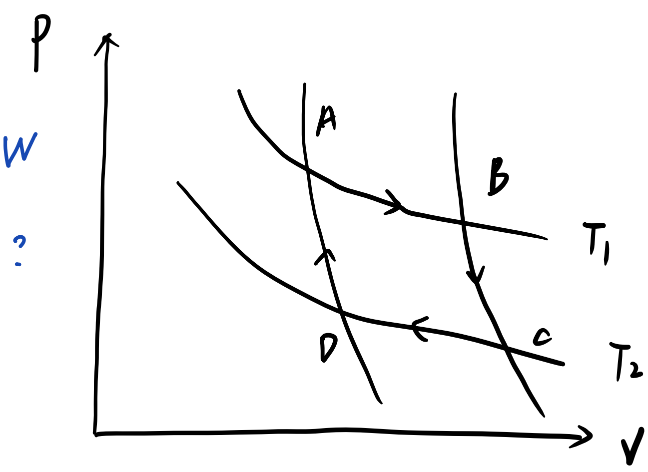
1. Carnot cycle :

an ideal thermodynamic cycle.

two adiabatic + two isothermal

Q: the work W in the cycle ?



B → C , D → A , 绝热过程

$pV = nRT$ $\quad (pV)_A = (pV)_B = nRT_1$

$pV^\gamma = const$ $\quad (pVV^{\gamma-1})_A < (pVV^{\gamma-1})_B$

$(V_A < V_B)$

$V^{\gamma-1}T = Const$

$V_B^{\gamma-1}T_1 = V_C^{\gamma-1}T_2 = C_1$ $\quad (C_1 > C_2)$

$V_A^{\gamma-1}T_1 = V_D^{\gamma-1}T_2 = C_2$

$$\left(\frac{V_B}{V_A}\right)^{\gamma-1} = \left(\frac{V_C}{V_D}\right)^{\gamma-1}$$

$$\frac{V_B}{V_A} = \frac{V_C}{V_D}$$

Isothermal process:

$A \to B$

$C \to D$

$$\Delta Q_{A\to B} = \Delta W_{A\to B} = \int_A^B p\,dV$$

吸热:

$$= \int_A^B \frac{nRT_1}{V}\,dV$$

$$= nRT_1 \ln \frac{V_B}{V_A}$$

$$\Delta Q_{C\to D} = \Delta W_{C\to D} = nRT_2 \ln \frac{V_D}{V_C}$$

放热

$$= -nRT_2 \ln \frac{V_C}{V_D} = -nRT_2 \ln \frac{V_B}{V_A}$$

$B \to C$, $D \to A$, 绝热过程

热量交换为 0

做功： $\Delta W_{B\to C} = \int_B^C p\,dV$

$$= \int_B^C \frac{const}{V^\gamma}\,dV$$

$$= const\ \frac{V^{1-\gamma}}{1-\gamma}\Big|_B^C$$

$$\Delta W_{D\to A} = \int_D^A p\,dV$$

$$= const\ \frac{V^{1-\gamma}}{1-\gamma}\Big|_D^A$$

$$\Delta W_{B\to C} + \Delta W_{D\to A}$$

$$pV = nRT$$

$$pV^\gamma = const$$

$$V^{1-\gamma} = nRT/const \rightarrow const\ V^{1-\gamma} = nRT$$

$$= \frac{1}{1-\gamma}\,nR(T_2 - T_1 + T_1 - T_2)$$

$$= 0$$

两个绝热过程做功为0，没有热交换

thermal efficiency：

$$\eta = \frac{\Delta W}{\Delta Q_{吸}}$$

（做功是目的投入产出比）

$$= \frac{Q_{A\to B} + Q_{C\to D}}{Q_{A\to B}}$$

（吸热不能完全用来做功，还好热功当量的实验是反过来做）

$$= \frac{nR(T_1 - T_2)\ln\frac{V_B}{V_A}}{nRT_1 \ln\frac{V_B}{V_A}}$$

$$= \frac{T_1 - T_2}{T_1} = 1 - \frac{T_2}{T_1}$$

$$= \frac{Q_{吸} - Q_{放}}{Q_{吸}} = \frac{T_1 - T_2}{T_1}$$

$$\Rightarrow \frac{Q_{放}}{Q_{吸}} = \frac{T_2}{T_1}$$

理想气体温标 （理想气体为工作物质）

↓

热源

↓

Energy transfer （conversion of heat into work）

remarkable.

（炉子在外烧 → 炉子在里面烧）

蒸汽机 → 内燃机

$$\frac{\Delta Q_2}{T_2} = -\frac{\Delta Q_1}{T_1}$$

Q：如何提高热机效率？

consider sign：

$$\boxed{\oint \frac{dQ}{T} = 0}$$

$\because \quad \Delta Q_{B-C} = \Delta Q_{D \to A} = 0$

$$\eta = \frac{T_h - T_l}{T_h}$$

two reservoirs

T_h, T_l (high / low temperature)

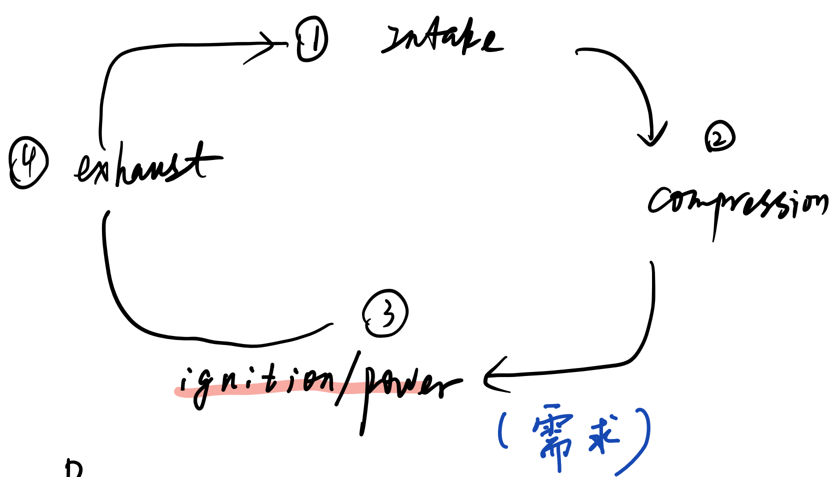
This quantity is named in honor of Sadi Carnot, who derived it in 1824. It was a remarkable feat: the concept of entropy had not yet been invented, and Carnot's derivation preceded some 15 years the recognition that heat is a form of energy.

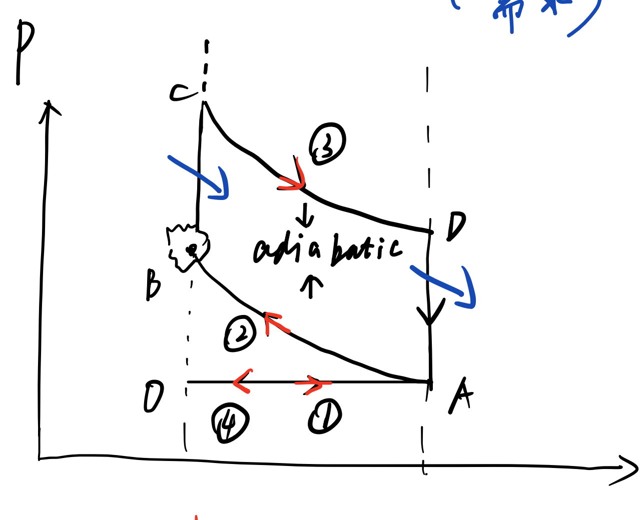
1832, Carnot died.

(June 1796 – 24 August 1832
French mechanical engineer in the French army, military scientist and physicist)

2. Otto cycle:

Otto engine (4-step engine)

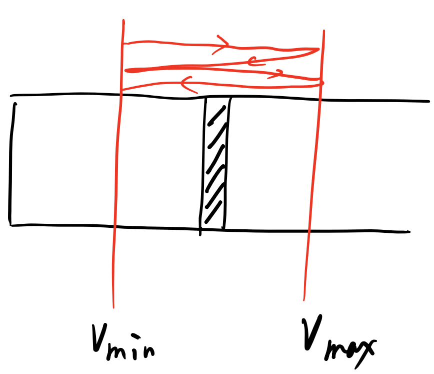




6-step

B → C too

D → A fast



(min ↔ max) volume

approximately, two adiabatic + two isochore
(no work)

吸放热计算：

$$Q_{in} = C_V (T_C - T_B) \quad (B \to C)$$

$$Q_{out} = C_V (T_D - T_A) \quad (D \to A)$$

$$\eta = \frac{\Delta W}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}} = 1 - \frac{T_D - T_A}{T_C - T_B}$$

adiabatic process $\quad PV^{\gamma} = \text{const}$

$$TV^{\gamma-1} = C \quad \Leftarrow \quad PV = nRT$$

$$\frac{T_D}{T_C} = \left(\frac{V_C}{V_D}\right)^{\gamma-1} = \left(\frac{V_{min}}{V_{max}}\right)^{\gamma-1}$$

$$\frac{T_A}{T_B} = \left(\frac{V_B}{V_A}\right)^{\gamma-1} = \left(\frac{V_{min}}{V_{max}}\right)^{\gamma-1}$$

$$\frac{T_D}{T_C} = \frac{T_A}{T_B} = m$$

$$\Downarrow$$

$$\frac{T_D - T_A}{T_C - T_B} = m$$

$$\eta = 1 - \left(\frac{V_{min}}{V_{max}}\right)^{\gamma-1}$$

air, $\gamma = 1.4$ $\quad (N_2, O_2)$

$\frac{V_{min}}{V_{max}} \sim \frac{1}{8}$

↓

$\eta = 56\%$ ideal otto engine

reality : $\eta \sim 15\% - 20\%$

/ˈgæsəliːn/ 汽油机

Realistic gasoline engine :

$\eta \sim 20\%$

Diesel engine : 柴油机

/ˈdiːzl/ $\eta \sim 30\%$ 内燃机

Rudolf Diesel internal combustion engine

gasoline / diesel

(air-fuel mixture) (air intake)

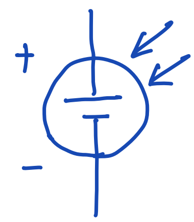
'spark' 'no spark'

compress air to a degree producing a temperature above the igniting-point of the fuel

How to generate energy in useful forms?

If according to $E = mc^2$

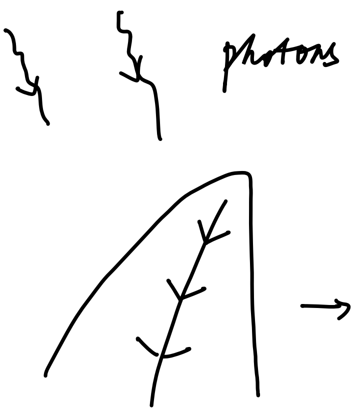
there are energy sources, how to convert it?



(symbol)

/ˌfautauvɔlˈtɛiks/

photovoltaics 太阳光伏电池



→ biomass ← "quantum"

photosynthesis

Science 332, 805 (2011)

"quantum"
↓
Nature 446, 782 (2007)

Nature 463, 644 (2010)

Q: What determines the efficiency of a heat engine?

Otto cycle in thermal physics II

Lec 1 heat engine

Lin Hsiu-Han (热统计物理)

heat engine: A device

converts "heat" into "work"