PHASE DIAGRAM

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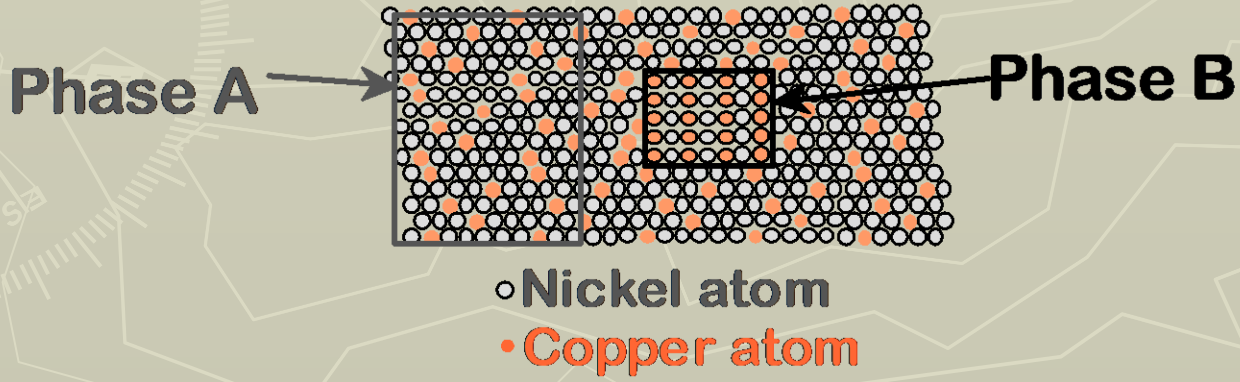
QUESTIONS

- Diff. between;
  (i) Phase rule and Phase diagram
  (ii) Solvus line and Solidus line
- What is phase? Explain invariant reaction with example.
- Explain lever rule with a tie line
- Expalin all transformation reaction.(p64)
- Explain eutectoid and eutectic reaction in Fe-C binary phase diagram (p45)
- Draw peritectic reaction of Fe-C system(p16)
- Explain why ferrite have low solubility of carbon than austenite

INTRODUCTION

ISSUES TO ADDRESS...

- 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?



Equilibrium phase diagram

or

Equilibrium diagram

or

Phase diagram

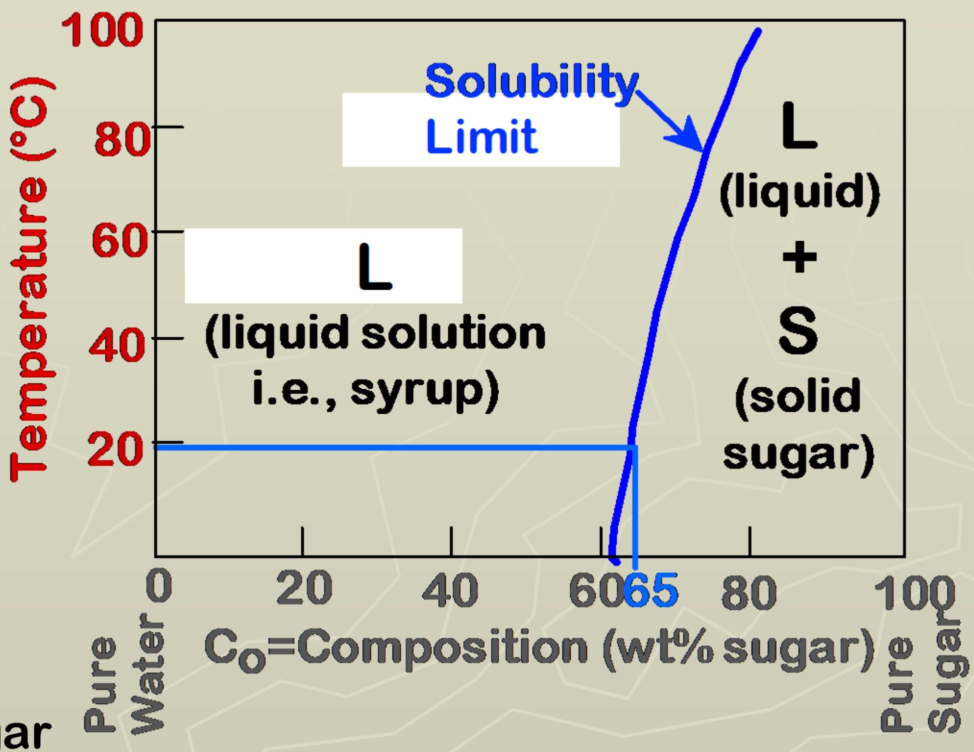
A diagram in the space indicating phases in equilibrium in relation with thermodynamic variables (like T, P, X etc.) is called a phase diagram.

THE SOLUBILITY LIMIT

- **Solubility Limit:**
  Max concentration for which only a solution occurs.

- **Ex: Phase Diagram: Water-Sugar System**

  Question: What is the solubility limit at 20C?
  Answer: 65wt% sugar.
  If C_o < 65wt% sugar: sugar
  If C_o > 65wt% sugar: syrup + sugar.



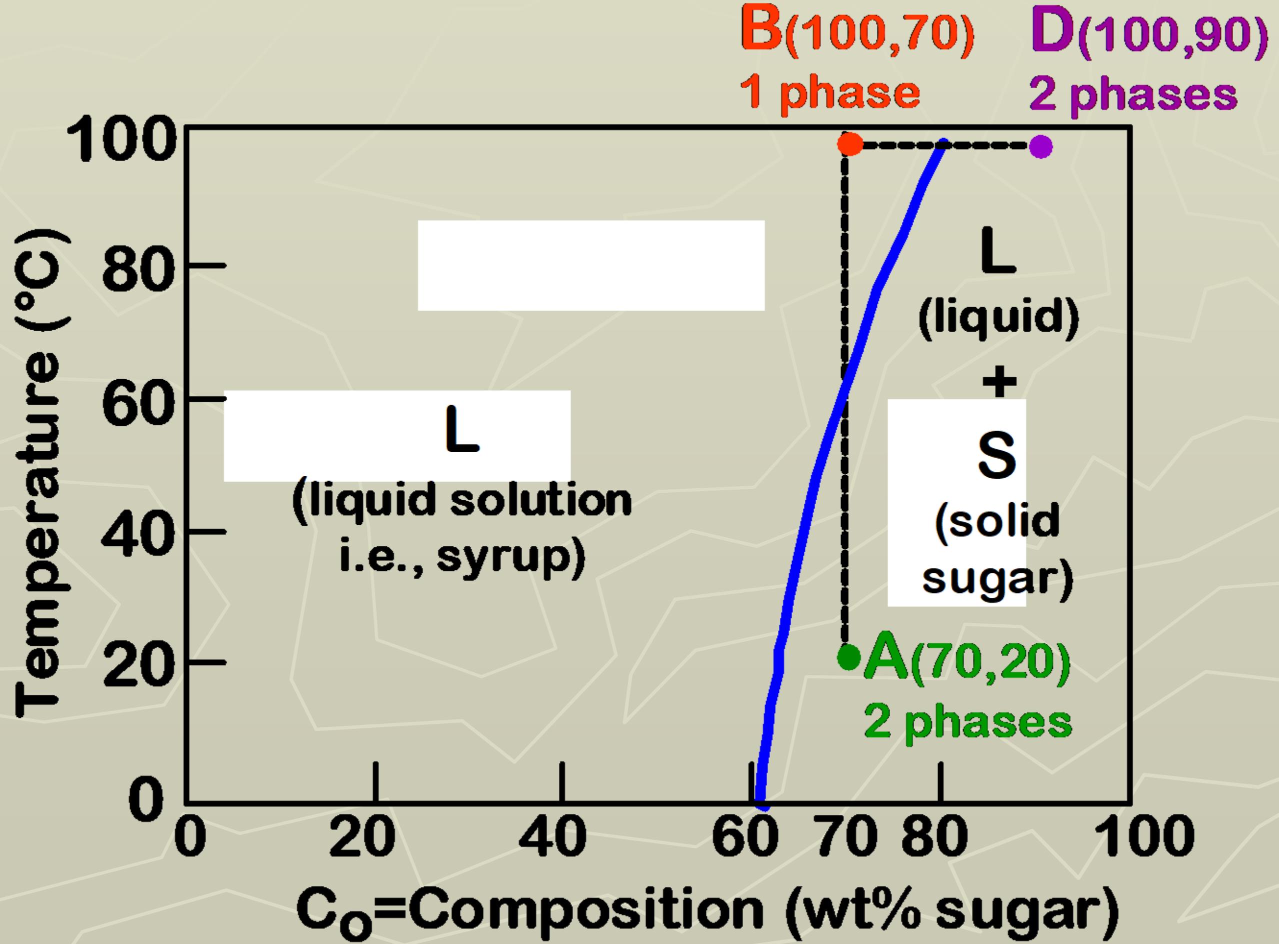
Adapted from Fig. 9.1, *Callister 6e.*

- **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.

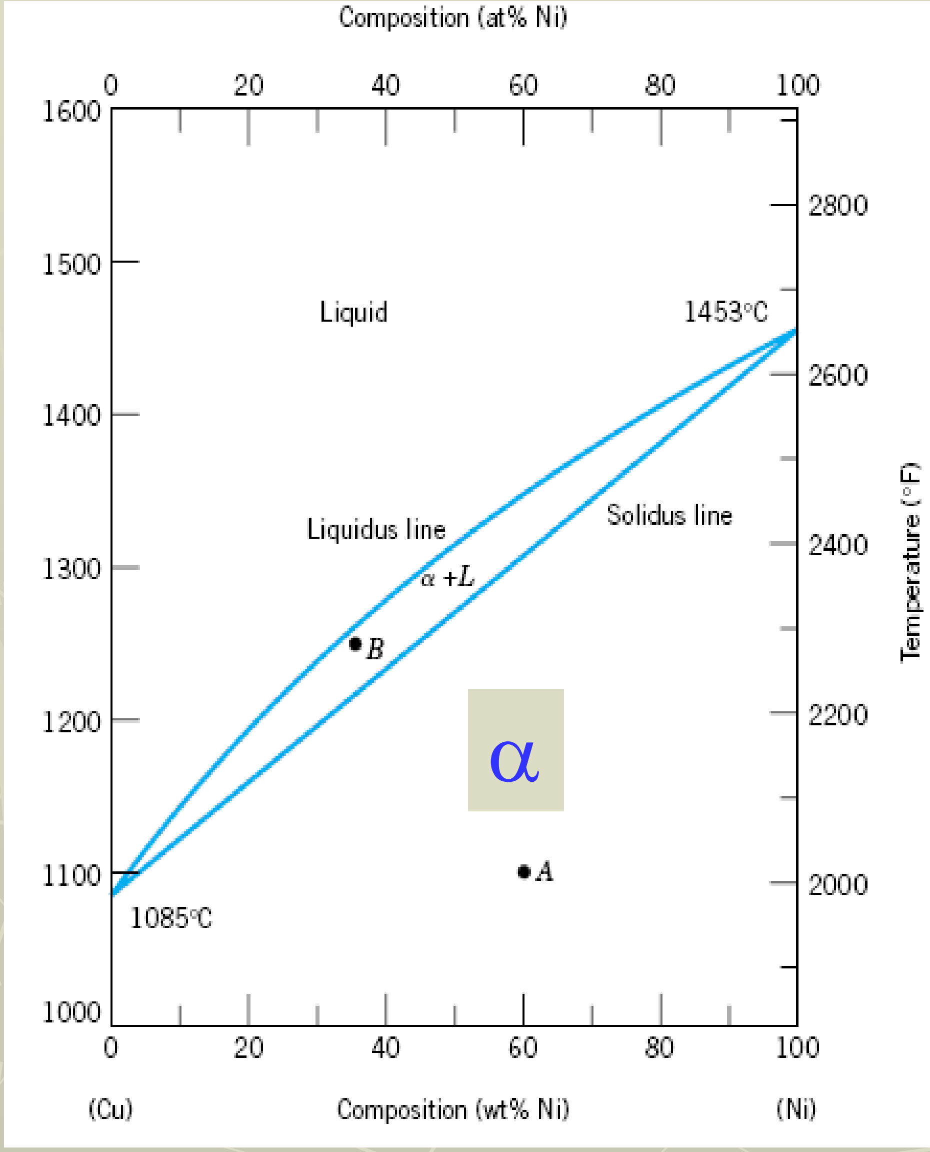
- water-sugar system



Phase Diagrams

For any given point (x,T) the phase diagram can answer the following:

1. What phases are present?
2. What are the phase compositions?
3. What are the relative amounts of the phases (phase proportions or phase fractions)?



Point A:

60 wt% Ni at 1100°C

Q: Phase present?

Ans: α

Q: Phase composition ?

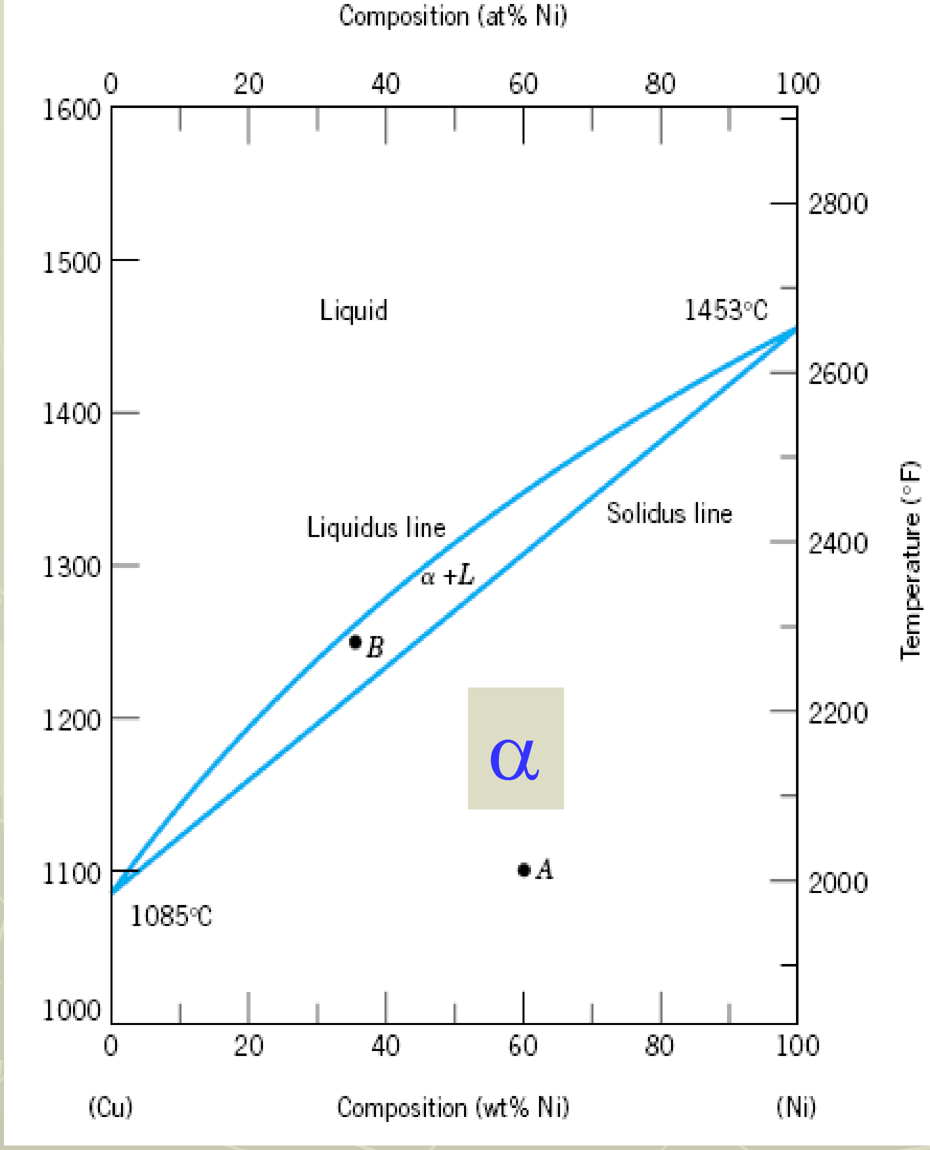
Ans: 60 wt%Ni

Q: Phase amount ?

Ans: 100%

Point B:

35 wt% Ni at 1250°C



Q: Phases present?

Ans: α + L

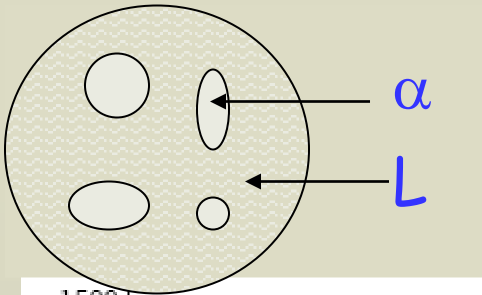
Q: Phase compositions ?

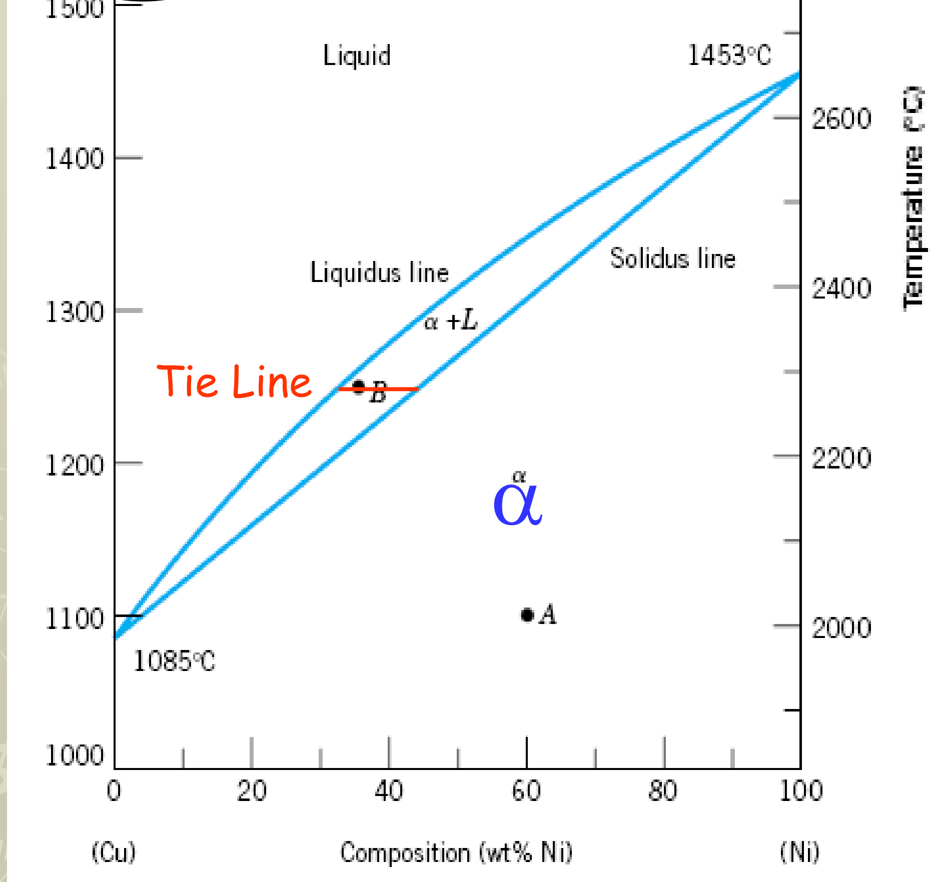
Tie Line Rule

Q: Phase amounts ?

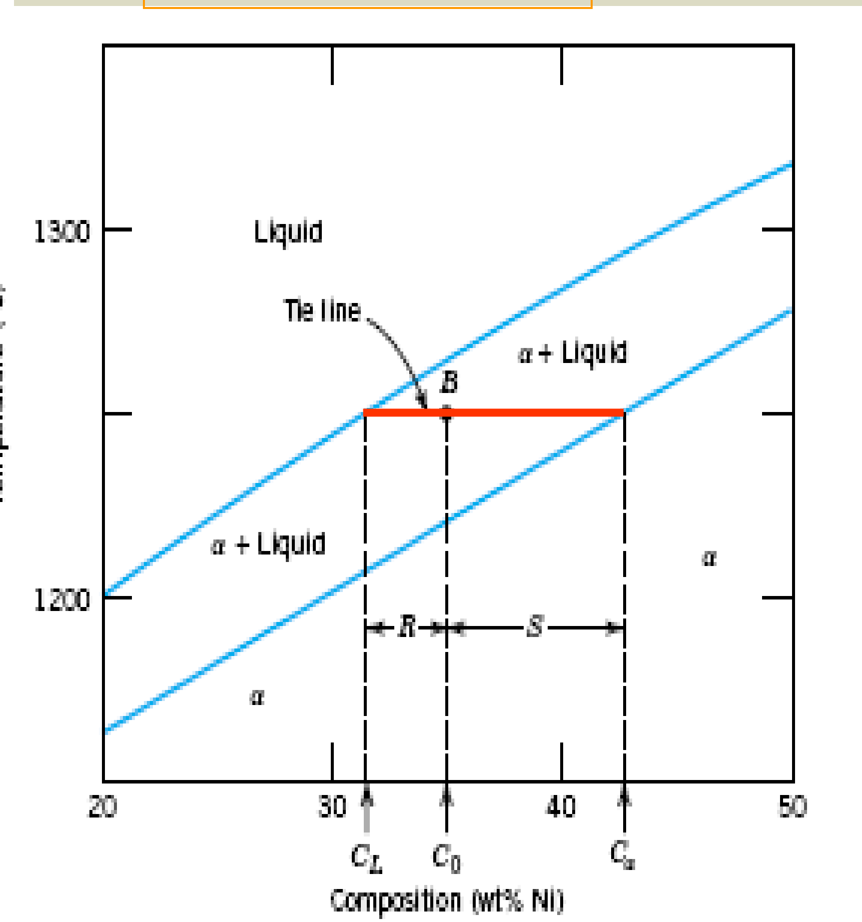
Lever Rule

Composition of phases in the two-phase region





Tie Line Rule



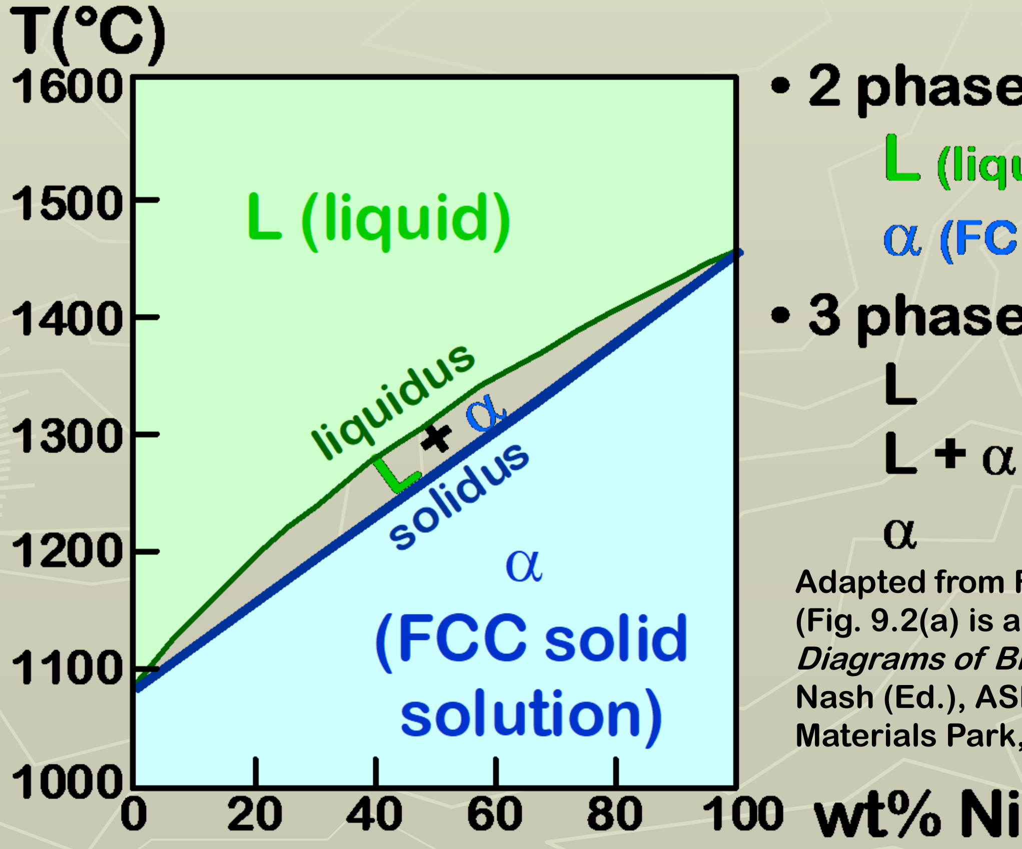
C_L= 31.5 wt% Ni

C_α= 42.5 wt% Ni

PHASE DIAGRAMS

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

- **Phase Diagram** for Cu-Ni system



- 2 phases:
  - L (liquid)
  - α (FCC solid solution)
- 3 phase fields:
  - L
  - L + α
  - α

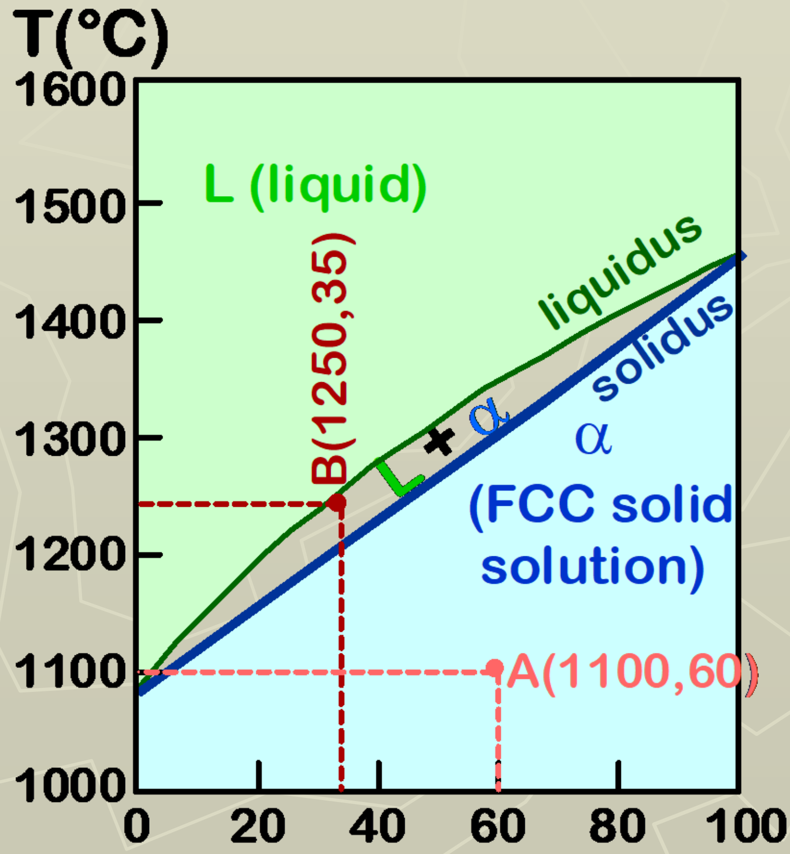
Adapted from Fig. 9.2(a), *Callister 6e.* (Fig. 9.2(a) is adapted from *Phase Diagrams of Binary Nickel Alloys*, P. Nash (Ed.), ASM International, Materials Park, OH (1991).

types of phases – RULE 1

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

- **Examples:**
  A(1100, 60):
  1 phase: α

  B(1250, 35):
  2 phases: L + α



Cu-Ni phase diagram

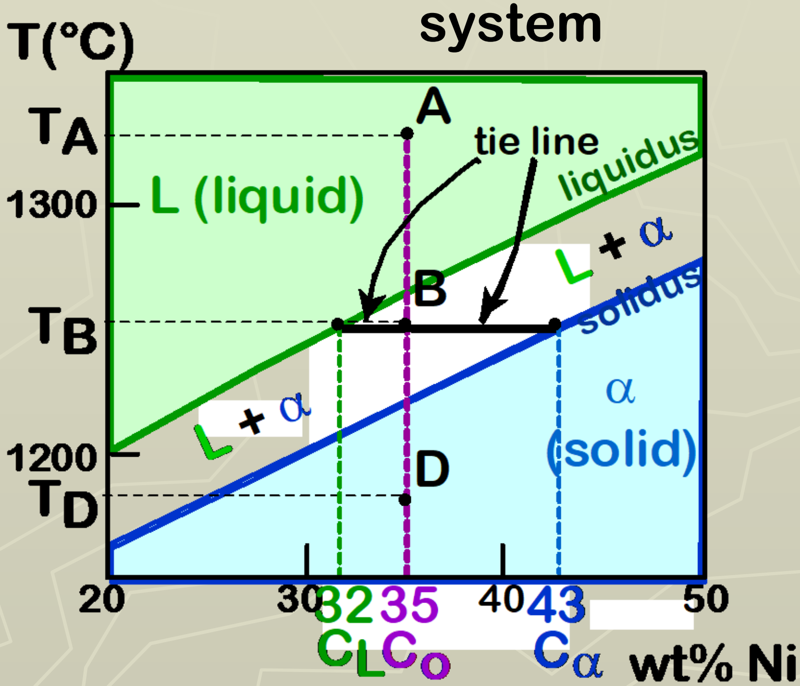
Adapted from Fig. 9.2(a), *Callister 6e.* (Fig. 9.2(a) is adapted from *Phase Diagrams of Binary Nickel Alloys*, P. Nash (Ed.), ASM International, Materials Park, OH, 1991).

composition of phases – RULE 2

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

- Examples:
  C_o = 35wt%Ni
  At T_A:
  Only Liquid (L)
  $C_L = C_o$ (= 35wt% Ni)
  At T_D:
  Only Solid (α)
  $C_\alpha = C_o$ (= 35wt% Ni)
  At T_B:
  Both α and L
  $C_L = C_{liquidus}$ (= 32wt% Ni here)
  $C_\alpha = C_{solidus}$ (= 43wt% Ni here)

Cu-Ni system



Adapted from Fig. 9.2(b), *Callister 6e.* (Fig. 9.2(b) is adapted from *Phase Diagrams of Binary Nickel Alloys*, P. Nash (Ed.), ASM International, Materials Park, OH, 1991.)

weight fractions of phases – RULE 3

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

C_o = 35wt%Ni

At T_A: Only Liquid (L)

W_L = 100wt%, W_α = 0

At T_D: Only Solid (α)

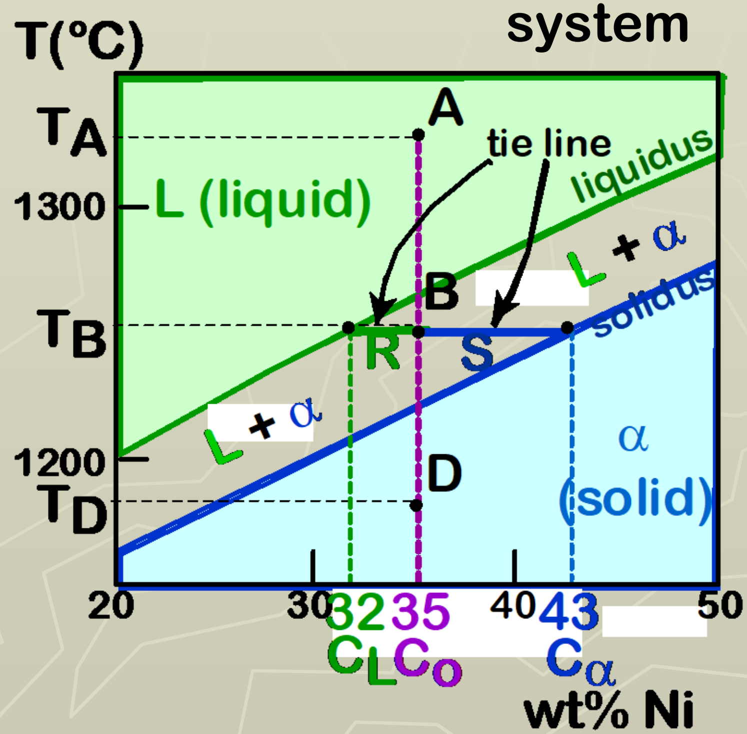
W_L = 0, W_α = 100wt%

At T_B: Both α and L

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

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

Cu-Ni system



Adapted from Fig. 9.2(b), *Callister 6e.* (Fig. 9.2(b) is adapted from *Phase Diagrams of Binary Nickel Alloys*, P. Nash (Ed.), ASM International, Materials Park, OH, 1991.)

GIBBS PHASE RULE

F = Degrees of freedom

C = No. of components in the system

P = No. of phases in equlibrium

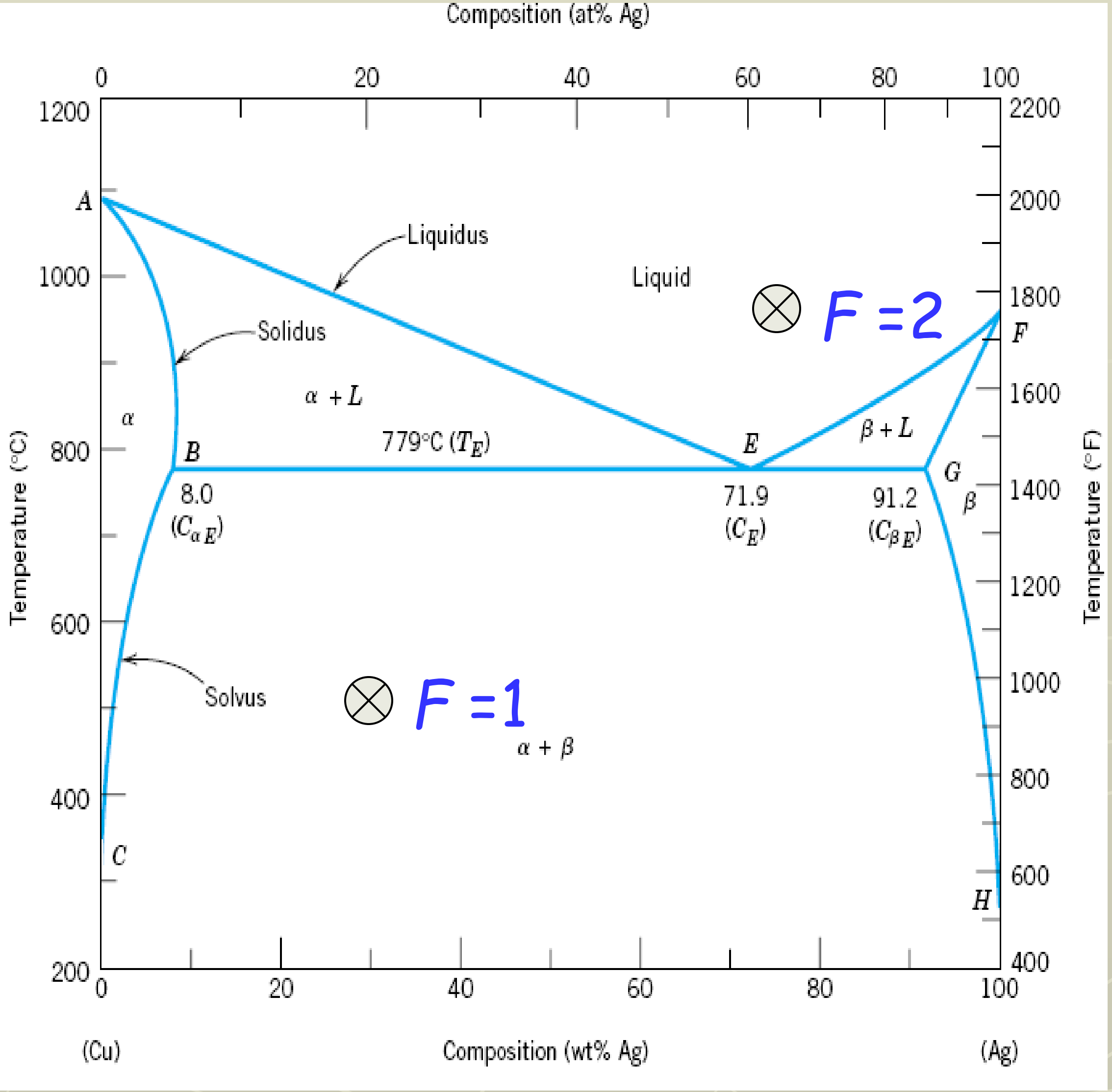
$$F = C - P + 2$$

If pressure and temp both are variables

$$F = C - P + 1$$

If pressure is held constant

$$F = C - P + 1$$



C=2

F=3-P

At eutectic reaction P=3

(L, α, β)

F=0

Invariant reaction

Example (Sept-2005)

- Calculate the degree of freedom of ice and water kept in a beaker at 1 atm. pressure.
- Calculate the degree of freedom for eutectic reaction for an iron-carbon alloy and iron-cr-ni alloy, under 1 atm.

$F = C - P + 1$ $C = ?, P = ?$

Ans:

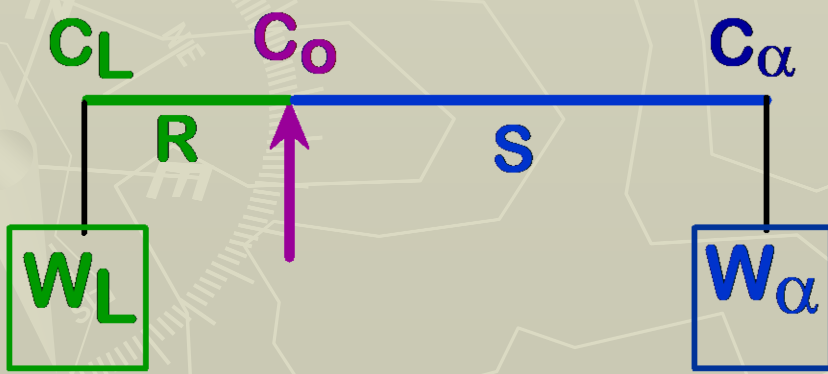
THE LEVER RULE: A PROOF

- **Sum of weight fractions:** $W_L + W_\alpha = 1$
- **Conservation of mass (Ni):** $C_o = W_L C_L + W_\alpha C_\alpha$
- **Combine above equations:**

$$W_L = \frac{C_\alpha - C_o}{C_\alpha - C_L} = \frac{S}{R+S}$$

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

- **A geometric interpretation:**



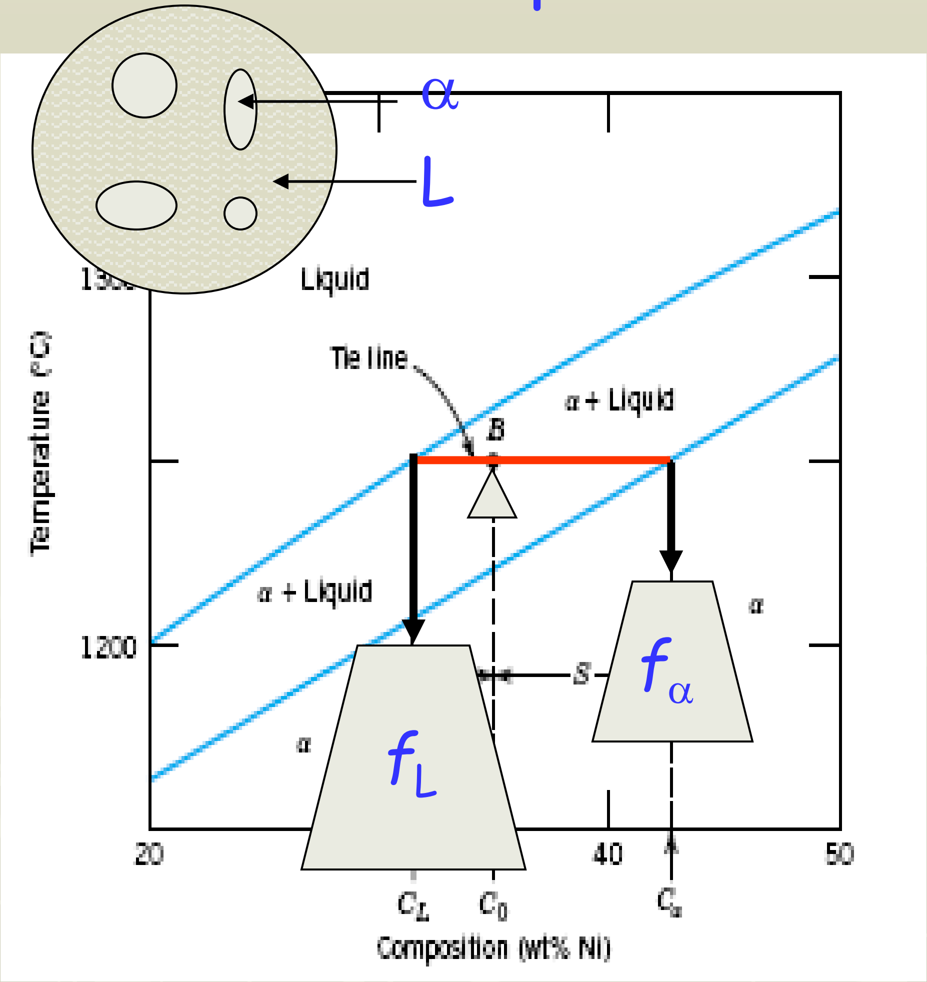
moment equilibrium:

$$W_L R = W_\alpha S$$

$$1 - W_\alpha$$

solving gives Lever Rule

Amount of phases in the two-phase region



Tie-Line: A lever

Alloy composition C_0: Fulcrum

f_L: weight at liquidus point

f_α: weight at solidus point

The lever is balanced

$$f_L(C_0 - C_L) = f_\alpha(C_\alpha - C_0)$$

$$f_L + f_\alpha = 1$$

Tie Lever Rule

$$f_L = \frac{C_\alpha - C_0}{C_\alpha - C_L} = \frac{opposite\ lever\ arm}{total\ lever\ arm}$$

Example

- Find the weight % of pro-eutectoid ferrite just above the eutectoid temperature of a 0.3 % carbon.

fproa = (0.8 – 0.3)/(0.8 – 0.0) = 0.625 = 62.5 %

fpearlite = 1 – 0.625 = 0.375 = 37.5 %

TRANSFORMATION REACTION

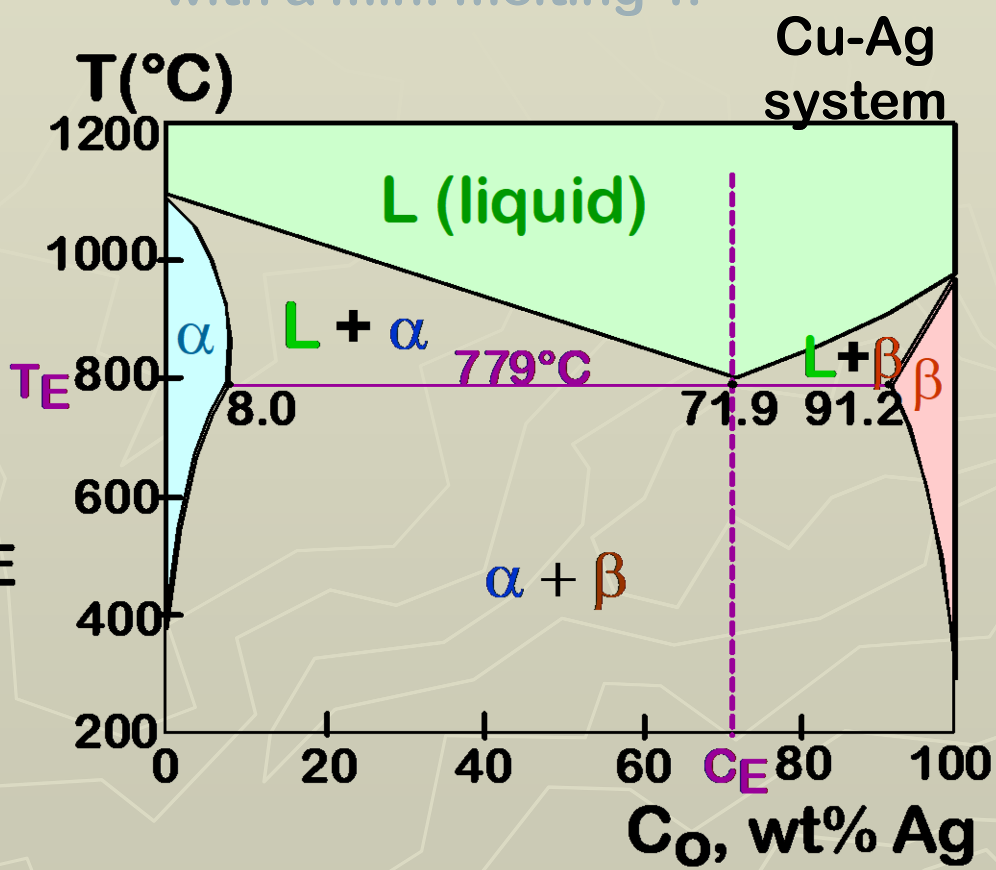
- **Monotectic Reaction:**
  L1 ----> L2 + Solid
- **Eutectic Reaction:**
  L ----> Solid1 + Solid2
- **Eutectoid Reaction:**
  Solid1 ----> Solid2 + Solid3
- **Peritectic Reaction:**
  L + Solid1 ----> Solid2
- **Peritectoid Reaction:**
  Solid1 + Solid2 ----> New Solid

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 Ni
- T_E: No liquid below T_E
- C_E: Min. melting T composition

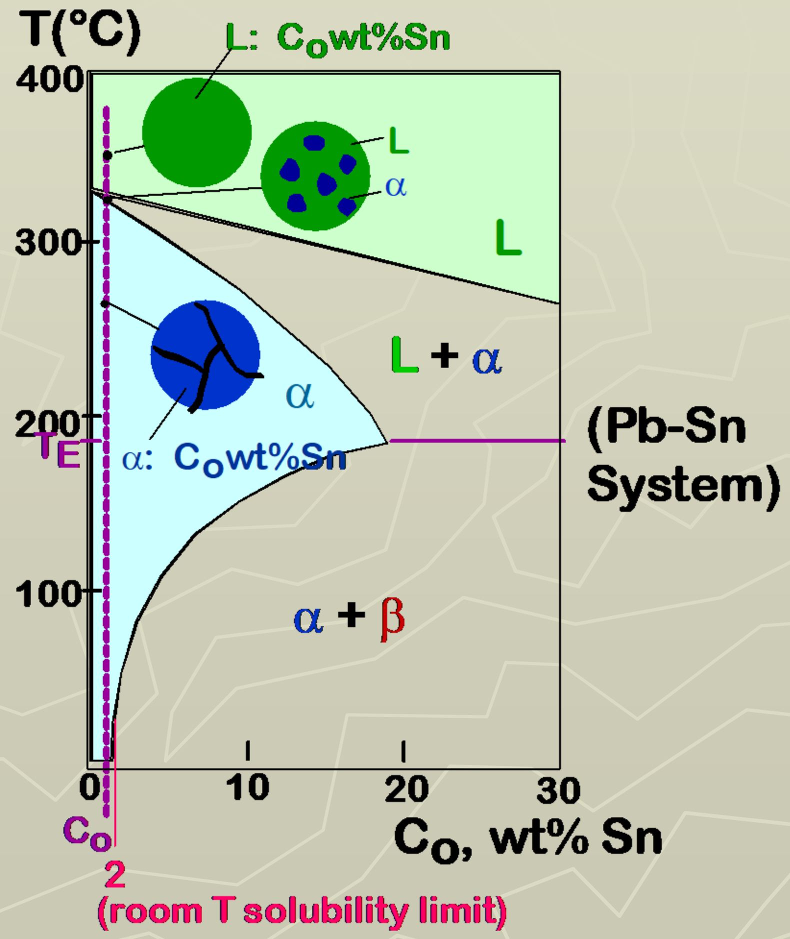


PERITECTIC REACTION

- **Basic Introduction (c pg: 16)**
- **Example:**Brass has a peritectic reaction at a temp. of 903 c, with 36.8 % Zn in the middle and 32.5 % Zn at a-phase end and 37.5 % Zn at liquidus end. Find out % of liquid phase and a-phase present at the peritectic point.

MICROSTRUCTURES IN EUTECTIC SYSTEMS-I

- C_o < 2wt%Sn
- Result:
  --polycrystal of α grains.

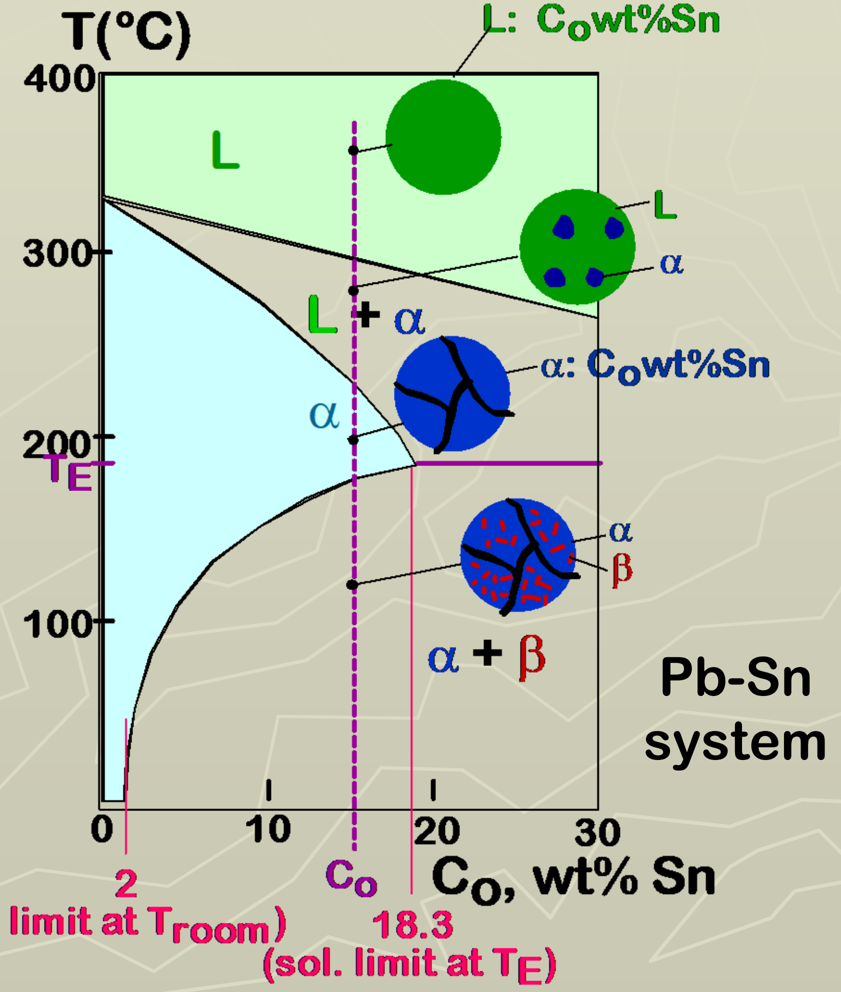


Adapted from Fig. 9.9, *Callister 6e.*

MICROSTRUCTURES IN EUTECTIC SYSTEMS-II

- $2wt\%Sn < C_o < 18.3wt\%Sn$
- Result:

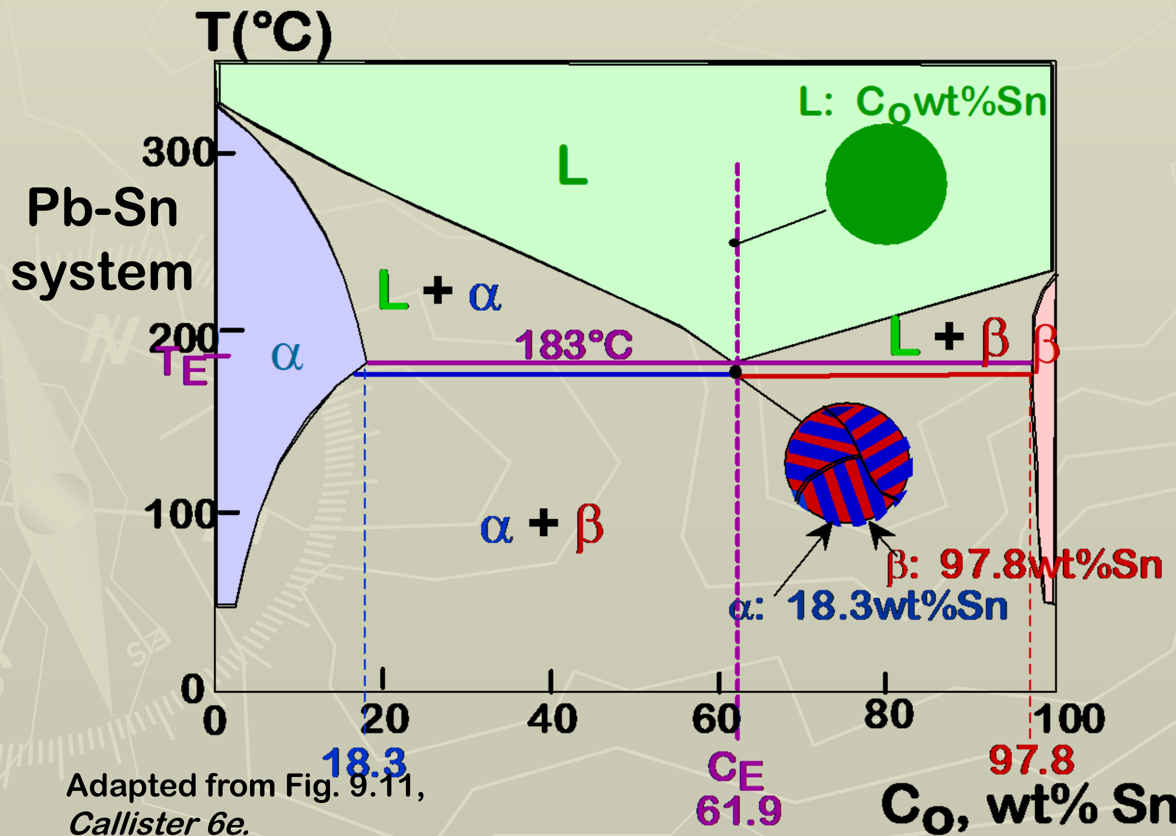
  --α polycrystal with fine β crystals.



Adapted from Fig. 9.10, *Callister 6e.*

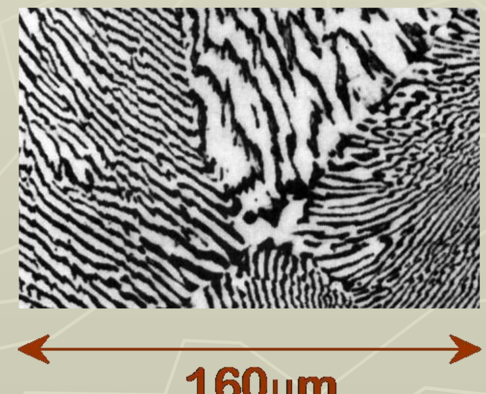
MICROSTRUCTURES IN EUTECTIC SYSTEMS-III

- $C_o = C_E$
- Result: Eutectic microstructure
  --alternating layers of α and β crystals.



Adapted from Fig. 9.11, *Callister 6e.*

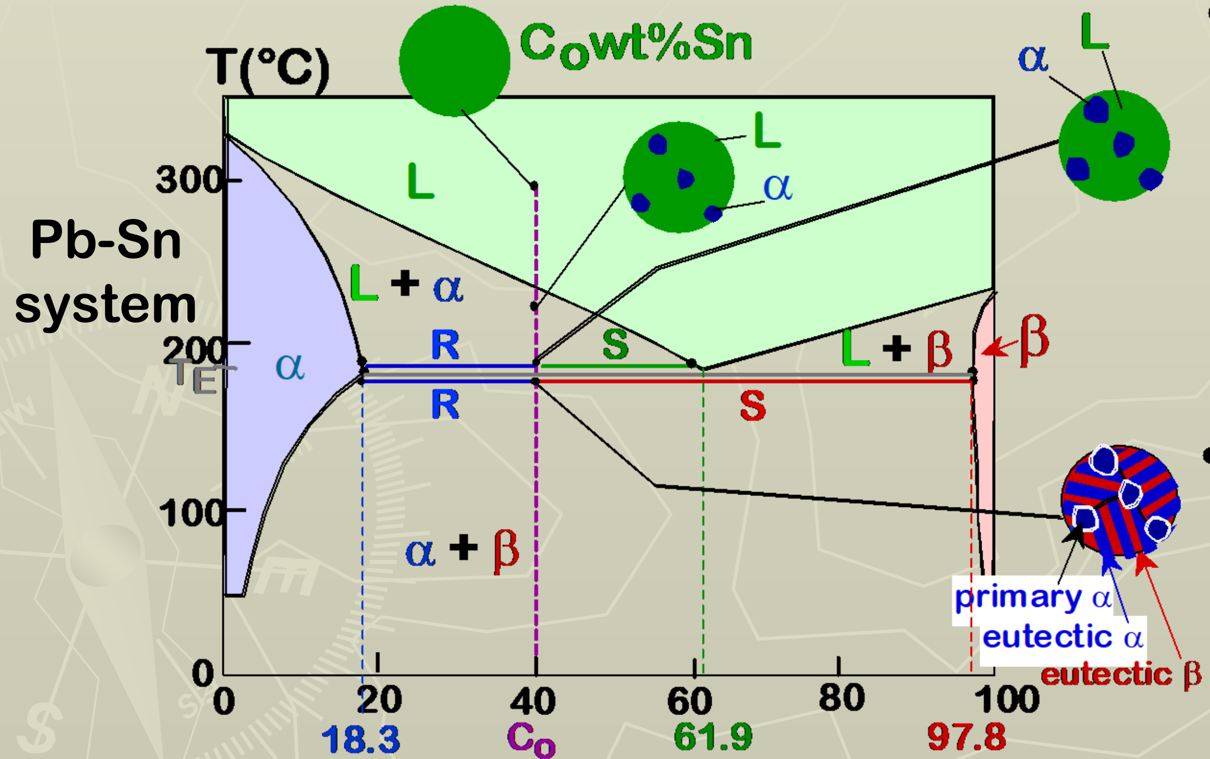
Micrograph of Pb-Sn eutectic microstructure



Adapted from Fig. 9.12, *Callister 6e.* (Fig. 9.12 from *Metals Handbook*, Vol. 9, 9th ed., *Metallography and Microstructures*, American Society for Metals, Materials Park, OH, 1985.)

MICROSTRUCTURES IN EUTECTIC SYSTEMS-IV

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

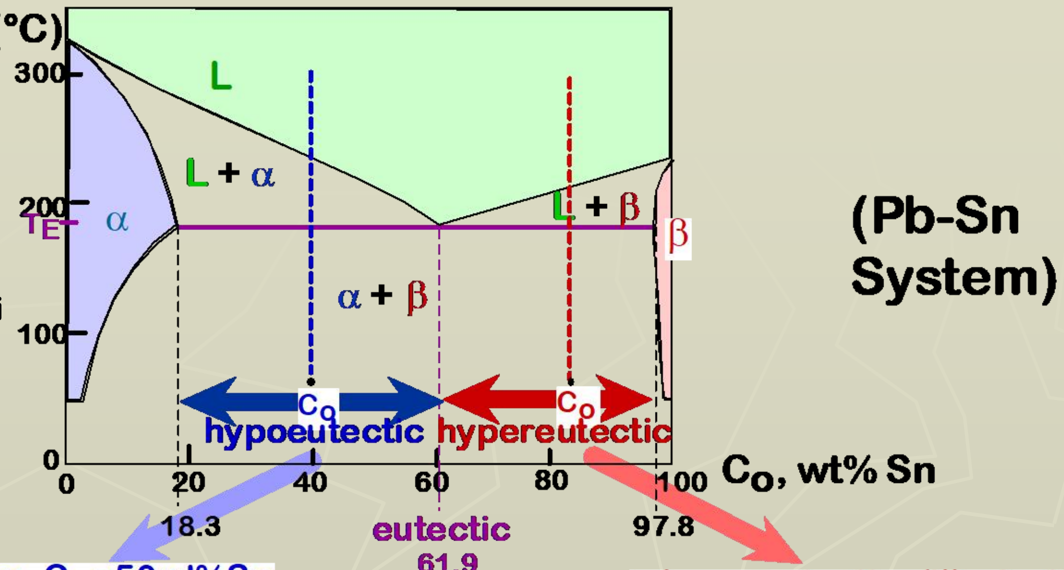


Adapted from Fig. 9.14, *Callister 6e.*

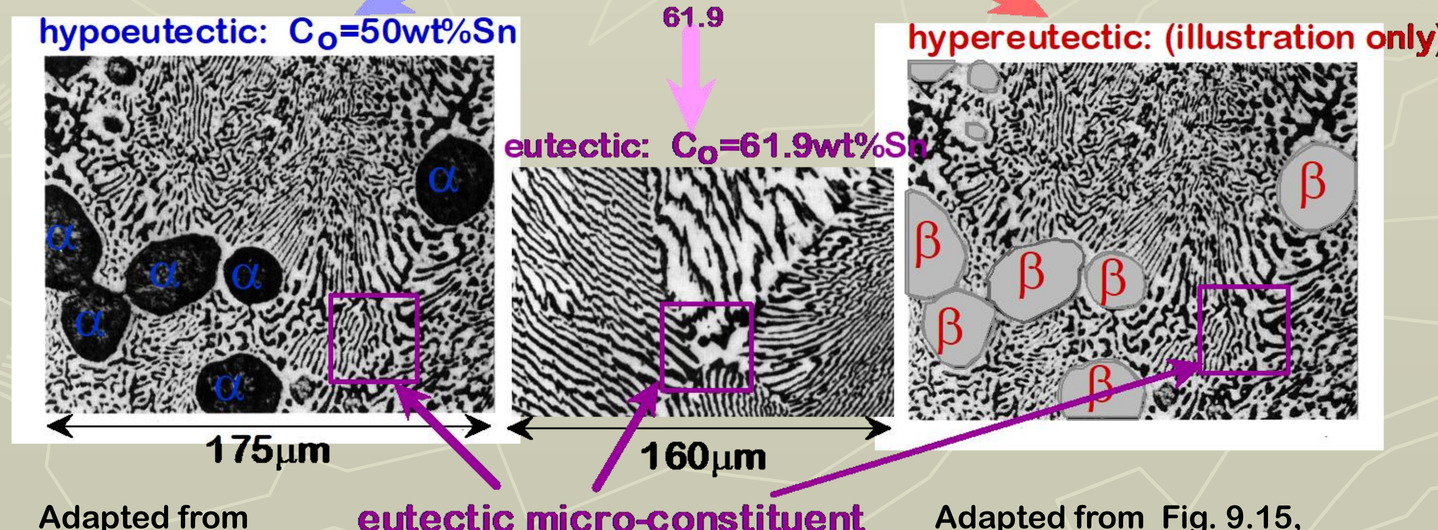
- **Just above T_E:**
  - $C_\alpha = 18.3wt\%Sn$
  - $C_L = 61.9wt\%Sn$
  - $W_\alpha = \frac{S}{R+S} = 50wt\%$
  - $W_L = (1-W_\alpha) = 50wt\%$
- **Just below T_E:**
  - $C_\alpha = 18.3wt\%Sn$
  - $C_\beta = 97.8wt\%Sn$
  - $W_\alpha = \frac{S}{R+S} = 73wt\%$
  - $W_\beta = 27wt\%$

HYPOEUTECTIC & HYPEREUTECTIC

Adapted from Fig. 9.7, *Callister 6e.* (Fig. 9.7 adapted from *Binary Phase Diagrams*, 2nd ed., Vol. 3, T.B. Massalski (Editor-in-Chief), ASM International, Materials Park, OH, 1990.)



(Figs. 9.12 and 9.15 from *Metals Handbook*, 9th ed., Vol. 9, *Metallography and Microstructures*, American Society for Metals, Materials Park, OH, 1985.)



Adapted from Fig. 9.15, *Callister 6e.*

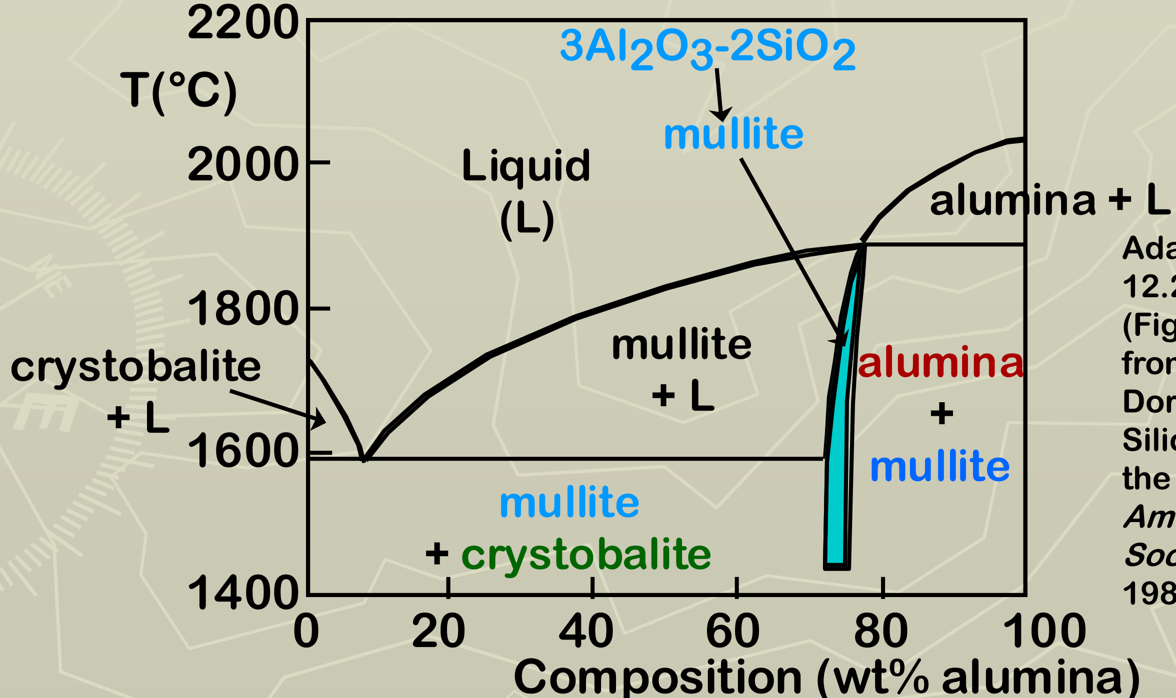
Adapted from Fig. 9.12, *Callister 6e.*

Adapted from Fig. 9.15, *Callister 6e.* (Illustration only)

APPLICATION: REFRACTORIES

- Need a material to use in high temperature furnaces.
- Consider Silica (SiO_2) - Alumina (Al_2O_3) system.
- Phase diagram shows:

  mullite, alumina, and crystobalite (made up of SiO_2) tetrahedra as candidate refractories.



Adapted from Fig. 12.27, *Callister 6e.* (Fig. 12.27 is adapted from F.J. Klug and R.H. Doremus, "Alumina Silica Phase Diagram in the Mullite Region", *J. American Ceramic Society* **70**(10), p. 758, 1987.)

SUMMARY

- Phase diagrams are useful tools to determine:

  --the number and types of phases,
  --the wt% of each phase,
  --and the composition of each phase

  for a given T and composition of the system.

- Alloying to produce a solid solution usually

  --increases the tensile strength (TS)
  --decreases the ductility.

- Binary eutectics and binary eutectoids allow for a range of microstructures.