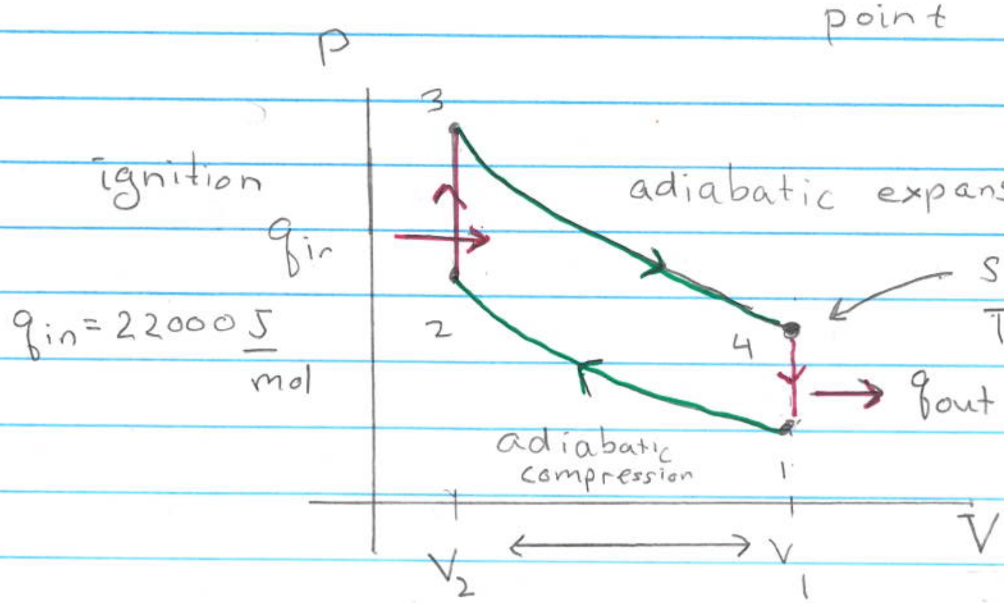
Otto Cycle

- The Otto cycle is an idealization of what happens in a car engine
- We start with air at room temperature which has fluid vapor interspersed. This is part of the intake process. The starting point is 1



spit out exhaust. The exhaust will deliver a certain amount of heat to environment q_{out}, then get fresh air

$$r \equiv \frac{V_1}{V_2} = 8$$

$r \equiv$ Compression ratio.

- The last $4 \to 1$ exhaust stage happens outside the engine block. The engine get any work from that. T
- Stages $1 \to 2$, $2 \to 3$, $3 \to 4$, the valves are closed and we can analyze with our thermodynamics, which applies for a closed system

- You will work out the details in homework.

Start / Intake

$T_1 = 300°K \qquad P = 1\,Atm \simeq 10^5$ bar

For definiteness take $V = 2.5L$ or about 0.1 mol.

Take air as diatomic molecule $\frac{\underline{C_v}}{mol} = \frac{5}{2}R$

$\gamma = \frac{C_p}{C_v} = \frac{7}{5}$

1 → 2

☆ $Q = 0 \qquad \Delta U = W \qquad \Delta U > 0$

Use; $TV^{\gamma-1} = const$, $T_2 = 690°K$, $W = 8100 \frac{J}{mol}$

$= C_v \Delta T$

2 → 3

☆ $Q = 22000 \frac{J}{mol} \qquad \Delta U = Q \qquad W = 0$

Use $\Delta U = C_v \Delta T \qquad T_3 = 1770°K$

3 → 4

☆ $Q = 0 \qquad \Delta U = W \qquad \Delta U = \Delta W < 0$

Use $TV^{\gamma-1} = const \qquad T_4 = 770°K \qquad W = -20800 \frac{J}{mol}$

$= C_v \Delta T$

Overall energetics

- The efficiency is (homework)

$$\eta \equiv \frac{W}{Q_{in}} = 1 - \frac{1}{r^{\gamma-1}} = 0.56$$

- The net work (by me) on gas is

$$W_{12} + W_{34} = -12{,}700 \text{ J/mol}$$

means the gas did positive work

- So for a 2.5L engine (0.1 mol), operating at 2000 rpm (or 1000 cycles/minute), we get a power output of

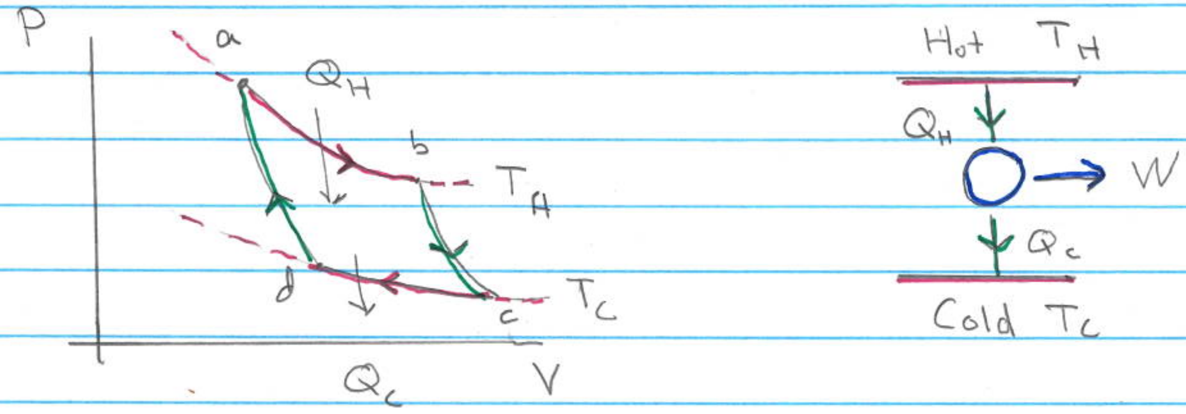
$$P = 12{,}700 \frac{\text{J}}{\text{mol}} \times 0.1 \text{ mol} \times \frac{1000}{60\text{s}} = 30 \text{ horsepower}$$

$$= 21{,}000 \text{ Watts}$$

- Typical cars get ~ 200 horsepower at 6000 rpm. So out estimates are a bit low.

Carnot Cycle

- Consider the following idealization of an engine



- Here $a \to b$ is an isothermal, $b \to c$ is adiabatic, $c \to d$ is isothermal, $d \to a$ is adiabatic.

- We go through each of these stages slowly, so that equilibrium is maintained at all times.

- All heat transfer occurs at constant temperature

- Let us analyze the energetics assuming an ideal gas with constant specific heat C_V and adiabatic index $\gamma = C_p/C_V$.

(1) in $a \to b$, the Heat Transfer is

$$\Delta U = 0 \quad \text{so} \quad Q_H = -W = + N k_B T_H \ln\left(\frac{V_b}{V_a}\right)$$

(2) Similarly in $c \rightarrow d$

$\Delta U = 0$ $\qquad Q_C = -W = -Nk_BT \ln\left(\frac{V_c}{V_d}\right)$

i.e.

$|Q_c| = Nk_BT \ln\left(\frac{V_c}{V_d}\right)$ the heat flows out

- Now for the two adiabatic processes $Q = 0$

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

$$T_H V_a^{\gamma-1} = T_C V_d^{\gamma-1}$$

- So $\frac{V_b}{V_a} = \frac{V_c}{V_d}$, and we find

$\frac{Q_H}{T_c} = -\frac{Q_c}{T_c}$ an important result $\boxed{\frac{Q_H}{T_H} + \frac{Q_c}{T_c} = 0}$

- We also note that the efficiency is

$$\eta = \underbrace{\frac{W}{Q_{in}} = \frac{Q_H - |Q_c|}{Q_H} = 1 - \frac{|Q_c|}{Q_H}}_{\text{This is general}} = \underbrace{\boxed{1 - \frac{T_c}{T_H}}}_{\text{This is for carnot}}$$