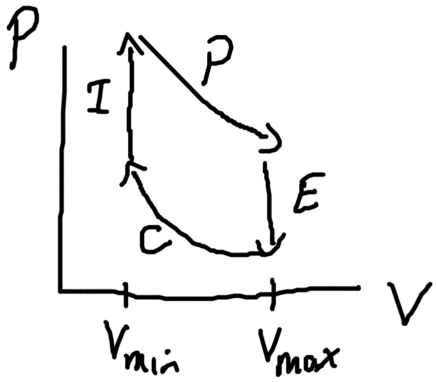
Otto cycle



air-gasoline mix

1) compression (adiabatic)
2) ignition at constant V
3) power (adiabatic)
4) exhaust

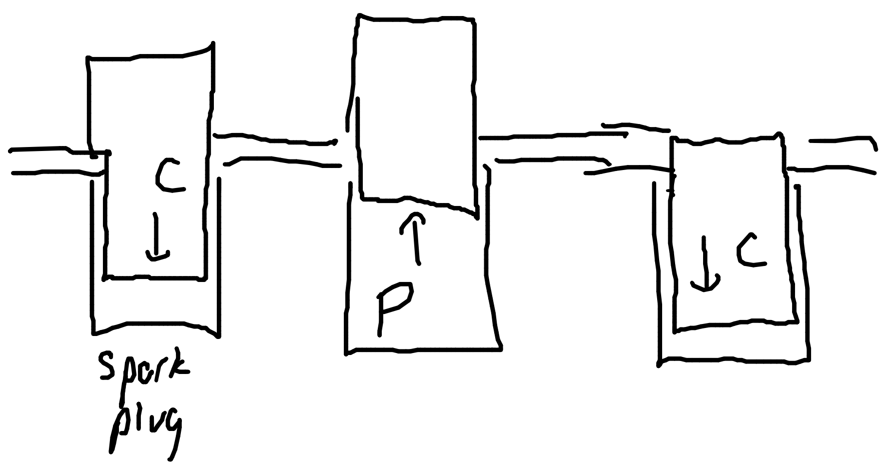
$\frac{V_{max}}{V_{min}} > 1$ compression ratio

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

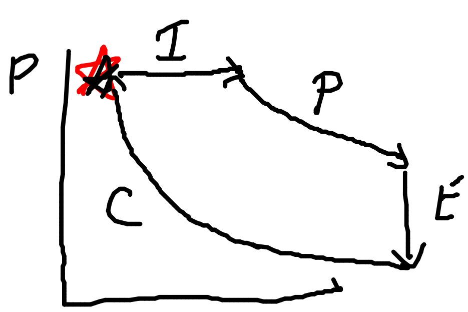
γ: adiabatic exponent

to increase efficiency, compress a lot

but ... if too much,
too hot,
& gasoline pre-ignites



Diesel engine

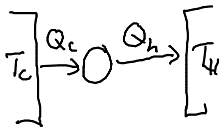


fuel is only added at the ☆ - no pre-ignition

engine has much larger compression ratios -
fuel can ignite due to temperature of the air -
no spark plugs

Refrigerator

- transfers heat from cold to hot



Violates 2nd law of thermodynamics

fridge gains $S_{in} = \dfrac{Q_{in}}{T_{in}} \geq \dfrac{Q_{in}}{T_c}$ $\quad (T_{in} \leq T_c)$

loses $S_{out} = \dfrac{Q_{out}}{T_{out}} \leq \dfrac{Q_{out}}{T_H}$ $\quad (T_{out} \geq T_H)$

$$0 = \Delta S = S_{in} - S_{out} \geq \frac{Q_{in}}{T_c} - \frac{Q_{out}}{T_H}$$

If $Q_{in} = Q_{out}$, then

$$\Delta S \geq Q_{in}\left(\frac{1}{T_c} - \frac{1}{T_H}\right)$$

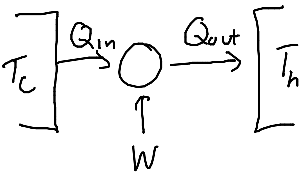
positive

positive $\quad T_c$ small $\quad T_H$ big

$\frac{1}{T_c}$ big $\quad \frac{1}{T_H}$ small

$\therefore \Delta S > 0$ not a cycle

Need $Q_{out} > Q_{in}$: I must put work in



$$Q_{in} + W = Q_{out}$$

Coefficient of Performance

$$\text{COP} = \frac{Q_{in}}{W} = \frac{Q_{in}}{Q_{out} - Q_{in}} = \frac{1}{\frac{Q_{out}}{Q_{in}} - 1}$$

e.g. if COP = 5, need 20 J of work to remove 100 J of heat from cold reservoir

$$0 \geq \frac{Q_{in}}{T_c} - \frac{Q_{out}}{T_H}$$

$$\frac{Q_{out}}{T_H} \geq \frac{Q_{in}}{T_c}$$

$$\frac{T_c}{T_H} \geq \frac{Q_{in}}{Q_{out}} \qquad \text{COP} = \frac{1}{\frac{Q_{out}}{Q_{in}} - 1} \leq \frac{1}{\frac{T_H}{T_c} - 1} = \frac{T_c}{T_H - T_c}$$

COP larger if $T_H - T_c$ is small

e.g. $T_c = 273\text{K}$ $\quad T_H = 300\text{K}$ $\rightarrow$ COP ≤ 10.

A Carnot refrigerator is a Carnot engine in reverse:

① lower T to just below T_c quickly
② let heat flow in from T_c isothermally
③ raise T to just above T_h quickly
④ let heat flow out to T_H isothermally