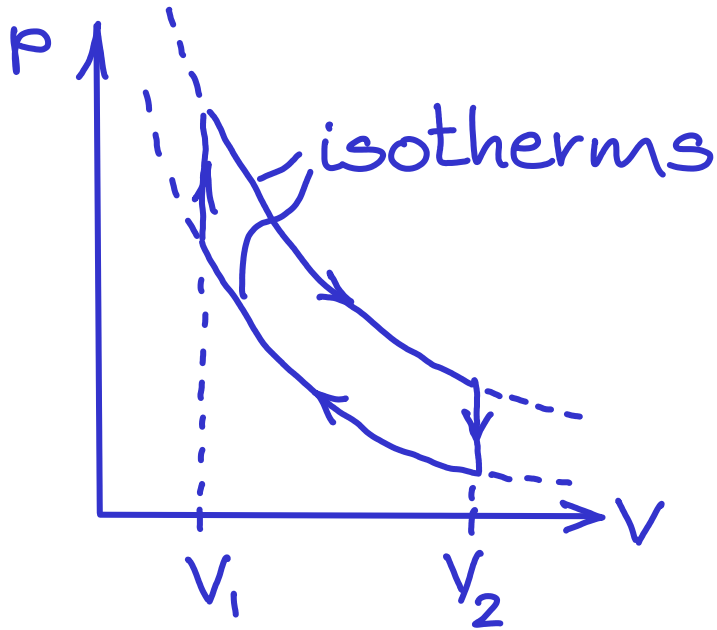
Carnot:

$\eta_{Carnot} = \frac{T_H - T_C}{T_H}$	$\kappa_{Carnot} = \frac{T_C}{T_H - T_C}$
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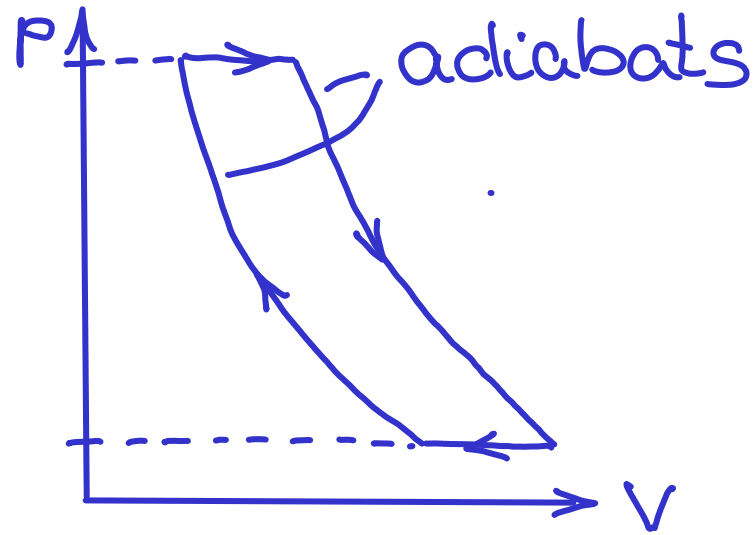
Second law: no heat engine operating between heat reservoirs with temperatures T_H and T_C can exceed the Carnot efficiency. (And no heat pump can exceed the Carnot coefficient of performance.)

Note: you cannot outperform the Carnot engine.

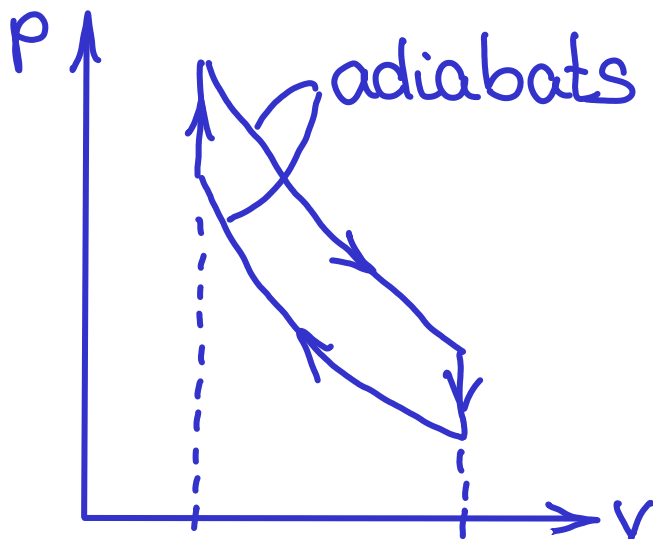
Examples of real engines



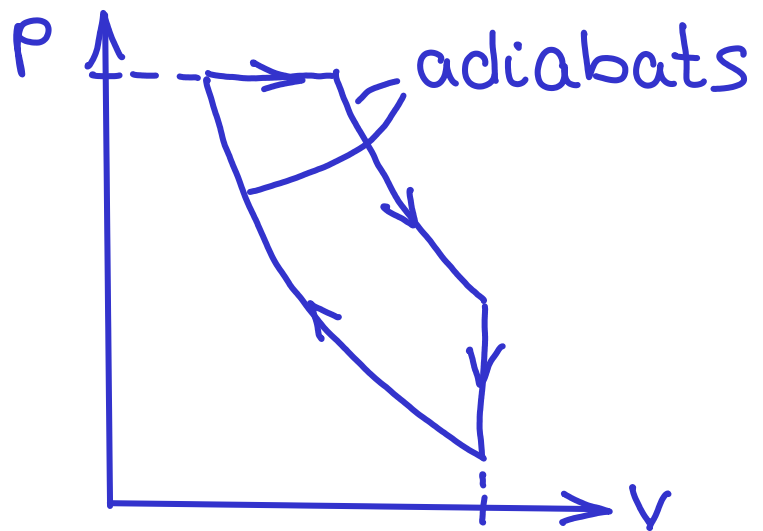
Stirling, 1816
reversible!



Brayton-Joule
(gas-turbine)



Otto, 1876
today's
cars



Rudolf Diesel, 1897
diesel-engine

The definition of entropy

Rudolf Clausius (1860-s):

"reduced heat" or entropy:
for any closed loop consisting
only reversible processes:

$$\sum_i \frac{\Delta Q_i}{T_i} = 0 \Rightarrow \text{there exists a}$$

single valued function S such that
 $\Delta S = S_f - S_i$ is path independent.
 S is a state function (like U), it
depends only on the state of the
system, and not how that state
was reached.

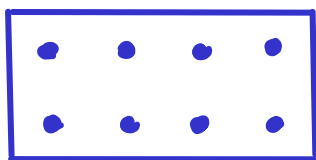
Clausius:

1st law: $\Delta U = Q + W$

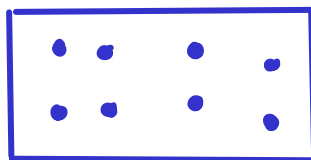
2nd law: $\frac{\Delta Q}{T} \leq \Delta S$ $\begin{cases} = & \text{for reversible} \\ < & \text{for irreversible} \end{cases}$

Ludwig Boltzmann: $S = k_B \cdot \log \Omega$

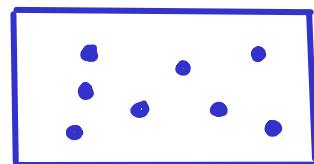
Ω : number of microstates realising
the same macrostate.



low S



medium S



high S

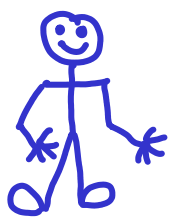
entropy $\approx$ randomness, disorder

The Second Law of Thermodynamics

Second Law with entropy: the entropy of a closed system cannot decrease. It remains the same for reversible processes and it increases for irreversible processes.

Q: Does life violate the 2nd law?

A: No!



← In: sugar, protein and other very complex molecules: low entropy.

→ Out: H_2O , CO_2 , NH_3 and other very simple molecules: high entropy.

