ESO 201A: Thermodynamics

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The Second Law of Thermodynamics: part 3

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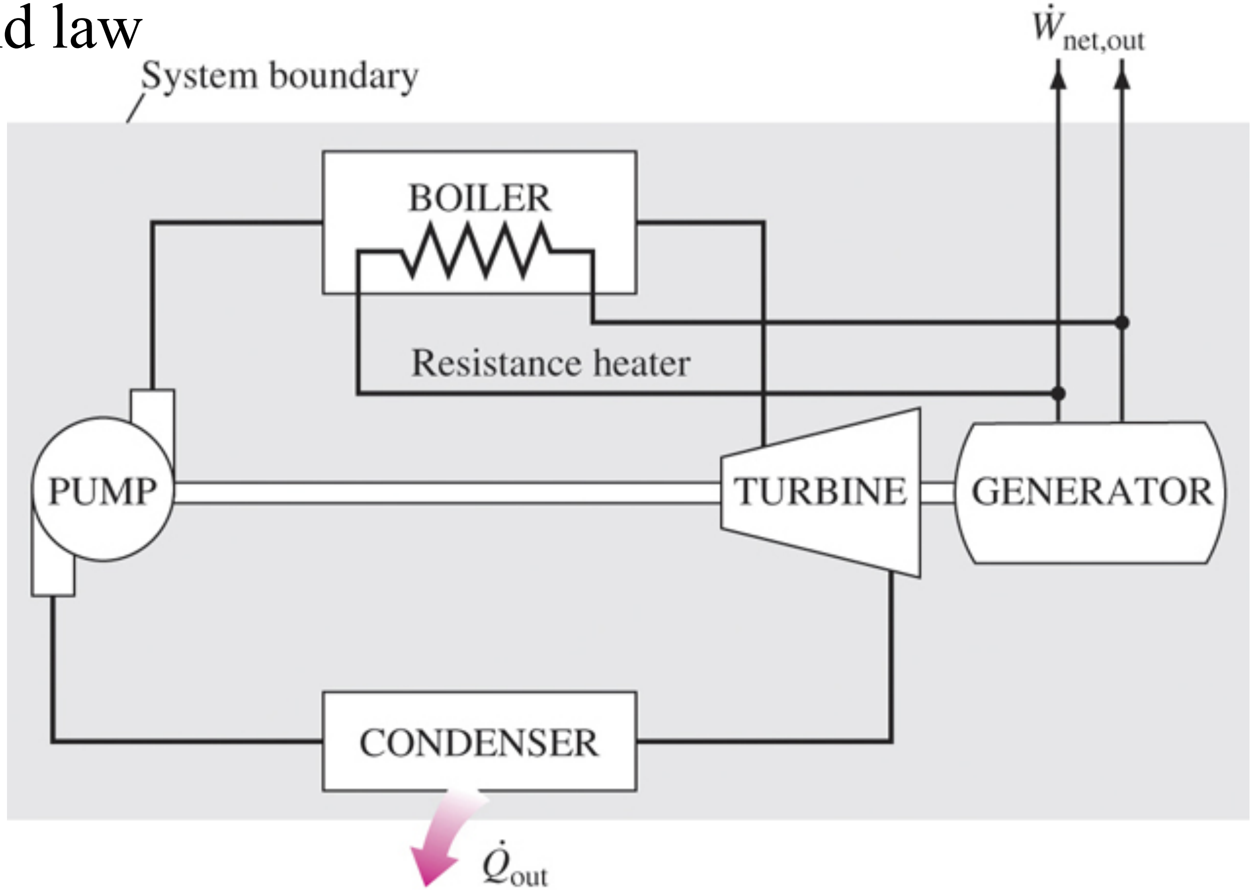
Learning objectives

- Introduce the second law of thermodynamics.
- Identify valid processes as those that satisfy both the first and second laws of thermodynamics.
- Discuss thermal energy reservoirs, heat engines
- Describe the Kelvin–Planck statement of the second law of thermodynamics
- Discuss refrigerators, and heat pumps and describe Clausius statement of the second law of thermodynamics
- Determine the expressions for the thermal efficiencies and coefficients of performance for reversible heat engines, heat pumps, and refrigerators.
- Discuss the concepts of perpetual-motion machines, reversible and irreversible processes
- Describe the Carnot cycle, examine the Carnot principles, idealized Carnot heat engines, refrigerators, and heat pumps.
- Apply the second law to develop the absolute thermodynamic temperature scale.

Perpetual-motion machines

Perpetual-motion machine: Any device that violates the first or the second law



A perpetual-motion machine that violates the first law (PMM1).

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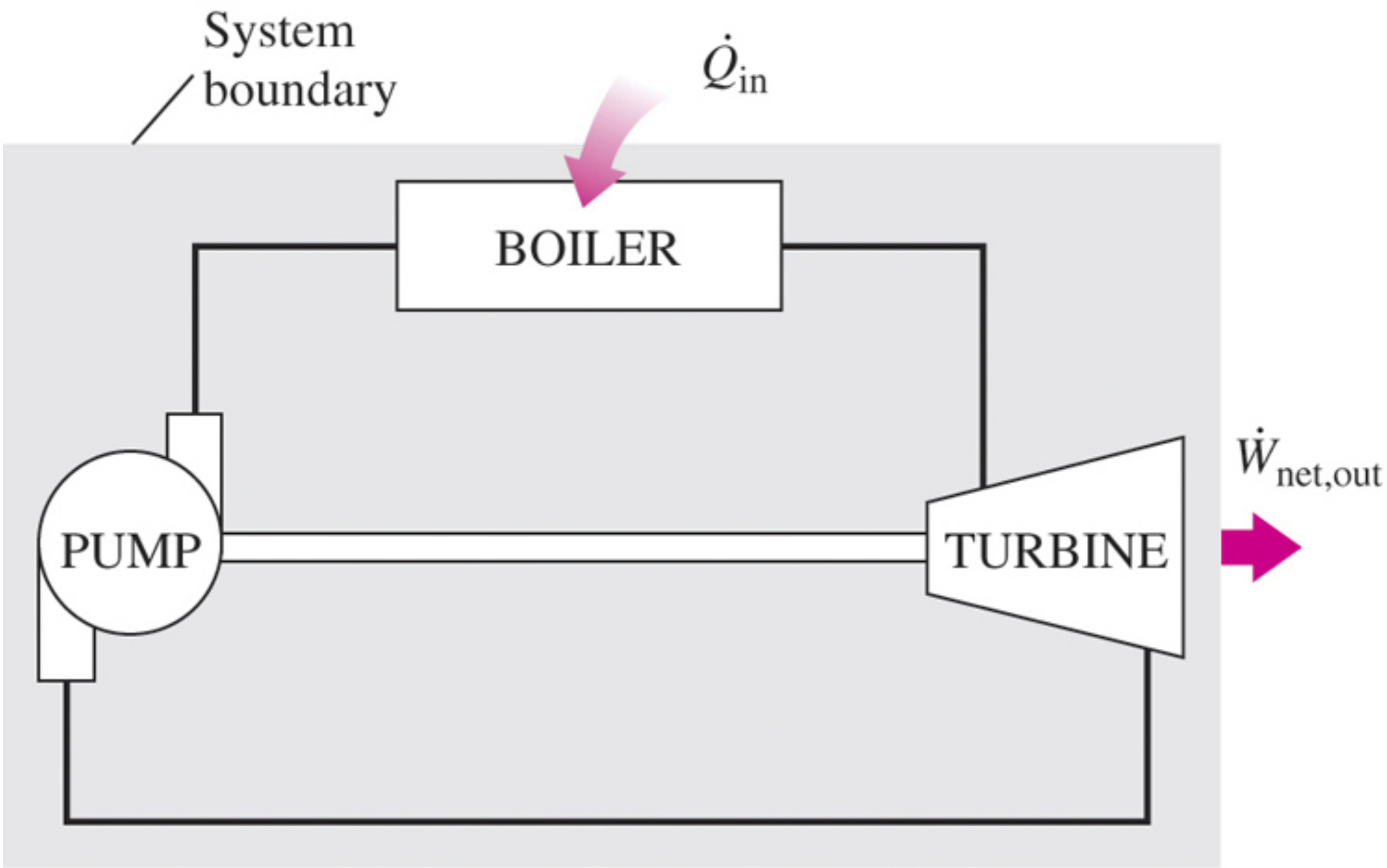
A device that violates the first law (by *creating* energy) is called a PMM1.

Perpetual-motion machines



A perpetual-motion machine that violates the second law of thermodynamics (PMM2).

A device that violates the second law is called a PMM2.

Despite numerous attempts, no perpetual-motion machine is known to have worked. ***If something sounds too good to be true, it probably is***.

Reversible and irreversible processes

- What is the highest possible efficiency of HE (it can't have 100 based on second law of thermodynamics)

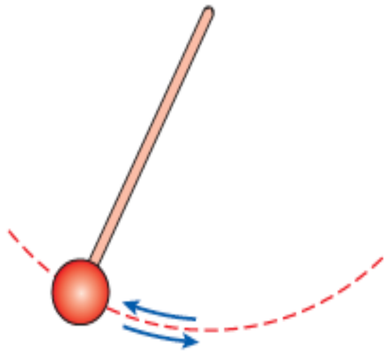
Reversible process

-a process that can be reversed without leaving any trace on the surroundings

i.e., both the system *and* the surroundings are returned to their initial states at the end of the reverse process

Quasi-equilibrium expansion and compression of a gas

$Q_{net,cycle}=W_{net,cycle}=0$



Frictionless pendulum

Idealization

Reversible and irreversible processes

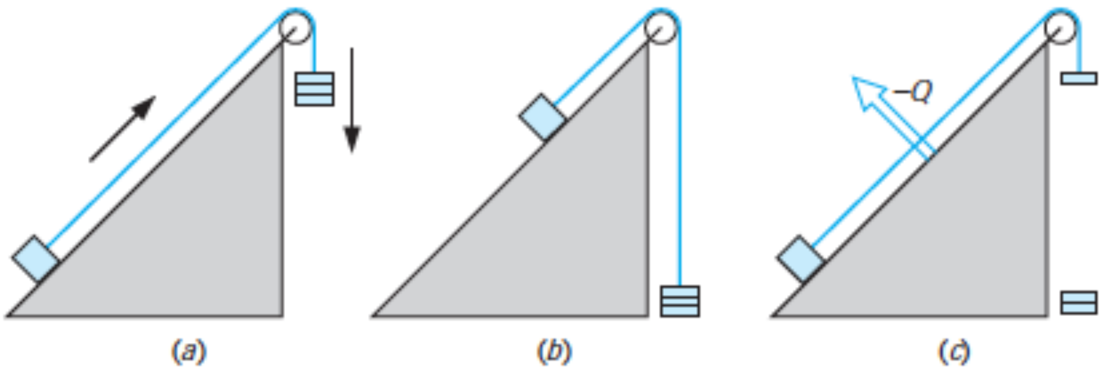
Irreversible process

-a process that cannot be reversed without leaving any trace on the surroundings

Unconstrained expansion

-Membrane rupture-gas fills the entire tank

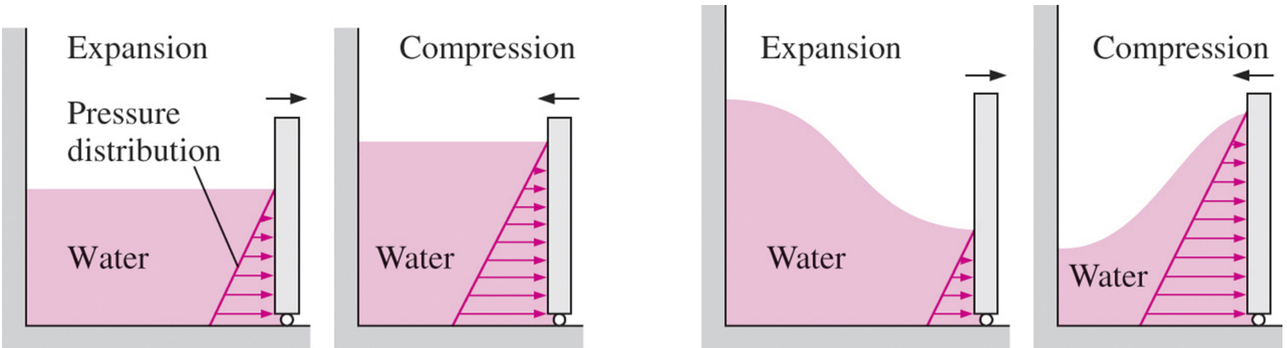
- To reverse, compress to original volume, while removing heat from the gas until it reaches its temperature.
- i.e, restoration of the surrounding involves conversion of heat completely to work



Friction makes a process irreversible

Reversible and irreversible processes

- All the processes occurring in nature are irreversible.
- ***Why are we interested* in reversible processes?**
  - they are easy to analyze and
  - they serve as idealized models (theoretical limits) to which actual processes can be compared.
- Some processes are more irreversible than others.
- We try to approximate reversible processes. **Why?**



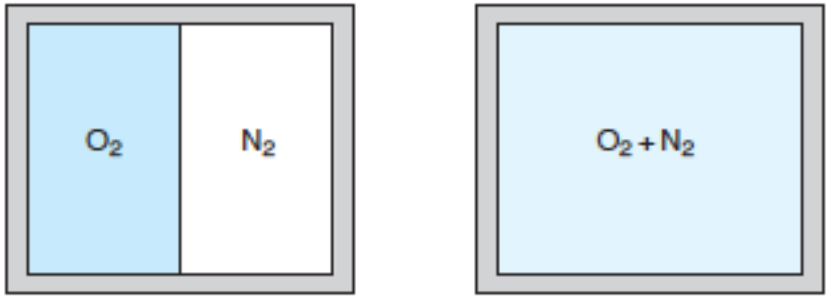
(*a*) Slow (reversible) process (*b*) Fast (irreversible) process

Reversible processes deliver the most and consume the least work.

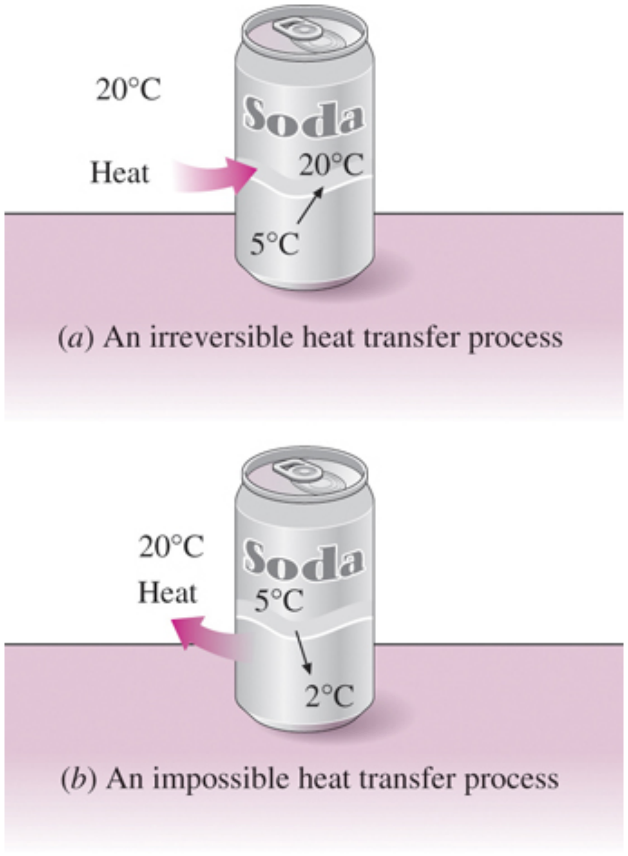
Irreversibility

- The factors that cause a process to be irreversible are called **irreversibilities**.
- They include friction, unrestrained expansion, mixing of two fluids, heat transfer across a finite temperature difference, electric resistance, inelastic deformation of solids, and chemical reactions.
- The presence of any of these effects renders a process irreversible.

Irreversible processes



Mixing of Two Different Substances

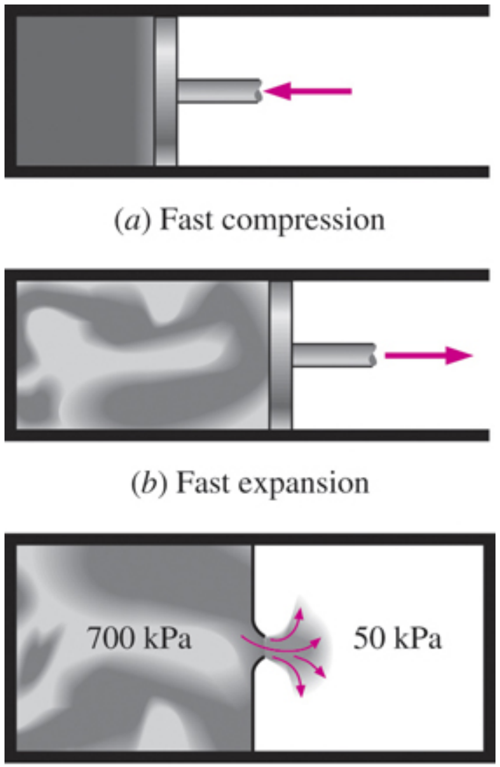


(*a*) An irreversible heat transfer process

(*b*) An impossible heat transfer process

(*a*) Heat transfer through a temperature difference is irreversible, and (*b*) the reverse process is impossible.

Irreversible compression and expansion processes.



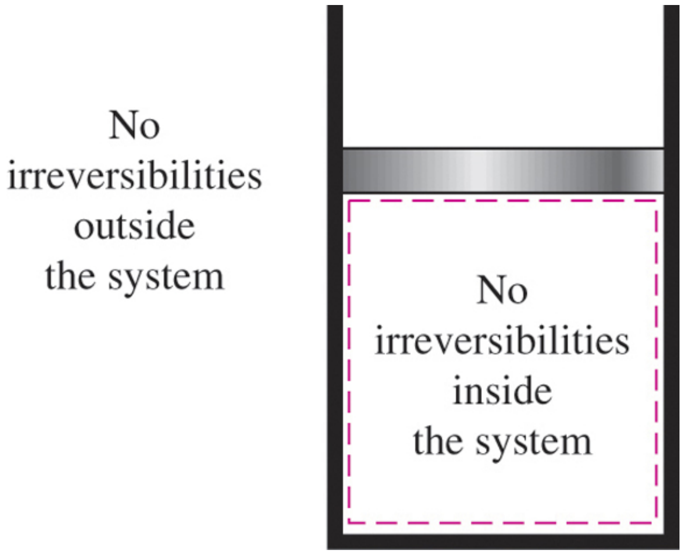
(*a*) Fast compression

(*b*) Fast expansion

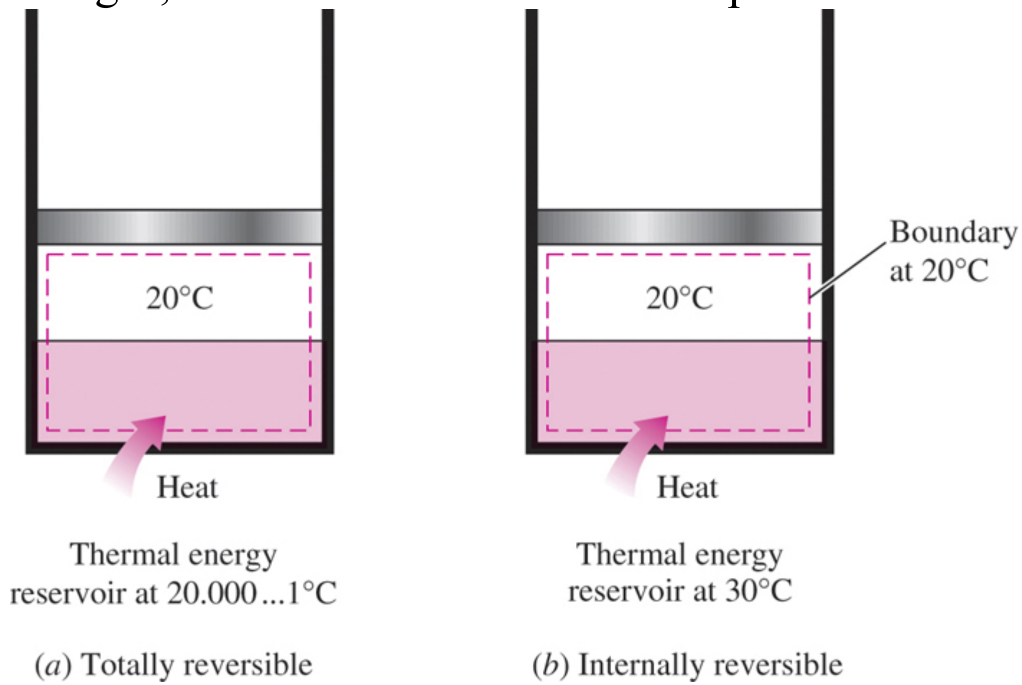
(*c*) Unrestrained expansion

Internally and Externally Reversible Process

- **Internally reversible process:** If no irreversibilities occur within the boundaries of the system during the process.
- **Externally reversible:** If no irreversibilities occur outside the system boundaries.
- **Totally reversible process:** It involves no irreversibilities within the system or its surroundings.
- A totally reversible process involves no heat transfer through a finite temperature difference, no nonquasi-equilibrium changes, and no friction or other dissipative effects.



A reversible process involves no internal and external irreversibilities.

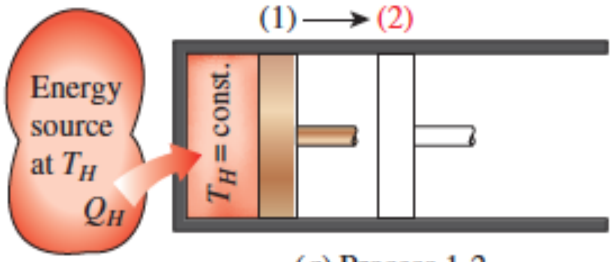


Totally and internally reversible heat transfer processes.

Carnot cycle

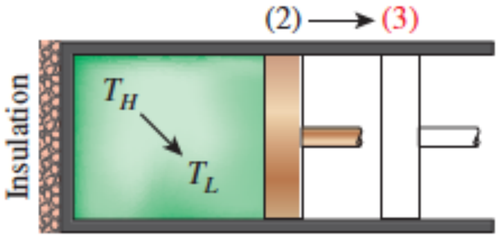
- HE efficiency depends on the net work, which can be maximize by using processes that require least amount of work and deliver the most. This can be achieved by reversible process.
- Reversible cycle provides upper limits on the performance of real cycles
- Carnot cycle-reversible cycle proposed in 1824 by French engineer Sadi Carnot
- HE based on Carnot cycle (theoretically) is called Carnot HE
  - Four reversible processes
  - Two isothermal and two adiabatic

Carnot cycle



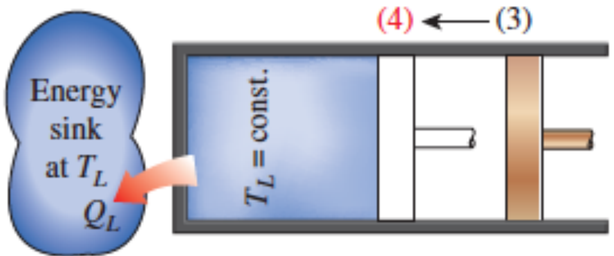
(a) Process 1-2

Reversible isothermal expansion: gas expands at constant T_H by transferring Q_H.



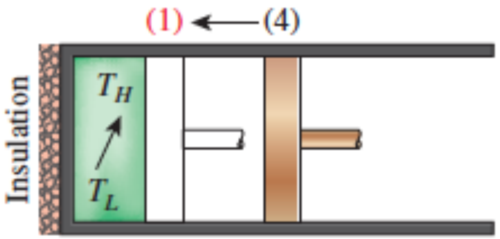
(b) Process 2-3

Reversible adiabatic expansion: gas further expands at Q=0, and lowers its temperature to T_L.



(c) Process 3-4

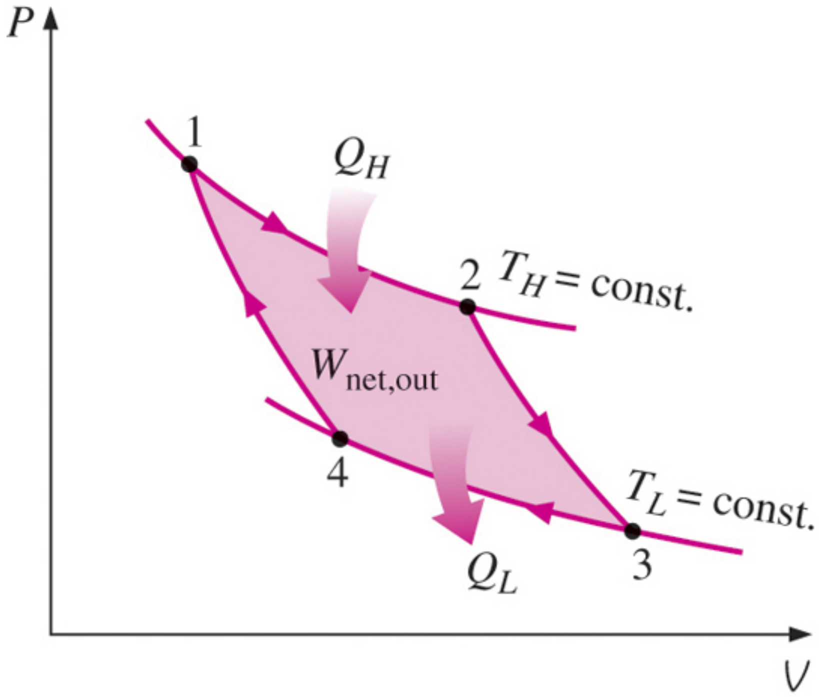
Reversible isothermal compression: Sink at T_L is brought in contact, and gas compresses at T_L with heat, Q_L, transferred to energy sink .



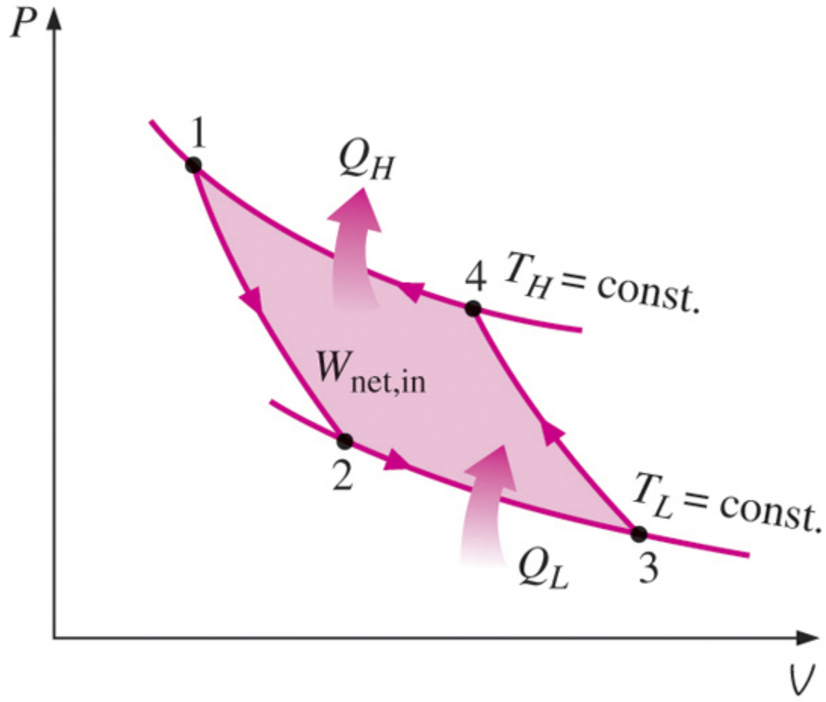
(d) Process 4-1

Reversible adiabatic compresion: gas further compresses and returns to initial state 1, with the temperature, T_H

Carnot and reversed Carnot cycles



P-V diagram of the Carnot cycle.



P-V diagram of the reversed Carnot cycle.

The Reversed Carnot Cycle

The Carnot heat-engine cycle is a totally reversible cycle.

Therefore, all the processes that comprise it can be *reversed*, in which case it becomes the **Carnot refrigeration cycle**.

Next lecture

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