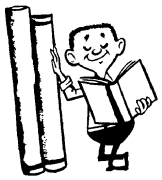
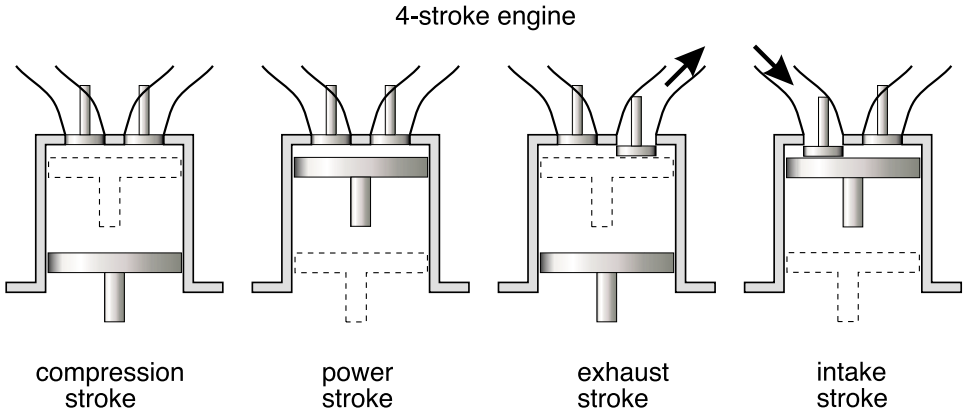
Internal Combustion Engines



Reading	**Problems**
8-3 → 8-7	8-35, 8-45, 8-52

The Gasoline Engine



- conversion of chemical energy to mechanical energy
- can obtain very high temperatures due to the short duration of the power stroke

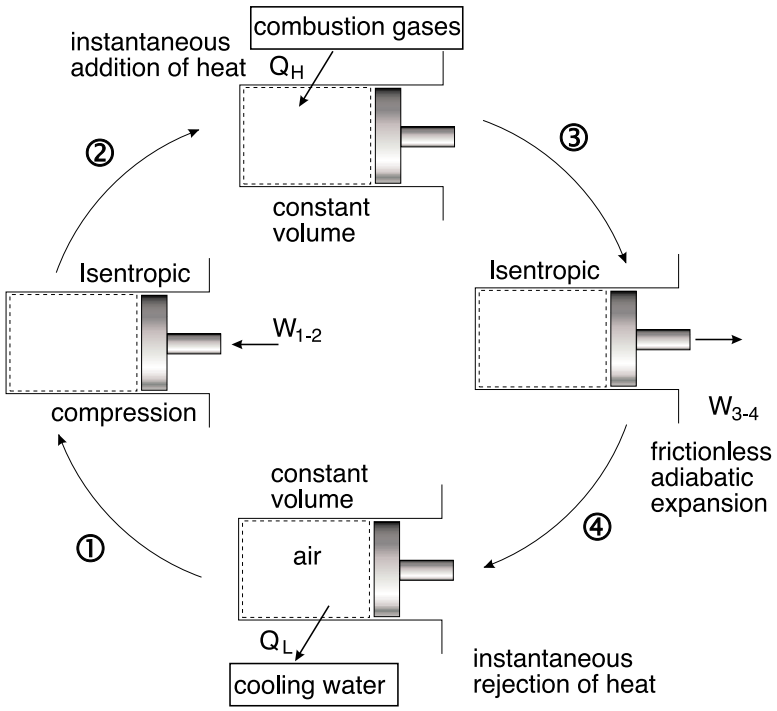
Air Standard Cycle

A closed cycle model for the IC engine, such as the gasoline or diesel cycle. Some assumptions must be made in order to model this complex process.

ASSUMPTIONS:

- air is an ideal gas with constant c_p and c_v
- no intake or exhaust processes
- the cycle is completed by heat transfer to the surroundings
- the internal combustion process is replaced by a heat transfer process from a TER
- all internal processes are reversible
- heat addition occurs instantaneously while the piston is at TDC

Otto Cycle



Otto Cycle Efficiency

We know the efficiency can be written as the benefit over the cost or in the case of the Otto cycle

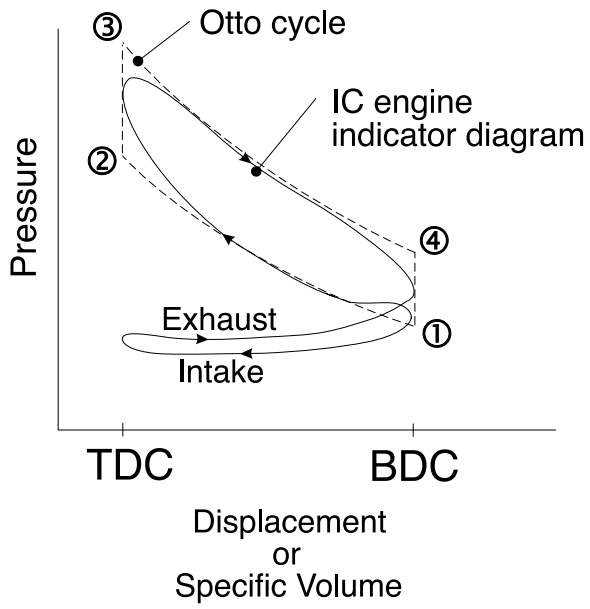
$$\eta = \frac{W_{net}}{Q_H} = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{Q_{4-1}}{Q_{2-3}}$$

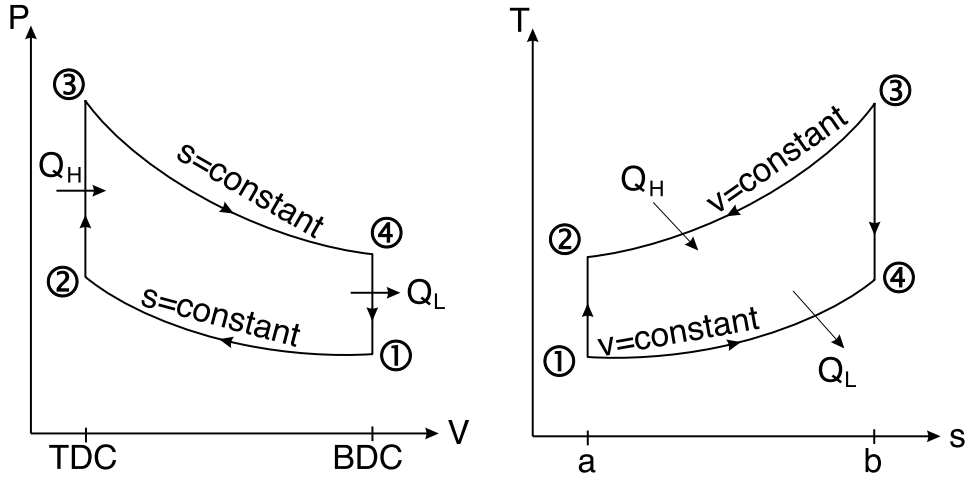
which can be reduced to

$$\eta = 1 - \frac{T_1}{T_2} = 1 - \left(\frac{V_2}{V_1}\right)^{k-1} = 1 - \left(\frac{V_1}{V_2}\right)^{1-k}$$

$$r = \frac{V_1}{V_2} = \frac{V_4}{V_3} = compression\ ratio$$

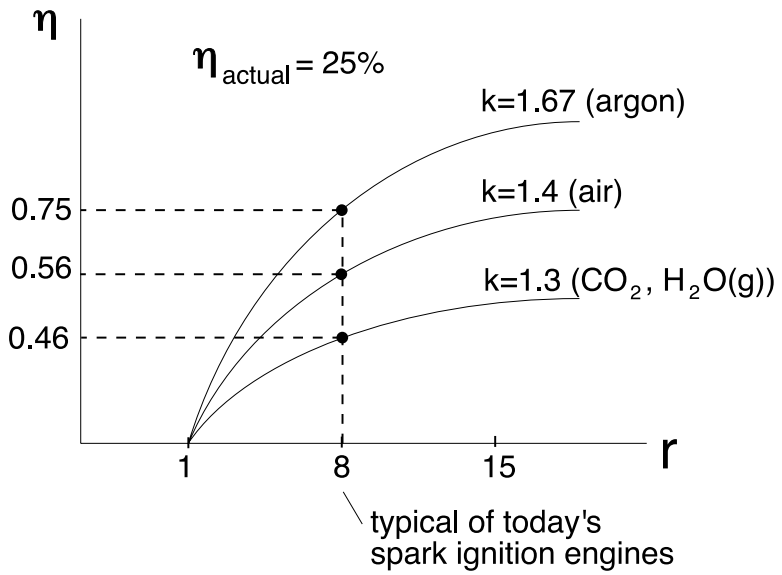
$$\boxed{\eta_{Otto} = 1 - r^{1-k}}.$$





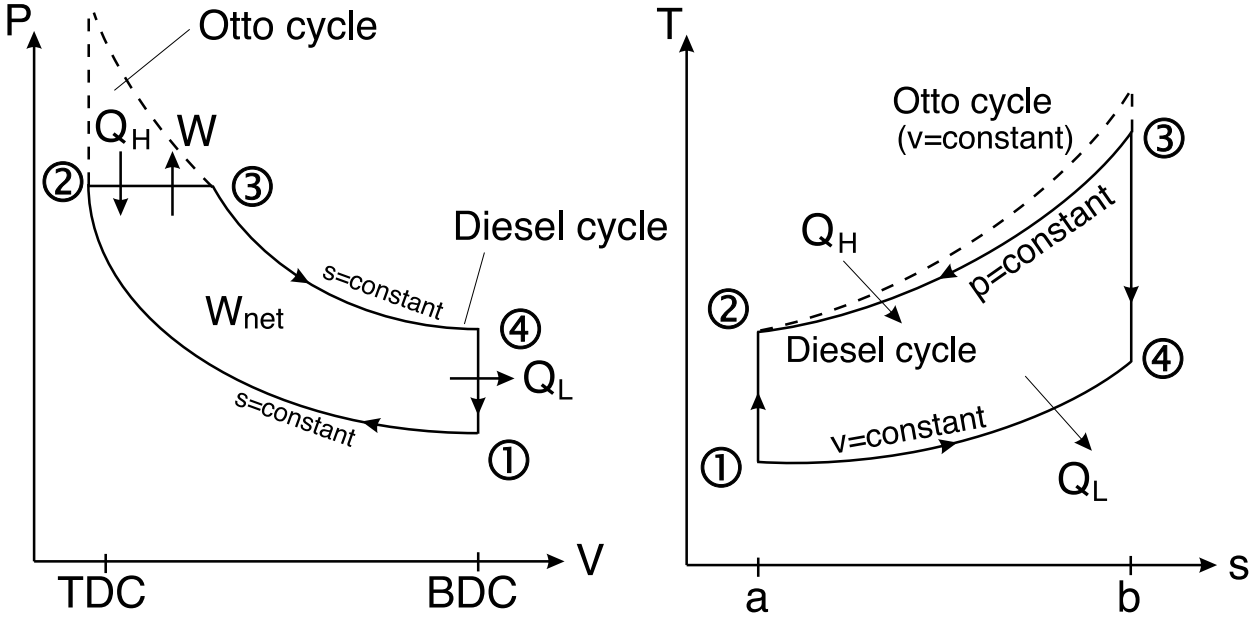
Why not go to higher compression ratios?

- there is an increased tendency for the fuel to detonate as the compression ratio increases
- the pressure wave gives rise to engine knock
- can be reduced by adding tetraethyl lead to the fuel
- not good for the environment



Diesel Cycle

- an ideal cycle for the compression ignition engine (diesel engine)
- all steps in the cycle are reversible
- heat is transferred to the working fluid at constant pressure
- heat transfer must be just sufficient to maintain a constant pressure



Diesel Cycle Efficiency

We know the efficiency can be written as the benefit over the cost or in the case of the Diesel cycle

$$\eta = \frac{W_{net}}{Q_H} = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{Q_{4-1}}{Q_{2-3}}$$

which leads to

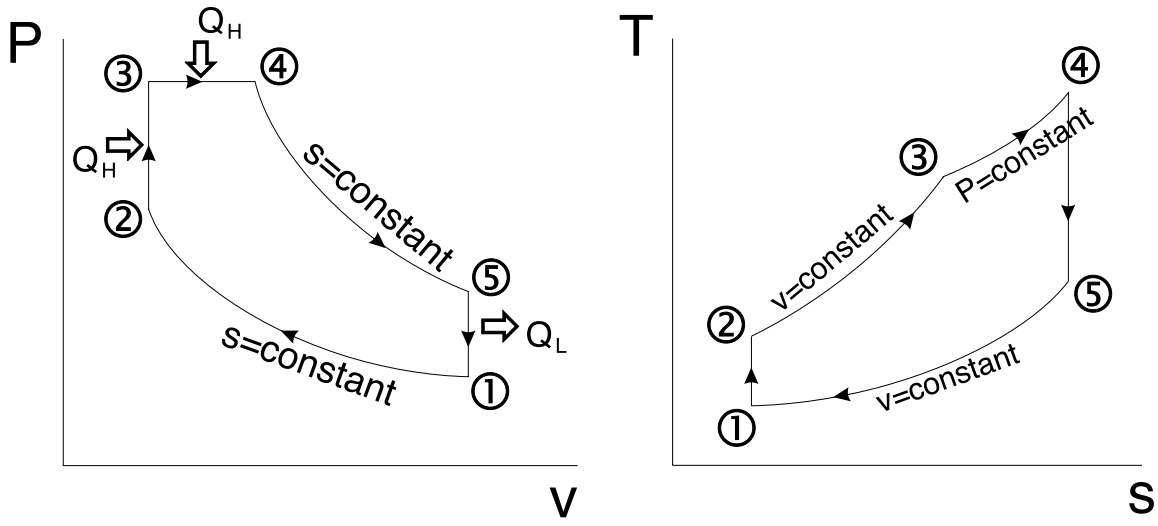
$$\boxed{\eta_{Diesel} = 1 - \frac{1}{r^{k-1}} \left(\frac{1}{k}\right) \left(\frac{r_v^k - 1}{r_v - 1}\right)}$$

Comparison of the Otto and the Diesel Cycle

- $\eta_{Otto} > \eta_{Diesel}$ for the same compression ratio
- but a diesel engine can tolerate a higher ratio since only air is compressed in a diesel cycle and spark knock is not an issue
- direct comparisons are difficult

Dual Cycle (Limited Pressure Cycle)

- this is a better representation of the combustion process in both the gasoline and the diesel engines
- in a compression ignition engine, combustion occurs at TDC while the piston moves down to maintain a constant pressure



Dual Cycle Efficiency

Given

$$r = \frac{V_1}{V_2} = \textit{compression ratio}$$

$$r_v = \frac{V_4}{V_3} = \textit{cutoff ratio}$$

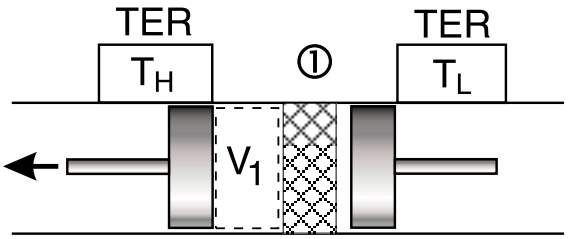
$$r_p = \frac{P_3}{P_2} = \textit{pressure ratio}$$

$$\boxed{\eta_{Dual} = 1 - \frac{r_p r_v^k - 1}{\left[(r_p - 1) + k r_p (r_v - 1)\right] r^{k-1}}}$$

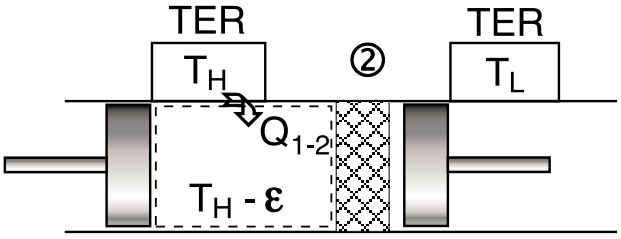
Note: if $r_p = 1$ we get the diesel efficiency.

Stirling Cycle

① → ②
isothermal expansion
at high temperature
- heat is added,
volume expands

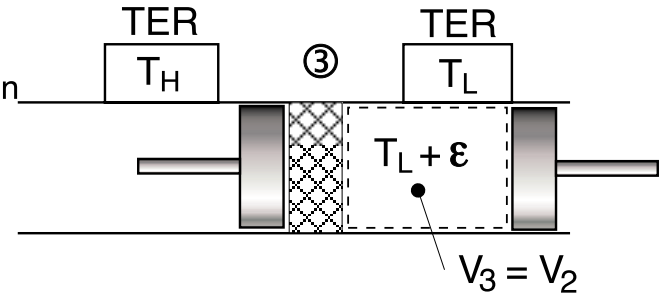


② → ③
constant volume
process



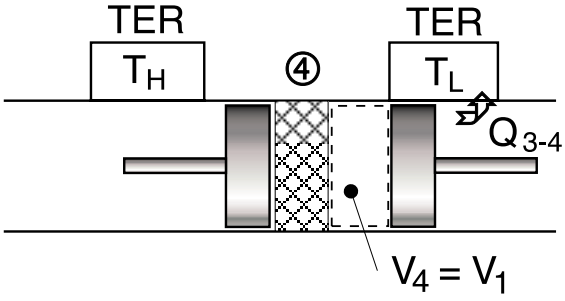
(isothermal expansion)

③ → ④
isothermal compression
at low temperature

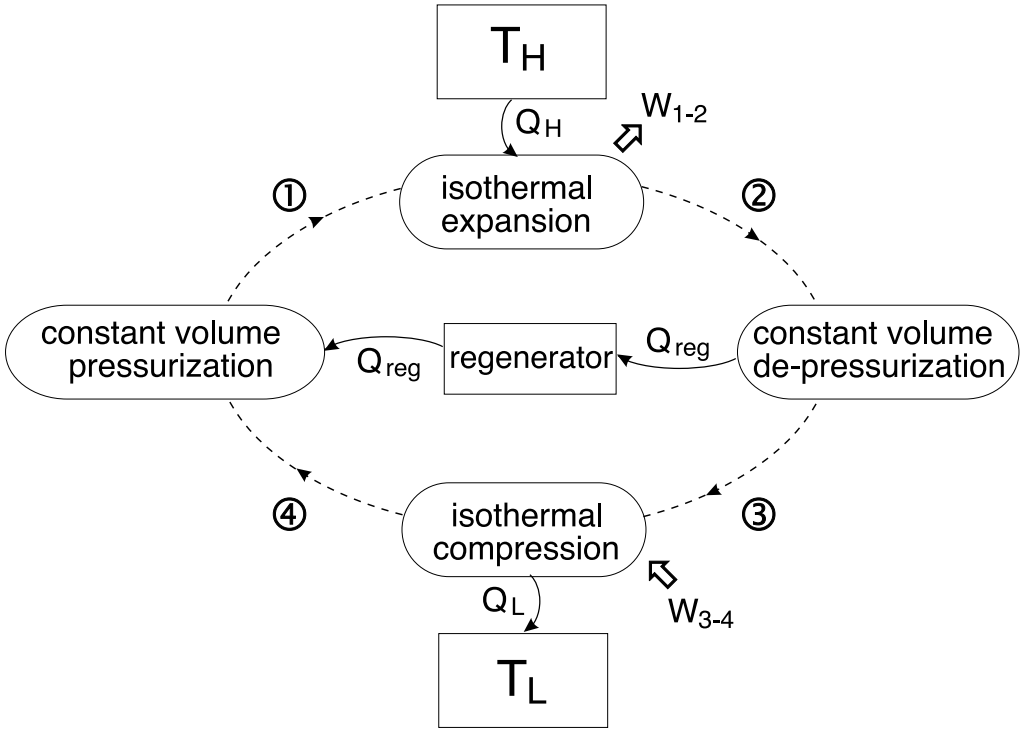


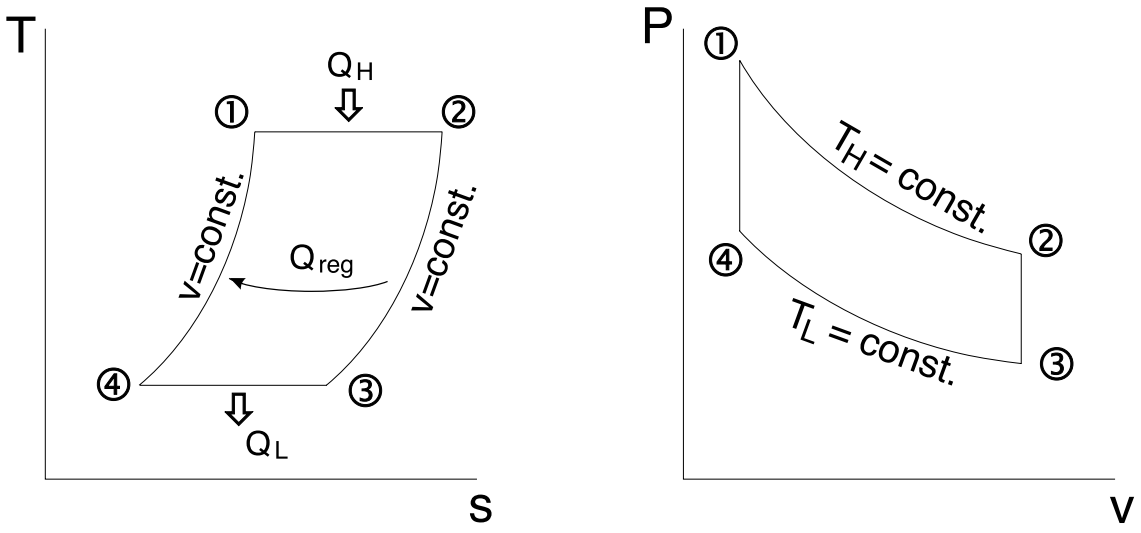
heat the regenerator
by pushing the hot
gas through it

④ → ①
constant volume
process



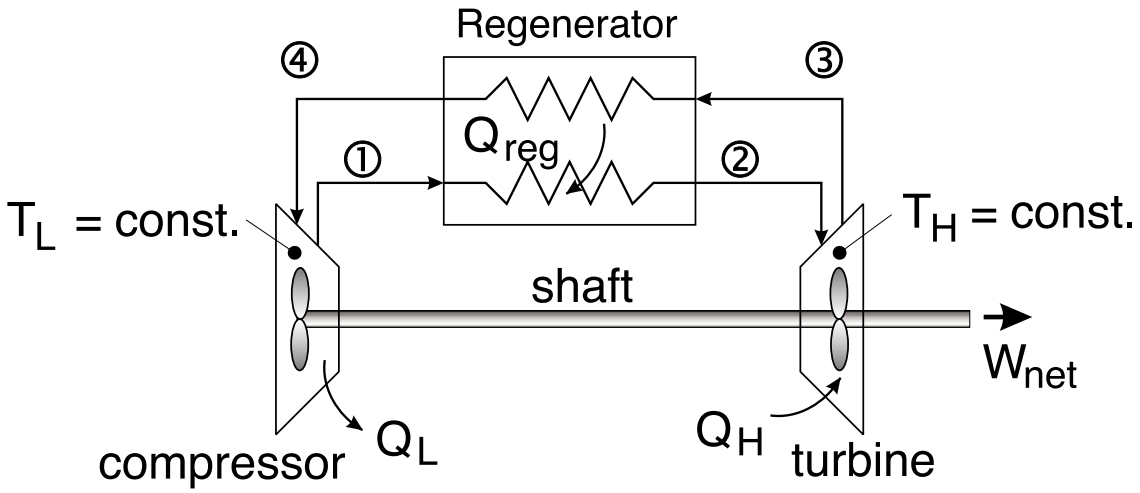
move both pistons
to the left to get back
to state 1.
During this process the
regenerator cools down
by giving off energy to
the gas





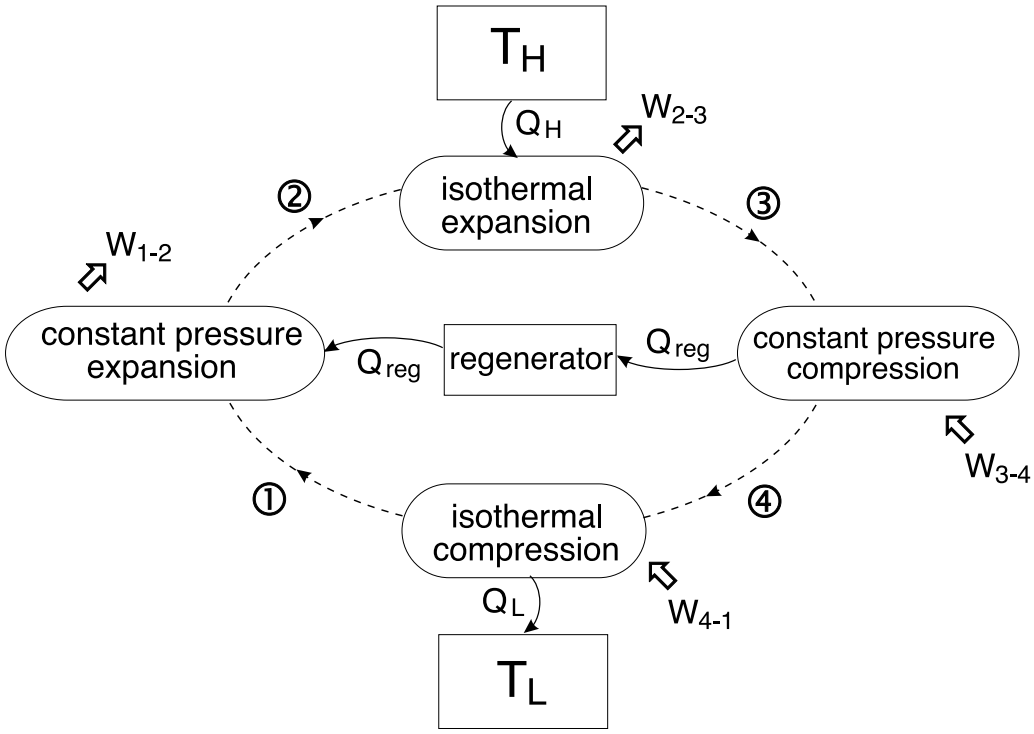
- reversible regenerator used as an energy storage device
- possible to recover all heat given up by the working fluid in the constant volume cooling process
- all the heat received by the cycle is at $\boldsymbol{T_H}$ and all heat rejected at $\boldsymbol{T_L}$
- $\boldsymbol{\eta_{Stirling} = 1 - T_L/T_H}$ (Carnot efficiency)

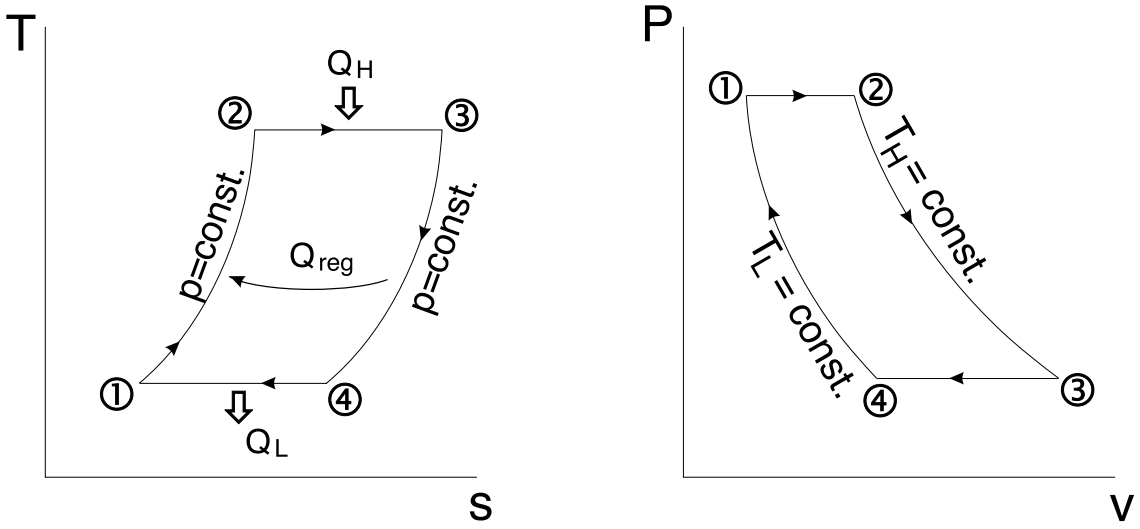
Ericsson Cycle



- hardware is not complicated
- but it is very difficult to operate turbines and compressors isothermally
- can approach isothermal conditions by repeated intercooling (compressor) and repeated reheating (turbines)
- $\eta_{Stirling} = 1 - T_L/T_H$ (Carnot efficiency)

$$\eta = \frac{W_{net}}{Q_H} = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{T_L(s_4 - s_1)}{T_H(s_3 - s_2)} = 1 - \frac{T_L}{T_H}$$


T_H
Q_H
W_2-3
isothermal expansion
②
③
W_1-2
constant pressure expansion
Q_reg
regenerator
Q_reg
constant pressure compression
W_3-4
①
④
isothermal compression
Q_L
W_4-1
T_L


T
Q_H
②
③
p=const.
Q_reg
p=const.
①
④
Q_L
s
P
①
②
T_H = const.
T_L = const.
④
③
v