2015 Fall

"Phase Transformation *in* Materials"

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- Binary System mixture/ solution / compound

- Gibbs Free Energy in Binary System

$$G_1 = X_A G_A + X_B G_B \quad J/mol$$

$$G_2 = G_1 + \Delta G_{mix} \quad J/mol$$

Ideal solution ($\Delta H_{mix}=0$) $\Delta G^{mix} = RT(X_A \ln X_A + X_B \ln X_B)$

$$G = X_A G_A + X_B G_B + RT(X_A \ln X_A + X_B \ln X_B)$$

Regular solution $\Delta H_{mix} = P_{AB}\varepsilon$ where $\varepsilon = \varepsilon_{AB} - \frac{1}{2}(\varepsilon_{AA} + \varepsilon_{BB})$

$$G = X_A G_A + X_B G_B + \Omega X_A X_B + RT(X_A \ln X_A + X_B \ln X_B)$$

- Chemical potential and Activity

$$\mu_A = \left(\frac{\partial G'}{\partial n_A}\right)_{T,P,n_B}$$

- $\mu_A = G_A + RT\ln a_A$

$$\ln\left(\frac{a_A}{X_A}\right) = \frac{\Omega}{RT}(1-X_A)^2$$

$$\frac{a_A}{X_A} = \gamma_A = \text{activity coefficient}$$

μ는 조성에 의해 결정되기 때문에 dn_A가 매우 작아서 조성변화 없어야

- Chemical equilibrium

Regular Solutions

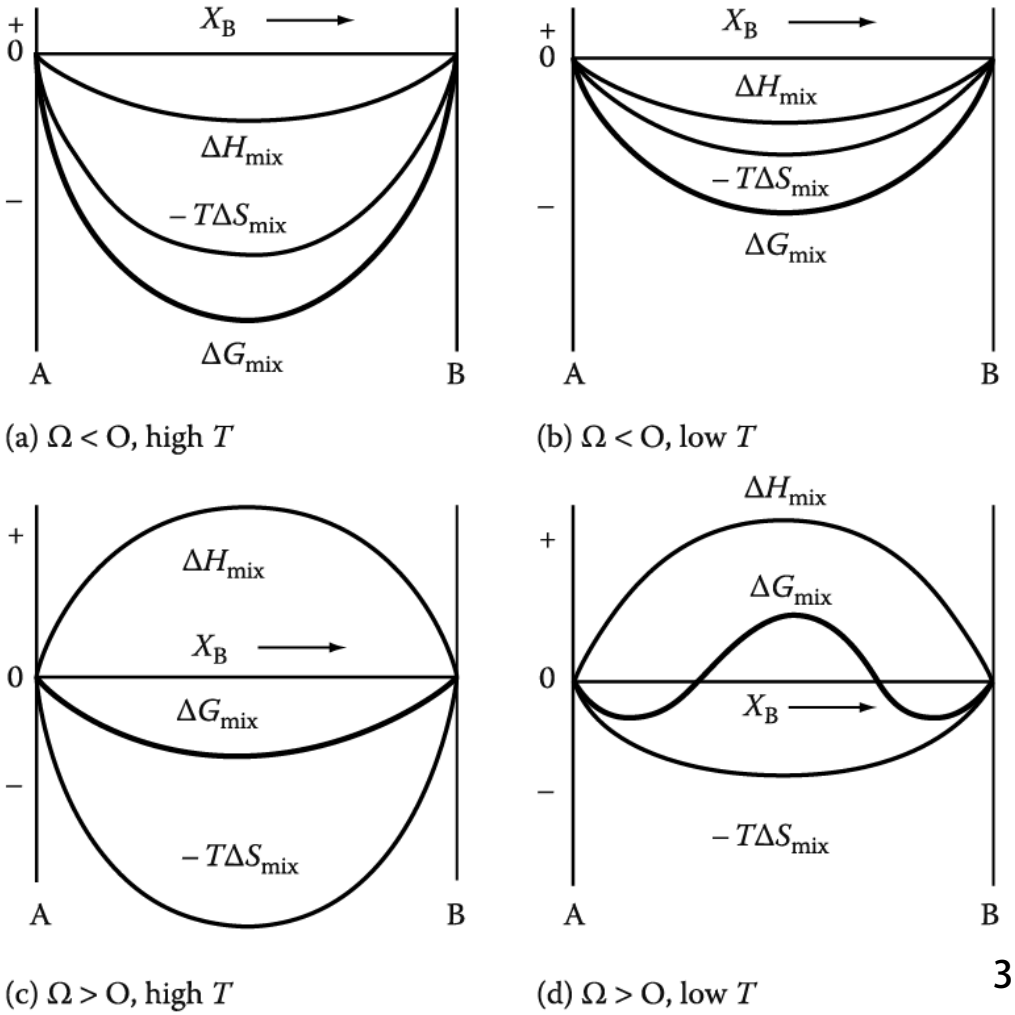
$$G_2 = G_1 + \Delta G_{mix}$$

$$G = X_A G_A + X_B G_B + \underbrace{\Omega\, X_A X_B}_{\Delta H_{mix}} + \underbrace{RT\,(X_A \ln X_A + X_B \ln X_B)}_{-T\Delta S_{mix}}$$

Reference state

Pure metal $G_A^0 = G_B^0 = 0$

$$\Delta G_{mix} = \Delta H_{mix} - T\Delta S_{mix}$$



(a) Ω < O, high T

(b) Ω < O, low T

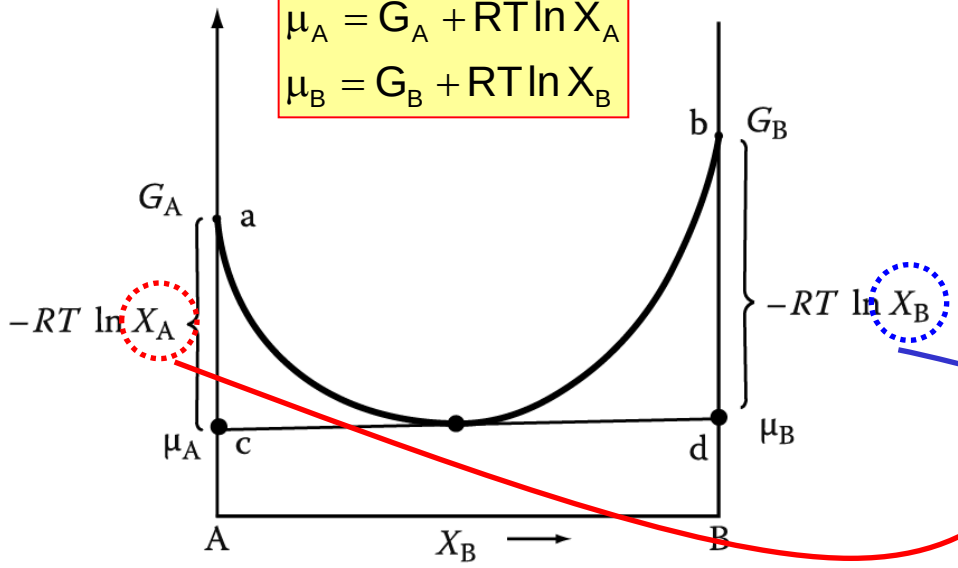
(c) Ω > O, high T

(d) Ω > O, low T

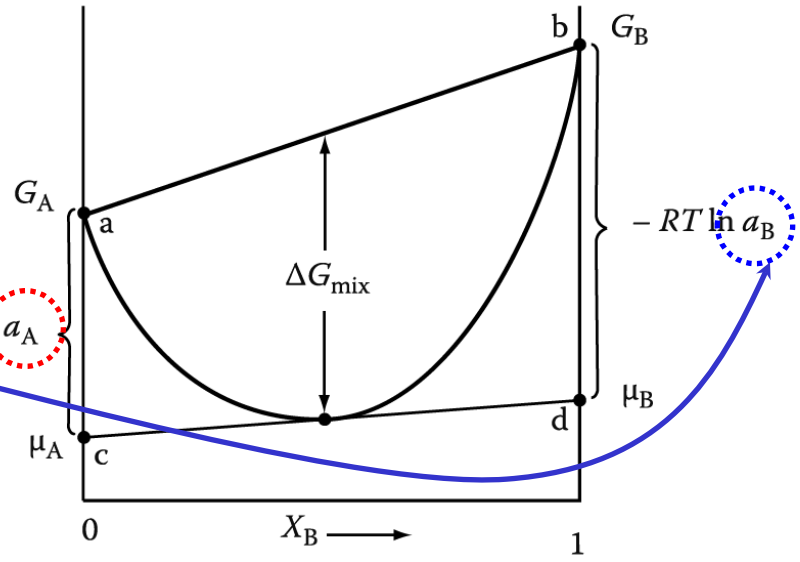
Activity, a : effective concentration for mass action

ideal solution

$$\mu_A = G_A + RT\ln X_A$$
$$\mu_B = G_B + RT\ln X_B$$



regular solution



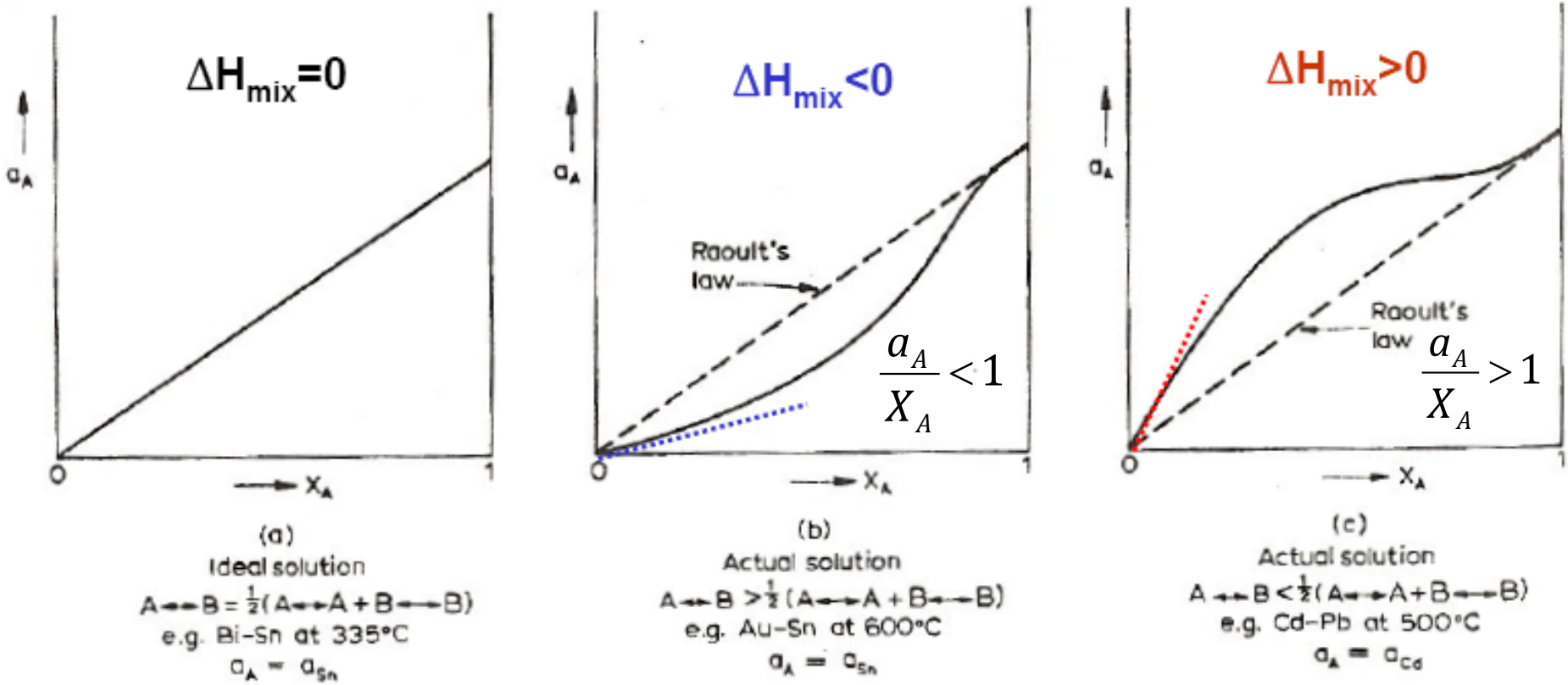
$$\mu_A = G_A + RT\ln a_A \qquad \mu_B = G_B + RT\ln a_B$$

$$\mu_A = G_A + \Omega(1-X_A)^2 + RT\ln X_A \qquad \mu_B = G_B + \Omega(1-X_B)^2 + RT\ln X_B$$

$$\ln\left(\frac{a_A}{X_A}\right) = \frac{\Omega}{RT}(1-X_A)^2 \qquad \ln\left(\frac{a_B}{X_B}\right) = \frac{\Omega}{RT}(1-X_B)^2$$

$$\frac{a_A}{X_A} = \gamma_A = \text{activity coefficient} \qquad \gamma_B = \frac{a_B}{X_B}$$

Activity-composition curves for solutions



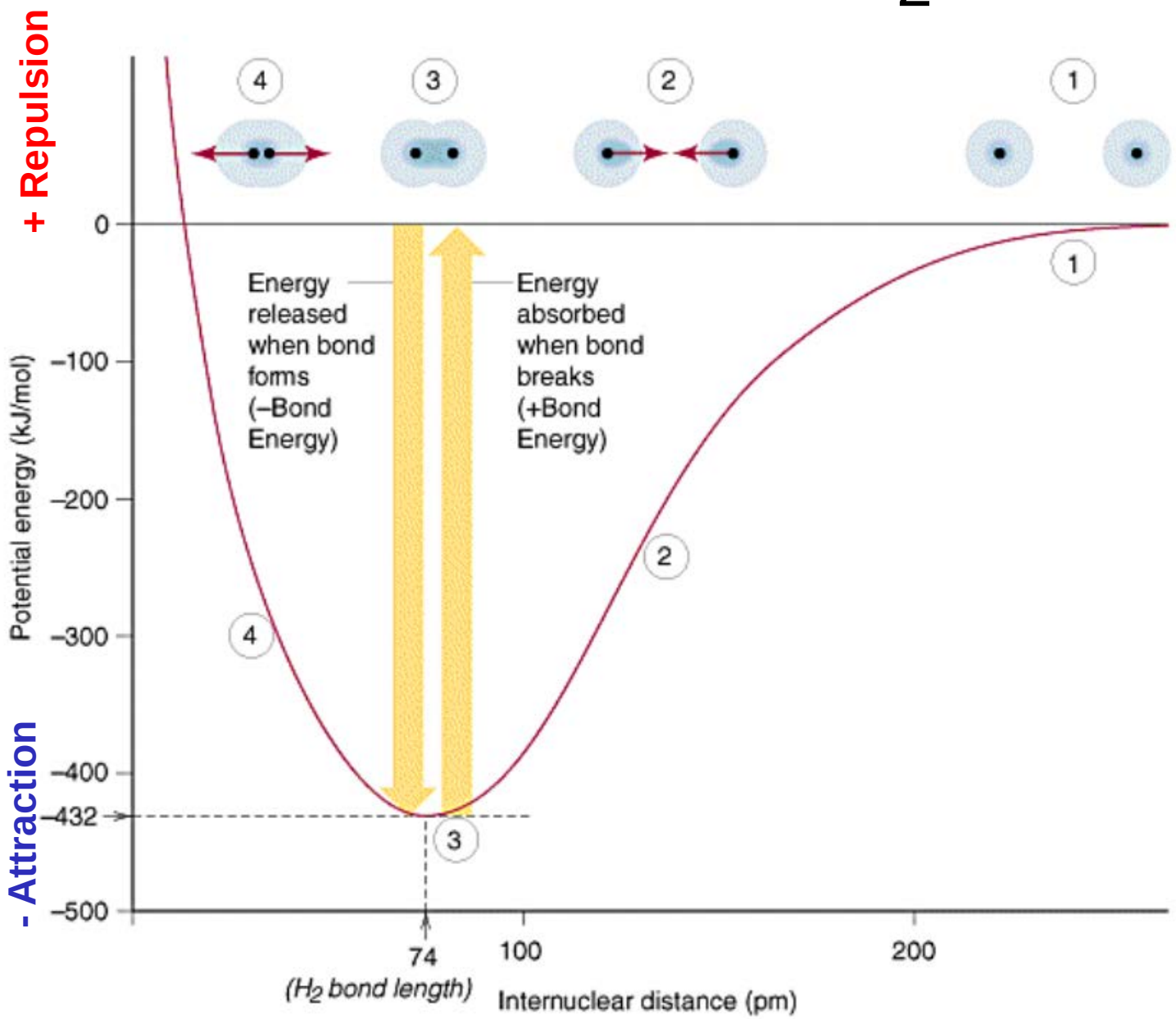
Degree of non-ideality

- **For a dilute solution of B in A ($X_B \to 0$)**

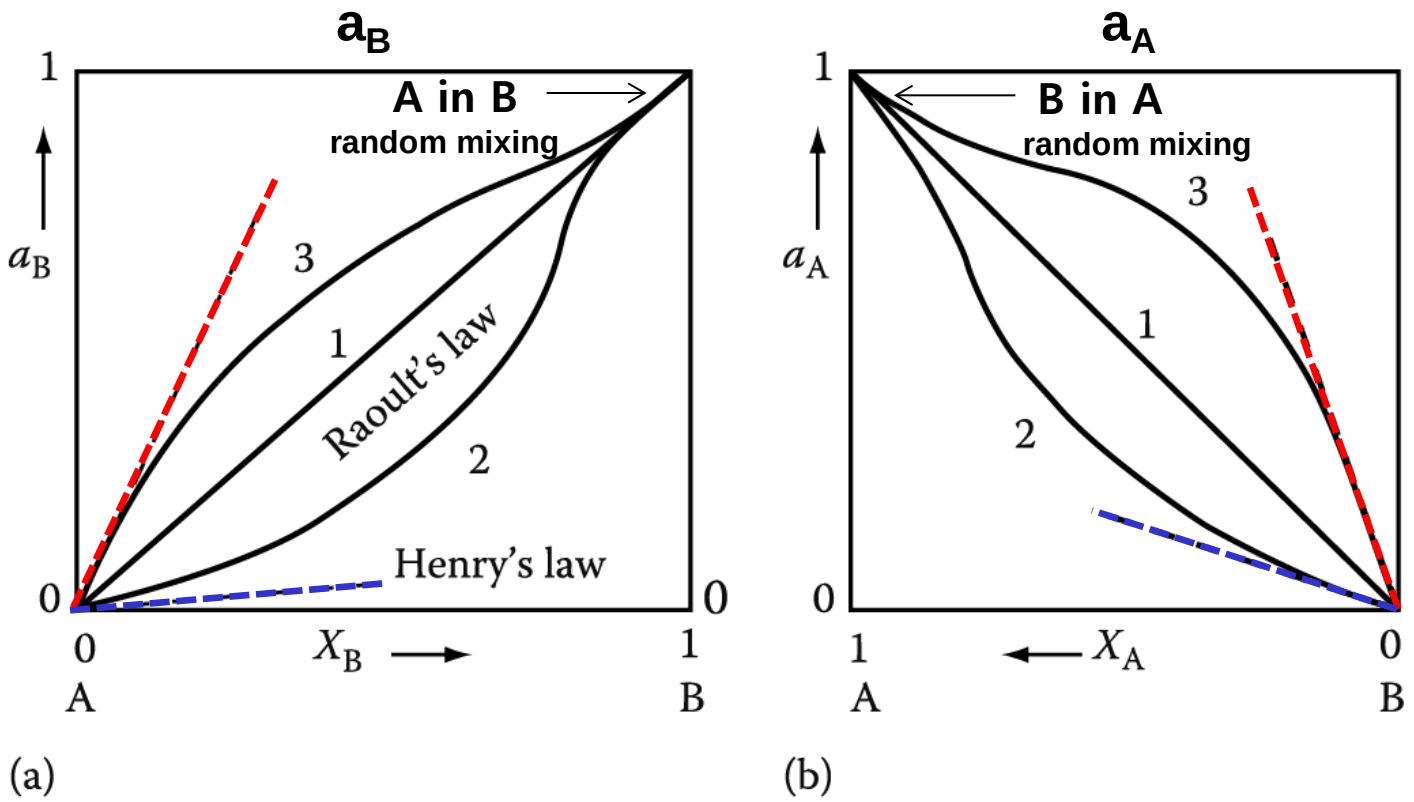
$$\gamma_B = \frac{a_B}{X_B} \cong \text{constant} \quad \text{(Henry's Law)}$$

$$\gamma_A = \frac{a_A}{X_A} \cong 1 \quad \text{(Rault's Law)}$$

$$\Delta H_{mix} = P_{AB}\varepsilon$$ where $$\varepsilon = \varepsilon_{AB} - \frac{1}{2}(\varepsilon_{AA} + \varepsilon_{BB})$$



Variation of activity with composition (a) a_B, (b) a_A



Line 1 : (a) $a_B=X_B$, (b) $a_A=X_A$ ideal solution…Rault's law

Line 2 : (a) $a_B<X_B$, (b) $a_A<X_A$ $\Delta H_{mix}<0$

Line 3 : (a) $a_B>X_B$, (b) $a_A>X_A$ $\Delta H_{mix}>0$

$$\ln\left(\frac{a_A}{X_A}\right)=\frac{\Omega}{RT}(1-X_A)^2$$

Contents for previous class

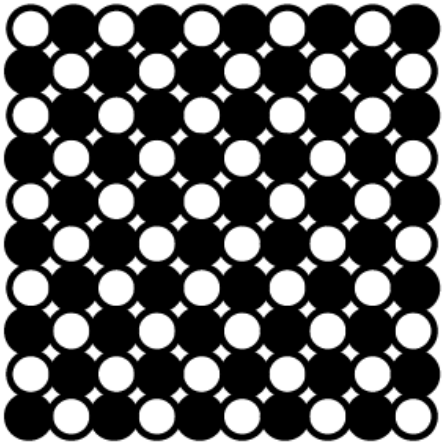
- **Binary System** mixture/ solution / compound

Ideal solution ($\Delta H_{mix}=0$) **Random distribution**

Regular solution $\Delta H_{mix} = P_{AB}\varepsilon$ where $\varepsilon = \varepsilon_{AB} - \frac{1}{2}(\varepsilon_{AA} + \varepsilon_{BB})$ $\varepsilon \approx 0$

$\Delta H_{mix} > 0$ or $\Delta H_{mix} < 0$

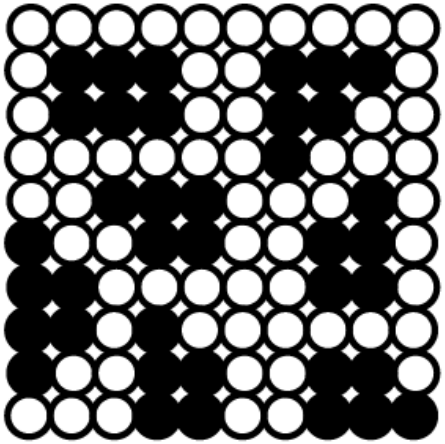
Real solution **Ordered structure**



(a) $\varepsilon < 0$, $\Delta H_{mix} < 0$

Ordered alloys

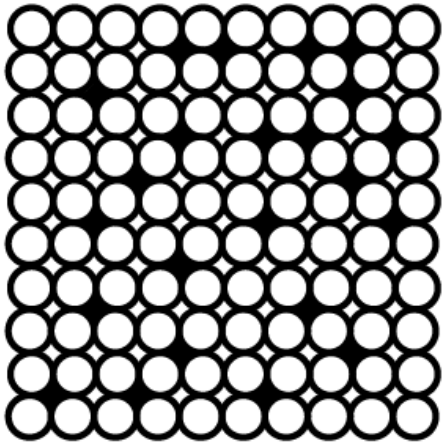
P_{AB} ↑ ⟶ Internal E ↓



(b) $\varepsilon > 0$, $\Delta H_{mix} > 0$

Clustering

P_{AA}, P_{BB} ↑



(c) when the size difference is large

strain effect

Interstitial solution

Ordered phase II: "Long range order (LRO)"

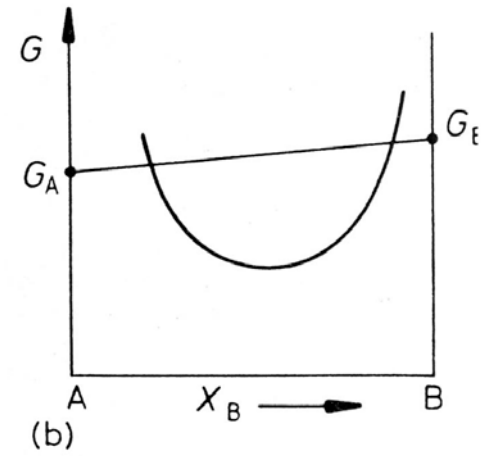
(①superlattice, ②intermediate phase, ③intermetallic compound)

*** Solid solution → ordered phase**

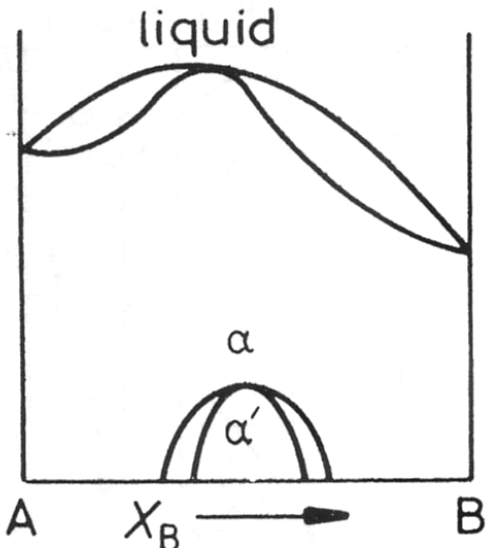
- → random mixing
- → entropy ↑
  negative enthalpy ↓

$$\Delta H^{S}_{mix} < 0$$

Large composition range
→ G ↓



diate phases: (a) for an intermetallic com-
(b) for an intermediate phase with a wide



*** Compound : AB, A_2B…**

- → entropy↓
- → covalent, ionic contribution.
- → enthalpy more negative ↓

$$\Delta H^{S}_{mix} << 0$$

Small composition range
→ G ↓

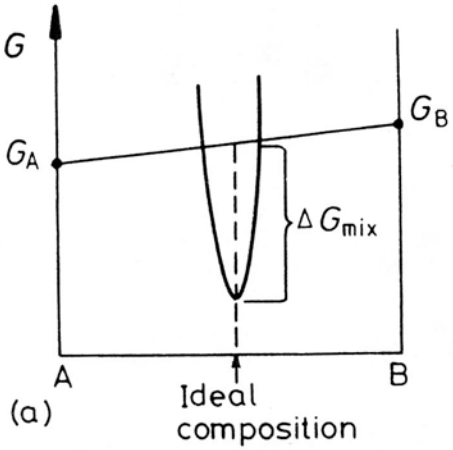
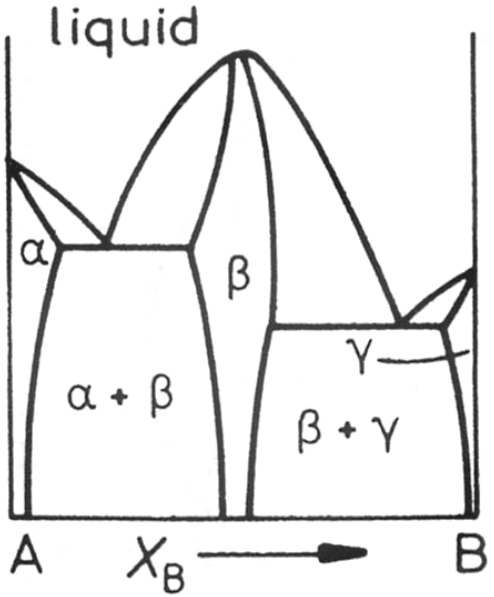


Fig. 1.23 Free energy curves for intermed
pound with a very narrow stability range, (
stability range.

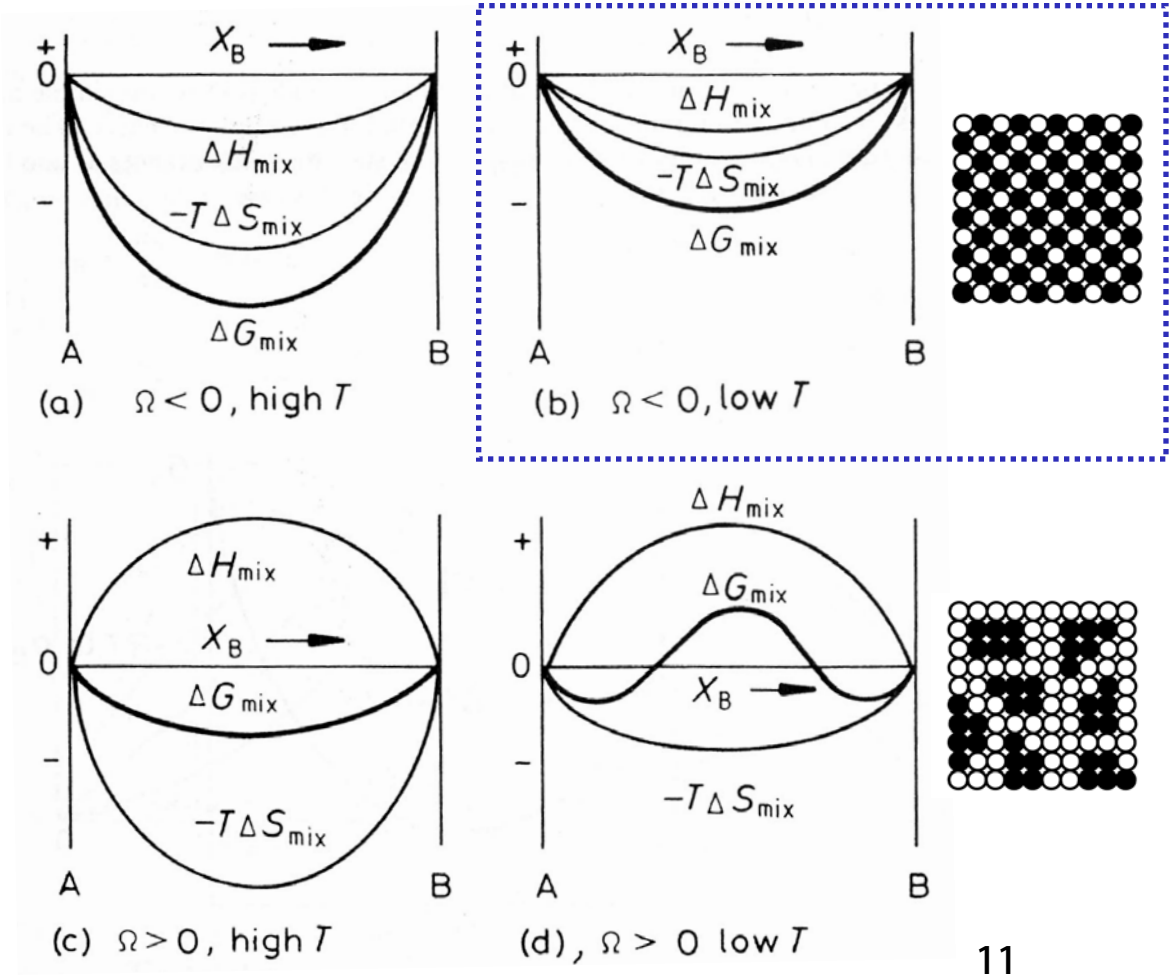


Q1: Superlattice

* **The degree of ordering or clustering will decrease as temp. increases due to the increasing importance of entropy.**

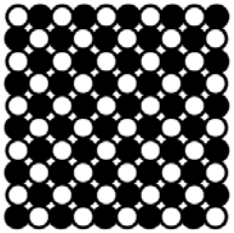
High temp. ⟶ Entropy effect ⬆ ⟶ Solution stability ⬆

$$\Delta G_{mix} = \Delta H_{mix} - T\Delta S_{mix}$$



Ordered phase $\varepsilon < 0,\ \Delta H_{mix} < 0$

* In solutions with compositions that are close to a simple ratio of A:B atoms another type of order can be found.

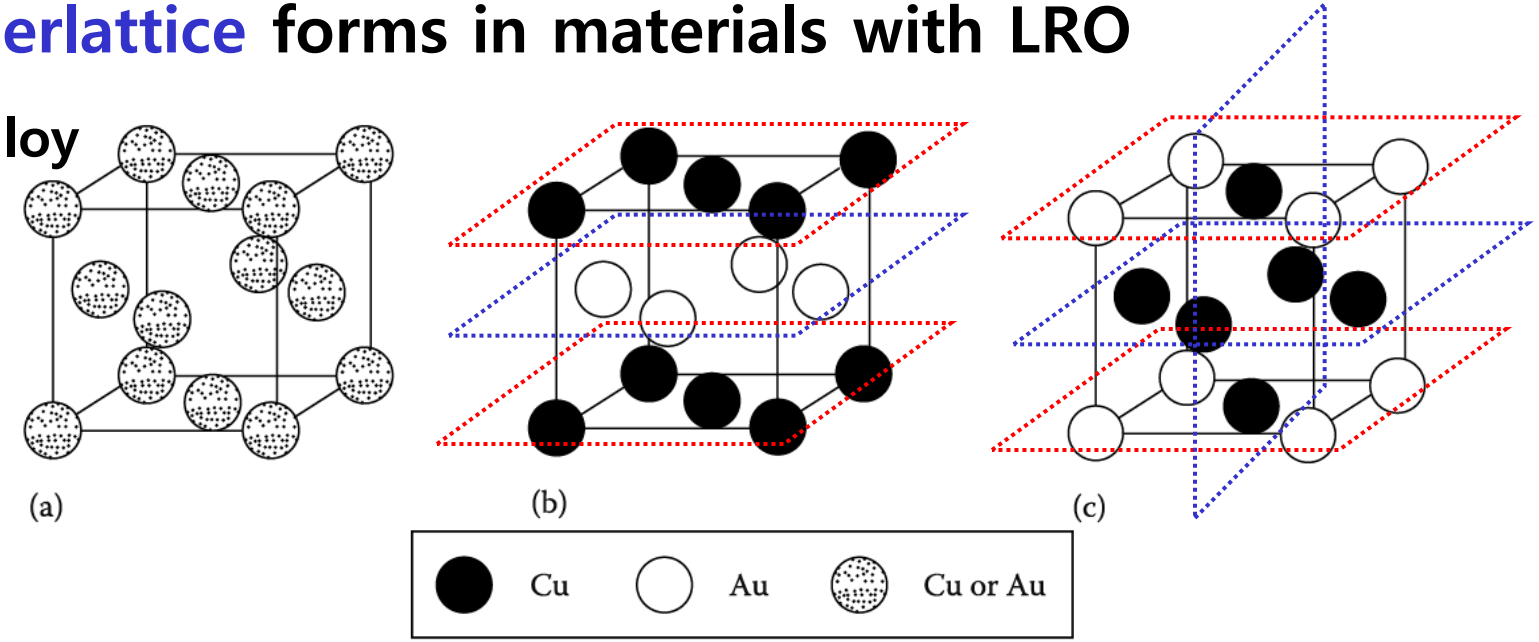


* This is known as long-range order (LRO) CuAu, Cu_3Au and many other intermetallics show LRO.

(The atom sites are no longer equivalent but can be labelled as A-sites and B-sites.)

* A superlattice forms in materials with LRO

Cu–Au alloy



High temp.
Disordered Structure

Low temp.
CuAu superlattice

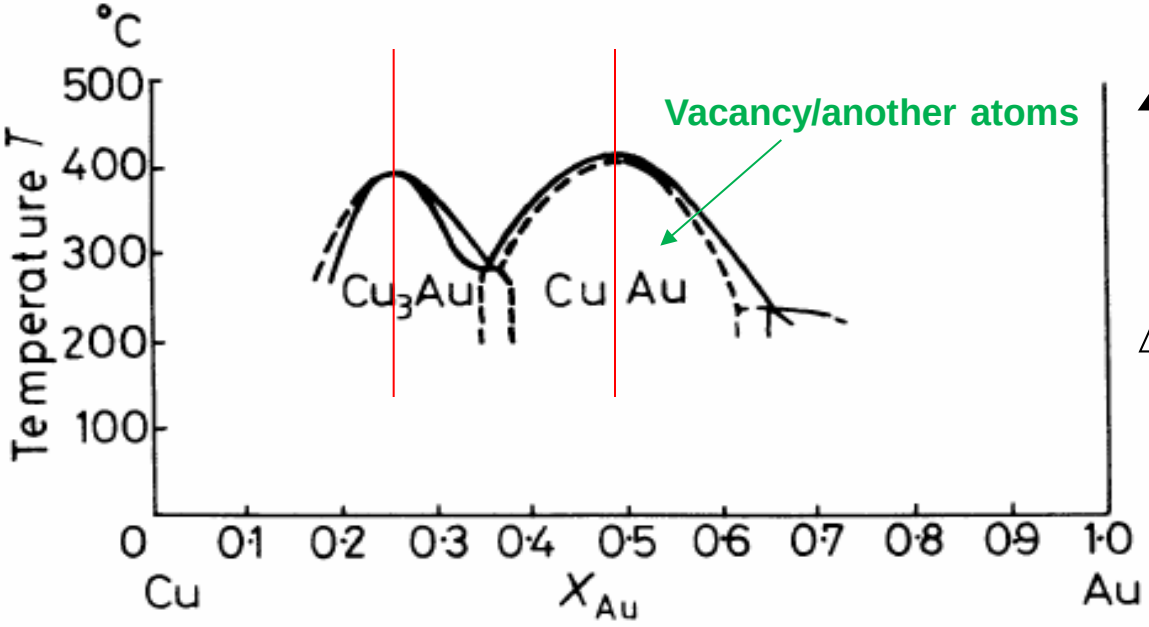
Cu_3Au superlattice

$\Delta G_{mix} = \Delta H_{mix} - T\Delta S_{mix}$

Ordered phase

$\varepsilon < 0,\ \Delta H_{mix} < 0$

Fig. 1.21. Part of the Cu-Au phase diagram showing the regions where the Cu_3Au and CuAu superlattices are stable.



ΔS_{mix}~*small*

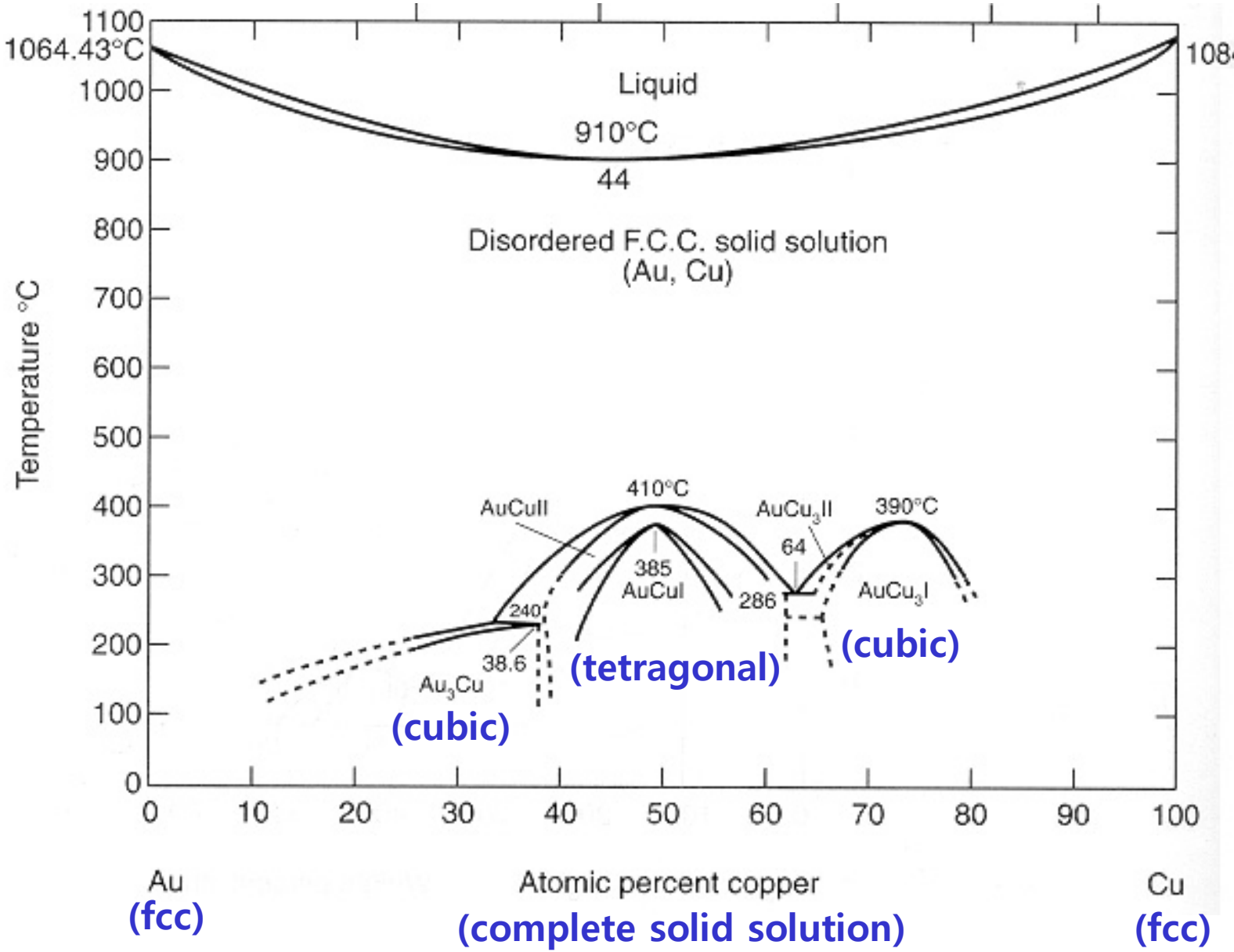
At high Temp.,

ΔG_{mix}~ *large (-)*

- **The entropy of mixing of structure with LRO is extremely small and the degree of order decrease with increasing temperature until above some critical temperature there is no LRO at all.**
- **This temperature is a maximum when the composition is the ideal required for the superlattice.**
- **The critical temperature for loss of LRO increases with increasing Ω or ΔH_{mix}, and in many systems the ordered phase is stable up to the melting point.**

Ordered Phase

$\varepsilon < 0$, $\Delta H_{mix} < 0$ / $\Delta H_{mix} \sim -20$ kJ/mol

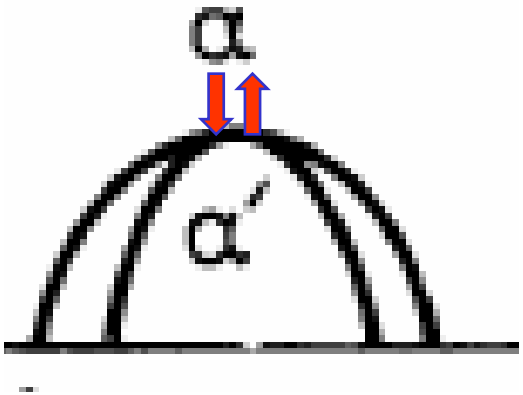


Q2: Order-disorder transition

Order-disorder phase transformation

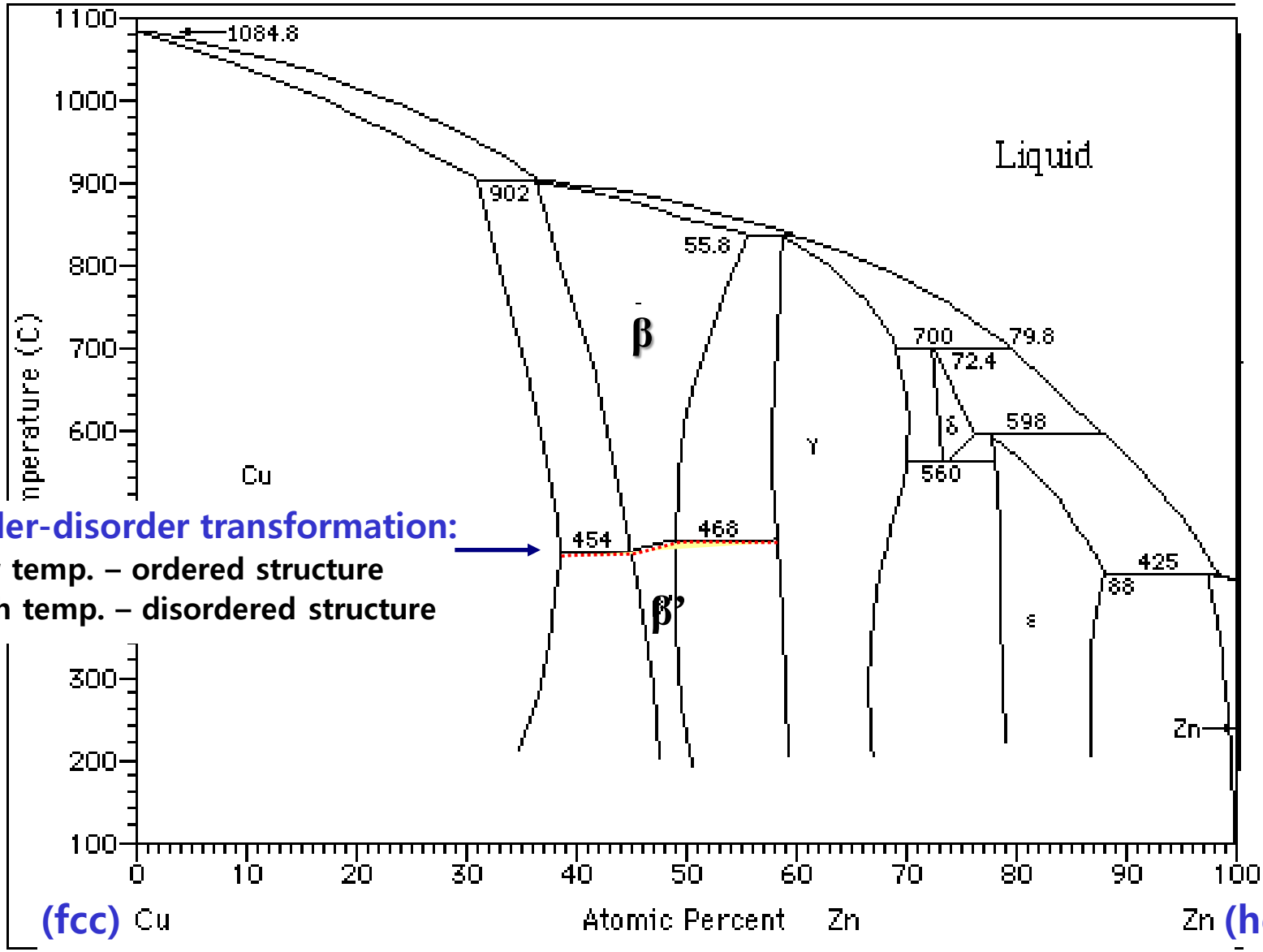
- Not classical phase change=~not depend on diffusion process
- change of temperature allowed a continuous re-arrangement of atoms without changing the phase = "2nd order transition"
- boundary: ordered lattice & disordered lattice/phase rule could not applied

  there are cases in which an ordered phase of one composition exists in equilibrium with a disordered phase of a different composition.
- Simple composition of the type AB or AB_3 can the transformation (i.e. at the temperature maximum) be considered diffusionless.



Intermediate Phase

$\varepsilon < 0$, $\Delta H_{mix} < 0$ / $\Delta H_{mix} \sim -21$ kJ/mol



Order-disorder transformation:

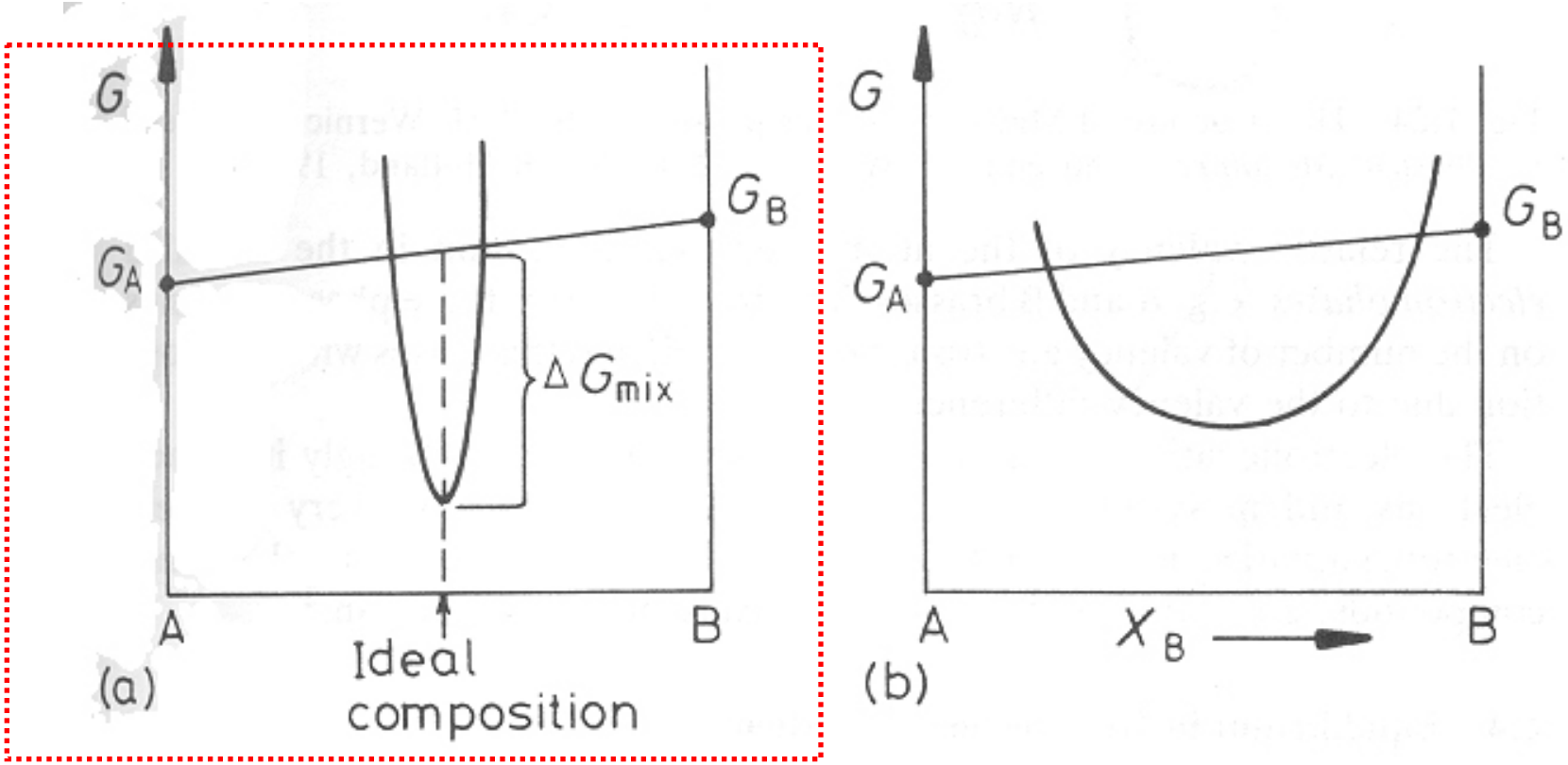
Low temp. – ordered structure

High temp. – disordered structure

- α and η are terminal solid solutions
- β, β', γ, δ and ε are intermediate solid solutions.

Q3: Intermediate phase vs Intermetallic compound

Intermediate Phase

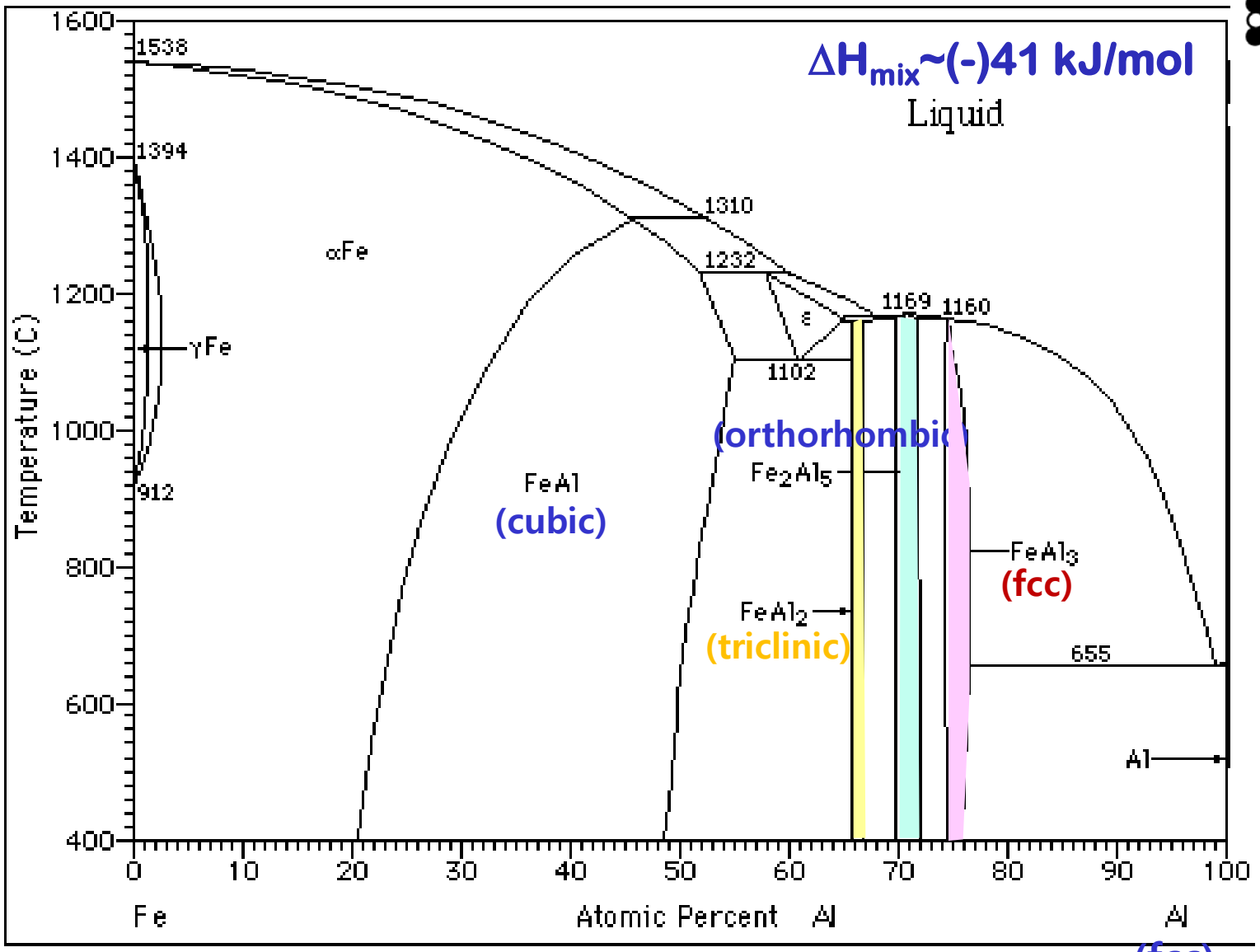


* **Many intermetallic compounds have stoichiometric composition A_mB_n and a characteristic free energy curve as shown in Fig (a).**

* **In other structure, fluctuations in composition can be tolerated by some atoms occupying 'wrong' position or by atom sites being left vacant, and in these cases the curvature of the G curve is much less, Fig (b).**

Intermediate Phase

$\varepsilon < 0,\ \Delta H_{mix} < 0$

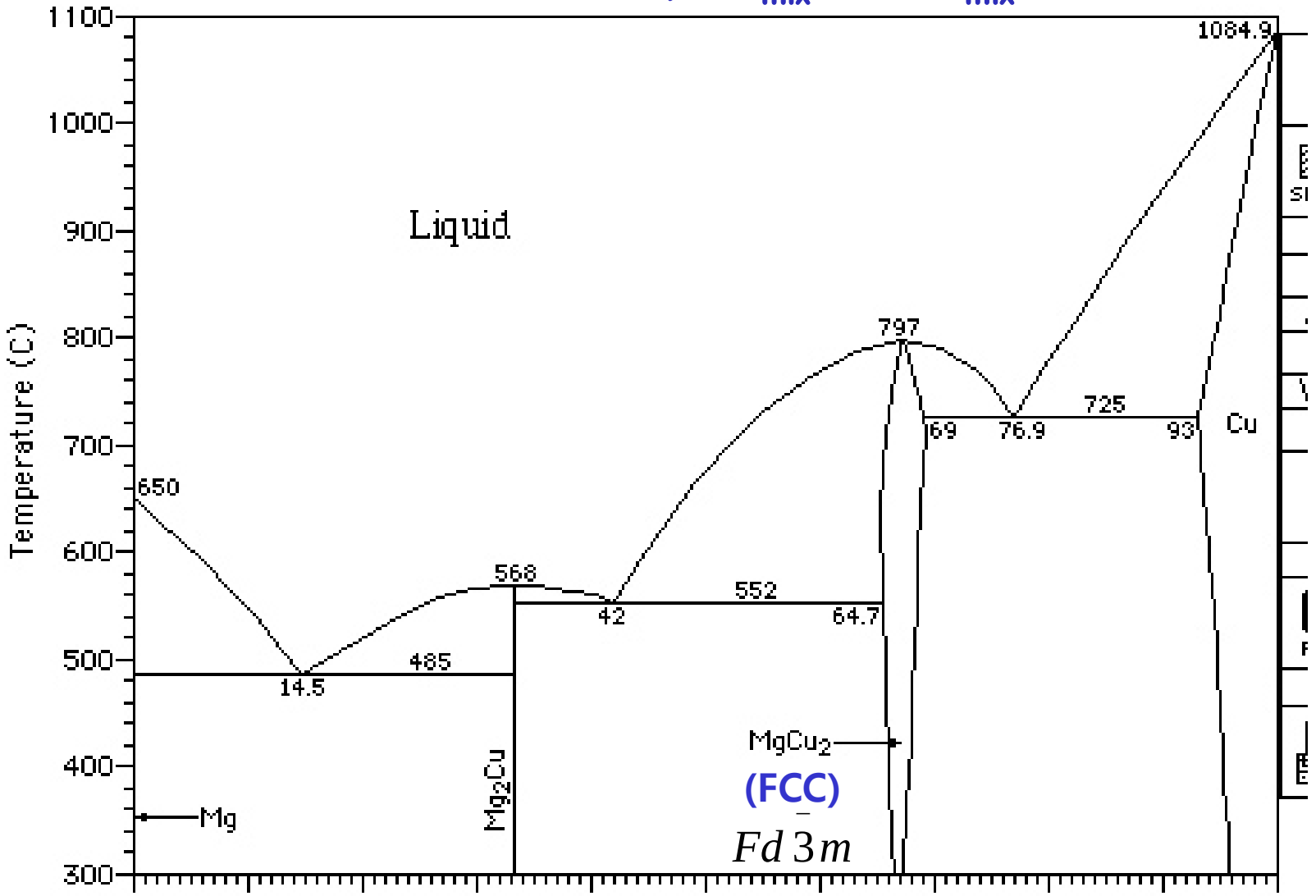


(bcc)

(fcc)

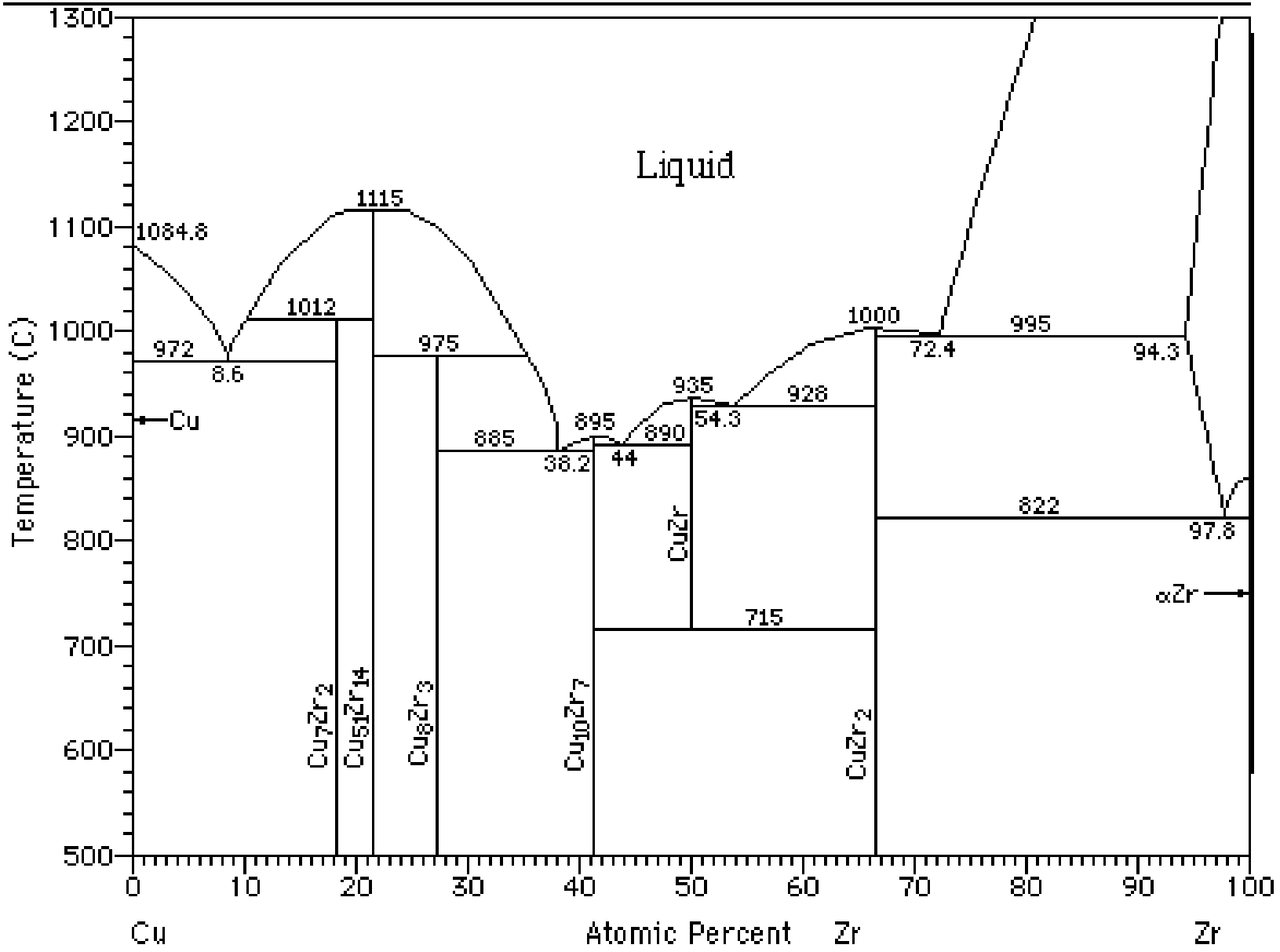
Intermediate Phase

$\varepsilon < 0$, $\Delta H_{mix} < 0$ / $\Delta H_{mix} \sim -38$ kJ/mol



Intermediate Phase

$\varepsilon << 0$, $\Delta H_{mix} << 0$ / $\Delta H_{mix} \sim -142$ kJ/mol



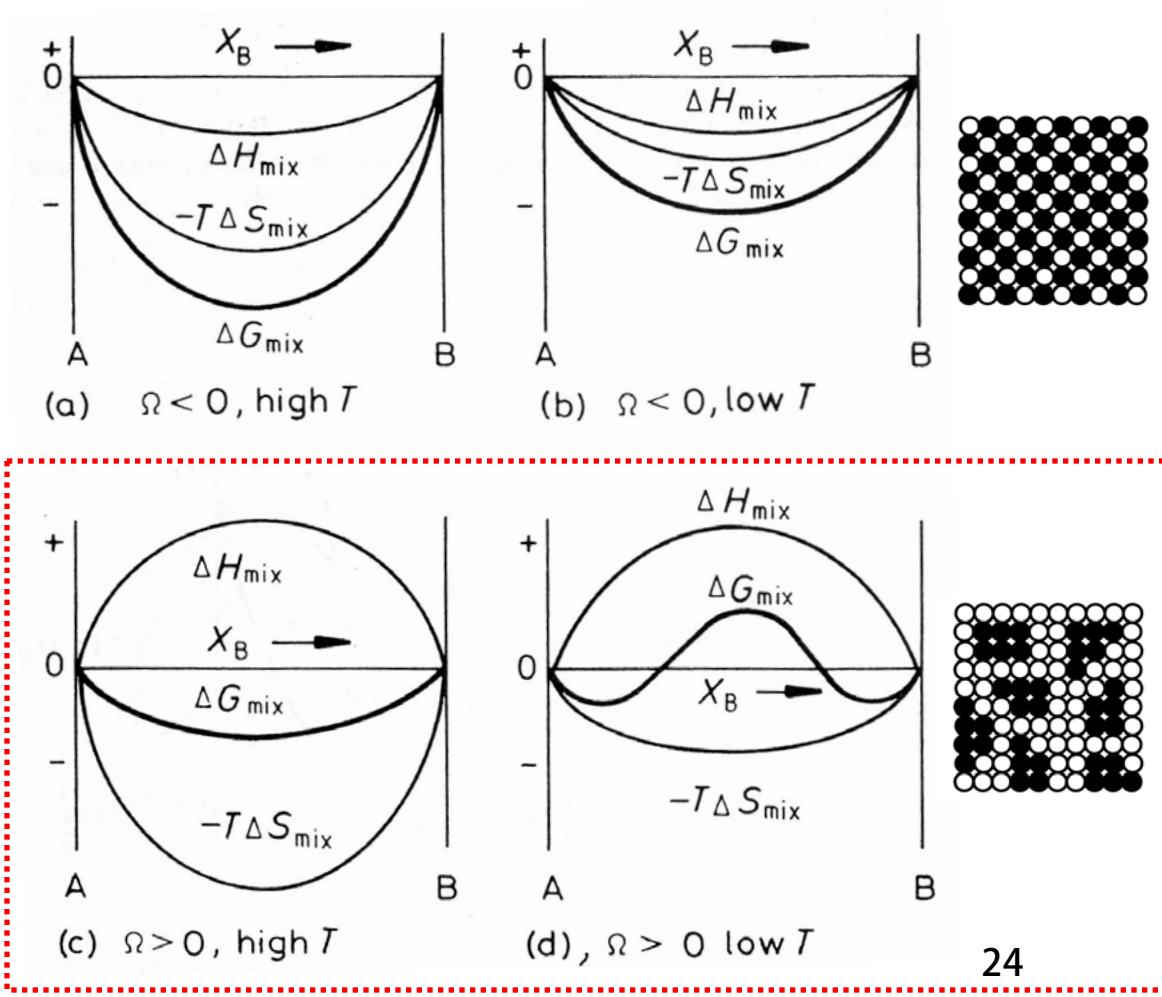
"Clustering"? → Phase separation

Q4: Metastable vs Stable miscibility gap

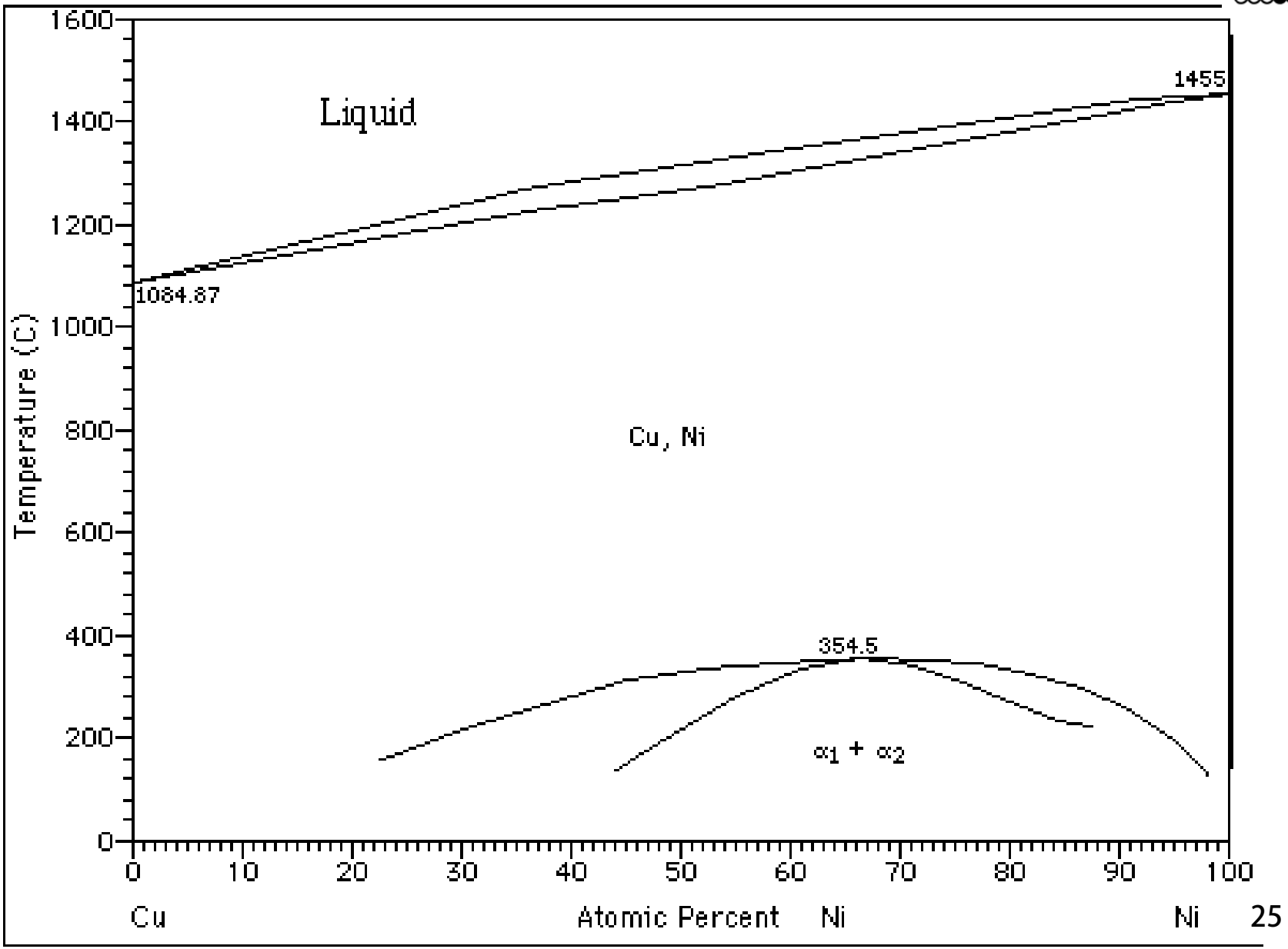
* **The degree of ordering or clustering will decrease as temp. increases due to the increasing importance of entropy.**

High temp. ⟶ Entropy effect ⬆ ⟶ Solution stability ⬆

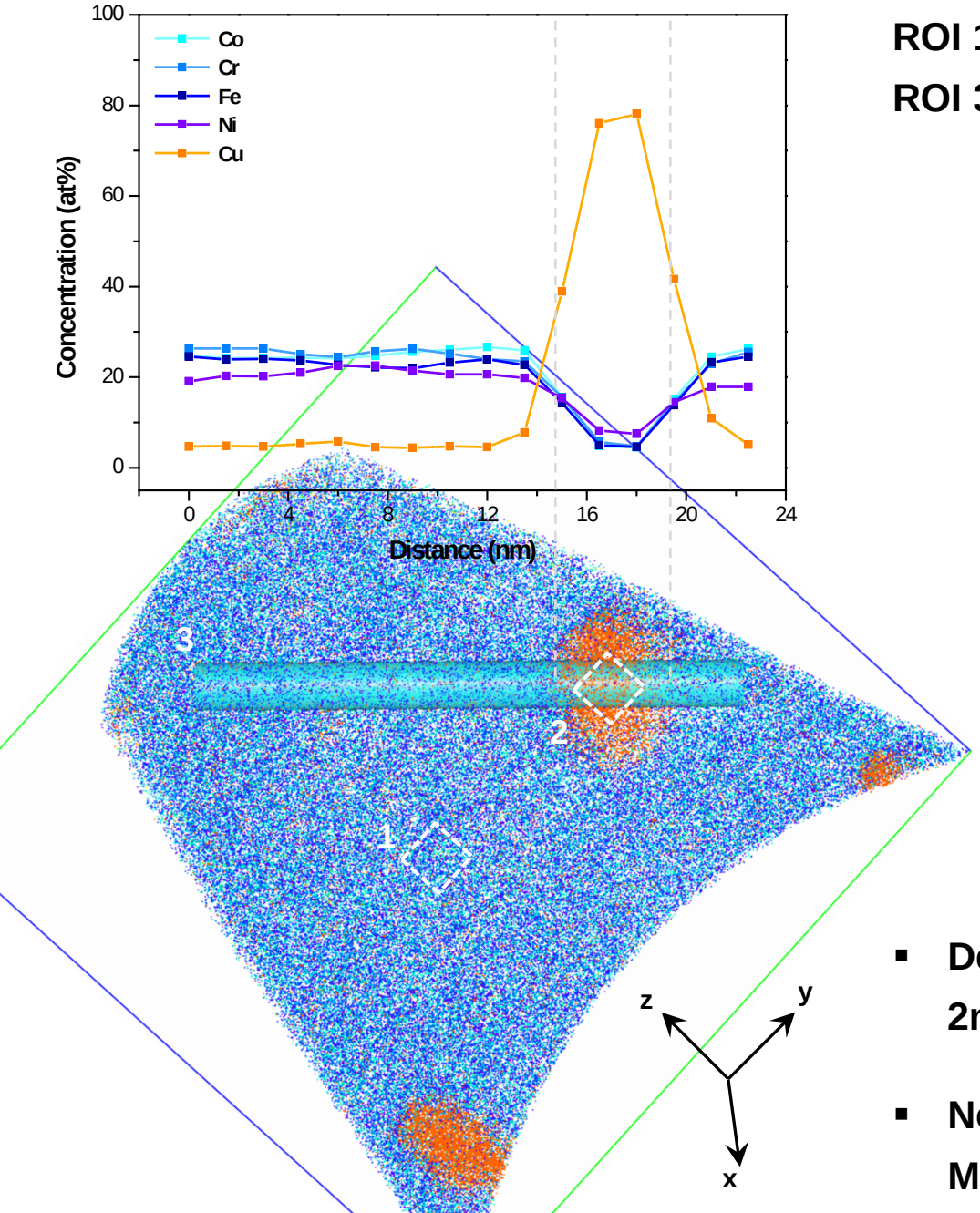
$$\Delta G_{mix} = \Delta H_{mix} - T\Delta S_{mix}$$



$\varepsilon > 0$, $\Delta H_{mix} > 0$ / $\Delta H_{mix} \sim +26$ kJ/mol



Compositional analysis of as-cast CoCrFeNi/Cu HEA (dendrite)



ROI 1, 2 : 1.4 nm x 2 nm x 2 nm

ROI 3 : 1.2 nm x 2 nm x 23 nm

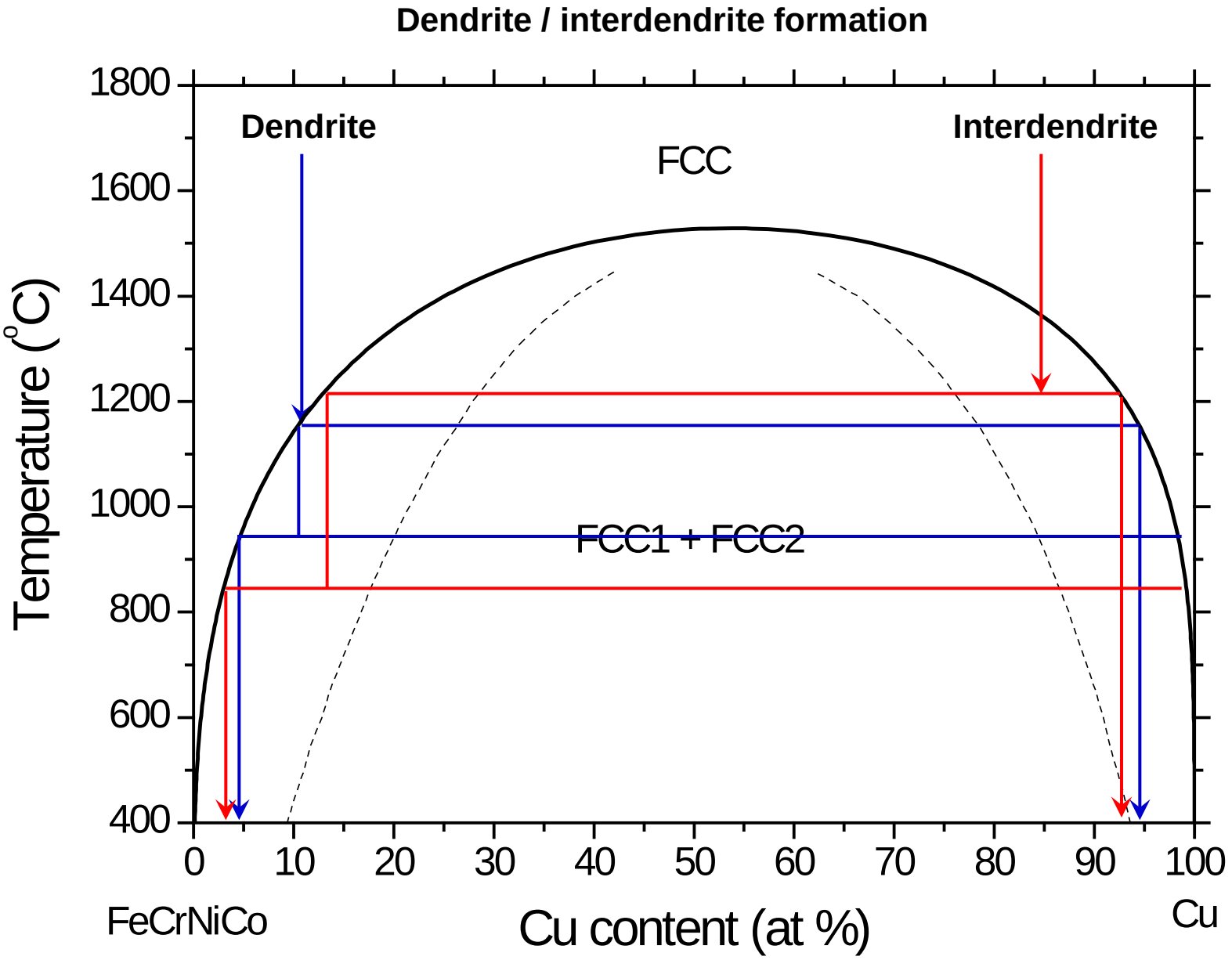
(1D concentration profile)

1	at%	2	at%
Co	26.19	Co	0.33
Cr	24.15	Cr	0.46
Fe	24.59	Fe	0.39
Ni	19.59	Ni	5.00
Cu	4.74	Cu	93.56

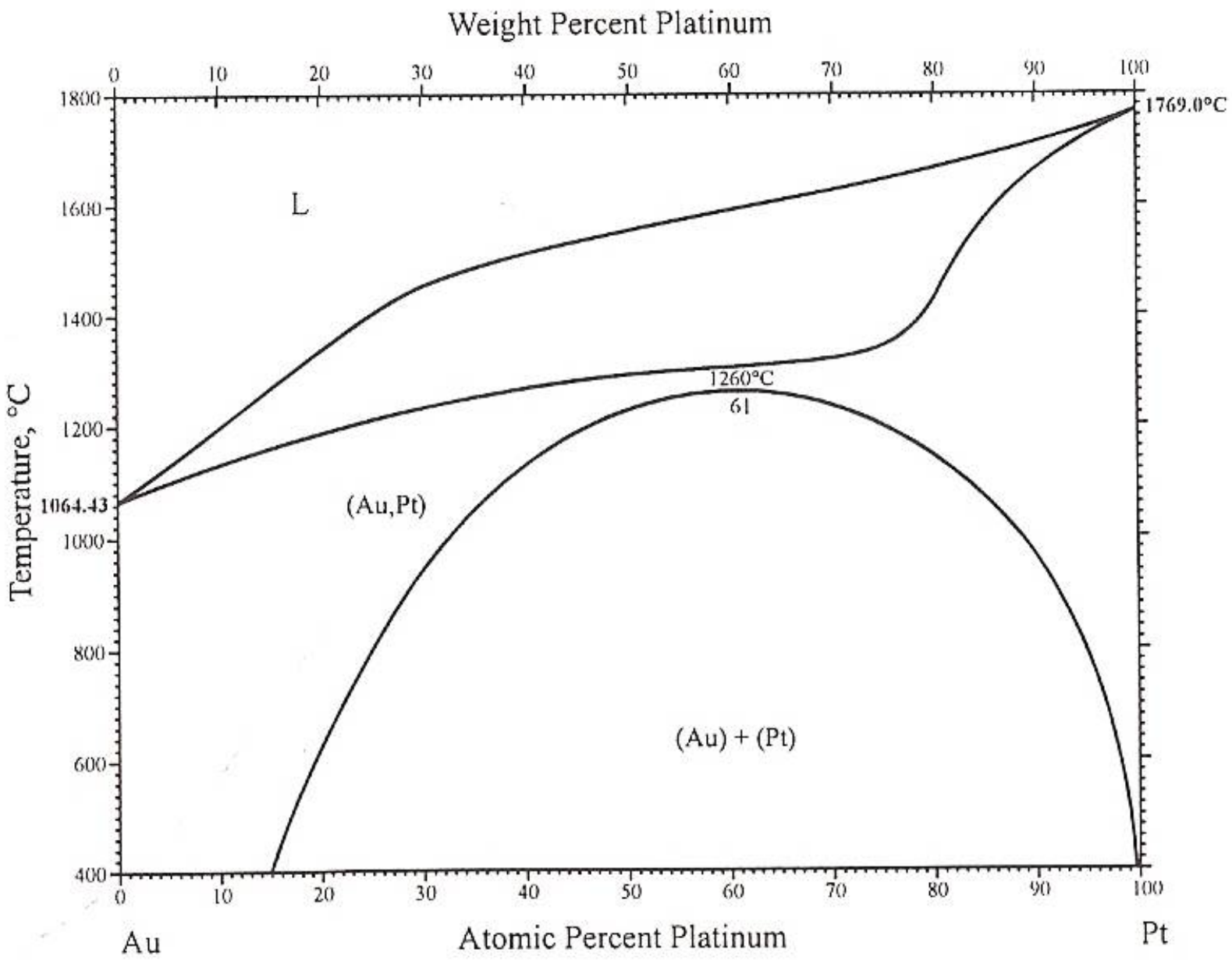
3-1’	at%	3-2’	at%
Co	25.29	Co	2.01
Cr	25.63	Cr	3.35
Fe	23.63	Fe	2.56
Ni	20.66	Ni	6.90
Cu	4.42	Cu	84.92

- **Dendrite region: matrix (4.74 at%Cu) + 2nd phase (93.56 at%Cu)**
- **No segregation at the interface between Matrix and 2nd phase**

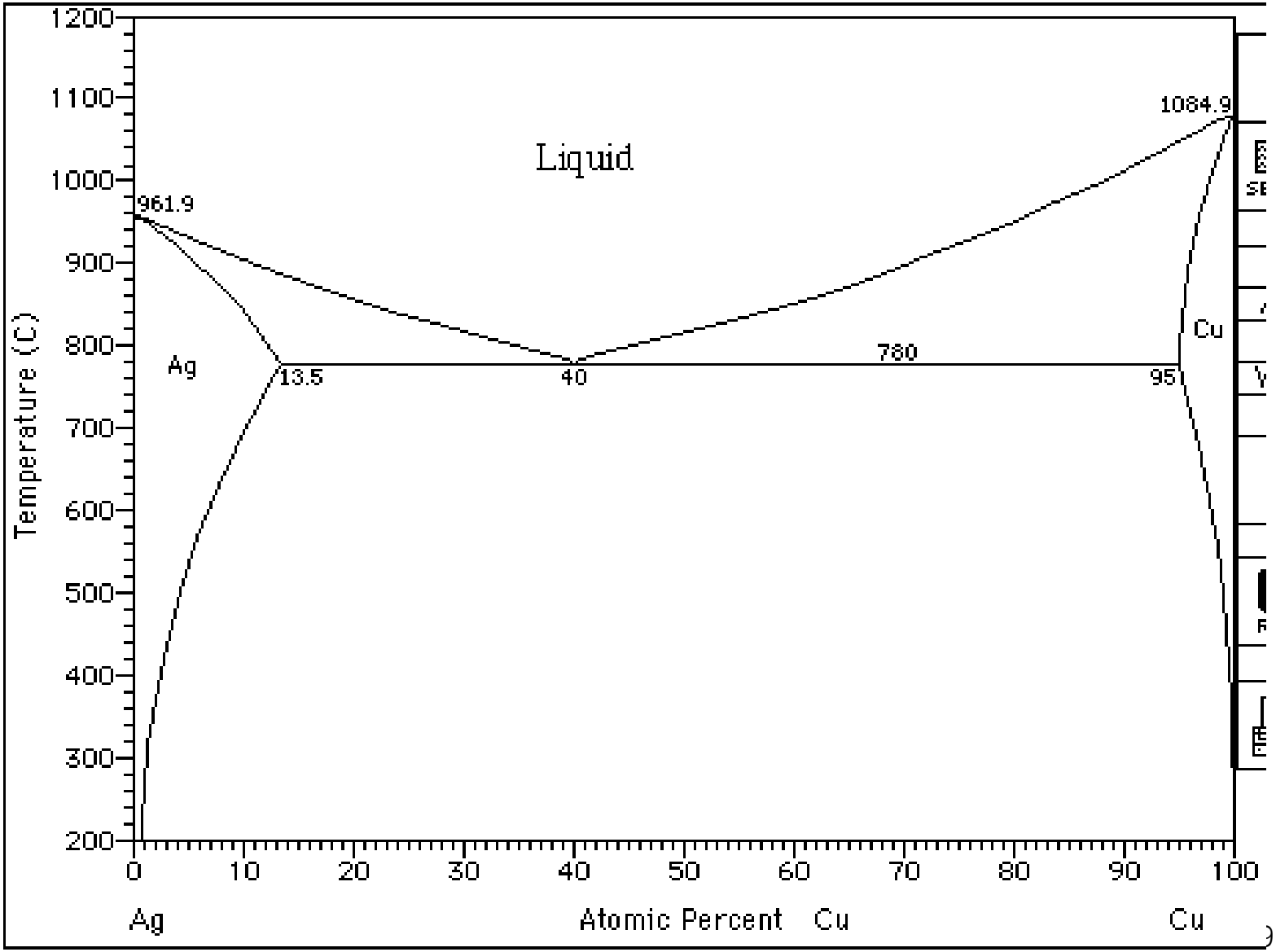
Cooling process in the miscibility gap



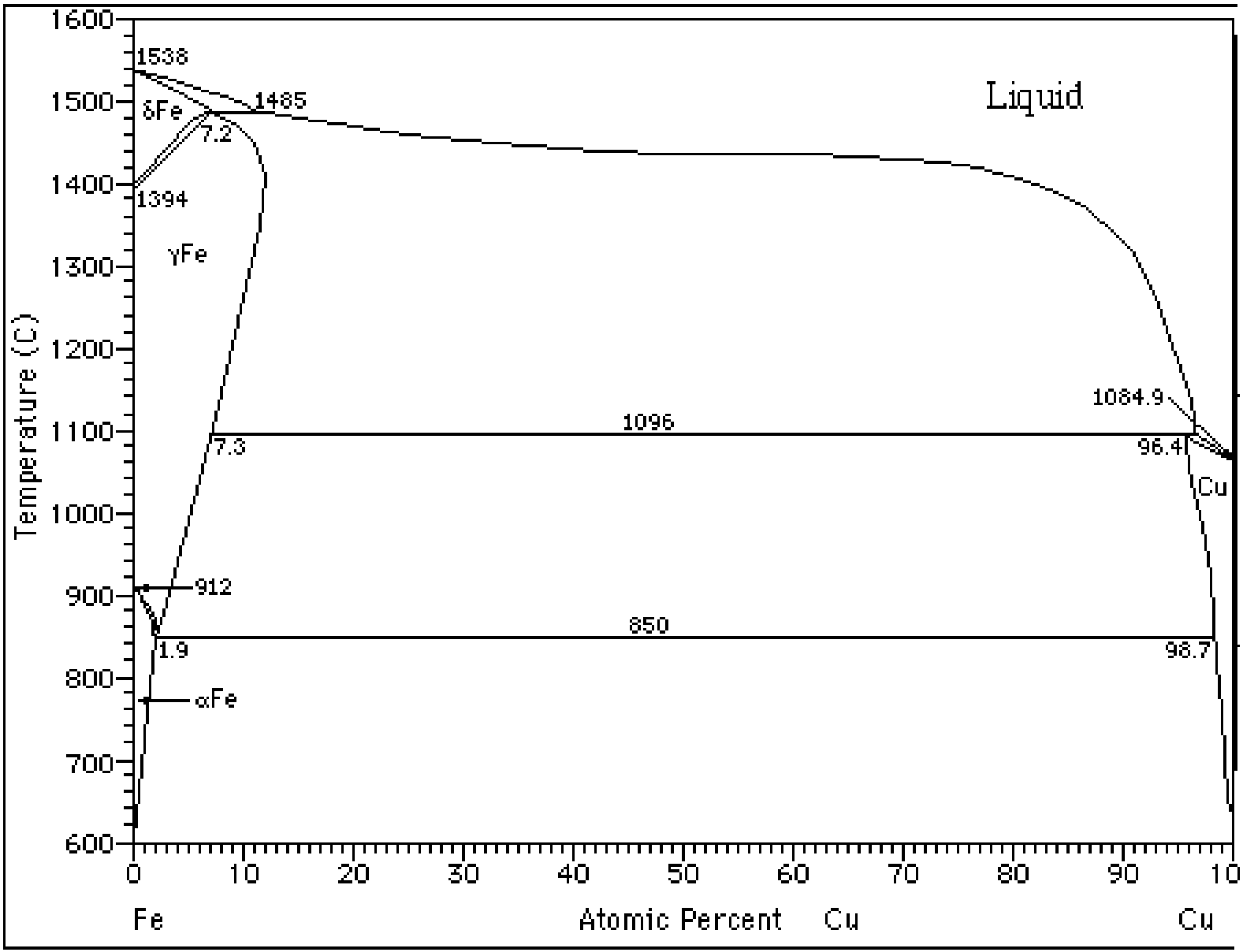
$\varepsilon > 0$, $\Delta H_{mix} > 0$ / $\Delta H_{mix} \sim +17$ kJ/mol



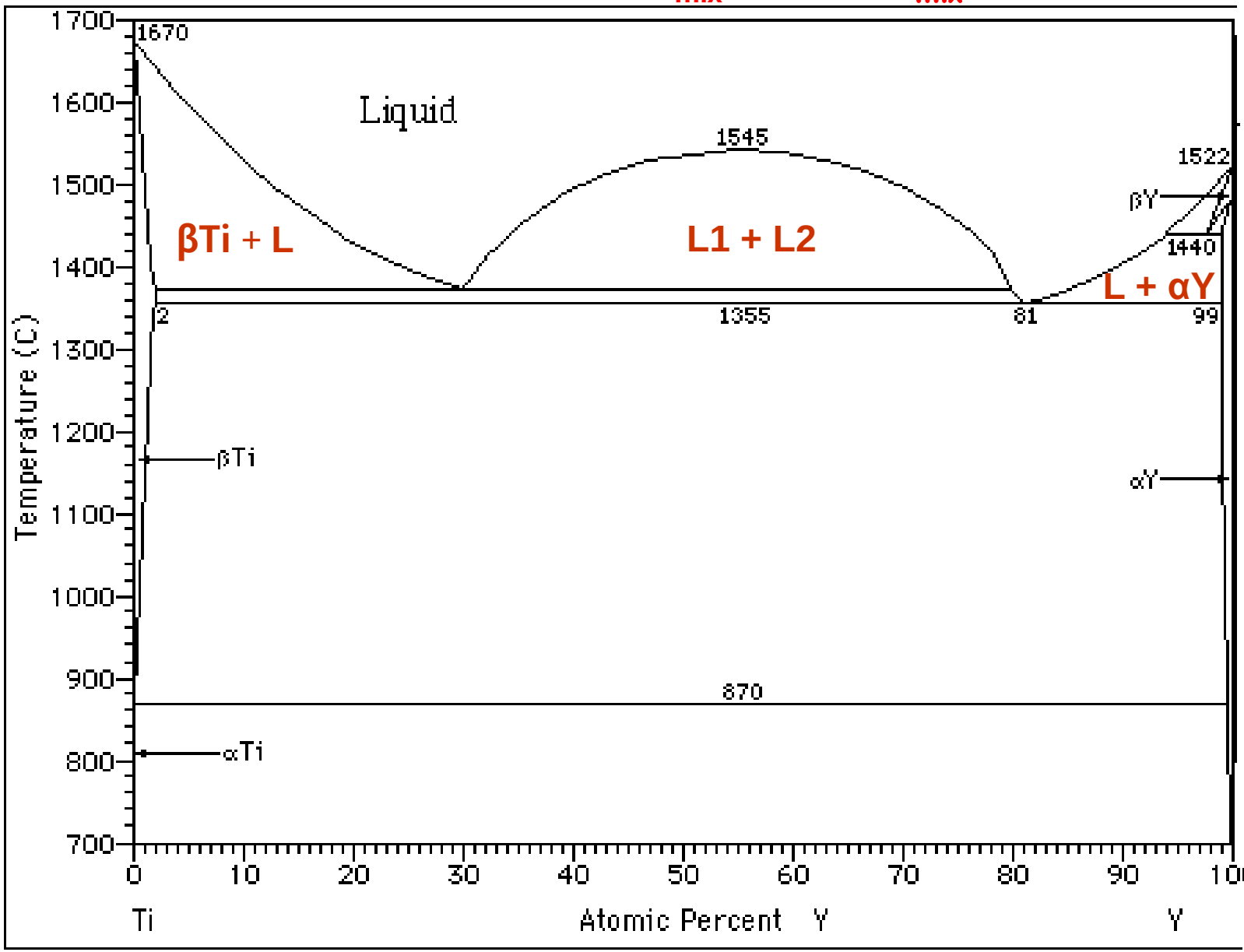
$\varepsilon > 0$, $\Delta H_{mix} > 0$ / $\Delta H_{mix} \sim +5$ kJ/mol



$\varepsilon >> 0$, $\Delta H_{mix} >> 0$ / $\Delta H_{mix} \sim +60$ kJ/mol



$\varepsilon >> 0$, $\Delta H_{mix} >> 0$ / $\Delta H_{mix} \sim +58$ kJ/mol



Positive heat of mixing relation among constituent elements

- Alloy design considering heat of mixing relation among constituent elements

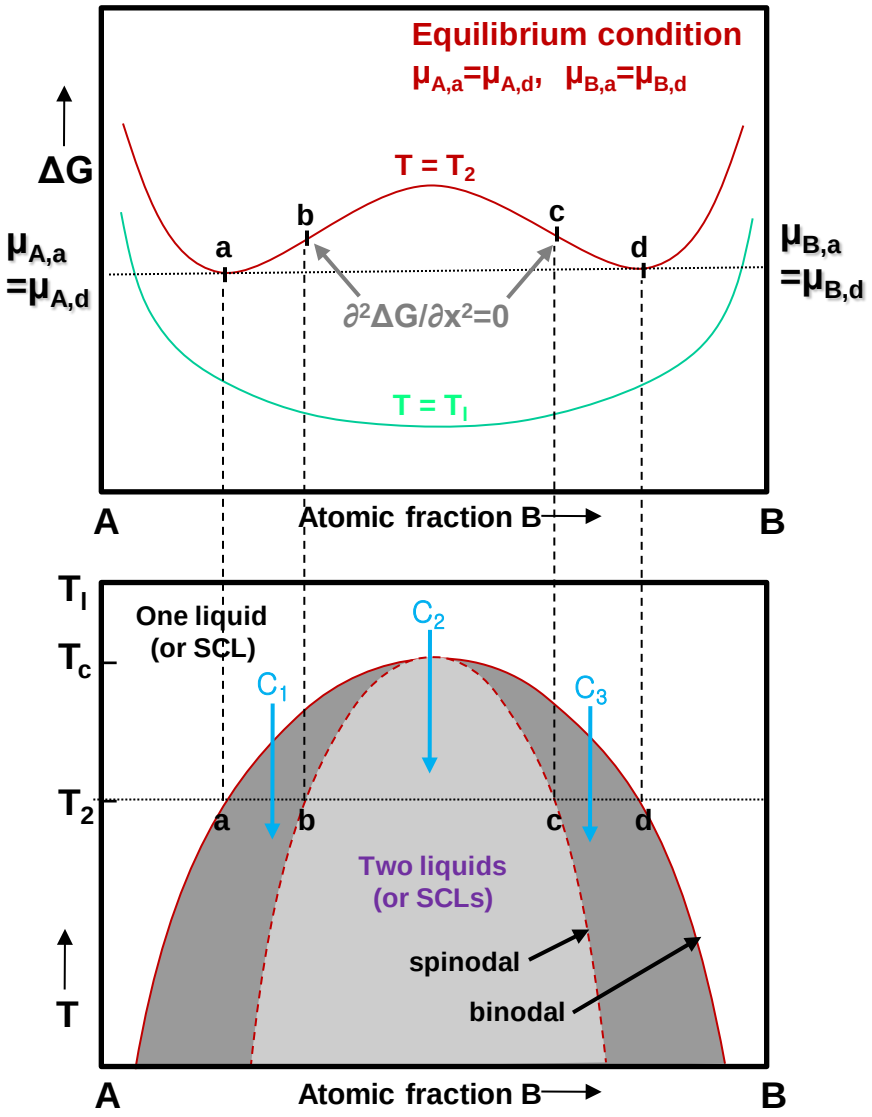
$\Delta H_{mix} \gg 0$ between A & B

⬇

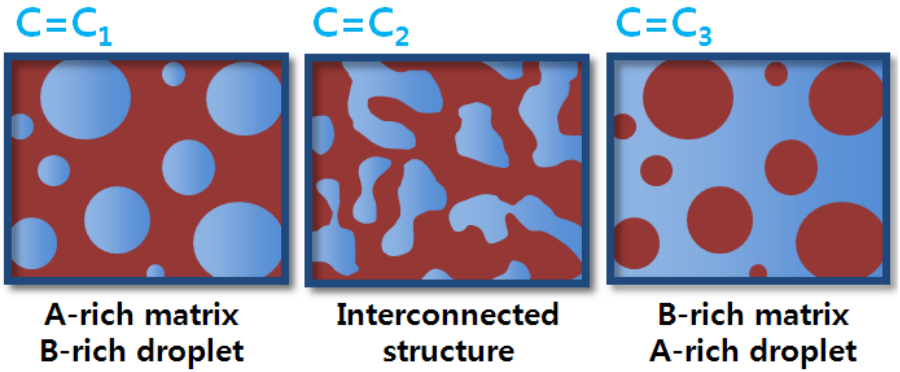
creates (meta)stable miscibility gap in limited composition range

⬇

Phase separation to A-rich & B-rich phase

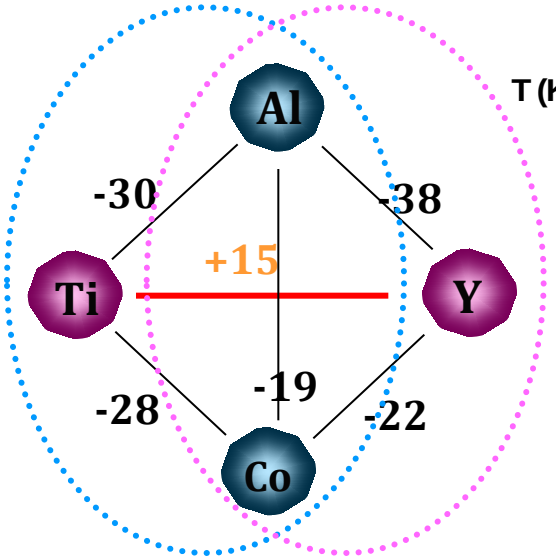


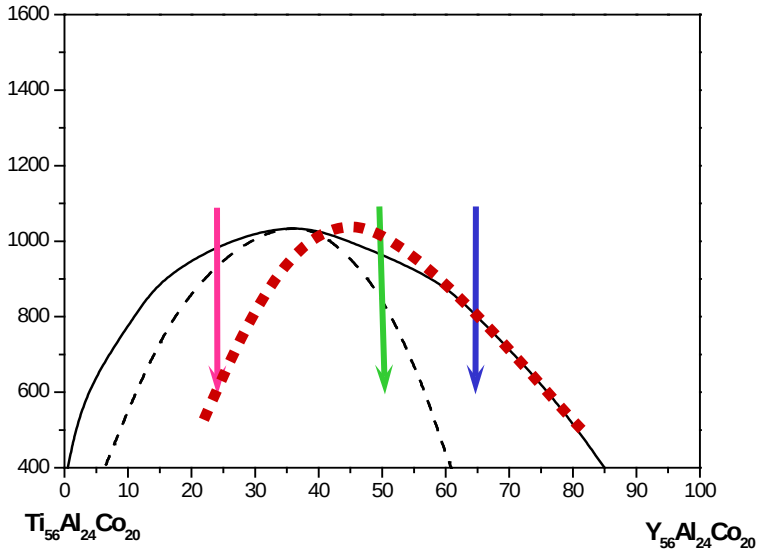
- Different two-phase structure by initial composition before phase separation

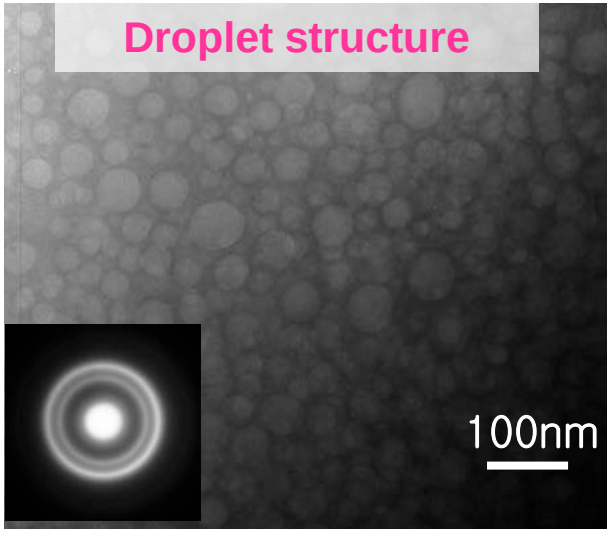


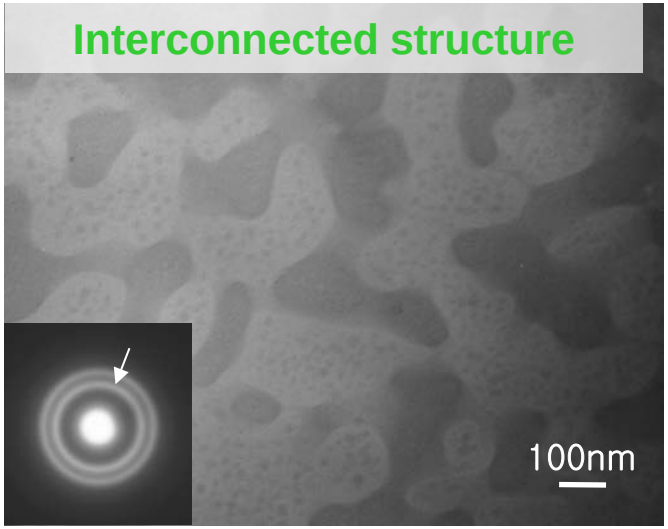
Nucleation and growth ↔ Spinodal decomposition without any barrier to the nucleation process

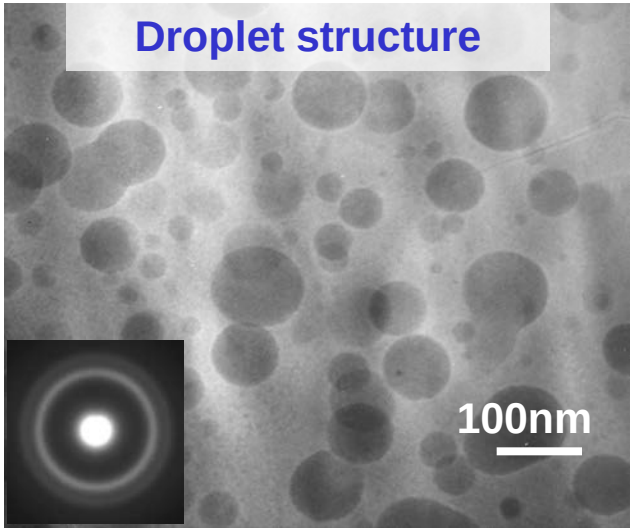
* Ti-Y-Al-Co system











$(Y_{56}Al_{24}Co_{20})_{25}(Ti_{56}Al_{24}Co_{20})_{75}$ $(Y_{56}Al_{24}Co_{20})_{50}(Ti_{56}Al_{24}Co_{20})_{50}$ $(Y_{56}Al_{24}Co_{20})_{65}(Ti_{56}Al_{24}Co_{20})_{35}$

* La-Zr-Al-Cu-Ni system

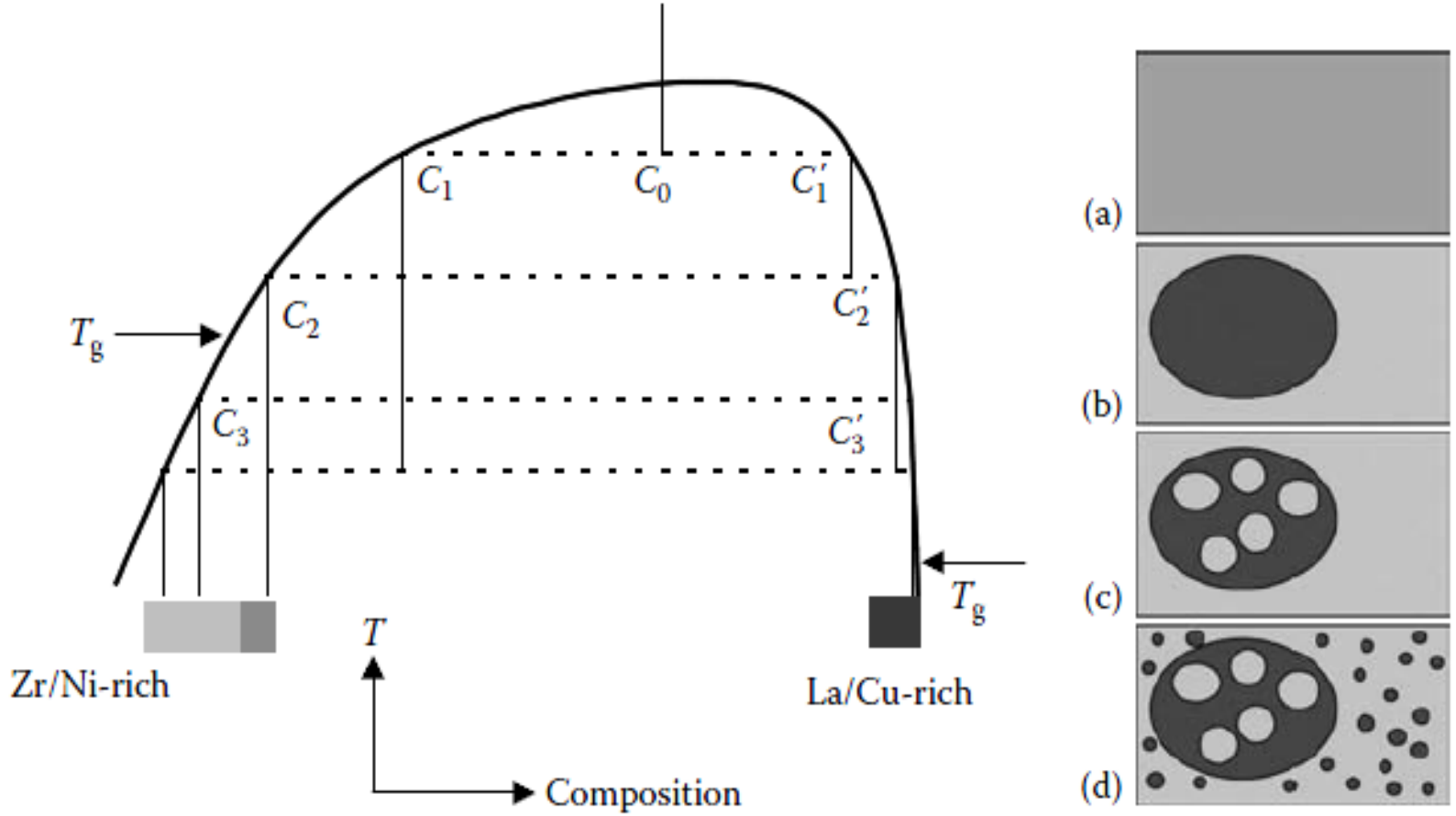
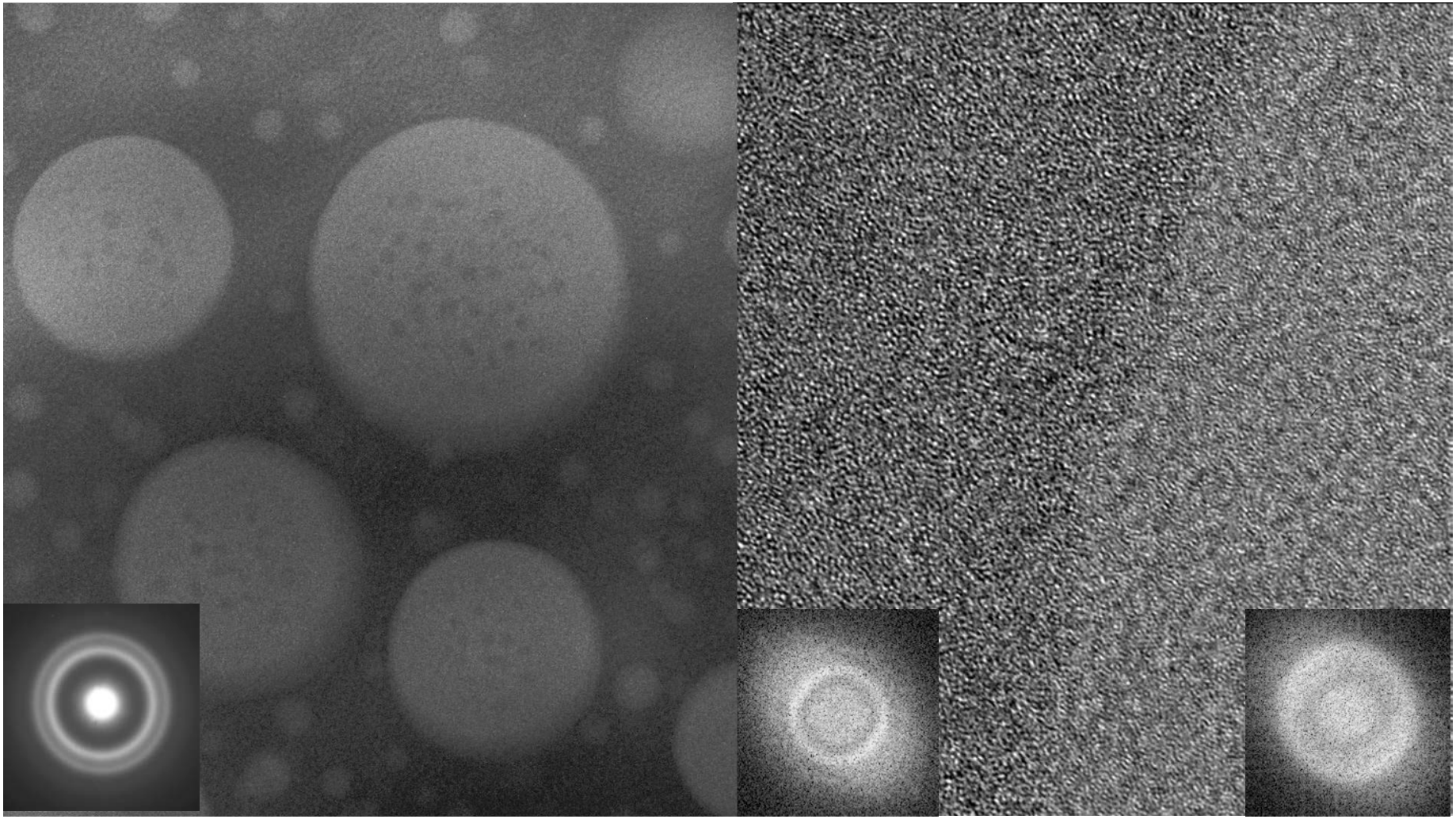


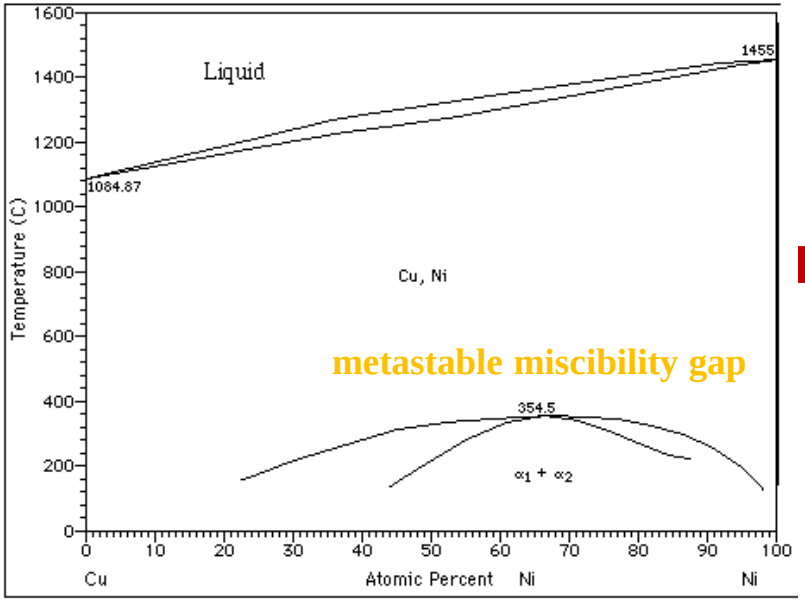
FIGURE 5.17
Schematic of the miscibility gap and the sequence of phase formation during cooling in the La–Zr–Al–Cu–Ni system. The positions of letters (a) to (d) in the diagram on the left correspond to the schematic microstructures (a) to (d) on the right. (Reprinted from Kündig, A.A. et al., *Acta Mater.*, 52, 2441, 2004. With permission.)

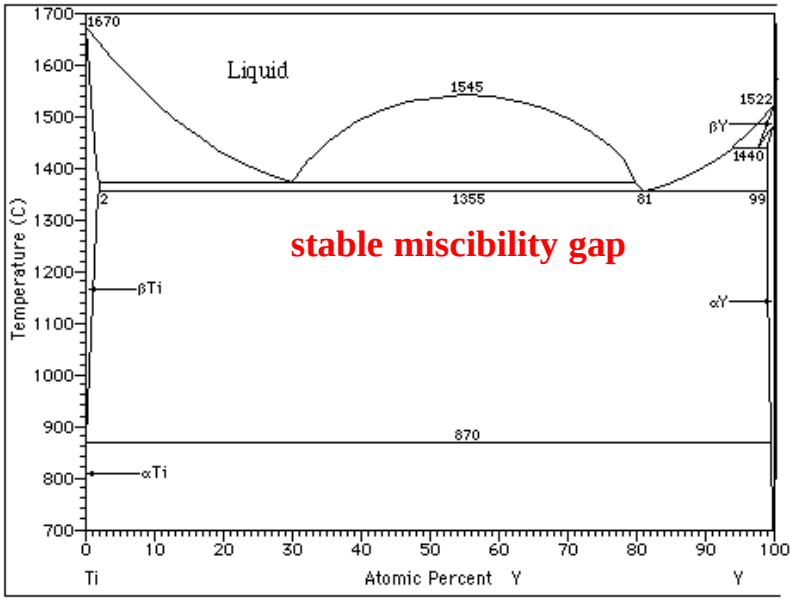
Phase separation in metallic glasses



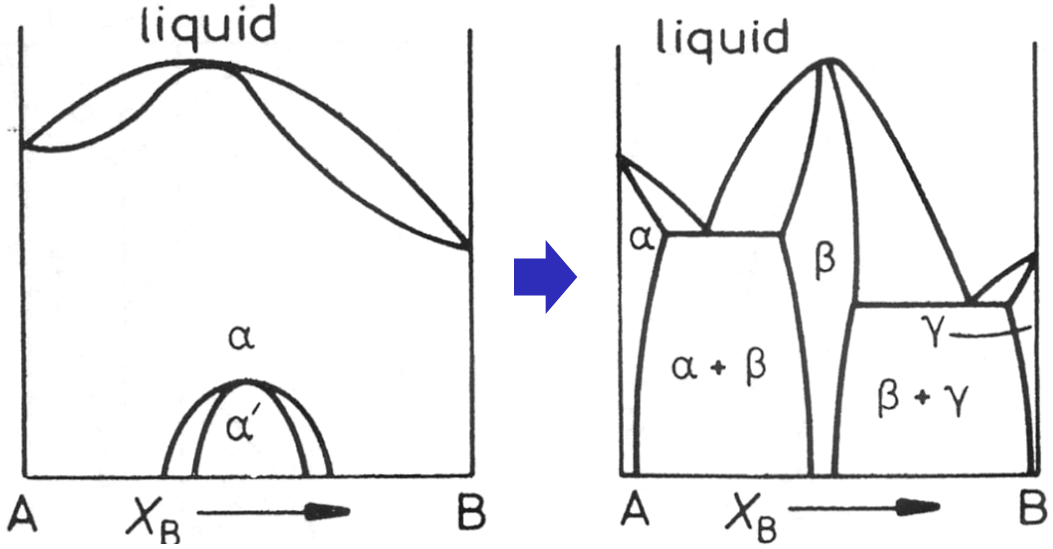
$\Delta H^S_{mix} > 0$: **Solid solution → solid state phase separation (two solid solutions)**

$\Delta H^S_{mix} >> 0$: **liquid state phase separation (up to two liquid solutions)**

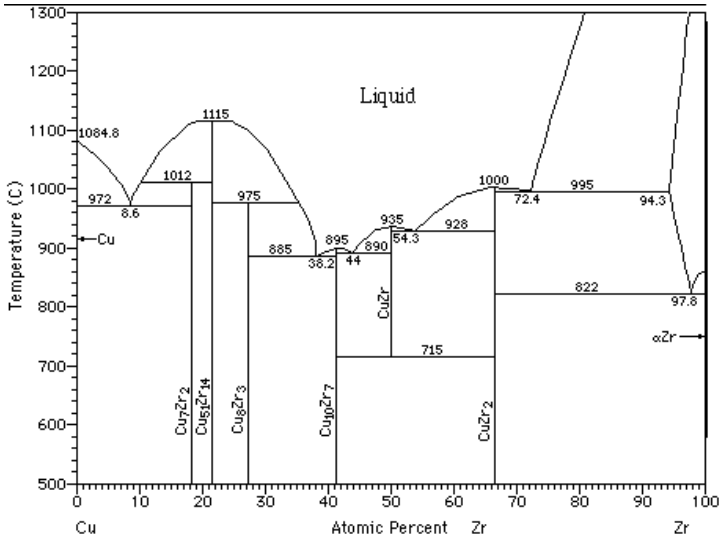




$\Delta H^S_{mix} < 0$: **Solid solution → ordered phase**



$\Delta H^S_{mix} << 0$: **Compound : AB, A_2B…**



Contents for today's class

- **Equilibrium in Heterogeneous Systems**
- **Binary phase diagrams**

How the equilibrium state of an alloy can be obtained from the free energy curves at a given temperature

→ How equilibrium is affected by temperature

a) Variation of temp.: $G^L > G^s$

b) At low temp. ($\because$ decrease of $-T\Delta S_{mix}$ effect): Decrease of curvature of G curve

1) Simple Phase Diagrams

2) Systems with miscibility gap

4) Simple Eutectic Systems

3) Ordered Alloys

5) Phase diagrams containing intermediate phases

Q5: How can we define equilibrium in heterogeneous systems?

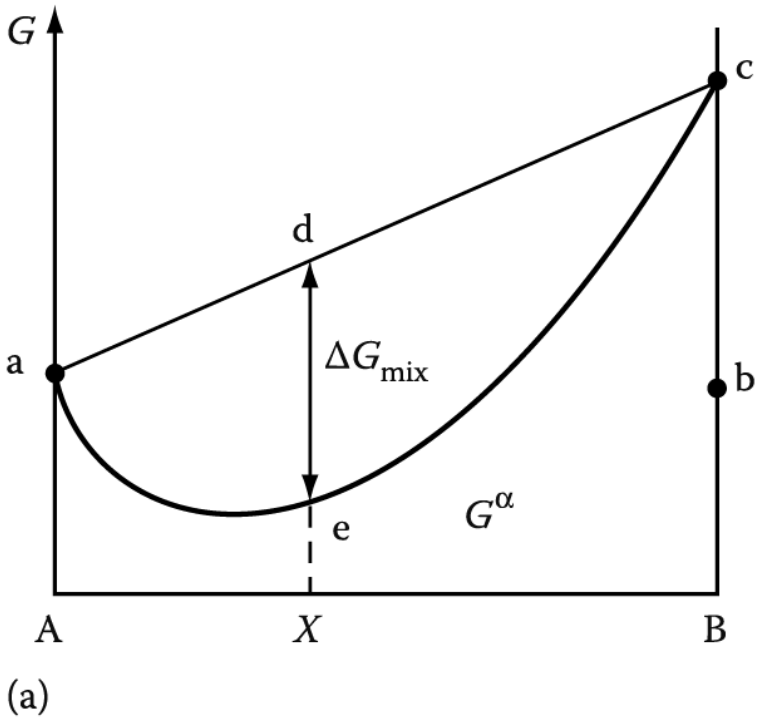
Equilibrium in Heterogeneous Systems

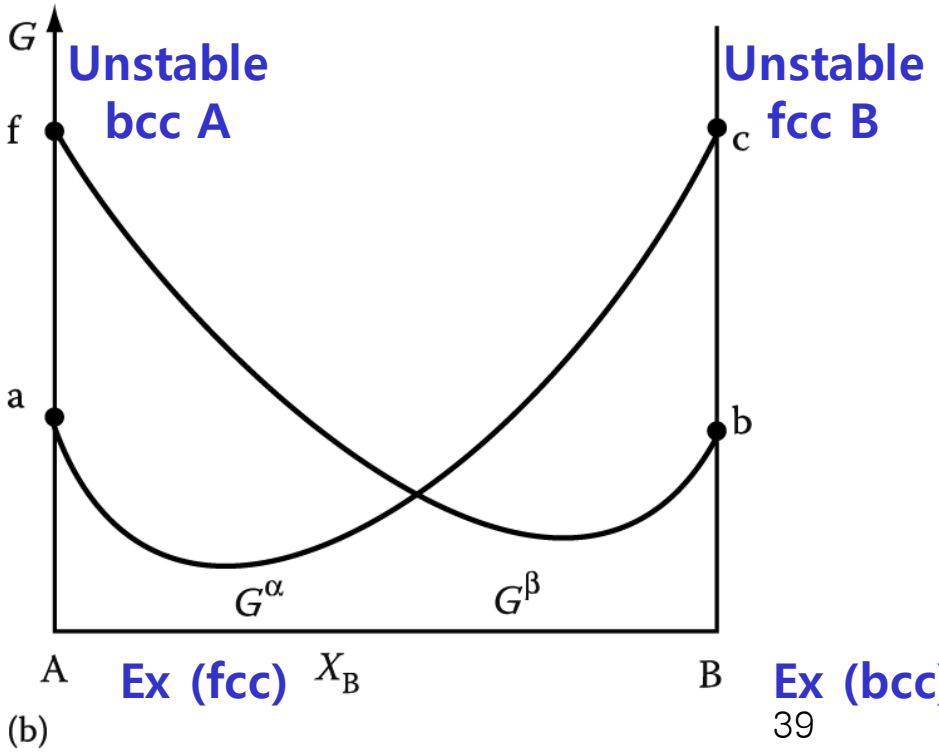
A, B different crystal structure → two free energy curves must be drawn, one for each structure.

We have dealt with the case where the components A and B have the same crystal structure.

$$G = X_A G_A + X_B G_B + \Omega X_A X_B + RT(X_A \ln X_A + X_B \ln X_B)$$

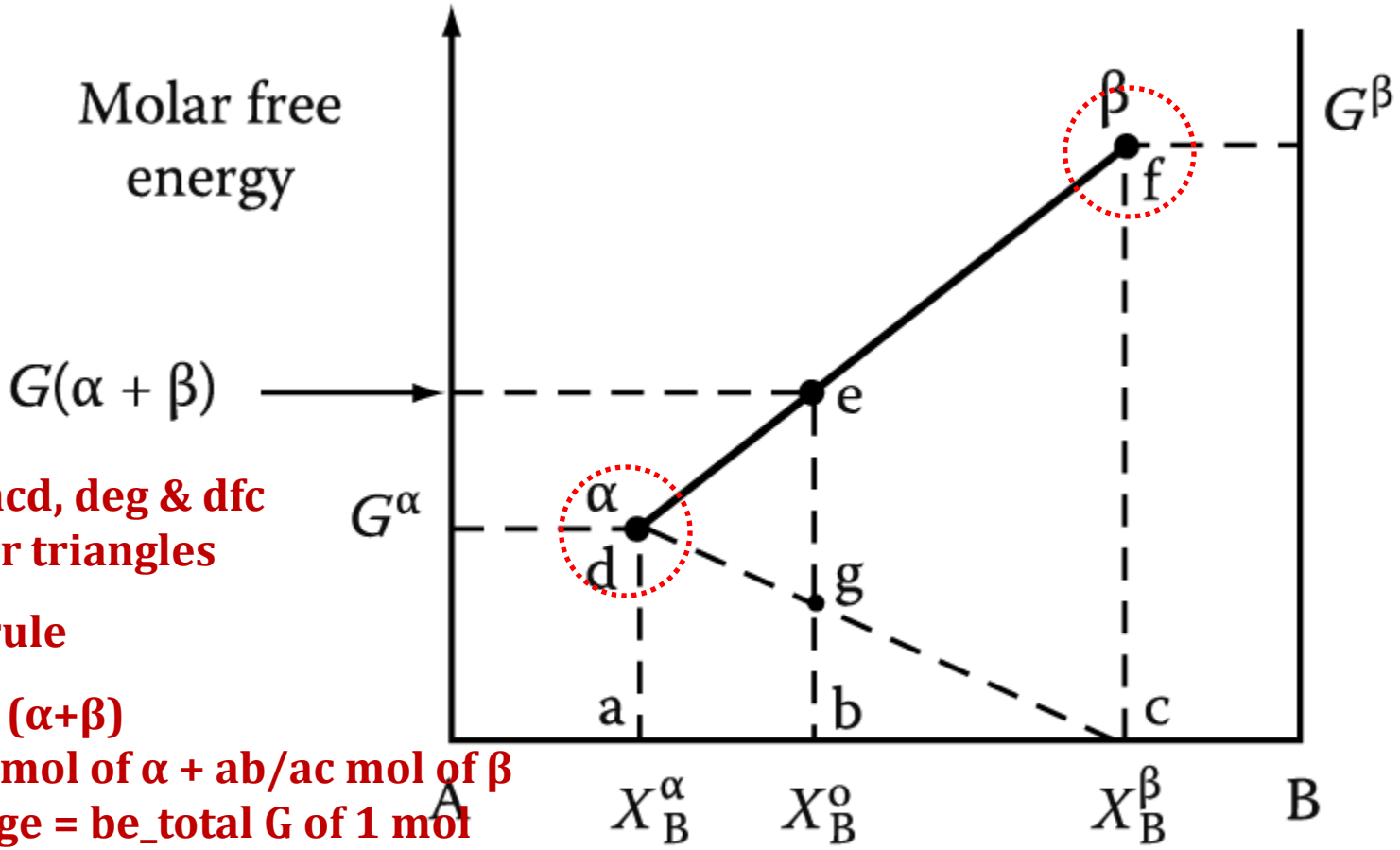
What would happen when the components A and B have a different crystal structure?
→ **heterogeneous system**





Equilibrium in Heterogeneous Systems

If $G^{\alpha}(X_B^{\alpha})$ and $G^{\beta}(X_B^{\beta})$ are given,
what would be $G(\alpha+\beta)$ *at* $X_B^o = ?$

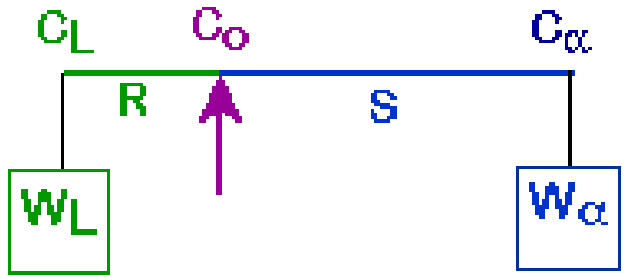


- bcg & acd, deg & dfc
  : similar triangles
- Lever rule
- 1 mole (α+β)
  : bc/ac mol of α + ab/ac mol of β
  → bg + ge = be_total G of 1 mol

Fig. 1.26 The molar free energy of a two-phase mixture (α+β)

Lever rule

A geometric interpretation:



moment equilibrium:

$$W_L R = W_\alpha S$$

$1 - W_\alpha$

solving gives Lever Rule

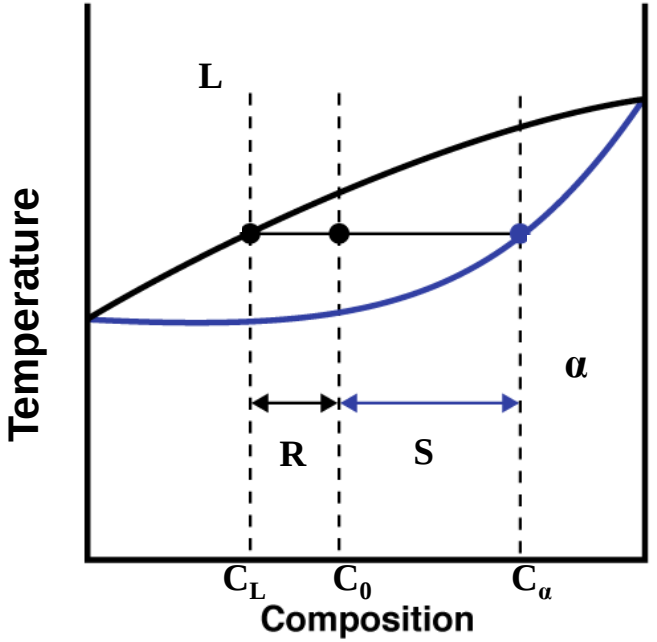
Sum of weight fractions: $W_L + W_\alpha = 1$

Conservation of mass (Ni): $C_o = W_L C_L + W_\alpha C_\alpha$

Combine above equations:

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

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

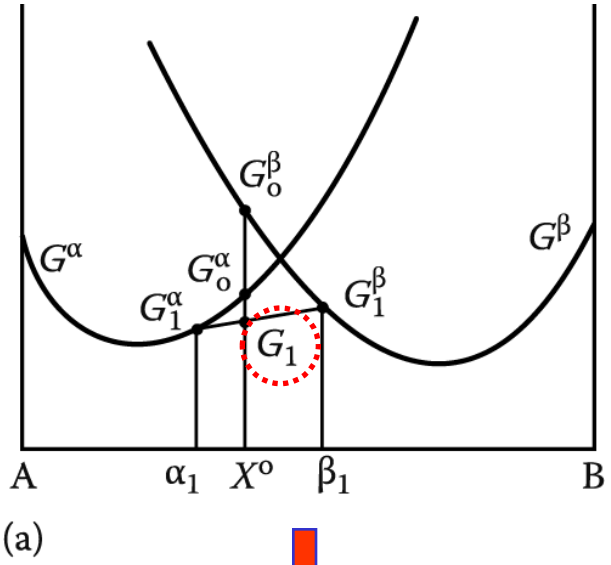


Equilibrium in Heterogeneous Systems

In X^0, $G_0^{\beta} > G_0^{\alpha} > G_1$

Exchange of A and B atoms

→ α + β phase separation

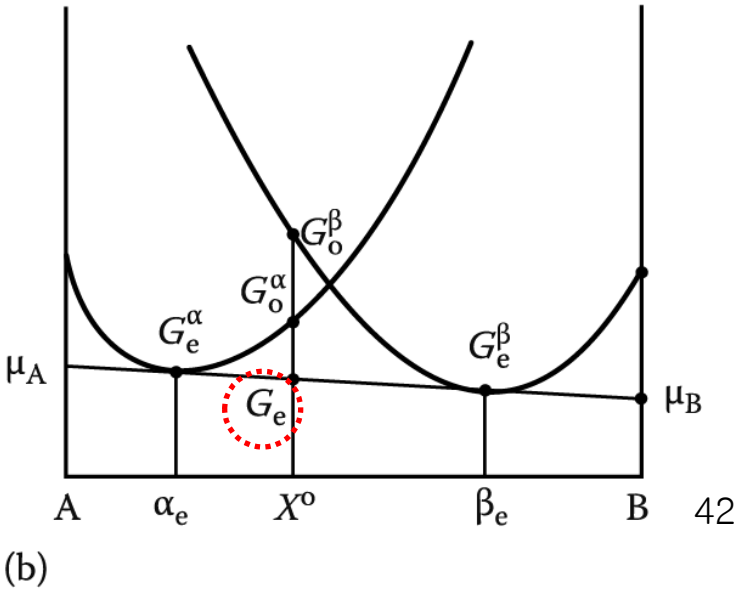


(a)

Chemical Equilibrium (μ, a)
→ multiphase and multicomponent
$(\mu_i^{\alpha} = \mu_i^{\beta} = \mu_i^{\gamma} = \ldots)$, $(a_i^{\alpha} = a_i^{\beta} = a_i^{\gamma} = \ldots)$

$$\mu_A^{\alpha} = \mu_A^{\beta} \qquad \mu_B^{\alpha} = \mu_B^{\beta}$$

Unified Chemical potential of two phases



(b)

Variation of activity with composition

The most stable state, with the lowest free energy, is usually defined as the state in which the pure component has unit activity of A in pure α.

$$when\ X_A = 1 \rightarrow a_A^{\alpha} = 1$$

$$when\ X_B = 1 \rightarrow a_B^{\beta} = 1$$

when α and β in equil.

$$a_A^{\alpha} = a_A^{\beta}$$

$$a_B^{\alpha} = a_B^{\beta}$$

Unified activity of two phase

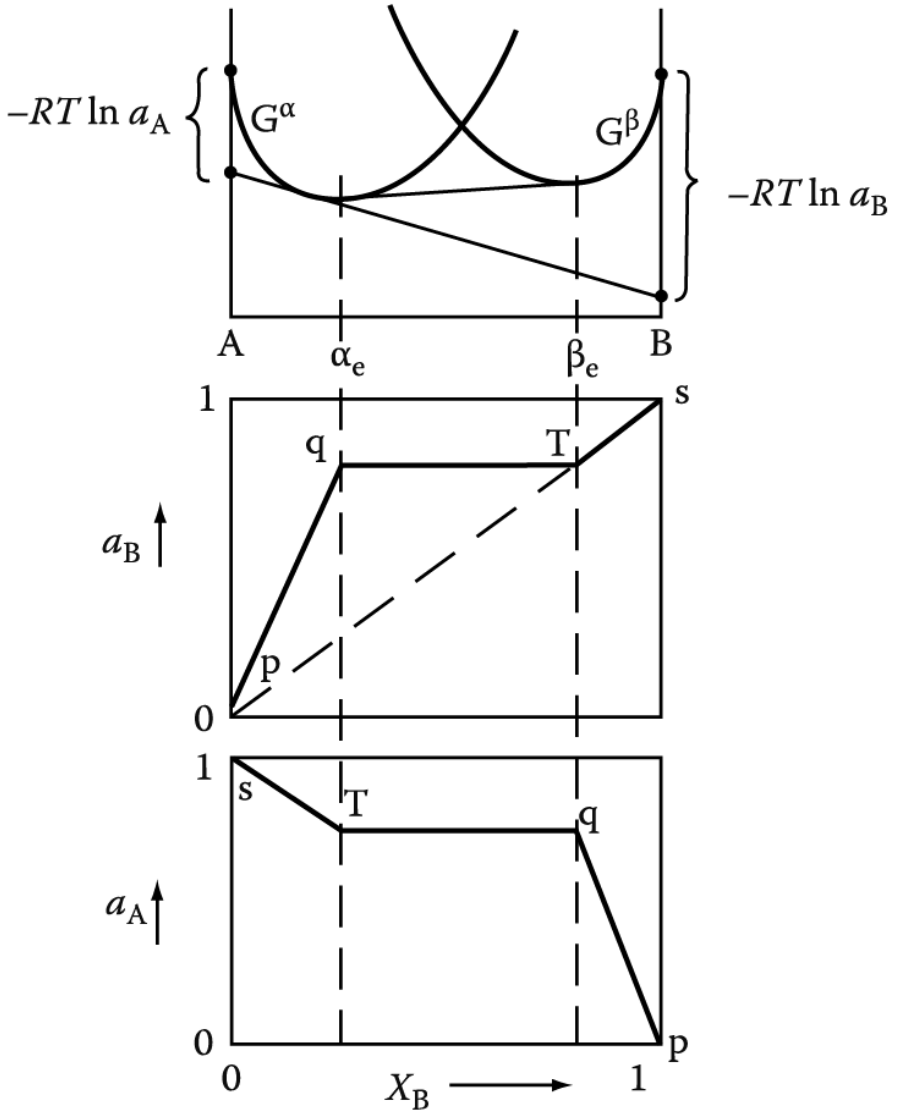
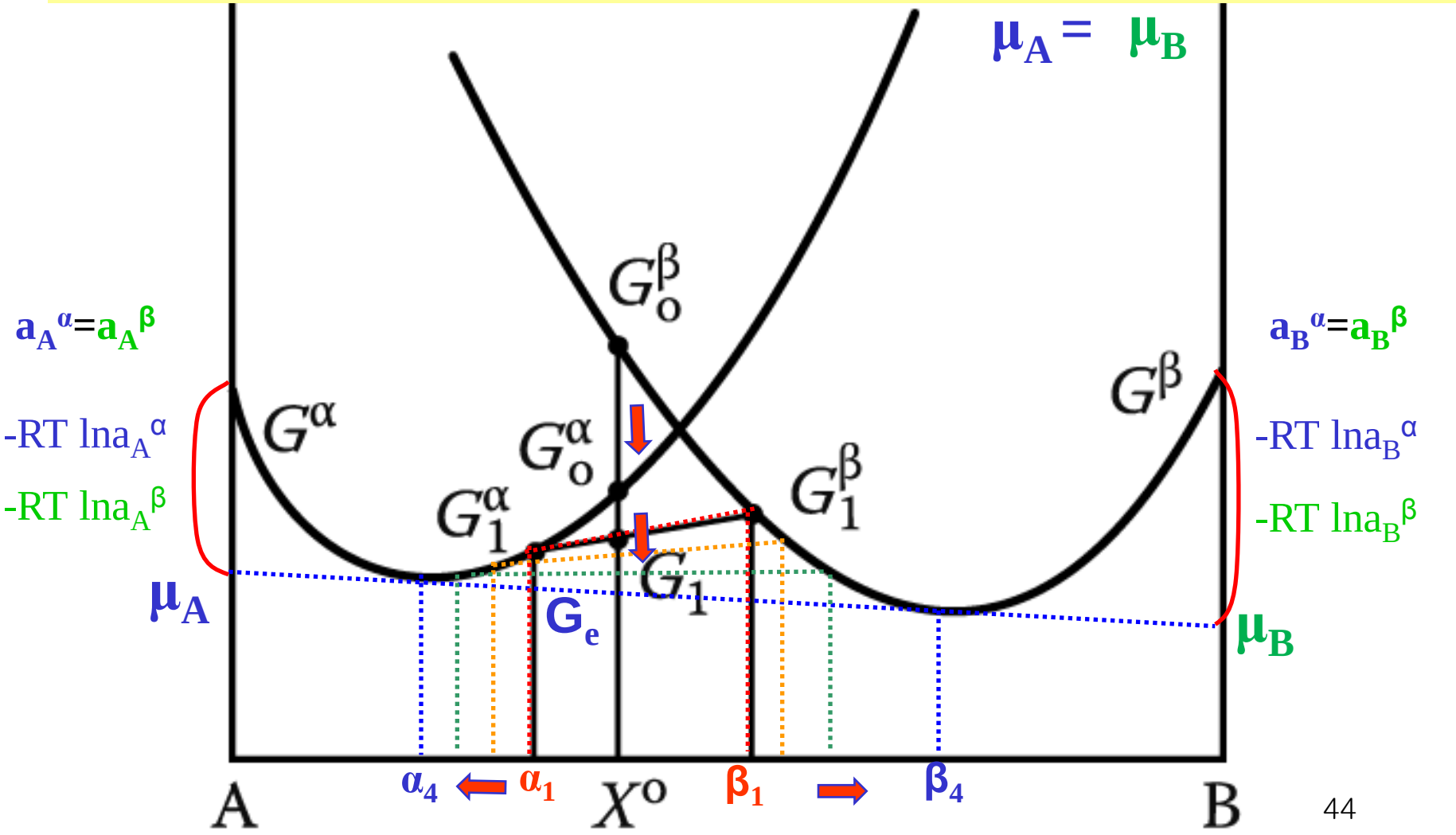


Fig. 1.28 The variation of a_A and a_B with composition for a binary system containing two ideal solutions, α and β

Equilibrium in Heterogeneous Systems

In X^0, $G_0^{\beta} > G_0^{\alpha} > G_1$ ⇒ α + β separation ⇒ unified chemical potential



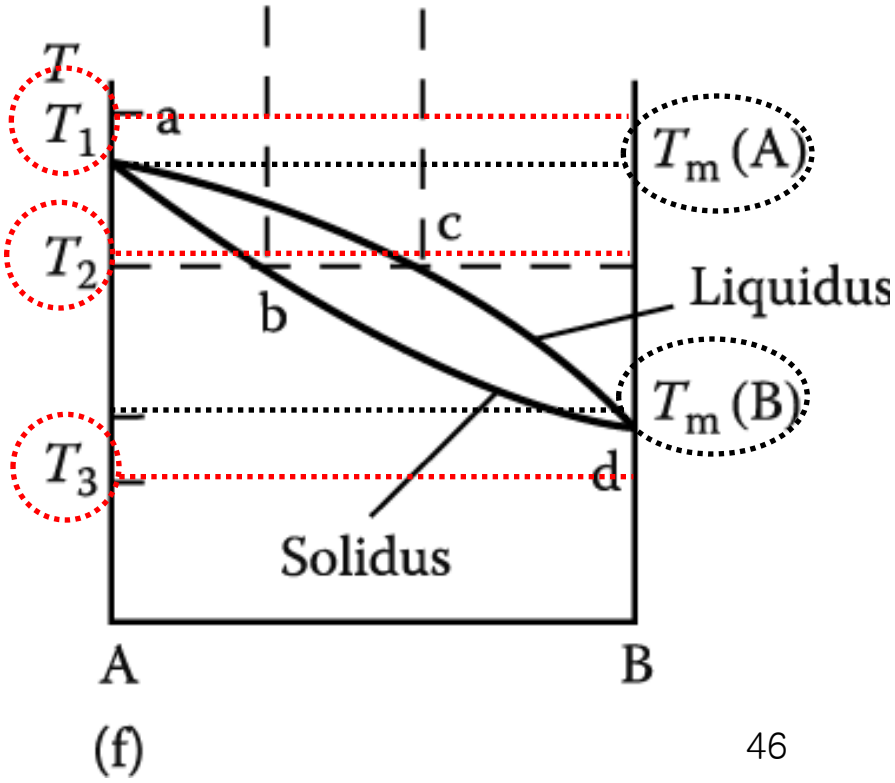
Q6: How equilibrium is affected by temperature in complete solid solution?

1) Simple Phase Diagrams

Assumption: (1) completely miscible in solid and liquid.
(2) Both are ideal soln.
(3) $T_m(A) > T_m(B)$
(4) $T_1 > T_m(A) > T_2 > T_m(B) > T_3$

$$\Delta H_{mix}^{L} = 0 \quad \Delta H_{mix}^{S} = 0$$

Draw G^L and G^S as a function of composition X_B at T_1, $T_m(A)$, T_2, $T_m(B)$, and T_3.



(f)

1) Simple Phase Diagrams

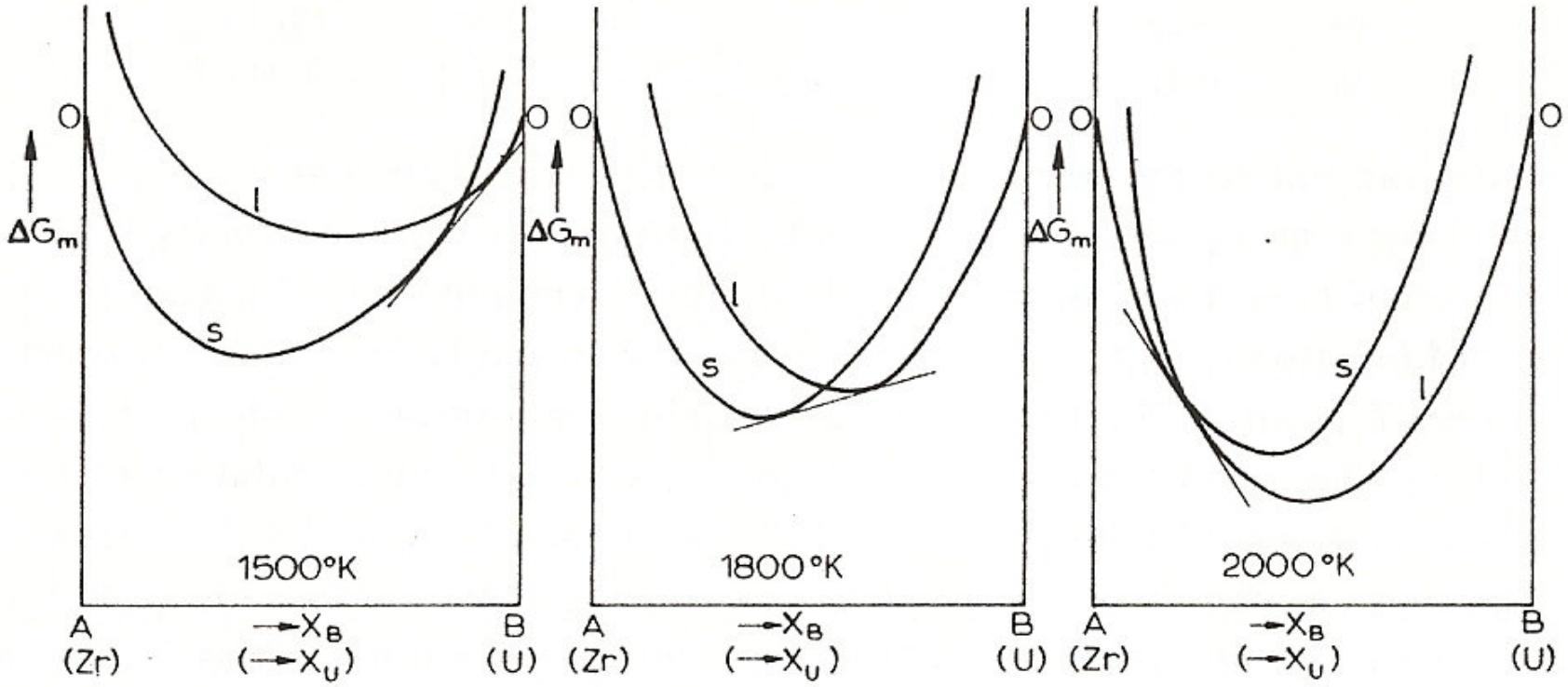


Fig. 26. Free energy curves for liquid and solid phases in the U–Zr system at 1500°, 1800° and 2000 °K.

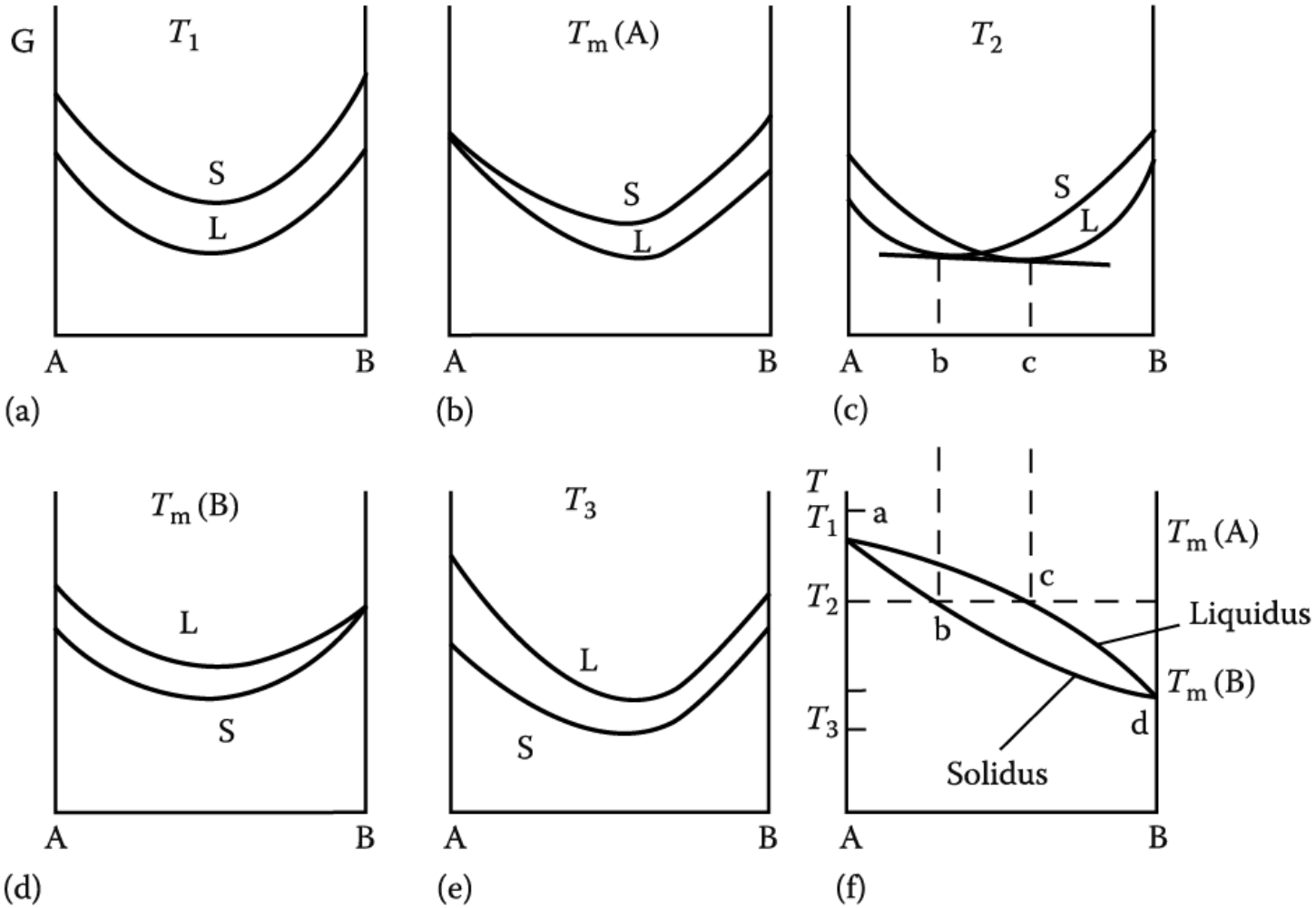
1.5 Binary phase diagrams

1) Simple Phase Diagrams

1) Variation of temp.: $G^L > G^s$
2) Decrease of curvature of G curve
   ($\because$ decrease of $-T\Delta S_{mix}$ effect)

Assumption:

(1) completely miscible in solid and liquid.
(2) Both are ideal soln.
(3) $T_m(A) > T_m(B)$
(4) $T_1 > T_m(A) > T_2 > T_m(B) > T_3$

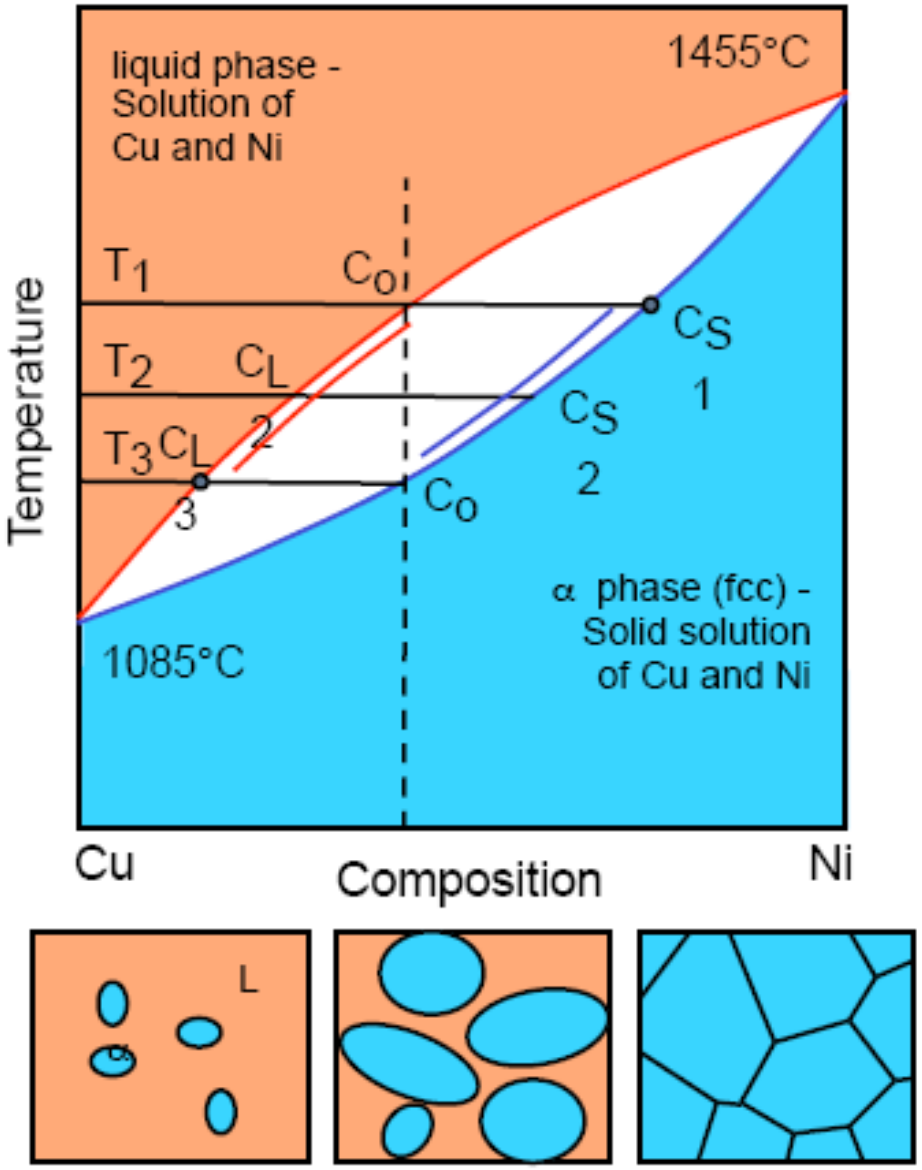


1.5 Binary phase diagrams

1) Simple Phase Diagrams

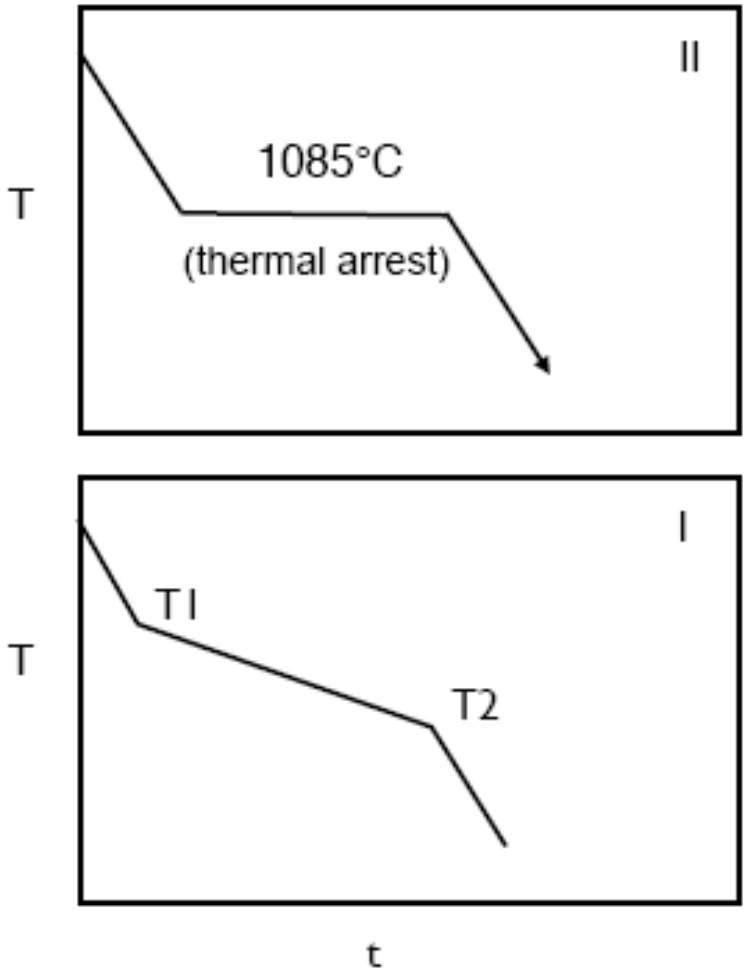
The simplest type of binary phase diagrams is the isomorphous system, in which the two constituents form a continuous solid solution over the entire composition range. An example is the Ni-Cu system.

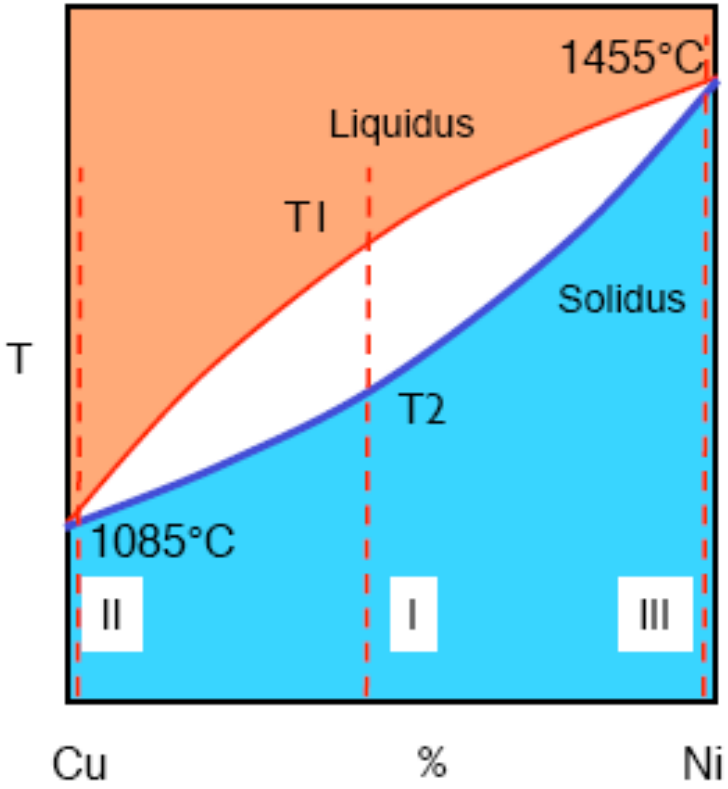
Solidification of alloy C_o starts on cooing at T_1. The first solid formed has a composition of C_{s1} and the liquid C_o. On further cooling the solid particles grow larger in size and change their composition to C_{s2} and then C_o, following the solidus whereas the liquid decrease in volume and changes its composition from C_o to C_{L3} following the liquidus. The solidification completes at T_3.



Q7: How can we draw cooling curve depending on compositions in complete solid solution?

Cooling Curves
determination of Phase diagrams

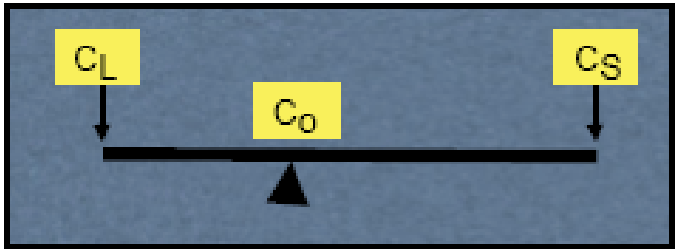




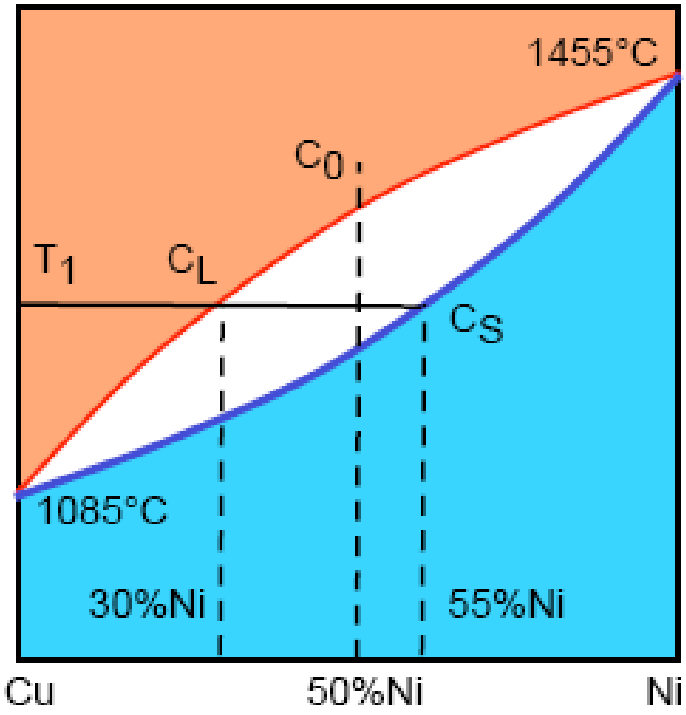
Example

At temperature T_1, alloy C_o is in the dual phase region, comprising the liquid phase and the α-phase.

(i) Determine the compositions of the two phases;
(ii) Determine the weight fractions of the two phases



Read from the tie line:
Liquid phase: Cu-30%Ni
α-phase: Cu-55%Ni



$$W_L = \frac{C_s - C_o}{C_s - C_L} = \frac{55-50}{55-30} = 0.2 = 20\%$$

$$W_\alpha = \frac{C_o - C_L}{C_s - C_L} = \frac{50-30}{55-30} = 0.8 = 80\%$$

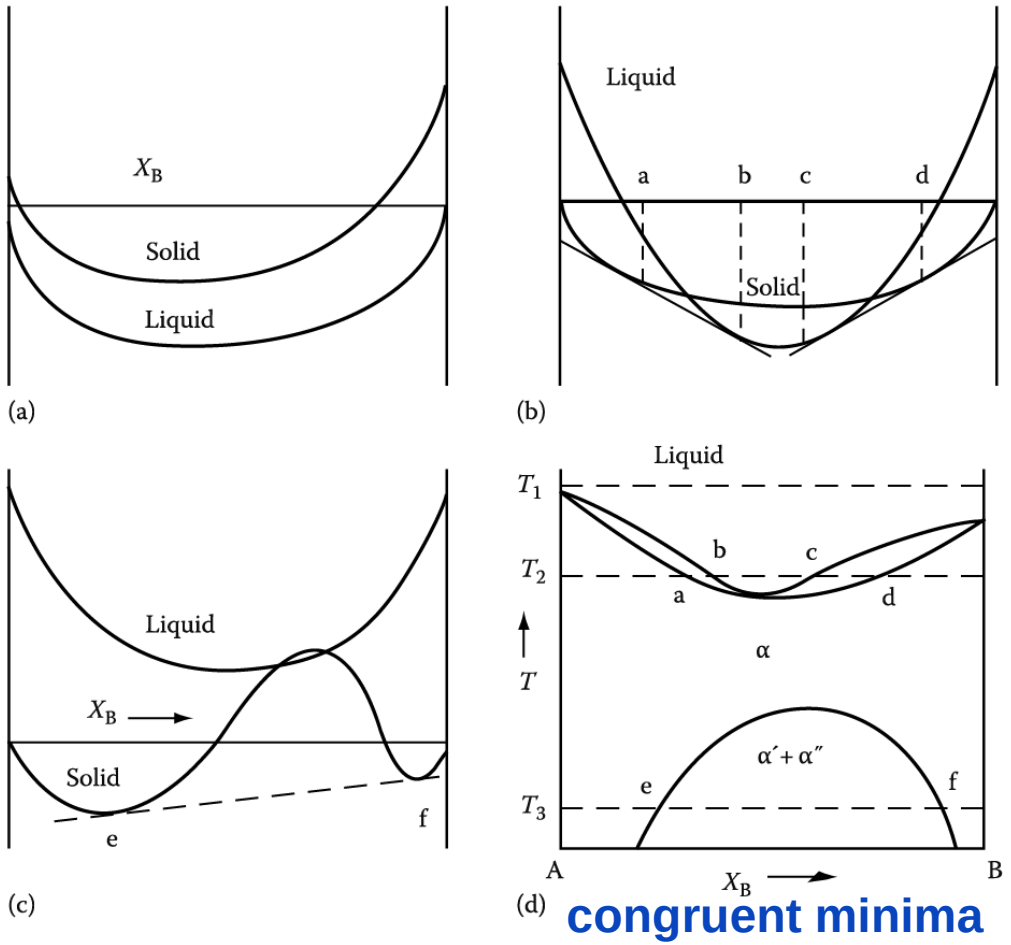
or

$$W_\alpha = 1 - W_L = 1 - 0.2 = 0.8 = 80\%$$

Q8: How equilibrium is affected by temperature in systems with miscibility gap?

2) Systems with miscibility gab

$$\Delta H^{L}_{mix} = 0 \qquad \Delta H^{S}_{mix} > 0$$

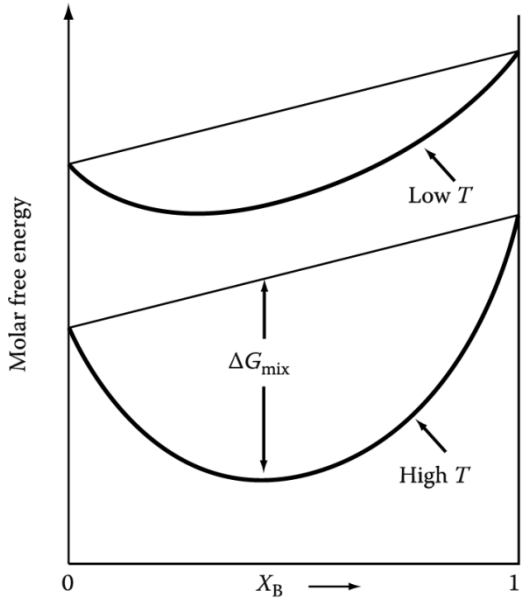


congruent minima

How to characterize G^s mathematically in the region of miscibility gap between e and f ?

Ideal Solutions

$$G_2 = G_1 + \Delta G_{mix}$$

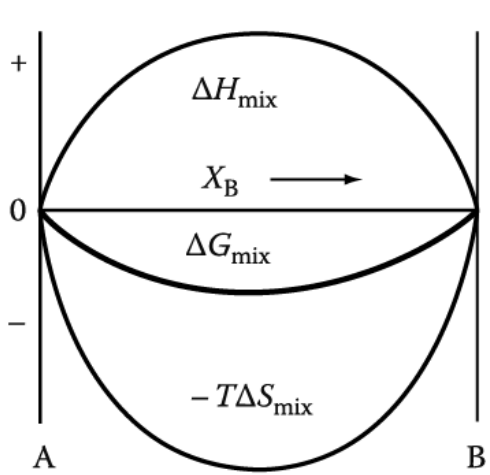


Regular Solutions

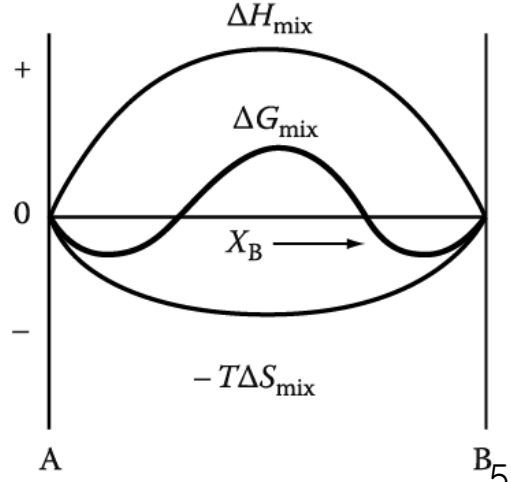
$$G = X_A G_A + X_B G_B + \underbrace{\Omega\, X_A X_B}_{\Delta H_{mix}} + \underbrace{RT\,(X_A \ln X_A + X_B \ln X_B)}_{-T\Delta S_{mix}}$$

Reference state

Pure metal $G_A^0 = G_B^0 = 0$



(c) $\Omega > 0$, high T



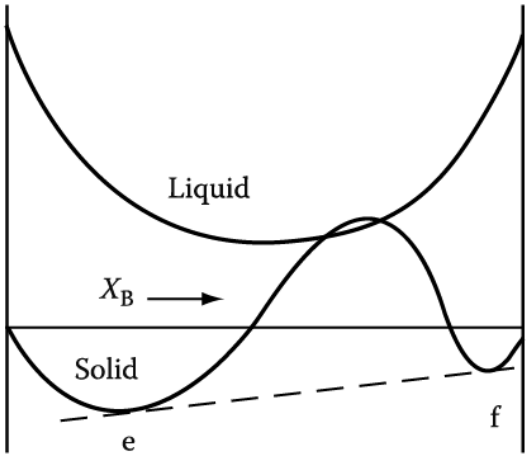
(d) $\Omega > 0$, low T

$$\Delta G_{mix} = \Delta H_{mix} - T\Delta S_{mix}$$

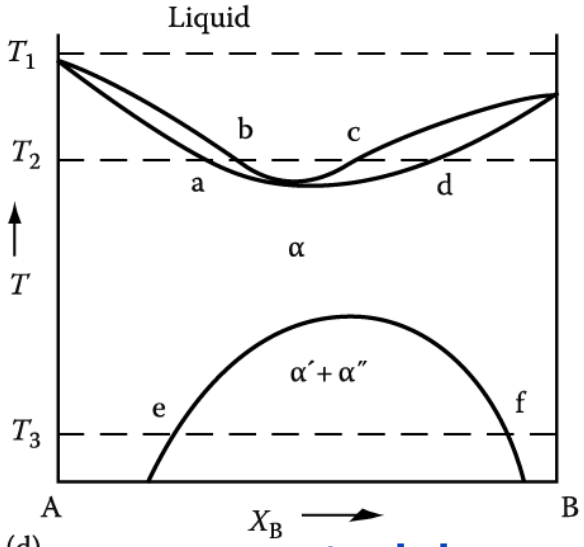
2) Systems with miscibility gab

$$\Delta H_{mix}^{L} = 0 \qquad \Delta H_{mix}^{S} > 0$$

- **When A and B atoms dislike each other,** $\Delta H_{mix} > 0$
- **In this case, the free energy curve at low temperature has a region of negative curvature,** $\frac{d^2G}{dX_B^2} < 0$
- **This results in a 'miscibility gap' of α′ and α″ in the phase diagram**



(c)



(d)

congruent minima

Q9: How equilibrium is affected by temperature in simple eutectic systems?

4) Simple Eutectic Systems $\Delta H_{mix}^{L} = 0 \quad \Delta H_{mix}^{S} >> 0$

- **$\Delta H_m >> 0$ and the miscibility gap extends to the melting temperature. (when both solids have the same structure.)**

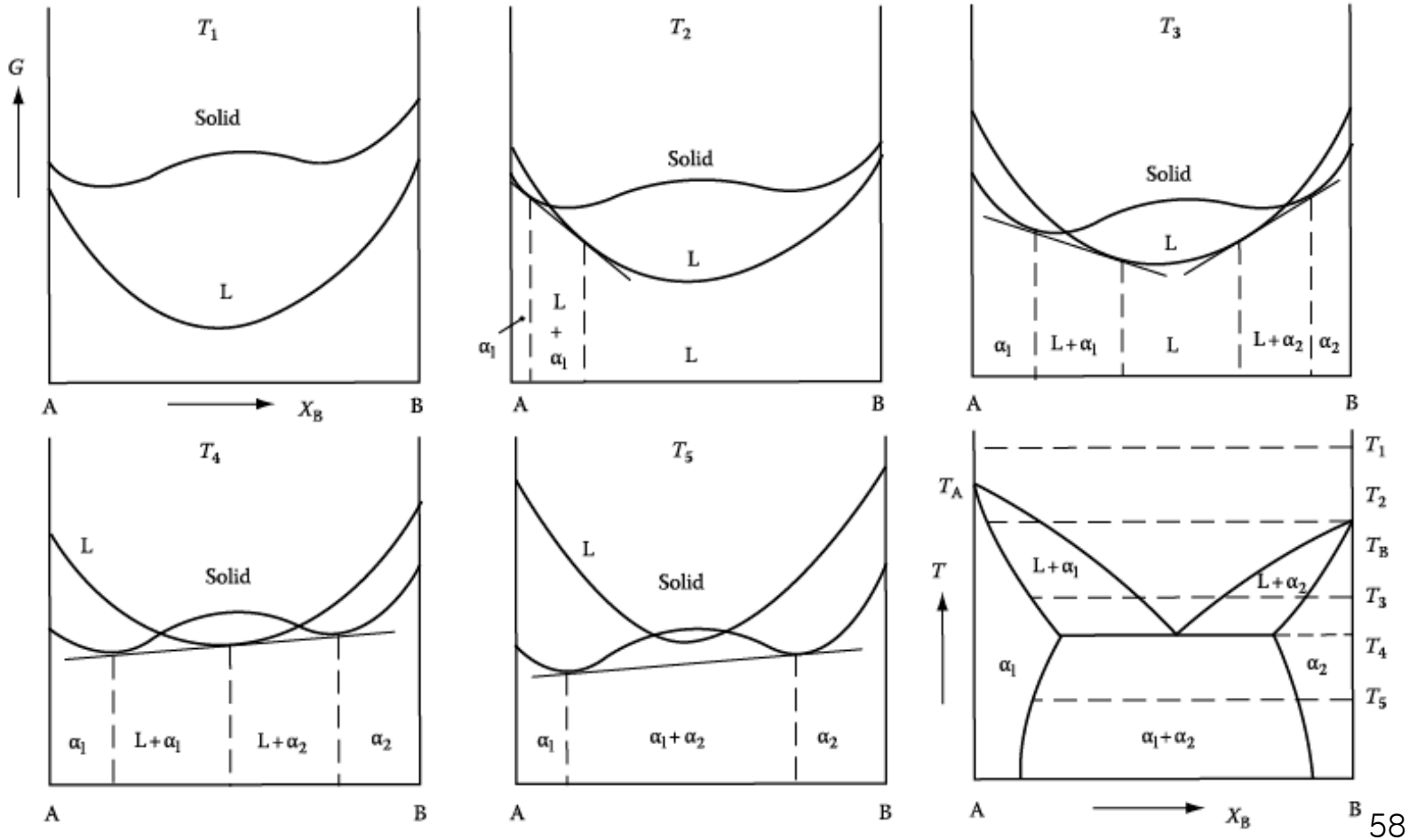


Fig. 1.32 The derivation of a eutectic phase diagram where both solid phases have the same crystal structure.

(when each solid has the different crystal structure.)

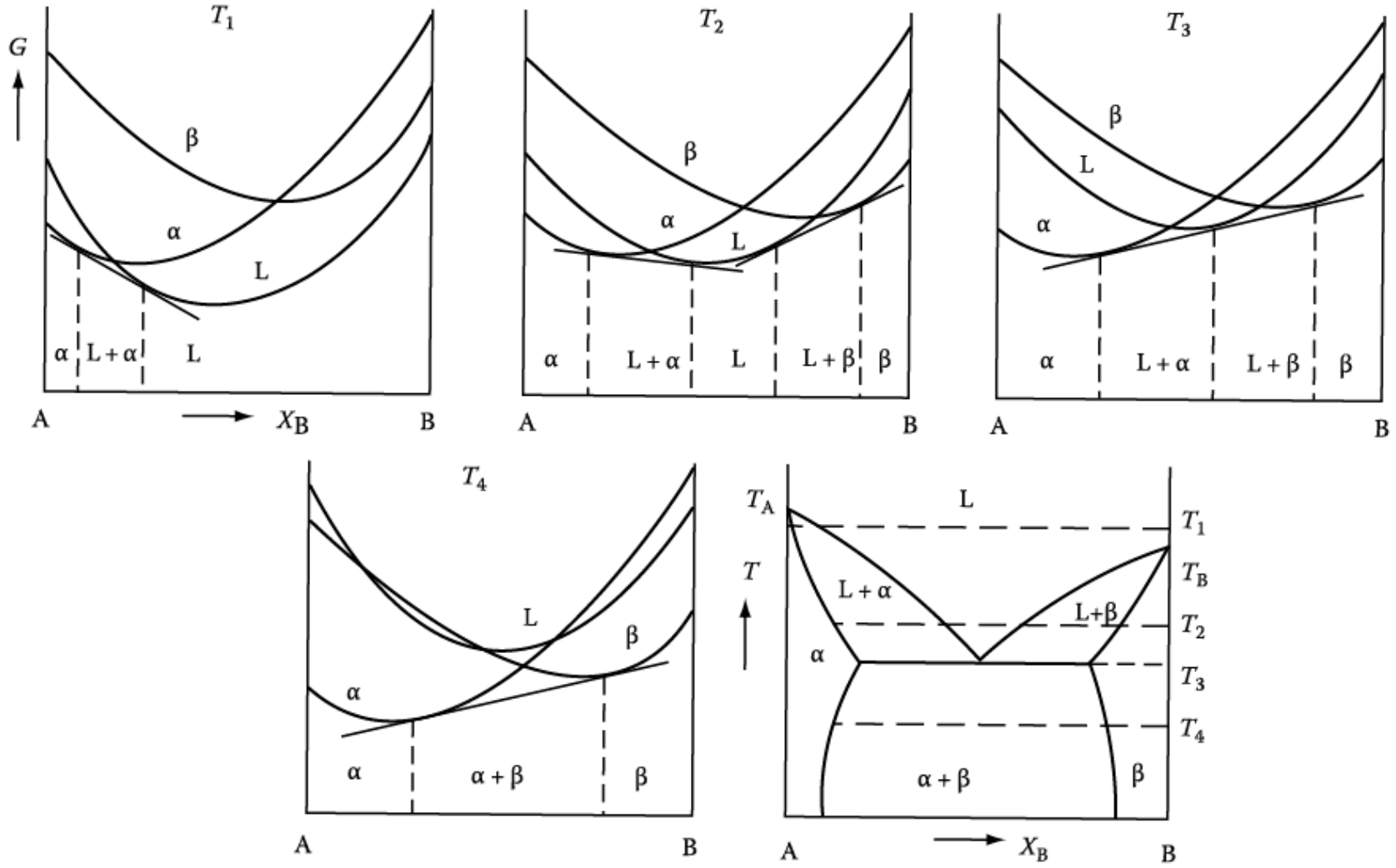
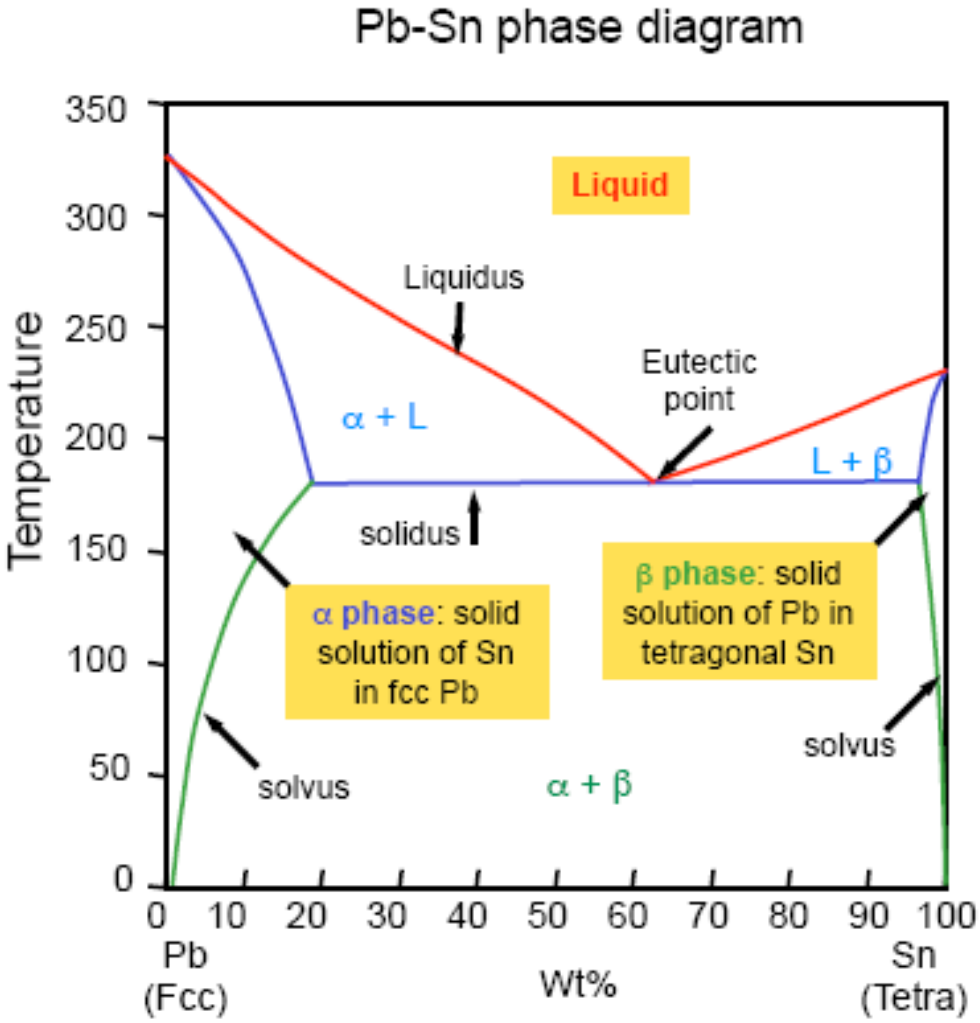


Fig. 1.32 The derivation of a eutectic phase diagram where each solid phases has a different crystal structure.

Eutectic Systems

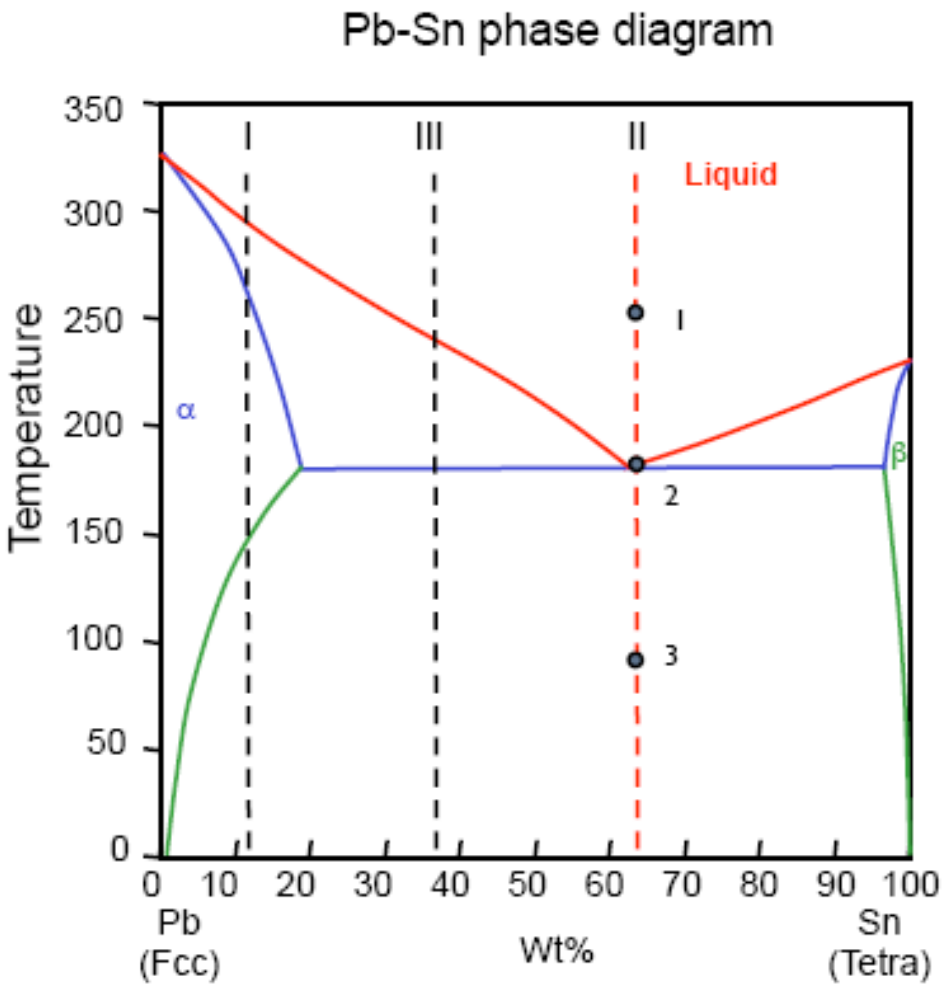
The Pb-Sn system is characteristic of a valley in the middle. Such system is known as the **Eutectic** system. The central point is the Eutectic point and the transformation though this point is called Eutectic reaction: **L**✦α+β

Pb has a fcc structure and Sn has a tetragonal structure. The system has three phases: L, α and β.

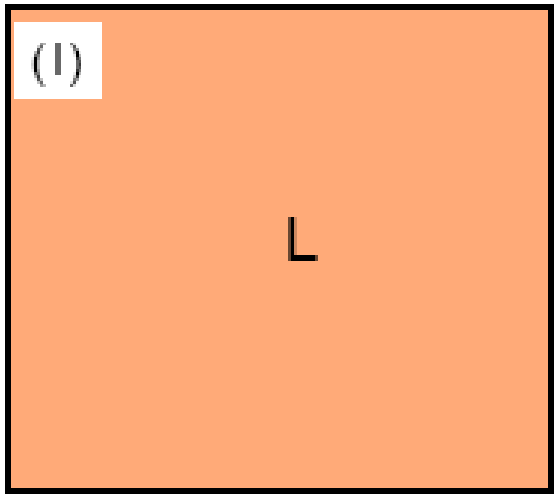


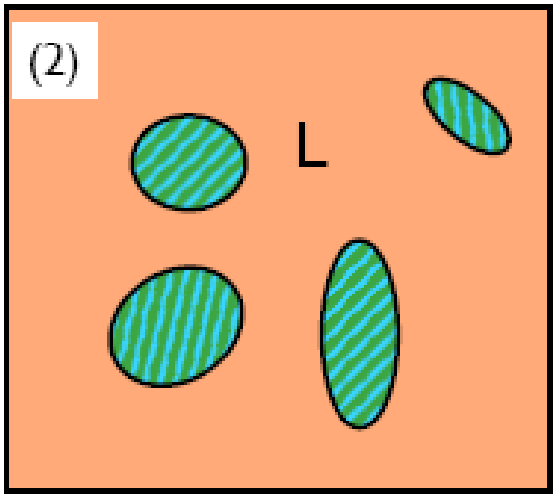
Solidification of Eutectic Systems

Alloy II:
At point 1: Liquid
Solidification starts at eutectic point (where liquidus and solidus join)
At point 2: L✦(α+β) (eutectic reaction)
The amounts of α and β increase in proportion with time.
Solidification finishes at the same temperature.
At point 3: α+β
Further cooling leads to the depletion of Sn in α and the depletion of Pb in β.

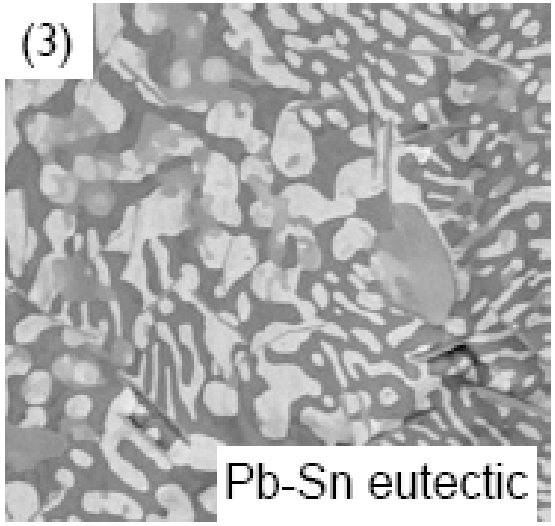


1.5 Binary phase diagrams





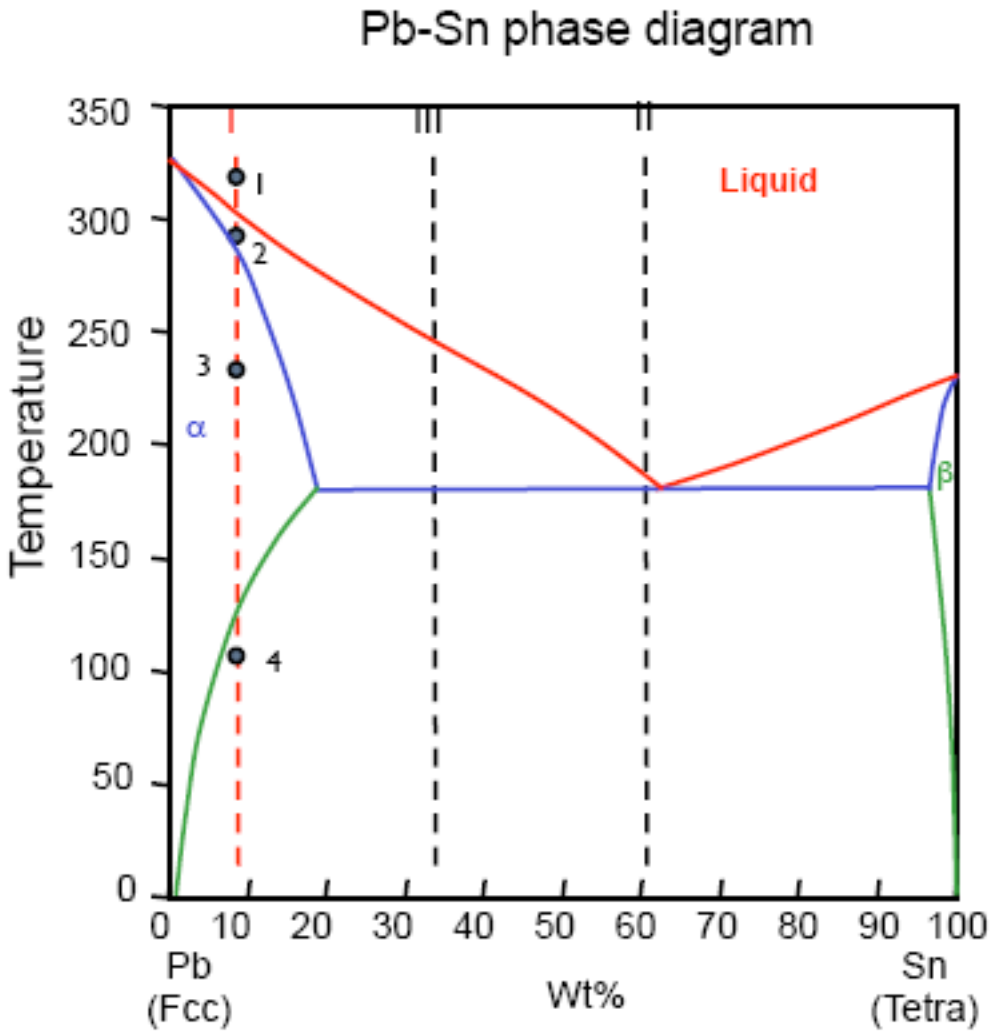
Nucleation of colonies of α and β laminates



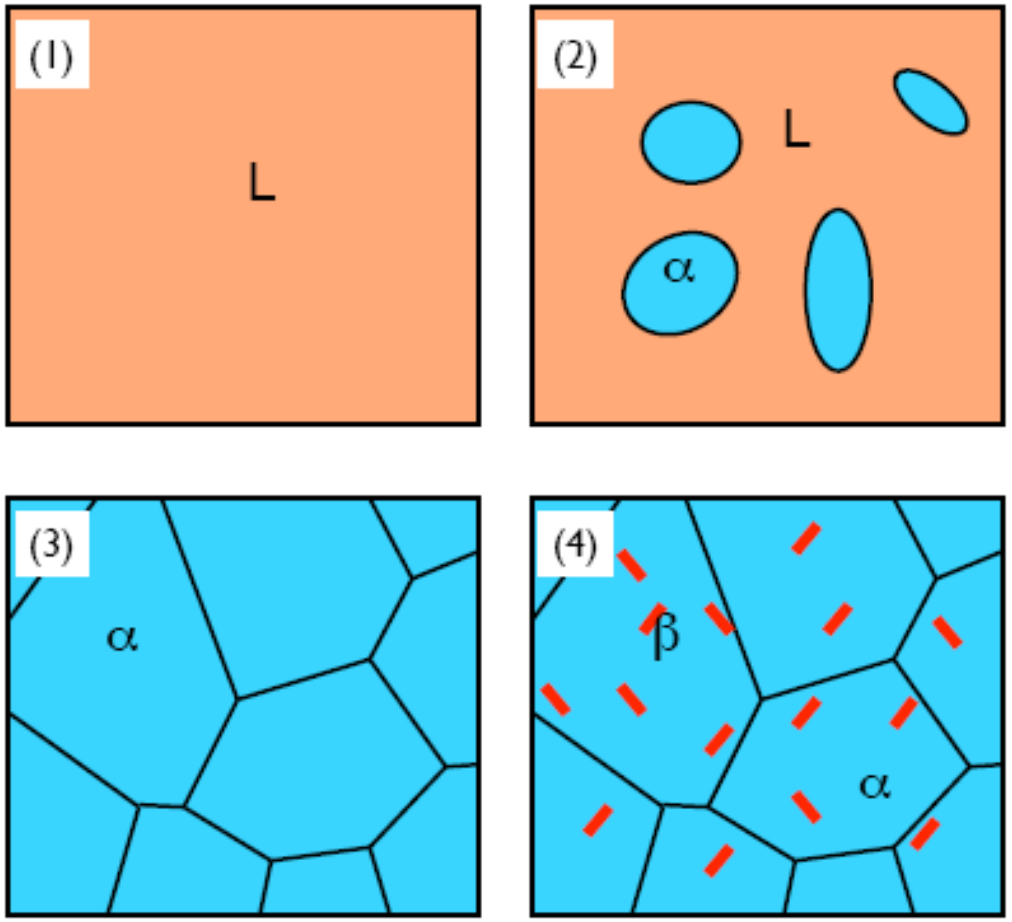
Eutectic structure of intimate mix of α and β to minimise diffusion path

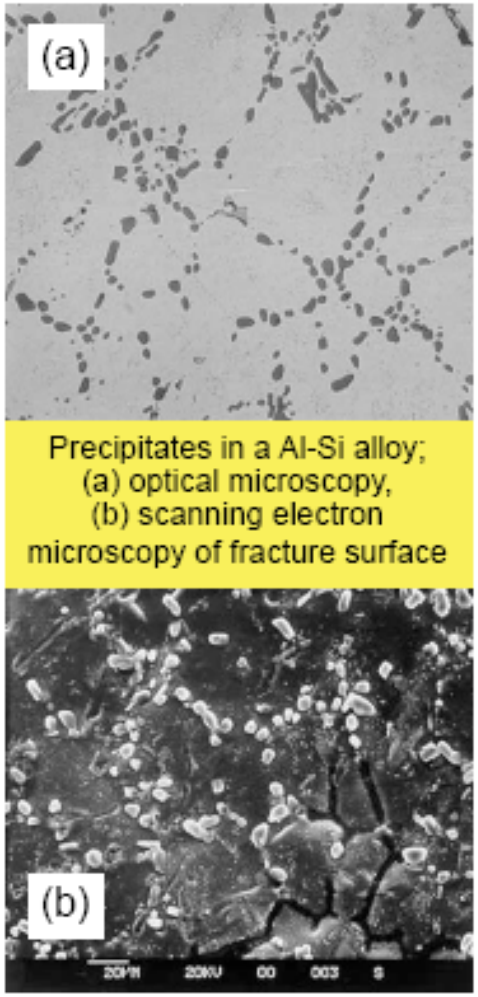
Solidification of Eutectic Systems

Alloy I:
At point 1: Liquid
Solidification starts at liquidus
At point 2: L+α
The amount α ↑ with ↓ T
Solidification finishes at solidus
At point 3: α
Precipitation starts at solvus
At point 4: α+β
Further cooling leads to formation and growth of more β precipitates whereas Sn% in α decreases following the solvus.



1.5 Binary phase diagrams



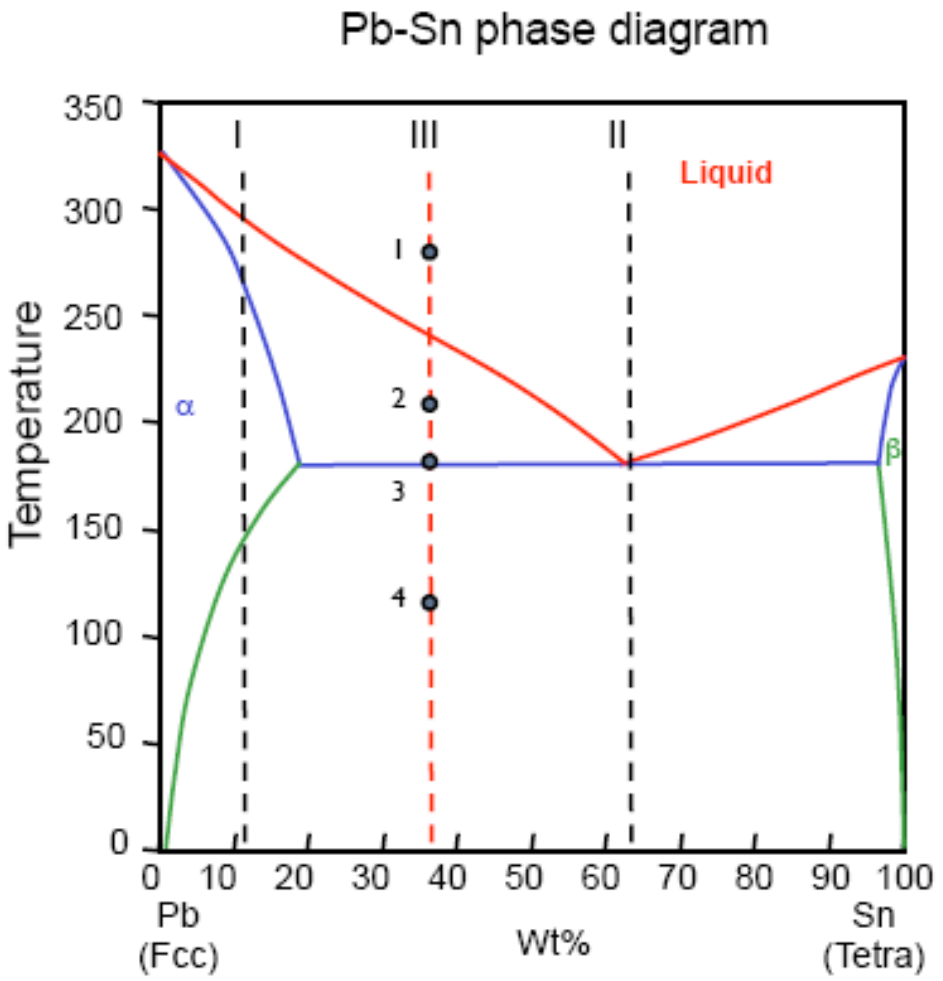


Precipitates in a Al-Si alloy;
(a) optical microscopy,
(b) scanning electron
microscopy of fracture surface

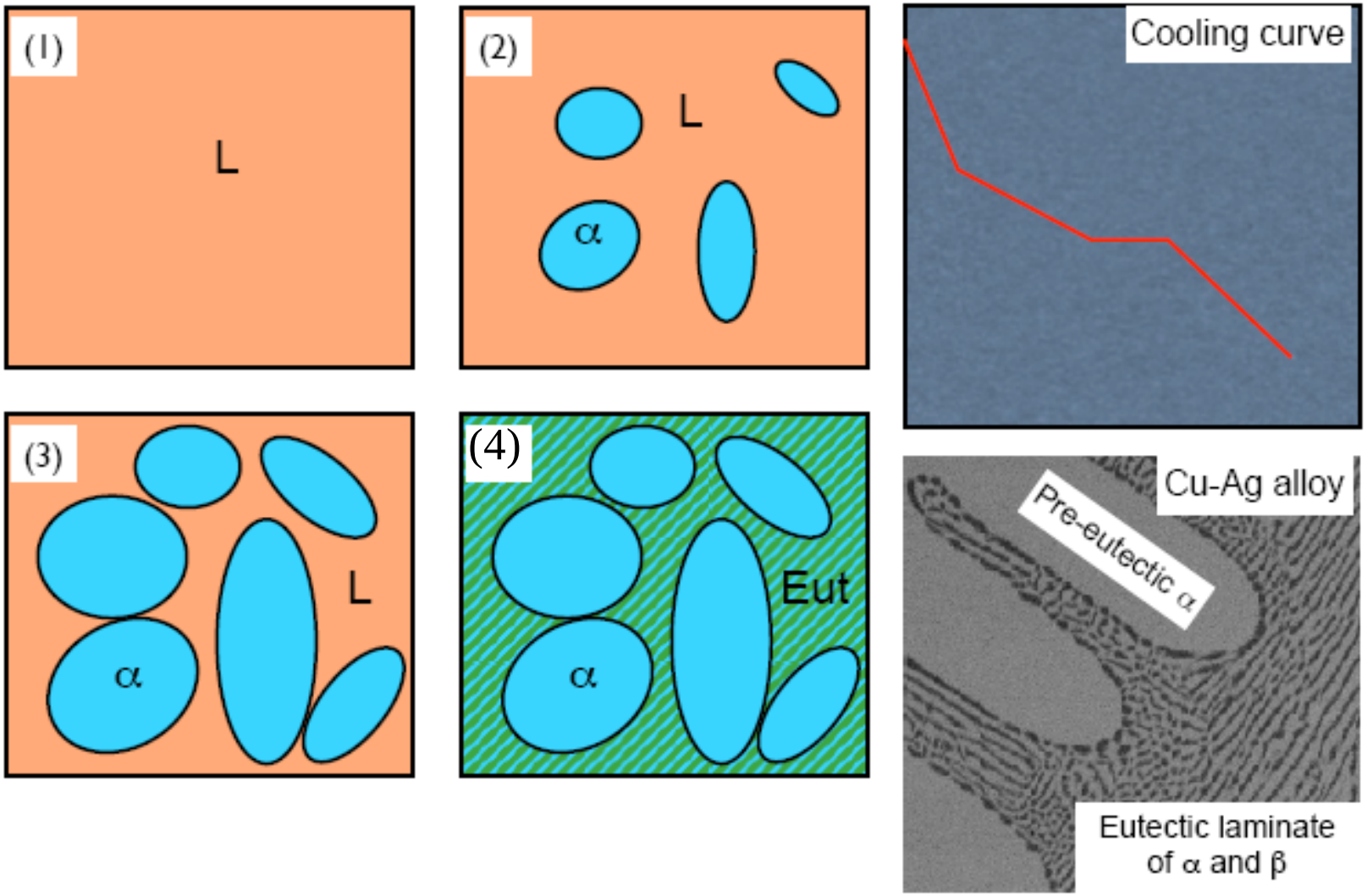
Solidification of Eutectic Systems

Alloy III:
At point 1: Liquid
Solidification starts at liquidus
At point 2: L✦L+α (pre-eutectic α)
The amount α ↑ with ↓T
At point 3: L✦ (α+β) (eutectic reaction)
Solidification finishes at the eutectic temperature
At point 4: α+β (pre-eutectic α + (α+β) eutectic mixture)
Further cooling leads to the depletion of Sn in α and the depletion of Pb in β.

The cooling curve of this alloy is a combination of the two cooling curves shown in slide 9.

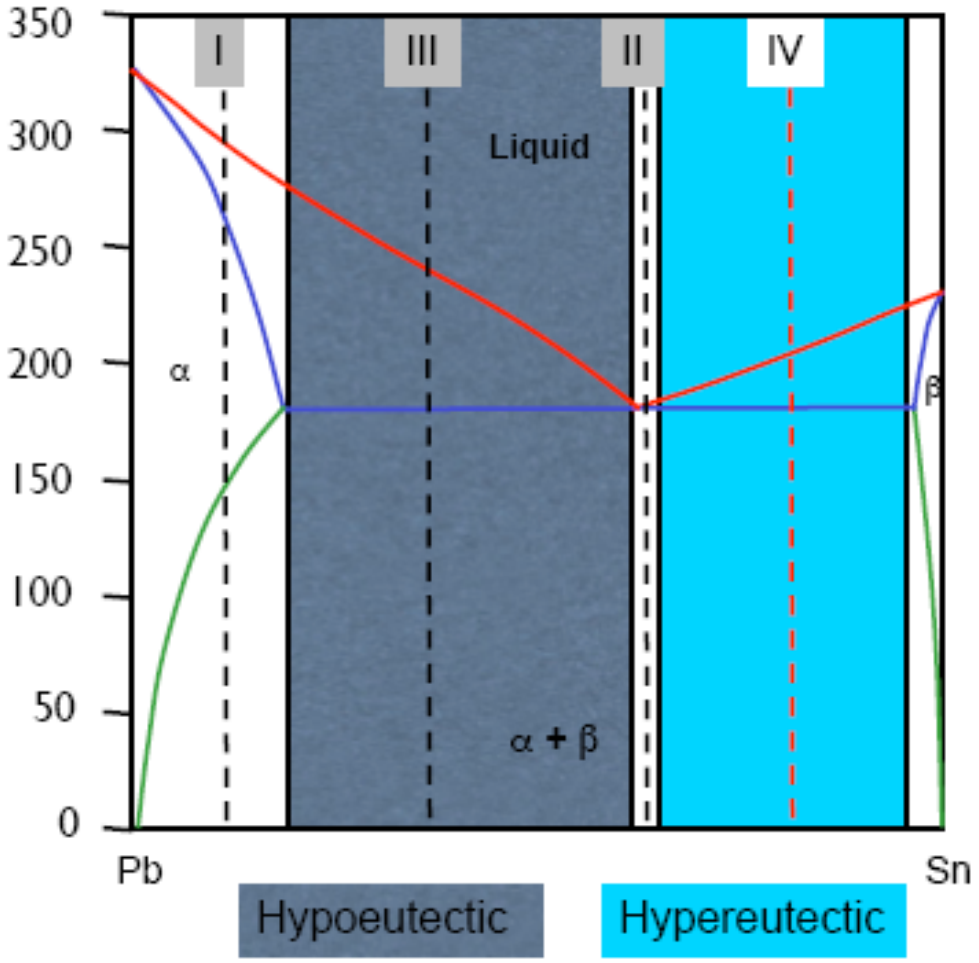


1.5 Binary phase diagrams: Hypoeutectic

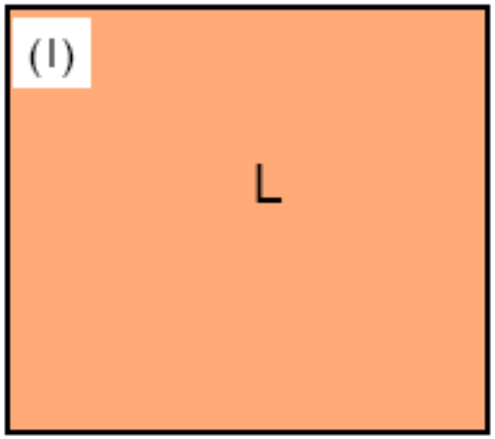


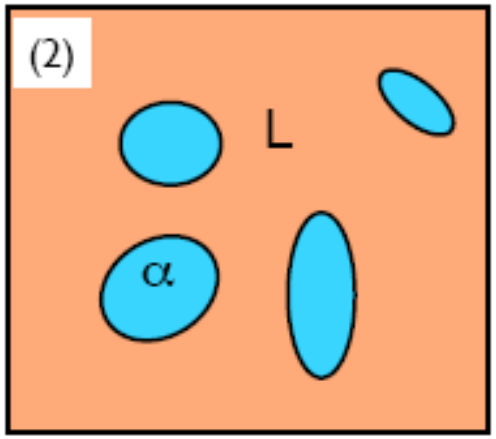
Solidification of Eutectic Systems

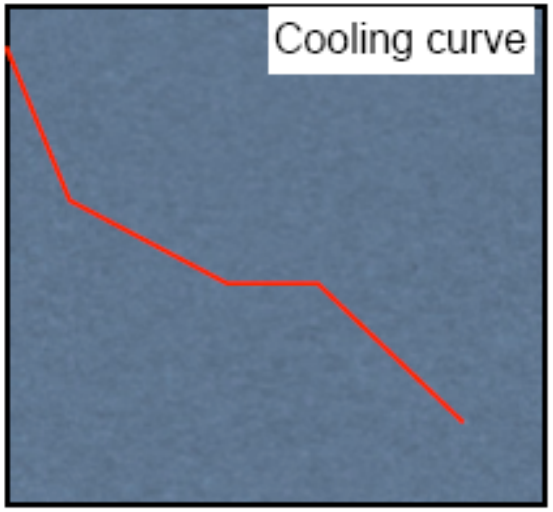
Can you describe the solidification process of alloy IV, including microstructure evolution, morphology of phases and cooling curve?

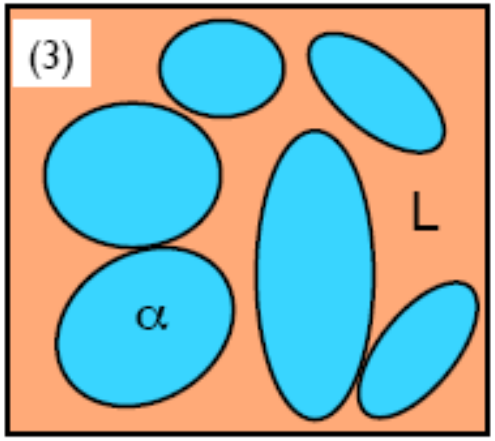


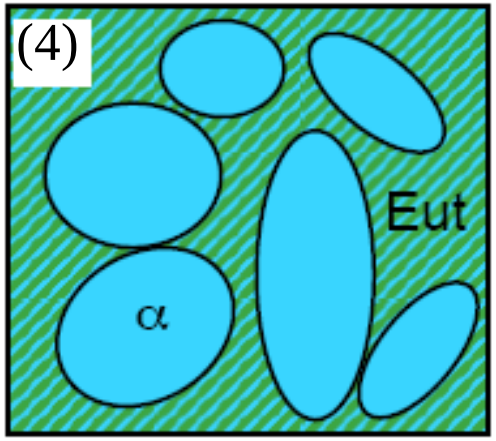
1.5 Binary phase diagrams : Hypereutectic

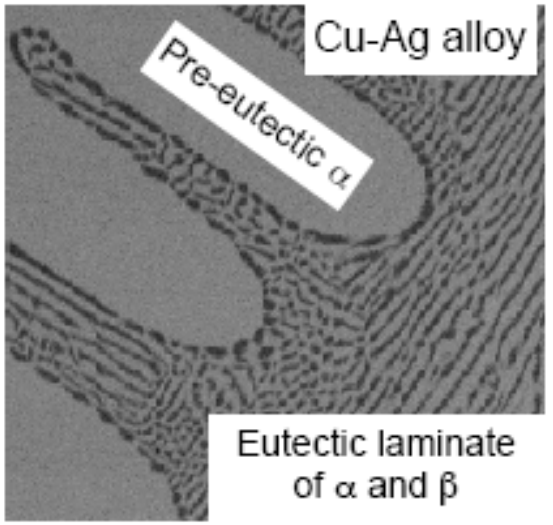








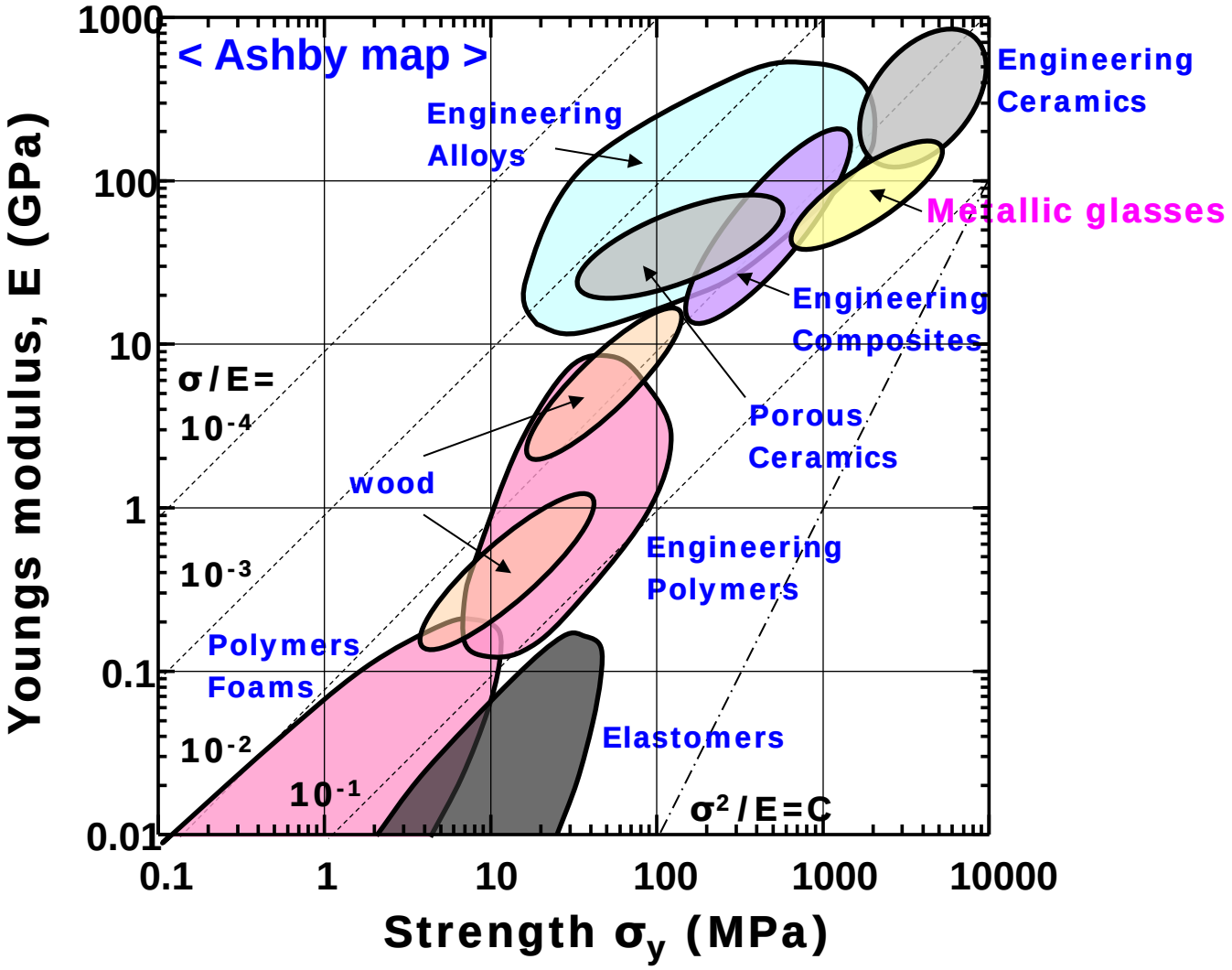




Q10: Materials design

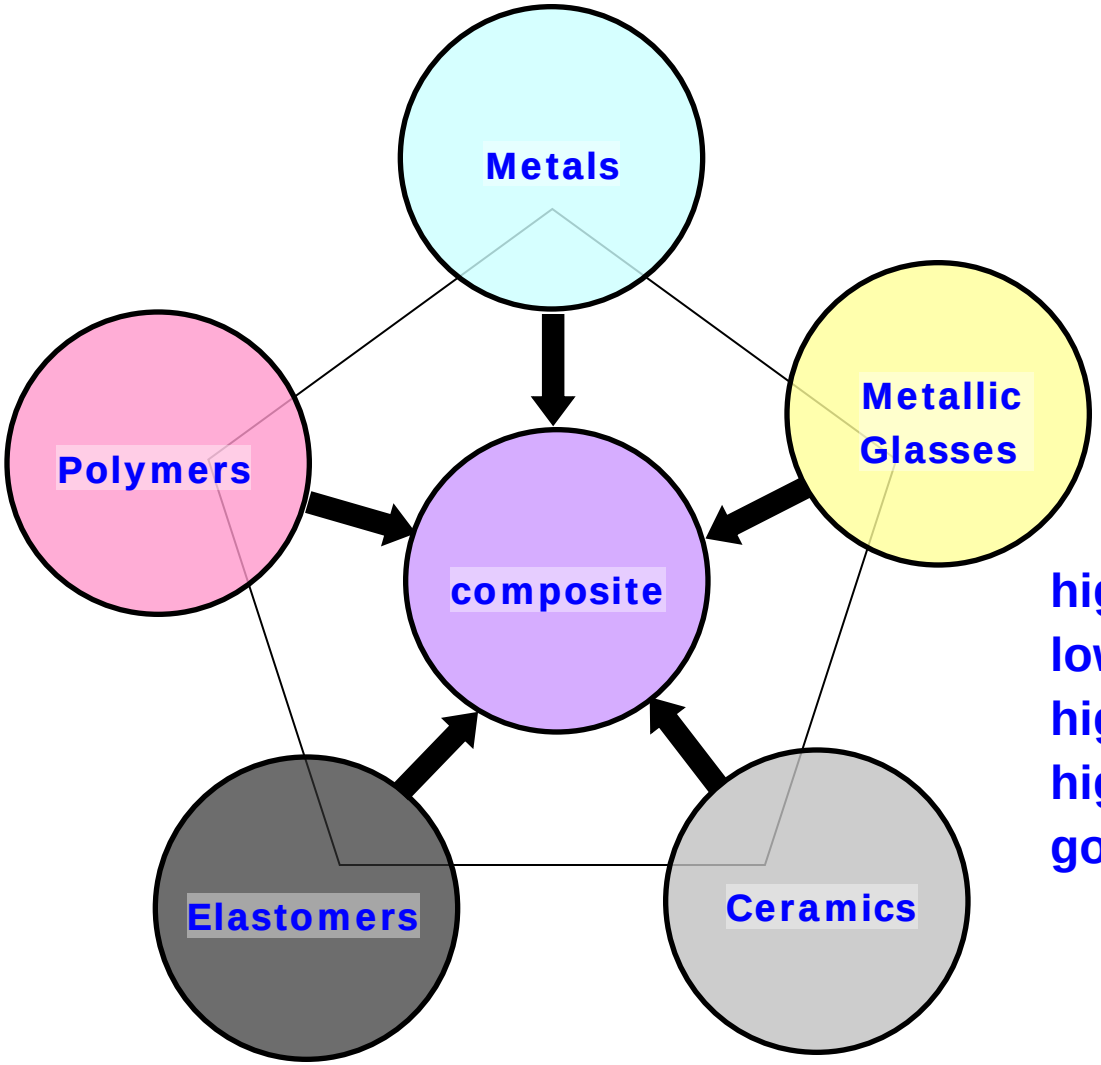
Proposal for final presentation?

Materials Design



Materials Design

Menu of engineering materials



High GFA

High plasticity

higher strength
lower Young's modulus
high hardness
high corrosion resistance
good deformability

Topic proposal for materials design

Please submit 3 materials that you want to explore for materials design and do final presentations on in this semester. Please make sure to thoroughly discuss why you chose those materials (up to 1 page on each topic). The proposal is due by September 23rd on eTL.

Ex) stainless steel/ graphene/ OLED/ Bio-material/ Shape memory alloy Bulk metallic glass, etc.