CH_6

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

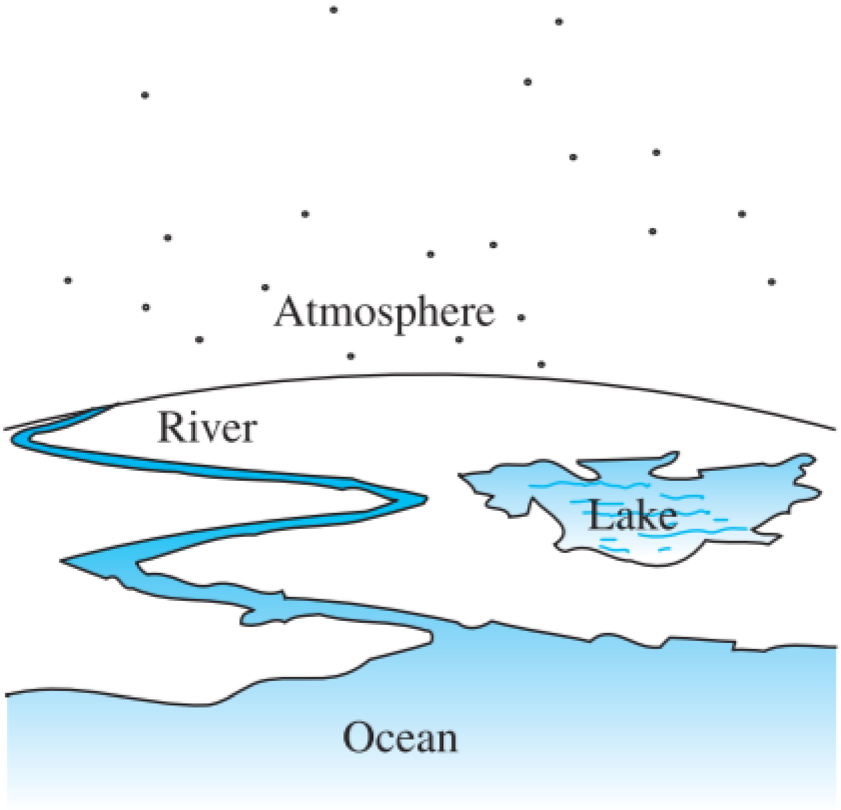
- identify the **direction** od processes
- assert that energy has **quality** as well as **quantity**
- determine the **theoretical limits** for the performance of commonly used engineering systems
- predicting the degree of completion of chemical reactions
- quantify **the level of perfection** of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

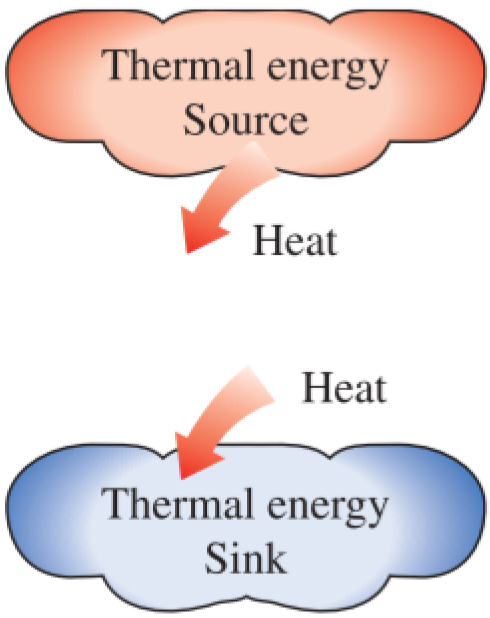
6.2 Thermal Energy Reservoirs

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

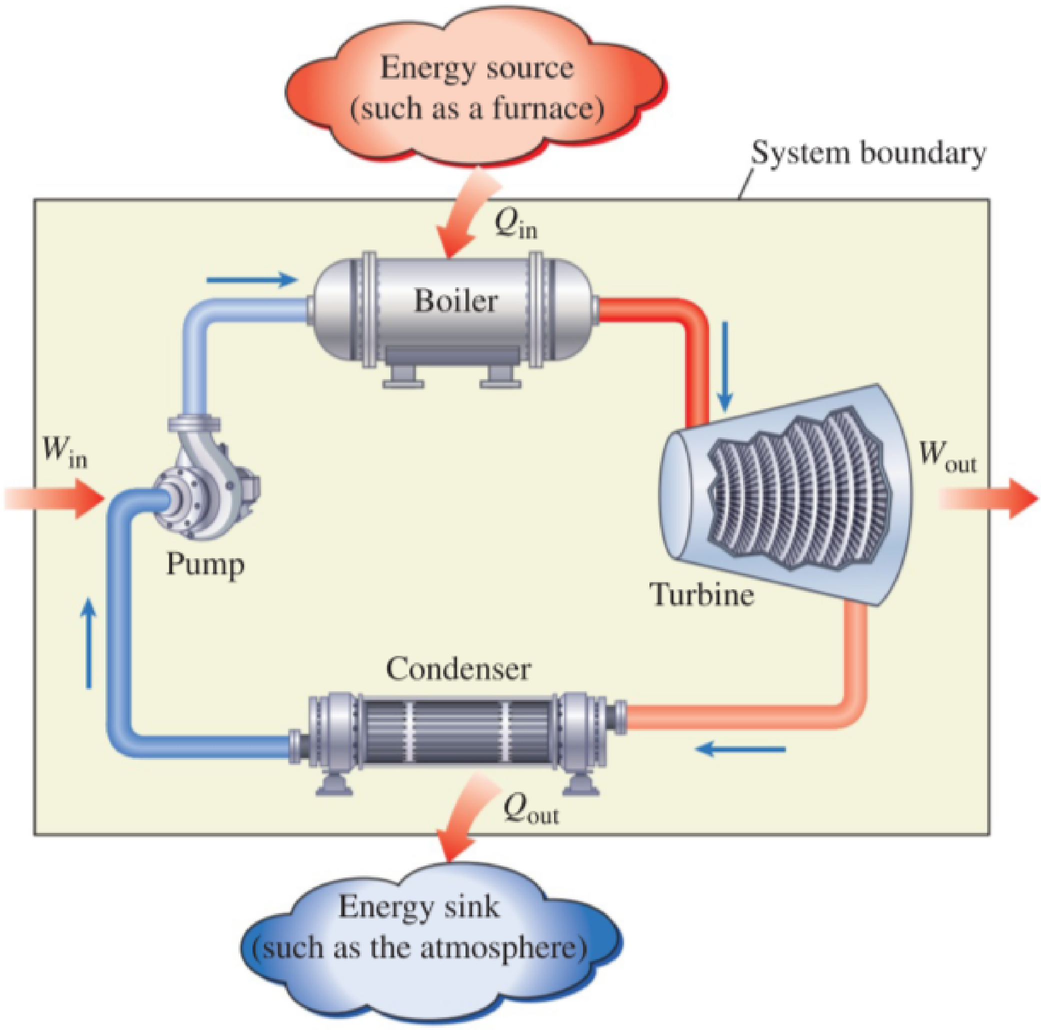
the special devices that convert heat to work

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

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

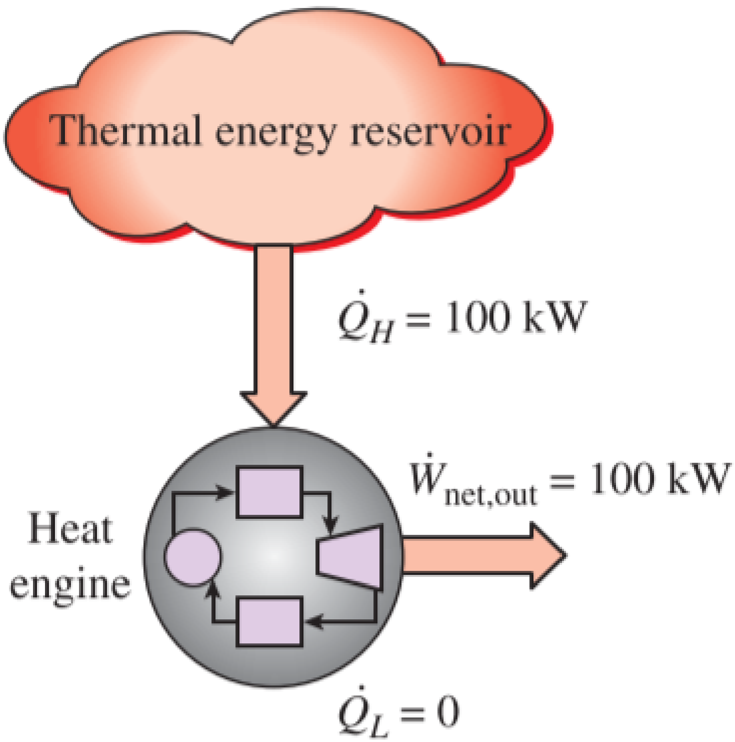
Thermal Efficiency

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

$$\text{Thermal Efficiency} = \frac{\text{Net Work Output}}{\text{Total Heat Input}}$$
$$\eta_{th} = \frac{W_{net,out}}{Q_{in}}$$
$$\eta_{th} = 1 - \frac{Q_{out}}{Q_{in}}$$

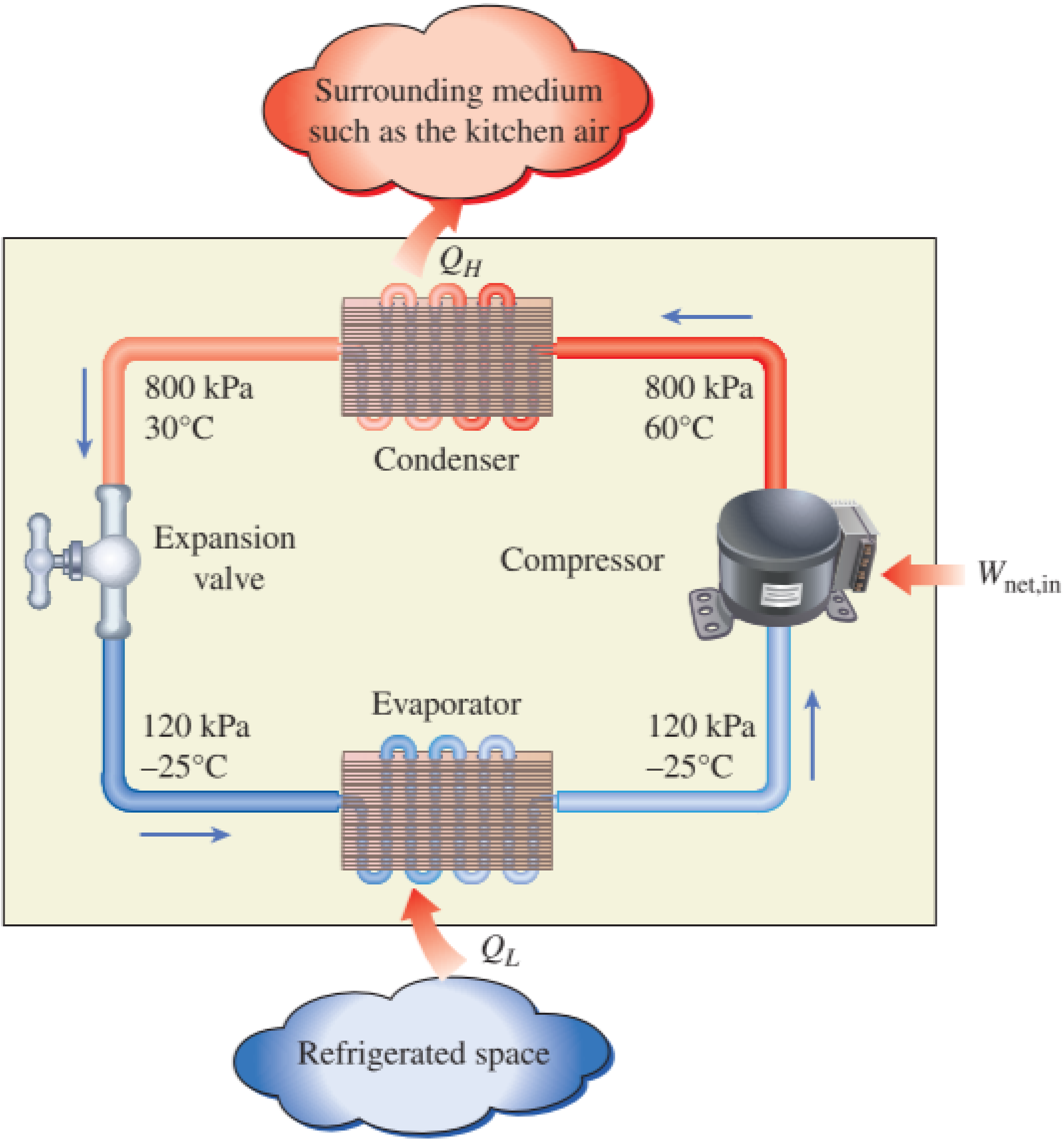
The Second Law of Thermodynamics: Kelvin-Planck Statement

> **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

$$COP_R = \frac{Desired\ Output}{Required\ Input} = \frac{Q_L}{W_{net,in}}$$
$$COP_R = \frac{Q_L}{Q_H - Q_L} = \frac{1}{Q_H/Q_L - 1}$$

Heat Pumps

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

$$COP_{HP} = \frac{Desired\ Output}{Required\ Input} = \frac{Q_H}{W_{net,in}}$$
$$COP_{HP} = \frac{Q_H}{Q_H - Q_L} = \frac{1}{1 - Q_L/Q_H}$$
$$COP_{HP} = COP_R + 1$$

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

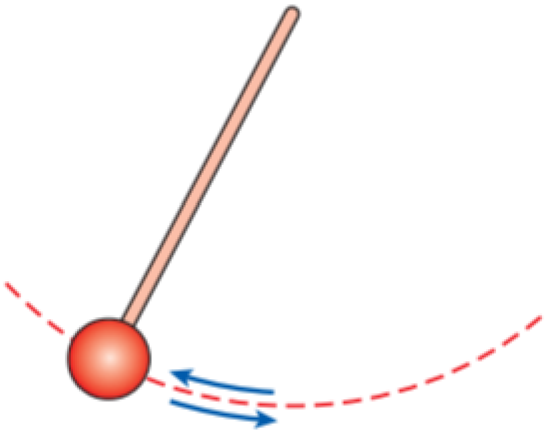
- PMM1: violate the first law of thermodynamics
- PMM2: violate the second law of thermodynamics

6.6 Reversible and Irreversible Processes

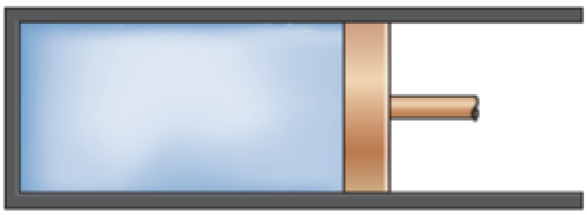
Definitions

- **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



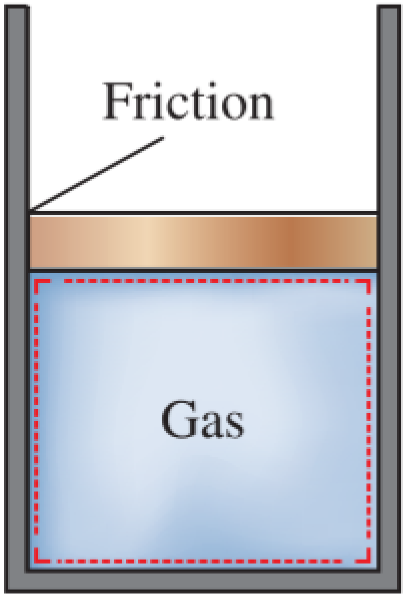
(*b*) Quasi-equilibrium expansion
and compression of a gas

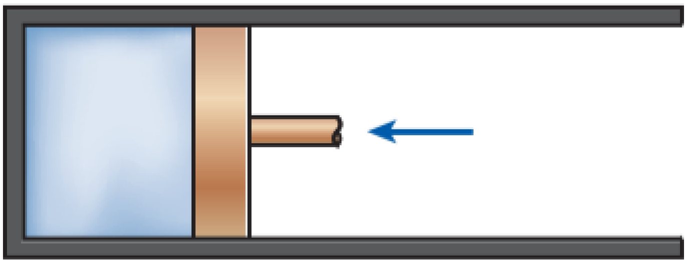
Irreversibilities

Definition

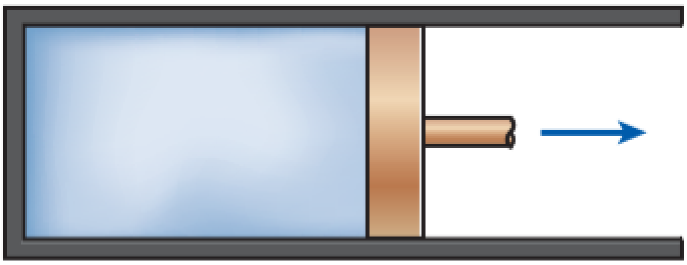
the factors that cause to be irreversible are called irreversibilities

> 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



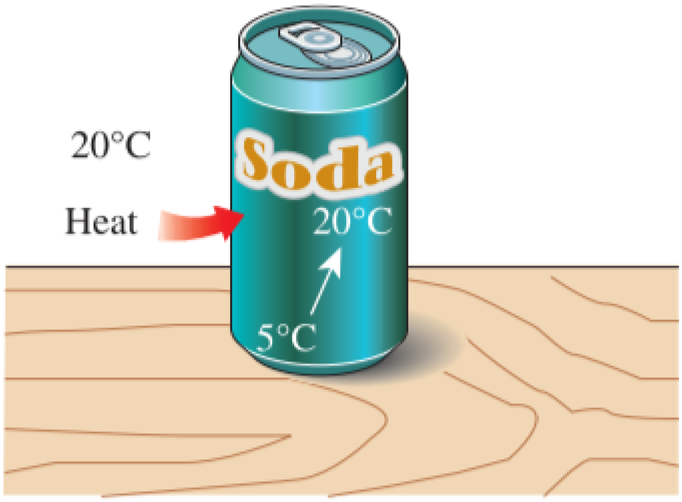


(*a*) Fast compression

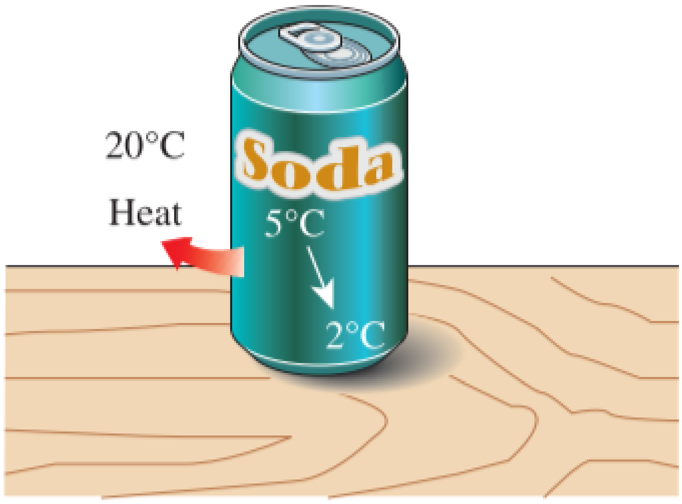


(*b*) Fast expansion

(*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

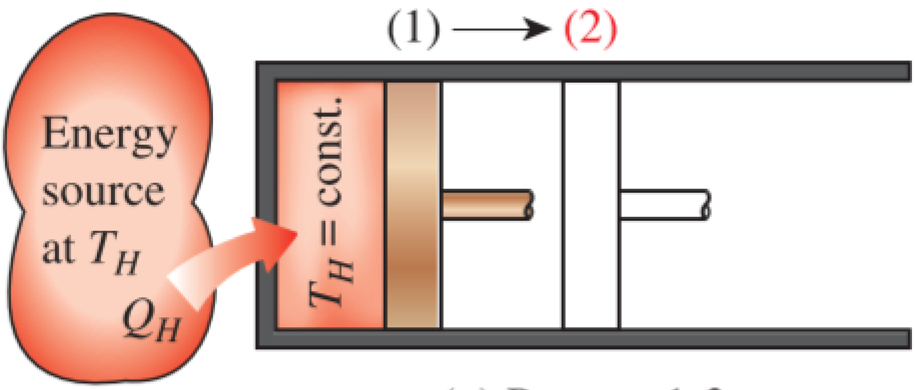
the best known reversible cycle is the **Carnot cycle**, and the theoretical heat engine that operates on the Carnot cycle is called the **Carnot heat engine**

The Carnot Process

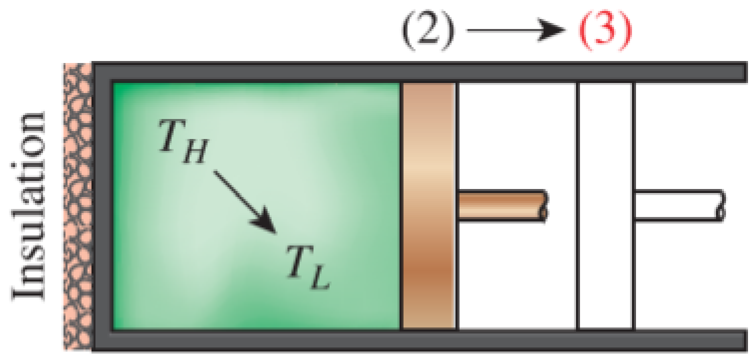
1. Reversible Isothermal Expansion
2. Reversible Adiabatic Expansion
3. Reversible Isothermal Compression

4. Reversible Adiabatic Compression

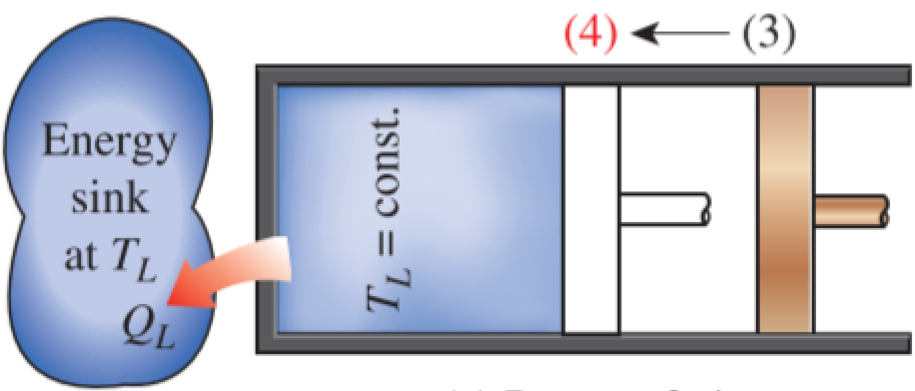
> adiabatic: occurring without loss or gain of heat



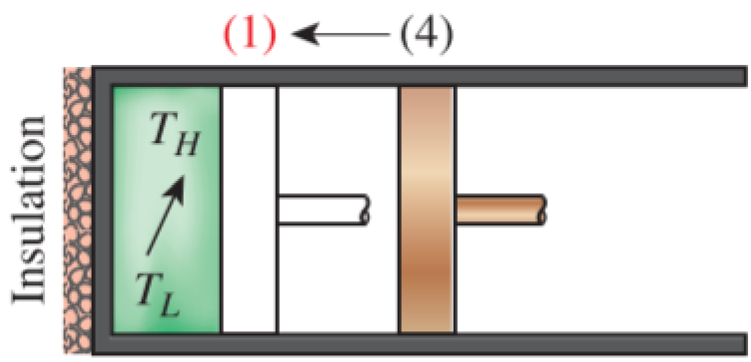
(a) Process 1-2



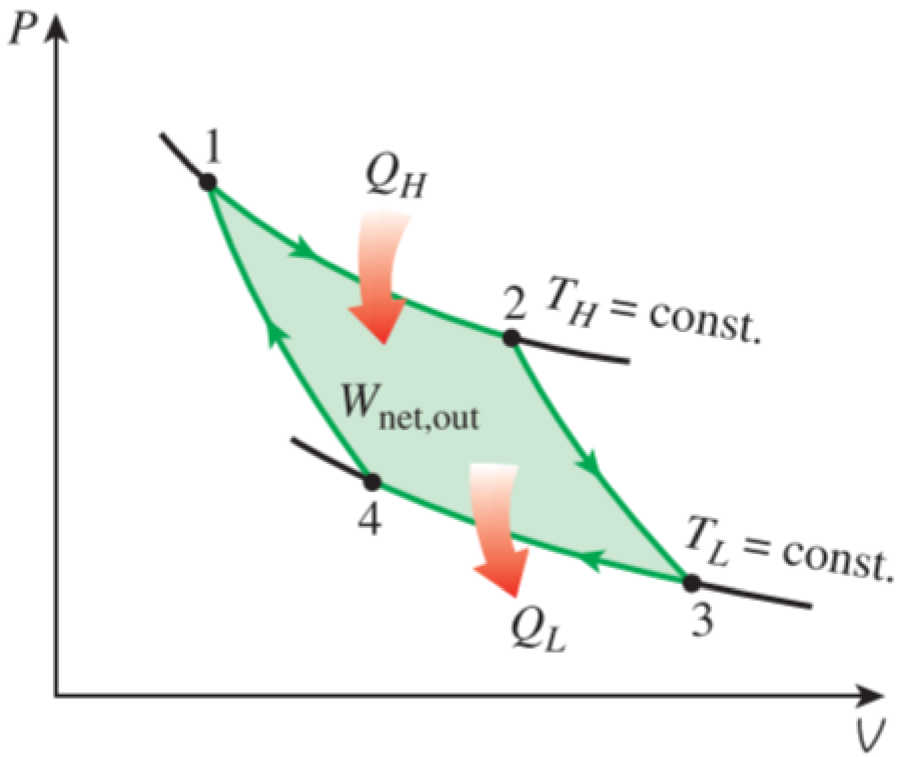
(b) Process 2-3



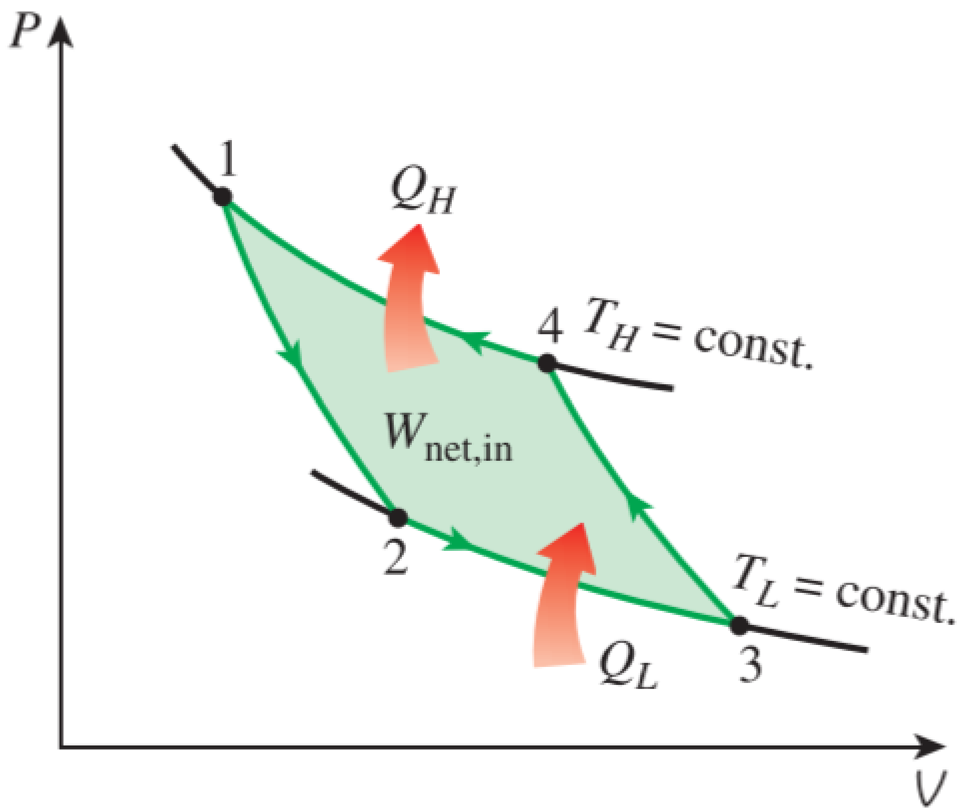
(c) Process 3-4



(d) Process 4-1



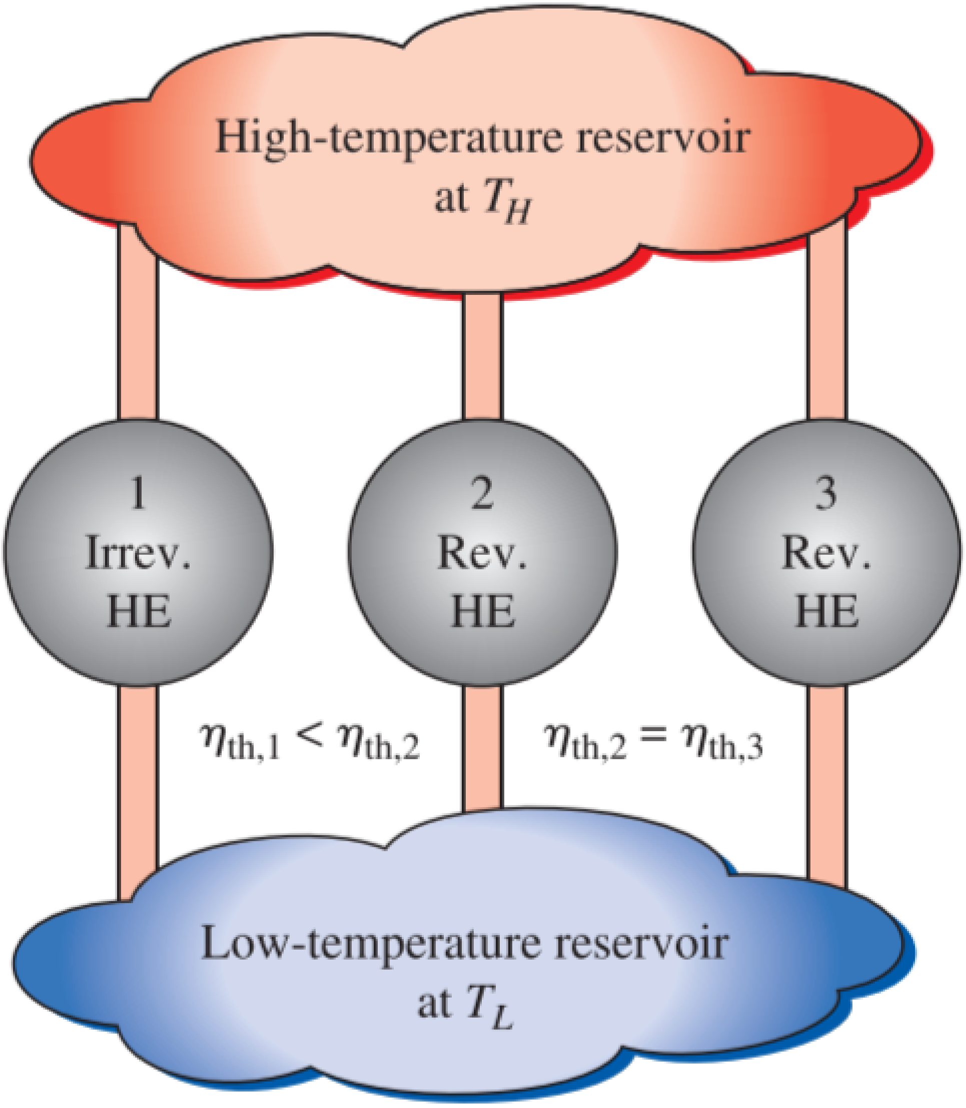
The Reversed Carnot Process

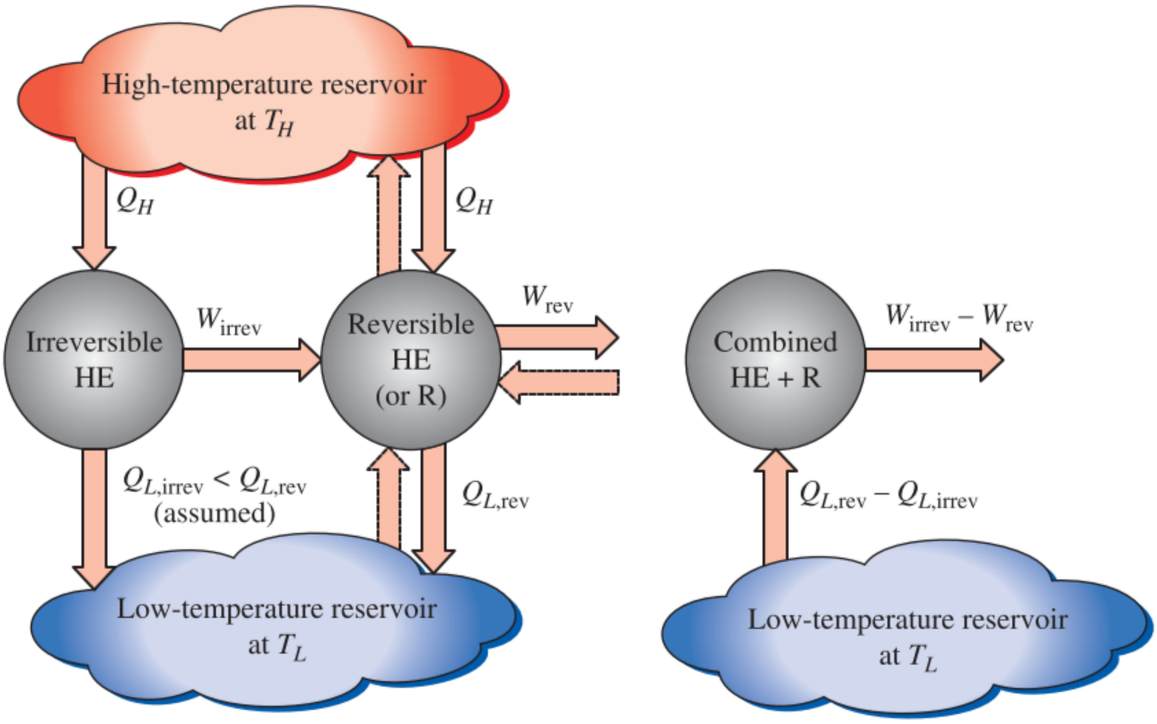


6.8 The Carnot Principles

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**

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

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 id often referred to as the Carnot efficiency

$$\eta_{th} \begin{cases} < \eta_{th,rev} & \text{irreversible heat engine} \\ = \eta_{th,rev} & \text{reversible heat engine} \\ > \eta_{th,rev} & \text{impossible heat engine} \end{cases}$$

6.11 The Carnot Refrigerator and Heat Pump

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

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

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