Chapter 9: Phase Diagrams

ISSUES TO ADDRESS...

- Common types of phase diagrams
  - Isomorphous
  - Eutectic
  - Others
- Phase diagram and microstructure evolution

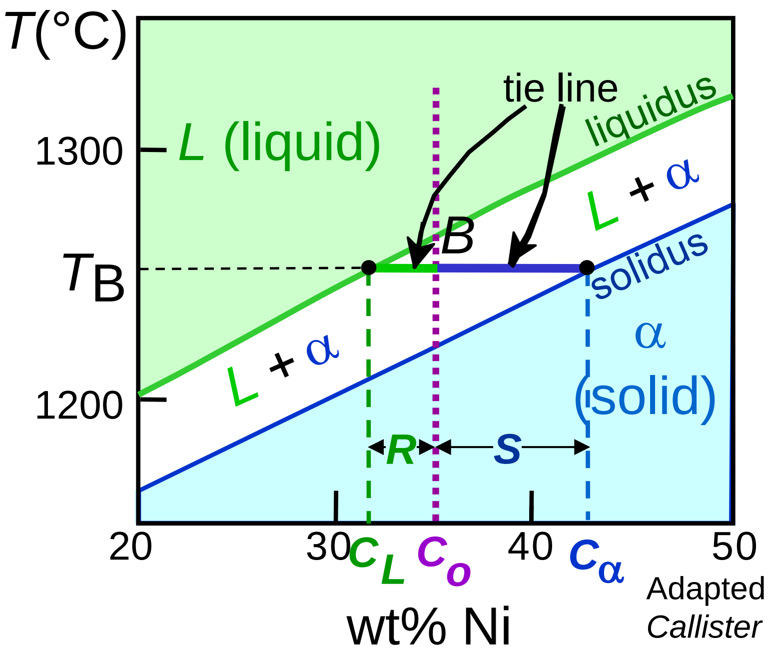
Class Exercise (1)

- **What is a phase?**
- **What is a component?**
- **For the following system, how many phases and how many components are present? What are they**
  - **Pure water with ice cubes in it?**
  - **Uniform hydrochloric acid solution in water?**
  - **Sugary water with pure ice cube in it?**
  - **A uniform solid solution of Cu and Ni**
  - **Cooking oil dropped into a cup of water and shaken up**
- **For binary phase diagram, what do the typical x-axis and y axis represent for?**

- **Right or Wrong:**
  - **A phase diagram describes the states for <u>any</u> condition for that given system**

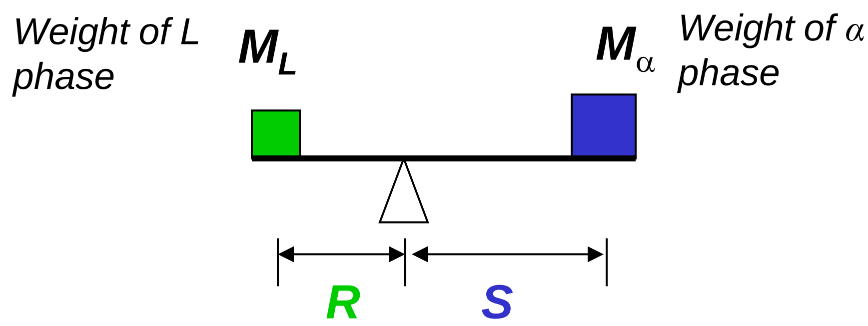
Relative Amount of Each Phase in Two Phase Region - The Lever Rule

- Tie line – connects the phases in equilibrium with each other – under isothermal (same temperature) condition



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

In two phase region, what is the relative weight fraction (*W, in unit of wt%*) of each phase? → “Lever” rule



$$M_\alpha \cdot S = M_L \cdot R$$

Weight fraction (*in unit of wt%*) of liquid L phase

$$W_L = \frac{M_L}{M_L + M_\alpha} = \frac{S}{R+S} = \frac{C_\alpha - C_0}{C_\alpha - C_L}$$

Weight fraction (*in unit of wt%*) of α solid solution phase

$$W_\alpha = \frac{R}{R+S} = \frac{C_0 - C_L}{C_\alpha - C_L}$$

Class Exercise

- What type of phase diagram is it?

Binary (isomorphous) phase diagram

- How many components? What are they?

Two: Cu and Ni

- What are the phases that can be present in the phase diagram?

L and α

- What are the single phase regions and two-phase region?

Single phase region: L, α;

Two phase region: L+α

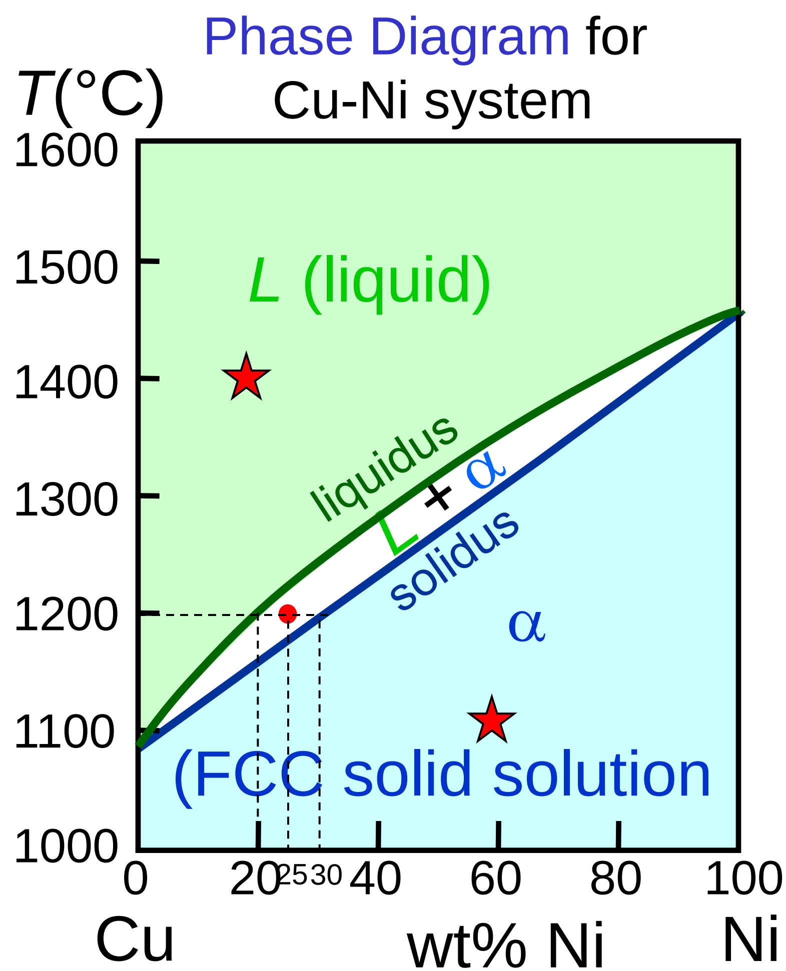
- What are the phases, their composition, & relative amount (weight fraction) for A system with
  - C=20 wt% at ~1400C?

  100 wt% L, C_L= 20 wt% Ni; 0 wt% α
  - C=60 wt% at ~1100C?

  100 wt% α, C_α = 60 wt% Ni, 0 wt% L
  - C=25wt% at ~1200C?

  $C_\alpha \cong 30$ wt% Ni; $C_L \cong 20$ wt% Ni

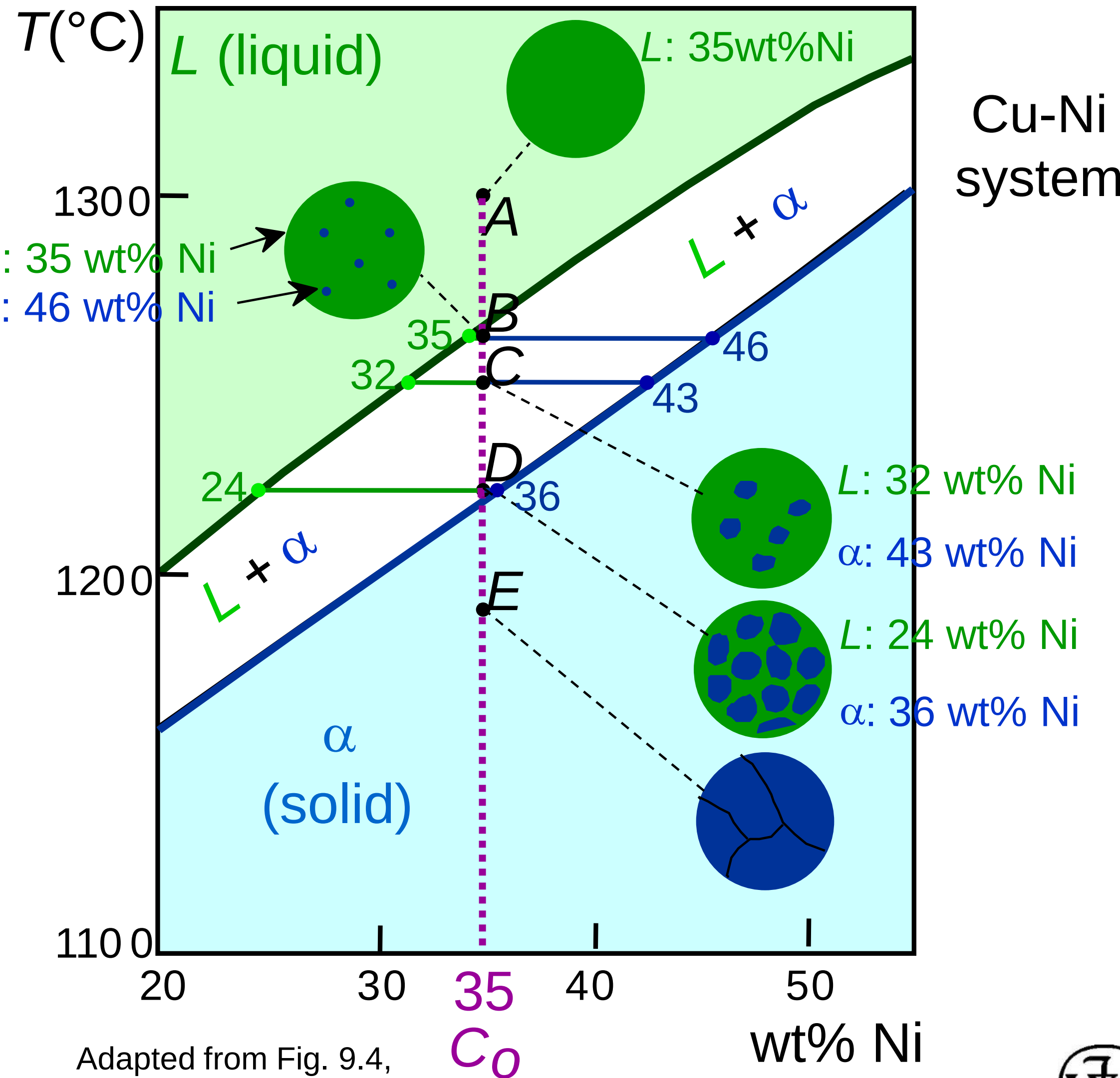
  W_α=(25-20)/(30-20)=50wt%, W_L=1-W_α=50wt%



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).

Application of Phase Diagram – Microstructure Evolution

- 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.
- Consider
  C_o = 35 wt%Ni.



Adapted from Fig. 9.4, *Callister 7e.*

Microstructures in Isomorphous Alloys

Microstructures will vary on the cooling rate (i.e. processing conditions)

1. Equilibrium Cooling: Very slow cooling to allow phase equilibrium to be maintained during the cooling process.

a (T>1260^{o}C): start as homogeneous liquid solution.

b (T ~ 1260^{o}C): liquidus line reached. α phase begins to nucleate. C_α = 46 wt% Ni; C_L = 35 wt% Ni

c (T= 1250^{o}C): the composition of each phase:

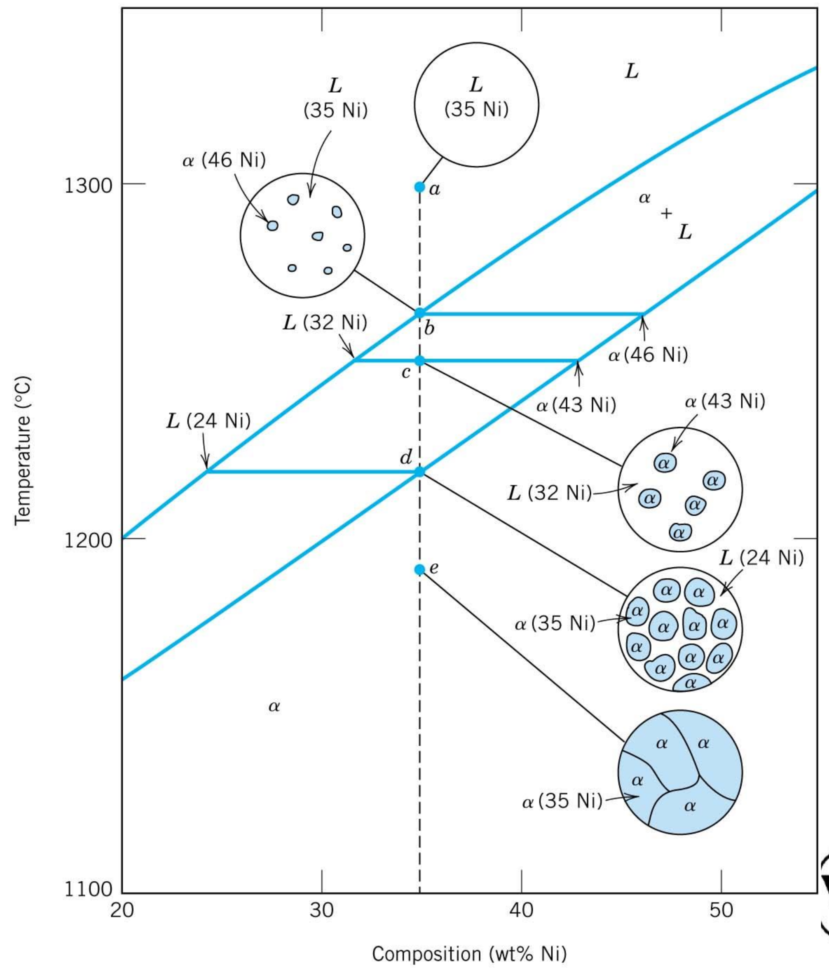
C_α = 43 wt% Ni; C_L = 32 wt% Ni

d (T~ 1220^{o}C): solidus line reached. Nearly complete solidification.

C_α = 35 wt% Ni; C_L = 24 wt% Ni

e (T<1220^{o}C): homogeneous solid solution with 35 wt% Ni.

FIGURE 9.3 Schematic representation of the development of microstructure during the equilibrium solidification of a 35 wt% Ni–65 wt% Cu alloy.



2 components

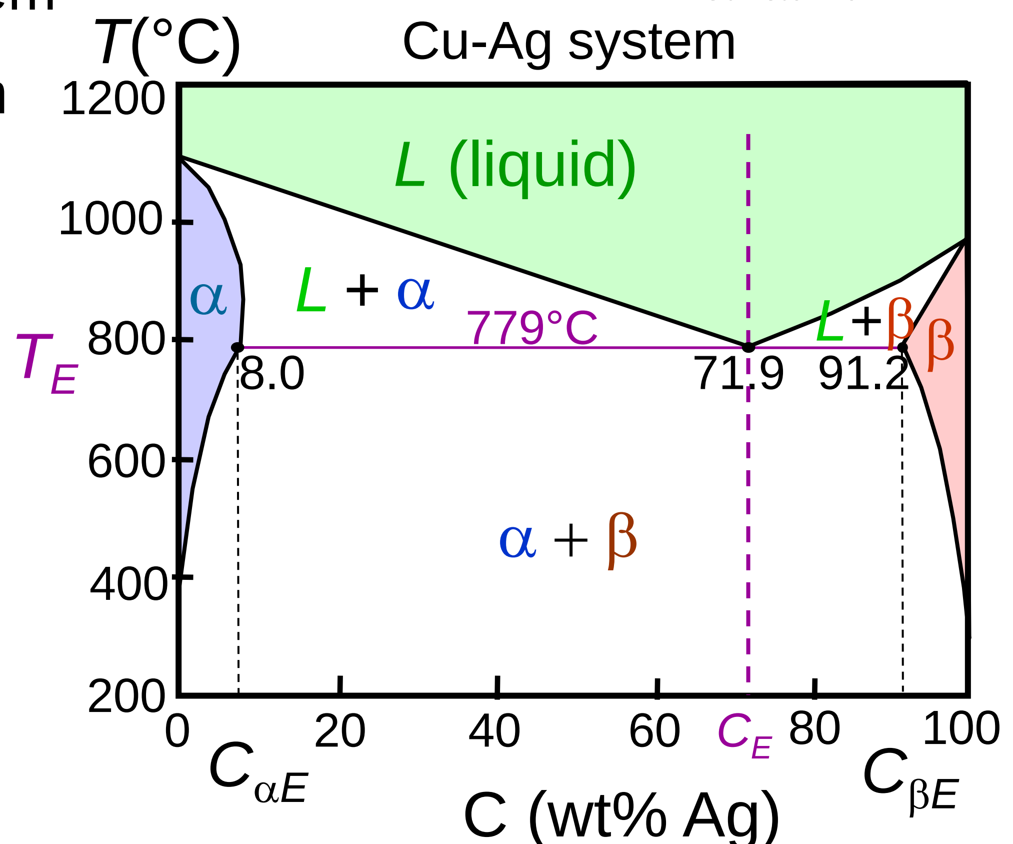
Binary Eutectic Phase Diagram

has a special composition with a min. melting T.

Ex.: Cu-Ag system

- Single phase regions: 3 of them
  L, α, β
- Two-phase regions: 3 of them
  $\alpha+\beta$, α+L and β+L
- Limited solubility:
  α : mostly Cu w/ a little Ag dissolved in it
  β : mostly Ag w/ a little Cu dissolved in it
- **Eutectic temperature T_E**
  No liquid below T_E
- C_E: Composition for eutectic point or min. melting T_E

Adapted from Fig. 9.7, *Callister 7e.*



- **Eutectic transition/reaction**

$$L(C_{E}=71.9wt\%\ Ag) \underset{\text{heat}}{\overset{\text{cool}}{\rightleftharpoons}} \alpha(C_{\alpha E}=8wt\%Ag) + \beta(C_{\beta E}=91.2\%Ag)$$

EX: Pb-Sn Eutectic System (1)

- For a 40 wt% Sn-60 wt% Pb alloy at **150°C**, find...
  --the phases present: α and β (i.e., two phases)
  --composition of each phase (in wt% Sn):

  C_α = 11 wt% Sn

  C_β = 99 wt% Sn

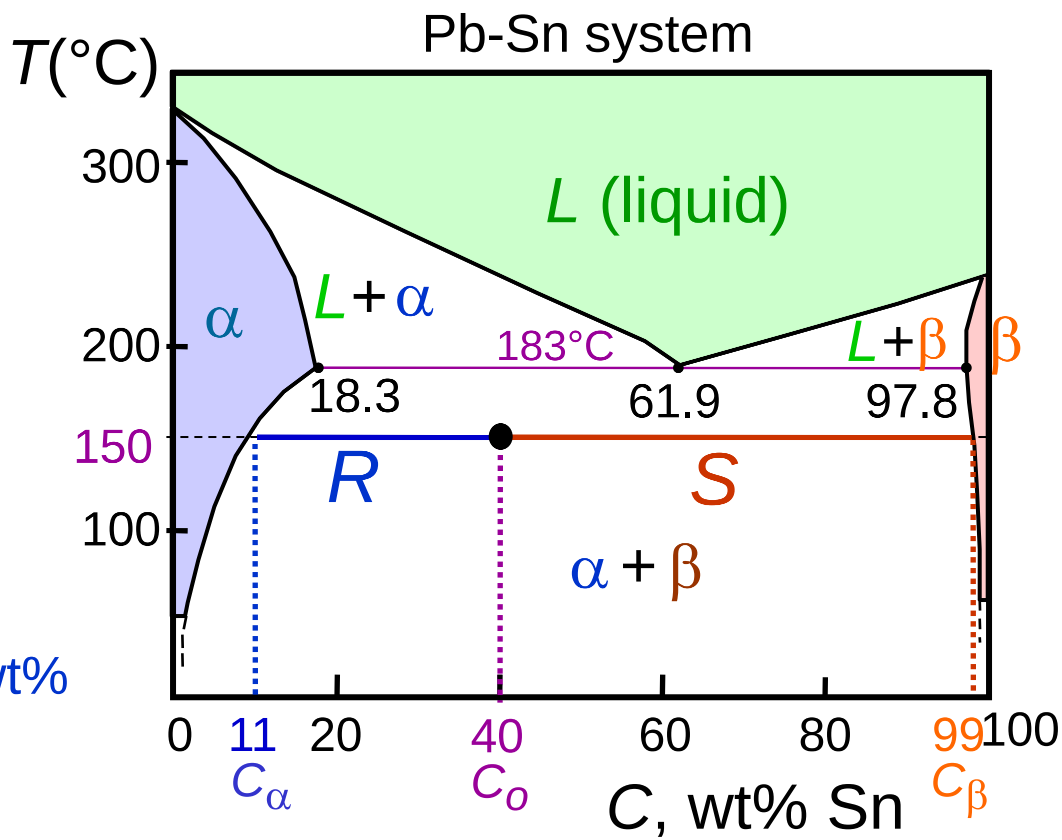
  --the relative amount of each phase:

$$W_\alpha = \frac{S}{R+S} = \frac{C_\beta - C_O}{C_\beta - C_\alpha}$$

$$= \frac{99 - 40}{99 - 11} = \frac{59}{88} = 67 \text{ wt\%}$$

$$W_\beta = \frac{R}{R+S} = \frac{C_O - C_\alpha}{C_\beta - C_\alpha}$$

$$= \frac{40 - 11}{99 - 11} = \frac{29}{88} = 33 \text{ wt\%}$$



Adapted from Fig. 9.8, *Callister 7e.*

EX: Pb-Sn Eutectic System (2)

- For a 40 wt% Sn-60 wt% Pb alloy at **220°C**, find...
  --the phases present: α + L (i.e., two phases)
  --compositions of each phase (in wt% Sn):

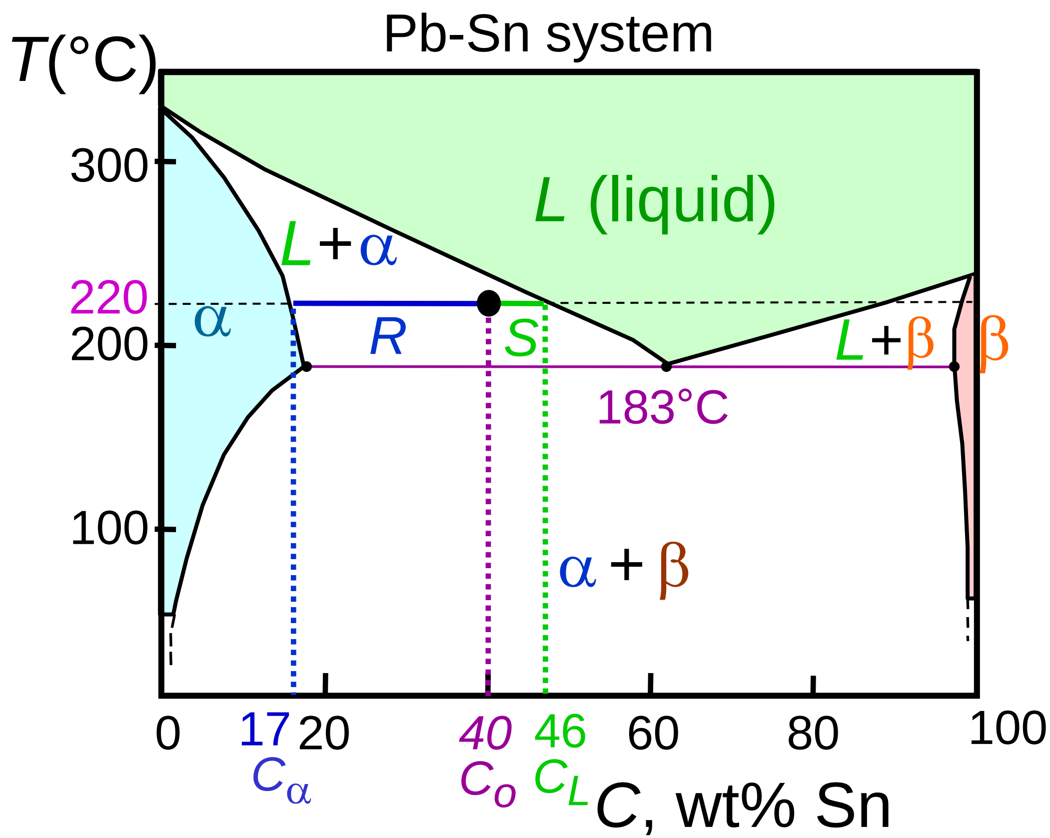
  C_α = 17 wt% Sn

  C_L = 46 wt% Sn

  --the relative amount of each phase:

$$W_\alpha = \frac{C_L - C_O}{C_L - C_\alpha} = \frac{46 - 40}{46 - 17} = \frac{6}{29} = 21 \text{ wt\%}$$

$$W_L = \frac{C_O - C_\alpha}{C_L - C_\alpha} = \frac{23}{29} = 79 \text{ wt\%}$$

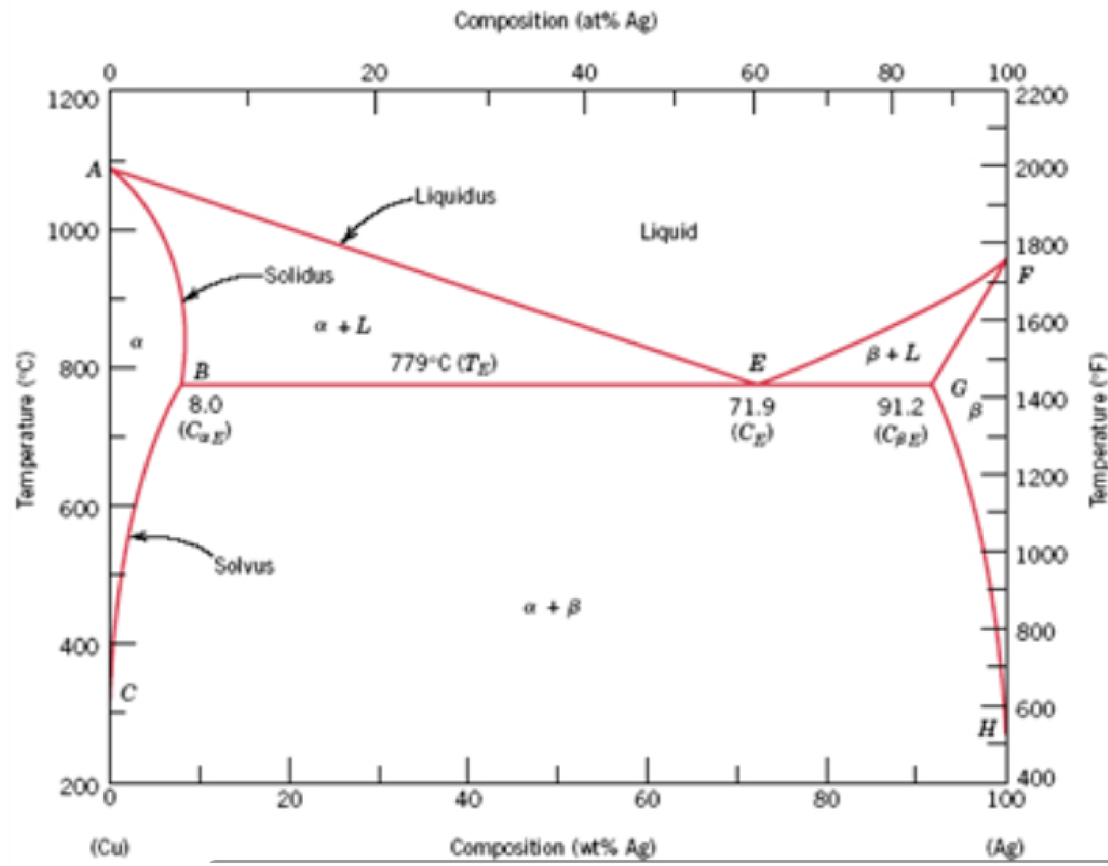


Adapted from Fig. 9.8, *Callister 7e.*

Application of Phase Diagram (1) – Stability/Reactivity/Solubility of Engineering Materials

Based on the Cu-Ag phase diagram, will a very thin Ag coating over Cu be stable at elevated temperatures?

NO because the system is very rich in Cu and low in Ag (near pure Cu in the phase diagram). At high T (e.g., 600C), Ag will form solid solution with Cu and mix uniformly instead of only staying over Cu surface



Summary

- Binary eutectic phase diagram is another type of binary phase diagram with lowest melting point at intermediate composition. Phase change at eutectic composition happen at a fixed temperature – eutectic temperature