\[ K = \frac{|Q_c|}{|W|} \]  want big as possible.

Typical \( \sim 2.5 \)

Cannot in practice get \( e = 1 \) or \( K = \infty \).

(Second law of thermodynamics)

Work \( \leftrightarrow \) Heat

Cannot be exchanged with 100\% efficiency

Otto Cycle

Otto

\[ \text{explosion (spark)} \]

\[ \text{adiabatic expansion (Power Stroke)} \]

\[ \text{adiabatic compression} \]

\[ \text{Diesel no spark} \]

\[ \text{exhaust} \]

\[ a \rightarrow \text{intake air} \]

\( r : \text{compression ratio} \)
Otto: (do math)

Theoretical

\[ e = 1 - \frac{1}{r(x-1)} \approx \sqrt{1.4} \approx 0.56 \]

Higher compression... Better efficiency, but danger of pre-detonation. (sparkless ignition)

**Diesel:** go with it, and manage isobaric expansion.

\[ r: 15-20, \quad e \sim 65-70\% \]

Violation: mass in/out of cylinders

---

**Second Law**

1. Cycle cannot convert heat directly into work.

2. Cannot yet work by extracting energy from a cold body making it colder, nothing else.
Carnot Cycle: highest efficiency

Isotherm: \( Q_H = nRT_H \ln \left( \frac{V_b}{V_a} \right) \)

Adiabatic: \( Q = 0 \)

\( Q_c = -nRT_c \ln \left( \frac{V_c}{V_D} \right) = -nRT_c \ln \left( \frac{V_c}{V_D} \right) \)

\[
\frac{Q_c}{Q_H} = -\frac{T_c}{T_H} \ln \left( \frac{V_c}{V_D} \right) = -\frac{T_c}{T_H}
\]

Adiabatic:

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

\[
T_H V_a^{\sigma-1} = T_c V_d^{\sigma-1}
\]

\[
\left( \frac{V_b}{V_a} \right)^{\gamma-1} = \left( \frac{V_c}{V_d} \right)^{\gamma-1}
\]

\[
\ln \left( \frac{V_b}{V_a} \right) = \ln \left( \frac{V_c}{V_d} \right)
\]
\[ E = \frac{W}{Q} = \frac{Q_0 + Q_c}{Q_0} \]

\[ E = 1 - \frac{I_c}{I_H} \]

Entropy

Top Down \rightarrow Quasi-Empirical

Bottom Up \rightarrow Entropy Quantifies probability. When heat is exchanged, probability must increase.

\( N \) identical molecules in a box of volume \( V \). \( P(V) \), \( P(\frac{V}{2}) \)?

\[
\frac{P\left(\frac{V}{2}\right)}{P(V)} = \left(\frac{1}{2}\right) \cdot \left(\frac{1}{2}\right) \cdot \left(\frac{1}{2}\right) \ldots \left(\frac{1}{2}\right) \\
= \left(\frac{1}{2}\right)^N
\]