Engine: Idealized cycles and processes

Dr. Md. Zahurul Haq

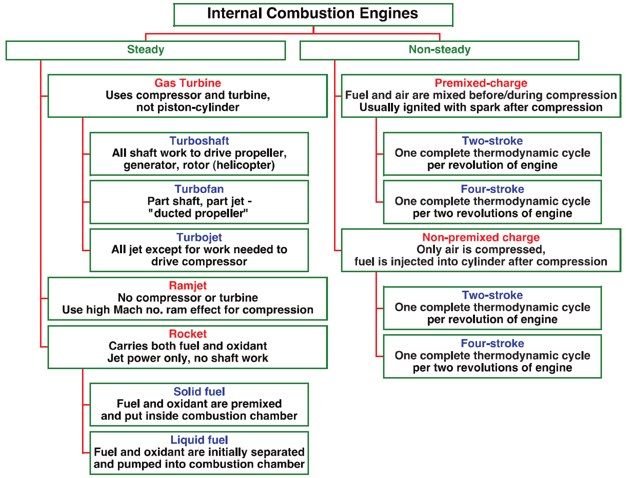
Professor
Department of Mechanical Engineering
Bangladesh University of Engineering & Technology (BUET)
Dhaka-1000, Bangladesh

zahurul@me.buet.ac.bd
http://teacher.buet.ac.bd/zahurul/

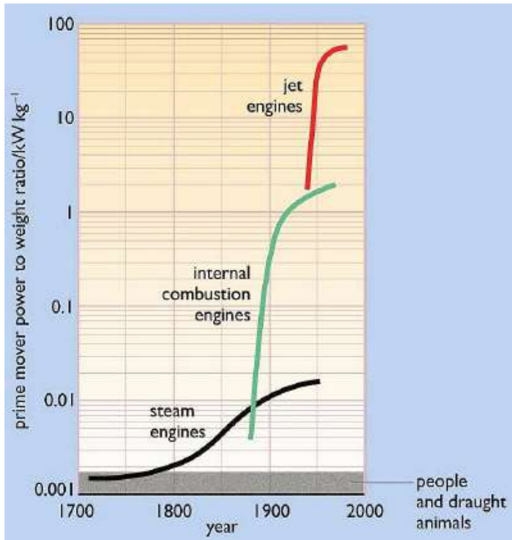
ME 417: Internal Combustion Engines

http://teacher.buet.ac.bd/zahurul/ME417/

IC Engine Classifications

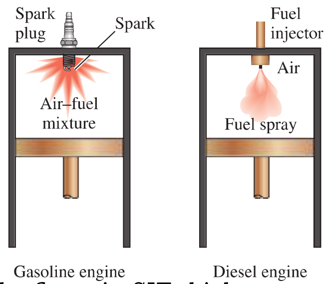


T533



T555

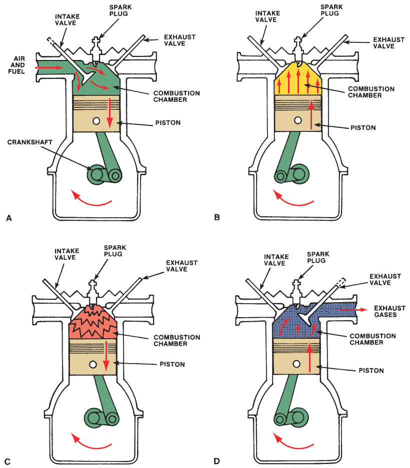
Spark or Compression Ignition Engines (SIE vs CIE)



T503

- Spark initiates the flame in SIE; high compression in CIE generates high temperature for ignition in CIE.
- Part-load efficiency of CIE is better as load is regulated by fuel injection adjustment; in SIE throttling is used to reduce load which increases pumping work.
- SIEs are high speed engines with higher temperature exhaust.

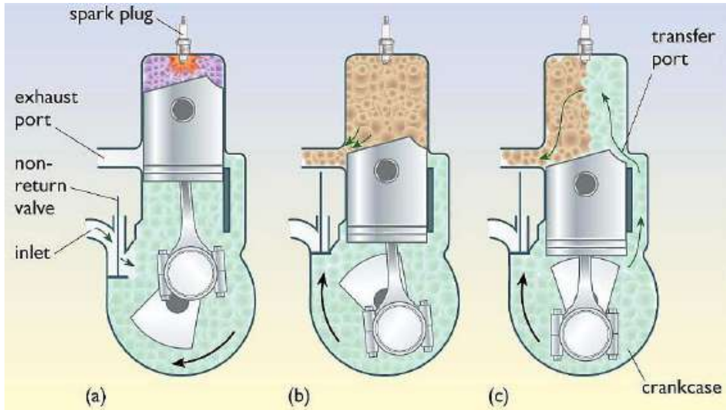
Four Stroke Reciprocating IC Engine



T523

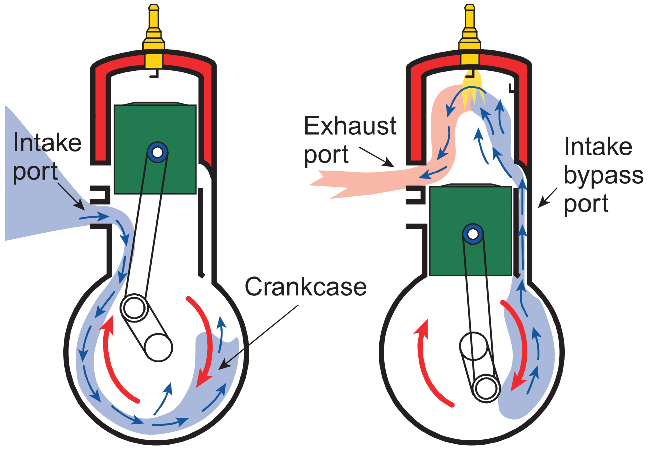
Four stroke cycle events

Two Stroke Reciprocating IC Engine



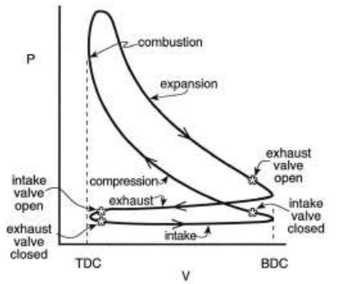
T524

Two stroke cycle events

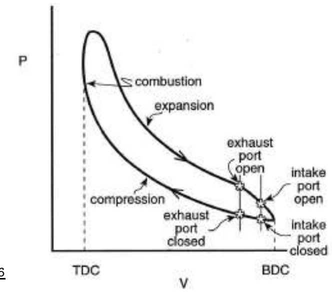


T924

4s vs. 2s IC Engines



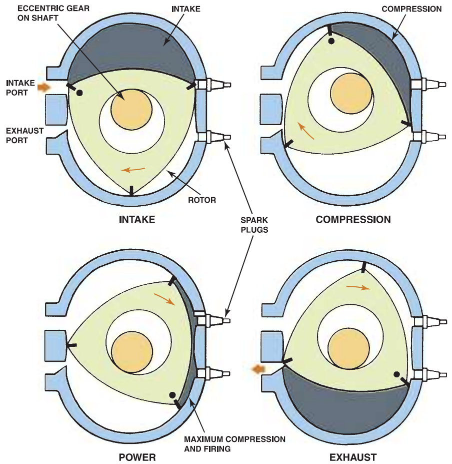
T515



T516

- Basic difference: 2s engine accomplishes the four processes (intake, compressing, expansion & exhaust) in a single revolution.
- Advantages of 4s engines: better fuel economy, better lubrication and easier control.
- Advantages of 2s engines: fewer moving parts, lighter weight and smoother operation.

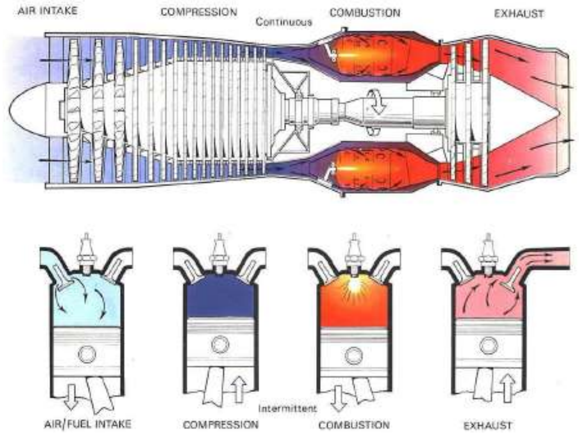
Wankel Four Stroke Rotary SI Engines



T906

- ▶ smooth rotary motion, ▶ sealing is critical.

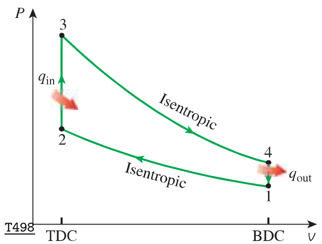
Gas Turbine



T371

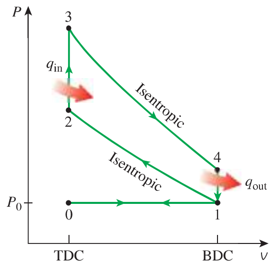
A comparison between the working cycle of a turbo-jet engine and a piston engine.

Four Stroke Reciprocating SI Engine: Otto Cycle



T498

P-v diagram of Otto cycle



T500

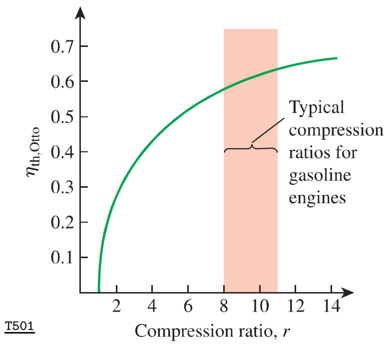
Cycle with gas-exchange processes

- **1-2:** Isentropic compression from BDC to TDC
- **2-3:** Constant-volume heat addition at TDC
- **3-4:** Isentropic expansion from TDC to BDC
- **4-1:** Constant-volume heat rejection at BDC

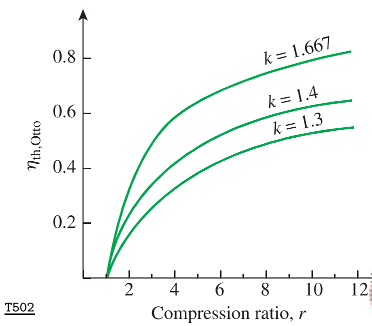
- thermal efficiency, $\boxed{\eta_{th,otto} = 1 - \frac{1}{r_c^{k-1}}}$

→ compression ratio, $r_c \equiv V_{BDC}/V_{TDC}$

→ ratio of specific heat capacities, $k = c_p/c_v$

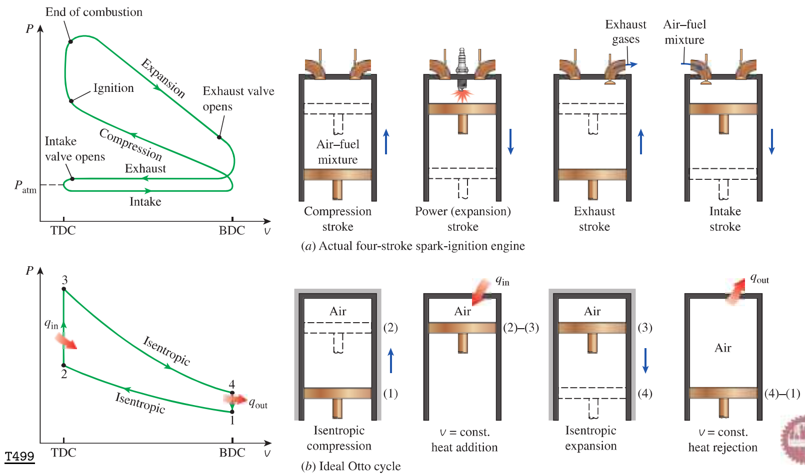


T501

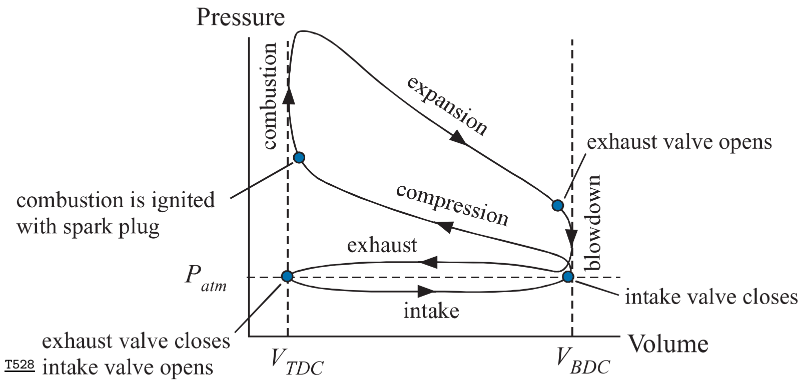


T502

Actual 4s SI engine cycle vs. Otto cycle

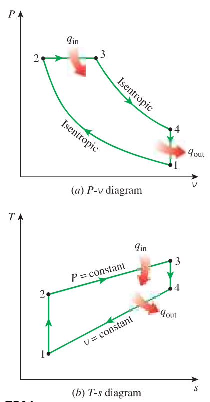


T499



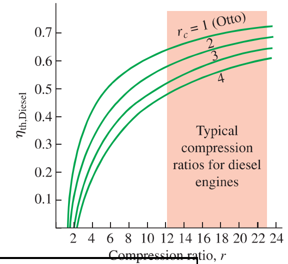
T528

Air Standard Diesel Cycle



T504

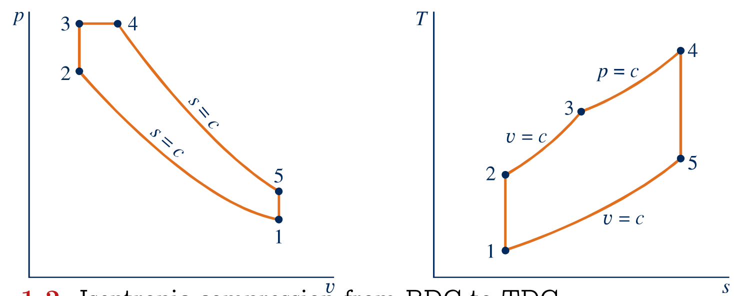
- **1-2:** Isentropic compression from BDC to TDC
- **2-3:** Constant-pressure heat addition at TDC
- **3-4:** Isentropic expansion to BDC
- **4-1:** Constant-volume heat rejection at BDC



T505

▶thermal efficiency, $\eta_{th,diesel} = 1 - \frac{1}{r_c^{k-1}}\left[\frac{\beta^k - 1}{k(\beta - 1)}\right]$; cut-off ratio, $\beta \equiv \frac{V_3}{V_2}$

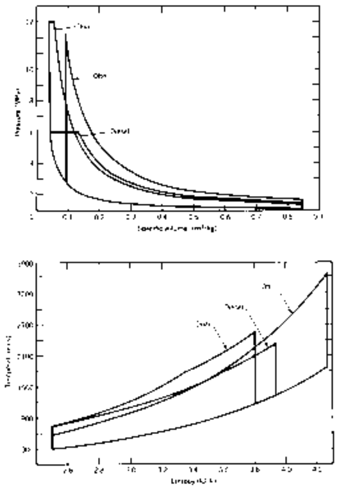
Air Standard Dual Cycle



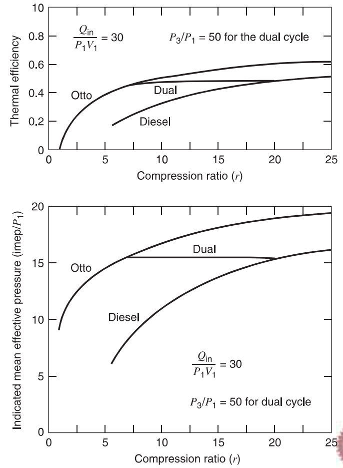
T506

- **1-2:** Isentropic compression from BDC to TDC
- **2-3:** Constant-volume heat addition at TDC
- **3-4:** Constant-pressure heat addition at TDC
- **4-5:** Isentropic expansion to BDC
- **5-1:** Constant-volume heat rejection at BDC

Comparison: Otto, Diesel & Dual Cycle

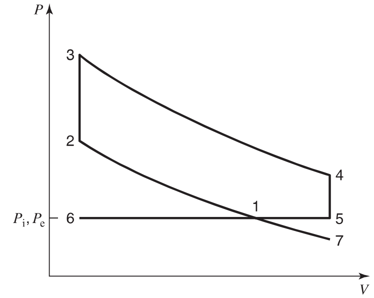


T603



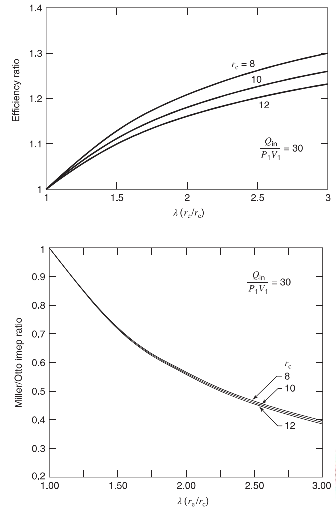
T509

Miller Cycle



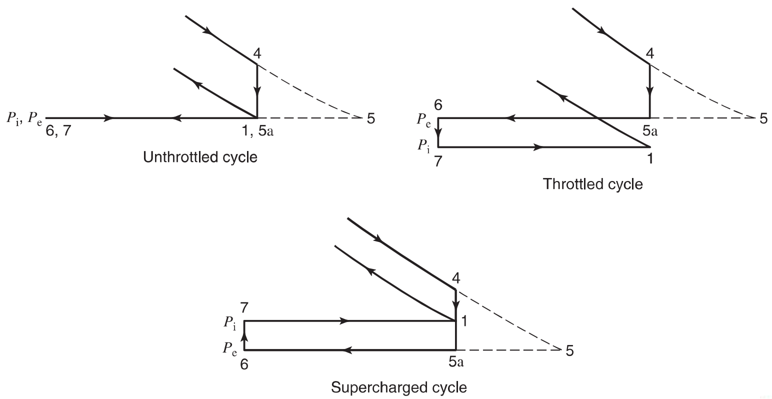
T891

- compression ratio, $r_c \equiv V_1/V_2$
- expansion ratio, $r_e \equiv V_4/V_3$



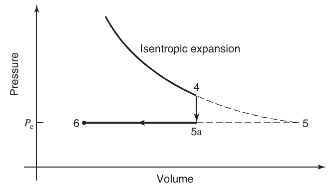
T892

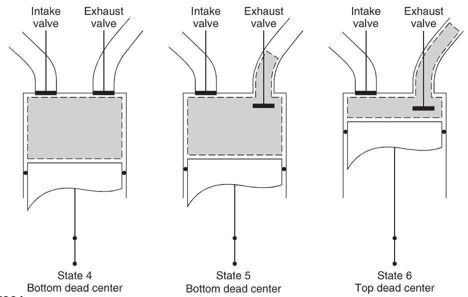
Ideal Four Stroke Processes : Inlet & Exhaust Flow



T893

Ideal Four Stroke Processes: Exhaust Stroke



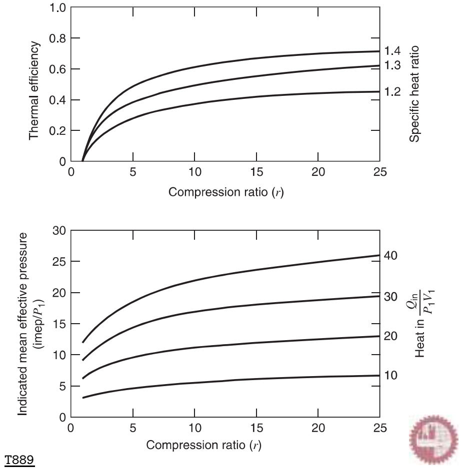


T894

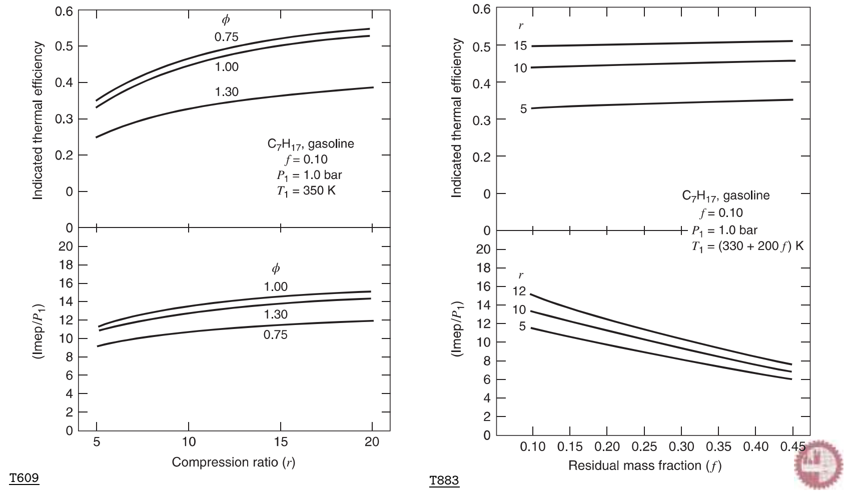
- $T_e = T_4 \left(\frac{P_e}{P_4}\right)^{\frac{k-1}{k}}$
- Residual gas fraction, f_r
- $f_r = \frac{1}{r_c}\left(\frac{P_e}{P_4}\right)^{\frac{k-1}{k}}$
- $0.03 <= f_r <= 0.12$
- $f_r(\ Diesel) < f_r(\ Otto)$

Otto Cycle: Effect of r_c and Heat Input

- $\eta_{otto} = 1 - \left(\frac{1}{r_c}\right)^{k-1}$
- $\frac{imep}{P_1} = \left(\frac{Q_{in}}{P_1 V_1}\right)\left(\frac{r_c}{r_c - 1}\right)\eta_{otto}$



Otto Cycle: Effect of r_c, f_r and ϕ



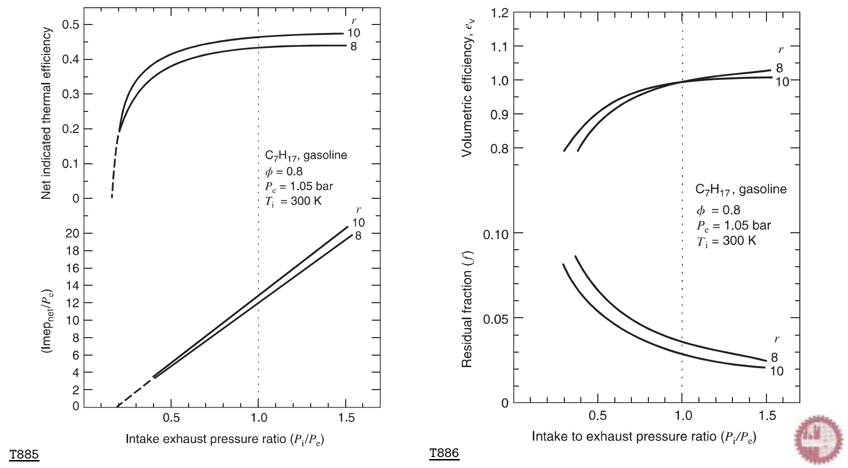
Otto Cycle: Effect of Fuel Type

Fuel	Formula	r	η_{Otto}	imep (bar)
Gasoline	C_7H_{17}	10	0.44	13.3
		15	0.49	14.4
Diesel	$C_{14.4}H_{24.9}$	10	0.44	13.7
		15	0.49	14.9
Methane	CH_4	10	0.44	12.2
		15	0.49	13.1
Methanol	CH_3OH	10	0.43	13.1
		15	0.48	14.2
Nitromethane	CH_3NO_2	10	0.39	21.0
		15	0.43	23.1

$\phi = 1.0$, $f = 0.10$, $P_1 = 1.0$ bar, $T_1 = 350$ K

T884

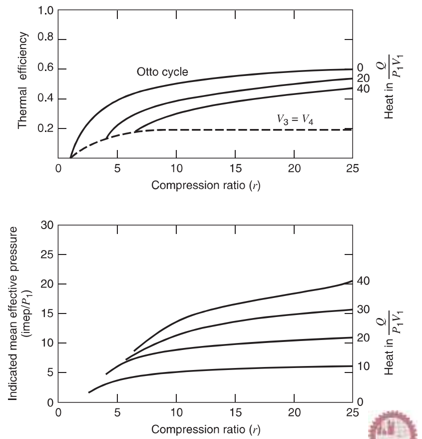
Otto Cycle: Effect of P_i/P_e



Diesel Cycle: Effect of r_c and Heat Input

- β is not an independent variable.
- $\beta = 1 + \frac{k}{k-1}\left(\frac{Q_{in}}{P_1 V_1}\right)\frac{1}{r_c^{k-1}}$

$\Rightarrow$ $Q_{in} = 0 \rightarrow \beta = 1 \rightarrow$ Otto cycle



T890