PHASE DIAGRAMS

ENT 145 Materials Engineering

Phase Equilibria: Solubility Limit

• Solution – solid, liquid, or gas solutions, single phase
• Mixture – more than one phase

Solubility Limit:
Maximum concentration of solute atom that may dissolve in solvent to form a solid solution.

Sugar/Water Phase Diagram

Effect of Temperature & Composition

• Altering \( T \) can change # of phases: path \( A \) to \( B \).
• Altering \( C \) can change # of phases: path \( B \) to \( D \).

Criteria for Solid Solubility

Simple system (e.g., Ni-Cu solution)

<table>
<thead>
<tr>
<th>Crystal Structure</th>
<th>electroneg</th>
<th>( r ) (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni</td>
<td>FCC</td>
<td>1.9</td>
</tr>
<tr>
<td>Cu</td>
<td>FCC</td>
<td>1.8</td>
</tr>
</tbody>
</table>

• Both have the same crystal structure (FCC) and have similar electronegativities and atomic radii (W. Hume – Rothery rules) suggesting high mutual solubility.
• Ni and Cu are totally soluble in one another for all proportions.
### Isomorphous Binary Phase Diagram

- **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; α phase field extends from 0 to 100 wt% Ni.

### Phase Diagrams: Determination of phase(s) present

- **Rule 1**: If we know T and C₀, then we know: which phase(s) is (are) present.
- **Examples**:
  - **A(1100°C, 60 wt% Ni)**: 1 phase: α
  - **B(1250°C, 35 wt% Ni)**: 2 phases: L + α

### Phase Diagrams: Determination of phase compositions

- **Rule 2**: If we know T and C₀, then we can determine: the composition of each phase.
- **Examples**:
  - Consider C₀ = 35 wt% Ni
    - At Tₐ = 1320°C: Only Liquid (L) present
    - At T₀ = 1190°C: Only Solid (α) present
    - At Tₐ = 1250°C: Both α and L present

### Phase Diagrams: Determination of phase weight fractions

- **Rule 3**: If we know T and C₀, then we can determine: the weight fraction of each phase.
- **Examples**:
  - Consider C₀ = 35 wt% Ni
    - At Tₐ: Only Liquid (L) present
    - At T₀: Only Solid (α) present
    - At Tₐ: Both α and L present

### The Lever Rule

- **Tie line** — connects the phases in equilibrium with each other — also sometimes called an **isotherm**

### Ex: Cooling of a Cu-Ni Alloy

- **Phase diagram**: Cu-Ni system.
- **Consider** microstructural changes that accompany the cooling of a C₀ = 35 wt% Ni alloy.
**Cored vs Equilibrium Structures**

- \( C_0 \) changes as we solidify.
- \( \text{Cu-Ni case} \):
  - First \( \alpha \) to solidify has \( C_0 = 46 \text{ wt}\% \text{ Ni} \).
  - Last \( \alpha \) to solidify has \( C_0 = 35 \text{ wt}\% \text{ Ni} \).

**Slow rate of cooling:**
- Equilibrium structure

**Fast rate of cooling:**
- Cored structure

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**Eutectic, Eutectoid, & Peritectic**

- **Eutectic** - liquid transforms to two solid phases
  \[ L \xrightarrow{\text{cool}} \alpha + \beta \]  (For \( \text{Pb-Sn, 183}^\circ\text{C, 61.9 wt}\% \text{ Sn} \))

- **Eutectoid** — one solid phase transforms to two other solid phases
  \[ S_2 \xrightarrow{\text{cool}} S_1 + S_3 \]
  \[ \gamma \xrightarrow{\text{cool}} \alpha + \text{Fe}_3\text{C} \]  (For \( \text{Fe-C, 727}^\circ\text{C, 0.76 wt}\% \text{ C} \))

- **Peritectic** — liquid and one solid phase transform to a second solid phase
  \[ S_1 + L \xrightarrow{\text{cool}} S_2 \]
  \[ \delta + L \xrightarrow{\text{cool}} \gamma \]  (For \( \text{Fe-C, 1493}^\circ\text{C, 0.16 wt}\% \text{ C} \))

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**Iron-Carbon (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

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**Mechanical Properties: Cu-Ni System**

- Effect of solid solution strengthening on:
  - Tensile strength (TS)
  - Ductility (%EL)

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**Hypoeutectoid Steel**

- (Fe-C System)

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**Eutectoid & Peritectic**

- Cu-Zn Phase diagram

- Peritectic transformation \( \gamma + L \xrightarrow{\text{cool}} \delta \)

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**Hypoeutectoid Steel**

- Proeuteectoid ferrite

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The amounts of pearlite and proeutectoid steel.

The amount of cementite (in grams) that forms in 100 g of steel.

Amount of Fe₃C in 100 g

Amount of pearlite in 100 g

Solution to Exercise Problem (cont.)

b) Using the VX tie line just above the eutectoid and realizing that

Using the lever rule with the tie line shown

Amount of Fe₃C in 100 g

Solution to Exercise Problem

a) Using the RS tie line just below the eutectoid

Using the lever rule with the tie line shown

Amount of Fe₃C in 100 g

Exercise

For a 99.6 wt% Fe-0.40 wt% C steel at a temperature just below the eutectoid, determine the following:

a) The compositions of Fe₃C and ferrite (α).

b) The amounts of pearlite and proeutectoid ferrite (α) in the 100 g.

c) The amount of cementite (in grams) that forms in 100 g of steel.
Alloying with Other Elements

- **\( T_{\text{eutectoid}} \) changes:**

  Adapted from Fig. 9.34, Callister & Rethwisch 8e.
  (Fig. 9.34 from Edgar C. Bain, Functions of the Alloying Elements in Steel, American Society for Metals, 1939, p. 127.)

- **\( C_{\text{eutectoid}} \) changes:**

  Adapted from Fig. 9.35, Callister & Rethwisch 8e.
  (Fig. 9.35 from Edgar C. Bain, Functions of the Alloying Elements in Steel, American Society for Metals, 1939, p. 127.)