## Chapter 6 The 2nd Law of Thermodynamics (Fundamentals)

- 1st Law ... $Q_{1\to2} = E_2 - E_1 + W_{1\to2}$
- 2nd Law ... 열과 일의 방향, 과정의 진행 방향.
- Note: We need to develop some primary concepts for 2nd Law.

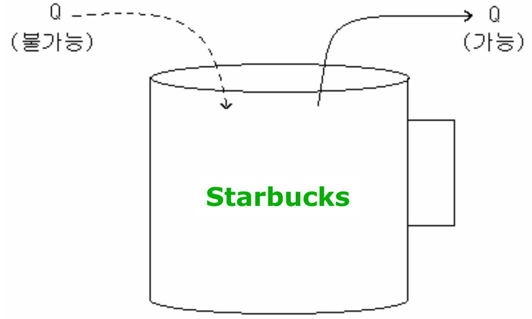
  1st Law in a cycle, $\oint W = \oint Q$

  the cyclic integral of Work = the cyclic integral of Heat

- A cycle will occur only if both the first and second laws of thermodynamics are satisfied.
- 2nd law acknowledges that processes proceed in a certain direction but not in the opposite direction.



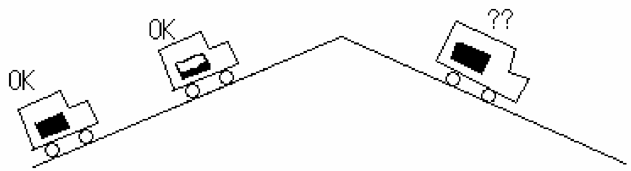

Coffee cools by heat transfer to the surrounding but not the opposite direction.







Gasoline is consumed on an incline.
It is not restored on a downhill.




→ Evidence of the validity of the 2nd law.

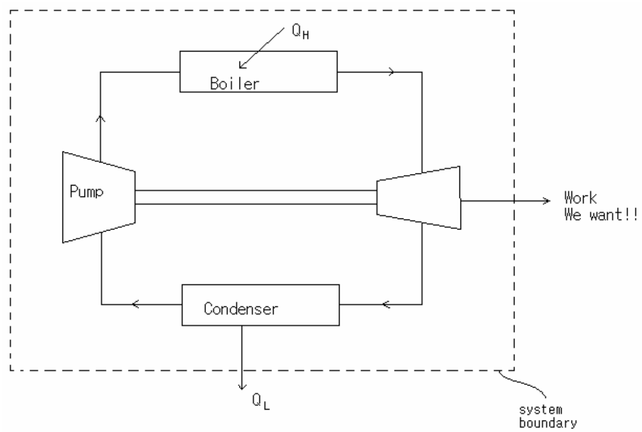



- In this chapter, we consider the second law for a system undergoing a cycle.
- In the next two chapters, we extend the principles to
  - a system undergoing a change of state and
  - a control volume.
- Heat Engine:

  A device that operates in a thermodynamic cycle and does a certain amount of net positive work through the transfer of heat from a high temperature body to a low temperature body.

- Ex) Internal combustion engine, turbine

- Example – Steam power plant (w/ steam being the working fluid)




Cost = $Q_H$,   Goal = work

Steady-State, Steady-flow process.



- An amount of heat $Q_H$ is transferred from a high-temperature body (via combustion in a furnace).
- Turbine drives the pump.
- $Q_L$ is rejected to a low temperature body, which is usually the cooling water in a condenser.
- ∴ A heat engine → a system operate in a cycle and have both the net work and the net heat transfer positive.
- Thermal Efficiency

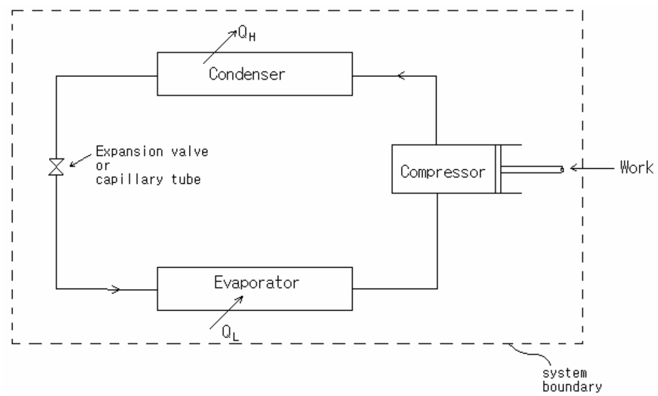
(we want)

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

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



- Example – Refrigerator (냉동기, for $Q_L$)
  (w/ Refrigerator, R-12 or Ammonia as working fluid)




Cost = W ,   Goal = $Q_L$

A vapor-compression refrigerator cycle



- Heat is transferred to the working fluid (refrigerant), where its pressure and temperature are low.
- Work is done on the refrigerant in the compressor.
- Heat is transferred from the refrigerant in the condenser,
- → Transferring heat from a low-temperature body to a high-temperature body.
- Efficiency of a refrigerator

$$\beta = \frac{Q_L\,(energy\ sought)}{W\,(energy\ cost)} = \frac{Q_L}{Q_H - Q_L}$$

- We are now ready to state 2nd law.

It consists of 2 statements.

"The Kelvin-Planck Statement"

It is impossible to construct a device that will operate in a cycle and produce no effect other than the work and the exchange of heat with a single reservoir. In short, for a heat engine . $Q_L \neq 0$

→ (열효율) $\eta_{thermal} = \frac{W}{Q_H} = 1 or 100\%$ 인 열기관을 제작할 수 없다.

→ $Q_L$ 이 0 인 device가 존재할 수 없다.

In short, for a Heat Engine,
$Q_L \neq 0$





"The Clausius Statement"

It is impossible to construct a device that operates in a cycle and produce no effect other than the transfer of heat from a cooler body to a hotter body.

→ No such refrigerator that require $W = 0$ input.

→ In other words $\beta = \infty$ is not possible.

In short, for a Refrigerator,
$W \neq 0$

- Statements 1) and 2) are equivalent.





- The Carnot Cycle

Reversible process (가역과정) – ideal process

한번 발생했던 과정이 역으로도 될 수 있고 이때 계(system)와 주위 (surrounding)에 아무 변화도 남기지 않는 과정

Irreversible (or Real) process – the opposite

Consider a heat engine with every process reversible and the cycle is also reversible -> i.e. if a cycle is reversed, the heat engine becomes a refrigerator

✓ This is the most efficient cycle that can operate between two constant temperature reservoirs – CARNOT CYCLE –