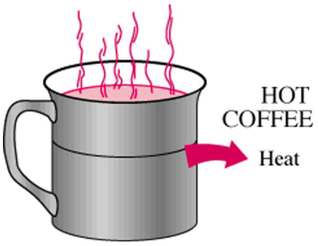
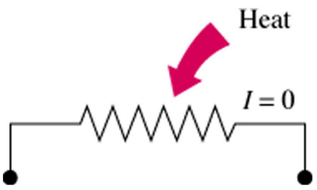
CHAPTER SIX

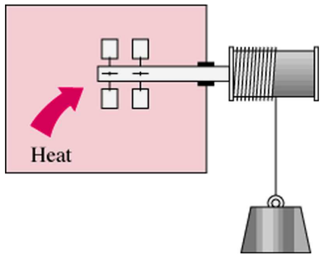
SECOND LAW OF THERMODYNAMICS

Introduction to the Second Law (Section 6.1)

- Satisfying the first law of thermodynamics is required for any process, but is not enough to ensure that it will actually happen
- The second law asserts that processes proceed in a certain direction and not in the reverse direction



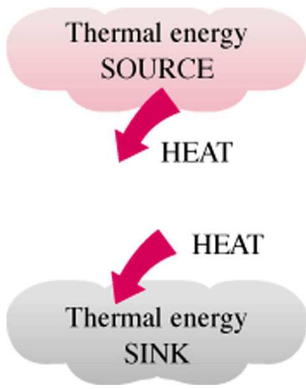




- The second law also asserts that energy has quality as well as quantity.
- If temperature is high, energy will have high quality and can produce more work.
- The second law is used to determine the theoretical limits of commonly used systems such as heat engines and refrigerators.

Thermal Energy Reservoirs (Section 6.2)

A thermal energy reservoir is a body whose temperature does not change as a result of absorbing or supplying heat.
Examples: Lakes, oceans, rivers, atmosphere

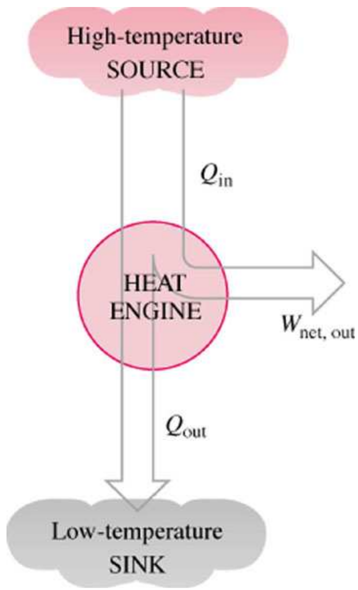


Source
A reservoir that **supplies** energy in the form of heat

Sink
A reservoir that **absorbs** energy in the form of heat

Heat Engines (Section 6.3)

It is easy to convert work into heat (e.g. rubbing your hands), but converting heat into work requires special devices, one of them is called a **heat engine.**



Characteristics of Heat Engines

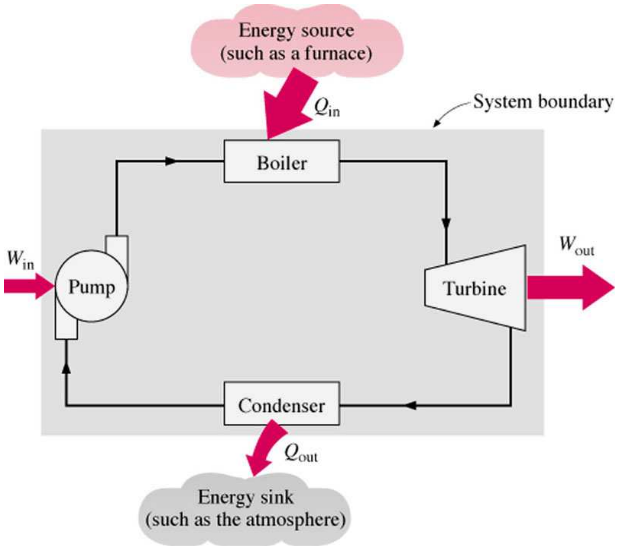
1. They receive heat from a high-temperature source (solar energy, oil furnace, etc.)
2. They convert part of this heat to work
3. They reject the remaining waste heat to a low-temperature sink (the atmosphere, rivers, etc.)
4. They operate in a cycle

Working Fluid
A fluid to and from which heat is transferred while undergoing a cycle

Example of a Heat Engine: Steam Power Plant

Q_{in} = amount of heat supplied to steam in the boiler from a high-temperature source (furnace)
Q_{out} = amount of heat rejected from steam in the condenser to a low-temperature sink (river)
W_{out} = amount of work delivered by steam as it expands in the turbine
W_{in} = amount of work required to pump water to boiler pressure

- $W_{net,out} = W_{out} - W_{in}$
- Energy Balance: $(Q_{in} - Q_{out}) + (W_{in} - W_{out}) = \Delta E_{system}$
- For a cycle: $\Delta E_{system} = 0$ ⇨ $W_{net,out} = Q_{in} - Q_{out}$



Performance

The performance of a device is defined as the ratio of the desired output to the required input:

$$\text{Performance} = \frac{\text{Desired output}}{\text{Required input}}$$

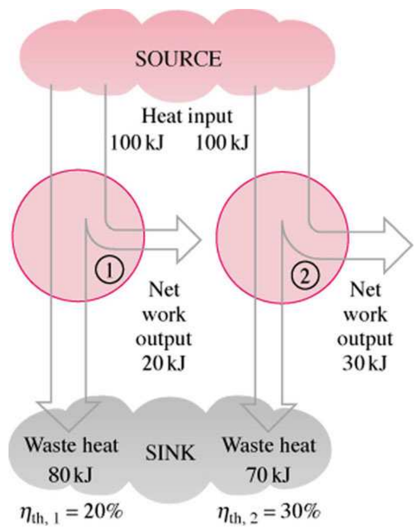
Thermal Efficiency

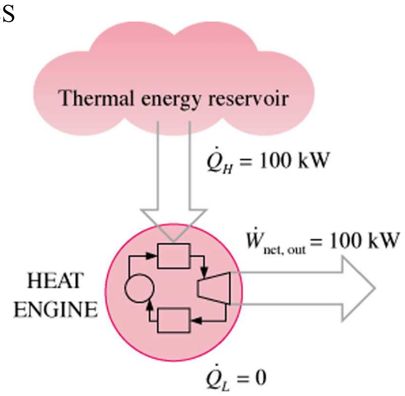
An expression of performance for heat engines. It is defined as the fraction of the heat input that is converted to net work output.

$$⇨\ \text{Thermal Efficiency} = \frac{\text{Net work output}}{\text{Total heat input}}$$

or: $\eta_{th} = \dfrac{W_{net,out}}{Q_{in}} \rightarrow \eta_{th} = \dfrac{Q_{in} - Q_{out}}{Q_{in}} = 1 - \dfrac{Q_{out}}{Q_{in}} \rightarrow \eta_{th} = 1 - \dfrac{Q_L}{Q_H}$

where: Q_L is the **magnitude** of heat rejected to the heat sink
Q_H is the **magnitude** of heat received from the heat source



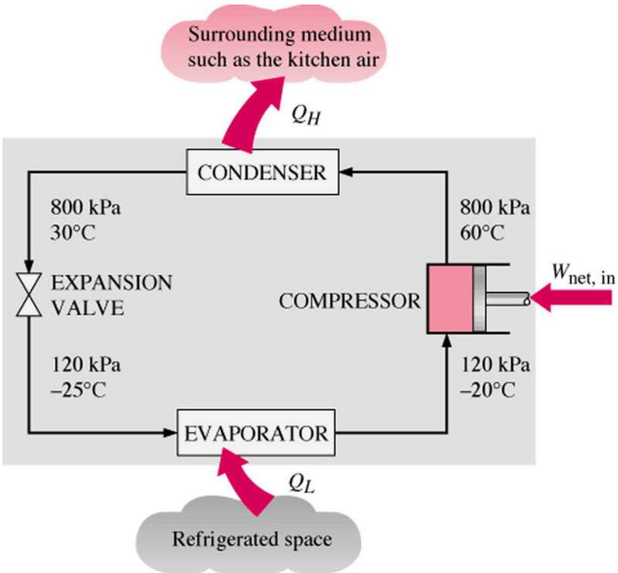


The Second Law of Thermodynamics: Kelvin-Planck Statement
It is impossible for any device that operates on a cycle to receive heat from a single reservoir and produce a net amount of work

What does this statement mean?
It means that no heat engine can have a 100% thermal efficiency.

Refrigerators and Heat Pumps (Section 6.5)

Refrigerators
- Devices that transfer heat from a low-temperature medium to a high-temperature one
- The objective of a refrigerator is to remove Q_L from the cooled space
- **Example**: *Vapor-compression refrigeration cycle*



Refrigerant
The working fluid used in the refrigeration cycle

Coefficient of Performance of Refrigerators (COP_R)
The performance of a refrigerator is expressed in terms of the **coefficient of performance** (COP), denoted by COP_R which can be expressed as:

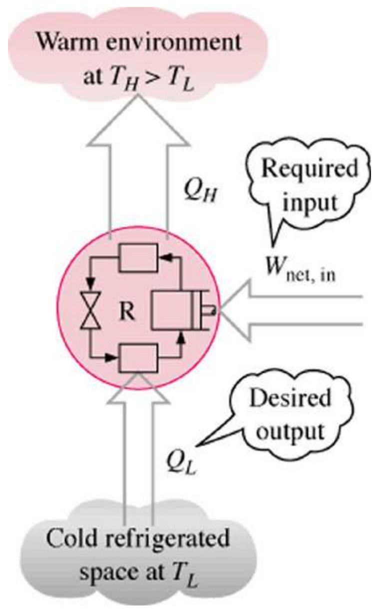
$$COP_R = \frac{\text{Desired output}}{\text{Required input}} = \frac{Q_L}{W_{net,in}}$$

where: $W_{net,in} = Q_H - Q_L$

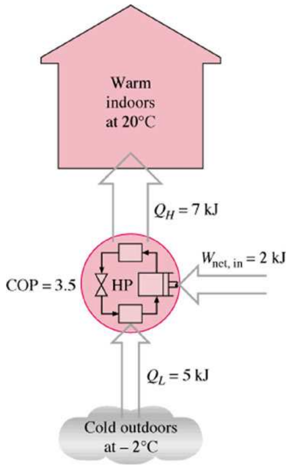
The COP can also be expressed as:

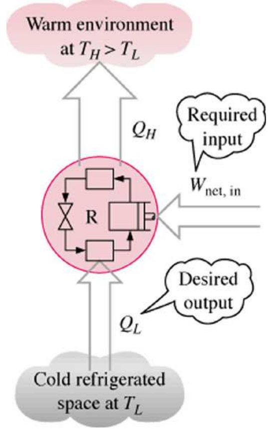
$$COP_R = \frac{Q_L}{Q_H - Q_L} = \frac{1}{Q_H / Q_L - 1}$$

Important Note
The COP can be greater than 1, while thermal efficiency of heat engines can *never* be greater than or equal to 1.



Heat Pumps
- Devices that transfer heat from a low-temperature medium to a high-temperature one
- The objective of a heat pump is to maintain a heated space at a high temperature





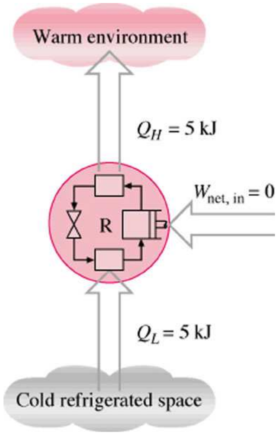
Coefficient of Performance of Heat Pumps (COP_{HP})

$$\mathrm{COP_{HP}} = \frac{\text{Desired output}}{\text{Required input}} = \frac{Q_H}{W_{\text{net,in}}}$$

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

Comparison of COP_R and COP_{HP}

$COP_{HP} = COP_R + 1$



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

Equivalence of the two statements

- The Kelvin-Planck statement and the Clausius statement of the second law are equivalent
- Violation of one of them leads to the violation of the other