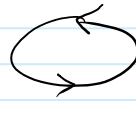
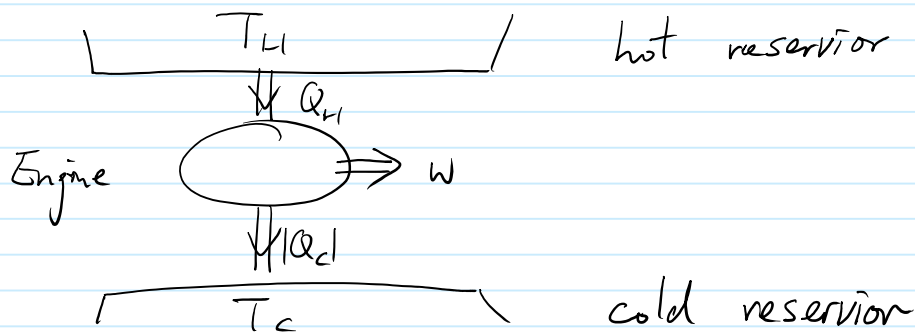


Heat Engine

- operates between two reservoirs : one hot & one cold.
 - large bath with fixed temperature.
 - allows heat extracting from or absorbing into it without changing its temperature.
- cyclic process.
- Absorb heat & Do work  e.g. steam engine
- Receive work & Release heat  e.g. refrigerator.
- It is the working substance doing work & exchanging heat e.g. coolant in refrigerator & air-conditioner

Schematic Picture



$$\Delta U = 0, \quad Q = |Q_H| - |Q_C|$$

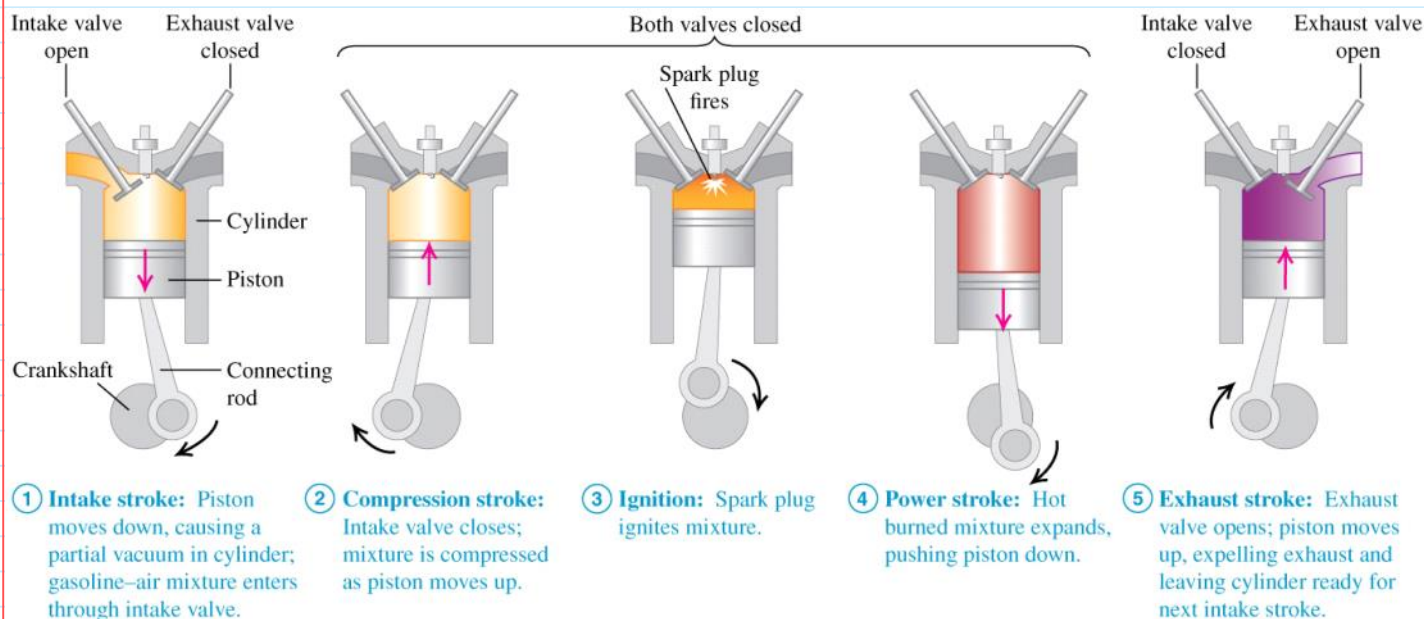
$$\Rightarrow Q = W + \Delta U \xrightarrow{\Delta U = 0}$$

$$W = |Q_H| - |Q_C|$$

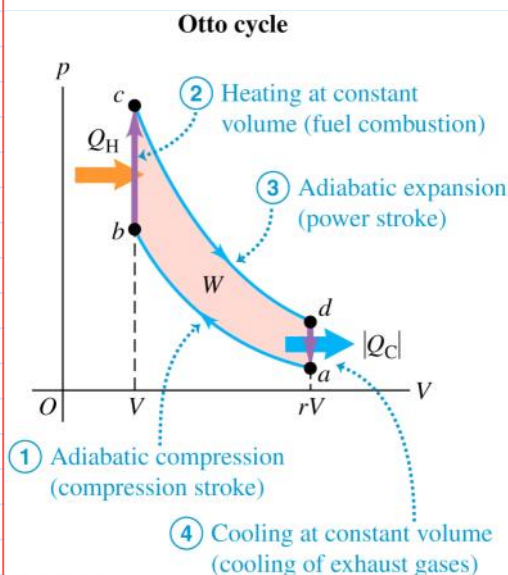
Efficiency :

$$e = \frac{\text{useful work}}{\text{energy input}} = \frac{W}{|Q_H|} = 1 - \frac{|Q_C|}{|Q_H|}$$

Practical Example: Otto Engine



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$$Q_H = n C_v (T_c - T_b) > 0$$

$$Q_c = n C_v (T_d - T_a) < 0$$

$$e = 1 - \frac{|Q_c|}{|Q_H|}$$

$$= 1 - \frac{n C_v (T_d - T_a)}{n C_v (T_c - T_b)}$$

$$= 1 - \frac{T_d - T_a}{T_c - T_b}$$

for the 2 adiabatic processes.

$$T_a V_a^{\gamma-1} = T_b V_b^{\gamma-1}$$

$$T_c V_c^{\gamma-1} = T_d V_d^{\gamma-1}$$

$$V_a = V_d = rV$$

$$V_b = V_c = V$$

$$T_a (rV)^{\gamma-1} = T_b V^{\gamma-1}$$

$$T_c V^{\gamma-1} = T_d (rV)^{\gamma-1}$$

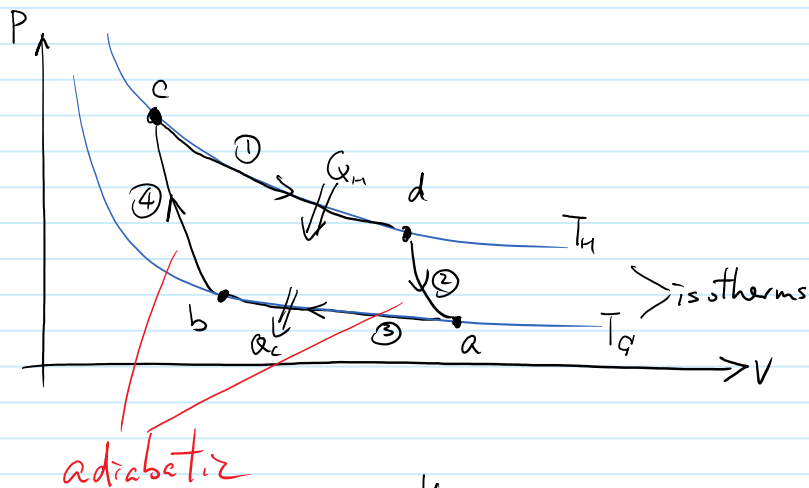
$$T_b = r^{\gamma-1} T_a$$

$$T_c = r^{\gamma-1} T_d$$

$$e_{\text{otto}} = 1 - \frac{T_d - T_a}{r^{\gamma-1} (T_d - T_a)} = 1 - \frac{1}{r^{\gamma-1}} \quad \text{or} \quad 1 - \frac{T_a}{T_b}$$

Carnot Engine (Carnot cycle)

2 isothermal + 2 adiabatic processes.



Consider ② & ④

$$T_c V_b^{\gamma-1} = T_h V_c^{\gamma-1}$$

$$T_c V_a^{\gamma-1} = T_h d^{\gamma-1}$$

$$\Rightarrow \left(\frac{V_b}{V_a} \right)^{\gamma-1} = \left(\frac{V_c}{V_d} \right)^{\gamma-1}$$

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

$$Q_c = W_{ab} = \int_{V_a}^{V_b} p dV = nRT_c \ln \left(\frac{V_b}{V_a} \right) < 0$$

$$Q_h = W_{cd} = \int_{V_c}^{V_d} p dV = nRT_h \ln \left(\frac{V_d}{V_c} \right) > 0$$

$$e_{\text{carnot}} = 1 - \frac{-T_c \ln \left(\frac{V_b}{V_a} \right)}{T_h \ln \left(\frac{V_d}{V_c} \right)} = 1 - \frac{T_c \ln \left(\frac{V_a}{V_b} \right)}{T_h \ln \left(\frac{V_d}{V_c} \right)}$$

$$e_{\text{carnot}} = 1 - \frac{T_c}{T_h}$$

Since : $e = 1 - \frac{|Q_c|}{|Q_h|}$

$\Rightarrow$ in Carnot cycle

$$\frac{|Q_c|}{|Q_h|} = \frac{T_c}{T_h}$$

$$\Rightarrow \frac{|Q_c|}{T_c} = \frac{|Q_h|}{T_h}$$

Comparing efficiency between Otto and Carnot Cycle operating in between T_c and T_H .

In Otto cycle, the highest temperature is at point c. while the lowest temp. is at point a.

efficiency of Otto cycle

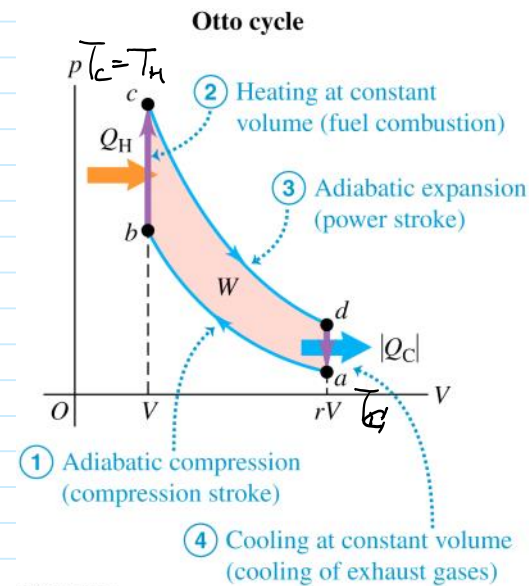
$$\begin{aligned} e_{\text{otto}} &= 1 - \frac{1}{r^{\gamma-1}} \quad \text{or} \quad 1 - \frac{T_a}{T_b} \\ &= 1 - \frac{T_c}{T_d} \end{aligned}$$

Since $T_b < T_c = T_H$,

$$e_{\text{otto}} < 1 - \frac{T_c}{T_H} = 1 - \frac{T_a}{T_H} = e_{\text{Carnot}}$$

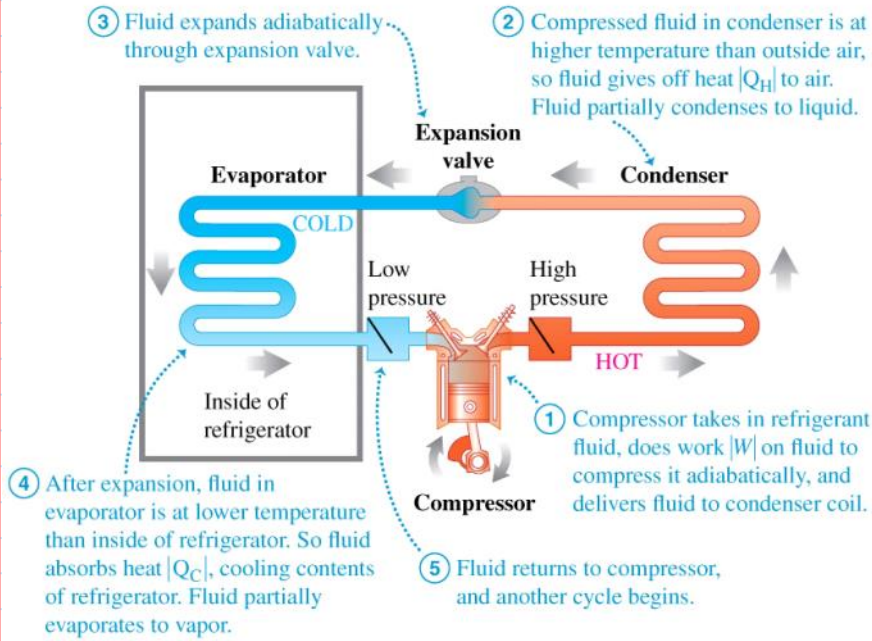
$$\Rightarrow \underline{e_{\text{otto}} < e_{\text{Carnot}}}$$

Carnot engine has a higher efficiency.

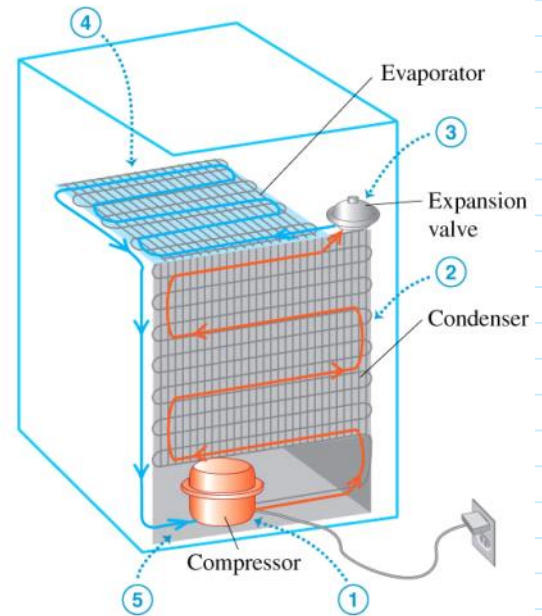


Refrigerator

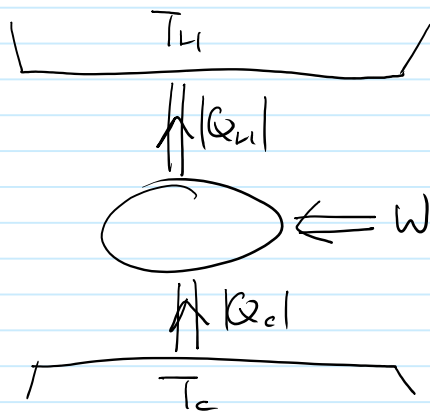
(a)



(b)

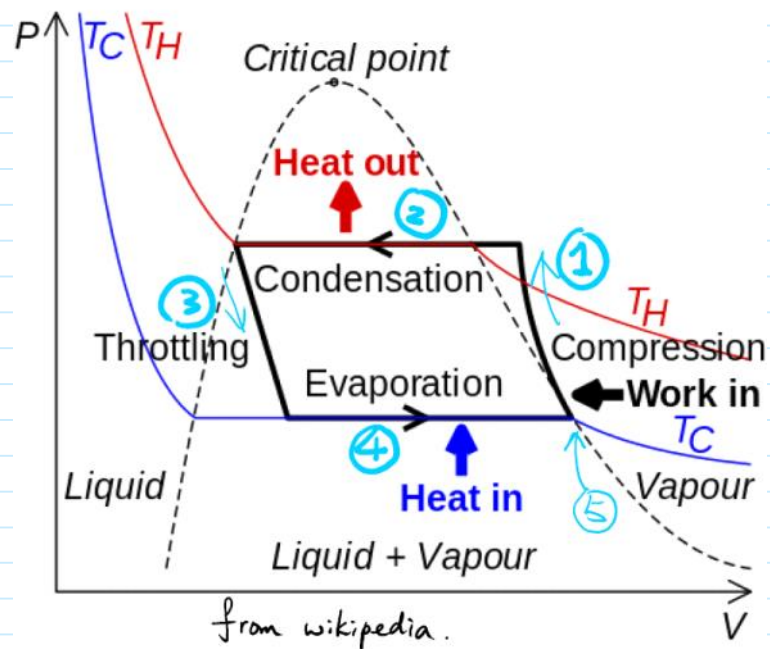


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Coefficient of Performance

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



Carnot cycle can be reversed and it runs as a refrigerator. $\because$ every steps in Carnot cycle are reversible.

in Carnot cycle :

$$\frac{|Q_C|}{|Q_H|} = \frac{T_C}{T_H}$$

$$\Rightarrow K_{\text{carnot}} = \frac{T_H}{T_H - T_C}$$