CHAPTER 10:
ONE COMPONENT SYSTEM

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RECAP CHAP 9

- **Thermodynamics** = science that tells us which minerals or mineral assemblages will be stable under different conditions.

- **Calculations: use of software (Themocalc, Perplex, Melts)**

- \[ \Delta G_r = \Delta G_f(\text{right}) - \Delta G_f(\text{left}) = \Delta E_r + P\Delta V_r - T\Delta S_r = \Delta H - T\Delta S \]

  - <0: the reaction proceeds to the right
  - >0: the reaction proceeds to the left
  - =0: equilibrium

- \( \Delta G_r \) varies with P, T and X ⇒ **phase diagrams**
RECAP CHAP 9

- \( \frac{dP}{dT} = \frac{\Delta S_{P,T}}{\Delta V_{P,T}} \): Clausius-Clapeyron equation ⇔ slope of the curve \( \Delta Gr = 0 \) in P-T diagram

- **Melting curve: positive slope** (most of the time)
  - Smaller volume more stable at HP
  - Liquid (high S) more stable than solid (low S) at HT

- Phase diagram = projection of the mineral with the lowest G
MINERAL STABILITY

- **Three** major processes by which minerals form:
  - **1) Crystallization** from a liquid:
    - From a magma: formation of igneous rocks
    - From a fluid (H2O or CO2) = **precipitation**:
      - **hydrothermal processes**: $T = 100 - 500^\circ C$, $P = 0.1$ (1 bar) - 1000 MPa (10 kb)
      - **Evaporation**: $T = 10 - 40^\circ C$, $P = 0.1$ MPa
      - **chemical weathering**: $T = 10 - 100^\circ C$, $P = 0.1$-10 MPa
      - **Diagenesis**: $T = 0 - 200^\circ C$, $P = 0.1$-300 MPa
      - **Biological activity**: $T = 10 - 40^\circ C$, $P = 0.1$-1 MPa
MINERAL STABILITY

- **Three** major processes by which minerals form:
  - 2) **Solid-solid reactions**:
    - **Diagenesis**: $T = 100 - 200^\circ C$, $P = 0.1 - 300$ MPa
    - **Metamorphism**: $T = 200^\circ$-melting, $P = 300-3000$ MPa?
  - 3) **Sublimation from vapor**:
    - Volcanic vent
    - Space

Thus, for any given system we can define temperature, pressure, and compositional variables that determine what minerals are stable.
PHASE DIAGRAM: DEFINITION

- **A system:** a portion of the universe that you wish to study
  Ex: salt + water in a beaker

  - **Isolated system:** cannot exchange mass or energy with the surroundings
    Ex.: we sealed the beaker with a lid and enclosed it in a perfect thermal insulator

  - **Closed system:** can exchange energy but not mass
    Ex: no thermal insulator but still sealed

  - **Open system:** can exchange both mass and energy
    Ex: beaker is open to the air and not insulated
Phase = a physically separable part of the system with distinct physical and chemical properties. A system must consist of one or more phases.

Ex1: system: salt-water: one phase (sodium choride – water solution or salt crystals), two phases (sodium choride – water solution and salt crystals) or three phases (sodium choride – water solution, salt crystals, gas phase – mostly water)

Ex2: magma with crystals of olivine and plagioclase: 3 phases because olivine and plagioclase are physically and chemically distinct
Component: Each phase in the system may be considered to be composed of one or more components. The number of components in the system must be the minimum required to define all of the phases.

Ex: salt-water system
- components Na, Cl, H, and O: four components
- NaCl, H, and O: three components
- **NaCl and H₂O**: two components
- NaCl-H₂O: one component.

Possible phases: NaCl crystal, H₂O (liquid or vapor), and NaCl-H₂O solution ⇒ only two components (NaCl and H₂O) are required to define the three phases (NaCl - H₂O solution).
ONE COMPONENT SYSTEM: EX.: H₂O

• One component – 3 phases: liquid, vapor solid
  • solid has the lowest specific entropy, liquid has intermediate specific entropy and vapor has the highest specific entropy (i.e., the entropies of fusion and boiling are positive).
  • Liquid has the smallest specific volume (highest density, at low pressure), solid has intermediate specific volume, and vapor has the highest specific volume.
ONE COMPONENT SYSTEM: EX.: H₂O

\[
\left( \frac{\partial G}{\partial T} \right)_p = -S
\]

\[
\left( \frac{\partial G}{\partial P} \right)_T = V
\]
One component system: only two independent variables: $P$ and $T$
ONE COMPONENT SYSTEM: POLYMORPHS

CO$_2$
ONE COMPONENT SYSTEM: POLYMORPHS

- **Critical point**: end point of a phase equilibrium curve
- **Supercritical fluid**: any substance at a temperature and pressure above its critical point where liquid and gas phases do not exist.
ONE COMPONENT SYSTEM: POLYMORPHS

The diagram illustrates the phase transitions of silica ($\text{SiO}_2$) under varying pressure and temperature conditions. The phases include:

- Stishovite
- Coesite
- $\alpha$-Quartz
- $\beta$-Quartz
- $\beta$-Cristobalite
- $\beta$-Tridymite

The diagram shows the approximate depth in kilometers on the y-axis, with pressure in GPa on the x-axis, and temperature in °C along the bottom. This provides a visual representation of the conditions under which each phase is stable.
ONE COMPONENT SYSTEM: POLYMORPHS

$\text{Al}_2\text{SiO}_5$
Fundamental relation between the minimum number of components \( (c) \) in a chemical system, the number of phases present \( (\Phi) \), and the number of variables that can be independently varied while maintaining equilibrium, i.e. the variance or the degrees of freedom \( (f) \): 

\[
f = c + 2 - \Phi + n
\]

- \( f \geq 0 \Leftrightarrow c + 2 = \Phi \Rightarrow \text{there can never be more than } c+2 \text{ phases in equilibrium}.\)
\[ f = c + 2 - \Phi \]

- \(c\): \(\text{Al}_2\text{SiO}_5 - c = 1\)
- \(P_1\): \(\Phi = 1 \Rightarrow f = 2\): this field stability is **divariant**
- \(P_2\): \(\Phi = 2 \Rightarrow f = 1\): the phase assemblage is **univariant**
- \(P_3\): \(\Phi = 3 \Rightarrow f = 0\): the point is **invariant**
CASE OF THE ISENTROPIC PROCESSES

- Isentropic process = S constant
- Ex.: adiabatic decompression of the mantle
CASE OF THE ISENTROPIC PROCESSES

- Ex.: adiabatic decompression of the mantle

In such a process, P and T are not independent variables but P and specific entropy (S) and equilibrium is achieved when the specific enthalpy (H) of the system reaches a minimum.

Fig.1, Stolper and Asimow, 2007
CASE OF THE ISENTROPIC PROCESSES

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Fig. 6 Stolper and Asimow, 2007
CASE OF THE ISENTROPIC PROCESSES

Ex.: adiabatic decompression of the mantle

\[ f = 1 + 2 - 2 = 1 \]
CASE OF THE ISENTROPIC PROCESSES

- Ex.: adiabatic decompression of the mantle

![Diagram of isentropic processes with labels 1, 2 (F=0), 3 (F=0.5), 4 (F=1), and 5.]

Batch Melting

Fig. 9 Stolper and Asimow, 2007
CASE OF THE ISENTROPIC PROCESSES

- Ex.: adiabatic decompression of the mantle

**FRACTIONATE MELTING**

![Diagram](image-url)