Adiabatic Expansion

\[ dq = 0 \text{, no heat in or out} \]

\[ dE = dq + d\omega \]
\[ = -pdV \]
\[ = -\frac{nRT(V)}{V}dV \]
De = G - AT

\[ \text{how much did E change?} \]

\[ \text{Adiabatic irreversible } dq \]

\[ \text{const T } dE = 0 \]

\[ \text{V} \]

\[ \text{Pf, Vf, Tf} \]

\[ \text{P}_1, V_1, T_1 \]

\[ \text{de} = C_L \Delta T \]
from 2 paths

\[-\frac{nRT}{V} \, dV = \int_{V_i}^{V_f} \frac{nR}{V} \, dV\]  
\[\text{adiabatic}\]

\[-\ln (x) = \ln (\frac{1}{x})\]

\[C_v \, dT\]
\[\Delta E \text{ for const } T\]
\[\text{then const } V\]
\[C_v \ln (\frac{T_f}{T_i})\]
\[= -nR \ln (\frac{V_f}{V_i})\]
\[ \ln (x^1) = \ln (y^1) \implies x = y \]

\[ \frac{T_f}{T_i} = \left( \frac{V_i}{V_f} \right)^{nR/Cv} \]

adiabatic expansion

\[ T_f = T_i \left( \frac{V_i}{V_f} \right)^{nR/Cv} \]

\[ < 1 \text{ for expansion} \]

\[ \text{non negative number} \]
\[ \frac{P_f V_f}{nR} = T_f \quad \frac{P_i V_i}{nR} = T_i \]

\[ \frac{P_f V_f}{P_i V_i} = \frac{T_f}{T_i} = \left( \frac{V_i}{V_f} \right)^{nR/CV} \]

\[ P_f / P_i = \frac{V_i}{V_f} \left( \frac{V_i}{V_f} \right)^{nR/CV} = \left( \frac{V_i}{V_f} \right)^{\left[ \frac{nR}{CV} + 1 \right]} \]
\[
P_f/P_i = \left( \frac{v_i}{v_f} \right)^{\frac{nR}{C_v}} + 1 \quad \Rightarrow \quad P_f = P_i \left( \frac{v_i}{v_f} \right)^{x} \]

\[
\frac{nR}{C_v} + 1 = \frac{nR + C_v}{C_v} = \frac{C_p}{C_v} \equiv \gamma
\]

for monatomic ideal gas \( \frac{\gamma}{\gamma - 1} = \gamma_{1/2} \)
General formula for adiabatic expansion/compression:

\[ P(v) = P_i \left( \frac{V_i}{V} \right)^{\frac{n}{\gamma - 1}} \]

\[ \omega = -\int_{V_i}^{V_f} P(v) dv = \frac{P_i V_i^{\frac{n}{\gamma - 1}}}{\frac{n}{\gamma - 1}} \left( \frac{1}{V_f^{\frac{n}{\gamma - 1}}} - \frac{1}{V_i^{\frac{n}{\gamma - 1}}} \right) \]
Second law of thermodynamic & entropy

Total energy is conserved

Spontaneous process

What sets direction of spontaneous processes?
Energy spreads out -> creation of entropy

Sound/friction
Original law (Clausius)

no process is possible where heat transfers from cold object to a hot object
Engine a "cycle" (ends where it starts) which converts Energy from one form to another (Mechanical work)

Diagram
Simple engine
Define “efficiency”:

$$\epsilon = \frac{W_{\text{done}}}{Q_{\text{in}}} = \frac{Q_{\text{in}} - Q_{\text{out}}}{Q_{\text{in}}} = 1 - \frac{Q_{\text{out}}}{Q_{\text{in}}}$$

Can we analyze $\epsilon$ for some “ideal” engine “Carnot Engine” [Otto cycle] see practice midterm
Carnot engine

4 steps in a cycle, all reversible

a) Isothermal expansion at $T_h$

Diagram:

[Diagram of a Carnot engine cycle with标注 $V$, $T_h$, and an arrow indicating work output.]
Step 2: adiabatic expansion

\[ \dot{q} = 0 \]

cooling off until \( @ T_c \)

Step 3

\( V_B \)

\( T_c \) compression

\( V_D, V_c, T_c \)
Step 4 adiabatic compression

$P_{A, V_A, T_h}$ $P_{B, V_B, T_h}$

$T$ goes up until back at $T_h$ at initial volume

$P_{c, U_c, T_{cold}}$
1. Isothermal expansion
   - ideal gas
   \[ \partial E = 0, \quad q = -w \]

2. Adiabatic expansion

3. Isochoric compression
   \[ nRT_c \ln \left( \frac{V_d}{V_c} \right) \]

4. Adiabatic compression
   \[ CV (T_h - T_c) \]
\[ w_{\text{done}} = -w_{\text{sys}} = nRT_m \ln \left( \frac{V_B}{V_A} \right) + nRT_c \ln \left( \frac{V_D}{V_C} \right) \]

\[ = \Phi_1 + \Phi_3 \]

\[ \varepsilon = \frac{w}{\Phi_1 m} = \Phi_1 + \Phi_3 = 1 + \frac{\Phi_3}{\Phi_1} \]

\[ \frac{\Phi_3}{\Phi_1} = \frac{nRT_c \ln \left( \frac{V_D}{V_C} \right)}{nRT_m \ln \left( \frac{V_B}{V_A} \right)} \]
\[ \frac{q^3}{q_1} = \frac{nRTc \ln(V_d/V_c)}{nRT_h \ln(V_B/V_A)} \]

for adiabatic expansions

\[ \frac{V_f}{V_i} = \left( \frac{T_f}{T_i} \right)^{-C_v/nR} \]

\[ \Rightarrow \ln\left( \frac{V_d/V_c}{} \right) / \ln\left( \frac{V_B/V_A}{} \right) = -1 \]

\[ E_{\text{carnot}} = 1 - \frac{T_c}{T_h} \] beyond IG