Chapter 4 The second law of thermodynamics

- Directions of thermodynamic processes
- Heat engines
- Internal-combustion engines
- Refrigerators
- The second law of thermodynamics
- The Carnot cycle
- Entropy

Directions of thermodynamic processes

- Thermodynamic processes are naturally irreversible processes.
- The second law of thermodynamics can determine the preferred direction for the processes.
- In reversible process, the thermodynamic process can be reversed and are thus equilibrium processes.
- In quasi-equilibrium process, the system can keep close to equilibrium state and nearly reversible.

Heat engine

Heat engine → Device that transforms heat partly into work or mechanical energy.

- Matter inside the engine undergoes inflow and outflow of heat, **expansion and compression, and sometimes changes of phase**.
- The simplest process is **cyclic process**.
  - heat engine absorbs heat from source at higher temperature
  - heat engine rejects some heat at a lower temperature.

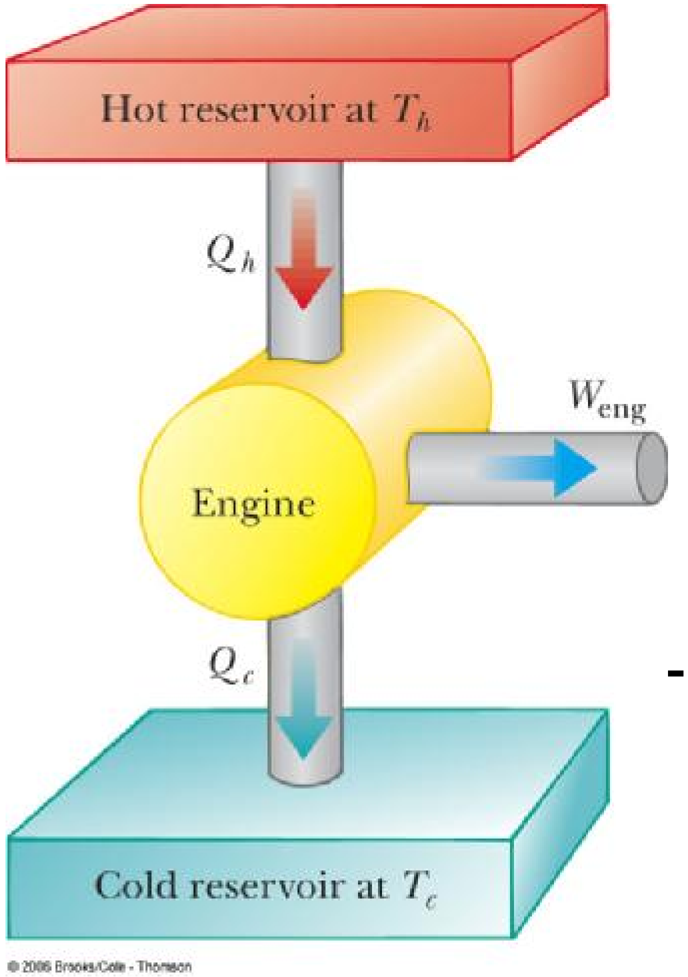
$$\mathbf{U_2 - U_1 = 0 = Q - W \quad or \quad Q = W}$$ in 1 cycle

Energy flow diagram of heat engine

- heat Q_H is supplied to the engine by the hot reservoir (the amount of heat show by the width of pipelines).
- heat Q_C is rejected from the engine into the cold reservoir in the exhaust.
- The portion of the heat supplied by the engine converts to mechanical work (W).

$$Q = W = Q_H + Q_C = |Q_H| - |Q_C|$$

$$\text{Thermal efficiency} = e = \frac{W}{Q_H} = 1 - \frac{|Q_C|}{|Q_H|}$$



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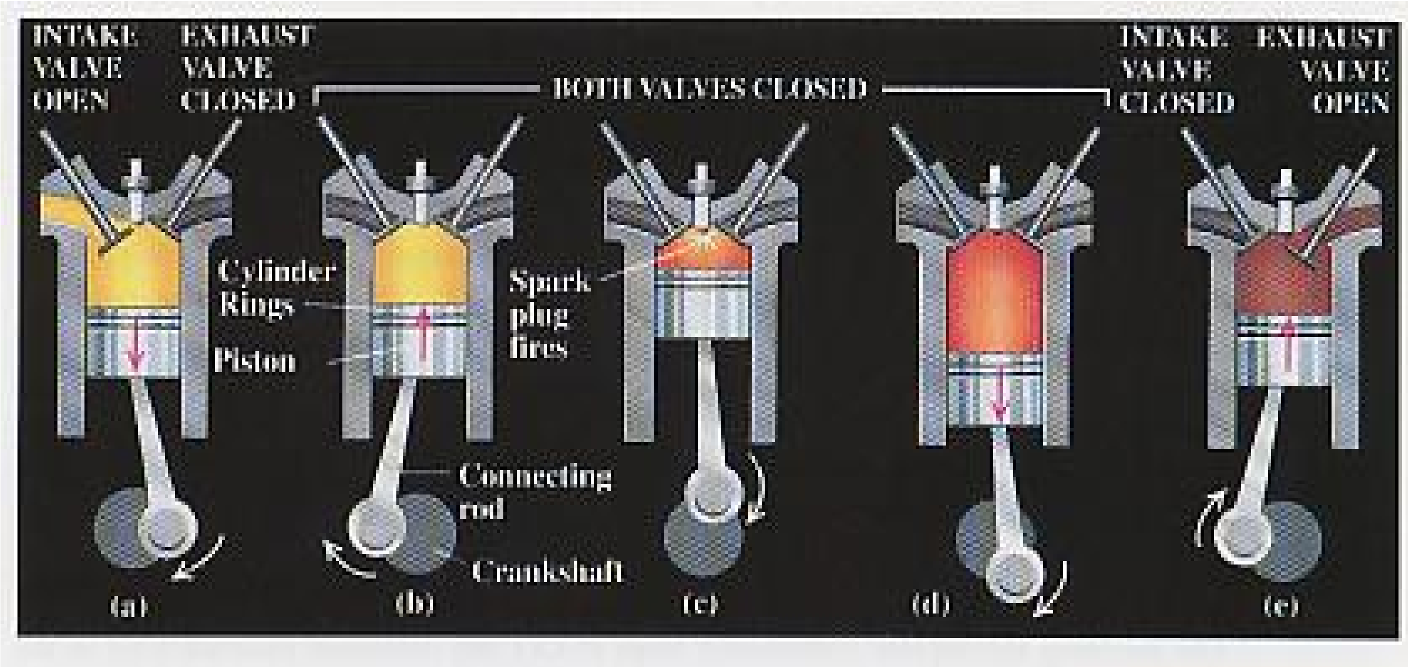
Internal-combustion engines

There are generally four strokes in combustion engine.

- Ø **Intake stroke** intake valve opens, piston descends, volume increases from minimum V to maximum rV (r is compression ratio).
- Ø **Compression stroke** intake valve closes, piston compresses adiabatically to volume V.
- Ø **Power stroke** spark plug ignites, heat gas expands adiabatically back to volume rV.
- Ø **Exhaust stroke** exhaust valve opens, the combusted gas are pushed out.



The Otto cycle

The Otto cycle → an idealized model of the thermodynamic process in a gasoline engine.

Ø from a to b, the system compresses adiabatically.

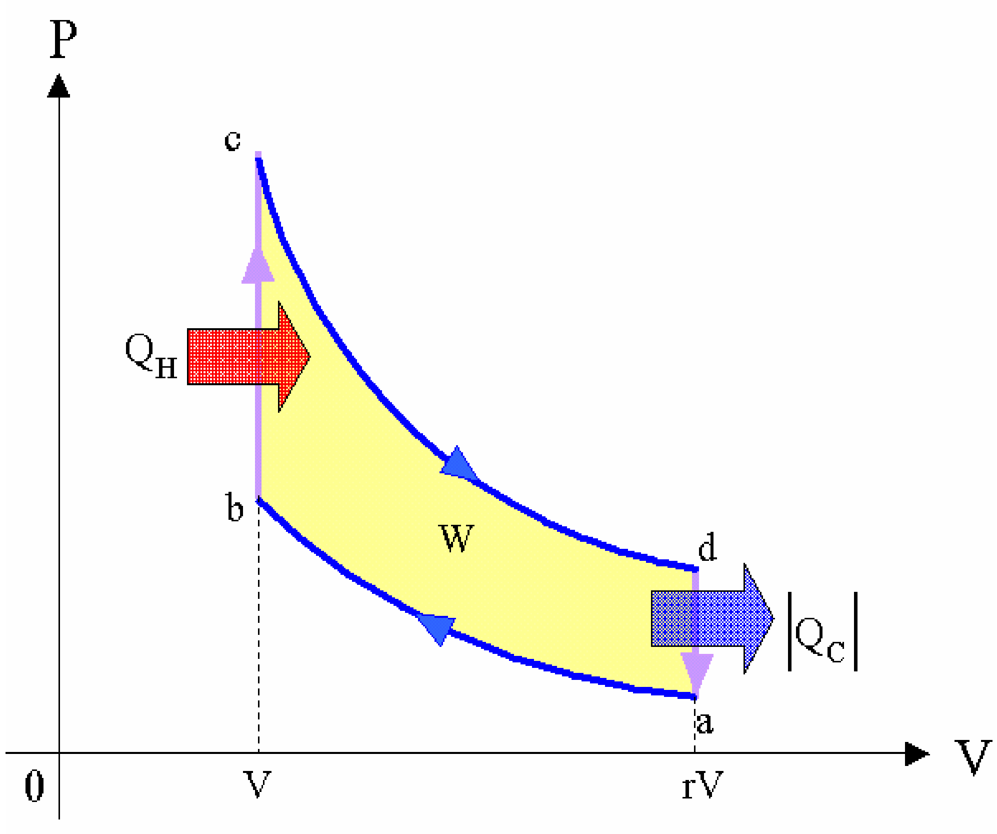
Ø from b to c, heat Q_H is added by burning gasoline by isochoric process.

$$\mathbf{Q_H = DU = nC_V(T_C - T_b) > 0}$$

Ø from c to d, the system expands adiabatically.

Ø from d to a, the gas is cooled to the temperature of the outside air, heat Q_C is rejected by isochoric process.

$$\mathbf{Q_C = DU = nC_V(T_a - T_d) < 0}$$



The Otto cycle

$$e = \frac{Q_H + Q_C}{Q_H} = \frac{T_C - T_b + T_a - T_d}{T_C - T_b}$$

<u>adiabatic process</u> $T_a (rV)^{\gamma-1} = T_b V^{\gamma-1}$ and $T_d (rV)^{\gamma-1} = T_c V^{\gamma-1}$

$$e = \frac{Q_H + Q_C}{Q_H} = \frac{T_d r^{\gamma-1} - T_a r^{\gamma-1} + T_a - T_d}{T_d r^{\gamma-1} - T_a r^{\gamma-1}} = \frac{(T_d - T_a)(r^{\gamma-1} - 1)}{(T_d - T_a) r^{\gamma-1}}$$

finally,

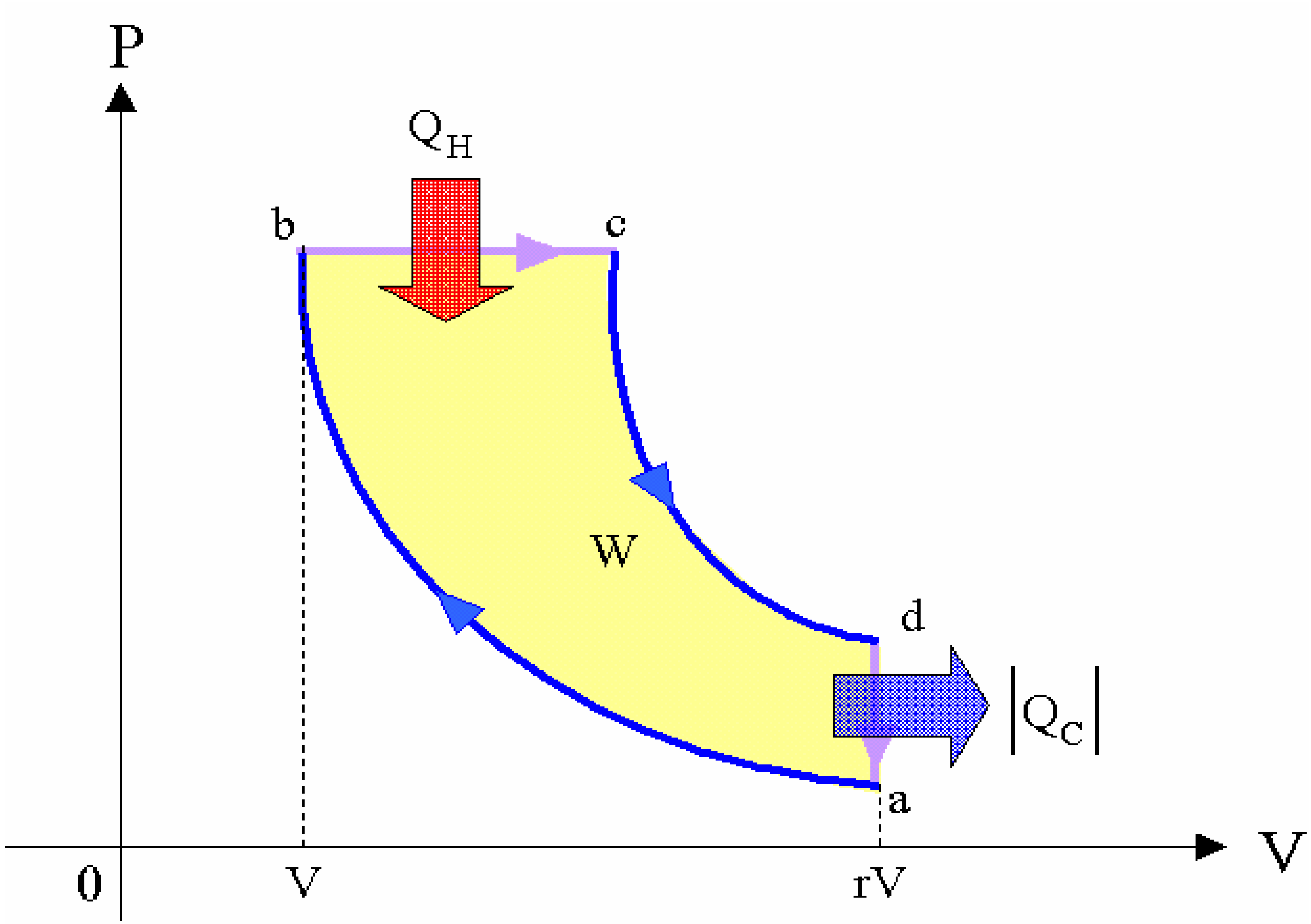
$$e = 1 - \frac{1}{r^{\gamma-1}}$$

Thermal efficiency in Otto cycle.

The Diesel cycle

- Diesel engine is similar in operation to the gasoline engine.
- The difference from gasoline engine is that no fuel at the beginning of the compression stroke.
- The fuel is injected to the engine at a little before the beginning of the power stroke.
- The high temperature occur when the system is compressed and is enough for ignition without spark plug.
- r for diesel engine is greater than the gasoline engine (r =15-20).
- This engine has more efficiency than gasoline engine, heavier, need no ignition system, and harder to start.

The diesel cycle



Refrigerators

Refrigerator ➡ Heat engine operating in reverse.

- Refrigerator takes heat from a cold place and give it off to a warmer place.
- Refrigerator requires a net input of mechanical work.

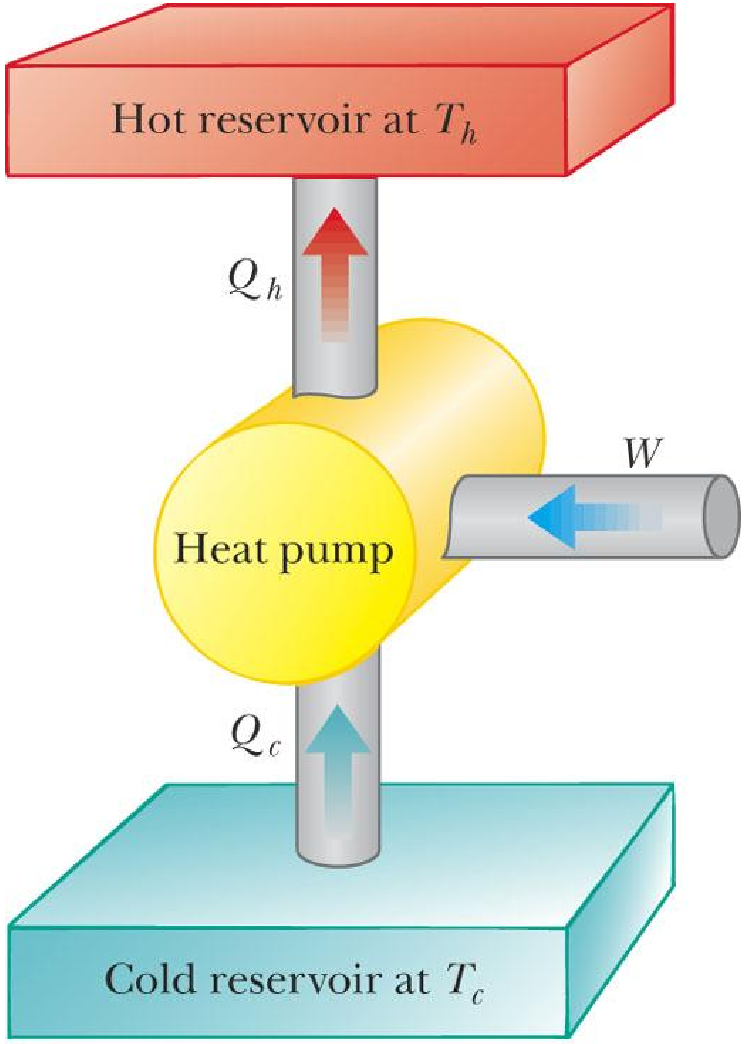
$$Q_C > 0 \text{ , } Q_H < 0 \text{ and } W < 0$$

First law ➡ $\mathbf{Q_H + Q_C = W}$

$$|Q_H| = |Q_C| + |W|$$

coefficient of performance (K)

$$K = \frac{|Q_C|}{|W|} = \frac{|Q_C|}{|Q_H| - |Q_C|}$$



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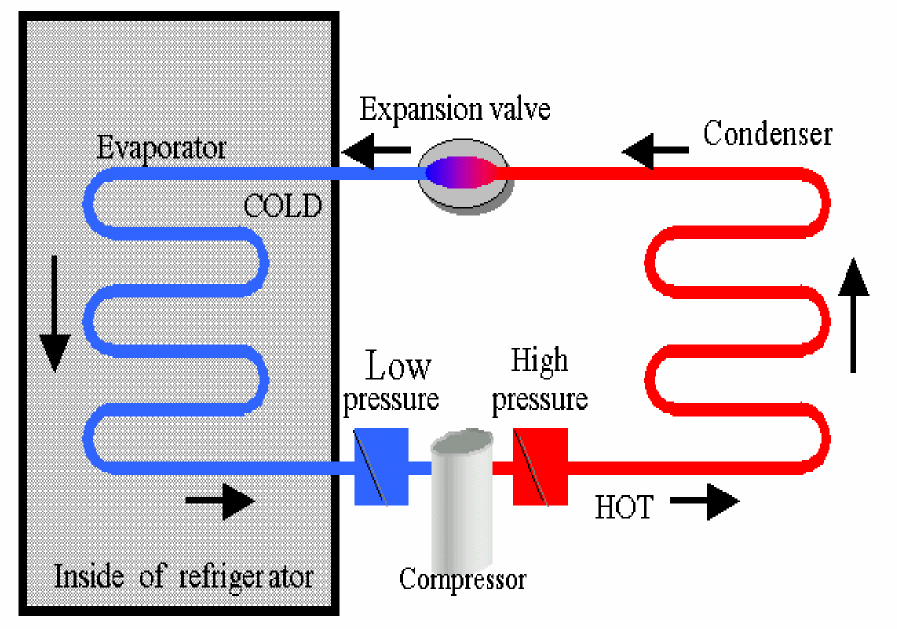
Refrigerators

- compressor compresses the refrigerant fluid adiabatically.
- the fluid with high temperature is delivered to the condenser coil and heat is give off Q_H to surrounding.
- the fluid expands adiabatically into the evaporator controlled by the expansion valve.
- while expanding, the fluid temperature decrease until lower than the surrounding at T_C
- Heat Q_C from surrounding can be absorbed, vaporizes, and then sent into the compressor.



$$K = \frac{|Q_C|}{|W|} = \frac{Ht}{Pt} = \frac{H}{P}$$

The second law of thermodynamics

Statement of impossibility

"It is impossible for any system to undergo a process in which it absorbs heat from a reservoir at a single temperature and converts heat completely into mechanical work, with the system ending in the same state in which it began."

One statement of **second law of thermodynamics**

- The conversion of work to heat is **irreversible process.**
- The heat flow from hot to cold across a finite temperature gradient is **irreversible process.**

The Carnot cycle

The Carnot cycle ➡ The heat engine that has the maximum possible efficiency consistent with the second law

- Heat flow should be at same temperature. ➡ isothermal process
- work should converse from internal energy without heat transfer

➡ adiabatic process

The Carnot cycle

- The gas expands isothermally at T_H, absorbing Q_H (ab).

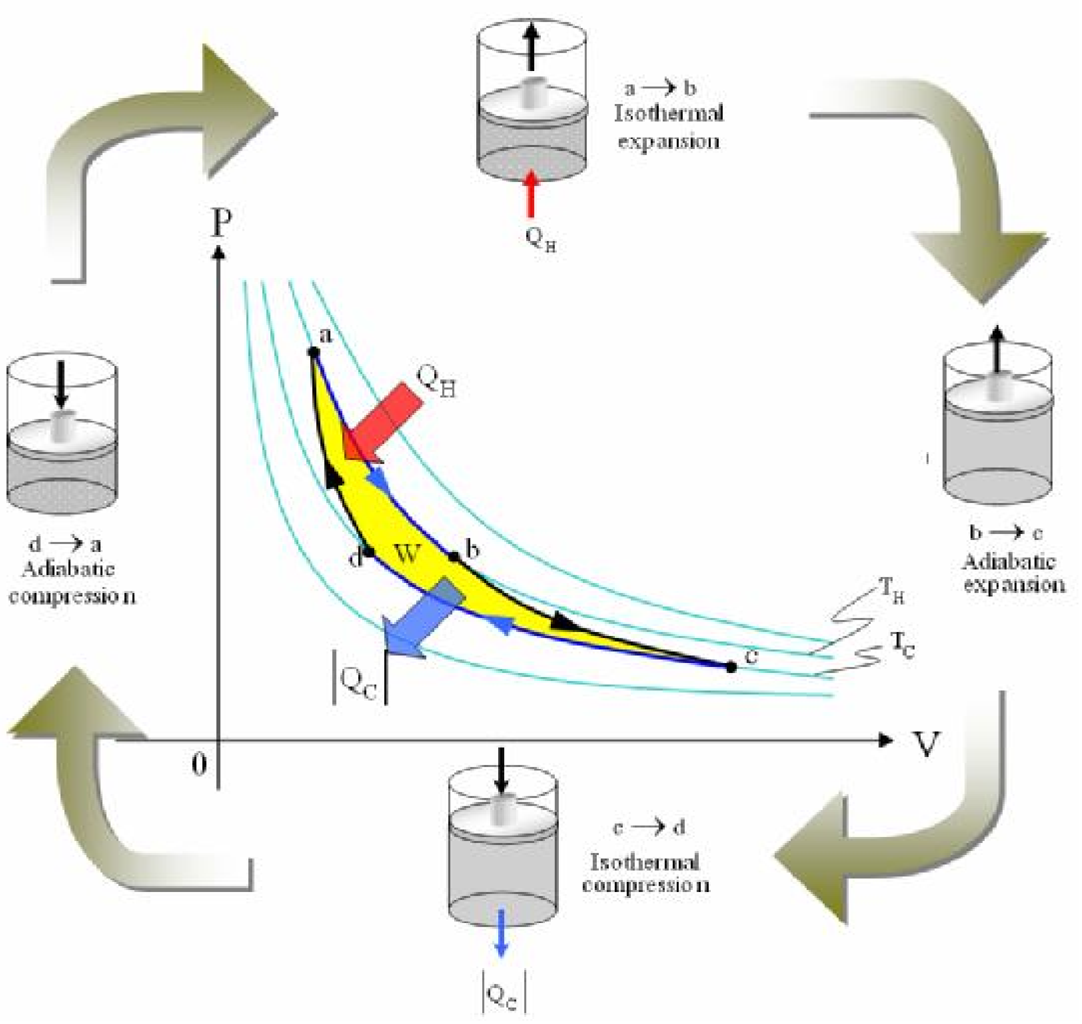
$$Q_H = W_{ab} = nRT_H \ln\frac{V_b}{V_a}$$

- It expands adiabatically until its temperature drops to T_C (bc).
- It is compressed isothermally at T_C, rejecting heat Q_C (cd).

$$Q_C = W_{cd} = nRT_C \ln\frac{V_d}{V_c} < 0$$

- It is compressed adiabatically back to its initial state at T_H(da).

$$\frac{Q_C}{Q_H} = -\frac{T_C}{T_H}\frac{\ln(V_C/V_d)}{\ln(V_b/V_a)}$$



The Carnot cycle

$$\frac{Q_C}{Q_H} = -\frac{T_C}{T_H}\frac{\ln(V_C/V_d)}{\ln(V_b/V_a)}$$

adiabatic process:

$$T_H(V_b)^{\gamma-1} = T_C V_C^{\gamma-1}$$

$$T_H(V_a)^{\gamma-1} = T_C V_d^{\gamma-1}$$

$$\frac{V_b}{V_a} = \frac{V_c}{V_d}$$

$$\frac{Q_C}{Q_H} = -\frac{T_C}{T_H}\frac{\ln(V_C/V_d)}{\ln(V_b/V_a)} \Rightarrow \frac{|Q_C|}{|Q_H|} = \frac{T_C}{T_H}$$

heat transfer in Carnot engine

$$e_{Carnot} = 1 - \frac{|Q_C|}{|Q_H|} = 1 - \frac{T_C}{T_H}$$

heat transfer in Carnot engine

The Carnot refrigerator

The Carnot cycle is reversible therefore all process, if revesed, give the Carnot refrigerator.

$$K = \frac{|Q_C|}{|Q_H| - |Q_C|} = \frac{|Q_C|/|Q_H|}{1 - |Q_C|/|Q_H|}$$

$$K_{Carnot} = \frac{T_C}{T_H - T_C}$$

Problem 4.1: Carnot engine ทำงานที่อุณหภูมิ T_H = 850 K และ T_C =300 K และให้งานออกมา 1200 J จงหา

1. ค่า e 2. ค่ากำลังของเครื่องยนต์ 3. ค่า Q_H และ Q_C

Entropy

- The second law can be stated as a quantitative relation with the concept of **"Entropy".**
- Several processes that proceed naturally in the direction of increasing disorder.
- Entropy (S) provides a quantitative measure of disorder.

ideal gas in isothermal process

$$dQ = dW = \frac{nRT}{V} dV \quad \Rightarrow \quad \frac{dV}{V} = \frac{dQ}{nRT}$$

sign of disorder

$$S = \frac{dQ}{T}$$

infinitesimal reversible process

$$\Delta S = S_2 - S_1 = \int_1^2 \frac{dQ}{T}$$

reversible process

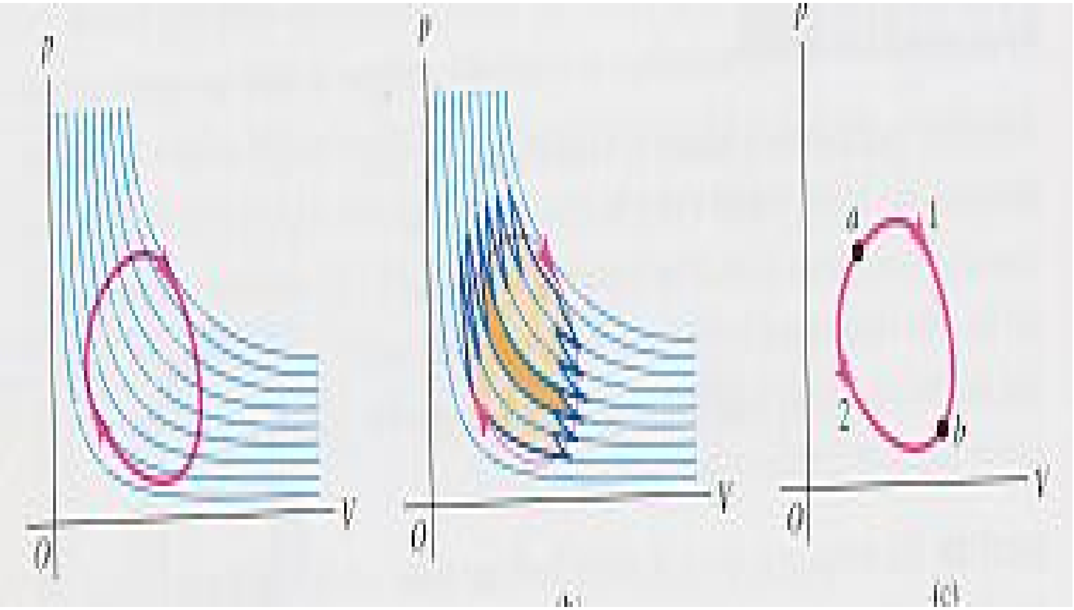
Entropy in cyclic process

Carnot cycle $\Rightarrow$ $$\frac{Q_H}{T_H} = -\frac{Q_C}{T_C}$$

$$\frac{Q_H}{T_H} + \frac{Q_C}{T_C} = 0$$

$$\Delta S_H + \Delta S_C = 0$$

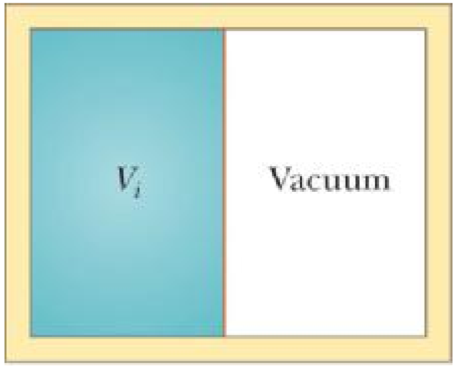
$$\Delta S_{cyclic} = \int \frac{dQ}{T} = 0$$



The total entropy change during any reversible cycle is zero

Problem 4.2: จาก Problem 4.1 จงหาการเปลี่ยนแปลงเอนโทรปีของวัฏจักรคาร์โนร์ดังกล่าว

Problem 4.3: จงหาค่าการเปลี่ยนแปลงเอนโทรปีของระบบแกสอุดมคติ จำนวน 1 โมล ที่มีการขยายตัวแบบ Isothermal จนกระทั่งมีปริมาตรเป็น 2 เท่าของปริมาตรเดิม



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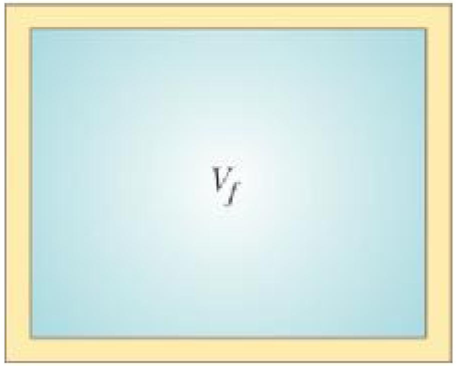

(b)

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Entropy and the second law

"When all systems taking part in a process are included, the entropy either remains constant or increases."

"No process is possible in which the total entropy decreases, when all systems taking part in the process are included."

$$\Delta S \geq 0$$

$S_{universe}$ is increasing

The end.
good luck in your
test.