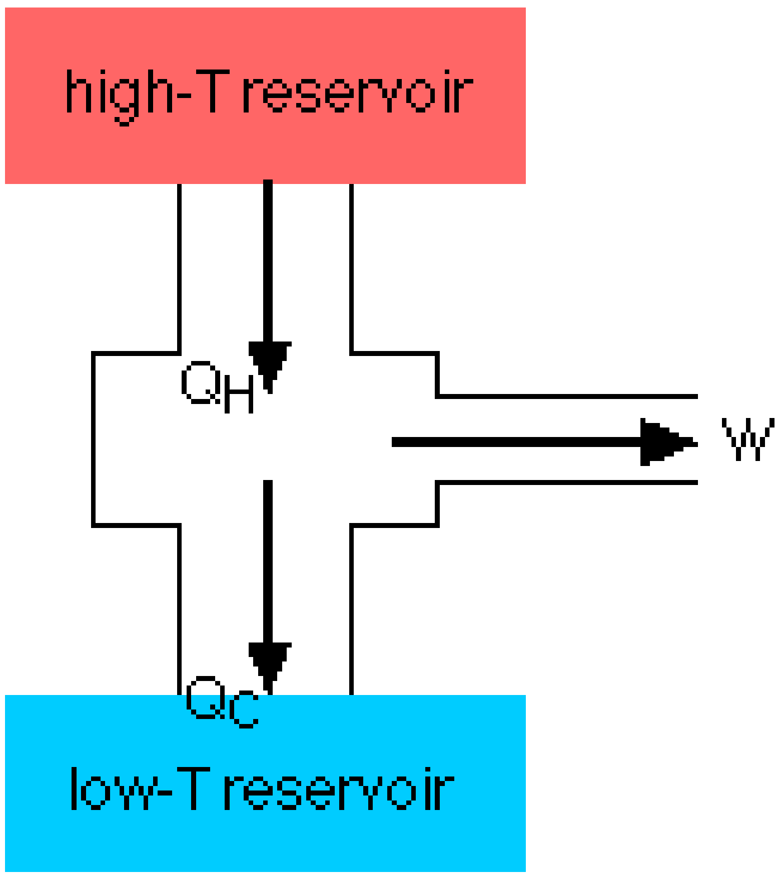
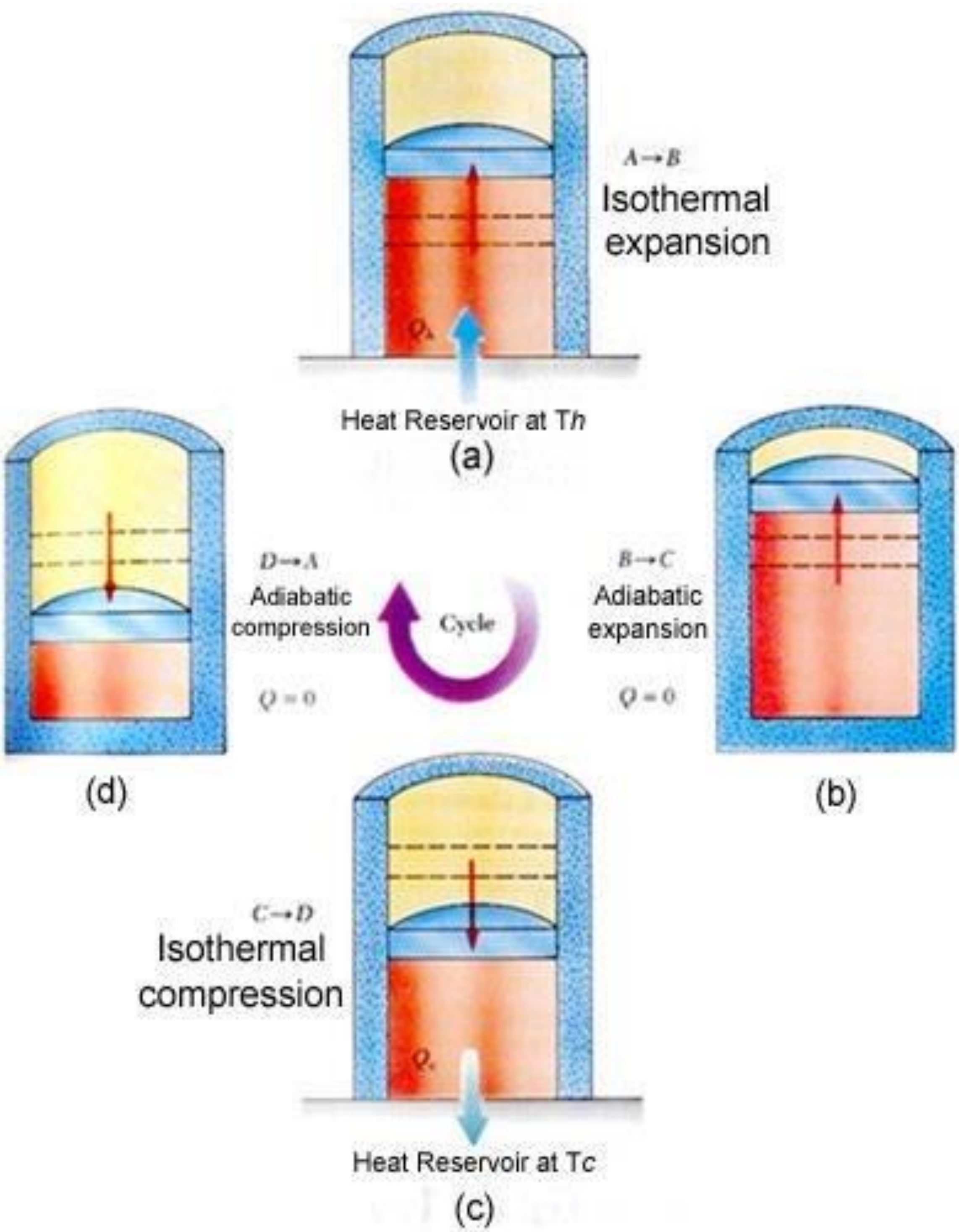
The Second Law of Thermodynamics is fundamental to understanding natural processes and developing more efficient technologies in energy, industry, and environmental fields.

The Carnot Cycle:

The efficiency of a heat-engine cycle greatly depends on how the individual processes that make up the cycle are executed. The net work (or efficiency) can be maximized by using reversible processes. The best known reversible cycle is the (*Carnot cycle)* which explained in figure below .



Consider a gas in a cylinder-piston (closed system).



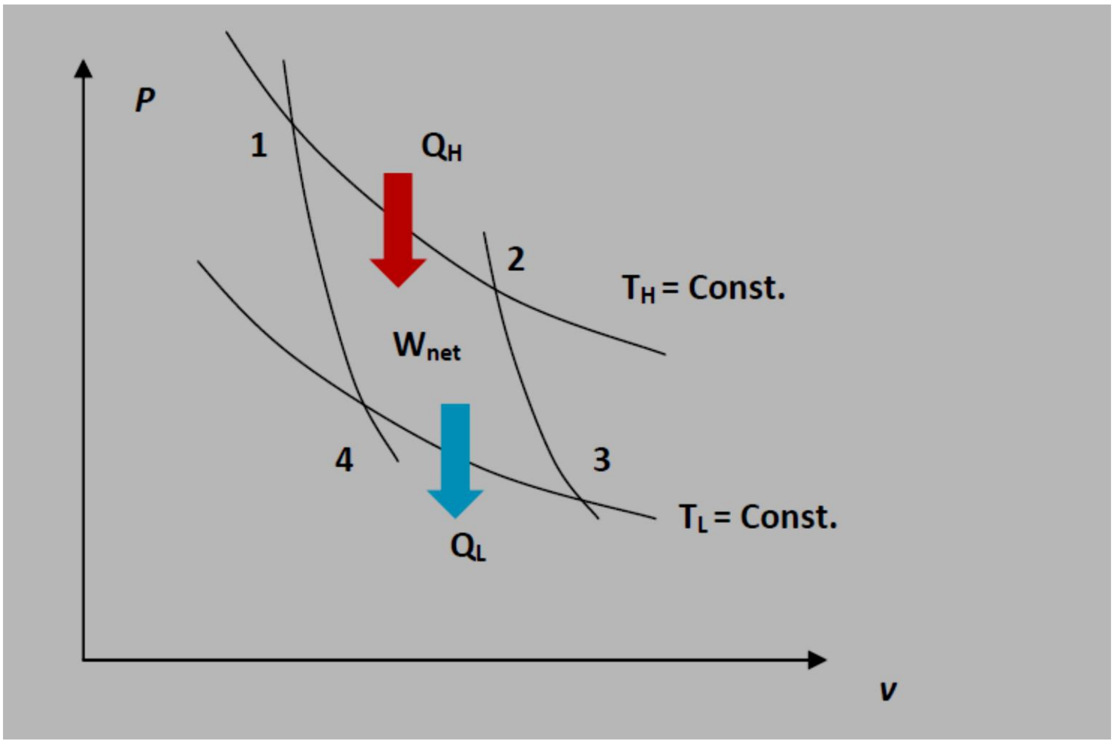
The Carnot cycle has four processes:

1-2 Reversible isothermal expansion: The gas expands slowly, doing work on the surroundings. Reversible heat transfer from the heat source at TH to the gas which is also at TH.

2-3 Reversible adiabatic expansion: The cylinder-piston is now insulated (adiabatic) and gas continues to expand reversibly (slowly). So, the gas is doing work on the surroundings, and as a result of expansion the gas temperature reduces from TH to TL

3-4: Reversible isothermal compression: The gas is allowed to exchange heat with a sink at temperature TL as the gas is being slowly compressed. So, the surroundings is doing work (reversibly) on the system and heat is transferred from the system to the surroundings (reversibly) such that the gas temperature remains constant at TL.

4-1: Reversible adiabatic compression: The gas temperature is increasing from TL to TH as a result of compression



Heat Engines (carnot engine):

Heat engines convert heat to work. There are several types of heat engines, but they are characterized by the following:

1- They all receive heat from a high-temperature source (oil furnace, nuclear reactor, etc.)

2- They convert part of this heat to work

3- They reject the remaining waste heat to a low-temperature sink

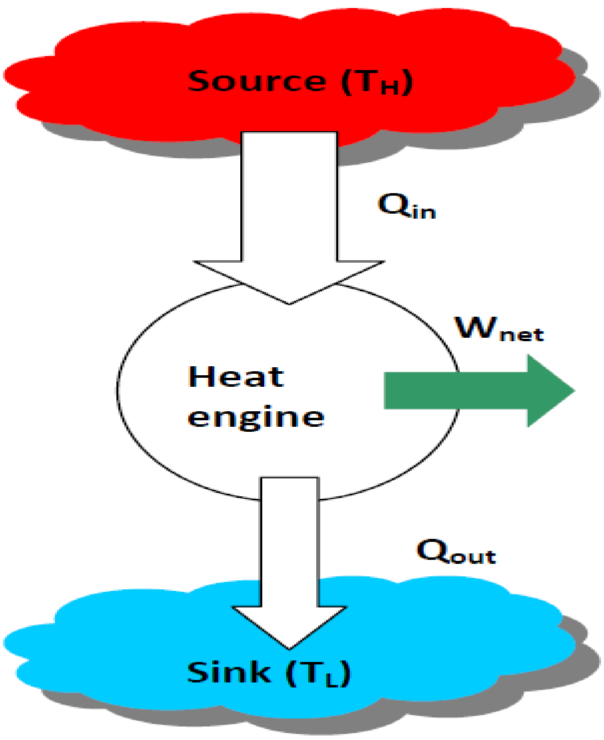
4- They operate in a cycle

The Efficiency of Carnot Engine:

Thermal efficiency: is the fraction of the heat input that is converted to the net work output (efficiency = benefit / cost).

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

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

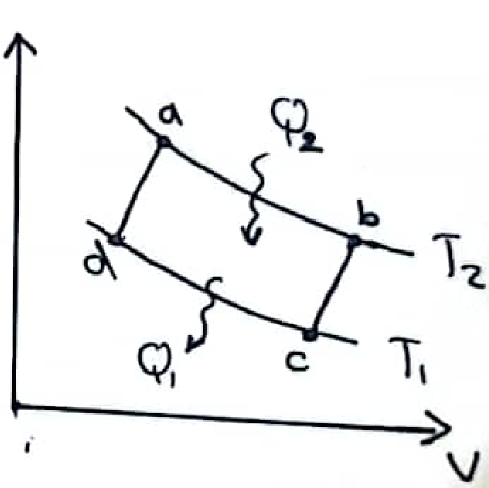


The effeciency of carnot engine:

Is the ratio between The work (W) done by the engin to the quantity of heat (Q_2) it absorbs from a hight-temprature Source.

$$\eta = \frac{W}{Q_2} \rightarrow W = Q_2 - Q_1$$

$$\eta = \frac{Q_2 - Q_1}{Q_2} \rightarrow \boxed{\eta = 1 - \frac{Q_1}{Q_2}}$$



$W_{abcd} = W_{ab} + W_{bc} + W_{cd} + W_{da}$
(Total)

0

$dQ = du + dw$

$$= nRT_2 \ln \frac{V_b(2)}{V_a(1)} \cancel{- n C_v (T_1 - T_2)} - nRT_1 \ln \frac{V_c}{V_d} \cancel{+ n C_v (T_1 - T_2)}$$

$$= \underbrace{nRT_2 \ln \frac{V_b}{V_a}}_{Q_2} - \underbrace{nRT_1 \ln \frac{V_c}{V_d}}_{Q_1}$$

$$W = Q_2 - Q_1$$

$$\eta = \frac{W}{Q_2} = \frac{Q_2 - Q_1}{Q_2} \Rightarrow \boxed{\eta = 1 - \frac{Q_1}{Q_2}}$$

$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2} \Rightarrow \therefore \frac{Q_1}{Q_2} = \frac{T_1}{T_2} \ast \frac{\ln V_c / V_d}{\ln V_b / V_a}$$

$$\therefore \boxed{\eta = 1 - \frac{T_1}{T_2}}$$

Refrigerators and Heat Pumps

In nature, heat flows from high-temperature regions to low-temperature ones. The reverse process, however, cannot occur by itself. The transfer of heat from a low temperature region to a high-temperature one requires special devices called *refrigerators*. Refrigerators are cyclic devices, and the working fluids used in the cycles are called *refrigerant*.

Heat pumps transfer heat from a low-temperature medium to a high-temperature one. Refrigerators and heat pumps are essentially the same devices; they differ in their objectives only. Refrigerator is to maintain the refrigerated space at a low temperature. On the other hand, a heat pump absorbs heat from a low-temperature source and supplies the heat to a warmer medium.

Coefficient of performance (COP):

The performance of refrigerators and heat pumps is expressed in terms of the coefficient of performance (COP) which is defined as

$$\boldsymbol{COP = \frac{Heat\ absorbed\ from\ cold\ reservior}{Work\ done\ on\ refrigerat}}$$

Prove: For a carnot (ideal) Refrigerator show that the work is given $\boldsymbol{W = Q_1 \left[\frac{T_{2-} T_1}{T_1}\right]}$

Example:

If the coefficient of performance of Refrigerator is (5) find the ratio of the heat rejected to the work done on the refrigerator.