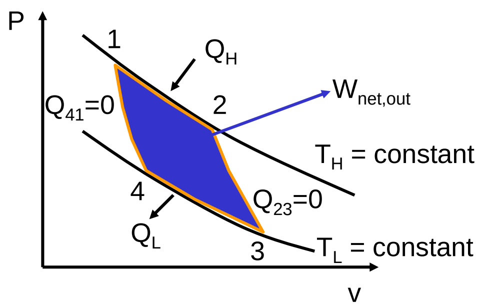
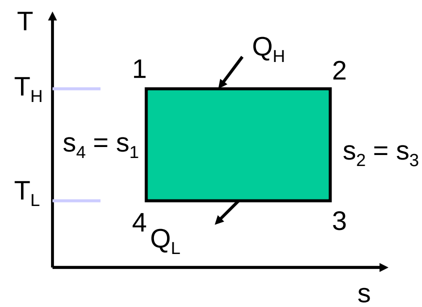
VII. Power and Refrigeration Cycles

C. The Carnot Power Cycle for an Ideal Gas

1. Description

- 1-2 reversible, isothermal expansion
- 2-3 reversible, adiabatic expansion
- 3-4 reversible, isothermal compression
- 4-1 reversible, adiabatic compression





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VII. Power and Refrigeration Cycles

2. Analysis

- 1-2 rev., isothermal expansion

$$Q_H = -W_{1-2} = mRT_H \ln\frac{v_2}{v_1}$$

- 2-3 rev., adiabatic expansion

$$Q_{2-3} = 0$$

- 3-4 rev., isothermal compression

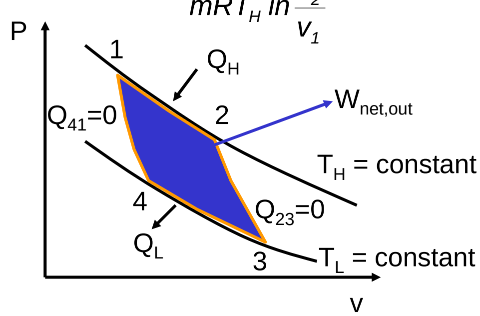
$$Q_L = W_{3-4} = mRT_L \ln\frac{v_3}{v_4}$$

- 4-1 rev., adiabatic compression

$$Q_{4-1} = 0$$

$$\eta_{th,rev} = \frac{W_{net,out}}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

$$\eta_{th,rev} = 1 - \frac{mRT_L \ln\frac{v_3}{v_4}}{mRT_H \ln\frac{v_2}{v_1}}$$



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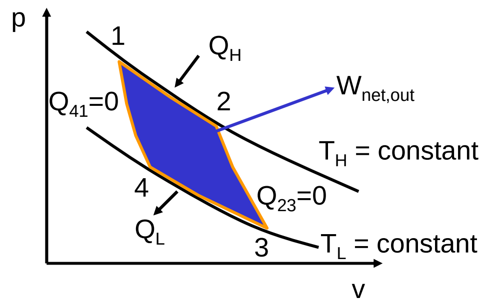
VII. Power and Refrigeration Cycles

2. Analysis (cont.)

$$\frac{T_3}{T_2} = \frac{T_L}{T_H} = \left(\frac{v_2}{v_3}\right)^{k-1}$$

$$\frac{T_4}{T_1} = \frac{T_L}{T_H} = \left(\frac{v_1}{v_4}\right)^{k-1}$$

$$\frac{v_3}{v_4} = \frac{v_2}{v_1}$$



This was derived for an ideal gas but applies to all working substances.

$$\eta_{th,rev} = 1 - \frac{mRT_L \ln \frac{v_3}{v_4}}{mRT_H \ln \frac{v_2}{v_1}} = 1 - \frac{T_L}{T_H} \qquad (6\text{-}18)$$

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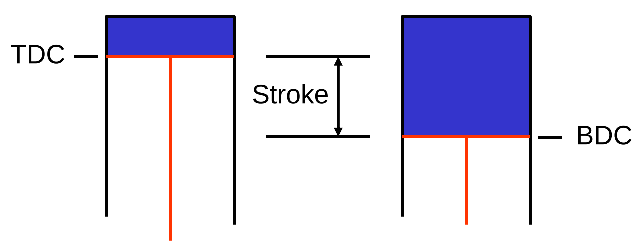
VII. Power and Refrigeration Cycles

D. Gas Power Cycle for Spark Ignition, Internal Combustion Engines (Otto Cycle)

1. Definitions

a. top dead center (TDC)

b. bottom dead center (BDC)



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VII. Power and Refrigeration Cycles

1. Definitions (cont.)
   c. mean effective pressure

$$W_{net,out} = (mep)(V_{max} - V_{min})$$

   d. compression ratio

$$r = \frac{V_{max}}{V_{min}} = \frac{V_{BDC}}{V_{TDC}}$$

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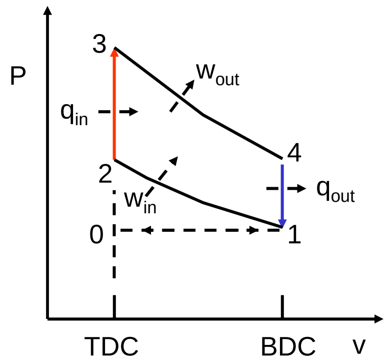
VII. Power and Refrigeration Cycles

2. The Air Standard Otto Cycle. The Otto cycle is used to model two- and four-stroke engines. The working fluid is air.



1-2 Isentropic compression. Flywheel carries piston into cylinder to give w_{in}.
2-3 Isometric heat addition. Combustion of gasoline provides heat addition q_{in}.
3-4 Isentropic expansion. Hot gas expands against piston to do work w_{out}.
4-1 Isometric heat removal. In four-stoke engines, hot gases are exhausted (1-0) and fresh air is drawn in (0-1). Steps (1-0) and (0-1) are not part of the two-stroke Otto cycle.

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VII. Power and Refrigeration Cycles

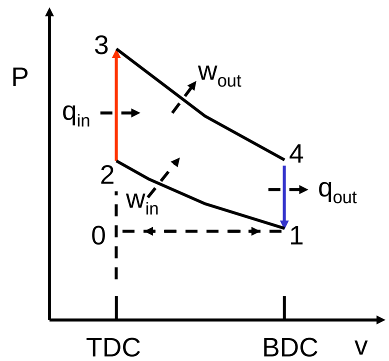
3. Efficiency of Otto Cycle (Two- and Four-Stroke)
   a. Otto cycle is closed

$$\eta_{th,otto} = \frac{w_{net,out}}{q_{in}} = \frac{q_{in} - q_{out}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}}$$

   b. heat transfer occurs at constant volume

$$q_{in} = u_3 - u_2 = C_v(T_3 - T_2)$$
$$q_{out} = u_4 - u_1 = C_v(T_4 - T_1)$$

$$\therefore \eta_{th,otto} = 1 - \frac{T_4 - T_1}{T_3 - T_2} = 1 - \frac{T_1\left(\frac{T_4}{T_1} - 1\right)}{T_2\left(\frac{T_3}{T_2} - 1\right)}$$



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VII. Power and Refrigeration Cycles

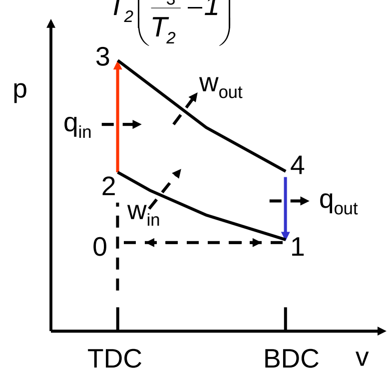
c. power stroke (3-4) and compression stroke (1-2) are isentropic with

$$v_2 = v_3 \qquad v_1 = v_4 \qquad \text{and} \qquad \eta_{th,otto} = 1 - \frac{T_1\left(\frac{T_4}{T_1} - 1\right)}{T_2\left(\frac{T_3}{T_2} - 1\right)}$$

Then $\frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{k-1} = \left(\frac{v_3}{v_4}\right)^{k-1} = \frac{T_4}{T_3}$

$$\eta_{th,otto} = 1 - \frac{T_1}{T_2} = 1 - \left(\frac{v_2}{v_1}\right)^{k-1} = 1 - \frac{1}{r^{k-1}} \qquad (9\text{-}8)$$

$$\text{where } k = \frac{c_p}{c_v} \text{ and } r = \frac{v_1}{v_2}$$



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VII. Power and Refrigeration Cycles

d. conclusions for Otto cycle

- η increases with increasing compression ratio, r, and k
- typical values of r are 7 to 10
- for r = 8 and k = 1.4, $\eta_{th,otto}$ = 56.5%
- actual efficiencies are 25 to 30%