Second Law of Thermodynamics

4-16-2021

Heat Engine and Refrigerator

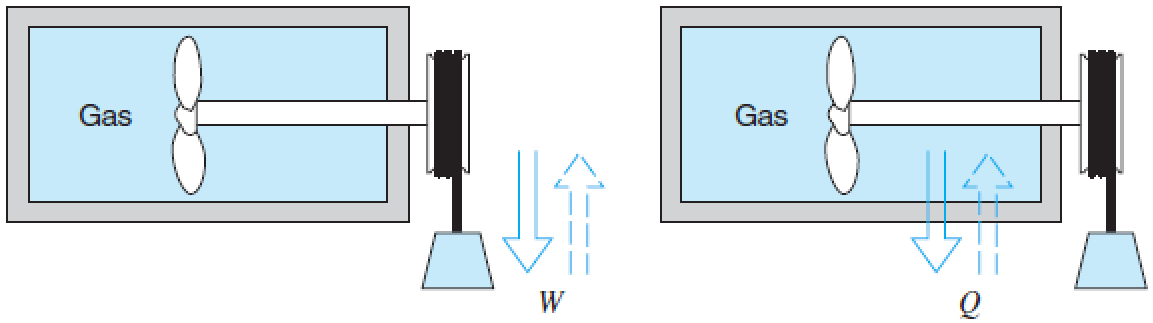
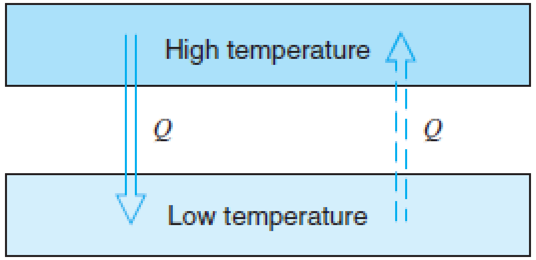


FIGURE 5.1 A system that undergoes a cycle involving work and heat.

- Heat engine and Refrigerator are opposite to each other
- In a heat engine, heat is produced upon work done on the system

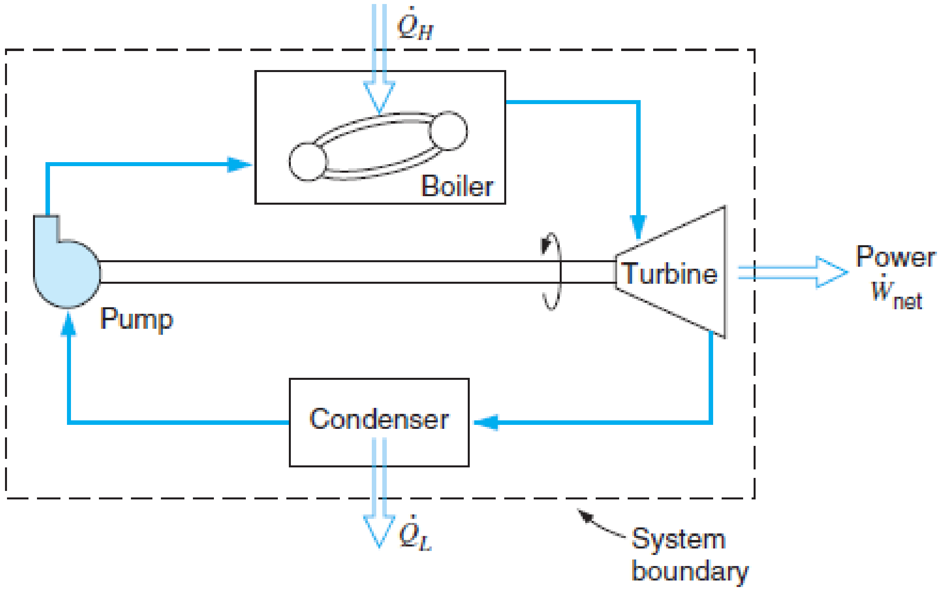
Heat Engine Vs Refrigerator



- Heat Engine- Heat flows from high to low
- Refrigeration- Heat flows from low to high

- Efficiency- Is a term to determine performance of the conversion of work to energy, or heat to work

An example of a heat engine



Power Generation system

$W_{net}=Q_H-Q_L$

$$\eta_{thermal} = \frac{W(\text{energy sought})}{Q_H(\text{energy that costs})} = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

- 100% conversion of heat to work is impossible.
- Then, Thermal efficiency
- η_{th} =(QH-QL)/QH=1-QL/QH

Example Problem

An automobile engine produces 136 hp on the output shaft with a thermal efficiency of 30%. The fuel it burns gives 35 000 kJ/kg as energy release. Find the total rate of energy rejected to the ambient and the rate of fuel consumption in kg/s.

W=136 hp= convert into kW?=136*0.746kW=100kW

η_{th} = 30%=0.3=(W/Q_H)
Then, Q_H=100/0.3=333kW

W_{net}=Q_H-Q_L
Q_L=QH-Went=333-100=233kW, Heat loss or rejection

Rate of fuel consumption=Q_H/q_H = (333kJ/s)/(35000 kJ/kg)= 0.0095 kg/s

η_{th} =(Q_H-Q_L)/Q_H=(333-233)/333=0.3=30%

Two Statements of 2nd Law

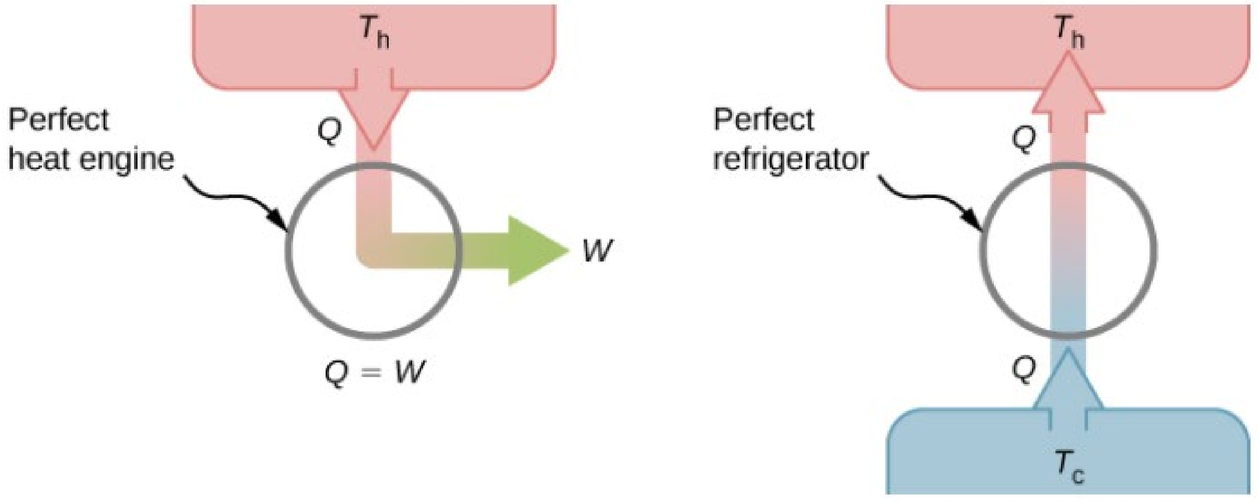
- Kelvin-Plank Statement-

The Kelvin–Planck statement: It is impossible to construct a device that will operate in a cycle and produce no effect other than the raising of a weight and the exchange of heat with a single reservoir. See Fig. 5.8.

The 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 cooler body to a warmer body. See Fig. 5.9.

Two statements of 2nD Law

Heat Reservoir

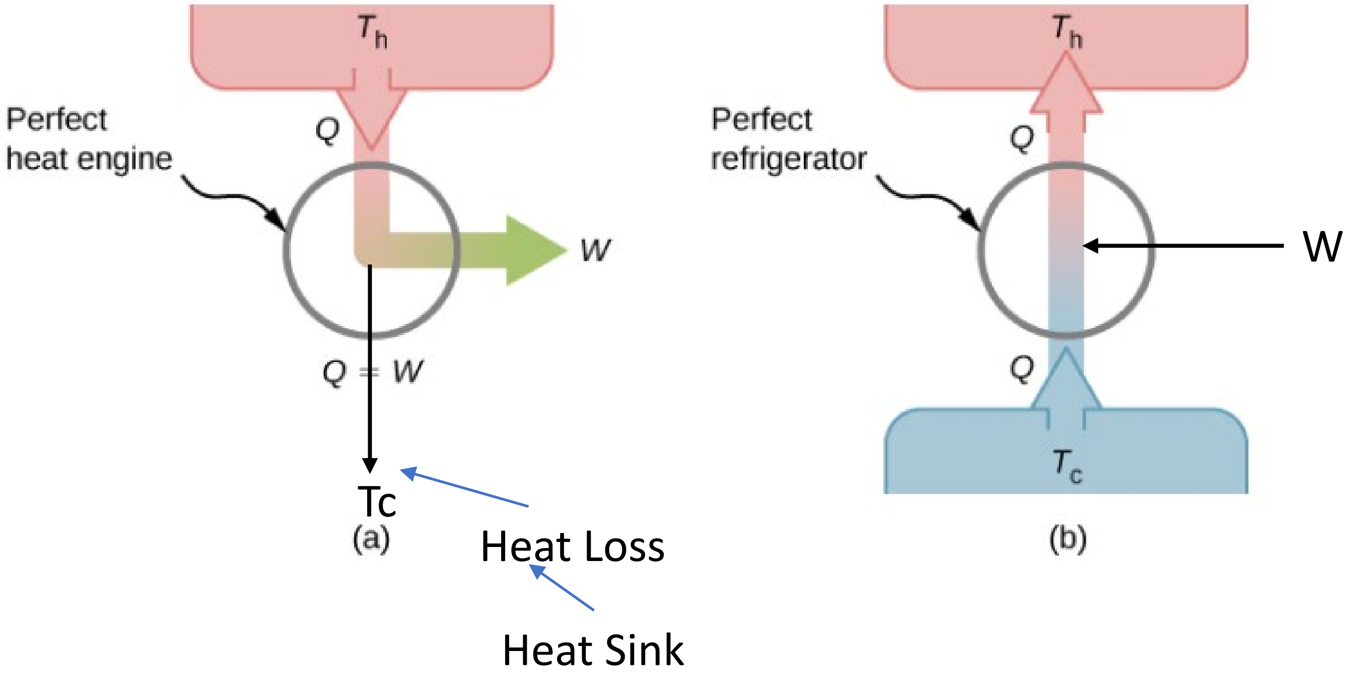


(a) (b)

Heat Sink

- Statement 1- Perfect heat engine is impossible.
- System cannot work on a single reservoir.
- Statement2-
- Perfect Refrigerator is impossible.

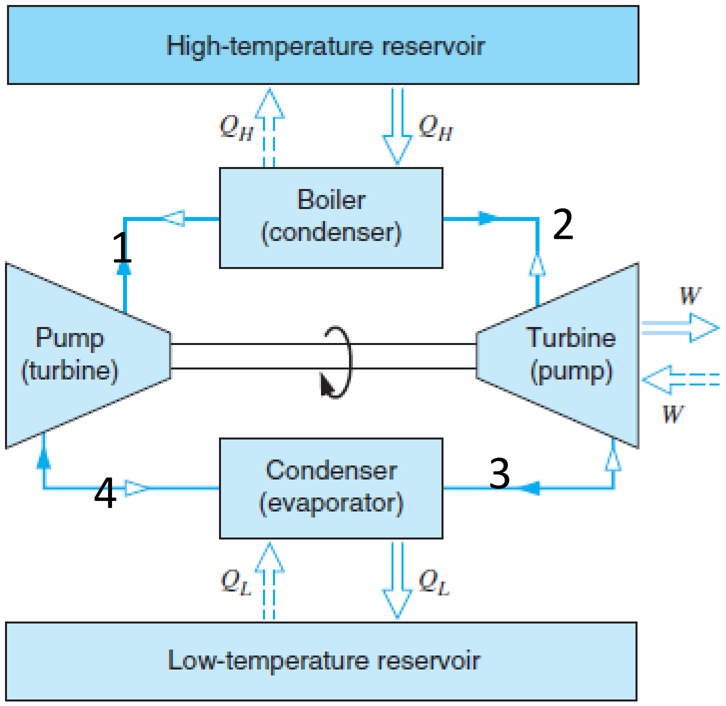
Possibility



Discuss with your group member about 2nd law and explore two examples

- 100% efficient heat engine is impossible
- Possibility-Some heat is being lost
- Refrigerator without work input - impossible
- Possibility-In the refrigerator, compressor donates work to the system

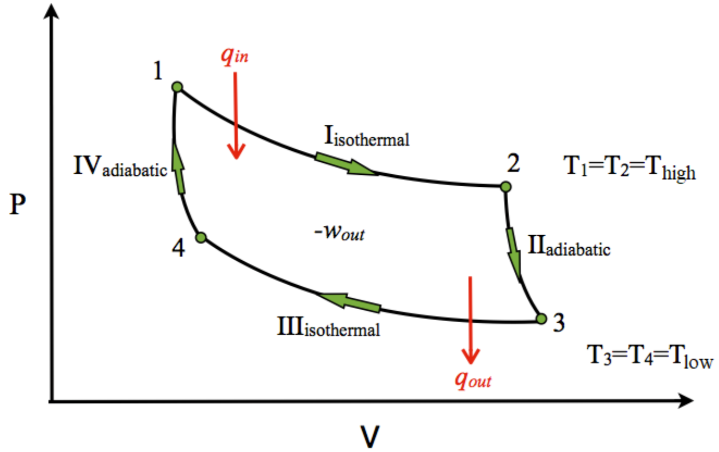
Carnot Cycle



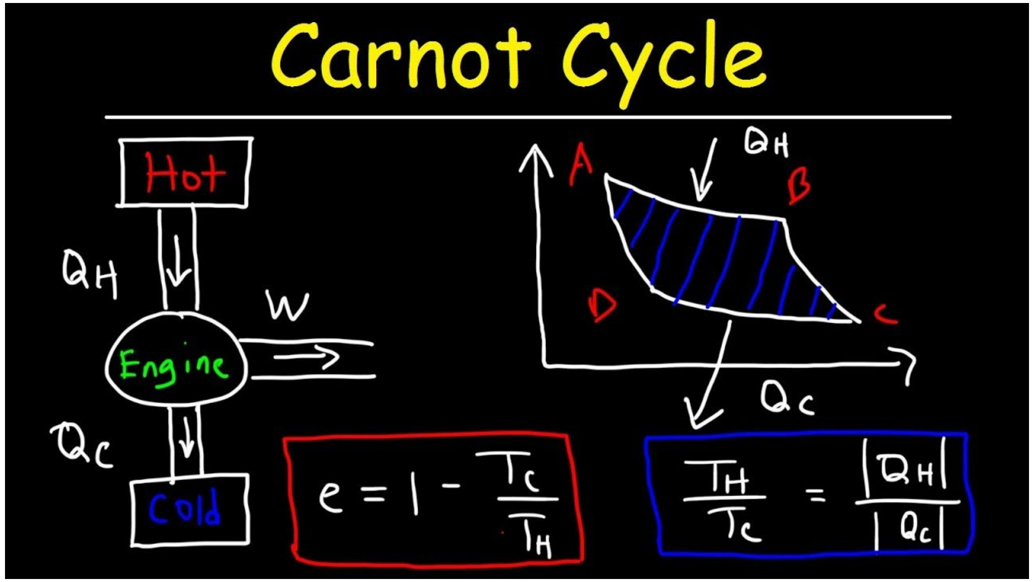
Heat engine operates on a Carnot cycle

- Nicholas Carnot, first expressed the foundations of 2nd Law of TD

- Heat Engine is an example

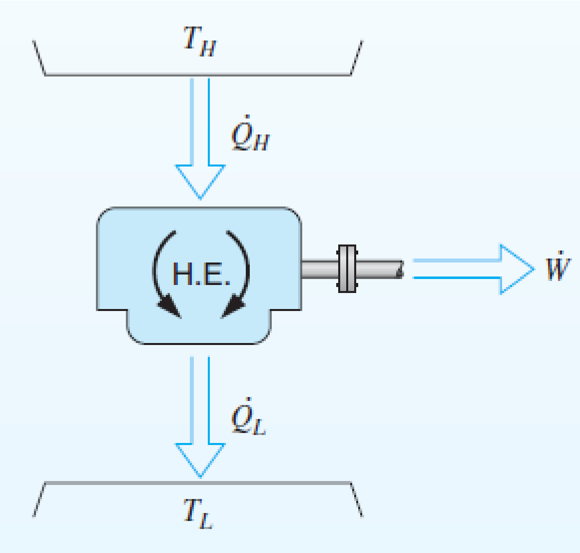


- Carnot Cycle Efficiency



Carnot Efficiency Example

Let us consider the heat engine, shown schematically in Fig. 5.25, that receives a heat-transfer rate of 1 MW at a high temperature of 550°C and rejects energy to the ambient surroundings at 300 K. Work is produced at a rate of 450 kW. We would like to know how much energy is discarded to the ambient surroundings and the engine efficiency and compare both of these to a Carnot heat engine operating between the same two reservoirs.



If we take the heat engine as a control volume, the energy equation gives

$$\dot{Q}_L = \dot{Q}_H - \dot{W} = 1000 - 450 = 550\ \text{kW}$$

and from the definition of efficiency

$$\eta_{\text{thermal}} = \dot{W}/\dot{Q}_H = 450/1000 = 0.45$$

For the Carnot heat engine, the efficiency is given by the temperature of the reservoirs:

$$\eta_{\text{Carnot}} = 1 - \frac{T_L}{T_H} = 1 - \frac{300}{550 + 273} = 0.635$$

The rates of work and heat rejection become

$$\dot{W} = \eta_{\text{Carnot}}\dot{Q}_H = 0.635 \times 1000 = 635\ \text{kW}$$

$$\dot{Q}_L = \dot{Q}_H - \dot{W} = 1000 - 635 = 365\ \text{kW}$$

The actual heat engine thus has a lower efficiency than the Carnot (ideal) heat engine, with a value of 45% typical for a modern steam power plant. This also implies that the actual engine rejects a larger amount of energy to the ambient surroundings (55%) compared with the Carnot heat engine (36%).