CARNOT ENGINE

Rita Prasetyowati
Fisika FMIPA UNY
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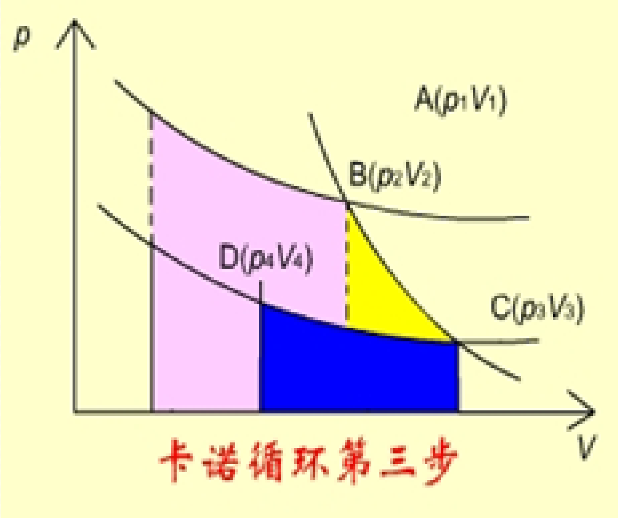
Process 3

Reversible compress at T_c from P_3,V_3 to P_4,V_4 ,(C→D)

$$\Delta U_3 = 0$$

$$Q_1 = Q_c = W_3 = \int_{V_3}^{V_4} pdV = RT_1 \ln \frac{V_4}{V_3}$$

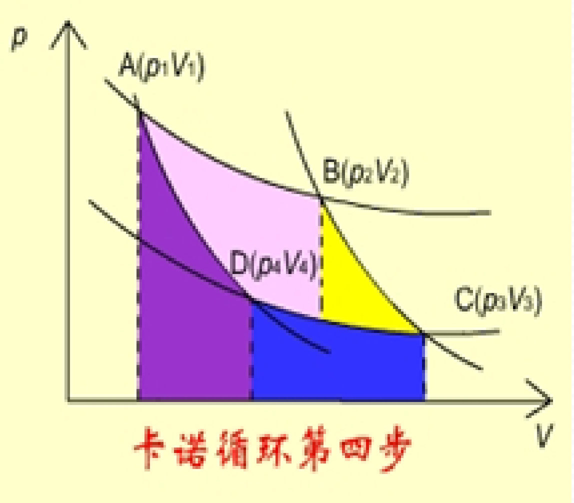


$$T_1 = T_c$$

The work is showed as the area under the curve DC.

Process 4

Adiabatic reversible compress from P_4, V_4, T_c to $P, V, T,$ (D→A)



$$Q = 0$$

$$W_4 = -\Delta U_4 = -\int_{T_1}^{T_2} C_{V,m} dT$$

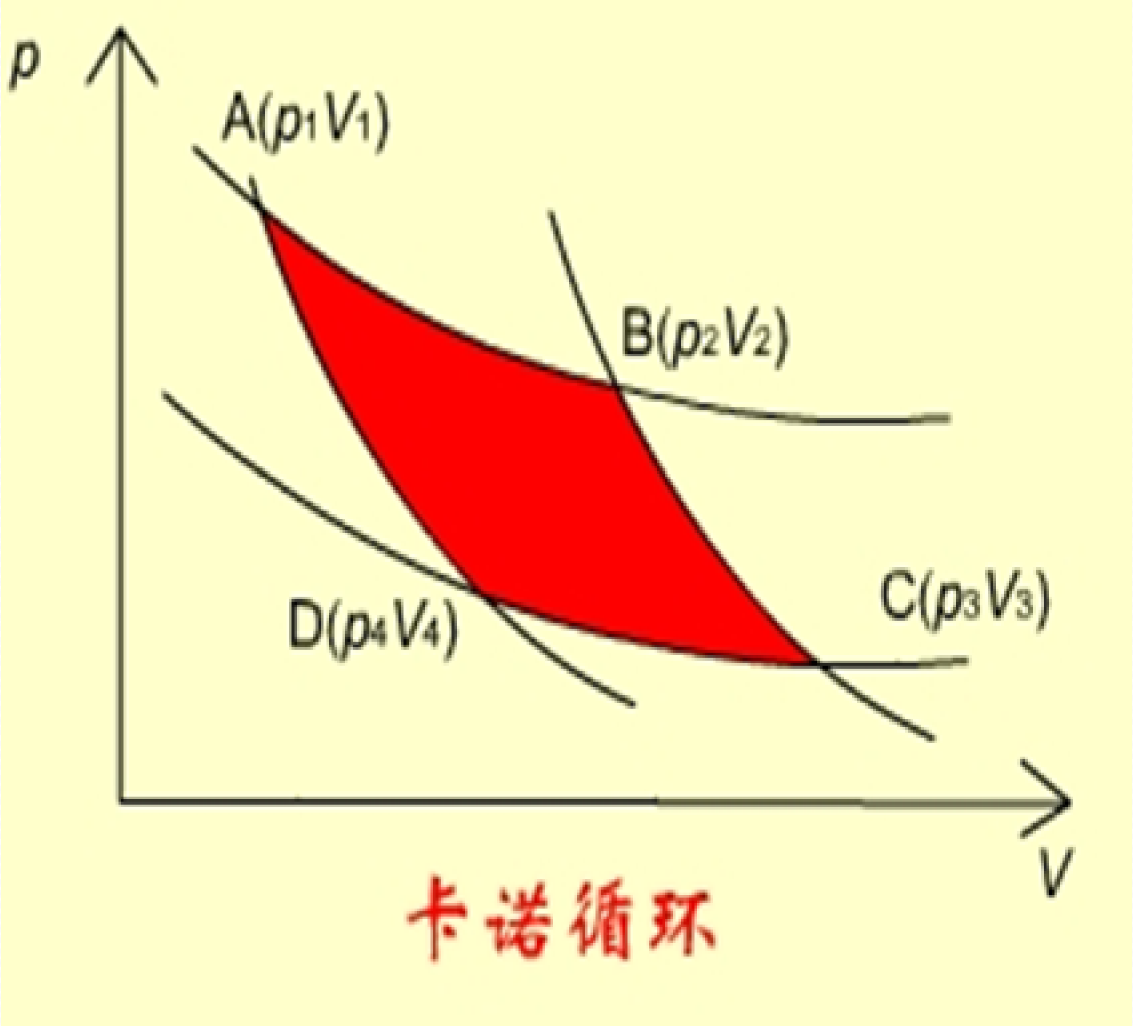
The work is showed as the area under the curve DA.

General heat & work

The whole cycle:

$$\Delta U = 0$$

$$Q = Q_h + Q_c$$



$Q_h > 0$

$Q_c < 0.$

$$W = W_1 + W_3 = RT_2 \ln \frac{V_2}{V_1} + RT_1 \ln \frac{V_4}{V_3}$$

(W2 and W4 can be eliminated)

According to the formula of the adiabatic reversible process

Process 2: $T_h V_2^{\gamma-1} = T_c V_3^{\gamma-1}$

Process 4: $T_h V_1^{\gamma-1} = T_c V_4^{\gamma-1}$

2 divide 4: $$\frac{V_2}{V_1} = \frac{V_3}{V_4}$$

$$W_1 + W_3 = RT_2 \ln\frac{V_2}{V_1} + RT_1 \ln\frac{V_4}{V_3} = R(T_2 - T_1)\ln\frac{V_2}{V_1}$$

Efficiency of the engine

Thermal machine absorbs heat Qh from Th source, part of heat is changed into work, other Qc go back to Tc source.

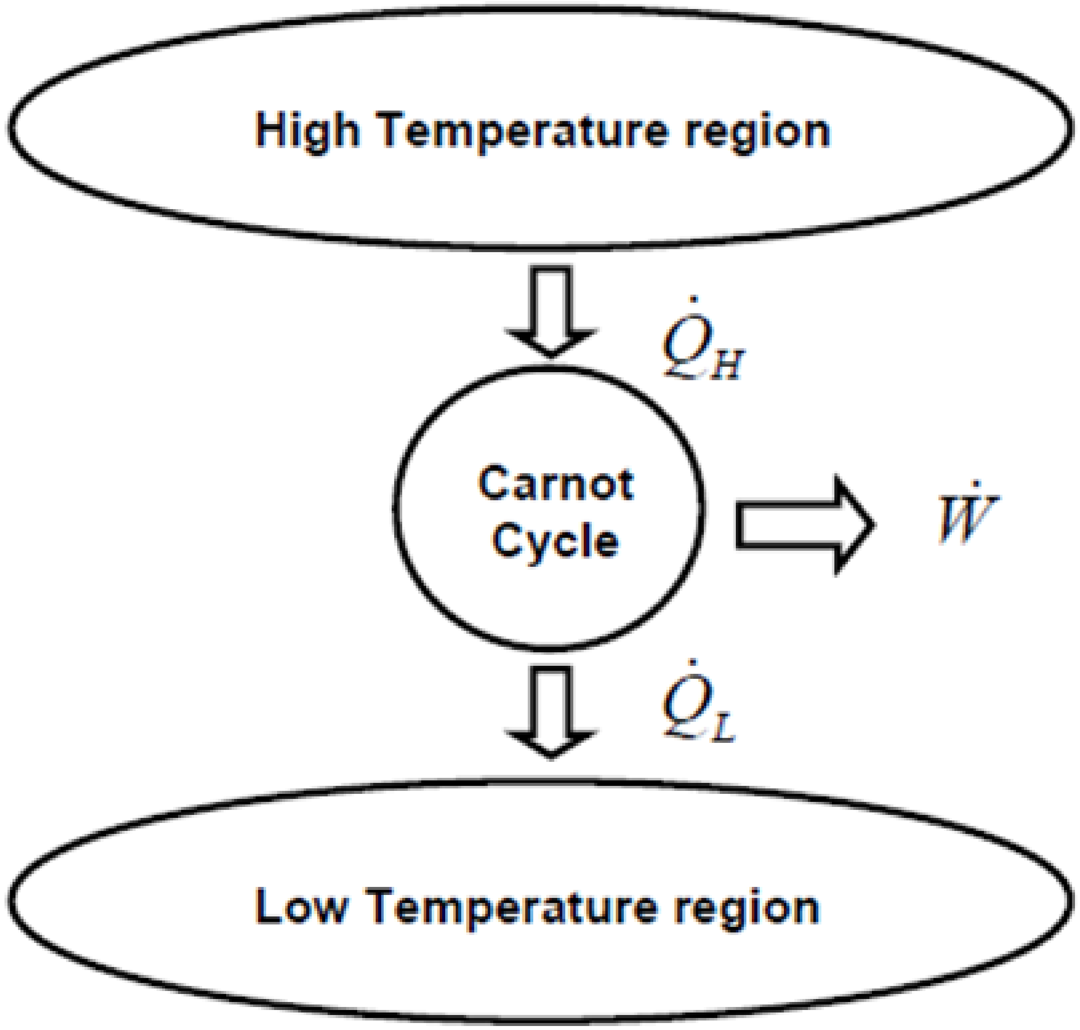
$$\eta = \frac{W}{Q_h} = \frac{Q_h + Q_c}{Q_h} (Q_c < 0)$$

or

$$\eta = \frac{nR(T_h - T_c)\ln(\frac{V_2}{V_1})}{nRT_h \ln(\frac{V_2}{V_1})} = \frac{T_h - T_c}{T_h} = 1 - \frac{T_c}{T_h} \qquad \eta < 1$$

Applications of the Carnot Cycle

a. Carnot Cycle Engine



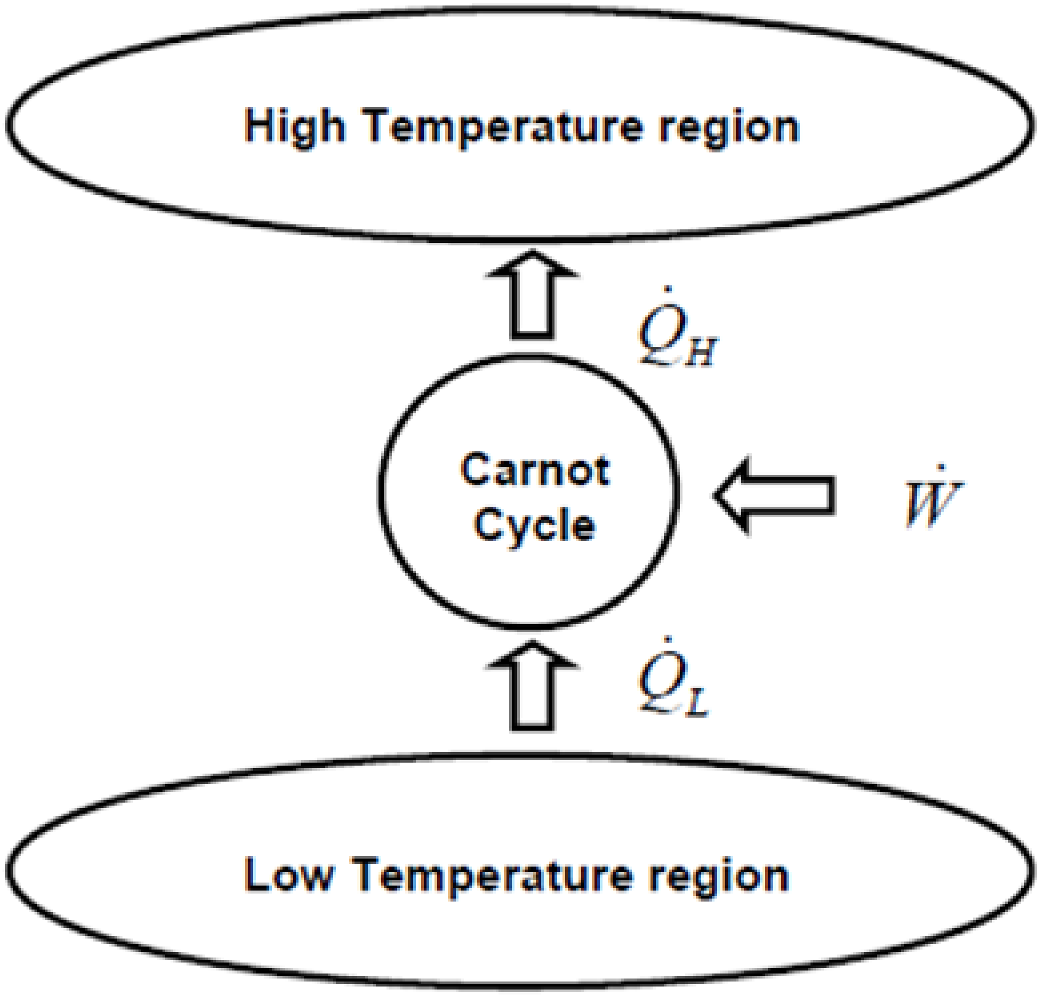
From the first law of thermodynamics:

$$\dot{Q}_H = \dot{Q}_L + \dot{W}$$

From the definition of efficiency, we find for the Carnot engine:

$$\eta = 1 - \frac{\dot{Q}_L}{\dot{Q}_H}$$ or $$\eta = 1 - \frac{T_L}{T_H}$$

b.Carnot Cycle Refrigerator



From the first law of thermodynamics:

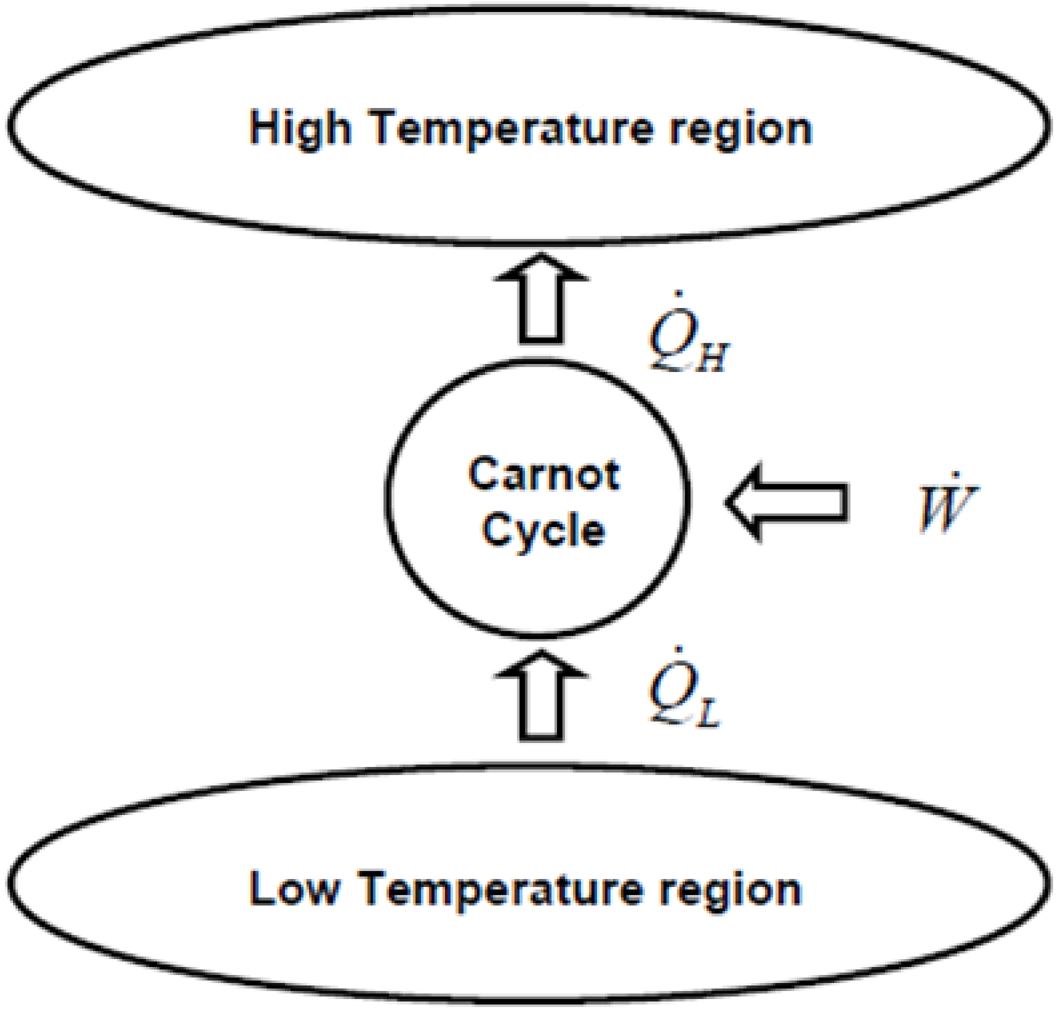
$$\dot{Q}_H = \dot{Q}_L + \dot{W}$$

From the definition of Coefficient of Performance (COP), we find for the Carnot refrigeration cycle:

$$COP = \frac{\dot{Q}_L}{\dot{W}} = \frac{\dot{Q}_L}{\dot{Q}_H - \dot{Q}_L} = \frac{1}{\frac{\dot{Q}_H}{\dot{Q}_L} - 1}$$

$$COP = \frac{1}{\frac{T_H}{T_L} - 1}$$

c. Carnot Cycle Heat Pump



From the first law of thermodynamics:

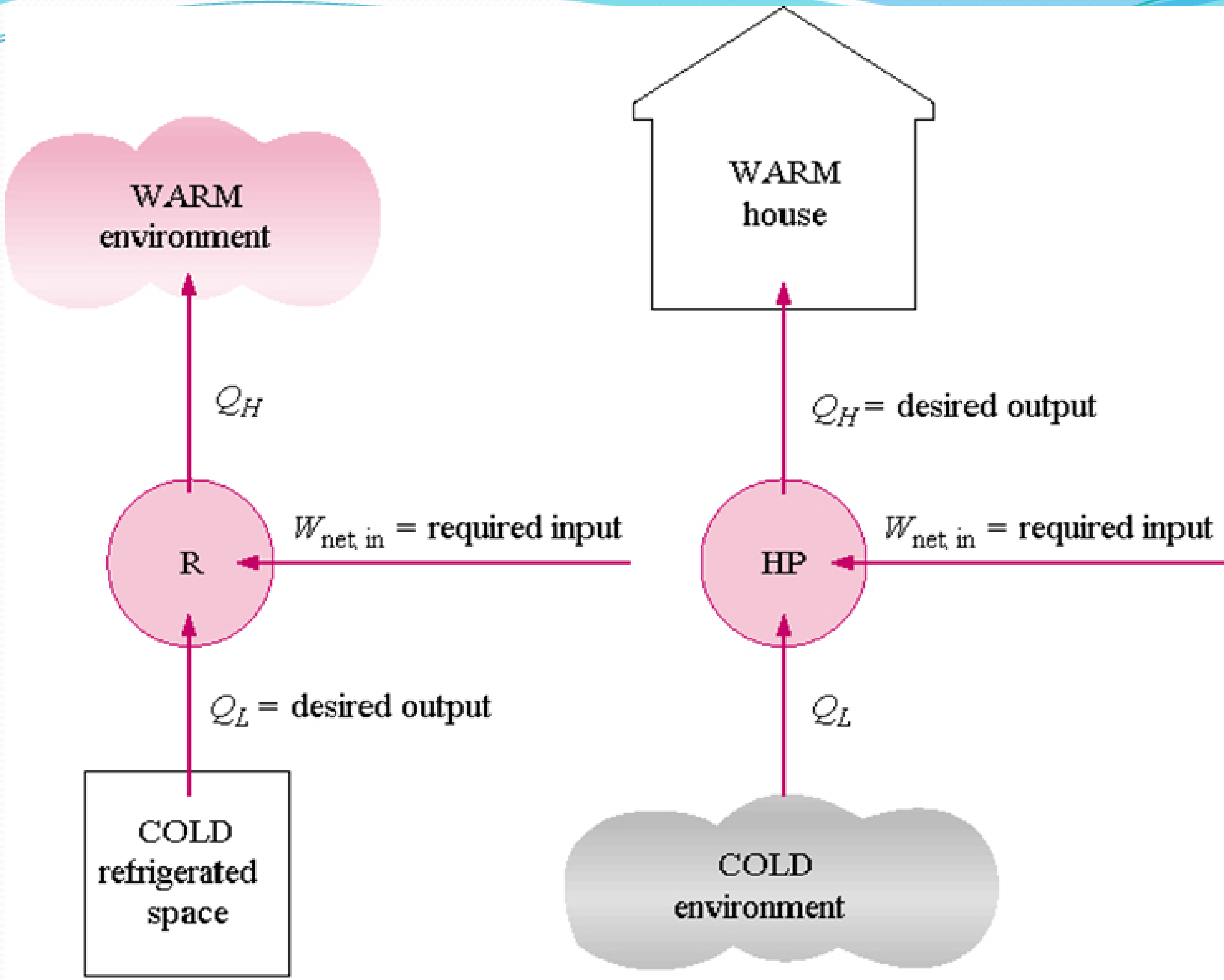
$$\dot{Q}_H = \dot{Q}_L + \dot{W}$$

From the definition of Coefficient of Performance (COP), we find for the Carnot refrigeration cycle:

$$COP = \frac{\dot{Q}_H}{\dot{W}} = \frac{\dot{Q}_H}{\dot{Q}_H - \dot{Q}_L} = \frac{1}{1 - \frac{\dot{Q}_L}{\dot{Q}_H}}$$

$$COP = \frac{1}{1 - \frac{T_L}{T_H}}$$

Refrigerator and heat pump



(*a*) Refrigerator (*b*) Heat pump

Refrigerator dan heat pumps pada dasarnya merupakan peralatan yang sama.

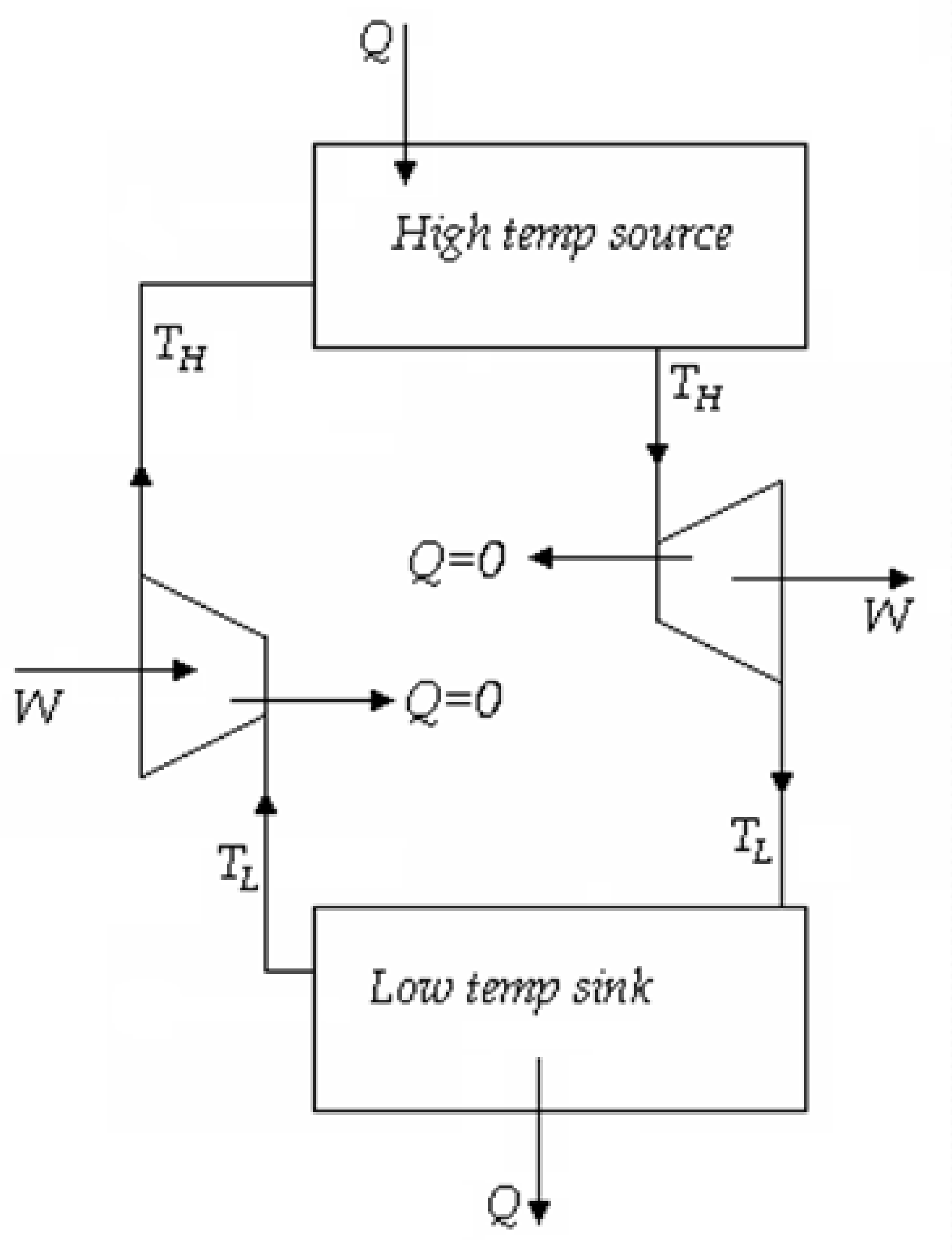
Refrigerator dan heat pumps berbeda hanya pada tujuannya saja.

- **Tujuan dari refrigerator adalah mengambil kalor (Q_L) dari medium bersuhu rendah (mempertahankan ruang pendingin tetap dingin)**

- **Tujuan dari heat pump adalah mensuplai kalor (Q_H) ke medium bersuhu tinggi (mempertahankan ruang pemanas tetap panas)**

The Carnot cycle was first proposed in 1824, by French engineer N.L.S. Carnot . The interest in the cycle is largely theoretical, as no practical Carnot cycle engine has yet been built.

Nevertheless, it can be shown to be the most efficient cycle possible, so that considerable attention has been given at discovering ways of making the more practical cycles look, as much as possible, like the Carnot.



- The closed cycle here has four stages
- Isothermal heat addition
- Adiabatic expansion
- Isothermal heat removal
- Adiabatic compression
- *Isothermal* = const. Temp
- *Adiabatic* = perfectly insulated

Next Meeting : Changes of Phase

Carnot Principle

The thermal efficiency of an irreversible power cycle is always less than the thermal efficiency of a reversible power cycle when each operates between the same two reservoirs.

Each engine receives identical amounts of heat Q_H and produces W_R or W_I.

Each discharges an amount of heat Q to the cold reservoir equal to the difference between the heat it receives and the work it produces

All reversible power cycles operating between the same two thermal reservoirs have the same thermal efficiencies.

Characteristic of Carnot Engine

We consider the standard Carnot-cycle machine, which can be thought of as having a piston moving within a cylinder, and having the following characteristics:

- ✓A perfect seal, so that no atoms escape from the working fluid as the piston moves to expand or compress it.
- ✓There is no friction.
- ✓An ideal-gas for the working fluid.
- ✓Perfect thermal connection at any time either to one or to none of two reservoirs, which are at two different temperatures, with perfect thermal insulation isolating it from all other heat transfers.
- ✓The piston moves back and forth repeatedly, in a cycle of alternating "isothermal" and "adiabatic" expansions and compressions

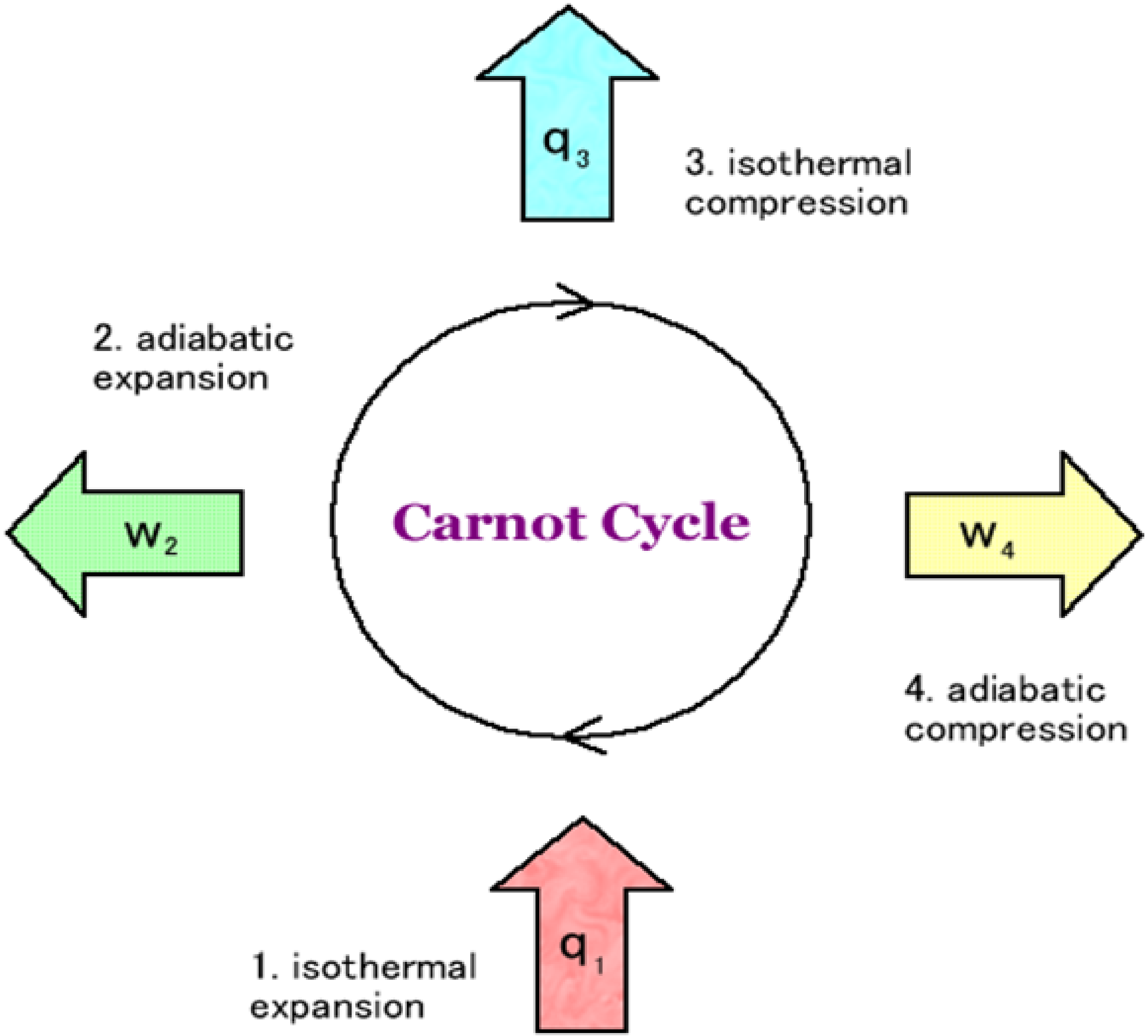
Characteristic of carnot cycle

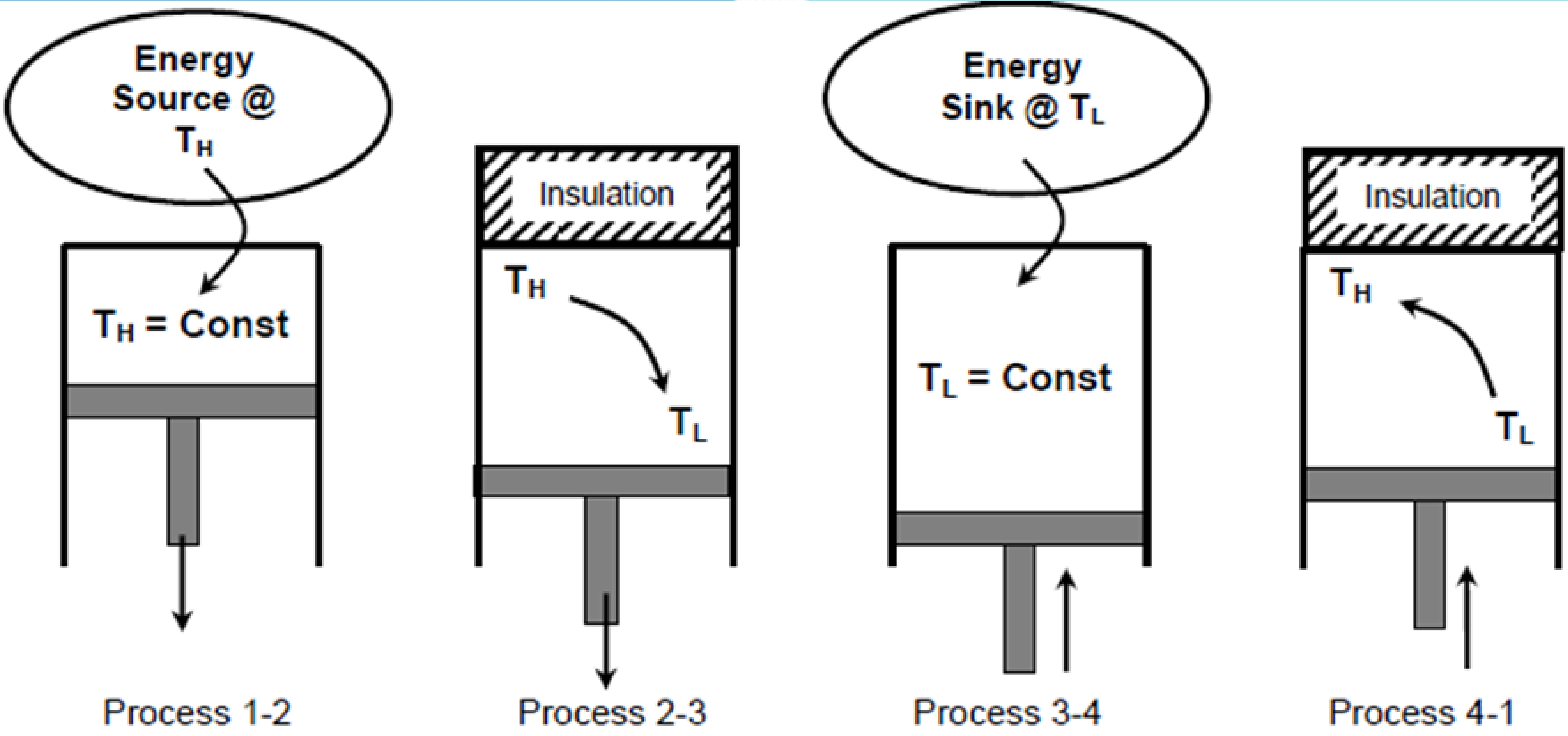
- ✓Any process that involves heat transfer must be isothermal in both the T_H and T_C.

- ✓Any process that changes the temperature don't have heat transfer (adiabatic process)

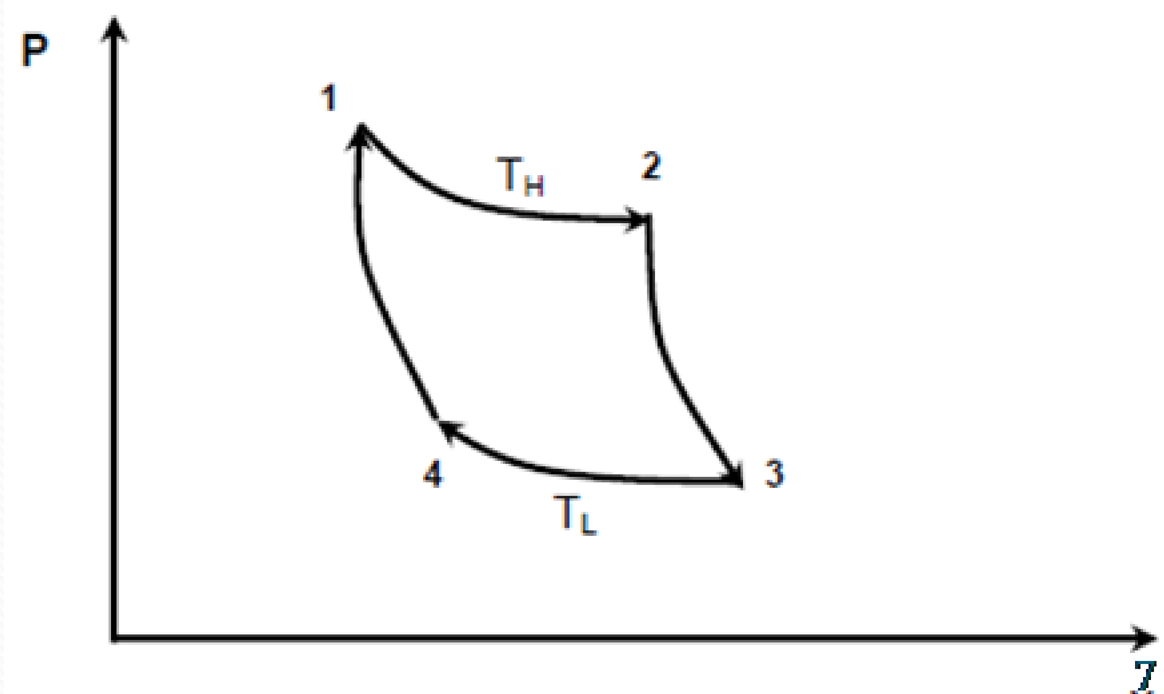
- ✓Carnot cycle consists of two reversible isothermal processes and two reversible adiabatic processes

Carnot Cycle





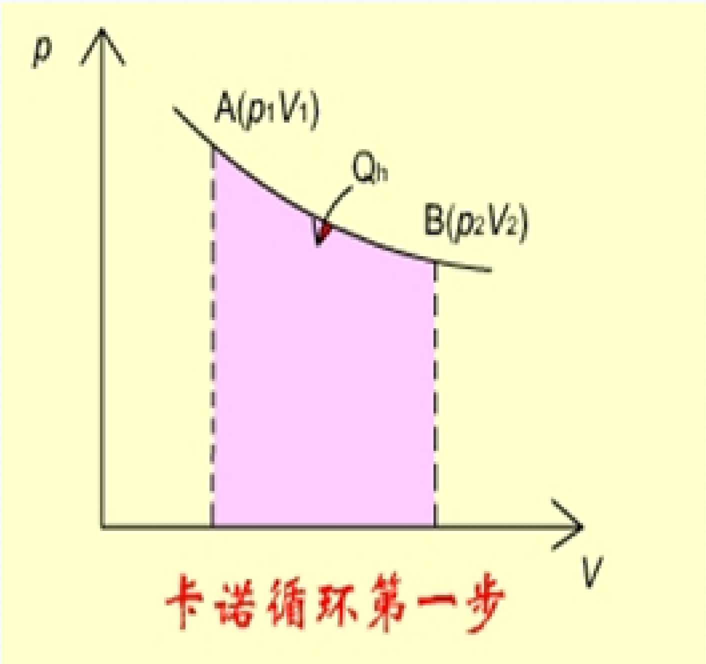
(Process 1-2) A constant temperature heat addition.
(Process 2-3) An adiabatic expansion
(Process 3-4) A constant temperature heat rejection.
(Process 4-1) An adiabatic compression



Processes in Carnot cycle

Process 1

Reversible expansion at T_h from P_1,V_1 to P_2 ,V_2 , (A→B)



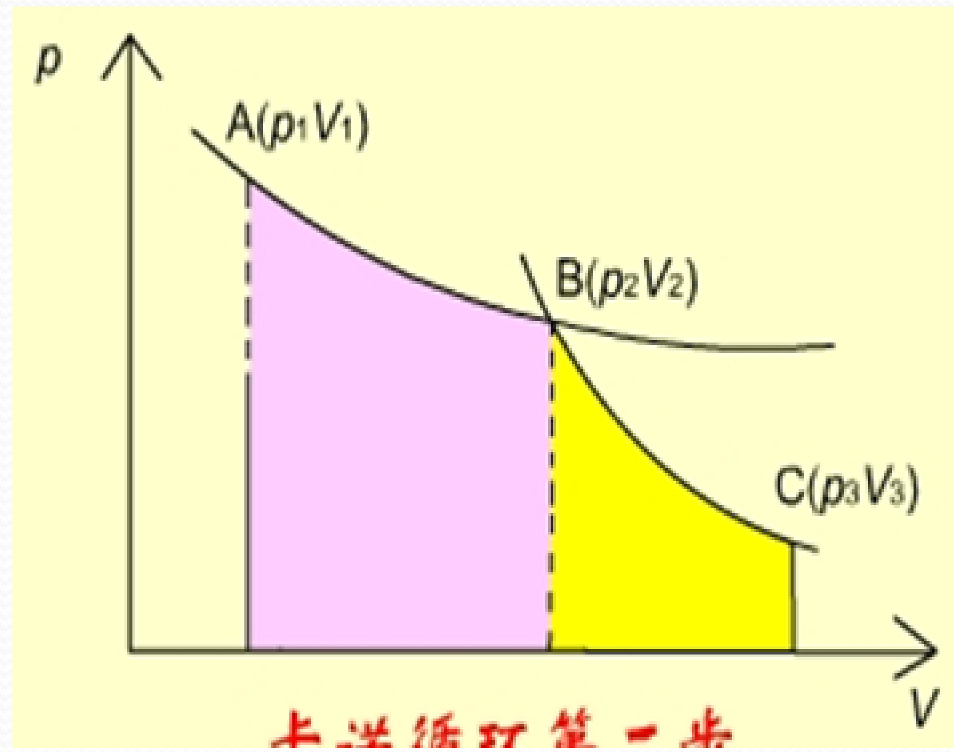
$$\Delta U_1 = 0 \qquad Q_2 = Q_h = W_1$$

$$W_1 = \int_{V_1}^{V_2} p dV = RT_2 \ln \frac{V_2}{V_1} \qquad T_2 = T_h$$

- The work is showed as the following area under the curve AB.

Process 2

Adiabatic reversible expansion from P_2, V_2, T_h to P_3, V_3, T_c, (B→C)



Q=0

$$W_2 = -\Delta U_2 = -\int_{T_2}^{T_1} C_{V,m} dT$$

The work is showed area under the curve BC.