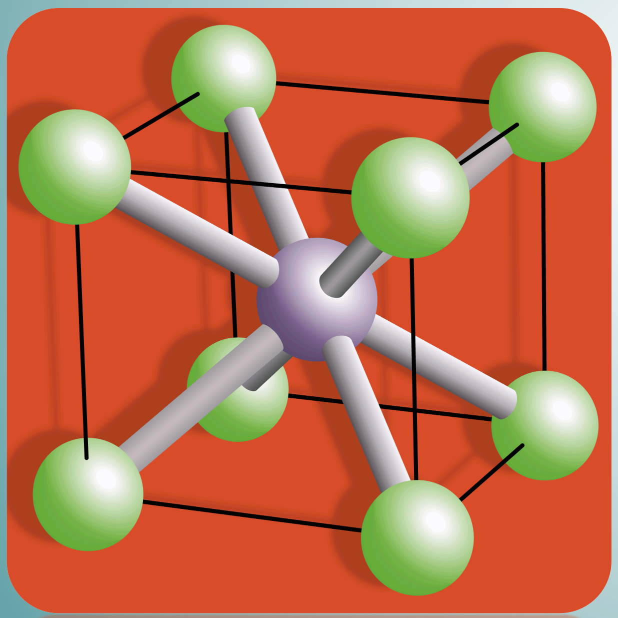
Materials

Topic 10. Phase diagrams



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10.1. INTRODUCTION

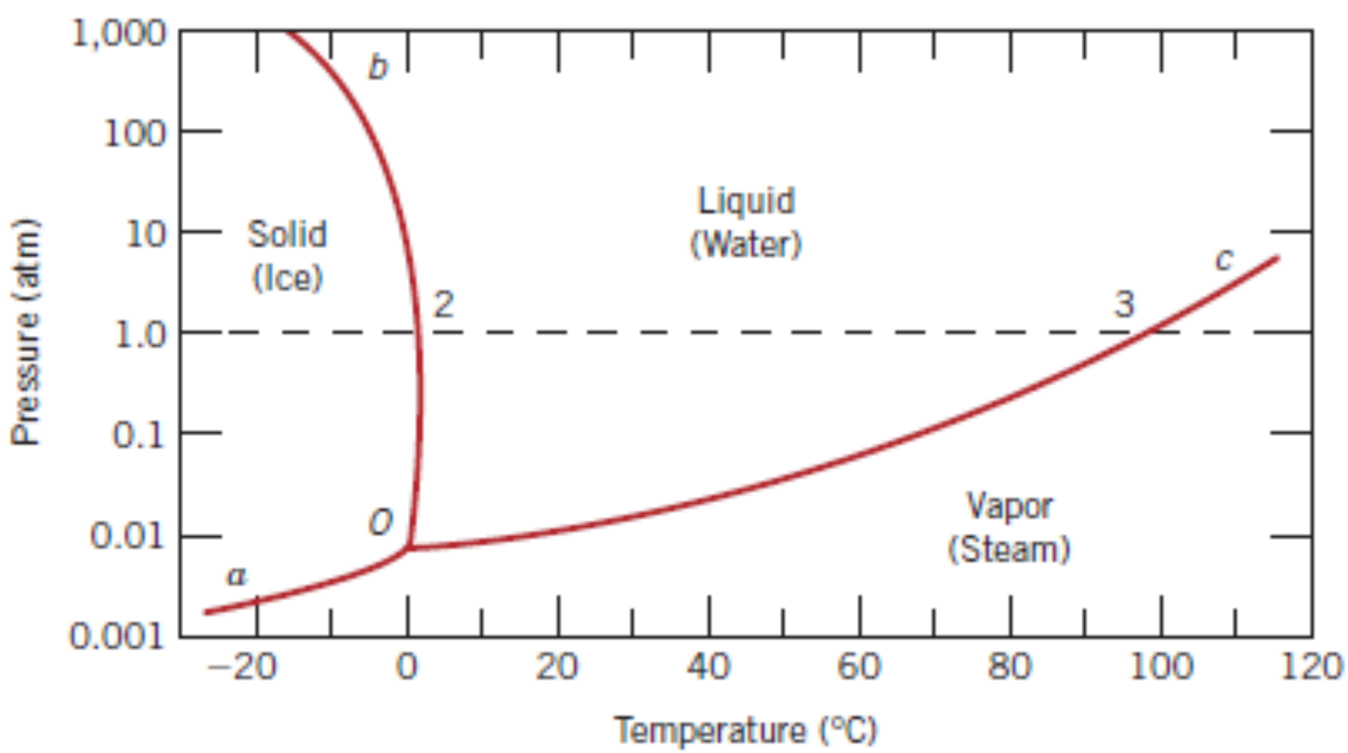
- A Phase is an homogeneous portion of a material system that has uniform physical and chemical characteristics. Microstructure is subject to direct microscopic observation, using optical or electron microscopes. In metal alloys, microstructure is characterized by the number of phases present, their proportions, and the way they are distributed or arrange.

- Phase Diagrams (or equilibrium diagrams) are graphical representations of the phases present in a material system at different temperatures, pressures and compositions.

- The information that can be obtain from the phase diagrams is the following:
  1) The phases present in the system at different compositions and temperatures under conditions of slow cooling (equilibrium).
  2) The temperature at which the different phases begin to melt.
  3) The presence of alotropy or solid-state polymorphism phenomena.

10.2. ONE-COMPONENT (OR UNITARY) PHASE DIAGRAMS

- A pure substance such as water can exist in the solid, liquid and gaseous phases, depending on the conditions of temperature and pressure.



10.3. GIBSS PHASE RULE

- The **Gibbs phase rule** represents a criterion for the number of phases that will coexist within a system at equilibrium, and it is expressed by the simple equation:

$$F + P = C + 2$$

- «P» is the number of phases present, «F» is the number of degrees of freedom or the number of externally controlled variables (e.g. temperature, pressure, composition), «C» is the number of components of the system and «2» is the number of non-compositional variables (e.g. temperature and pressure).

- If pressure is constant (1 atm): $F + P = C + 1$

$\left.\begin{array}{l} C = 1 \\ P = 1 \end{array}\right\}$ F = 2 (P, T)

$\left.\begin{array}{l} C = 1 \\ P = 2 \end{array}\right\}$ F = 1 ; P = P (T)

$\left.\begin{array}{l} C = 2 \\ P = 1 \end{array}\right\}$ F = 3 (P, T, C)

$\left.\begin{array}{l} C = 2 \\ P = 2 \end{array}\right\}$ F = 2 (P, T)

10.4. SOLID SOLUTIONS

- **Solution:** macroscopically homogeneous mixture of one substance (solute) dispersed in another (solvent).
- **Solid solution:** solution in which both substances are solid (offers the possibility of order).
- When two or more substances are mixed in a liquid state it can happen that they are:

Complete solubility

Water and alcohol

Partialy soluble

Water and salt

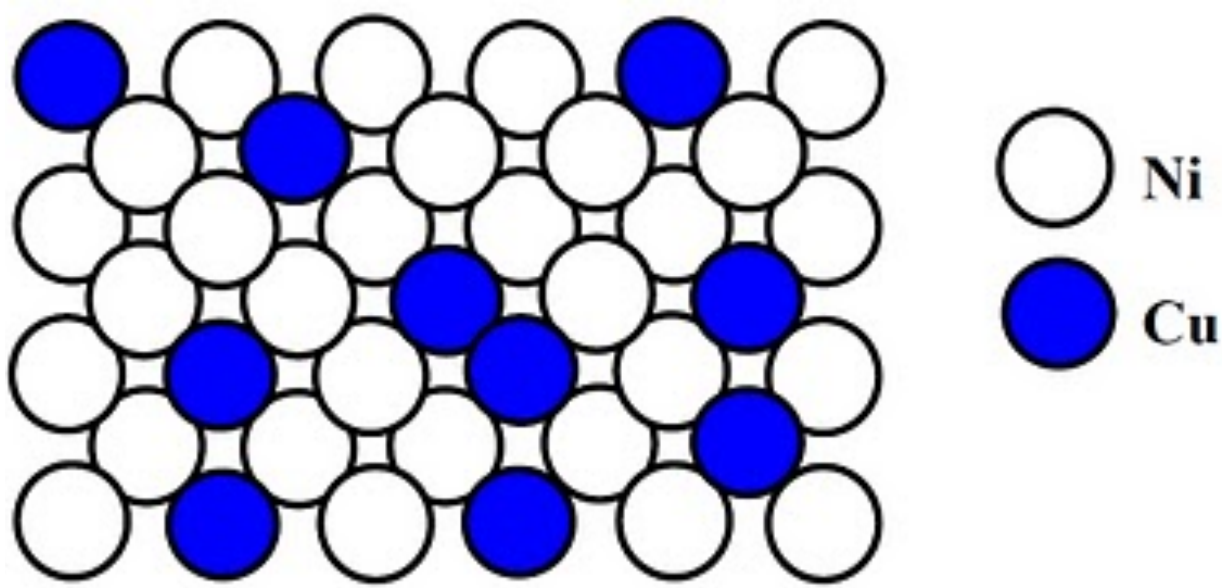
Salt

Complete insolubility

Oil

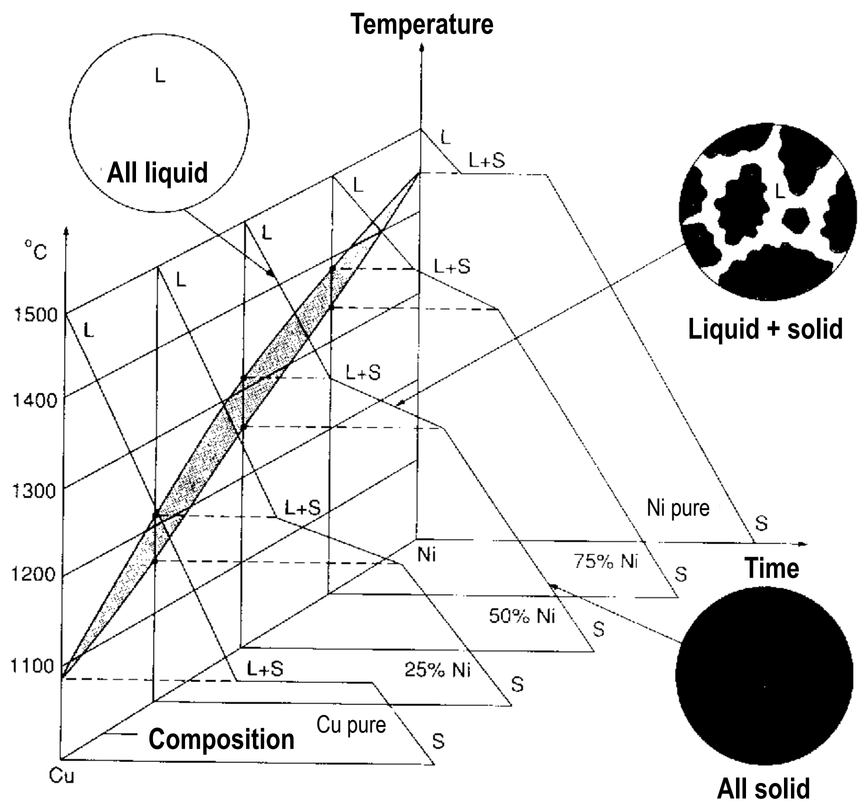
Water

- When solidifying it can happen that:
  - The solubility is total.
  - The solubility is partial.
  - The solubility is zero.
  - New chemical compounds are formed.
- All these possibilities are reflected in the phase diagrams.



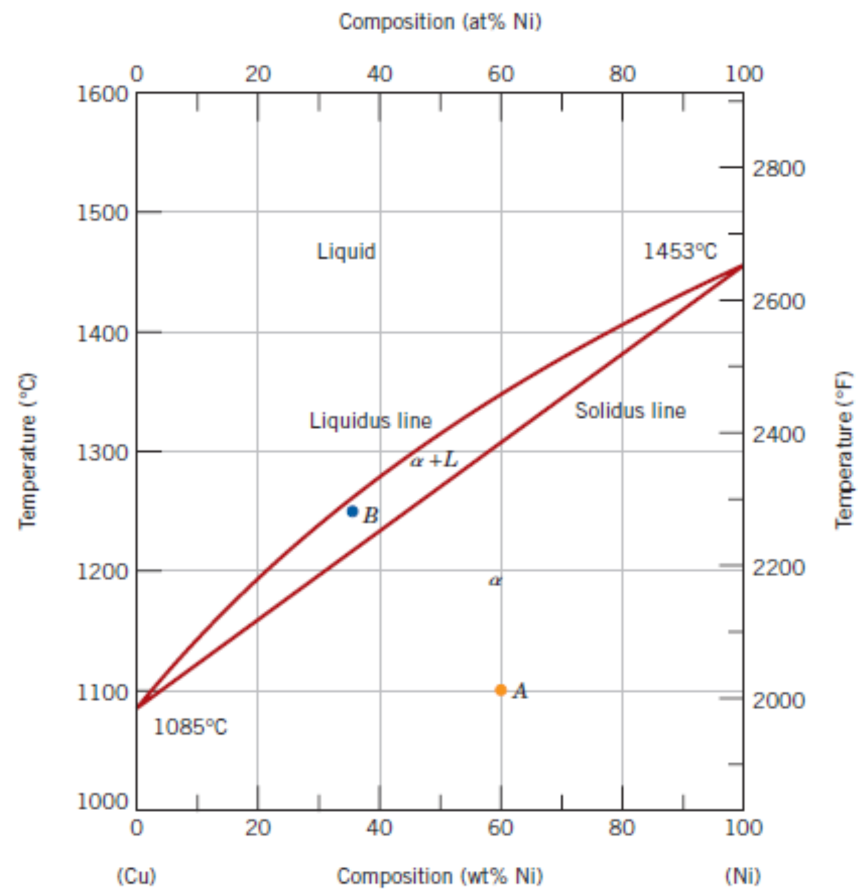
10.5. BINARY PHASE DIAGRAMS

- The phase diagrams are maps **temperature - composition** of systems (at P = cte.) that are obtained from a series of cooling curves.
- They show the existing **phases** and their **compositions** for any temperature and composition of the alloy, allowing to predict the transformations between phases and the resulting **microstructure**.

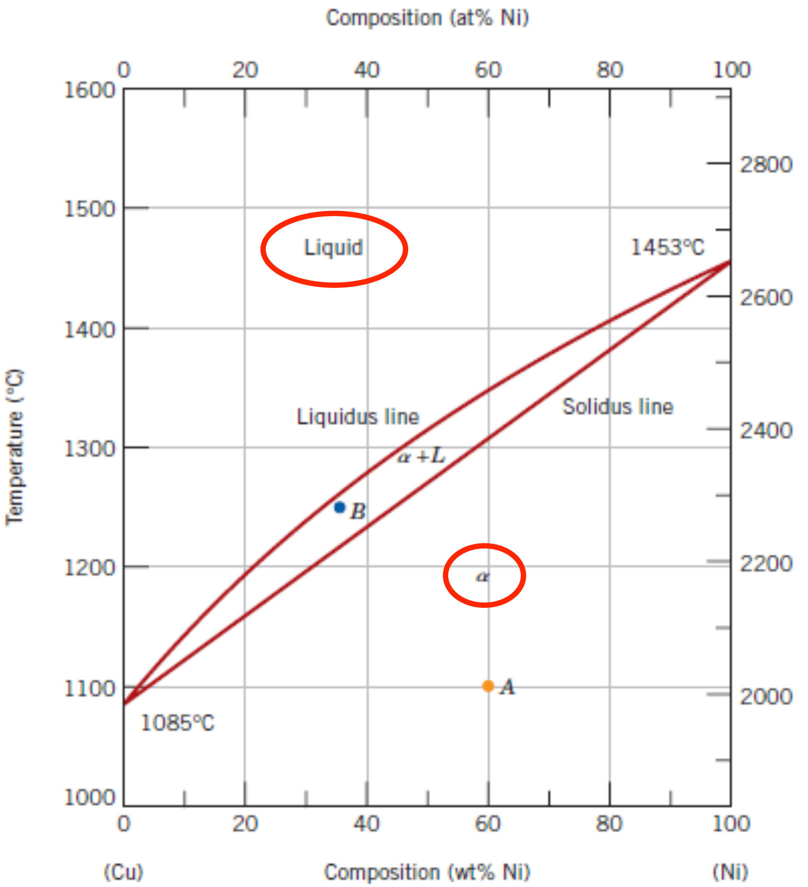


10.6. INTERPRETATION OF BINARY PHASE DIAGRAMS

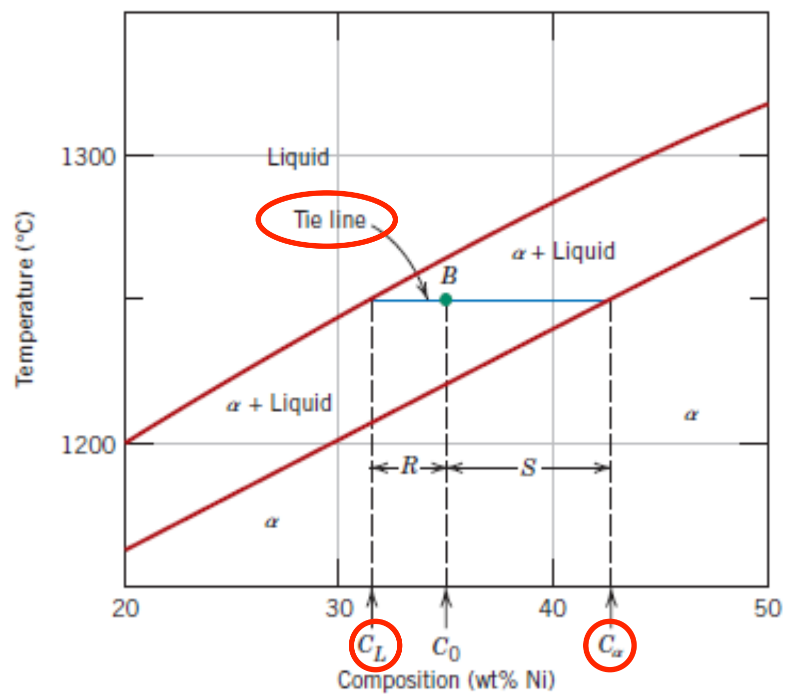
- **The constitution of an alloy is described by:**
  - **The overall composition of the alloy.**
  - **The number of phases present.**
  - **The composition of each phase.**
  - **The fraction, percentage or proportion by weight of each phase.**



- **Monophasic regions:**
  1) **The chemical composition of the phase coincides with the total composition of the original alloy.**
  2) **Physically, the alloy will consist of 100% homogeneous liquid phase or 100% homogeneous solid phase.**



- **Biphasic regions**:
  1) **At the temperature of interest for the alloy under consideration, the distribution line (isotherm) is constructed, which connects two phases (L and S, in this case) through the biphasic region.**
  2) **The chemical composition of the two phases (C_L and C_S) is given by the intersections of this line with those of the phase limits at each end, moved vertically downwards and read directly on the horizontal axis of the compositions.**
  3) **The proportion or percentage of each phase is calculated based on the Lever Rule.**

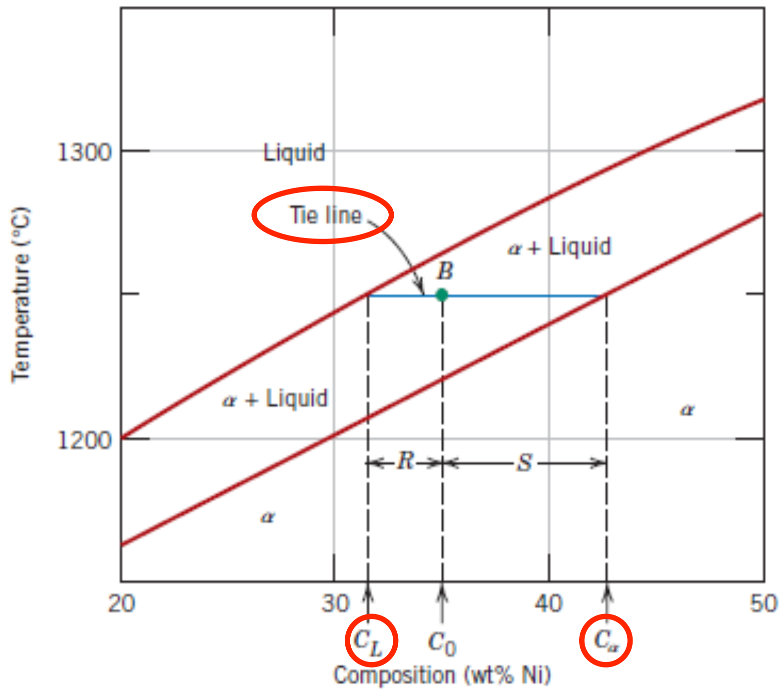


- **Percentage of liquid phase of composition C_L:** $W_L = \dfrac{R}{R+S} = \dfrac{C_0 - C_S}{C_L - C_S}$

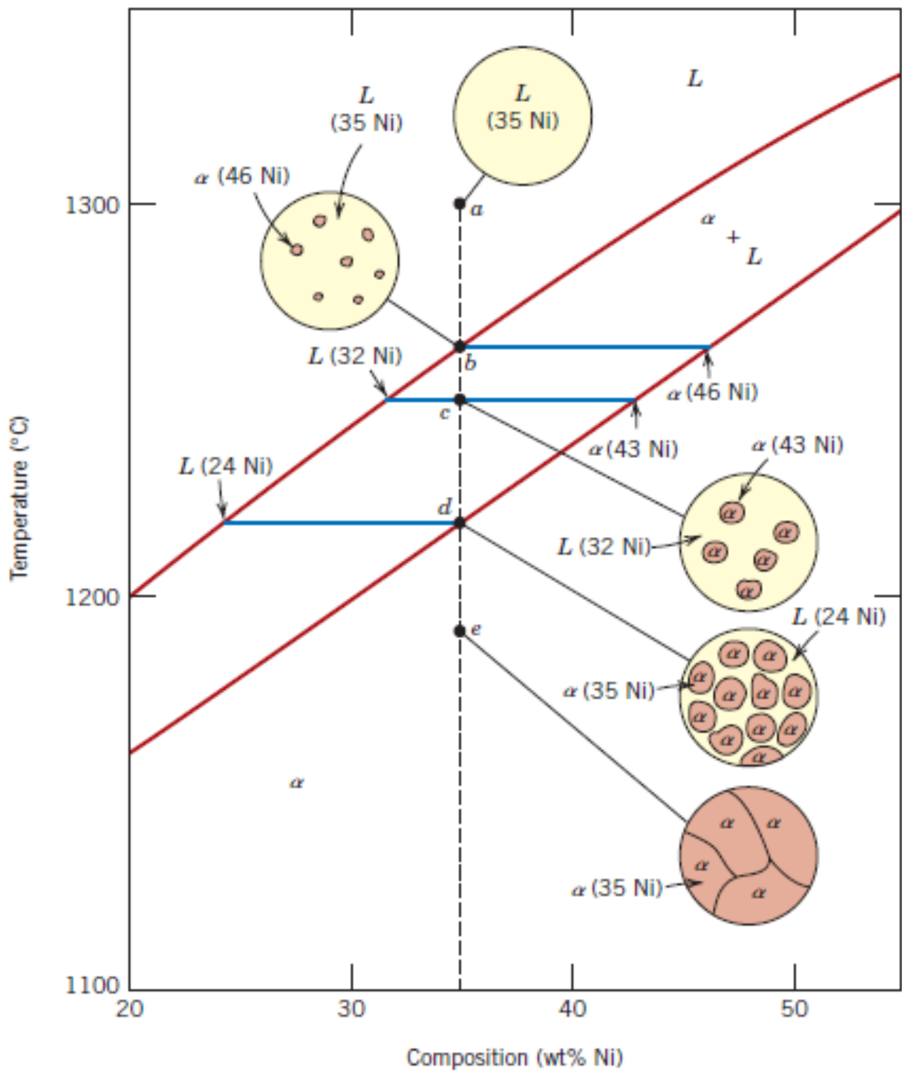
- **Percentage of solid phase of composition C_S:** $W_S = \dfrac{S}{R+S} = \dfrac{C_L - C_0}{C_L - C_S}$

- **As there are only two phases involved it is verified that:**

$$W_L + W_S = 1 \quad ; \quad W_L(\%) + W_S(\%) = 100$$

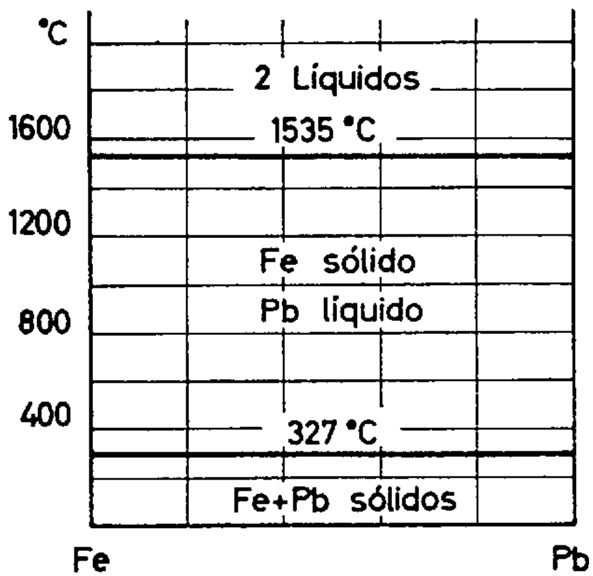


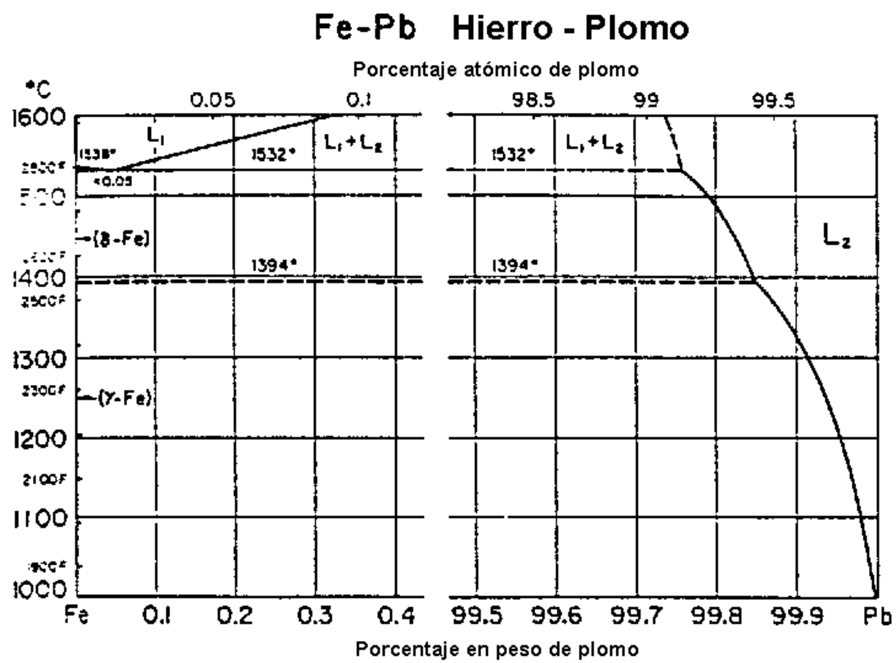
- **Development of microstructure**:



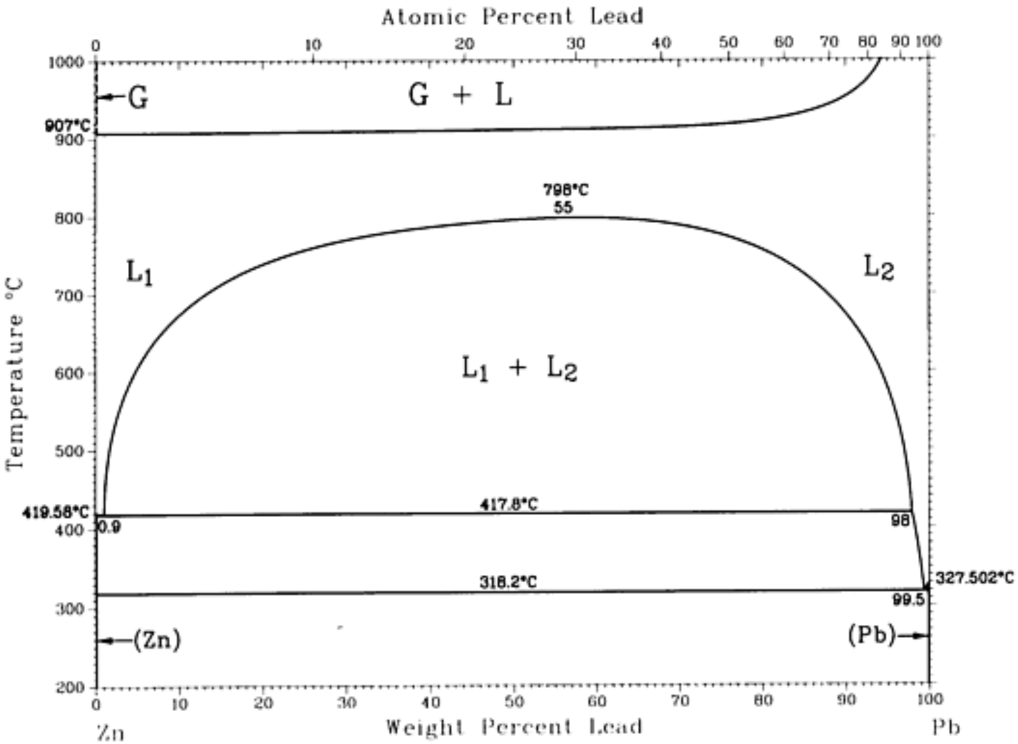
10.7. TYPES OF PHASE DIAGRAMS

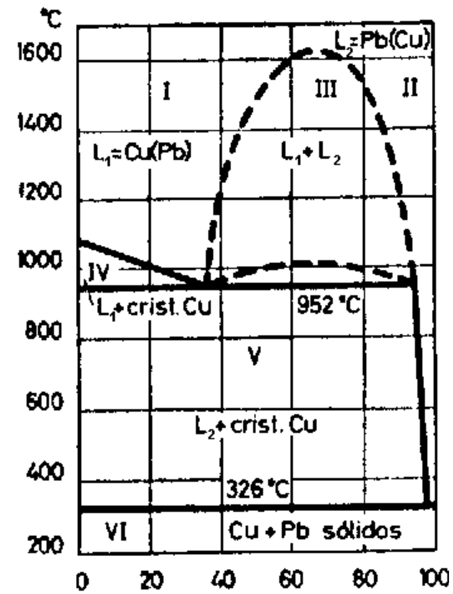
- **Total imiscibility in liquid state.**

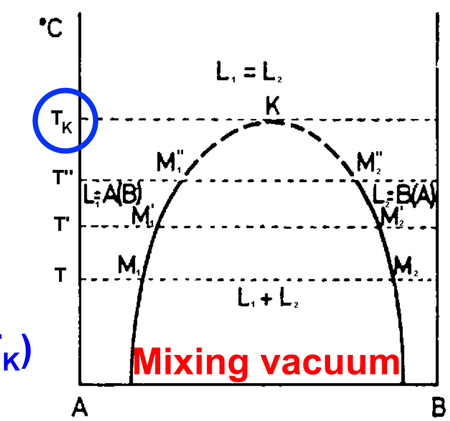




- **Liquid partial miscibility. Diagrams with MONOTECTIC.**
- **Monotectic: invariant point (f = 0) at which a liquid (L_1) is transformed into another liquid (L_2) and a solid α.**
- **Monotectic reaction:** $L_1 \rightarrow L_2 + \alpha$

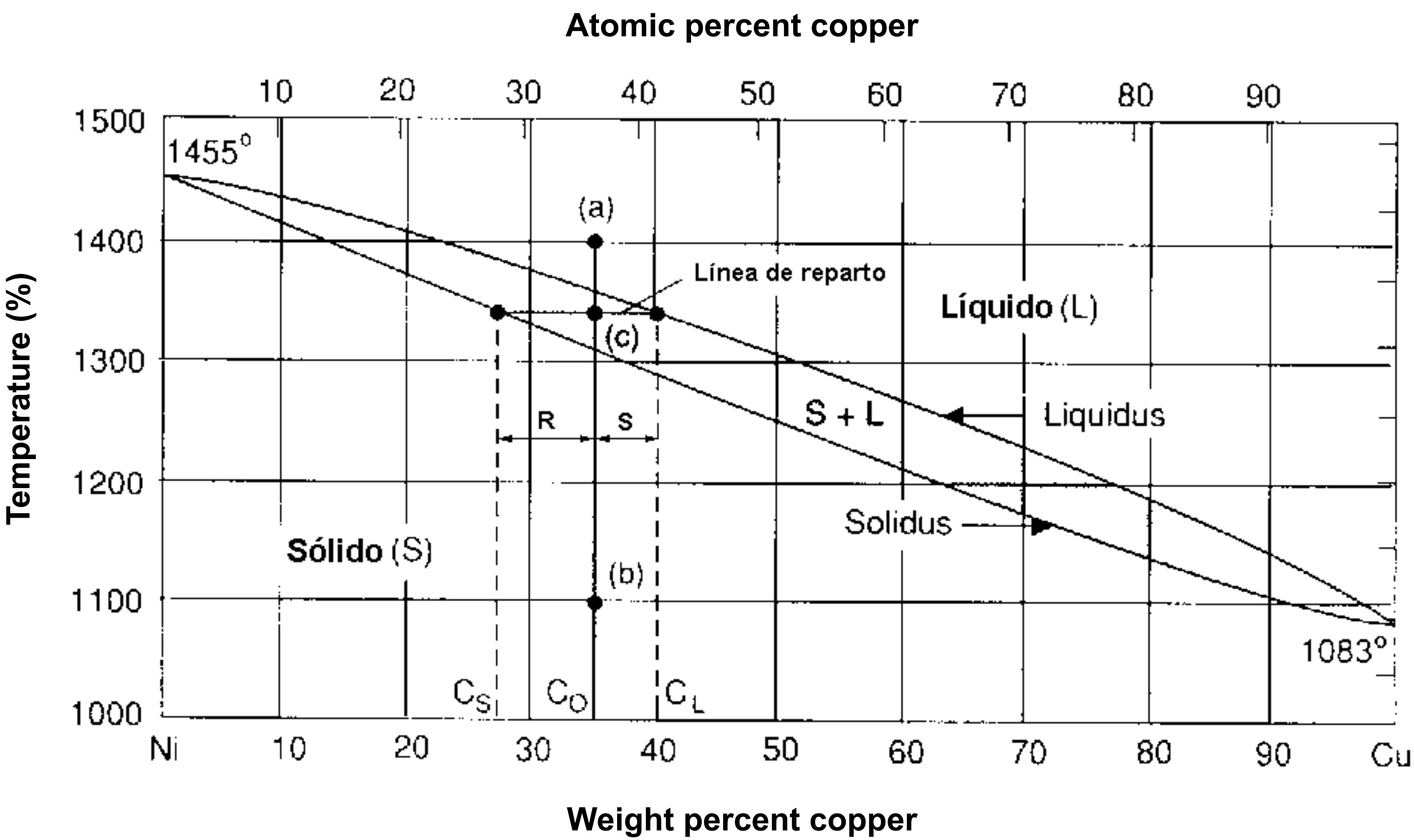




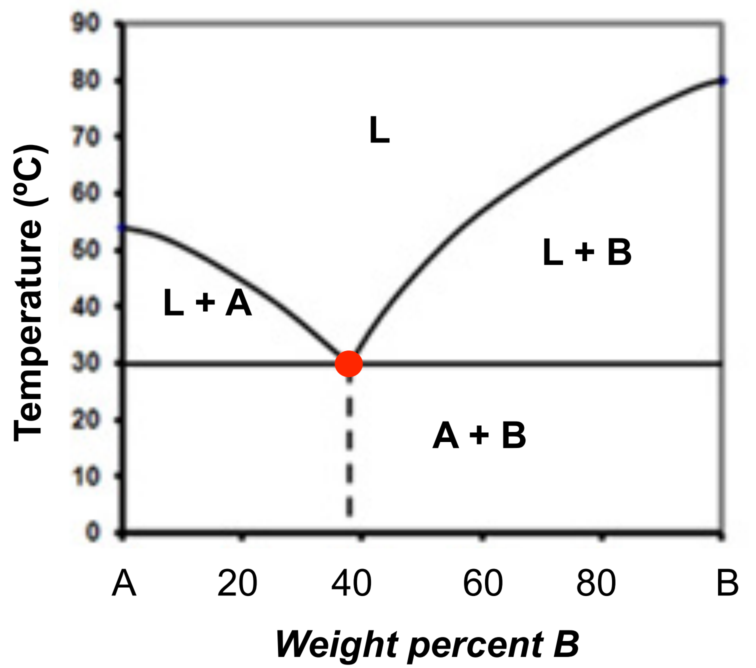


Critical solubility temperatura (T_K)

- **Total solubility in solid and liquid state. Isomorphic systems.**



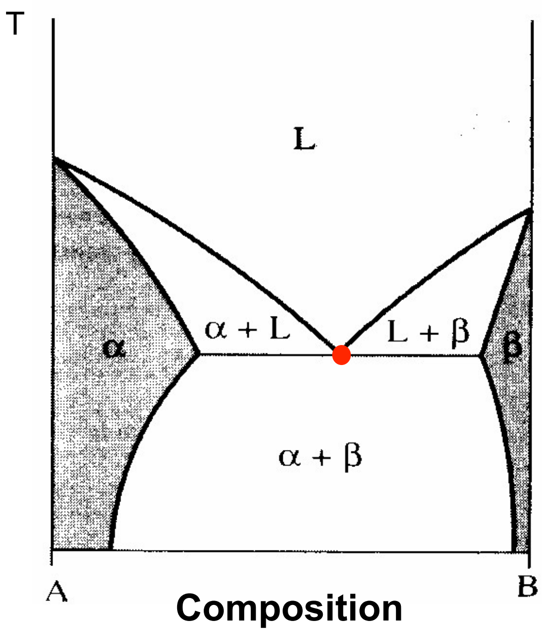
- **Total solubility in liquid state and null in solid. EUTECTIC Diagram.**
- **Eutectic: invariant point (f = 0) at which a liquid (L) is transformed into two other different solids (α and β).**

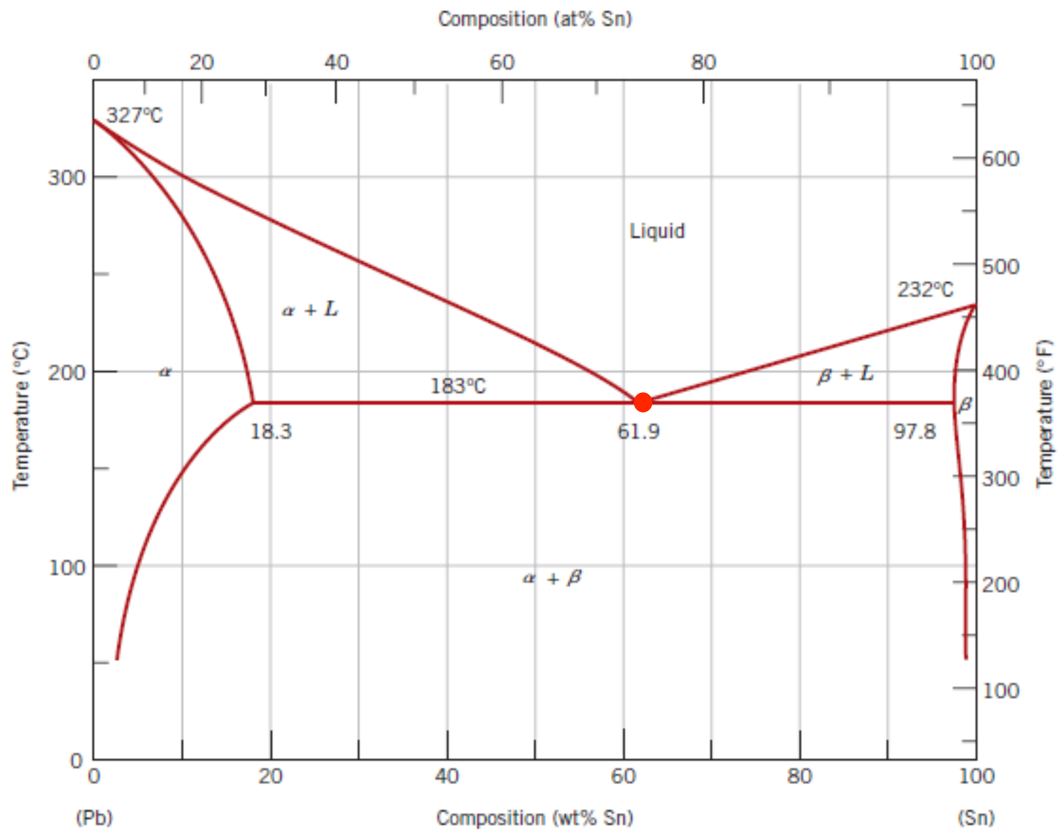


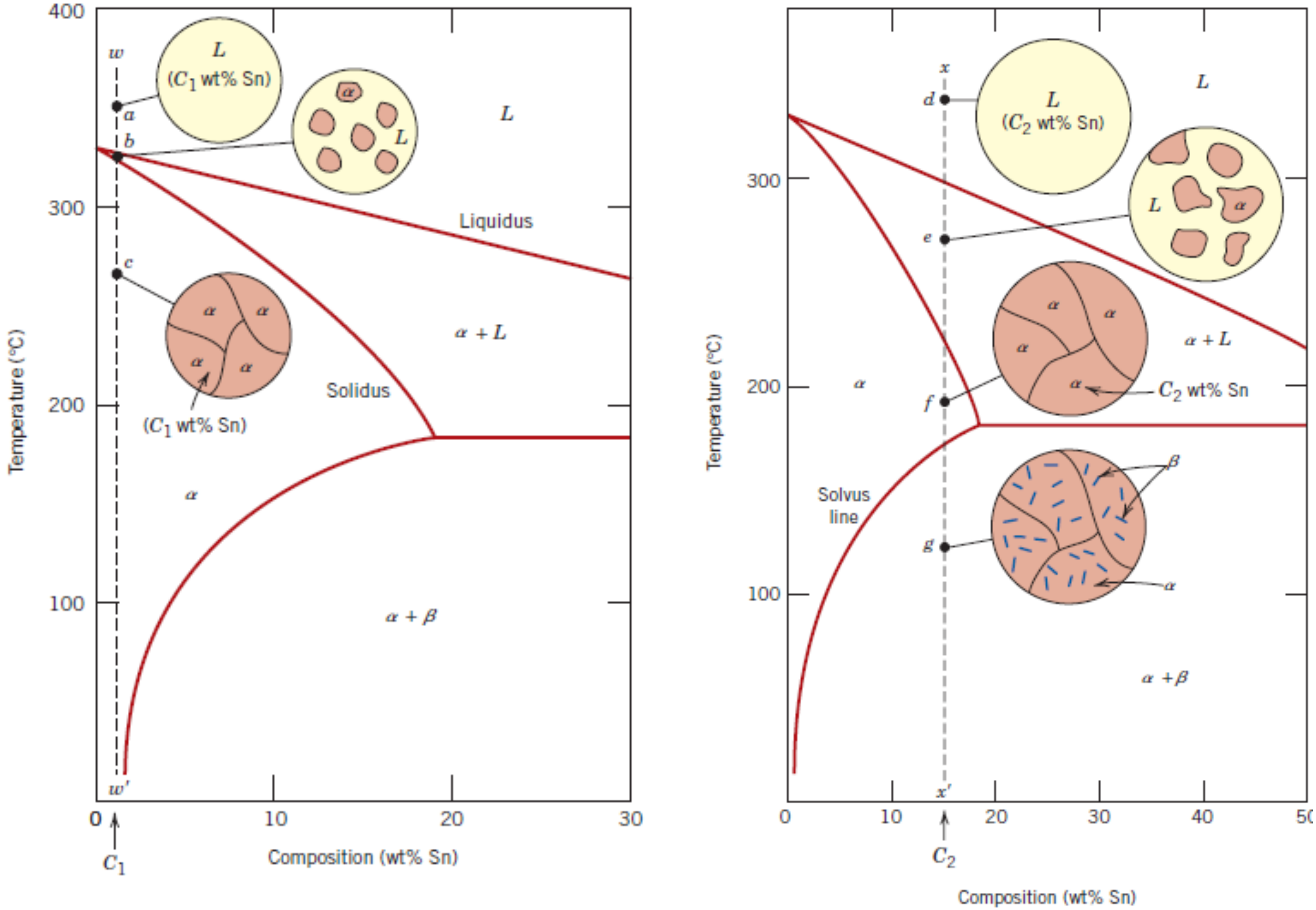
Eutectic reaction:

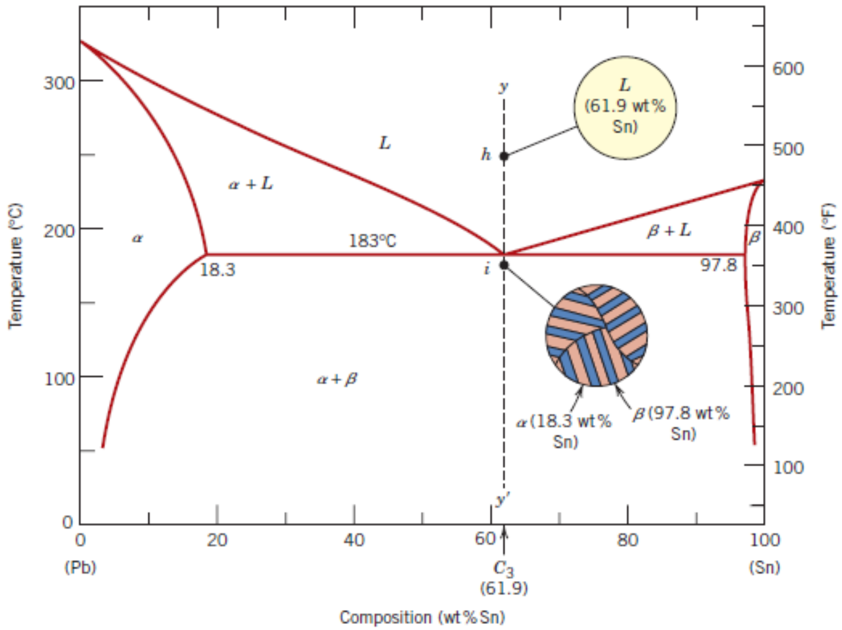
$$L \rightarrow \alpha + \beta$$

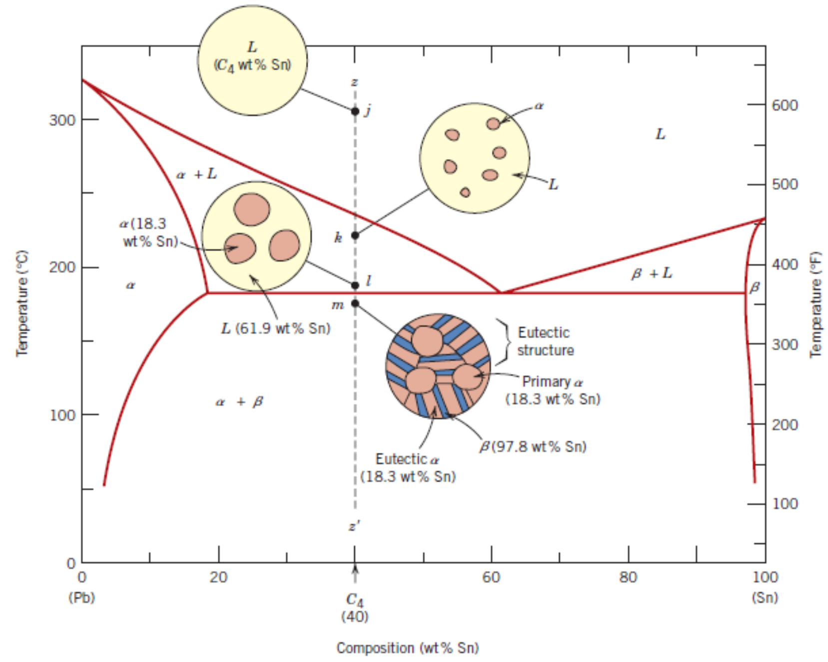
- **Total solubility** in liquid state and **partial** solubility in solid state. Diagrams with **EUTECTIC.**

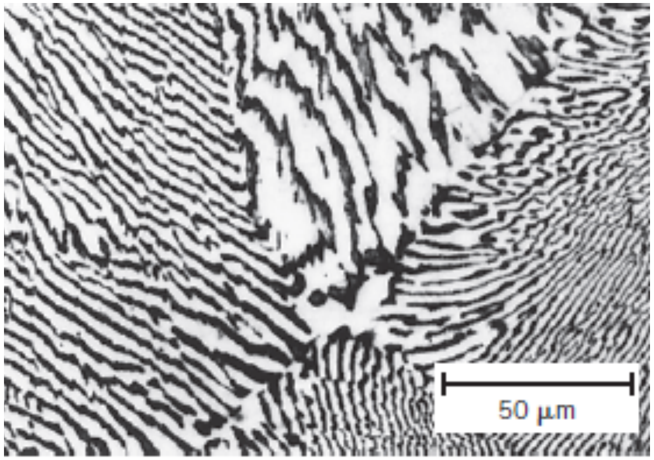


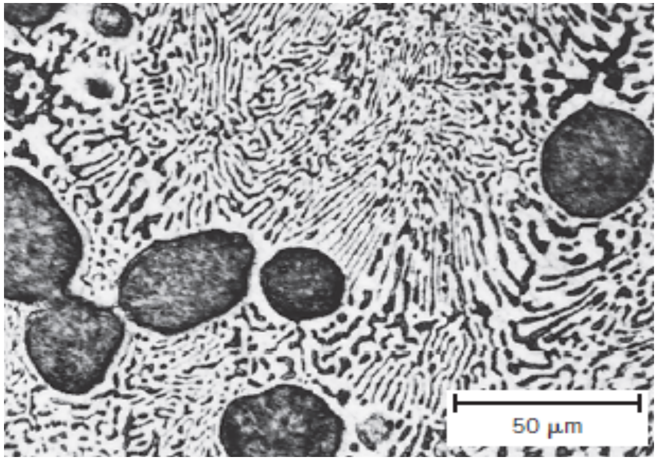



400
300
200
100
0
10
20
30
w
a
b
c
w'
L
(C_1 wt% Sn)
α
L
Liquidus
α + L
α
α
α
α
Solidus
(C_1 wt% Sn)
α
α + β
C_1
Composition (wt% Sn)
Temperature (°C)
300
200
100
0
10
20
30
40
x
d
e
f
g
x'
L
(C_2 wt% Sn)
L
L
α
α
α
α
α
α + L
C_2 wt% Sn
α
β
α
Solvus line
α + β
C_2
Composition (wt% Sn)
Temperature (°C)

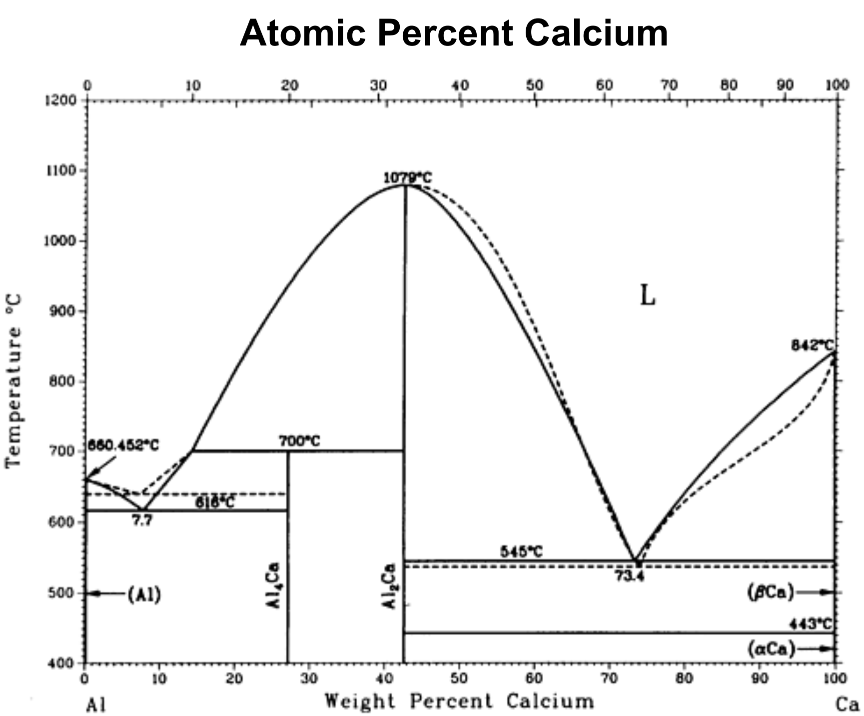

L
(61.9 wt% Sn)
y
h
L
α + L
α
183°C
β + L
β
18.3
i
97.8
α + β
α (18.3 wt% Sn)
β (97.8 wt% Sn)
y'
Temperature (°C)
Temperature (°F)
0
100
200
300
400
500
600
20
40
60
80
100
(Pb)
(Sn)
C_3
(61.9)
Composition (wt% Sn)


L
(C_4 wt% Sn)
z
j
α
L
α + L
k
α (18.3 wt% Sn)
l
m
L (61.9 wt% Sn)
β + L
β
Eutectic structure
Primary α (18.3 wt% Sn)
α + β
β (97.8 wt% Sn)
Eutectic α (18.3 wt% Sn)
z'
Temperature (°C)
Temperature (°F)
0
100
200
300
400
500
600
20
60
80
100
(Pb)
(Sn)
C_4
(40)
Composition (wt% Sn)

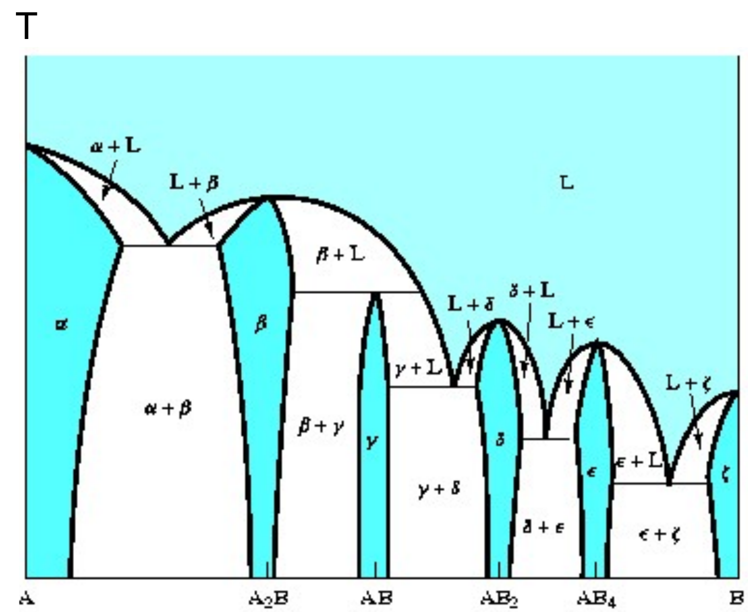

50 μm


50 μm

- **Equilibrium diagram with phases and/or intermediate compounds.**

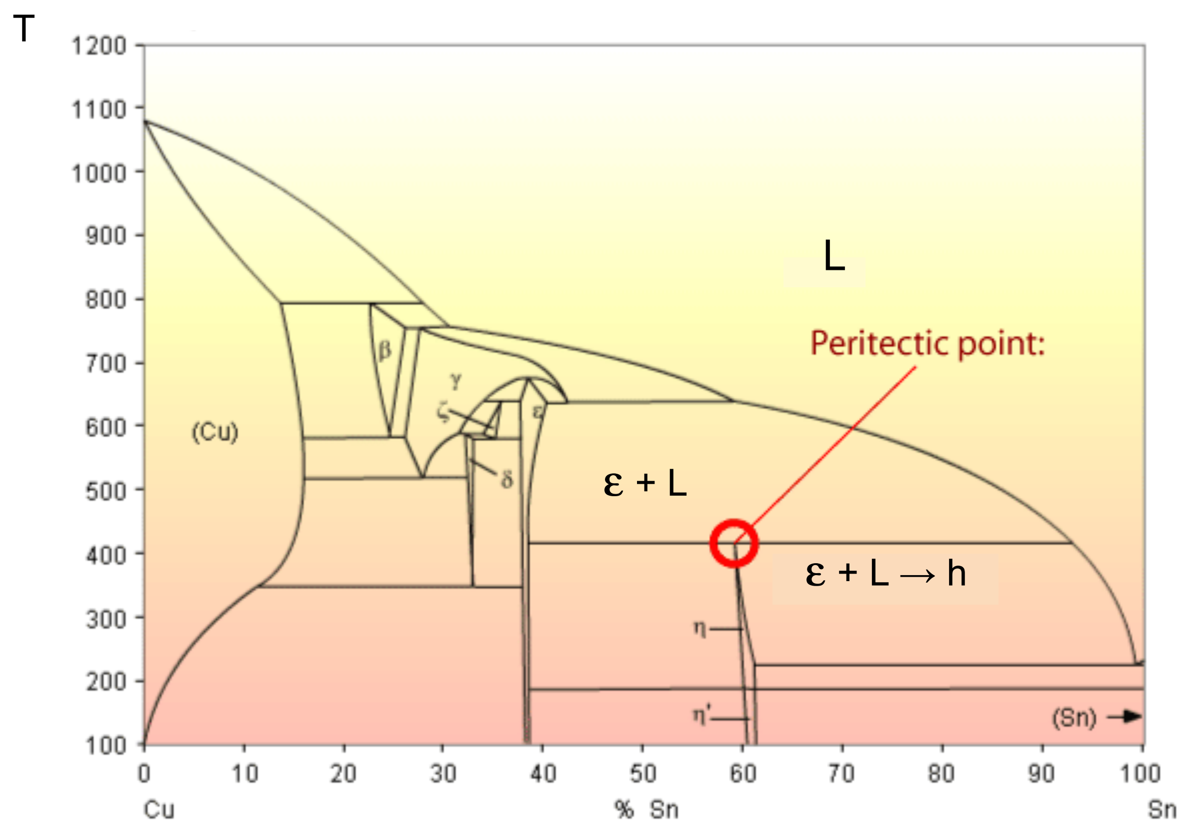


Dashed lines = calculated.



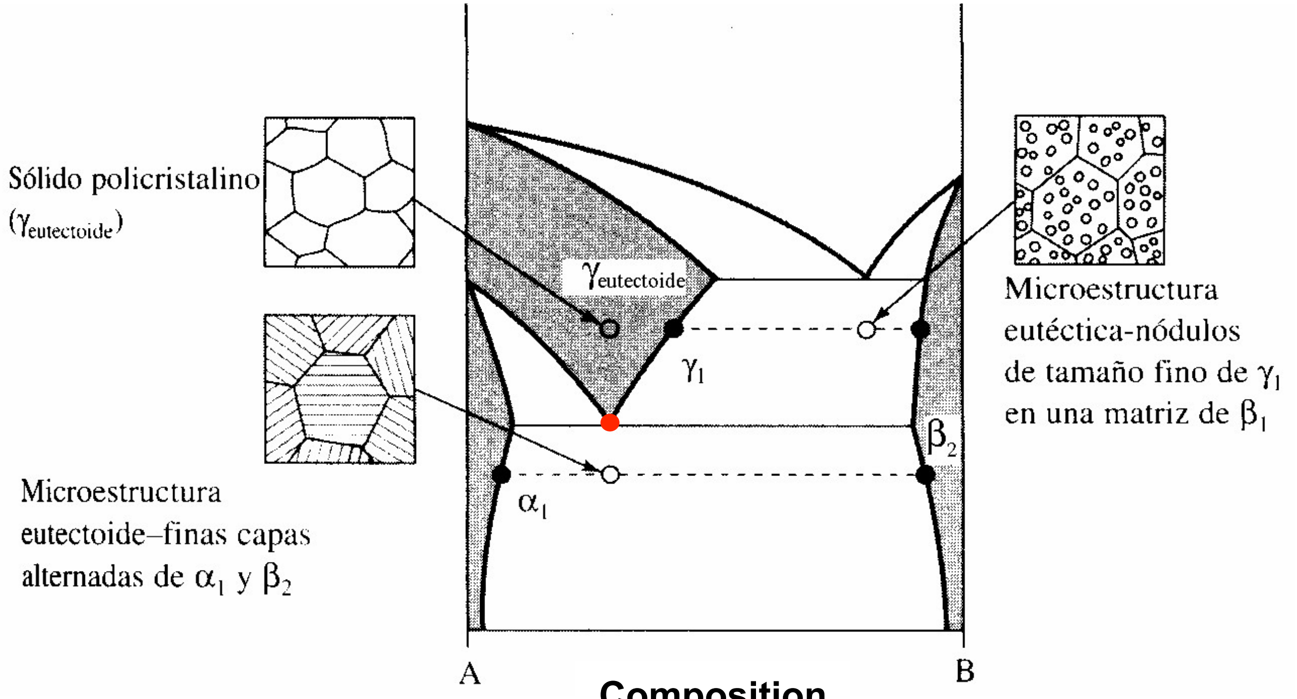
Composition, wt % B

- **Equilibrium diagram with PERITECTIC.**
- **Peritectic: invariant point (f = 0) at which a liquid (L) and a solid phase (α) are transformed into a different solid (β).**
- **Peritectic reaction:** $L + \alpha \rightarrow \beta$



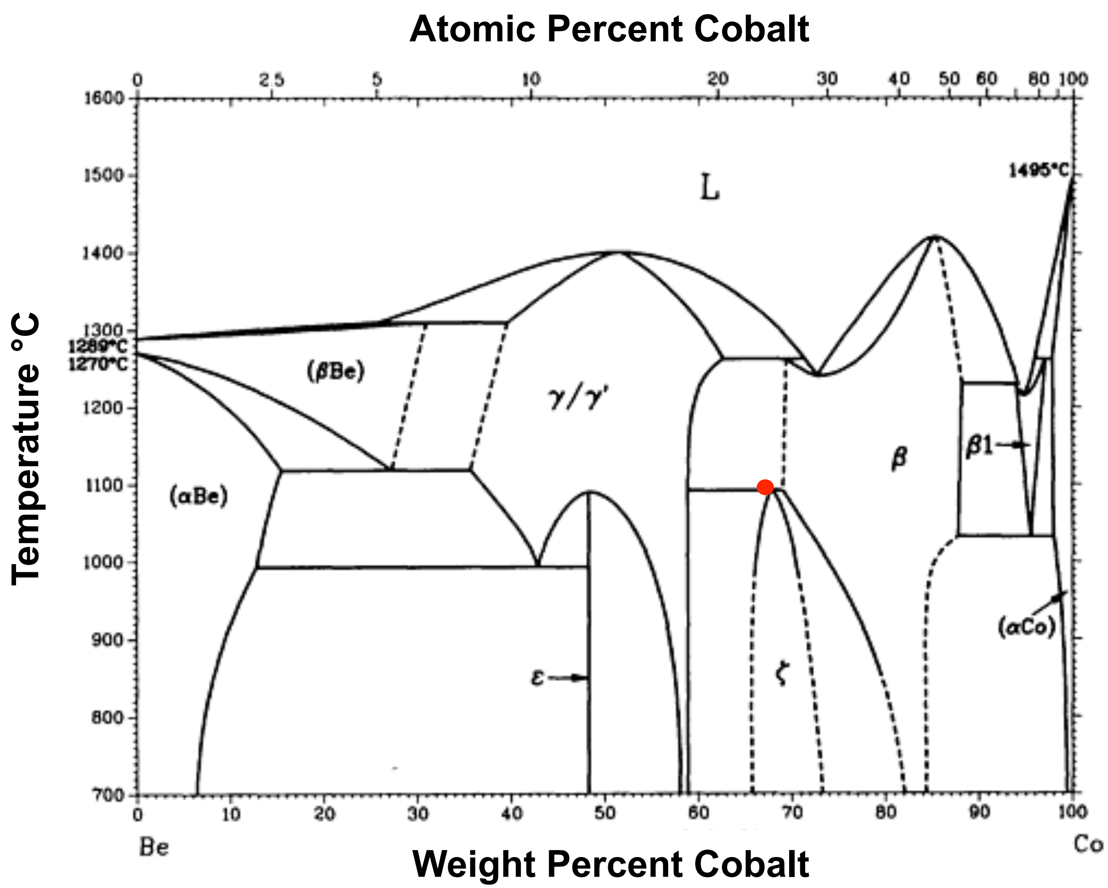
- **Equilibrium diagram with EUTECTOID.**
- **Eutectoid: invariant point (f = 0) at which a solid (γ) is transformed into two other different solids (α and β).**
- **Eutectoid reaction:** $\gamma \rightarrow \alpha + \beta$

Temperature

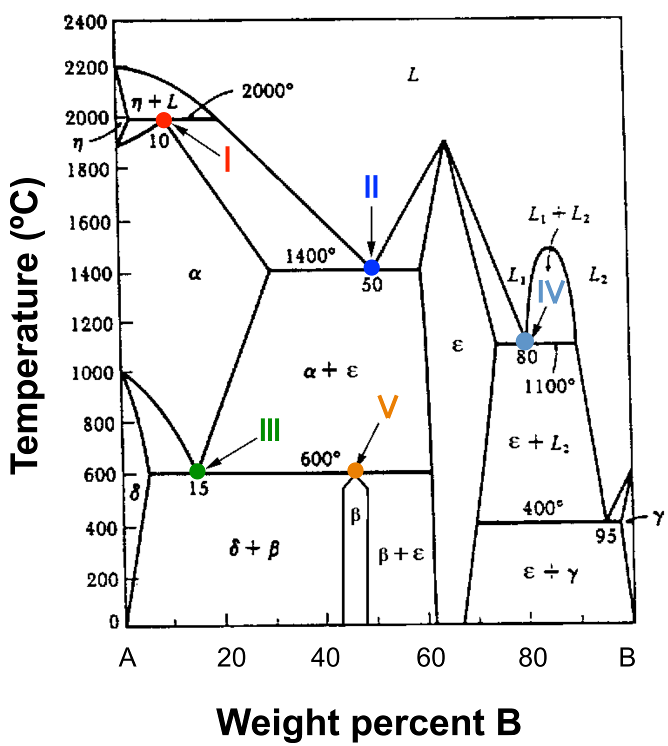


Composition

- **Equilibrium diagram with PERITECTOID.**
- **Peritectoid: invariant point (f = 0) at which two solids (α and β) are transformed into a different solid (γ).**
- **Peritectoid reaction:** $\alpha + \beta \rightarrow \gamma$



- **General Binary Phase Diagrams.**
    - **I. Peritectic.**
    - **II. Eutectic.**
    - **III. Eutectoid.**
    - **IV. Monotectic.**
    - **V. Peritectoid.**



Eutectic $L \rightarrow \alpha + \beta$

Peritectic $\alpha + L \rightarrow \gamma$

Monotectic $L_1 \rightarrow L_2 + \beta$

Eutectoid $\gamma \rightarrow \alpha + \beta$

Peritectoid $\alpha + \beta \rightarrow \gamma$