Adiabatic Work Interactions - CHAPTER 3

An interaction between two closed systems for which all events external to each of the two systems can be duplicated entirely by the rise and fall of equal weights in a gravitational field.

Example:

Is this an adiabatic work interaction?
Between which systems? $A \leftrightarrow B$ Yes √

A' $\leftrightarrow$ B' No ×

Definition of Energy - POSTULATE III

For any states A and B of a closed system, there is at least one process that involves just adiabatic work interactions between the system and its environment and takes the system from state $A \rightarrow B$ or from $B \rightarrow A$. The amount of work required (or produced) is determined uniquely by specifying states A and B.

This allows us to define the energy difference $E_A - E_B = -W_{A \rightarrow B}$ ↑ negative
From postulate I: for simple systems,
\[ E = U = \mathcal{E} \ (N+2 \ \text{independent variables}) \]

For composite simple

**Definition of heat** \( Q \)

For a non-adiabatic process:
\[ Q = E_{\text{final}} - E_{\text{initial}} - W \] ("missing work")

Old sign convention from days of heat engines (not used)

\( W \) is positive when performed by the system
\( Q \) is positive when "added" to the system

Now, we need to make a link between thermometric temperature and the direction of heat interactions - consider insulated composite system with an internal diathermal well:

Any interaction between \( A \) and \( B \) must be a pure heat interaction
\[ \Delta E_A = -\Delta E_B \Rightarrow Q_A = -Q_B \]
\[ W = 0 \]

From experience, we know that heat interactions stop when the thermometric temperatures of \( A \) and \( B \) are the same \( \rightarrow \) generalize as

**Postulate IV**

If the systems \( A-C \) and \( B-C \) have no heat interactions when connected by nonadiabatic walls, there will be no heat interaction if \( A \) and \( B \) are also connected
**First Law, Closed Systems**

\[ \Delta E = Q + W \]
\[ \Delta E = \delta Q + \delta W \] ; use \( \delta \) to distinguish between state function \( E \) and non-state functions \( Q, W \).

Examples 3.3 + 3.4

![Diagram of a system with pistons](image)

A: He 2 bar
B: He 1 bar
L = 10 cm
300 K
300 K

When stops are removed, pistons move - there is some friction, and the pistons eventually stop when the pressures are equal.

He is an ideal gas - a substance for which:

\[ PV = NRT \]

Define \( C_v = \frac{\partial U}{\partial T} \) at constant volume.

What is the final temperature in the two compartments?

For Helium, \( C_V = \text{constant} \), so that \( U = u_0 + C_V T \)

First-law balance, total system \( A + B \):

\[ \Delta E = \delta Q + \delta W \Rightarrow \Delta U_A + \Delta U_B = 0 \Rightarrow \]

\[ \delta Q \neq 0 \]

\[ \Delta U_A = - \Delta U_B \quad \text{(1)} \]

\[ \Delta U_A = N_A \cdot \delta u_A = N_A \cdot C_v \cdot (T_A, f - T_A, i) \]

\[ \Delta U_B = N_B \cdot \delta u_B = N_B \cdot C_v \cdot (T_B, f - T_B, i) \]
\[ \Rightarrow \quad N_A \cdot \chi_i (T_{A,i} - T_{A,i}) = -N_B \cdot \chi_i (T_{B,i} - T_{B,i}) \quad (2) \]

From Equation-of-State:

\[ N_A = \frac{P_{A,i} \cdot V_{A,i}}{RT_{A,i}} \quad (3) \]
\[ N_B = \frac{P_{B,i} \cdot V_{B,i}}{RT_{B,i}} \quad (4) \]

(a) Rod connecting pistons is metallic (adiabatic)

\[ T_{A,i} = T_{B,i} = T_e \quad (2) \quad \Rightarrow \quad T_e = \frac{N_AT_{A,i} + N_BT_{B,i}}{N_A + N_B} \quad (5) \]

with \( T_{A,i} = T_{B,i} = T_i \quad \Rightarrow \quad T_e = T_i \)

(b) Rod connecting pistons is insulating

→ problem cannot be solved without further assumptions on the path: how is friction distributed between \( A \) and \( B \)?

Two limiting cases: no friction in \( A \) → \( T_{A,f} = 267 \text{ K} \)

\( T_{B,f} = 366 \text{ K} \)

no friction in \( B \) → \( T_{A,f} = 270 \text{ K} \)

\( T_{B,f} = 360 \text{ K} \)

**First Law, Open Systems**

For open systems, we can redefine the boundaries so as to use the relationships of closed systems:

Consider open system over a short period of time:

\[ \delta Q_o \]

\[ \delta W_o \]

\[ \delta \text{Pin at Pin} \]

\[ \vec{V}_{In} \]

\[ \vec{V}_{Un} \]
System that includes entering mass at pressure \(P_{in}\), with sp. volume \(V_{in}\) and energy \(U_{in}\) is closed:

\[
dE = \delta Q_\sigma + \delta W_\sigma + \text{work performed on system by environment, to "push" \(\delta E_{in}\) miles into system against pressure \(P_{in}\)}
\]

Original (open) system:

\[
dE = dE_\sigma + \delta E_{in}U_{in}
\]

is initially missing \(\delta E_{in}\)

\[1 + 2 \Rightarrow dE = \delta Q_\sigma + \delta W_\sigma + (U_{in} + P_{in}V_{in}) \delta E_{in}
\]

Define **enthalpy** \(H = U + PV\) (for simple systems only!)

\[3 \Rightarrow dE = \delta Q_\sigma + \delta W_\sigma + H_{in} \delta E_{in}
\]

If system is simple, \(E \rightarrow U\), generalize to multiple entering/leaving streams:

\[
dU = \delta Q_\sigma + \delta W_\sigma + \sum_{\text{in}} H_{in} \delta E_{in} - \sum_{\text{out}} H_{out} \delta E_{out}
\]

**First Law, Open Systems, differential form**

or to take into account kinetic + potential energy:

\[
dE = \delta Q_\sigma + \delta W_\sigma + \sum_{\text{in}} \left[H_{in} + g_{z_{in}} + \frac{V_{in}^2}{2}\right] \delta E_{in} - \sum_{\text{out}} \left[H_{out} + g_{z_{out}} + \frac{V_{out}^2}{2}\right] \delta E_{out}
\]