

CH_6

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- 6.1 Introduction to the Second Law
- 6.2 Thermal Energy Reservoirs
 - Definition
- 6.3 Heat Engines
 - Definition
 - Characterization
 - Working Fluid
 - Thermal Efficiency
 - The Second Law of Thermodynamics: Kelvin-Planck Statement
- 6.4 Refrigerators and Heat Pumps
 - Coefficient of Performance
 - Heat Pumps
 - The Second Law of Thermodynamics: Clausius Statement
- 6.5 Perpetual-Motion Machine
- 6.6 Reversible and Irreversible Processes
 - Definitions
 - Irreversibilities
 - Definition
 - Internally and Externally Reversible Processes
 - Definition
- 6.7 The Carnot Cycle
 - The Carnot Process
 - The Reversed Carnot Process
- 6.8 The Carnot Principles
 - Principles
- 6.9 The Thermodynamic Temperature Scale
- 6.10 The Carnot Heat Engine

6.1 Introduction to the Second Law

Since satisfying the first law **does not ensure that the process can actually occur**, *the second law of thermodynamics* is introduced to identify whether a process can actually occur

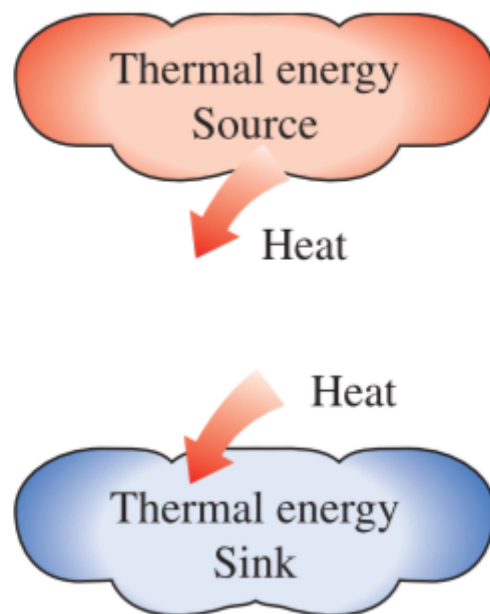
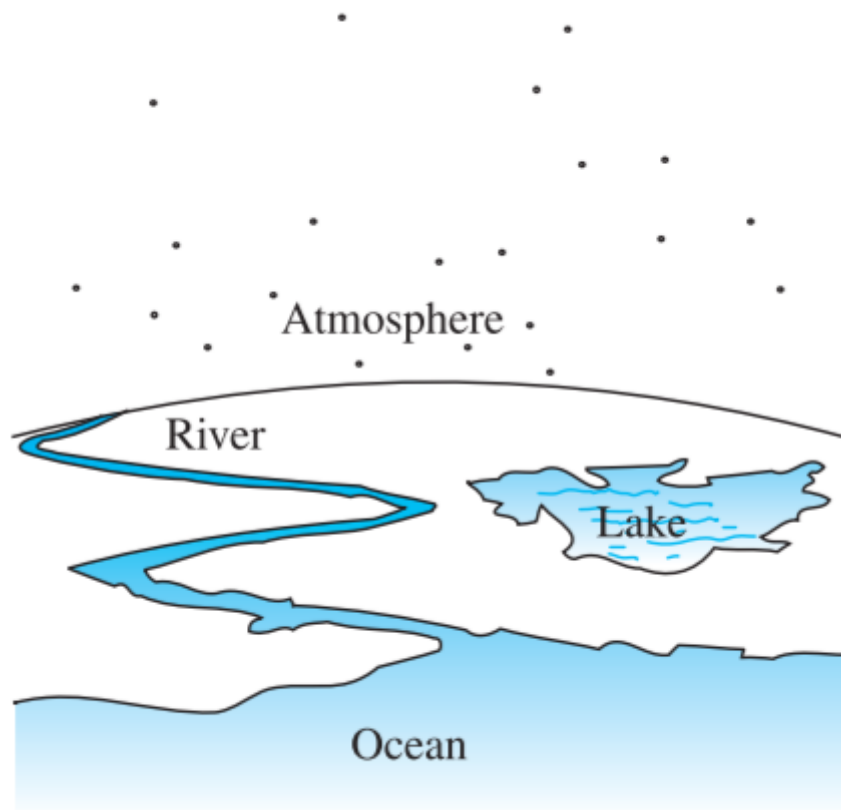
- identify the **direction** of processes
- assert that energy has **quality** as well as **quantity**
- determine the **theoretical limits** for the performance of commonly used engineering systems
- predicting the degree of completion of chemical reactions
- quantify **the level of perfection** of a process
- point the direction to **eliminate imperfections** effectively

6.2 Thermal Energy Reservoirs

Definition

a hypothetical body with **a relatively large thermal energy capacity** that can supply or absorb finite amounts of heat *without undergoing any change in temperature*

- **Source:** a reservoir that supplies energy (heat)
- **Sink:** a reservoir that absorbs energy (heat)



6.3 Heat Engines

Definition

the special devices that convert heat to work

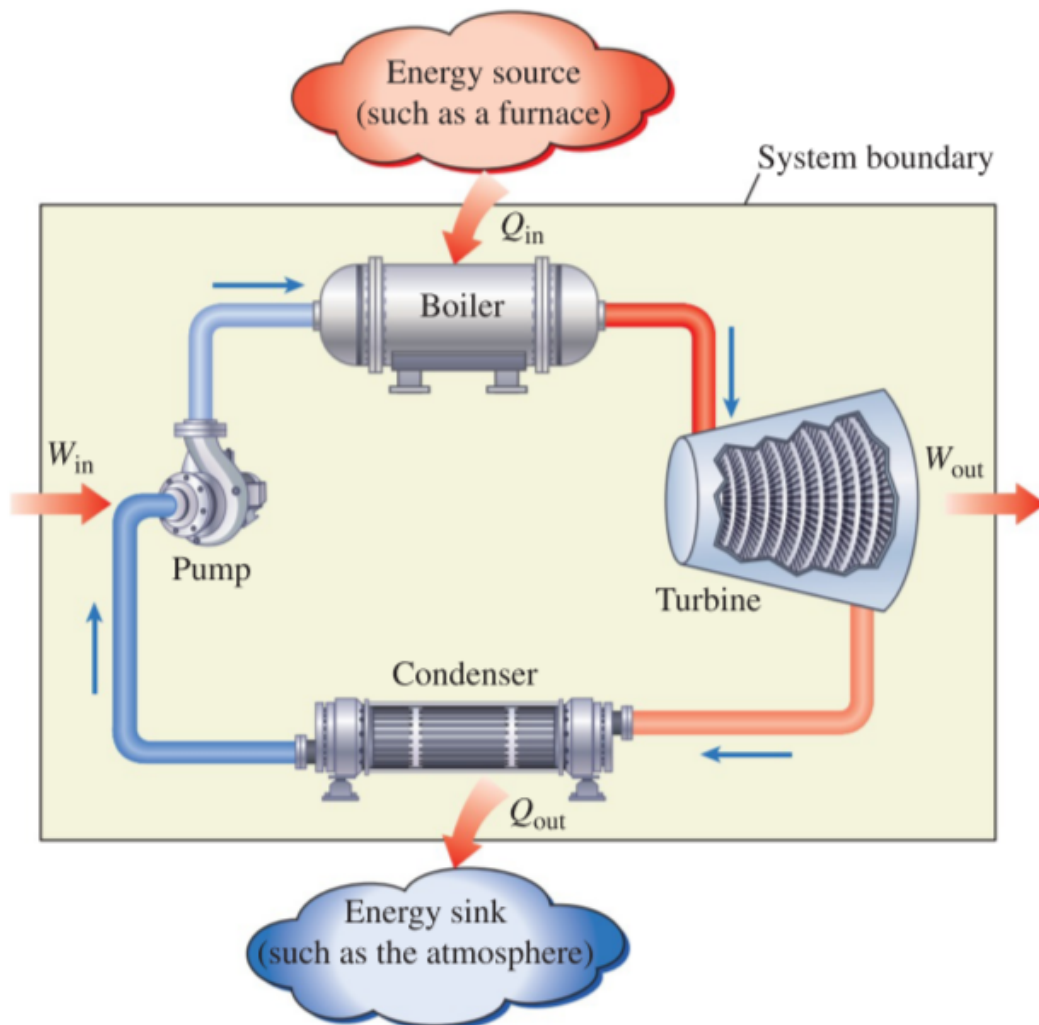
Characterization

1. they receive heat from a high-temperature source
2. they convert part of this heat to work

3. they reject the remaining waste to a low-temperature sink
4. they operate on a cycle

Working Fluid

the fluid that transfers heat while undergoing a cycle



- Q_{in} : amount of heat supplied to steam in boiler from a high-temperature source
- Q_{out} : amount of heat rejected from steam in condenser to a low-temperature sink
- W_{out} : amount of work delivered by steam as it expands in turbine
- W_{in} : amount of work required to compress water to boiler pressure

$$W_{net,out} = W_{out} - W_{in}$$

Thermal Efficiency

the fraction of the heat input that is converted to net work output, which is a measure of the performance of a heat engine

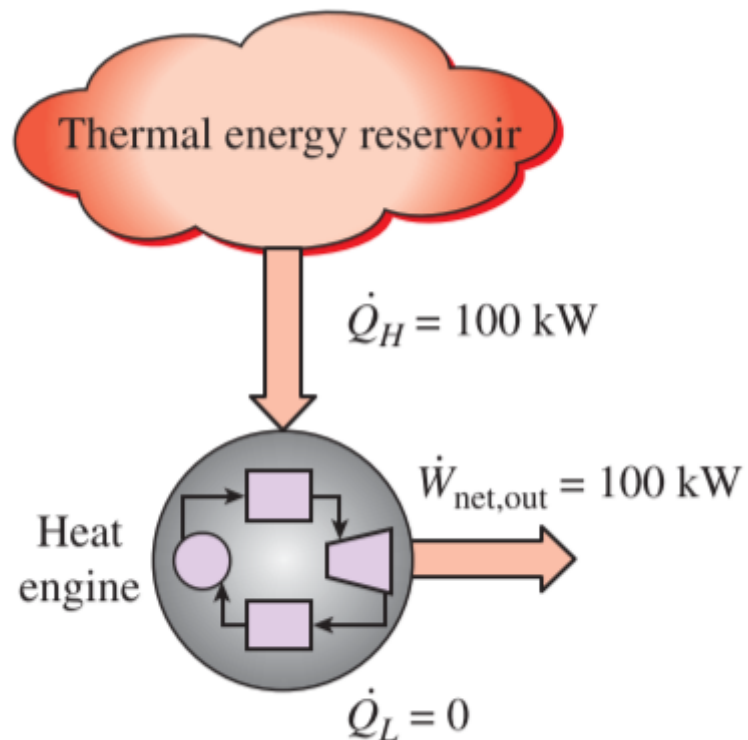
$$\text{Thermal Efficiency} = \frac{\text{Net Work Output}}{\text{Total Heat Input}}$$

$$\eta_{th} = \frac{W_{net,out}}{Q_{in}}$$

$$\eta_{th} = 1 - \frac{Q_{out}}{Q_{in}}$$

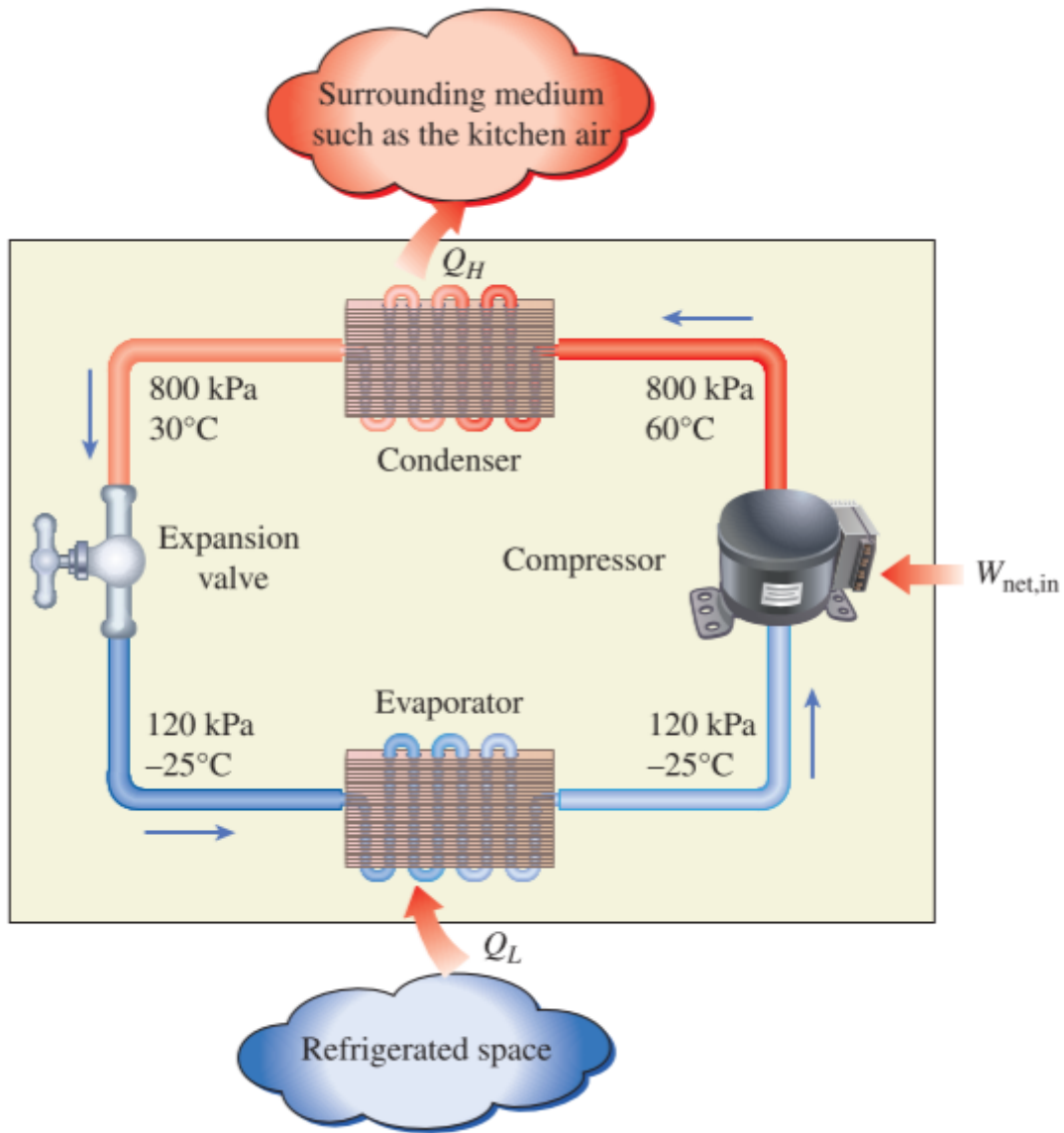
The Second Law of Thermodynamics: Kelvin-Planck Statement

It is impossible for any device that operates on a cycle to receive heat from a single reservoir and produce a net amount of work



6.4 Refrigerators and Heat Pumps

refrigerators: the device which transfer heat from a low-temperature medium to a high-temperature one



Coefficient of Performance

the efficiency of a refrigerator is expressed in terms of the coefficient of performance

$$COP_R = \frac{\text{Desired Output}}{\text{Required Input}} = \frac{Q_L}{W_{net,in}}$$

$$COP_R = \frac{Q_L}{Q_H - Q_L} = \frac{1}{Q_H/Q_L - 1}$$

Heat Pumps

the device that transfer heat from a low-temperature medium to a high-temperature one

$$COP_{HP} = \frac{\text{Desired Output}}{\text{Required Input}} = \frac{Q_H}{W_{net,in}}$$

$$COP_{HP} = \frac{Q_H}{Q_H - Q_L} = \frac{1}{1 - Q_L/Q_H}$$

$$COP_{HP} = COP_R + 1$$

The Second Law of Thermodynamics: Clausius Statement

It is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a lower-temperature body to a higher-temperature body

6.5 Perpetual-Motion Machine

Any device that violates either law of thermodynamics is called a perpetual-motion machine

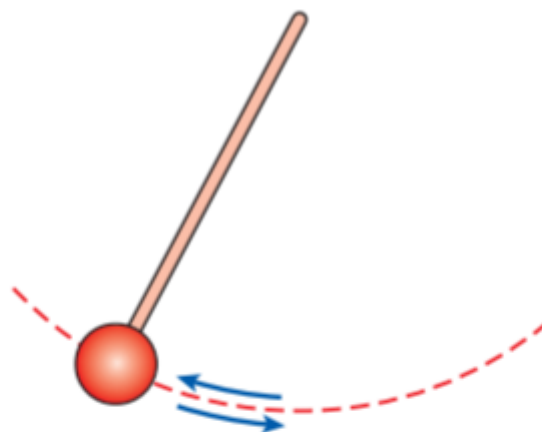
- PMM1: violate the first law of thermodynamics
- PMM2: violate the second law of thermodynamics

6.6 Reversible and Irreversible Processes

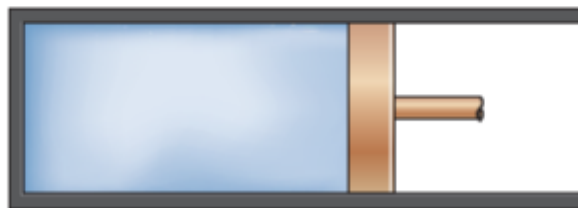
Definitions

- **reversible process:** a process that can be reversed without leaving any trace on the surroundings
- **irreversible process:** a process that is not reversible

reversible process is only possible only if the net heat and net work exchange between the system, and the surroundings is zero for the combined (original and reverse) process



(a) Frictionless pendulum



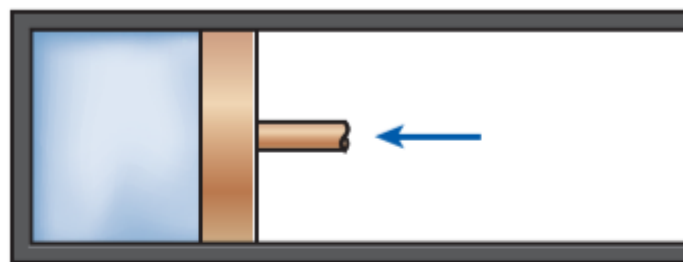
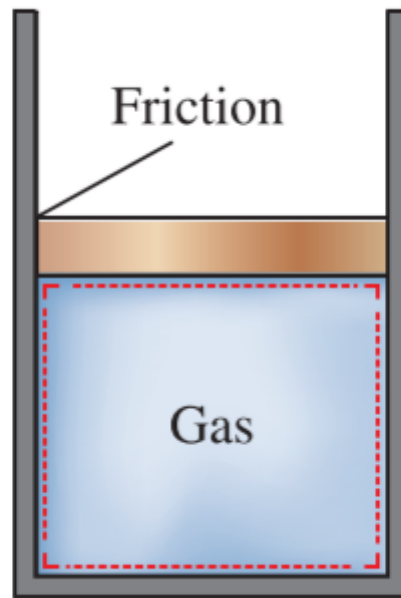
(b) Quasi-equilibrium expansion and compression of a gas

Irreversibilities

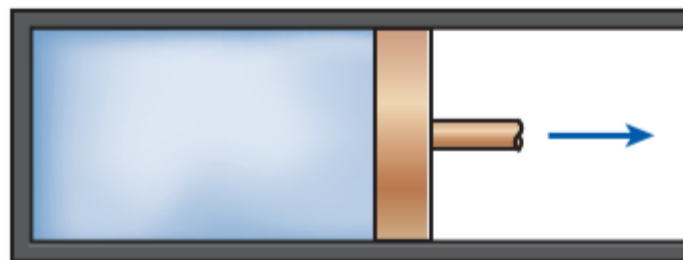
Definition

the factors that cause to be irreversible are called irreversibilities

which include **friction**, **unstrained expansion**, mixing of two fluids, **heat transfer** across a finite temperature difference, electric resistance, inelastic deformation of solids and chemical reactions



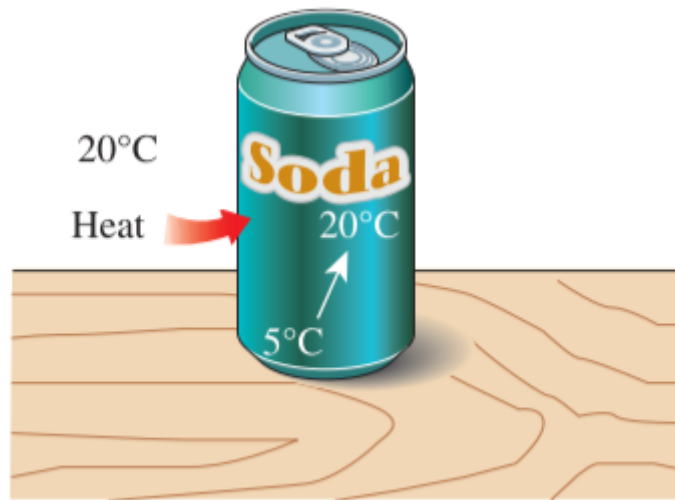
(a) Fast compression



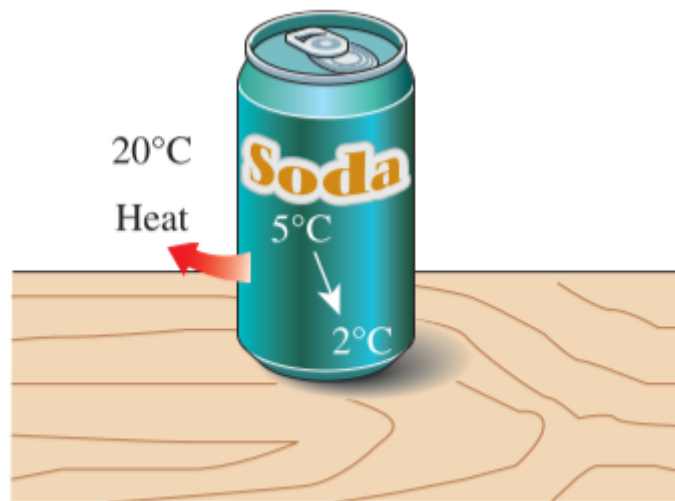
(b) Fast expansion



(c) Unrestrained expansion



(a) An irreversible heat transfer process



(b) An impossible heat transfer process

Internally and Externally Reversible Processes

Definition

- **internally reversible:** if no irreversibilities occur within the boundaries of the system during the process
- **externally reversible:** if no irreversibilities occur outside the system boundaries during the process
- **totally reversible (reversible):** if it involves no irreversibilities within the system or its surroundings

6.7 The Carnot Cycle

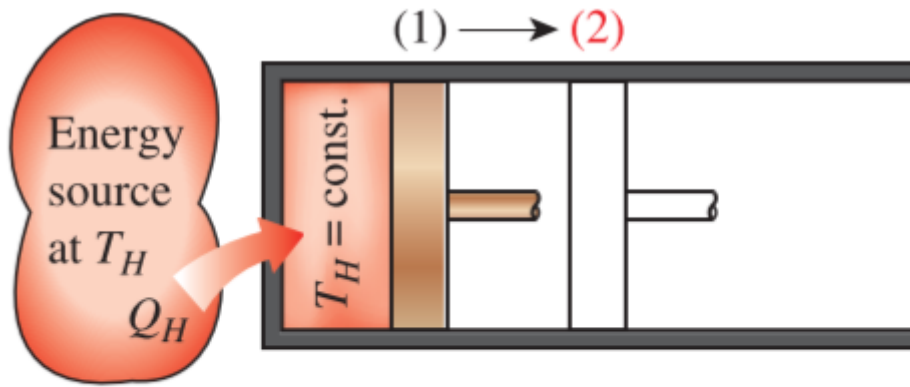
the best known reversible cycle is the **Carnot cycle**, and the theoretical heat engine that operates on the Carnot cycle is called the **Carnot heat engine**

The Carnot Process

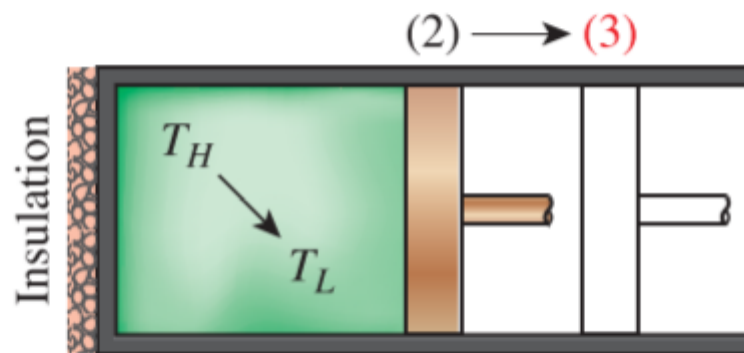
1. Reversible Isothermal Expansion
2. Reversible Adiabatic Expansion
3. Reversible Isothermal Compression

4. Reversible Adiabatic Compression

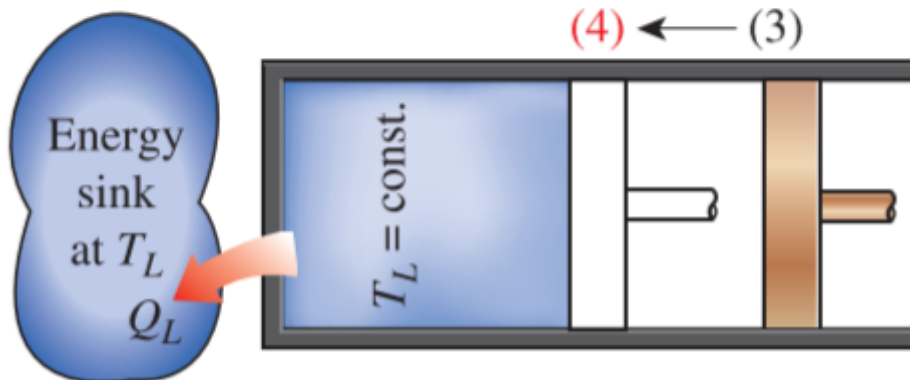
adiabatic: occurring without loss or gain of heat



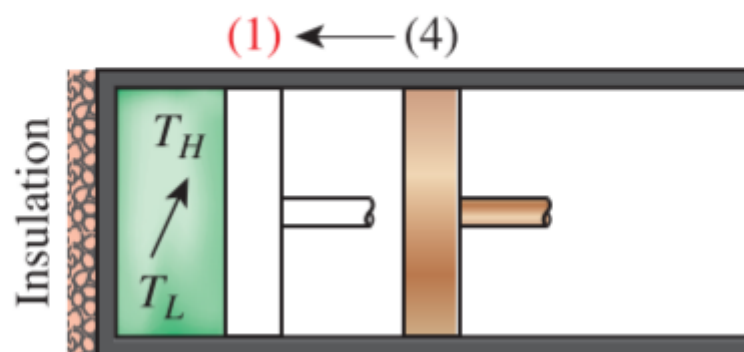
(a) Process 1-2



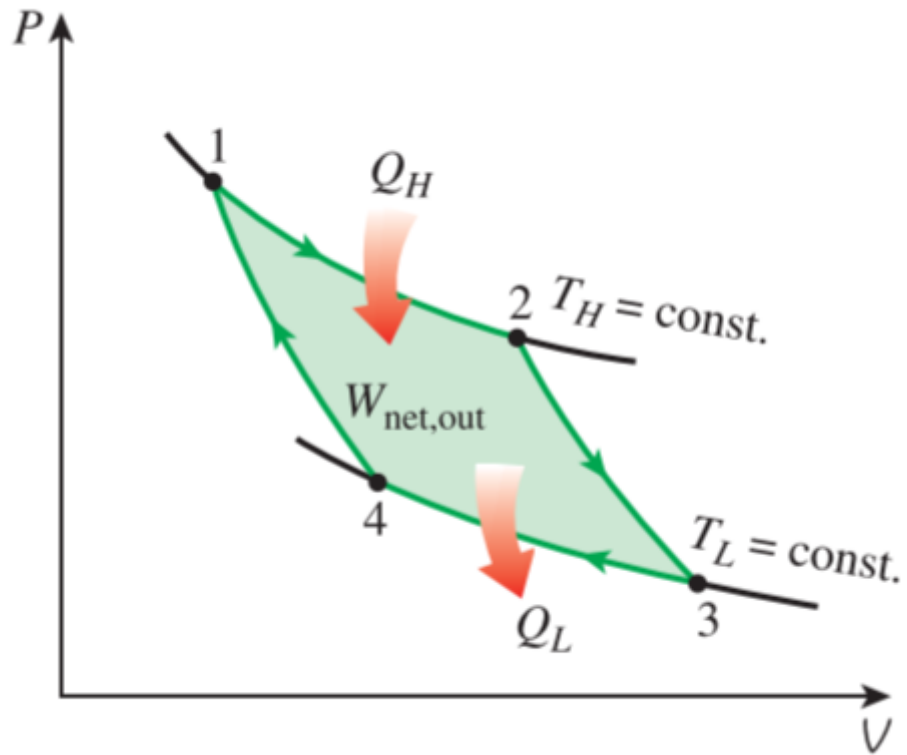
(b) Process 2-3



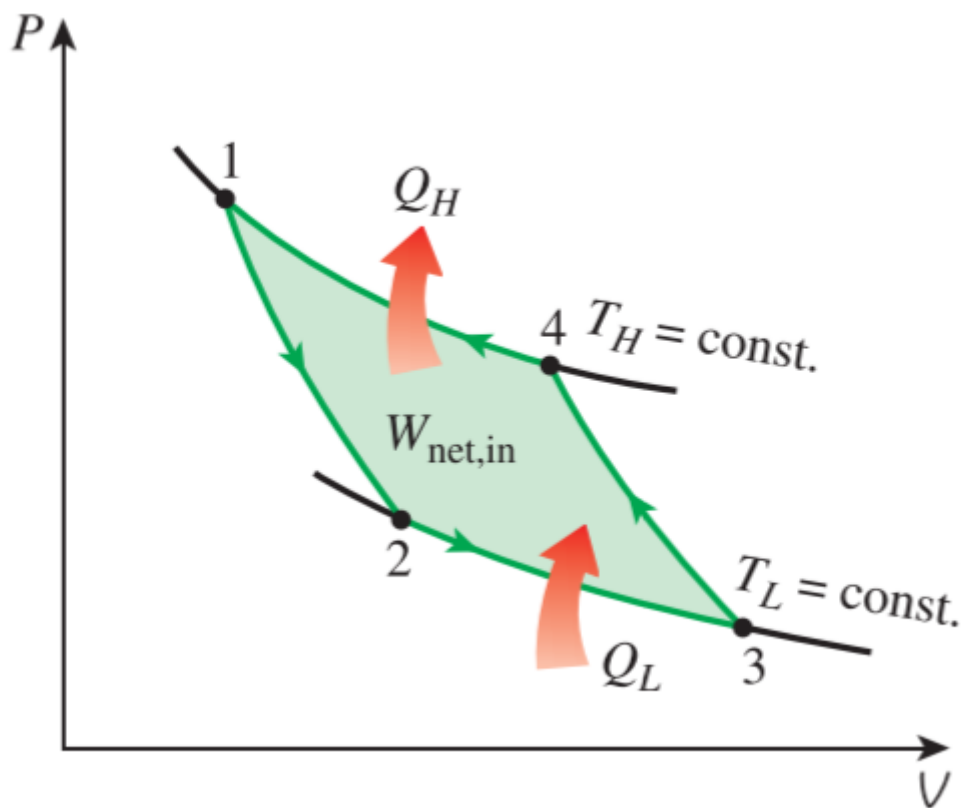
(c) Process 3-4



(d) Process 4-1



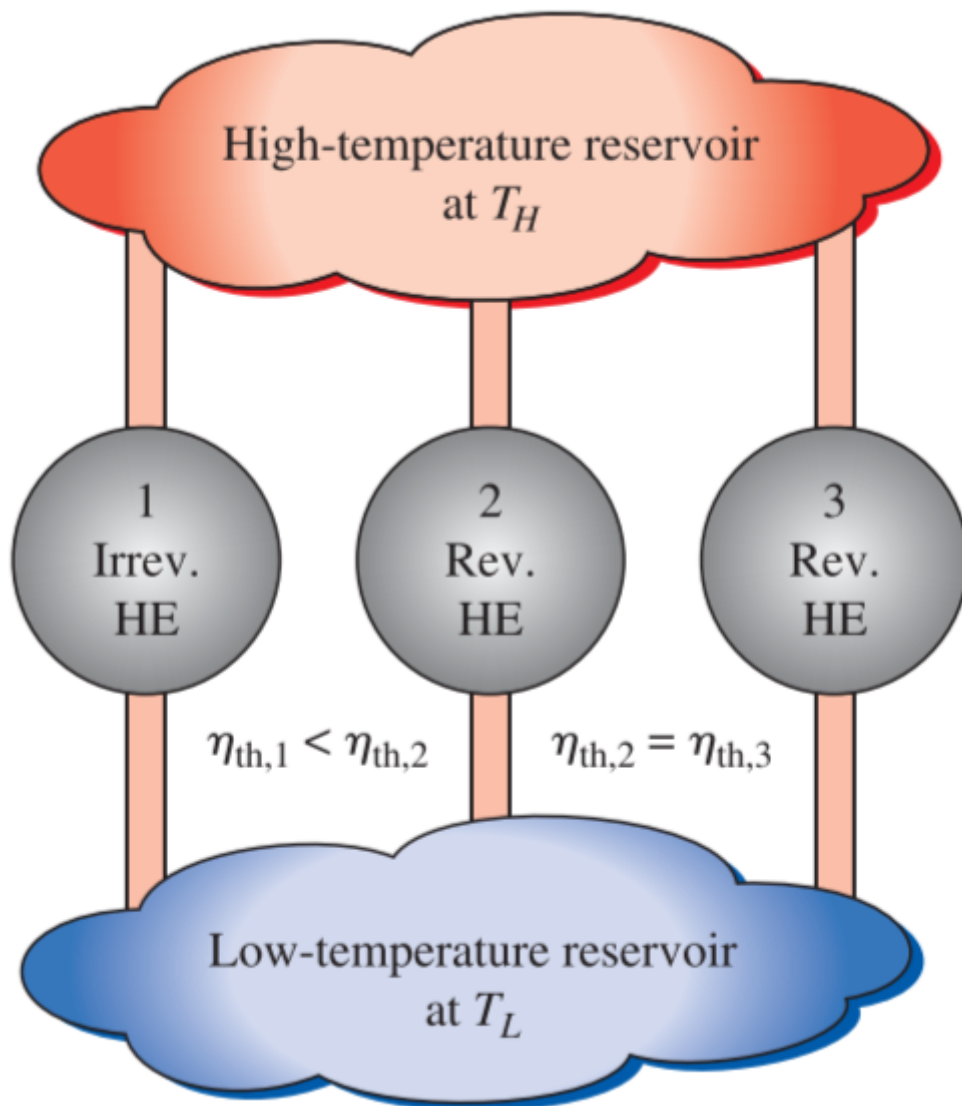
The Reversed Carnot Process

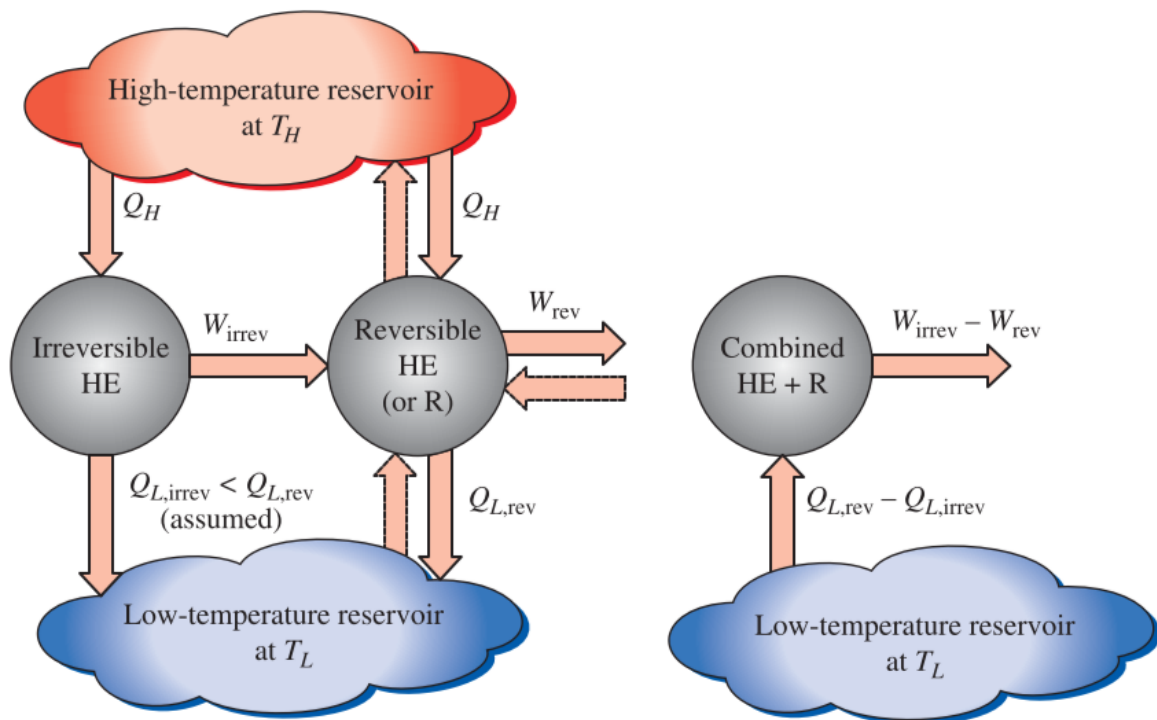


6.8 The Carnot Principles

Principles

1. The efficiency of an irreversible heat engine is **always less** than the efficiency of a reversible one operating between the same two reservoirs;
2. The efficiencies of all reversible heat engines operating between the same two reservoirs are the same;





(a) A reversible and an irreversible heat engine operating between the same two reservoirs (the reversible heat engine is then reversed to run as a refrigerator)

(b) The equivalent combined system

6.9 The Thermodynamic Temperature Scale

a temperature scale that is **independent** of the properties of the substances that are used to measure temperature

$$\left(\frac{Q_H}{Q_L}\right)_{rev} = \frac{T_H}{T_L}$$

the temperature scale is called the **Kelvin scale**, and the temperatures on this scale are called **absolute temperatures**

$$T(^{\circ}\text{C}) = T(\text{K}) - 273.15$$

6.10 The Carnot Heat Engine

$$\eta_{th} = 1 - \frac{Q_L}{Q_H}$$

$$\eta_{th,rev} = 1 - \frac{T_L}{T_H}$$

the relation is often referred to as the Carnot efficiency

η_{th}

\begin{cases}

$< \eta_{th,rev} \Rightarrow$ irreversible heat engine

$= \eta_{th,rev} \Rightarrow$ reversible heat engine

$> \eta_{th,rev} \Rightarrow$ impossible heat engine

\end{cases}

$$COP_{R,rev} = \frac{1}{T_H/T_L - 1}$$

$$COP_{R,rev} = \frac{1}{1 - T_H/T_L}$$

$$COP_R \begin{cases} < COP_{R,rev} & \text{irreversible refrigerator} \\ = COP_{R,rev} & \text{reversible refrigerator} \\ > COP_{R,rev} & \text{impossible refrigerator} \end{cases}$$