Phase equilibria: solubility limit

Introduction
  - Solutions – solid solutions, single phase
  - Mixtures – more than one phase

• Solubility Limit:
  Max concentration for which only a single phase solution occurs.

Adapted from Fig. 9.1, Callister 7e.
Components and phases

- **Components:**
  The elements or compounds which are present in the mixture (e.g., Al and Cu)

- **Phases:**
  The physically and chemically distinct material regions that result (e.g., $\alpha$ and $\beta$).

![Image of Aluminum-Copper Alloy](image)

Adapted from chapter-opening photograph, Chapter 9, *Callister 3e.*
Phase diagrams

- Indicate phases as function of $T$, $C_o$, and $P$.
- For this course:
  - binary systems: just 2 components.
  - independent variables: $T$ and $C_o$ ($P = 1$ atm is almost always used).

- Phase Diagram for Cu-Ni system

  - 2 phases:
    - $L$ (liquid)
    - $\alpha$ (FCC solid solution)

  - 3 phase fields:
    - $L$
    - $L + \alpha$
    - $\alpha$

Adapted from Fig. 9.3(a), Callister 7e. (Fig. 9.3(a) is adapted from Phase Diagrams of Binary Nickel Alloys, P. Nash (Ed.), ASM International, Materials Park, OH (1991).
Phase diagrams

• Rule 1: If we know $T$ and $C_o$, then we know:
  --the # and types of phases present.

• Examples:

Adapted from Fig. 9.3(a), Callister 7e.
(Fig. 9.3(a) is adapted from Phase Diagrams of Binary Nickel Alloys, P. Nash (Ed.), ASM International, Materials Park, OH, 1991).
Phase diagrams

- Rule 2: If we know $T$ and $C_o$, then we know:
  -- the composition of each phase.

- Examples:

Adapted from Fig. 9.3(b), *Callister 7e.*
(Fig. 9.3(b) is adapted from *Phase Diagrams of Binary Nickel Alloys*, P. Nash (Ed.), ASM International, Materials Park, OH, 1991.)
Phase diagrams

• Rule 3: If we know $T$ and $C_o$, then we know:
  -- the amount of each phase (given in wt%).

• Examples:
  $C_o = 35$ wt% Ni
  
  At $T_A$: Only Liquid ($L$)
  \[ W_L = 100 \text{ wt\%}, \ W_\alpha = 0 \]
  
  At $T_D$: Only Solid ($\alpha$)
  \[ W_L = 0, \ W_\alpha = 100 \text{ wt\%} \]
  
  At $T_B$: Both $\alpha$ and $L$

Adapted from Fig. 9.3(b), *Callister 7e.*
(Fig. 9.3(b) is adapted from *Phase Diagrams of Binary Nickel Alloys*, P. Nash (Ed.), ASM International, Materials Park, OH, 1991.)
The lever rule

Tie line – connects the phases in equilibrium with each other - essentially an isotherm

How much of each phase?
Think of it as a lever (teeter-totter)

\[ M_\alpha \cdot S = M_L \cdot R \]

Adapted from Fig. 9.3(b), Callister 7e.
Cooling

- Phase diagram: Cu-Ni system.

- System is:
  --binary
  i.e., 2 components: Cu and Ni.
  --isomorphous
  i.e., complete solubility of one component in another; \( \alpha \) phase field extends from 0 to 100 wt% Ni.

- Consider \( C_o = 35 \text{ wt}\% \text{Ni} \).

Adapted from Fig. 9.4, Callister 7e.
**Binary eutectic systems**

2 components

has a special composition with a min. melting T.

Ex.: Cu-Ag system

- 3 single phase regions
  
  \((L, \alpha, \beta)\)

- Limited solubility:
  
  \(\alpha\): mostly Cu
  
  \(\beta\): mostly Ag

- \(T_E\): No liquid below \(T_E\)

- \(C_E\): Min. melting \(T_E\) composition

- **Eutectic transition**

  \[ L(C_E) \rightleftharpoons \alpha(C_{\alpha E}) + \beta(C_{\beta E}) \]

Adapted from Fig. 9.7, *Callister 7e.*
Binary eutectic systems

- For a 40 wt% Sn-60 wt% Pb alloy at 150°C, find...
  --the phases present:

Adapted from Fig. 9.8, Callister 7e.
Binary eutectic systems

- For a 40 wt% Sn-60 wt% Pb alloy at 200°C, find...
  --the phases present:

adapted from Fig. 9.8, Callister 7e.
Microstructures in eutectic systems

• $C_o < 2$ wt% Sn
• Result:
  -- at extreme ends
  -- polycrystal of $\alpha$ grains
    i.e., only one solid phase.

Adapted from Fig. 9.11, Callister 7e.
Microstructures in eutectic systems

- 2 wt% Sn $< C_o < 18.3$ wt% Sn
- Result:
  - Initially liquid + $\alpha$
  - then $\alpha$ alone
  - finally two phases
    - $\alpha$ polycrystal
    - fine $\beta$-phase inclusions

Adapted from Fig. 9.12, Callister 7e.
Microstructures in eutectic systems

- $C_o = C_E$
- Result: Eutectic microstructure (lamellar structure)
  --alternating layers (lamellae) of $\alpha$ and $\beta$ crystals.

Adapted from Fig. 9.13, Callister 7e.

Adapted from Fig. 9.14, Callister 7e.

Micrograph of Pb-Sn eutectic microstructure

Adapted from Fig. 9.14, Callister 7e.
Microstructures in eutectic systems

- 18.3 wt% Sn < C_o < 61.9 wt% Sn
- Result: α crystals and a eutectic microstructure

Adapted from Fig. 9.16, Callister 7e.
Hypoeutectic & hyper-eutectic

Adapted from Fig. 9.8, Callister 7e. (Fig. 9.8 adapted from Binary Phase Diagrams, 2nd ed., Vol. 3, T.B. Massalski (Editor-in-Chief), ASM International, Materials Park, OH, 1990.)

(Pb-Sn System)


Adapted from Fig. 9.17, Callister 7e.

Adapted from Fig. 9.14, Callister 7e.

Adapted from Fig. 9.17, Callister 7e. (Illustration only)

Adapted from Fig. 9.17, Callister 7e. (Illustration only)
Note: intermetallic compound forms a line - not an area - because stoichiometry (i.e. composition) is exact.
Peritectic & eutectoid

- Cu-Zn Phase diagram

![Cu-Zn Phase diagram](image)

Adapted from Fig. 9.21, *Callister 7e.*
Fe-C phase diagram

- 2 important points
  - Eutectic (A):
    \[ L \Rightarrow \gamma + \text{Fe}_3\text{C} \]
  - Eutectoid (B):
    \[ \gamma \Rightarrow \alpha + \text{Fe}_3\text{C} \]

Result: Pearlite = alternating layers of \( \alpha \) and \( \text{Fe}_3\text{C} \) phases

(Adapted from Fig. 9.27, Callister 7e.)

Adapted from Fig. 9.24, Callister 7e.
Hypoeutectoid steel

Adapted from Figs. 9.24 and 9.29, Callister 7e.
(Fig. 9.24 adapted from Binary Alloy Phase Diagrams, 2nd ed., Vol. 1, T.B. Massalski (Ed.-in-Chief), ASM International, Materials Park, OH, 1990.)

Fe₃C (cementite)

(Fe-C System)

α + Fe₃C

γ + Fe₃C

γ (austenite)

L

L + Fe₃C

0 1 2 3 4 5 6 6.7

C₀, wt% C

100 μm

Hypoeutectoid steel

proeutectoid ferrite

Adapted from Fig. 9.30, Callister 7e.

\[ w_α = \frac{S}{(R+S)} \]

\[ w_γ = (1 - w_α) \]

\[ w_{Fe₃C} = (1 - w_α) \]

\[ w_α = \frac{S}{(R+S)} \]

\[ w_γ = (1 - w_α) \]
Hyper-eutectoid steel

Adapted from Figs. 9.24 and 9.32, Callister 7e. (Fig. 9.24 adapted from Binary Alloy Phase Diagrams, 2nd ed., Vol. 1, T.B. Massalski (Ed.-in-Chief), ASM International, Materials Park, OH, 1990.)

Adapted from Fig. 9.33, Callister 7e.