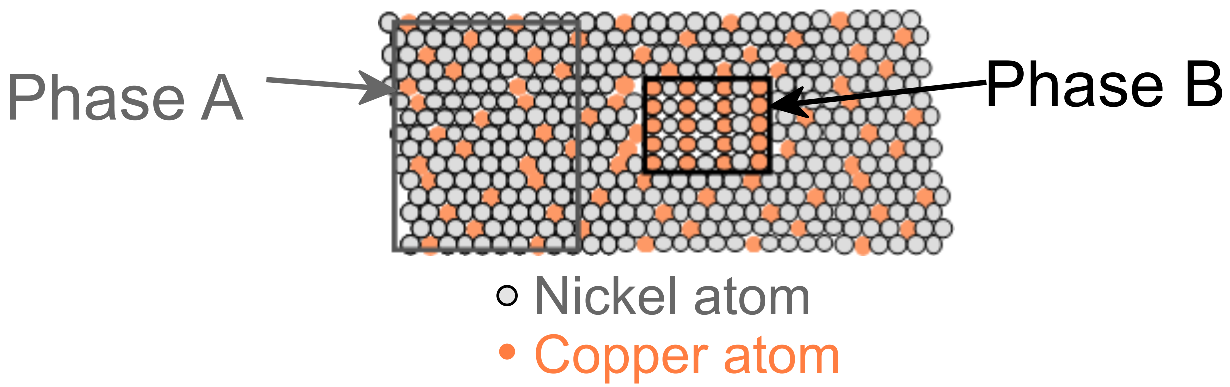
Chapter 9: Phase Diagrams

- When we combine two elements...
  what equilibrium state do we get?
- In particular, if we specify...
  --a composition (e.g., wt% Cu - wt% Ni), and
  --a temperature (*T*)
  then...
  How many phases do we get?
  What is the composition of each phase?
  How much of each phase do we get?

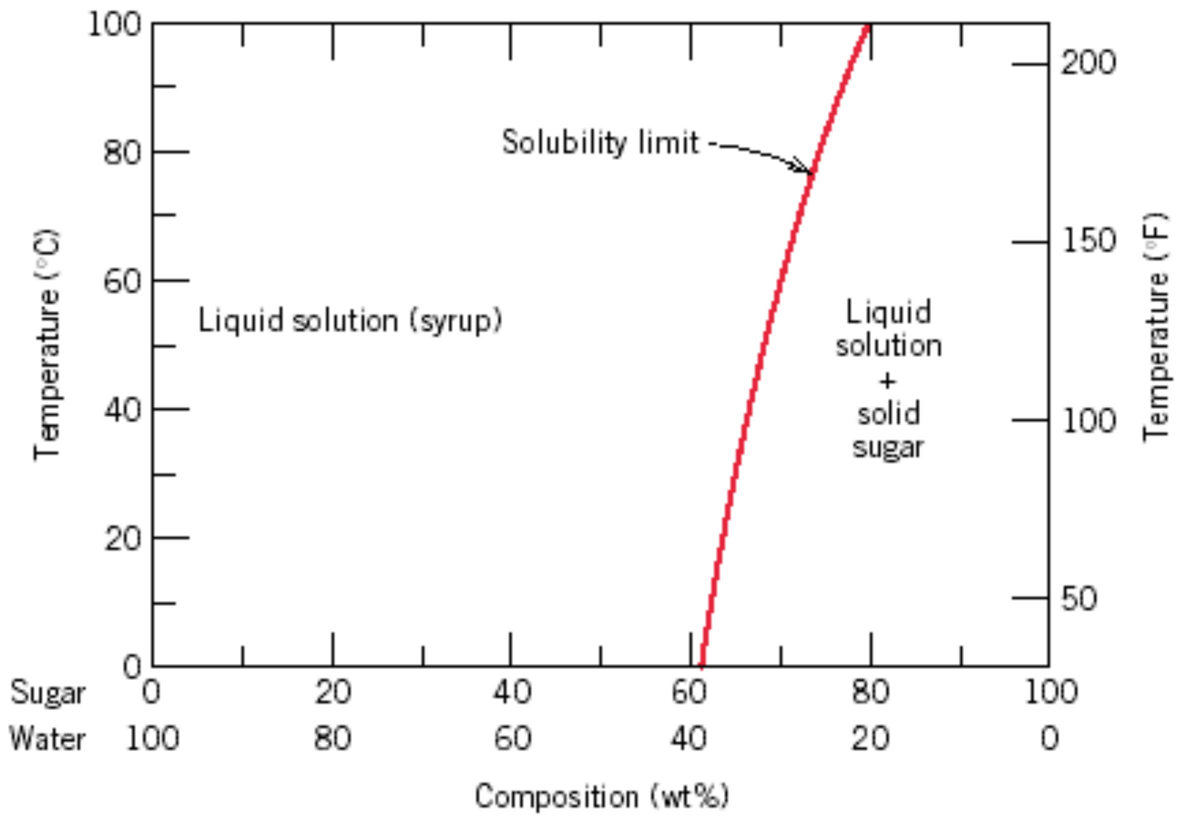


Definitions and basic concepts

- **Component: pure metals and/or compounds of which an alloy is composed**
- **System: a specific body of material under consideration**
- **A phase: a homogeneous portion of a system that has uniform physical and chemical characteristics**
- **Equilibrium: a system is at equilibrium if its free energy is at a minimum under some specified combination of temperature, pressure, and composition.**
- **Phase equilibrium: minimum energy for a system with multiple phases**
- **Phase diagram: information about phases as function of T, composition, and pressure**

Solubility limit

- **A maximum concentration of solute atoms may dissolve in the solvent**
- **Solubility increases with T**

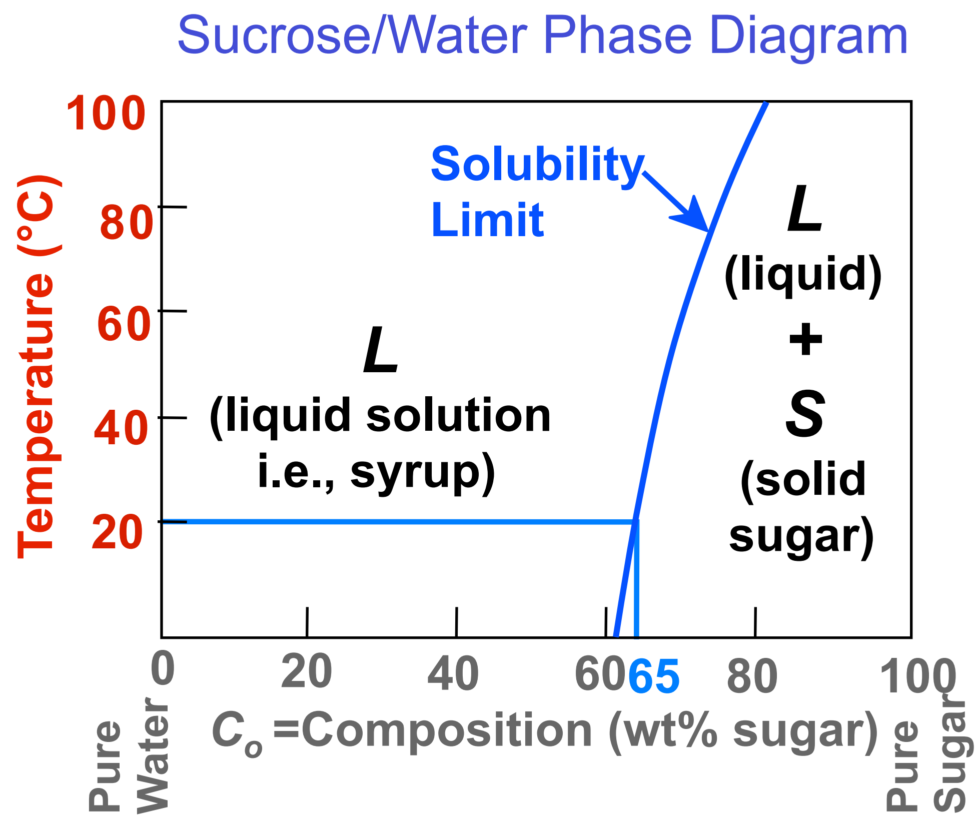


Phase Equilibria: Solubility Limit

***Question:** What is the solubility limit at 20C?*
***Answer:** 65wt% sugar.*

If C_o < 65wt% sugar: syrup
If C_o > 65wt% sugar: syrup + sugar.

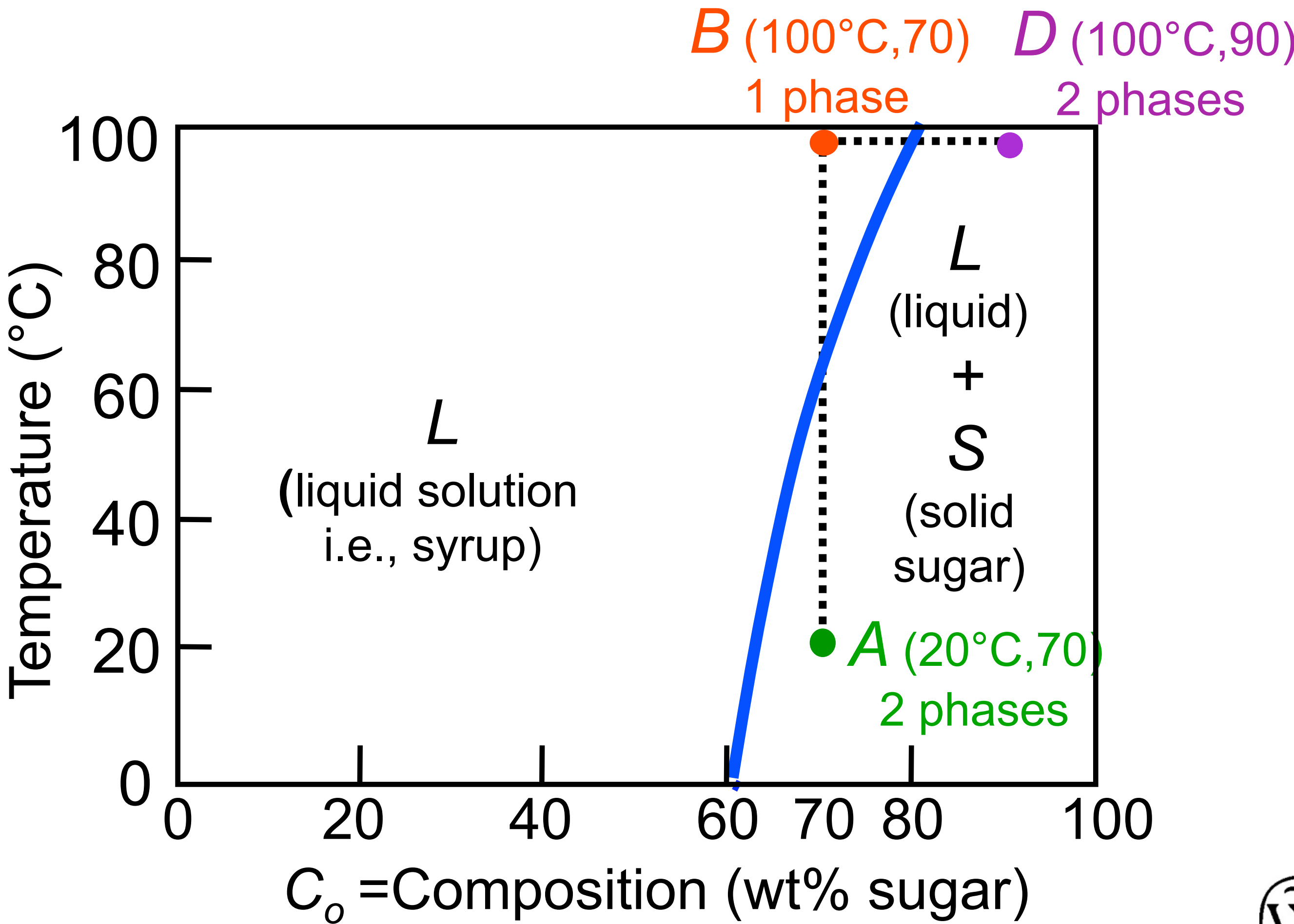
- ***Solubility limit increases with T:***
  e.g., if T = 100C, solubility limit = 80wt% sugar.



Effect of *T* & Composition (C_o)

- Changing *T* can change # of phases: path *A* to *B*.
- Changing C_o can change # of phases: path *B* to *D*.

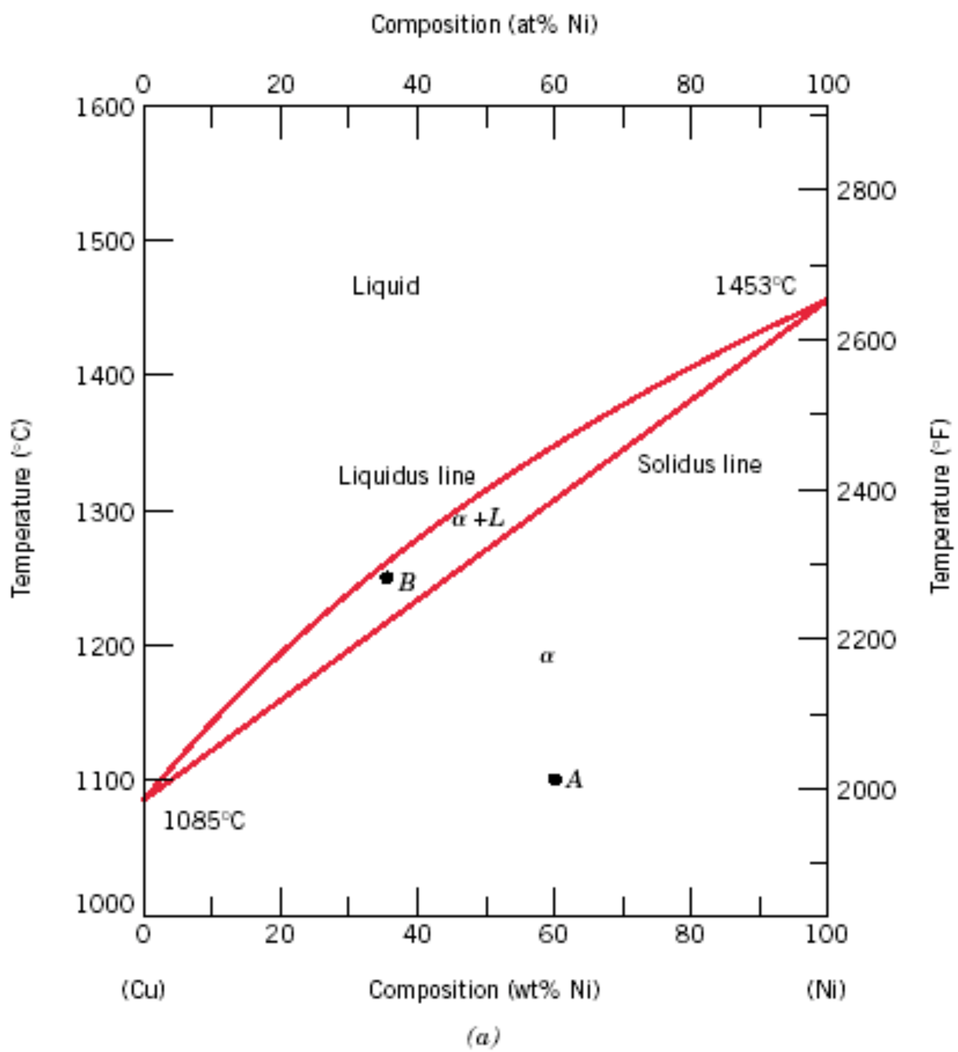
water-
sugar
system



Adapted from
Fig. 9.1,
Callister 7e.

Binary isomorphous systems

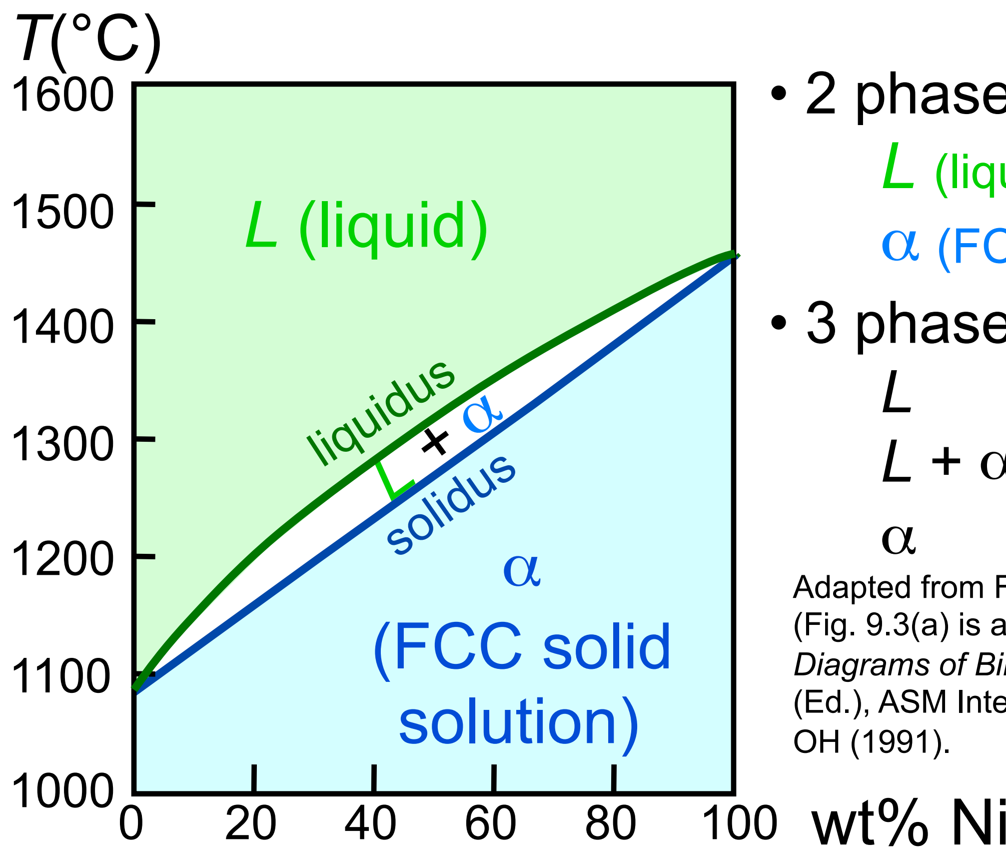
- Complete liquid and solid solubility of the two components
- Cu-Ni solid solution
- liquidus line
- solidus line
- melting temperatures
- phase composition
- phase relative amount: tie line and lever rule



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)
  - α (FCC solid solution)
- 3 phase fields:
  - *L*
  - *L* + α
  - α

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:
composition of phases

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

- Examples:

  C_o = 35 wt% Ni

  At T_A = 1320°C:

  Only Liquid (L)

  C_L = C_o (= 35 wt% Ni)

  At T_D = 1190°C:

  Only Solid (α)

  C_α = C_o (= 35 wt% Ni)

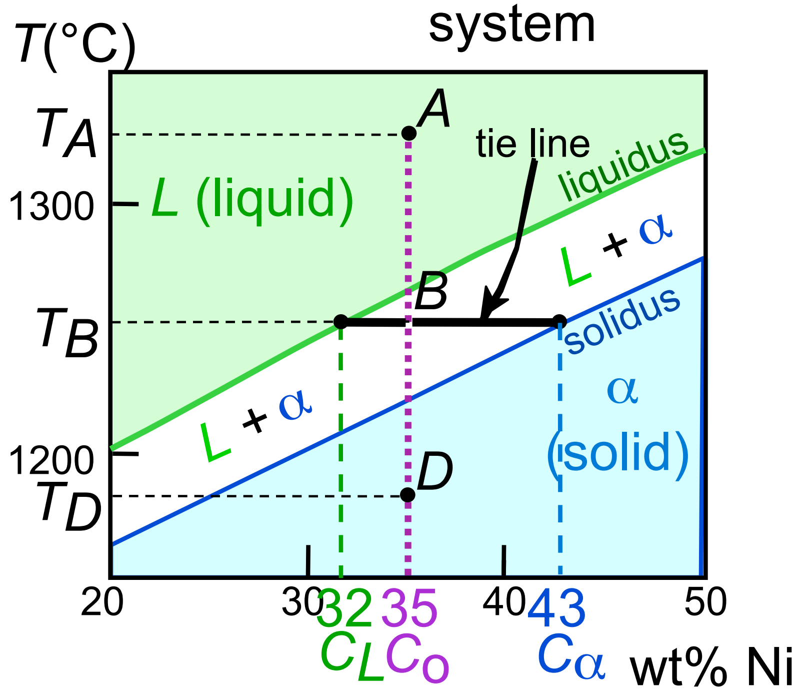
  At T_B = 1250°C:

  Both α and L

  C_L = $C_{liquidus}$ (= 32 wt% Ni here)

  C_α = $C_{solidus}$ (= 43 wt% Ni here)

Cu-Ni system



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:
weight fractions of phases

- 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 wt%, W_α = 0

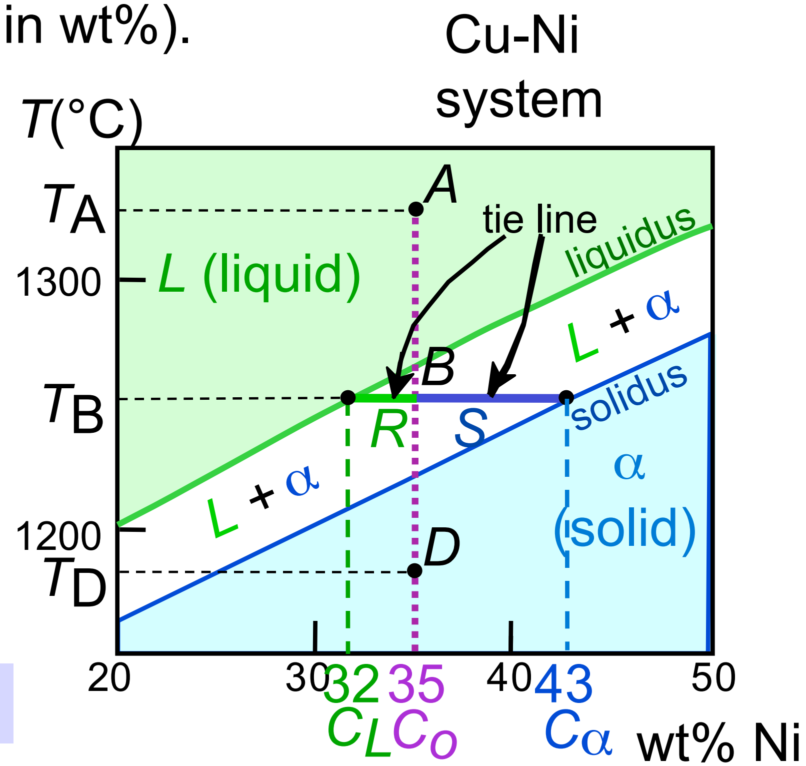
At T_D: Only Solid (α)

W_L = 0, W_α = 100 wt%

At T_B: Both α and L

$$W_L = \frac{S}{R+S} = \frac{43-35}{43-32} = 73\ wt\%$$

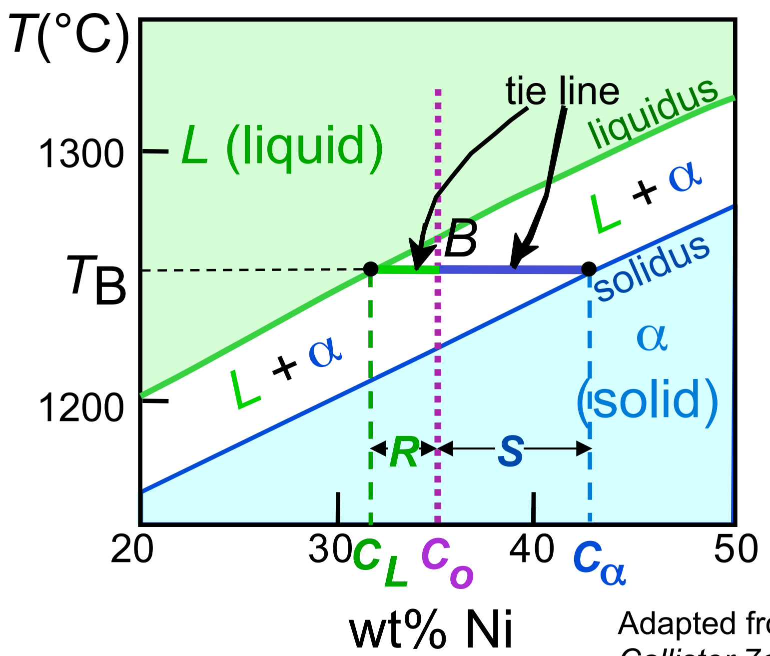
$$W_\alpha = \frac{R}{R+S} = 27\ wt\%$$



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

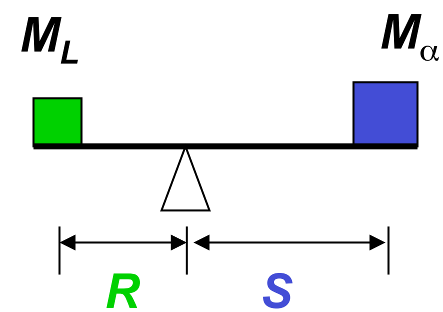
- Tie line – connects the phases in equilibrium with each other - essentially an isotherm



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

How much of each phase?

Think of it as a lever (teeter-totter)



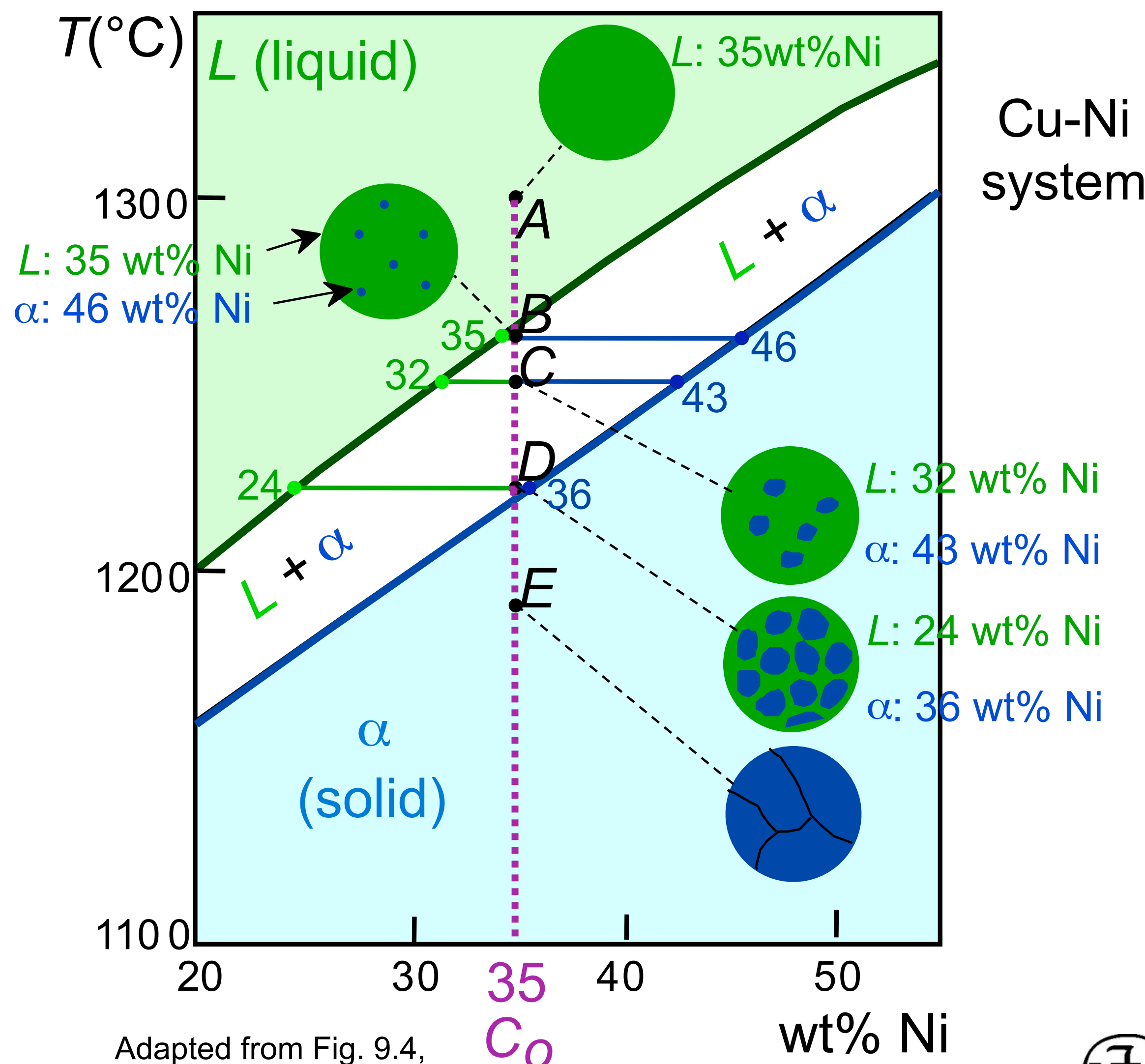
$$M_\alpha \cdot S = M_L \cdot R$$

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

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

Ex: Cooling in a Cu-Ni Binary

- 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.

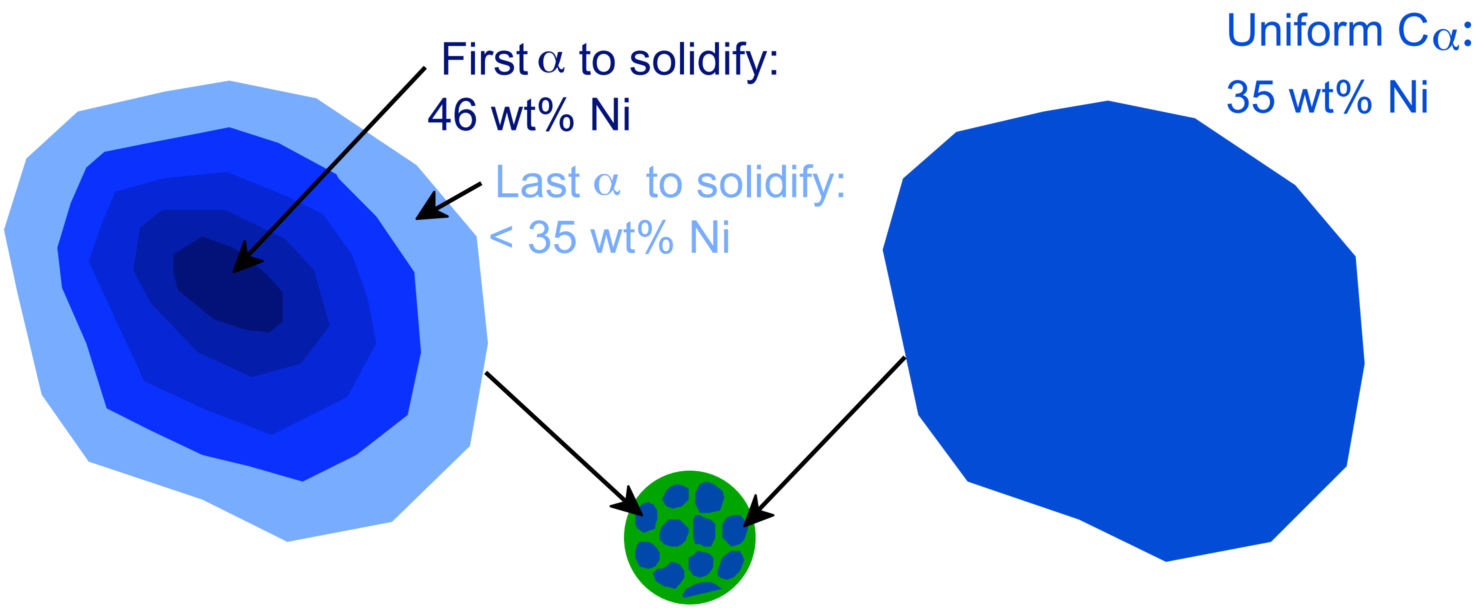


Adapted from Fig. 9.4, *Callister 7e.*

Cored vs Equilibrium Phases

- C_α changes as we solidify.
- Cu-Ni case: First α to solidify has C_α = 46 wt% Ni.
  Last α to solidify has C_α = 35 wt% Ni.

- Fast rate of cooling:
  Cored structure
- Slow rate of cooling:
  Equilibrium structure



Binary-Eutectic Systems

2 components

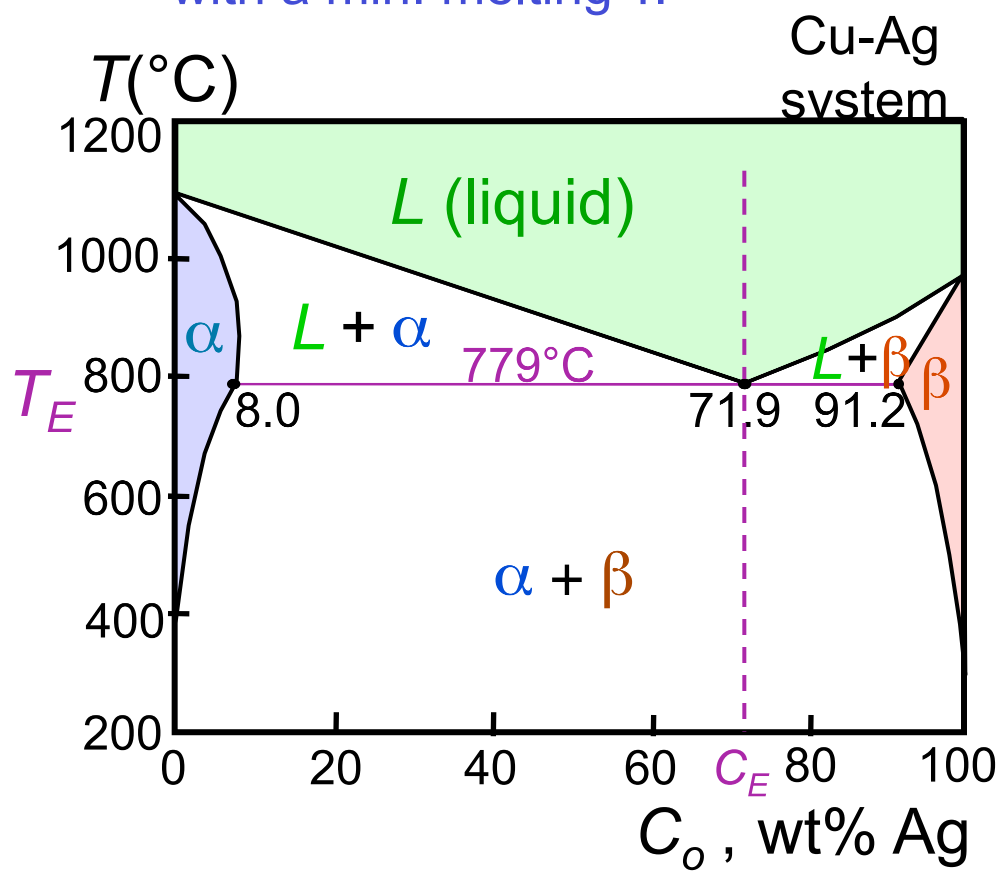
has a special composition with a min. melting T.

Ex.: Cu-Ag system

- 3 single phase regions (L, α, β)
- Limited solubility:
  - α: mostly Cu
  - β: mostly Ag
- T_E : No liquid below T_E
- C_E : Min. melting T_E composition

- **Eutectic transition**

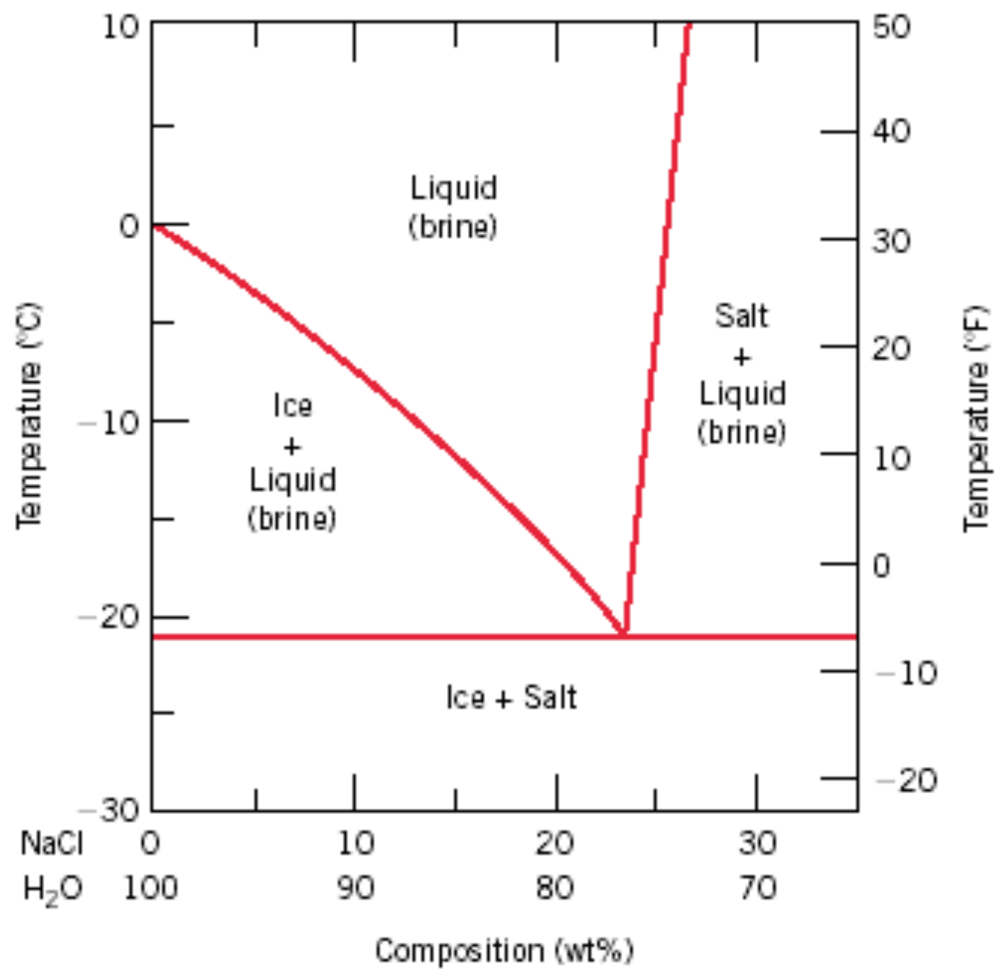
$$L(C_E) \rightleftharpoons \alpha(C_{\alpha E}) + \beta(C_{\beta E})$$



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

Binary eutectic systems (Example)

- **Explain how spreading salt on ice that is at a temperature below 0^0C can cause the ice to melt.**



EX: Pb-Sn Eutectic System (1)

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

--the phases present: $\alpha + \beta$

--compositions of phases:

C_O = 40 wt% Sn

C_α = 11 wt% Sn

C_β = 99 wt% Sn

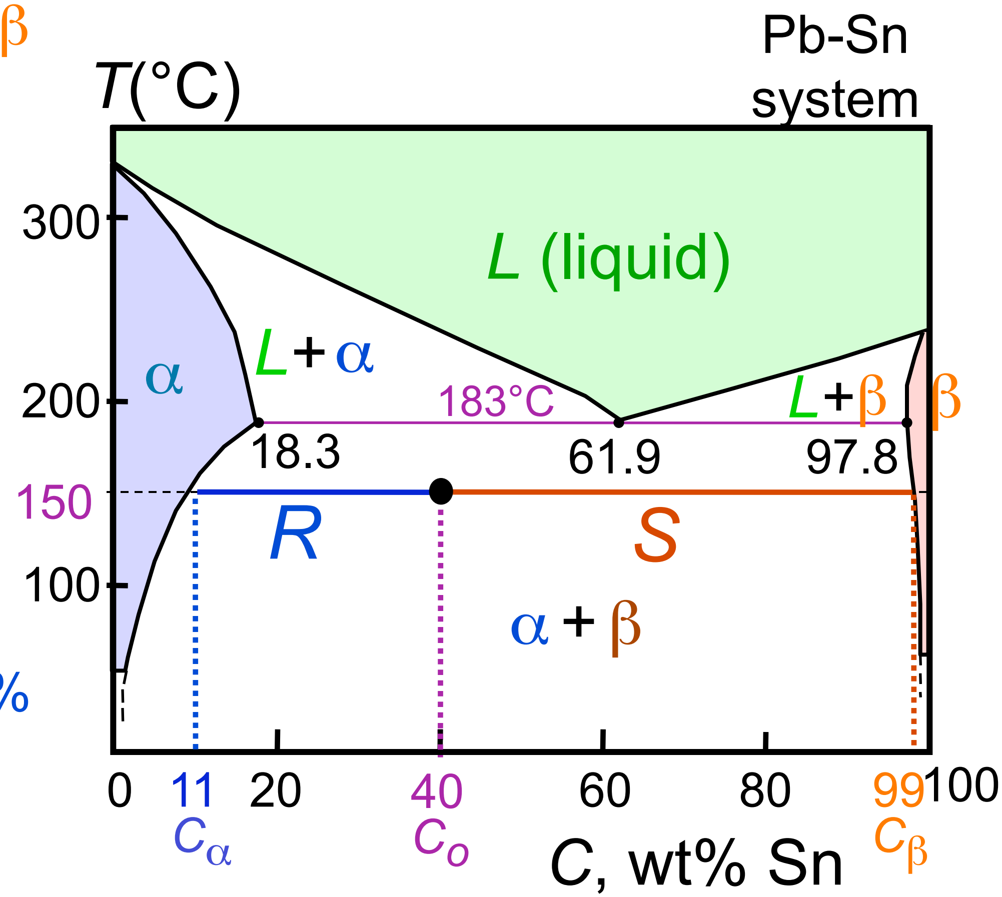
--the relative amount of each phase:

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

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

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

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



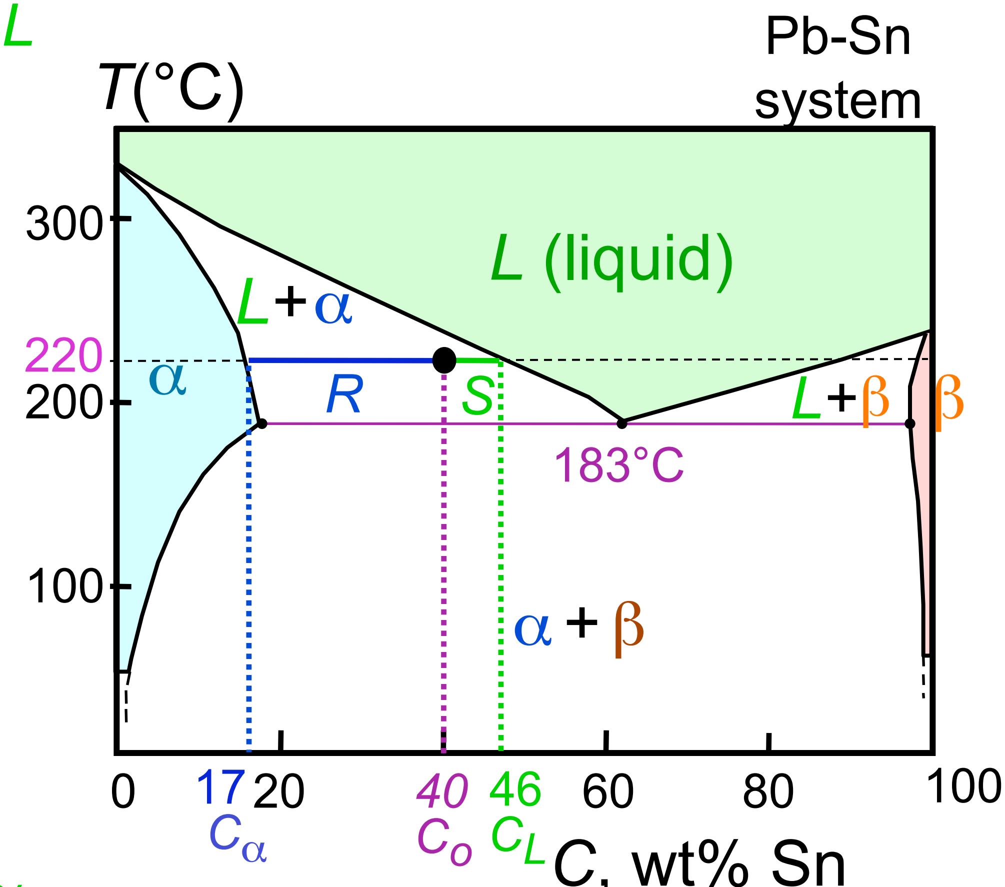
Adapted from Fig. 9.8, *Callister 7e.*

EX: Pb-Sn Eutectic System (2)

- For a 40 wt% Sn-60 wt% Pb alloy at 200°C, find...
  - --the phases present: α + L
  - --compositions of phases:
    - C_O = 40 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.*