Lecture 16

- Temperature change: specific heat
- Phase change: heat of transformation
- Calorimetry: calculating heat exchanges
- Specific heats of gases
- Adiabatic processes
Thermal properties of matter (I)

Joule: heat and work are energy transferred; change in thermal energy $\rightarrow$ change in temperature or phase

- Temperature change and Specific Heat

specific heat, $c = \text{energy to raise } T \text{ of } 1 \text{ kg by } 1 \text{ K ("thermal inertia")}$

$$\Delta E_{th} = Mc\Delta T \text{ (temperature change)}$$

$\Delta E_{th} = W + Q$ for solids/liquids, $W = 0 \Rightarrow$

$$Q = Mc\Delta T \text{ (temperature change)}$$

Molar specific heat, $C$: $Q = nC\Delta T$

Using $n = \frac{M \text{ (in g)}}{M_{mol}} = \frac{1000 \text{ (g/kg)}}{M_{mol} \text{ (in g/mol)}} M \text{ (in kg)}$:

$$C \text{ (in J/mol/K)} = \frac{M_{mol} \text{ (in g/mol)}}{1000 \text{ (g/kg)}} c \text{ (in J/kg/K)}$$
Thermal properties of matter (II)

- Phase change and heat of transformation, \( L \)

At the same temperature, heat transferred breaks bonds (instead of speeding up atoms)

\[ L = \text{heat energy for 1 kg to change phase} \]

\[ Q = \begin{cases} \pm ML_f & \text{melt/freeze} \\ \pm ML_v & \text{boil/condense} \end{cases} \]

\( L_f, v \): heat of fusion (solid/liquid) or vaporization (liquid/gas)

\( L_v > L_f \): bonds not completely broken during melting...
Calorimetry

- 2 systems interacting thermally, but isolated from others

start at $T_1 \neq T_2$, heat transferred till equilibrium $T_f$ ($Q_1$ is energy transferred to system 1: $> 0$ if energy enters...)

- Strategy for (> 2 systems)

$$Q_{net} = Q_1 + Q_2 + \ldots = 0$$

Systems with temperature change:

$$Q = Mc(T_f - T_i) \Rightarrow Q > 0 \text{ if } T_f > T_i$$

Systems with phase change:

$$Q + \pm ML_f \text{ or } v: \text{ for melting/freezing...}$$

(check: $T_f$ not higher/lower than all $T_i$)
Specific Heats of Gases

- same $\Delta T$, different $Q$ since $W$ different...

- **Two versions of molar specific heat**
  
  $Q = nC_p\Delta T$ (temperature change at constant pressure)
  
  $Q = nC_v\Delta T$ (temperature change at constant volume)

  (if $p$ or $V$ not constant, use $Q = W - \Delta E_{th}$)

  **Relation between $C_P$ and $C_V$**

- $\Delta E_{th}$ depends only on $\Delta T$

  $\Delta E_{th} = Q + W \Rightarrow$ no distinction between $Q$, $W$

  isochoric: $(\Delta E_{th})_A = W + Q = 0 + Q_{\text{const vol}} = nC_v\Delta T$

  isobaric: $(\Delta E_{th})_B = W + Q = -p\Delta V + Q_{\text{const vol}} = -nR\Delta T + nC_p\Delta T$

  (using ideal gas law: $pV = nRT$)

  $\Delta (E_{th})_A = (\Delta E_{th})_B \Rightarrow$

  $C_p = C_v + R$

  $\Delta E_{th} = nC_v\Delta T$ (any ideal-gas process)

- $Q$ not same even if $\Delta T$ same: $Q = W - \Delta E_{th}$
**Heat depends on path**

\[ \Delta E_{th} = E_{th f} - E_{th i} \]  
\( \text{same} \) (\( E_{th} \) is state variable)  
\( \Rightarrow W_A + Q_A = W_B + Q_B \)  
\(|W_B| > |W_A| \) (area under curve); \( W_A, B < 0 \)  
\( \Rightarrow Q_B > Q_A \) (\( Q, W \) are not state variables)

**Adiabatic Process (Q=0)**

- e.g. gas in thermally insulated cylinder or rapid expansion/compression (no time for heat transfer via atomic-level collisions)  
  \( \Delta E_{th} = W \Rightarrow \text{expansion lowers T...} \)

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\[ W = nC_v \Delta T \]  
(adiabatic process)

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**pV diagram (adiabat: steeper than isotherm)**

\[ \gamma = \frac{C_P}{C_V} = \begin{cases} 1.67 & \text{monoatomic gas} \\ 1.40 & \text{diatomic gas} \end{cases} \]

\[ pV^\gamma = \text{constant} \quad \text{or} \quad p_1V_1^\gamma = p_iV_i^\gamma \]

Using ideal gas law \( p = nRT/V \):  
\( TV^{\gamma-1} = \text{constant} \)