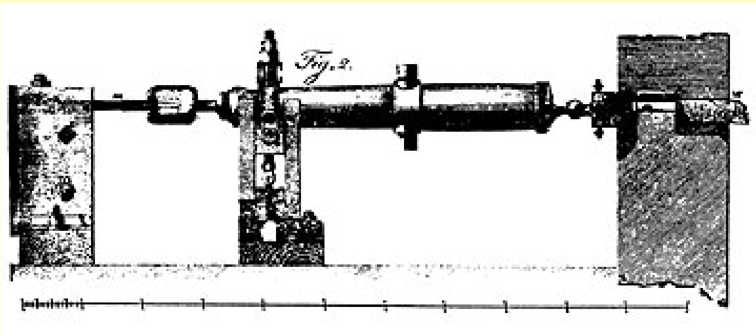
Thermodynamics of Materials

3rd Lecture

2008. 3. 10 (Mon.)

Benjamin Thomson, Count Rumford (1753 - 1815)



“Frictional heat appears to be inexhaustible,
it is given off in a constant flux in all directions
without interruption or intermission and
without any signs of exhaustion.
It is hardly necessary to add that anything
which any insulated body or system of bodies
can furnish without limitation cannot possibly
be a material substance; and it appears to me
to be extremely difficult, if not impossible,
to form any distinct idea of anything being excited
and communicated in these experiments,
except it be motion.”

Count Rumford

In 1803, Lazare Carnot wrote
an article on “potential energy”.

In 1784, he wrote his first mathematical
work on mechanics, which contains
the earliest proof that kinetic energy
is lost in the collision of imperfectly
elastic bodies.

엔진의 분석

- 팽창과 수축을 반복
- 팽창 → **heat intake**
- **heat source** → 보일러
- 팽창 → 외부에 일을 함 **($P\Delta V = N/M^2 \times M^3 = J$)**
- 수축 → **heat outgoing**
- **heat sink** → 컨덴서
- 수축 → 외부로부터 일을 받음
- 핵심은 보일러와 컨덴서의 온도 차이

Nicolas Léonard Sadi Carnot (1796–1832), France

"Reflections on the Motive Power of Fire and the Machines Equipped to Give Birth to it"

Carnot's work is distinguished for his careful, clear analysis of the units and concepts employed and for his use of both an adiabatic working stage and an isothermal stage in which work is consumed.

http://www.th.physik.uni-frankfurt.de/~jr/physlist.html

Ecole Polytechnique (1794)

Lagrange, Fourier, Laplace,
Ampere, Durong, Cauchy, Coriolis,
Piossion, Guy-Lussac, Petit,
Carnot, Clausius, Clapeyron,
and Poiseuille

(for the first 40 years)

Bastille Day Military Parade is a French military parade held each year in Paris, in the morning of the 14 July.

떨어지는 물체로부터 얻을 수 있는
최대 운동에너지 (K.E)는 높이 (h)에 만
의존한다는 사실로부터

열 엔진으로부터 얻을 수 있는 최대 일은
온도에만 의존할 것이라고 유추.

The amount of work the engine can do depends only on the amount of heat transferred and the difference in temperature between the source and the sink.

Carnot's idea

1. Consider the maximum efficiency
2. Comparison of temperature
   with the height in potential energy
3. Cyclic process of engine
4. Consider two extremes of reversible isothermal and adiabatic processes
   → **"Thought Experiment"**
5. Consider the reverse process

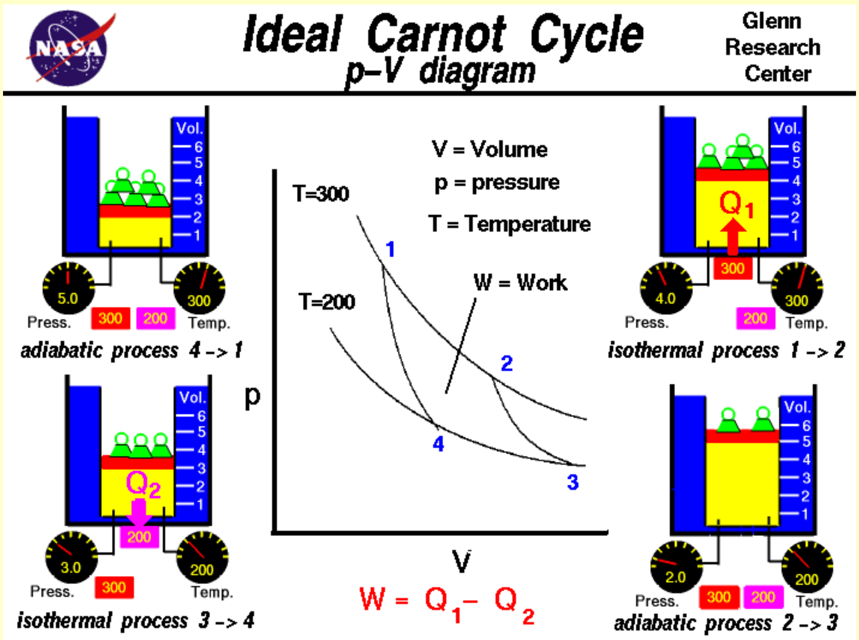
Cycle for Maximum Efficiency

→ Carnot Cycle (Reversible)

ideal heat transfer (intake) → ideal cooling
→ ideal heat transfer (outgoing) → ideal heating

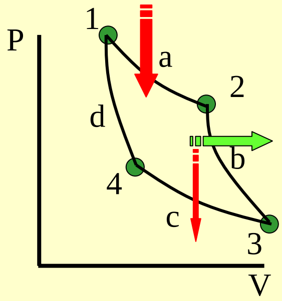
1. Isothermal Expansion (ideal heat transfer)
2. Adiabatic Expansion (ideal cooling)
3. Isothermal Compression (ideal heat transfer)
4. Adiabatic Compression (ideal heating)

→ one cycle (original position)



Carnot Cycle – Ideal Gas

$Q_a = Q_c + W$ $\eta = \frac{W}{Q_a}$



- $dU = đQ - đW$
- On isotherm a $dU = 0$
- $đQ = đW = PdV$

$$Q_a = W_{1a2} = \int_{a\,1}^{2} PdV = NRT_H \int_{a\,1}^{2} \frac{dV}{V} = NRT_H \ln\left(\frac{V_2}{V_1}\right)$$

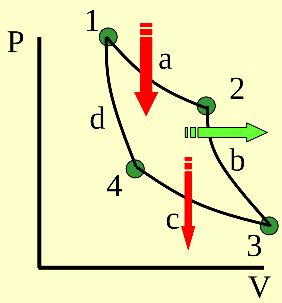
- On isotherm c

$$Q_c = W_{3c4} = \int_{c\,3}^{4} PdV = NRT_C \int_{c\,3}^{4} \frac{dV}{V} = NRT_C \ln\left(\frac{V_4}{V_3}\right)$$

- $dU = đQ - đW$
- We know ΔU for cycle = 0

$$\oint dU = \oint dQ - \oint dW \equiv 0$$

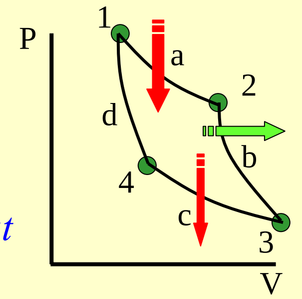
- On adiabat b and d $đQ = 0$



$$\oint dQ = Q_a + Q_c = \oint dW$$

$$\oint dQ = NRT_H \ln\left(\frac{V_2}{V_1}\right) + NRT_C \ln\left(\frac{V_4}{V_3}\right)$$

$$\oint dQ = NR\left[T_H \ln\left(\frac{V_2}{V_1}\right) + T_C \ln\left(\frac{V_4}{V_3}\right)\right]$$



- On adiabat b and d
- We know

$$PV^{\gamma} = const \rightarrow \frac{T}{V}V^{\gamma} = TV^{\gamma-1} = const$$

$$T_H V_2^{\gamma-1} = T_C V_3^{\gamma-1} \qquad T_H V_1^{\gamma-1} = T_C V_4^{\gamma-1}$$

$$\frac{V_2}{V_1} = \frac{V_3}{V_4} \qquad \oint dQ = NR\left[T_H \ln\left(\frac{V_2}{V_1}\right) + T_C \ln\left(\frac{V_4}{V_3}\right)\right]$$

$$\oint dQ = NR\left[(T_H - T_C)\ln\left(\frac{V_2}{V_1}\right)\right] = \oint dW$$

$Q_a = Q_c + W$

$Q_a - Q_c = W$

- We have calculated the work done by the system:

$$NR\left[(T_H - T_C)\ln\left(\frac{V_2}{V_1}\right)\right]$$

- Since $\frac{V_2}{V_1} = \frac{V_3}{V_4} \rightarrow$ $$\frac{|Q_H|}{|Q_C|} = \frac{\left|NRT_H \ln\left(\frac{V_2}{V_1}\right)\right|}{\left|NRT_C \ln\left(\frac{V_4}{V_3}\right)\right|} = \frac{T_H}{T_C}$$
- This is the definition of the Kelvin temperature scale. It is important as it is only defined by the temperatures of the reservoirs.

- We can calculate the efficiency of the cycle. We turn heat from the hot reservoir into useful work and discard the remainder into the cold reservoir.

$$W = NR\left[(T_H - T_C)\ln\left(\frac{V_2}{V_1}\right)\right]$$

- Efficiency = Work out / Heat energy put in

$$\eta = \frac{W}{Q_a} = \frac{NR\left[(T_H - T_C)\ln\left(\frac{V_2}{V_1}\right)\right]}{NRT_H \ln\left(\frac{V_2}{V_1}\right)} = \frac{T_H - T_C}{T_H} = 1 - \frac{T_C}{T_H}$$

Carnot Cycle – Ideal Gas

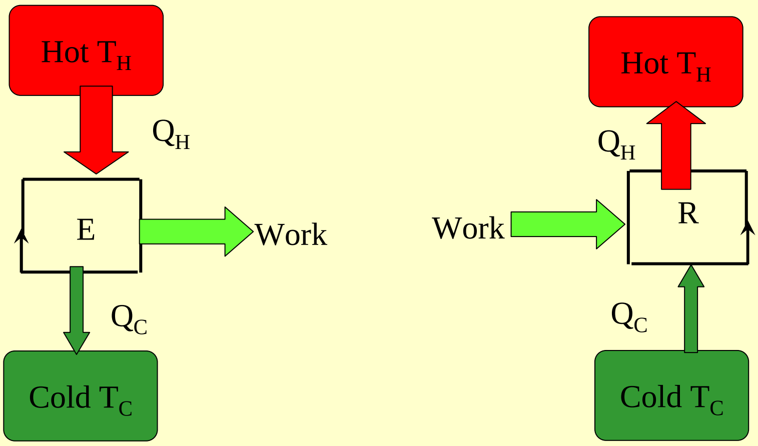
- The Carnot Cycle works between two reservoirs at differing temperatures. Its efficiency is uniquely defined by the two temperatures.

$$\eta = 1 - \frac{T_C}{T_H}$$

- It is reversible – we can go round the system backwards. It then uses work to extract heat from a cold reservoir to a hot reservoir.

→ This may be considered a refrigerator!

Engines and Refrigerators



Carnot Cycle – Ideal Gas

- In a refrigerator the coefficient of performance is given by how much heat can be removed from the cold reservoir per unit of work put in.

$$\beta = \frac{|Q_C|}{W} = \frac{T_C}{T_H - T_C}$$

- Note this can be > 1

One reversible engine can be used to drive another reversible engine in reverse order.

If the engine does more work than the heat pump consumes, then work is created from nothing.

Carnot assumed that perpetual motion of this kind is impossible.

$$\Delta Q = C_V \Delta T + L_T \Delta V$$

isothermal expansion

C_V : heat capacity of the body when its volume is held constant.

L_T : "Latent Heat" required to change the volume at constant temperature

$$\Delta Q = C_V \Delta T + L_T \Delta V$$

At constant temperature,

$$\Delta Q = L_T \Delta V$$

$$J\Delta Q = JL_T \Delta V = P\Delta V$$

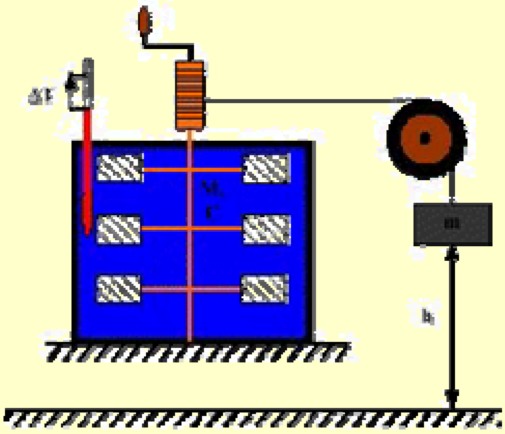
$$JL_T = P$$

So L_T is not a material property but a purely mechanical quantity.

$$J\Delta Q = JL_T \Delta V = P\Delta V$$

→ Q (heat) is the same as $P\Delta V$ (work).

James Prescott Joule (1818-1889)



1 calorie = 4.1868 joules

http://www.corrosion-doctors.org/Biographies/JouleBio.htm