Diagramas de Fases

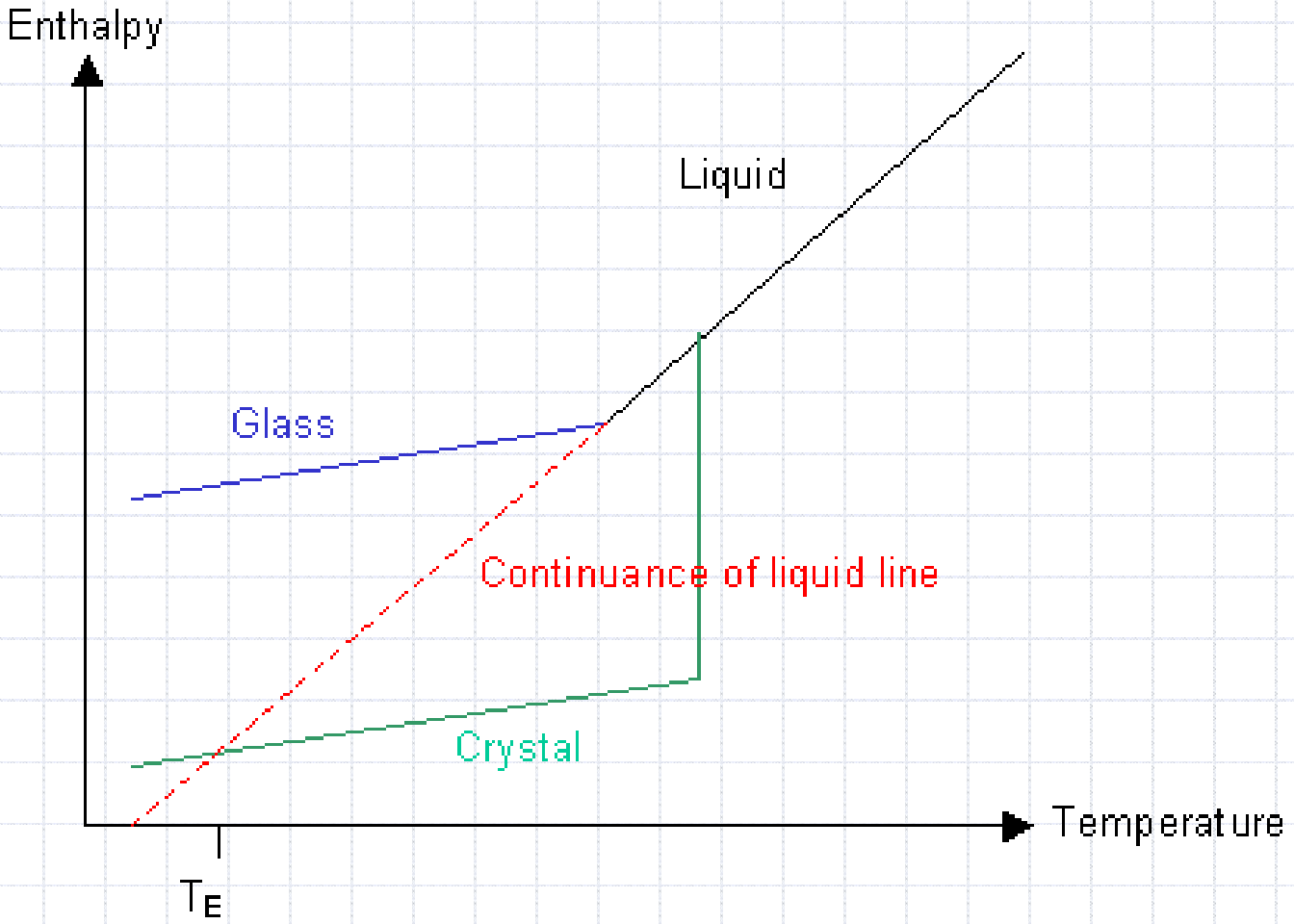
Princípios de Termodinâmica

- Energia interna: U
  - dU=dQ-dW (1ª lei – conservação da energia)
  - dU=dQ-pdV
- Entalpia: H
  - H=U+pV
  - $C_p = \left(\frac{\partial H}{\partial T} \right)_p$
- Entropia: S
  - ΔS=ΔQ/T=ΔU+pΔV/T
  - Num sistema isolado ΔS>0 (2ª lei)
  - $\lim_{T \to 0} S = 0$ (3ª lei)

Princípios de Termodinâmica

- Entropia (estatística):
  - $S=k_B.\ln\Omega$
- Energia livre de Gibbs: G
  - G=H-TS
  - Processos espontâneos $\Delta G<0$
  - Processos em equilíbrio $\Delta G=0$
- Potencial químico: μ
  - $$\mu_i = \left(\frac{\partial G}{\partial n_i}\right)_{T,P,n_{j\neq i}}$$
  - no equilíbrio $\sum \mu_i dn_i = 0$

Transições de Primeira e Segunda Ordem

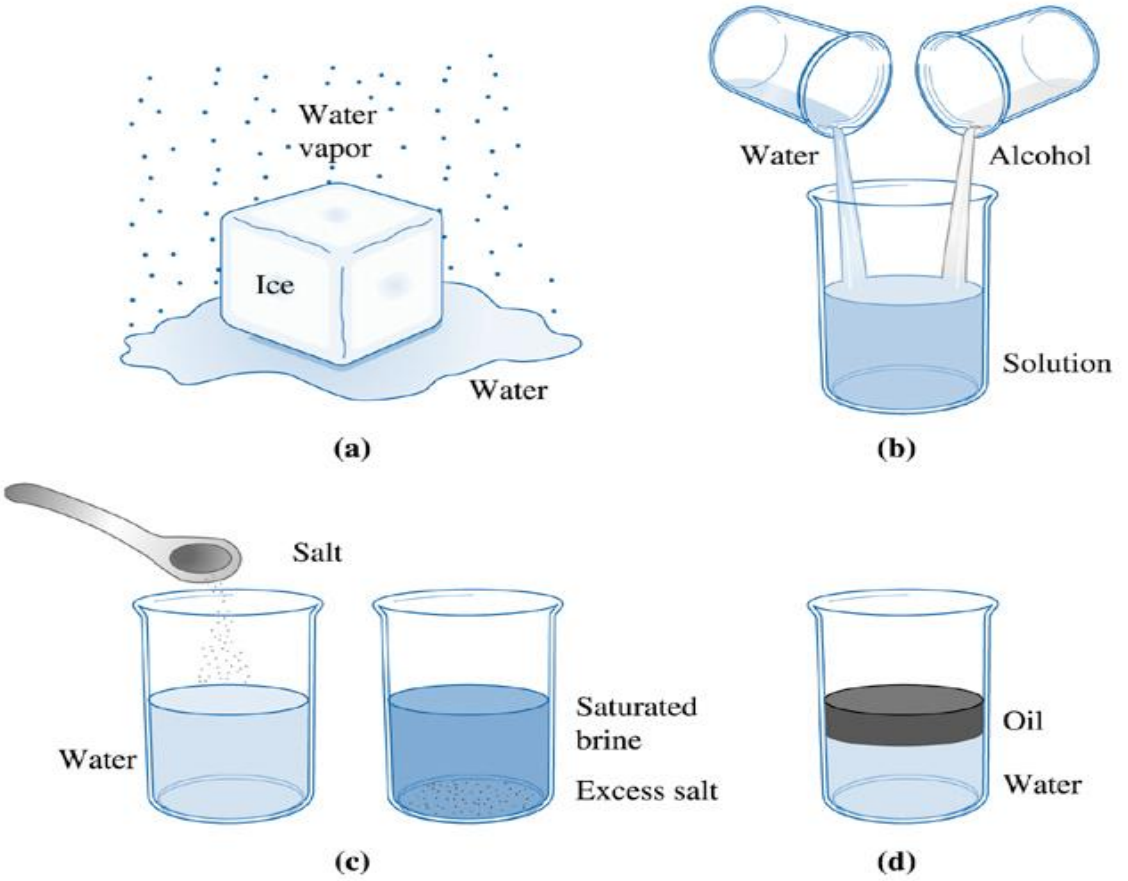


O que é fase?

- Toda FASE possui três características fundamentais:
  - Homogeneidade estrutural
  - Homogeneidade química
  - Interfaces

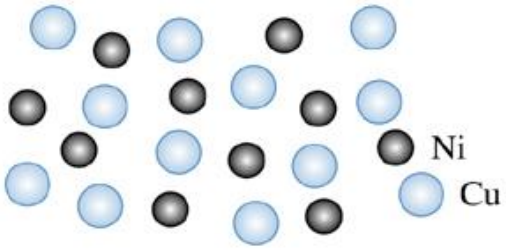
Exemplos

Quantas fases temos em cada situação?



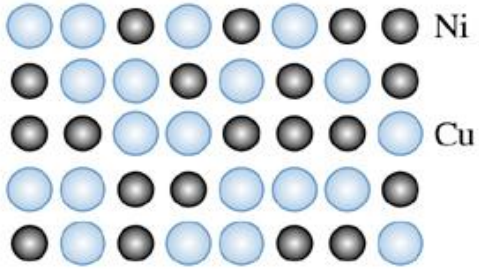
Exemplos

Quantas fases temos em cada situação?



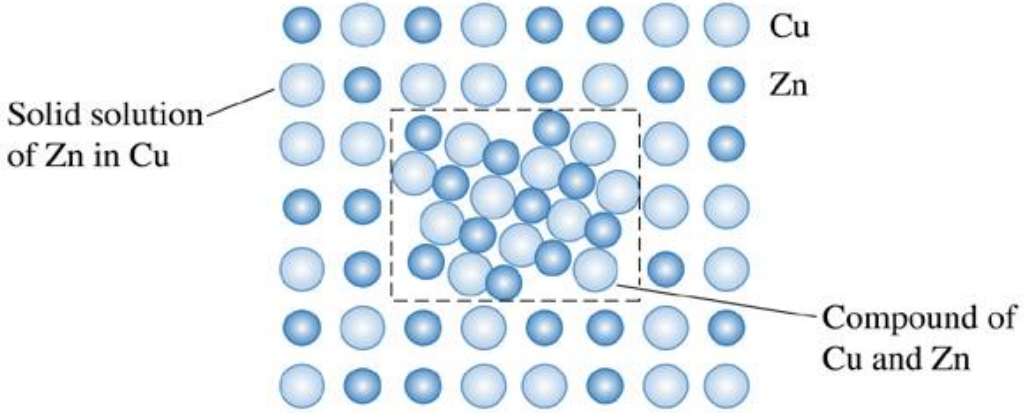
líquido

(a)



(b)

sólido



(c)

Exemplos

Quantas fases temos em cada situação?

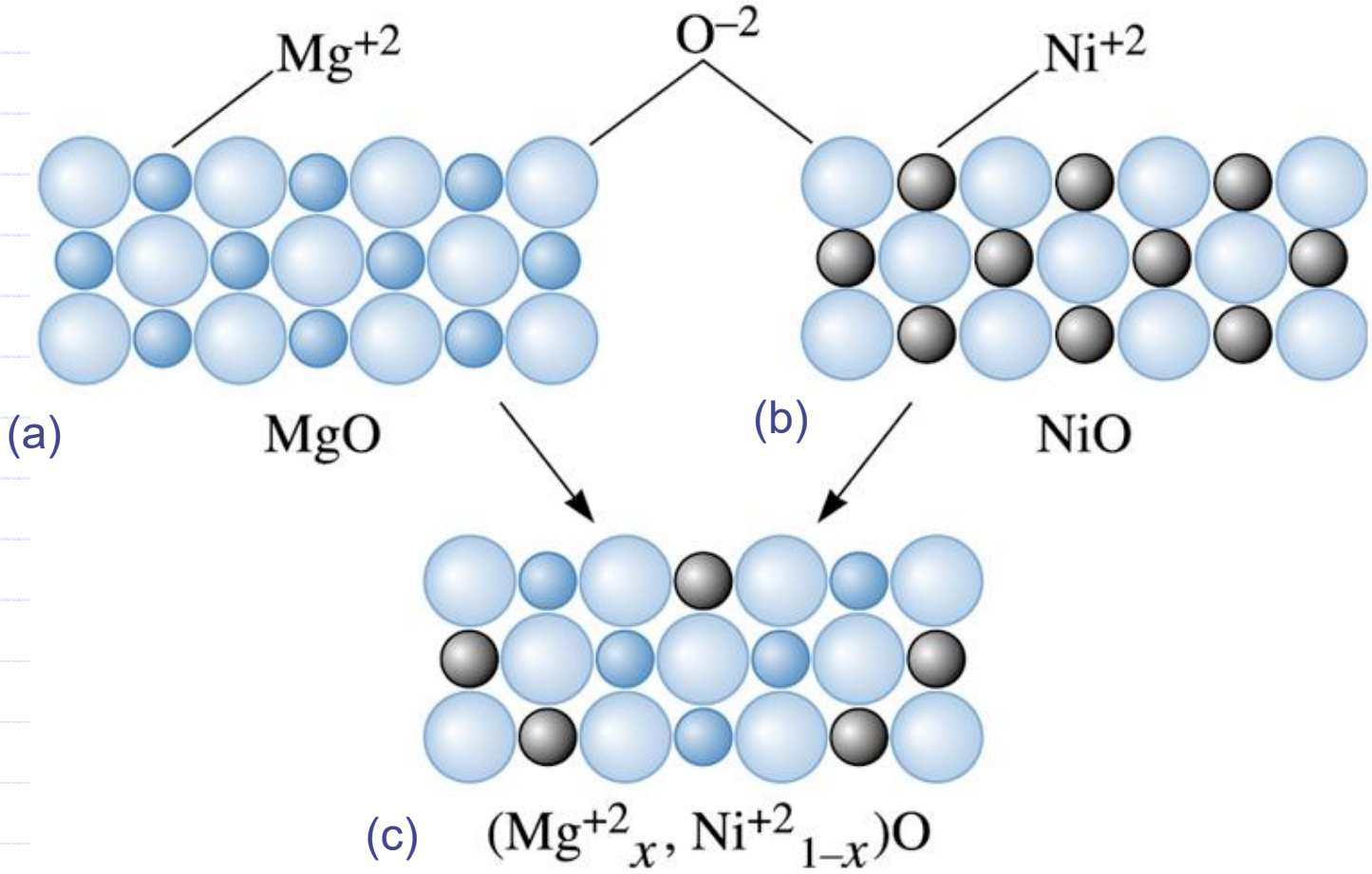


Diagrama unário

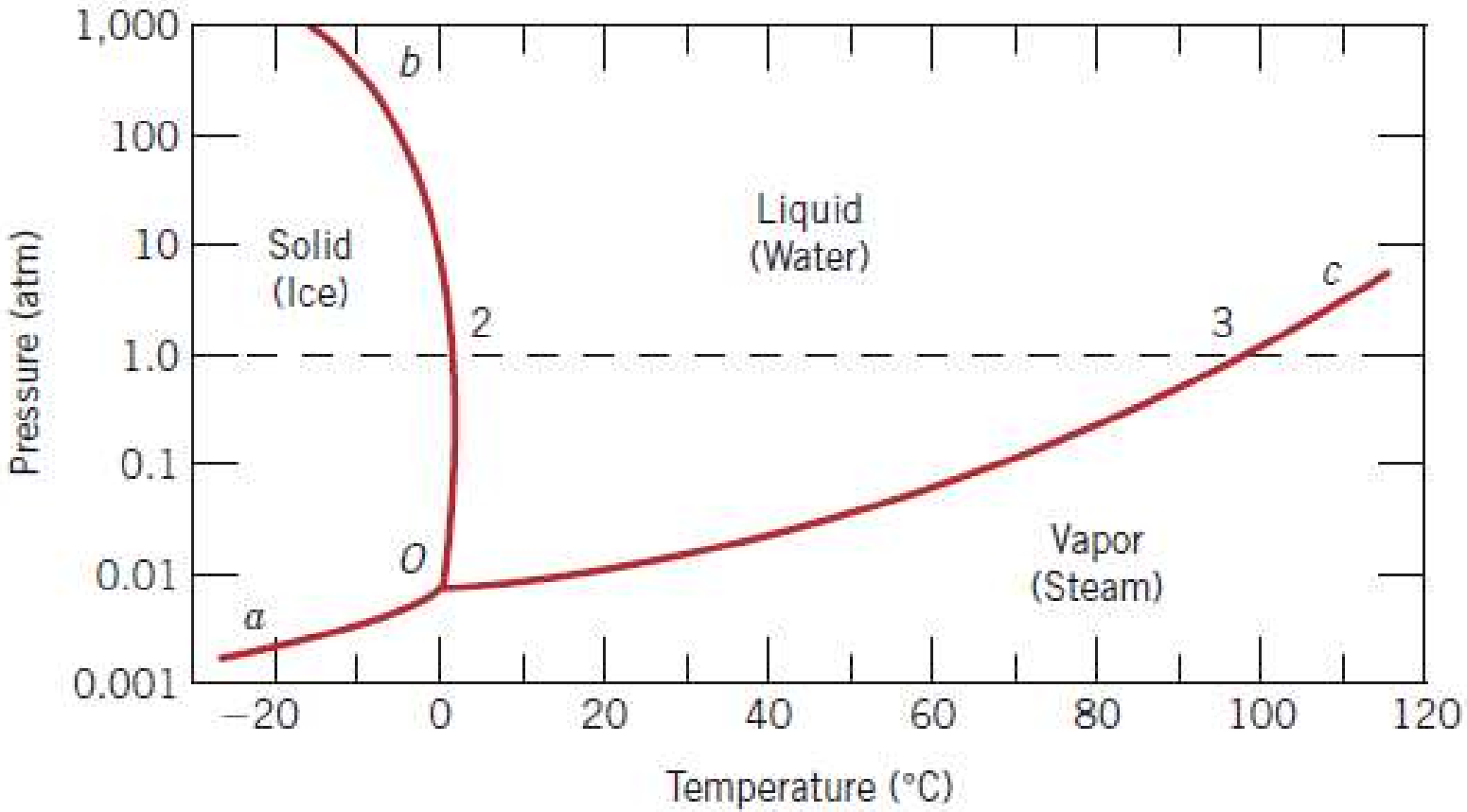
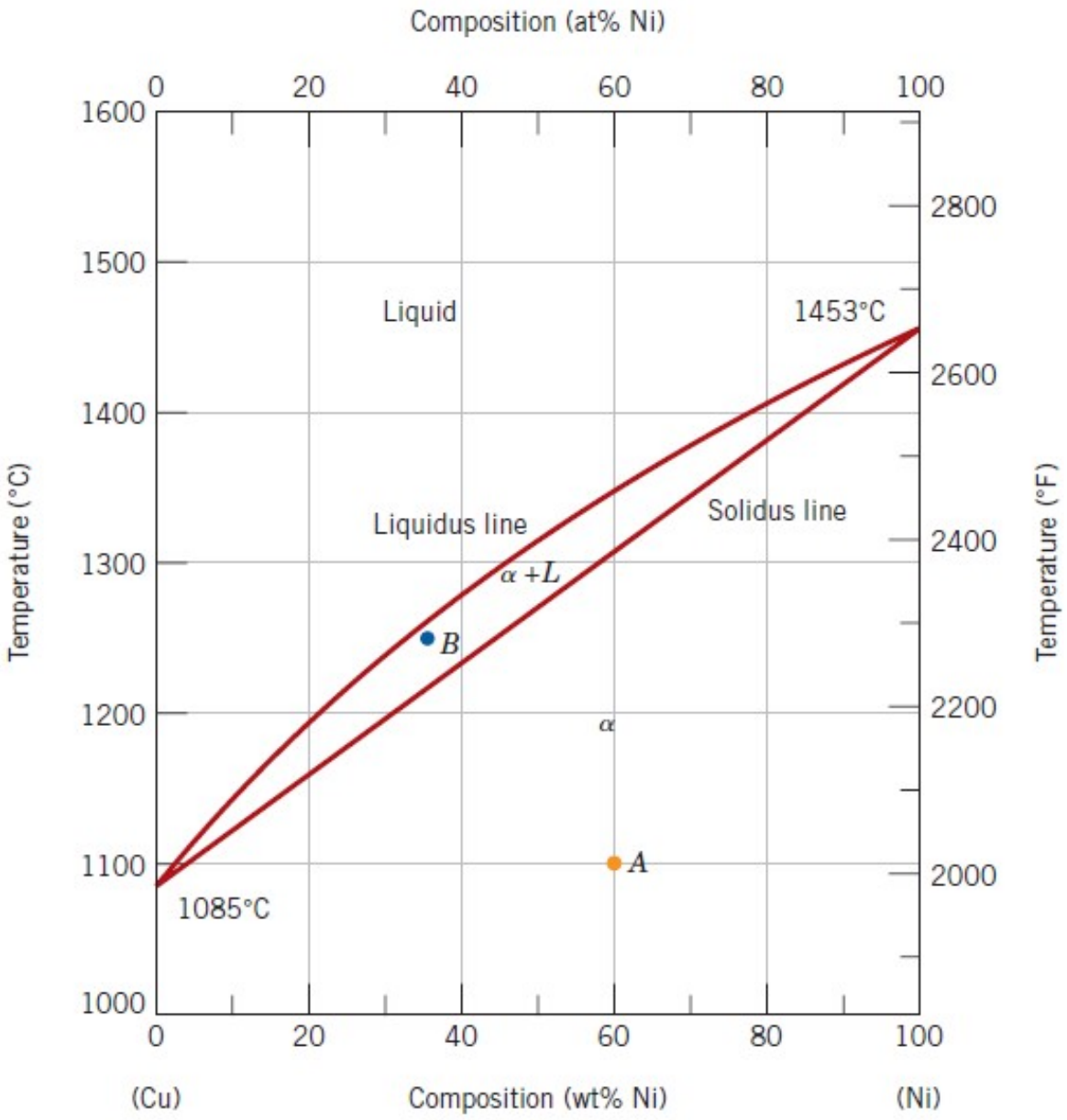
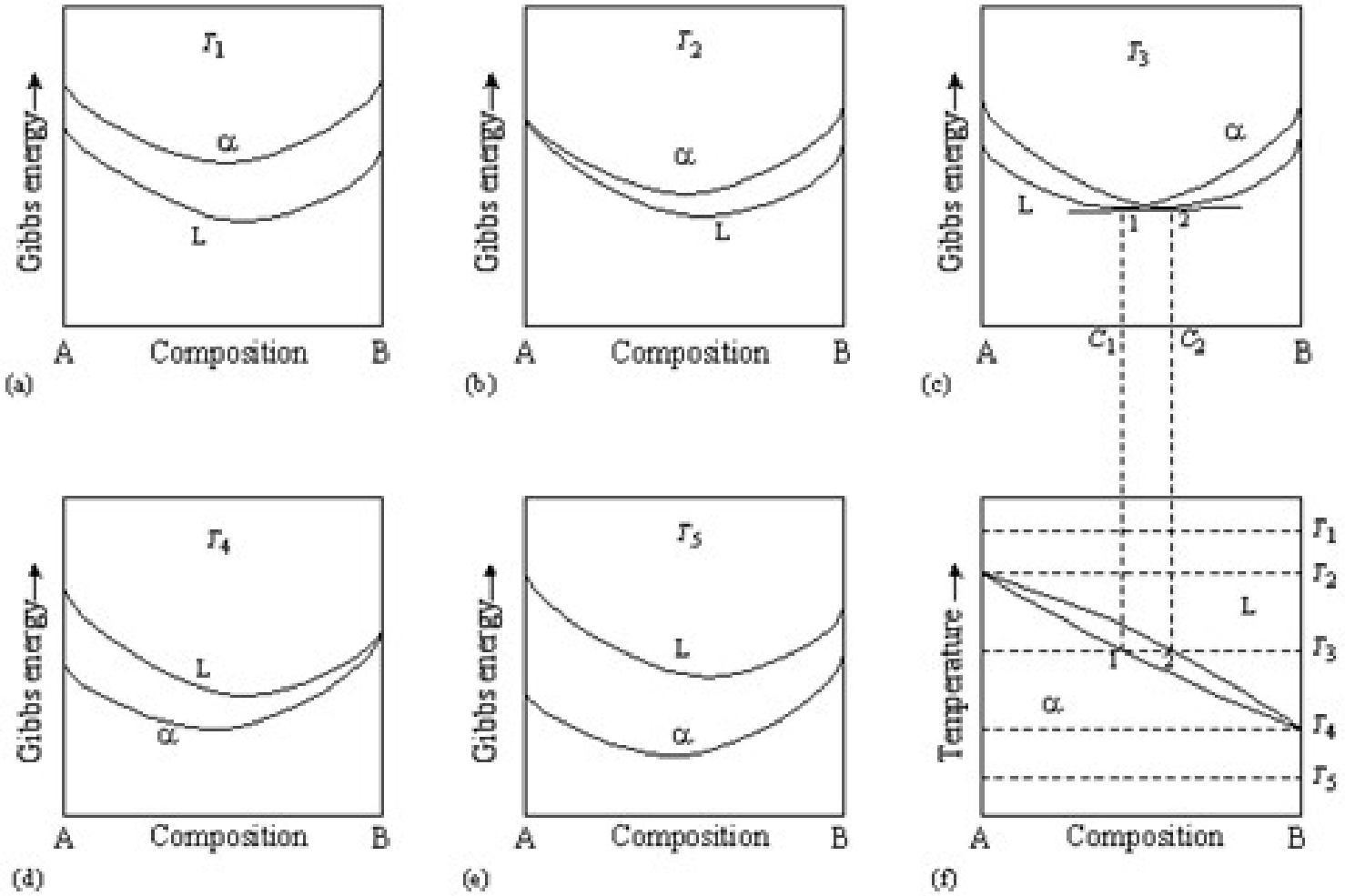


Diagrama de fase binário e isomórfico

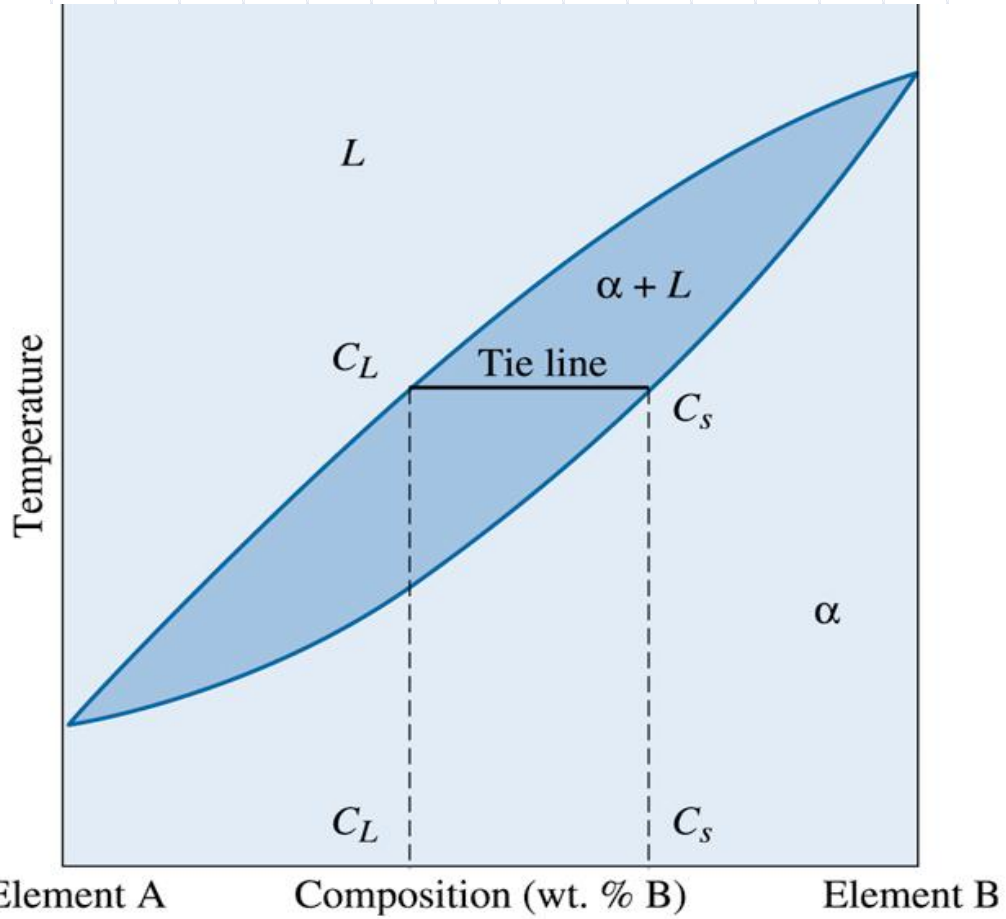


Origem termodinâmica



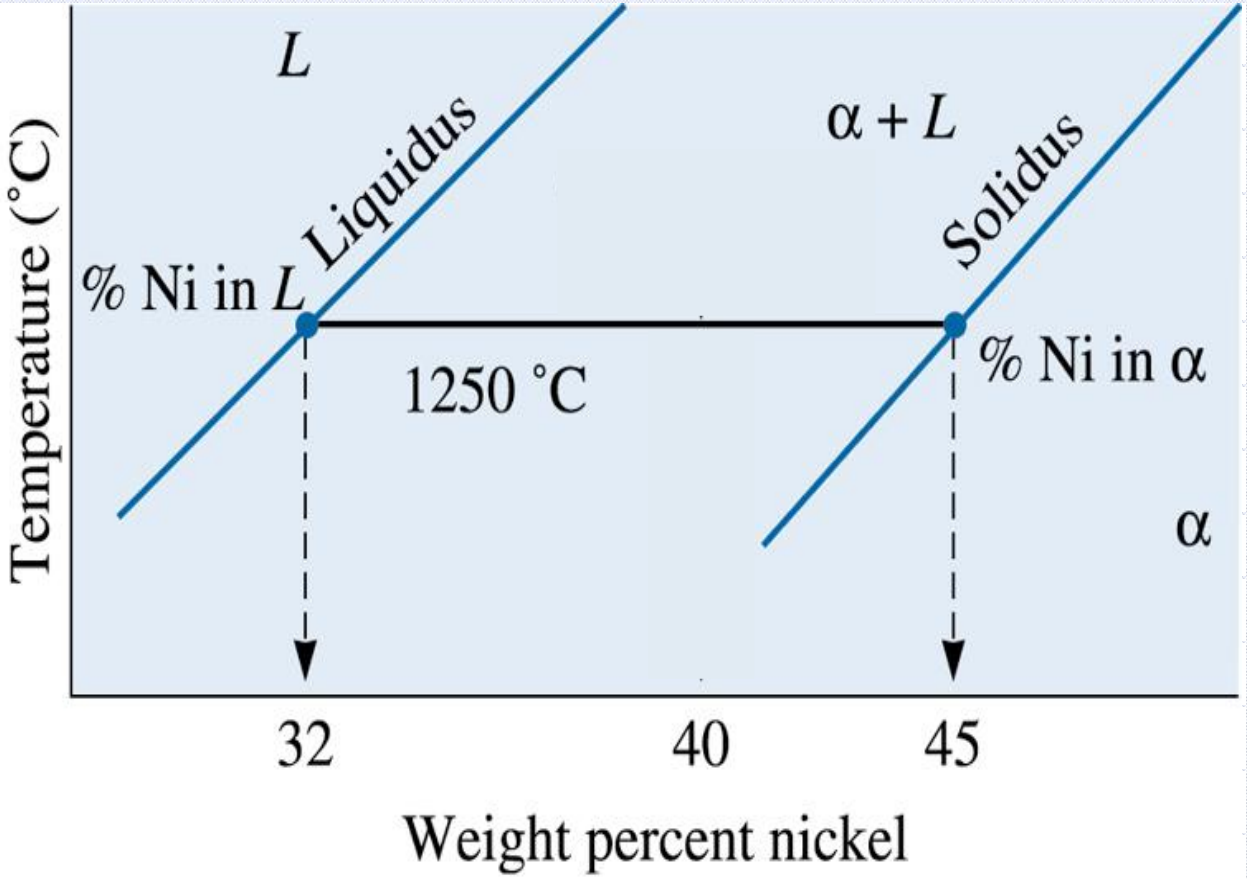
Linha de ligação

- Usada em campos bifásicos



Linha de ligação

- Fornece a composição química de cada fase



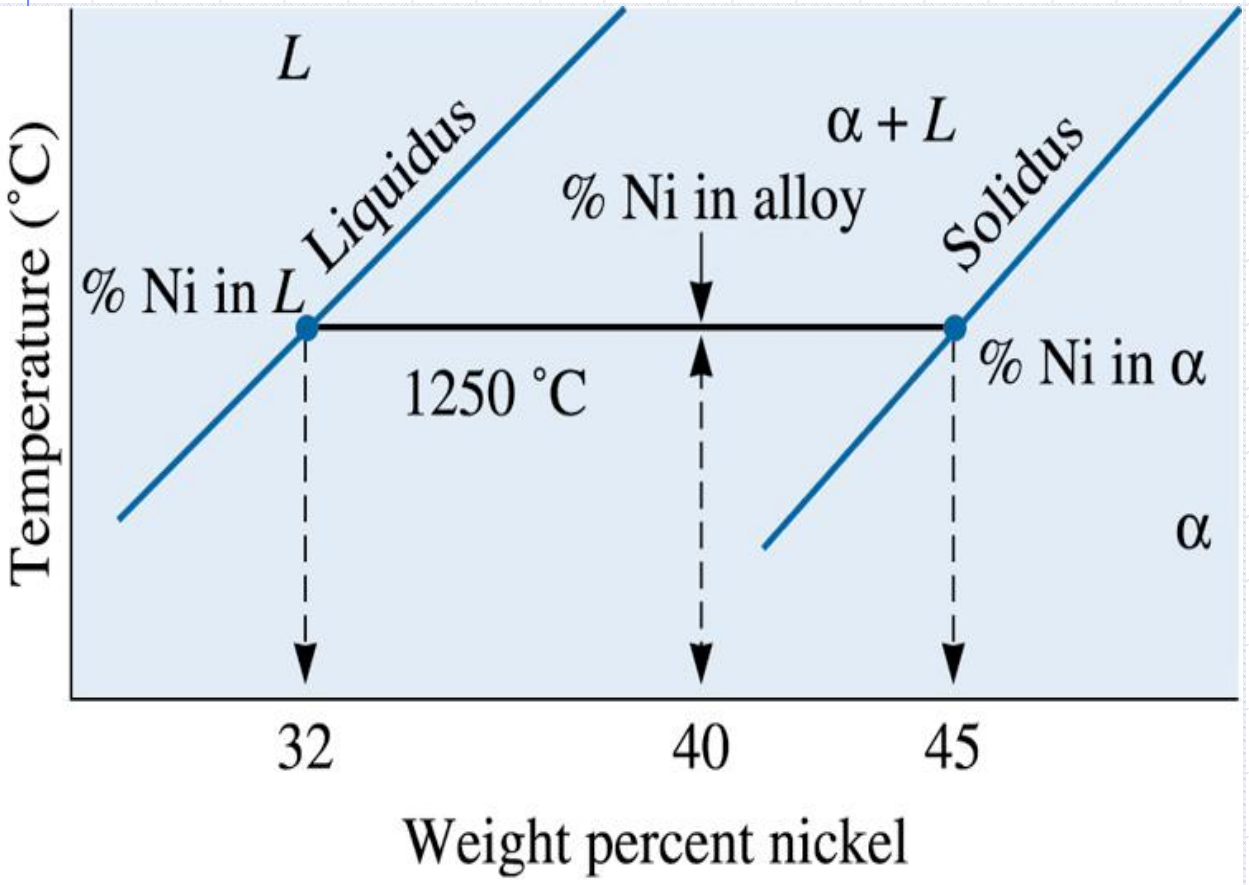
Para qualquer liga Cu-Ni entre 32 e 45% de Ni a 1250°C

Líquido:
32% Ni, 68% Cu

Sólido:
45% Ni, 55% Cu

Regra da alavanca

- Fornece a quantidade (fração) de cada fase

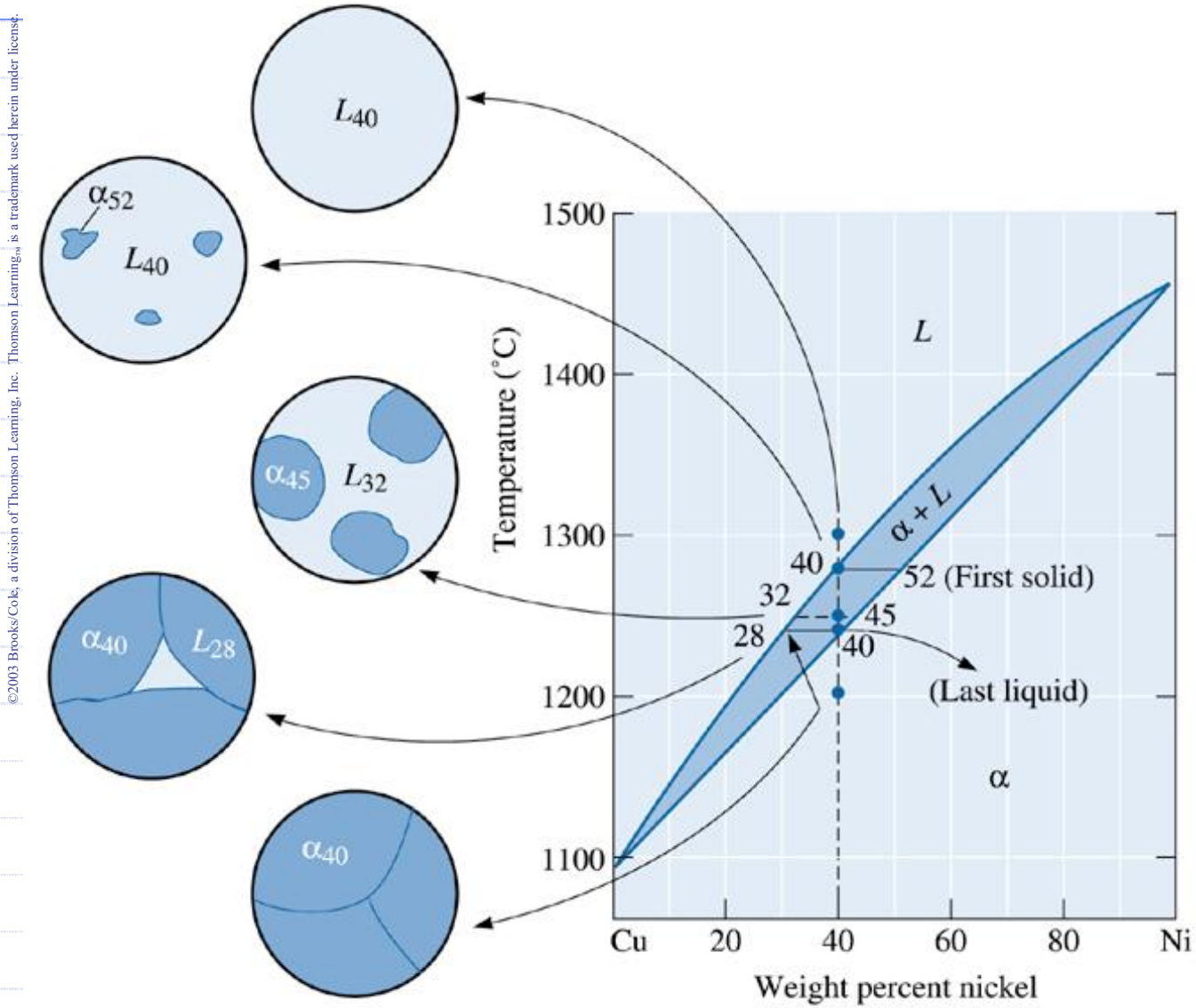


Liga Cu-Ni com 40% de Ni a 1250°C

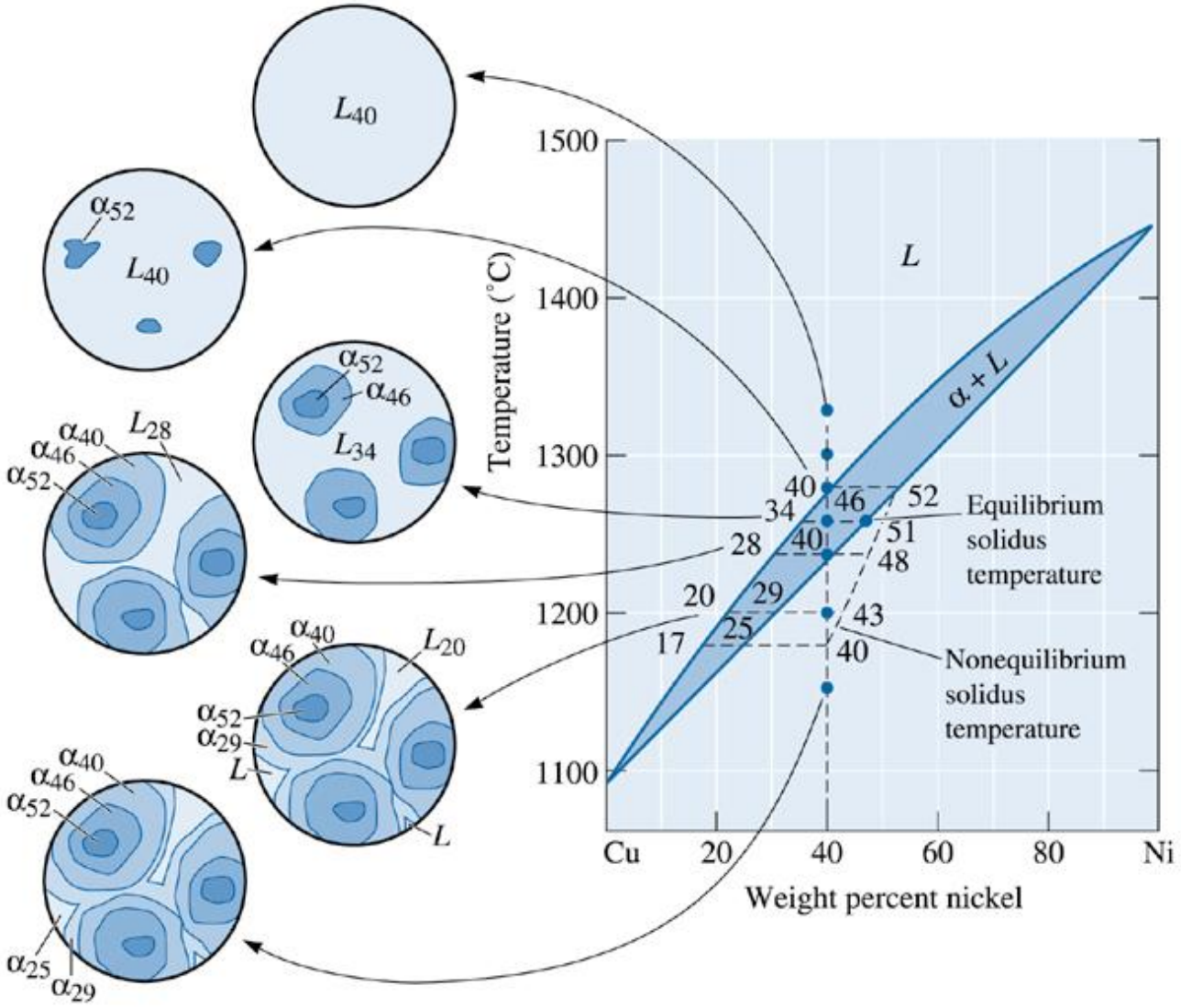
$$\%L = \frac{45-40}{45-32} x100\% = 38{,}5\%$$

$$\%S = \frac{40-32}{45-32} x100\% = 61{,}5\%$$

Exemplo (Solidificação de uma liga Cu-Ni)



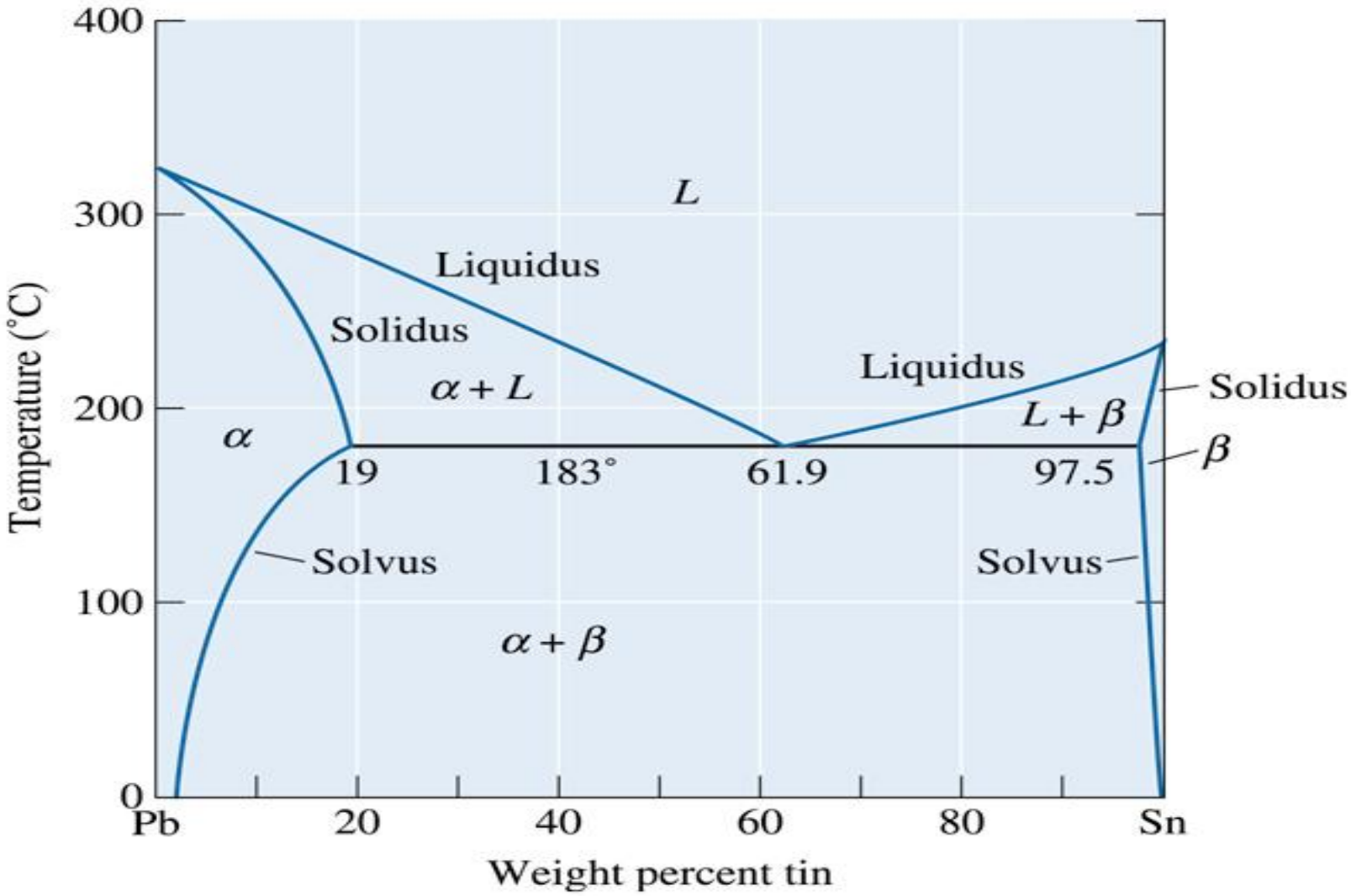
Quando não há tempo para difusão no sólido (fora do equilíbrio)



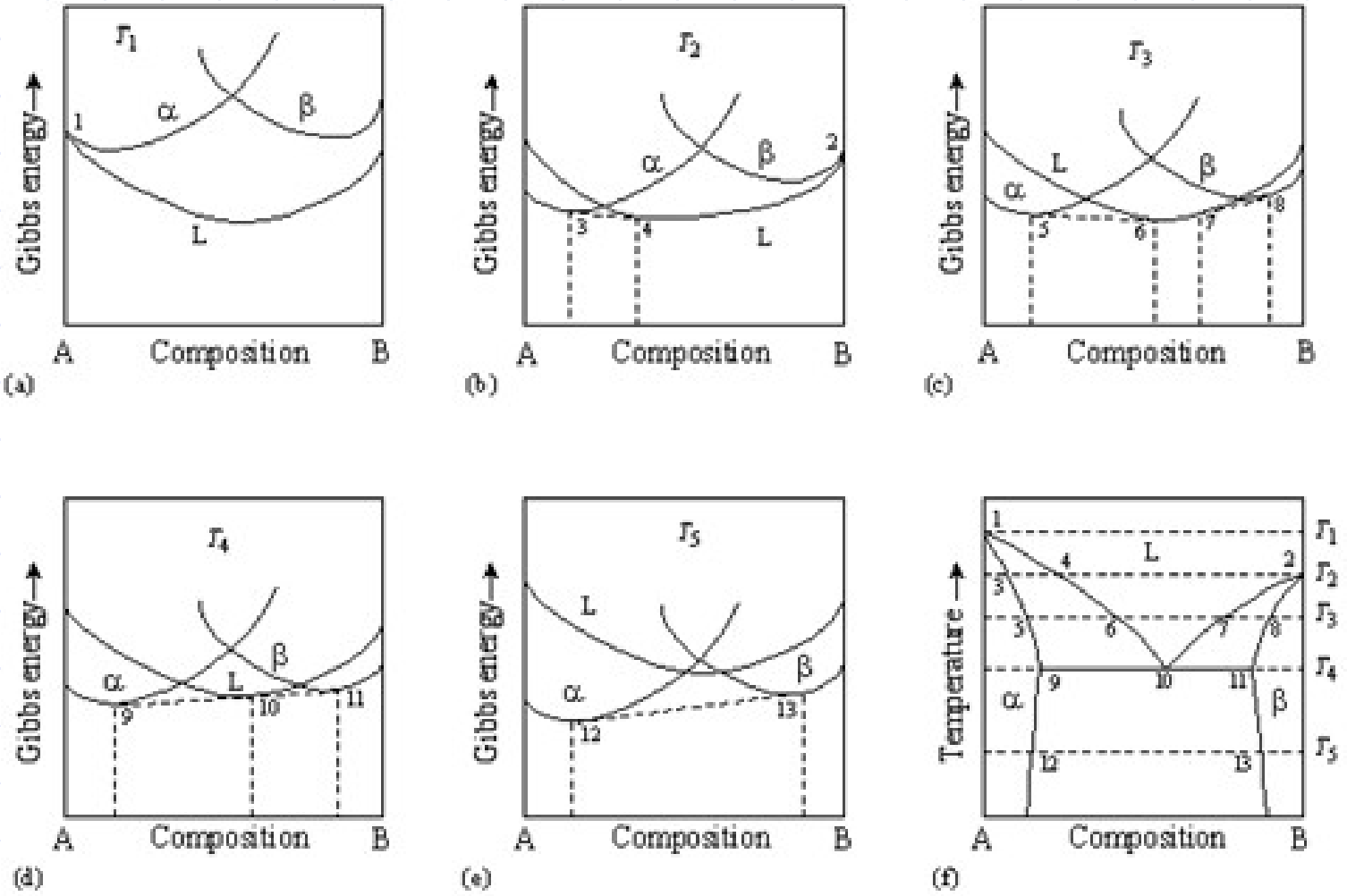
Liga com 40% de Ni

Ocorre segregação de Cu

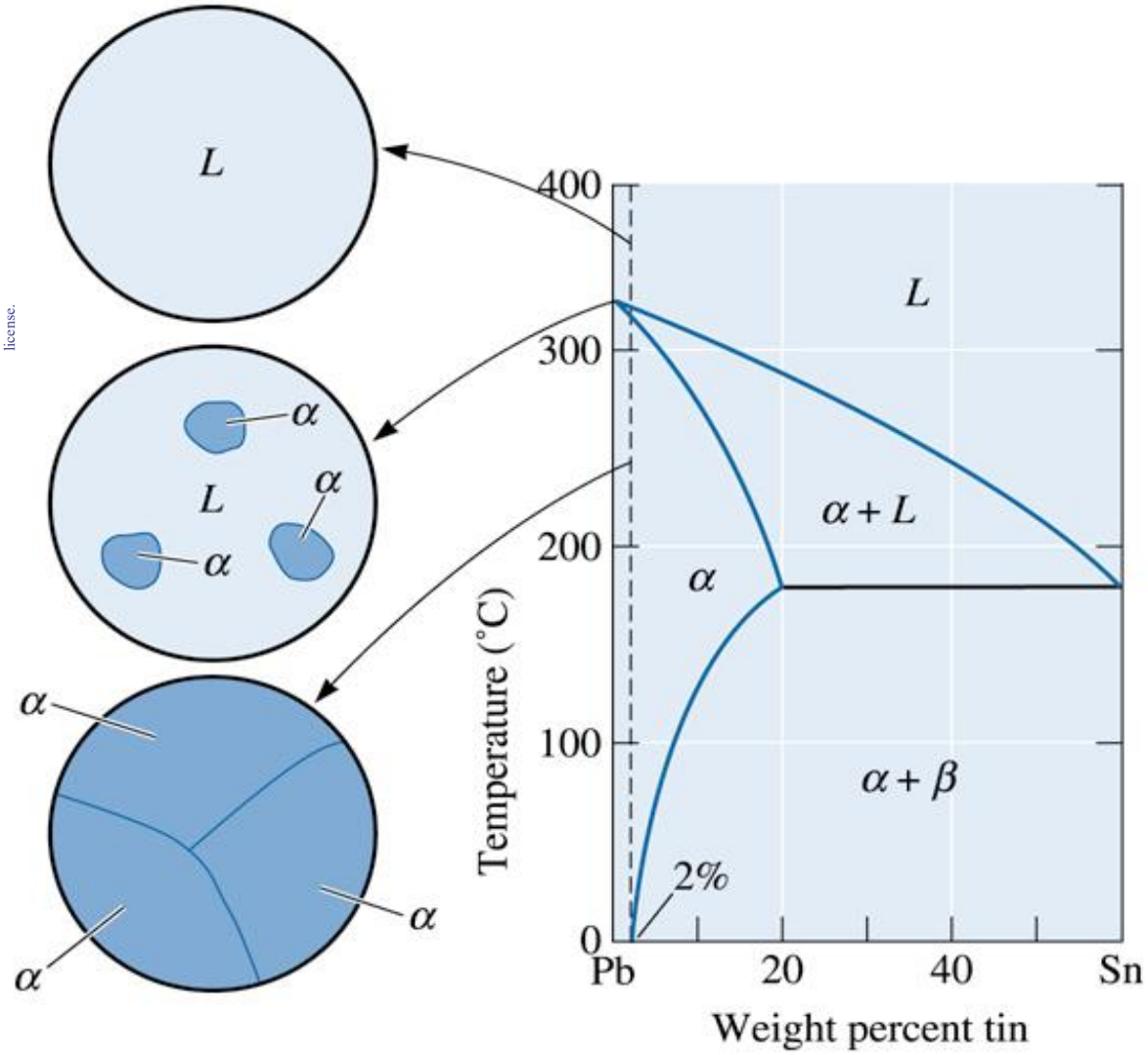
Diagrama Binário Eutético



Origem termodinâmica

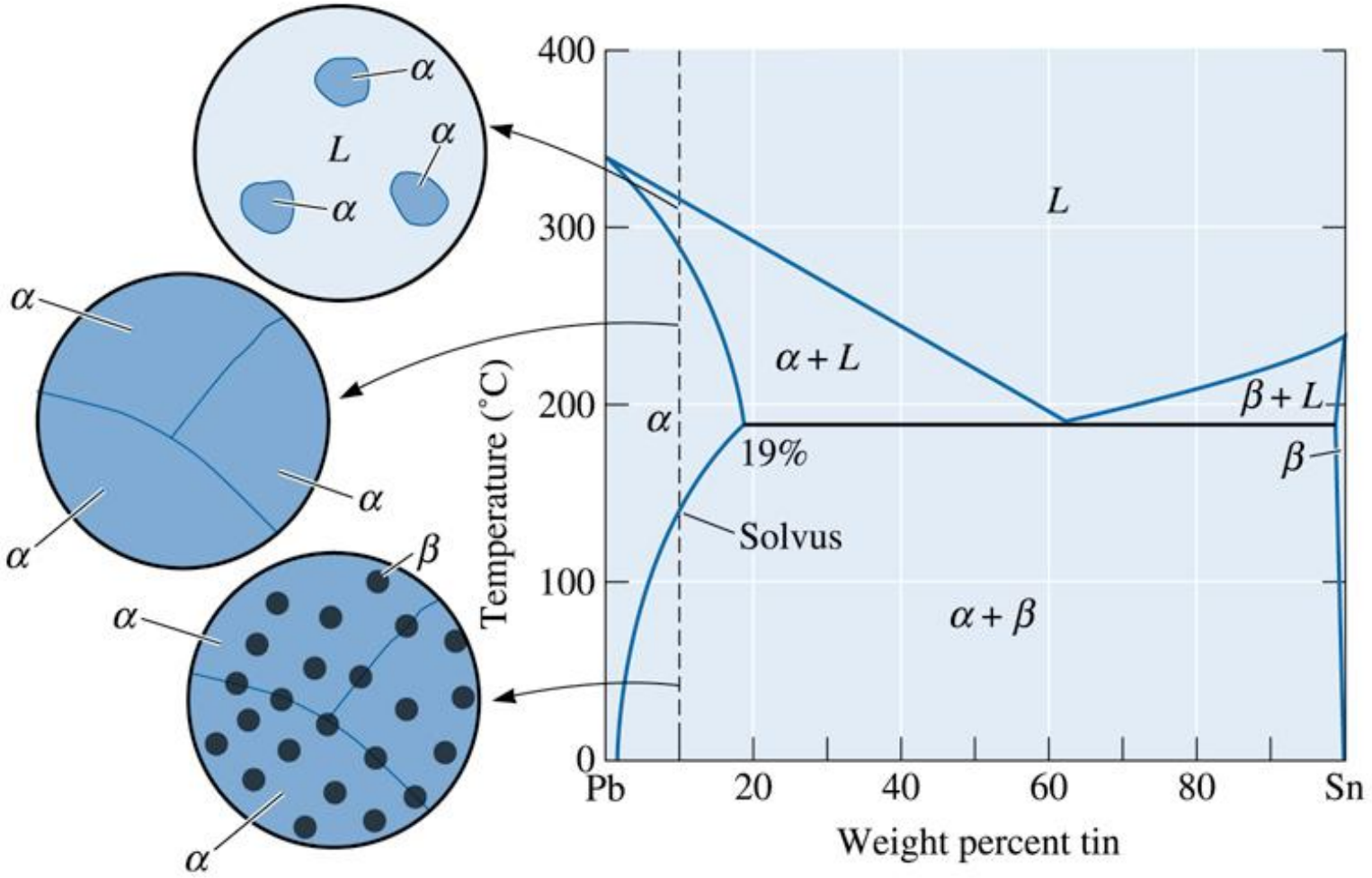


Liga rica em Pb



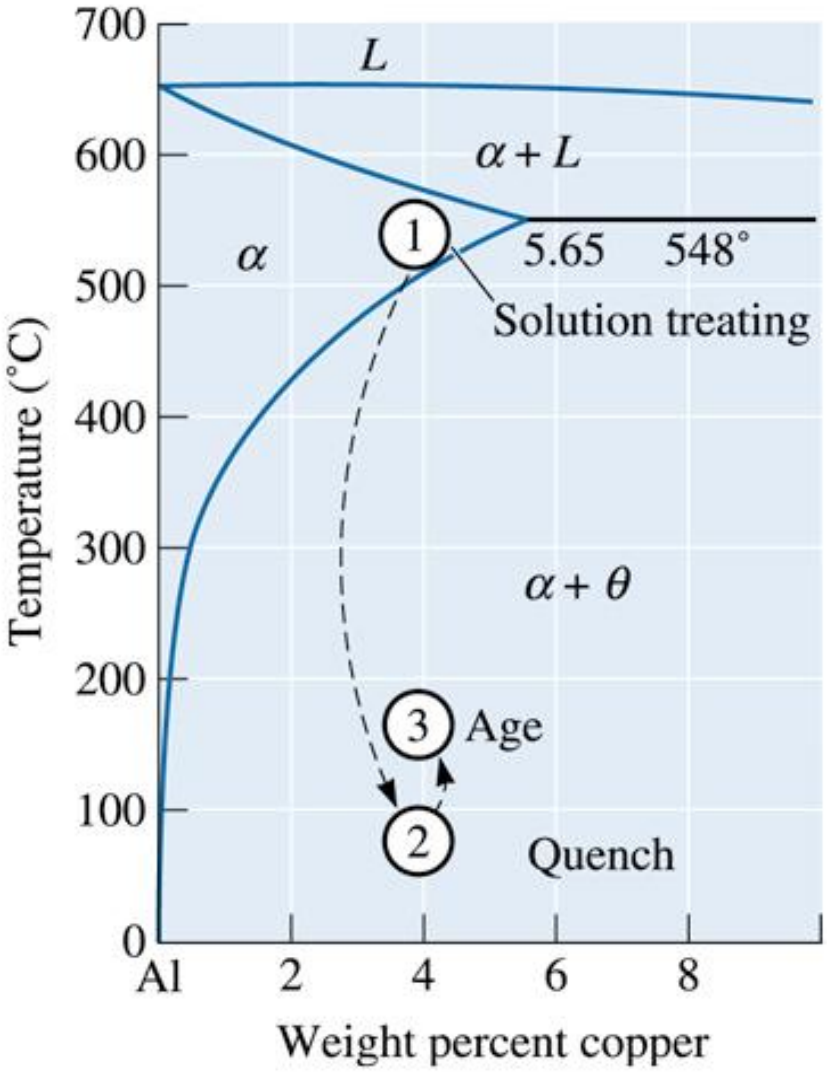
Liga com mais Sn (mas ainda abaixo do limite de solubilidade)

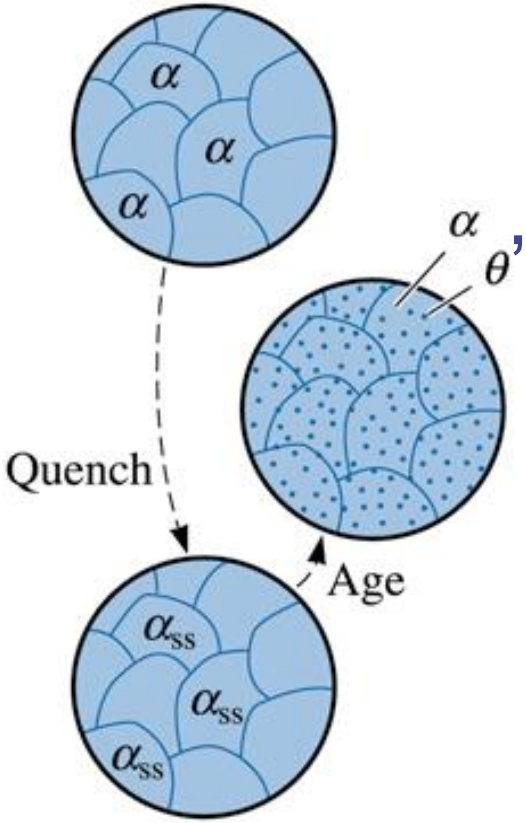
- Precipitação, em equilíbrio, de uma fase incoerente com a matriz. Ocorre endurecimento por dispersão dessa fase na matriz.



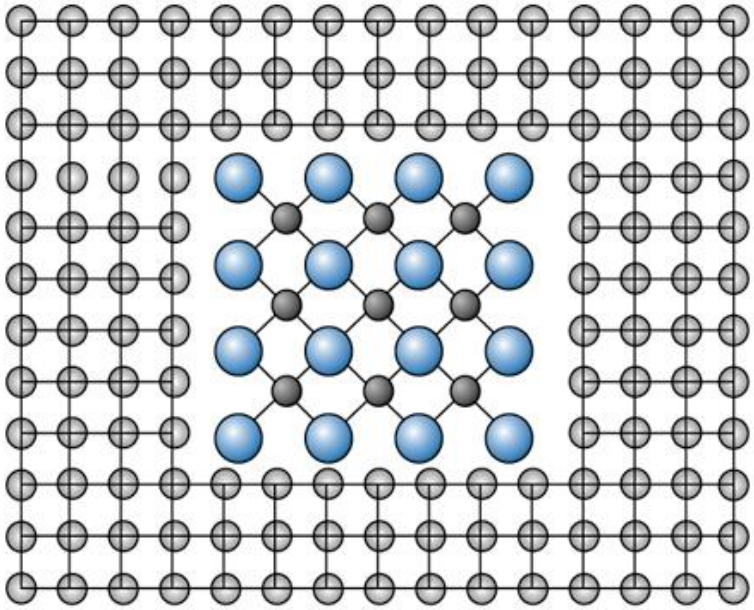
Precipitação no estado sólido

Al-Cu



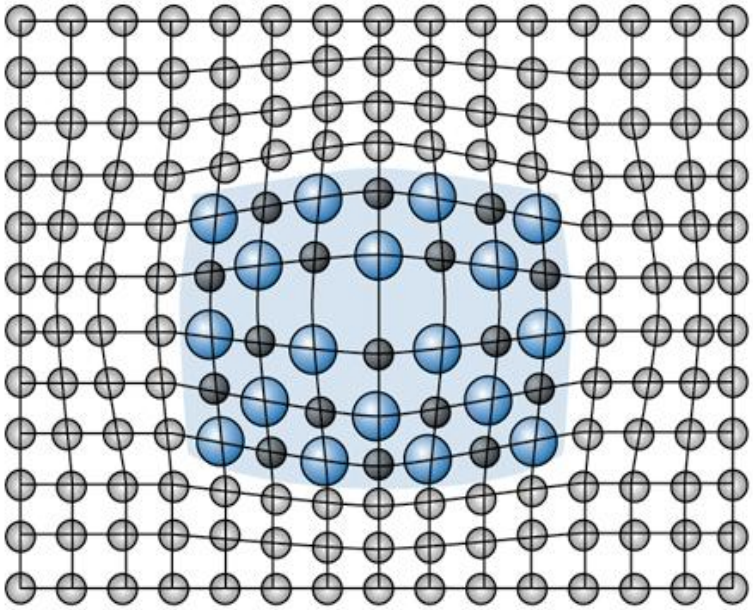


Diferença entre fases coerentes e incoerentes



(a)

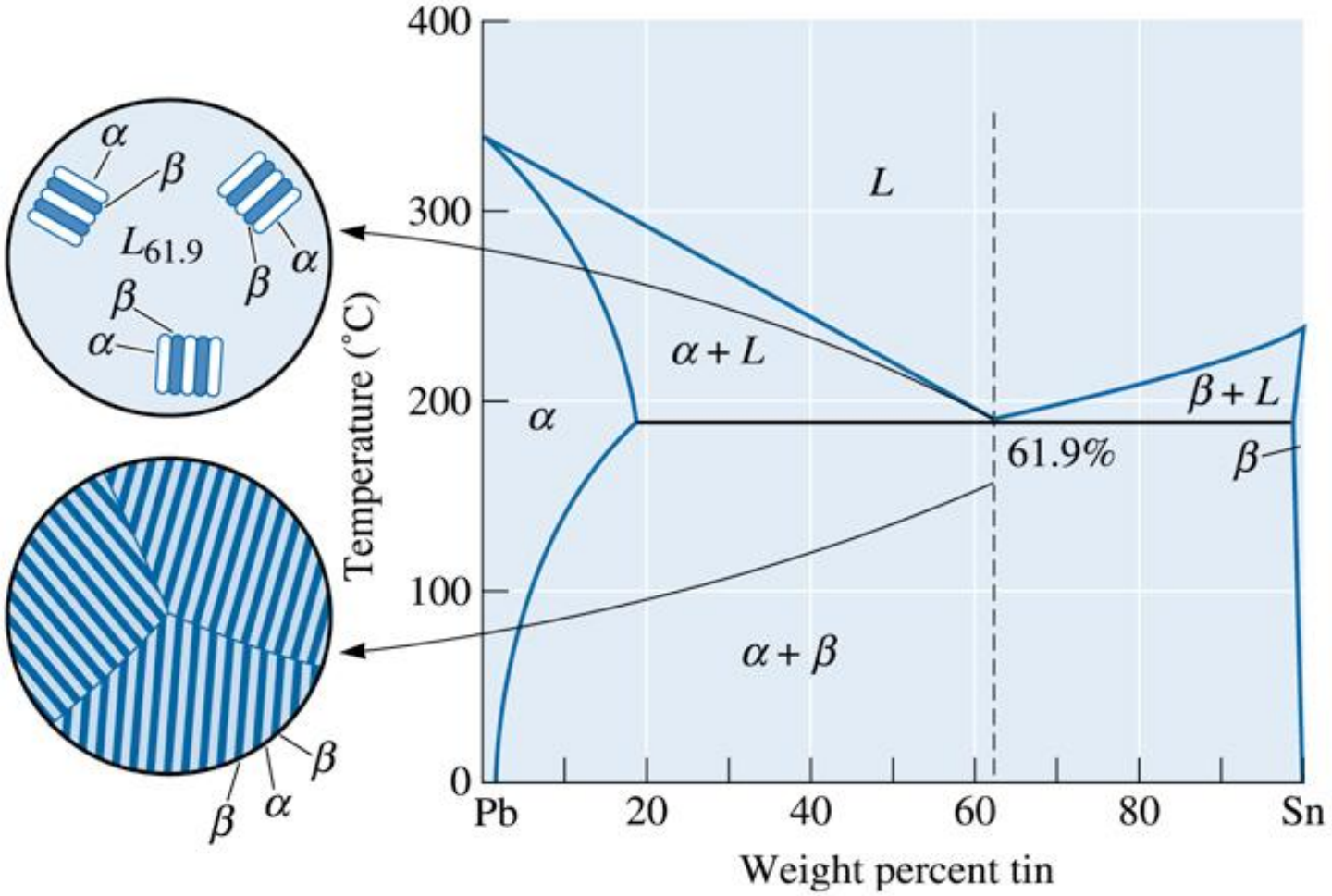
Incoerente



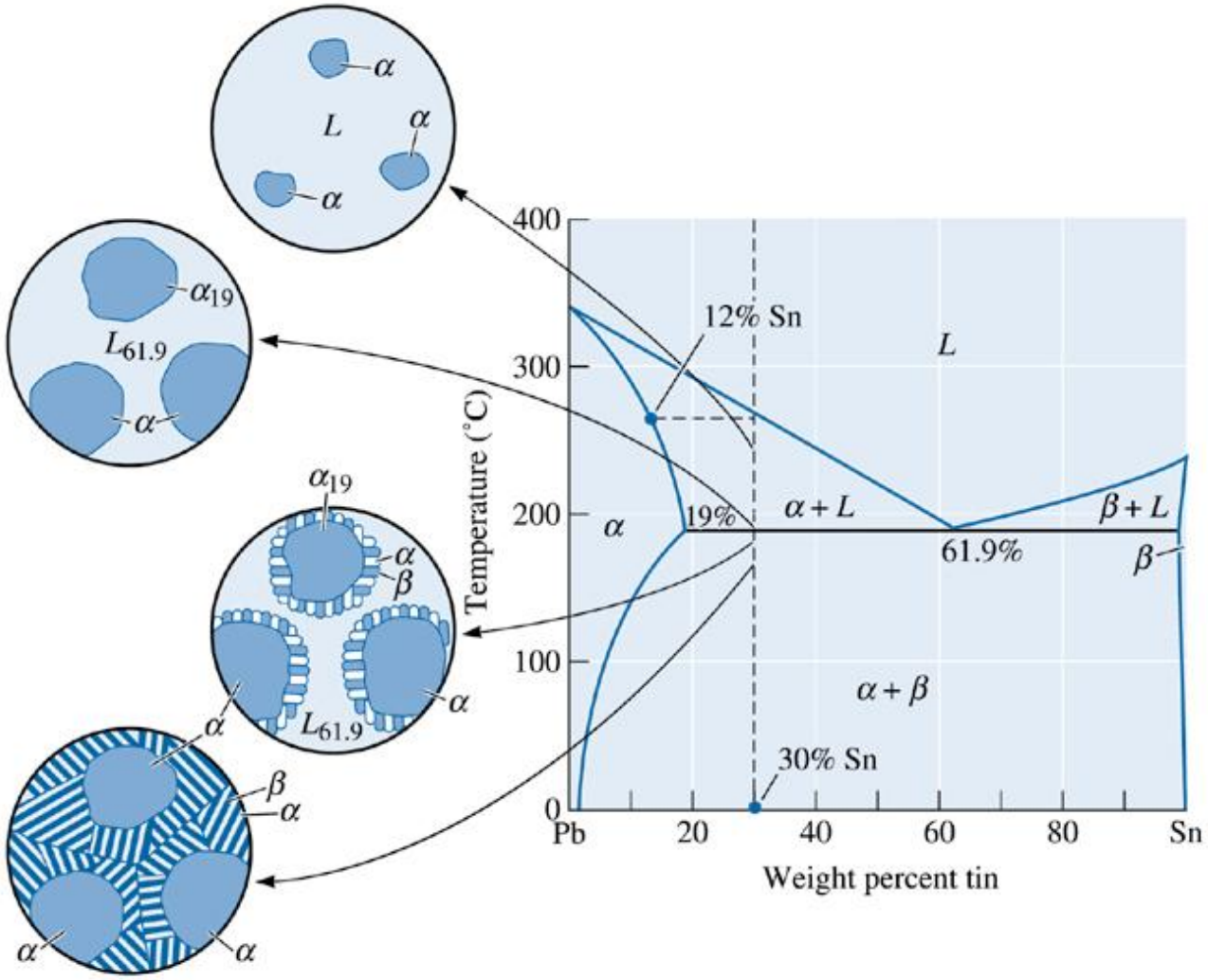
(b)

Coerente

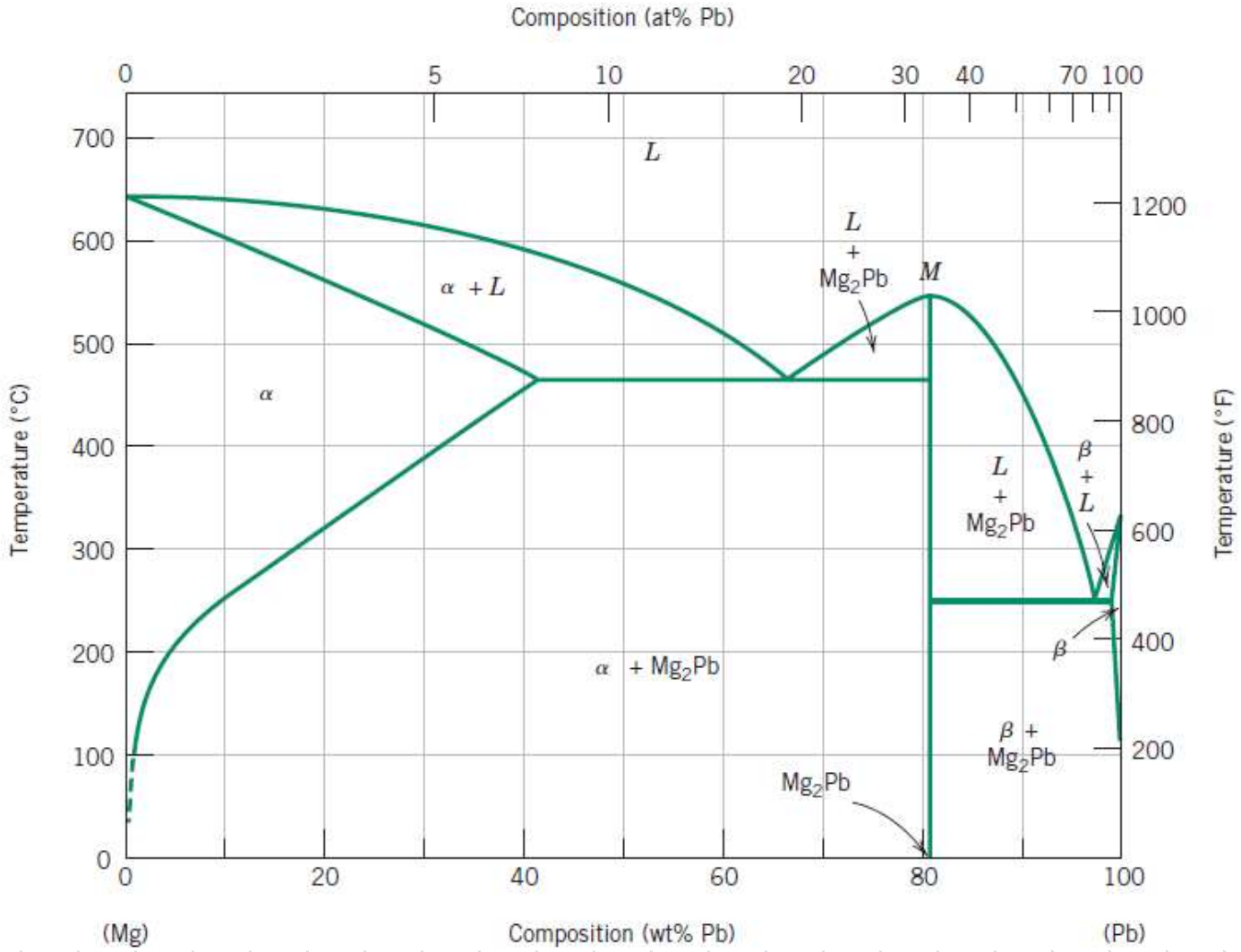
Formação do eutético



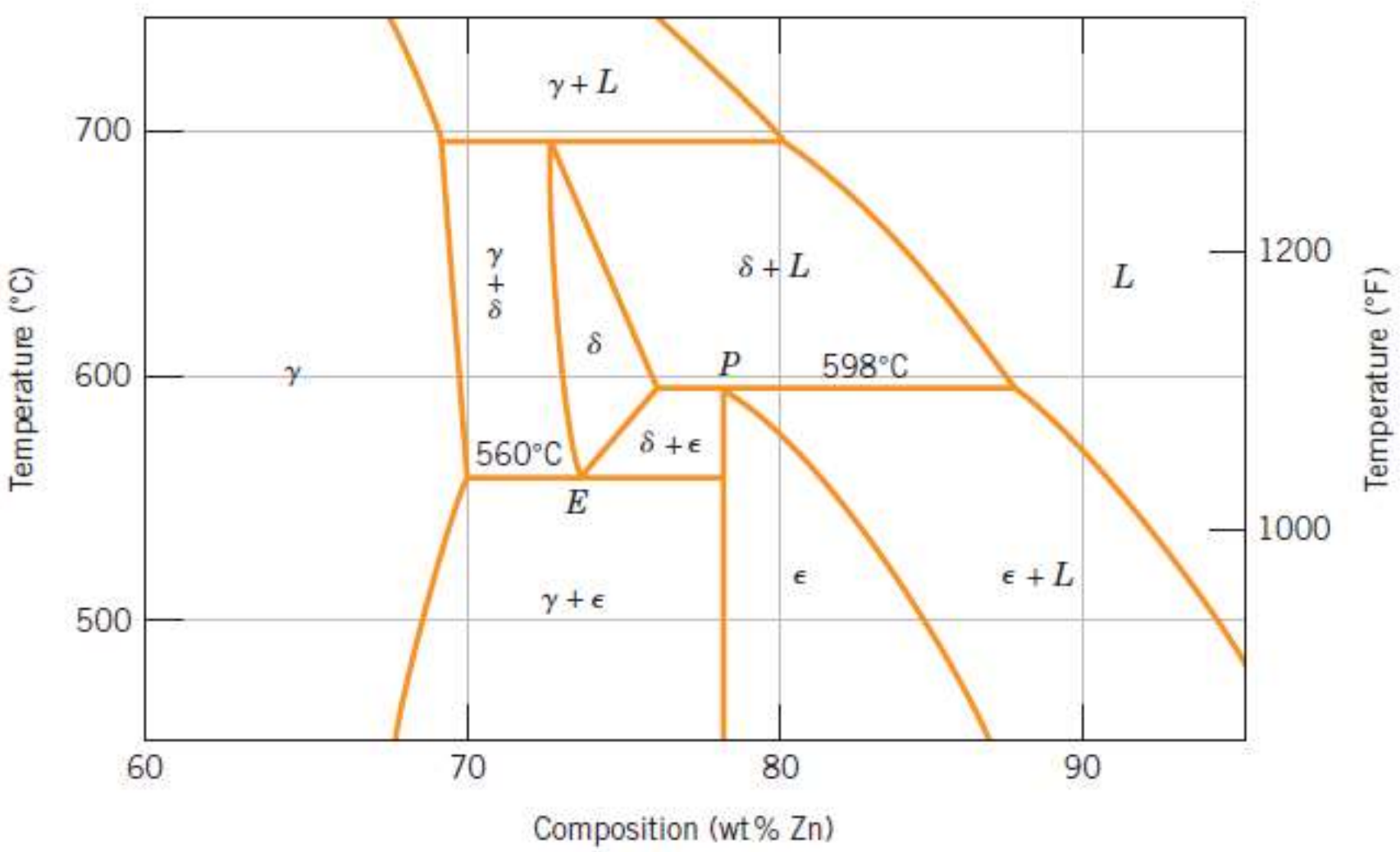
Liga hipoeutética



Diagramas com compostos intermediários



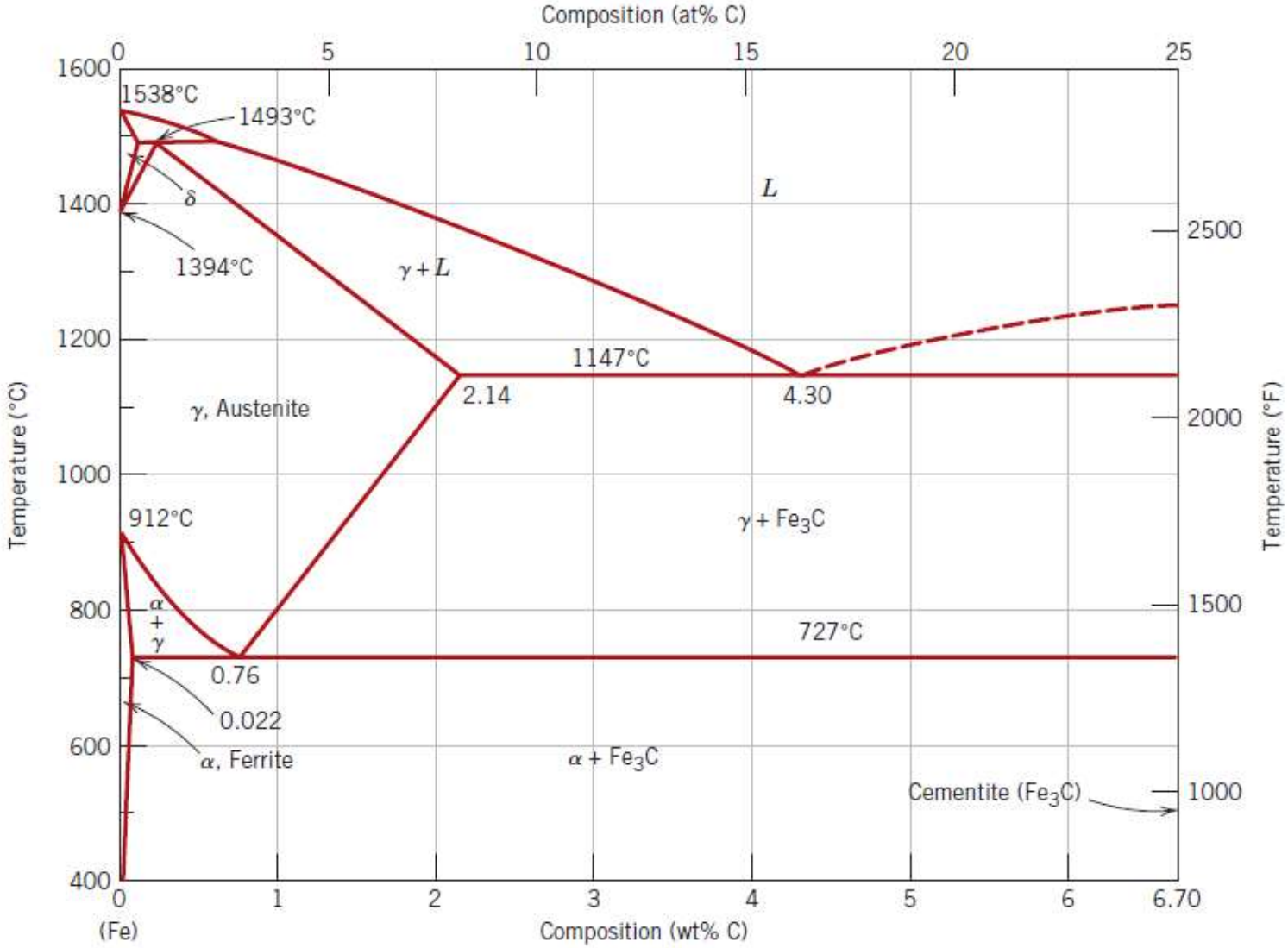
Reações Eutetóides e Peritéticas



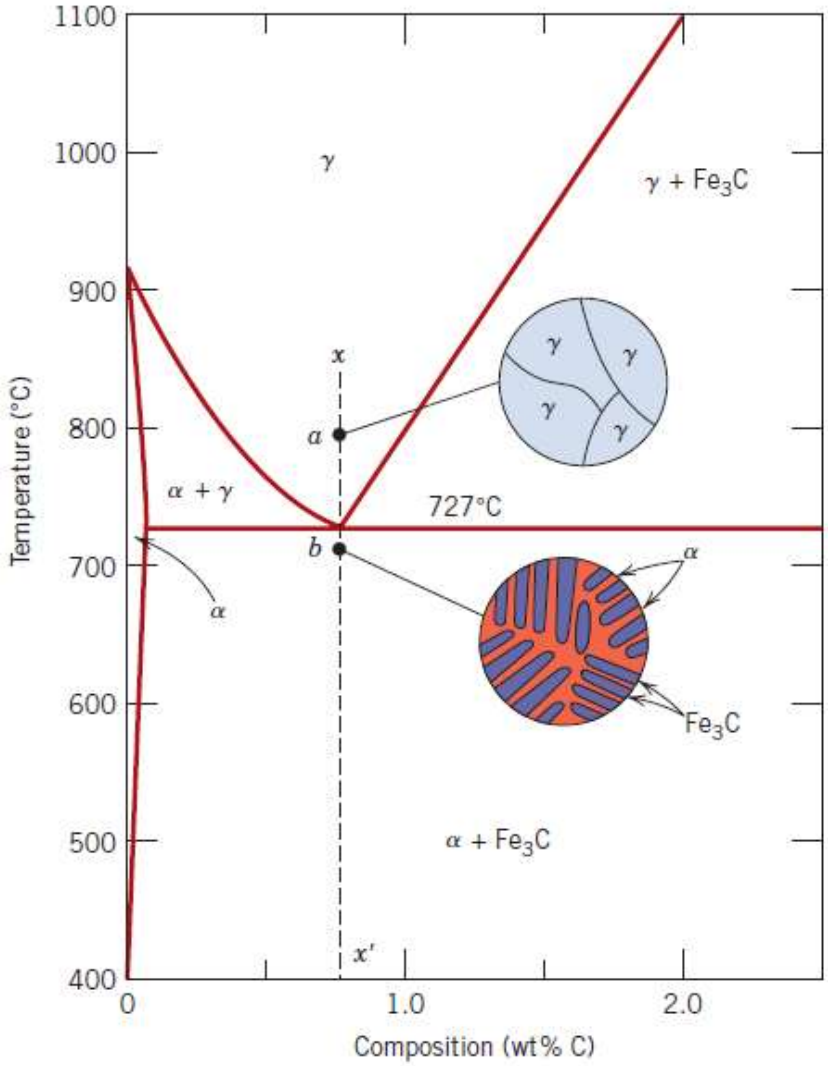
Regra das Fases de Gibbs

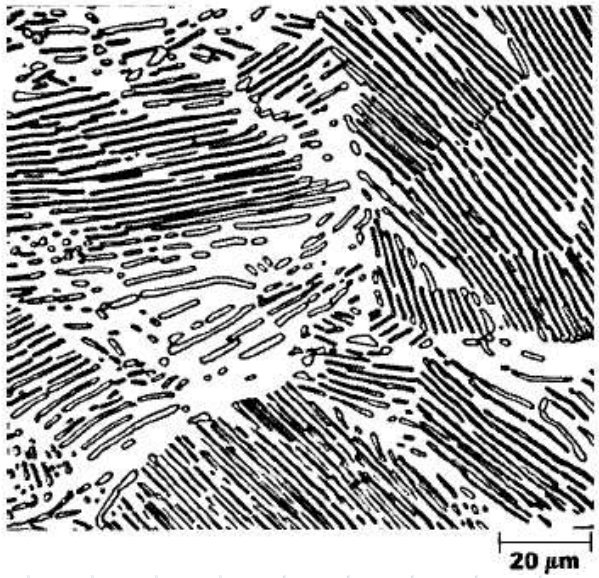
- F + P = C + 2 (2 = pressão + temp.)
  - F: número de graus de liberdade ou variáveis independentes
  - P: número de fases
  - C: número de componentes
- Para pressão cte. ou sistemas pouco dependentes da pressão:
  - F + P = C + 1

O diagrama Fe-Fe_3C

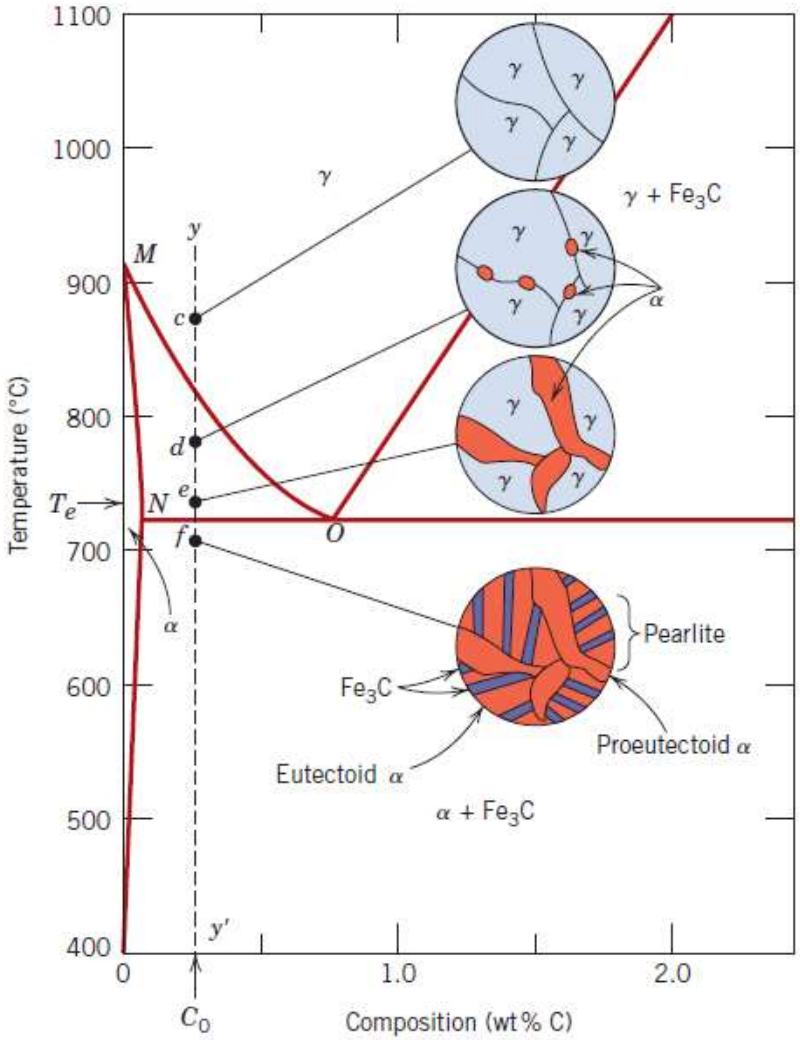


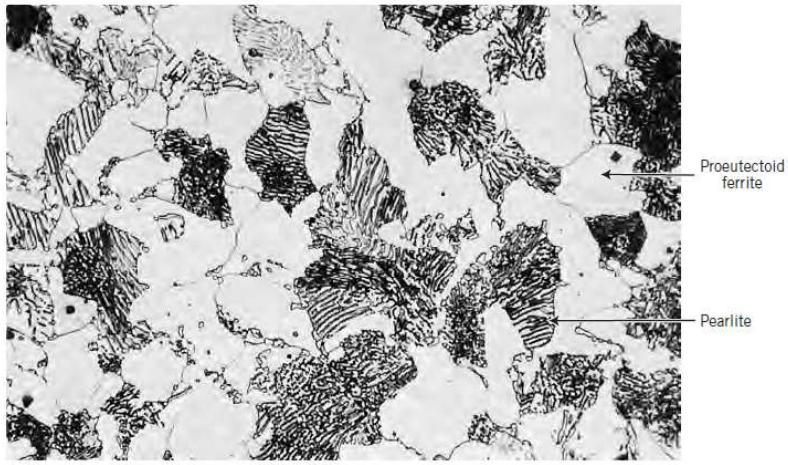
O eutetóide Fe-Fe_3C (perlita)



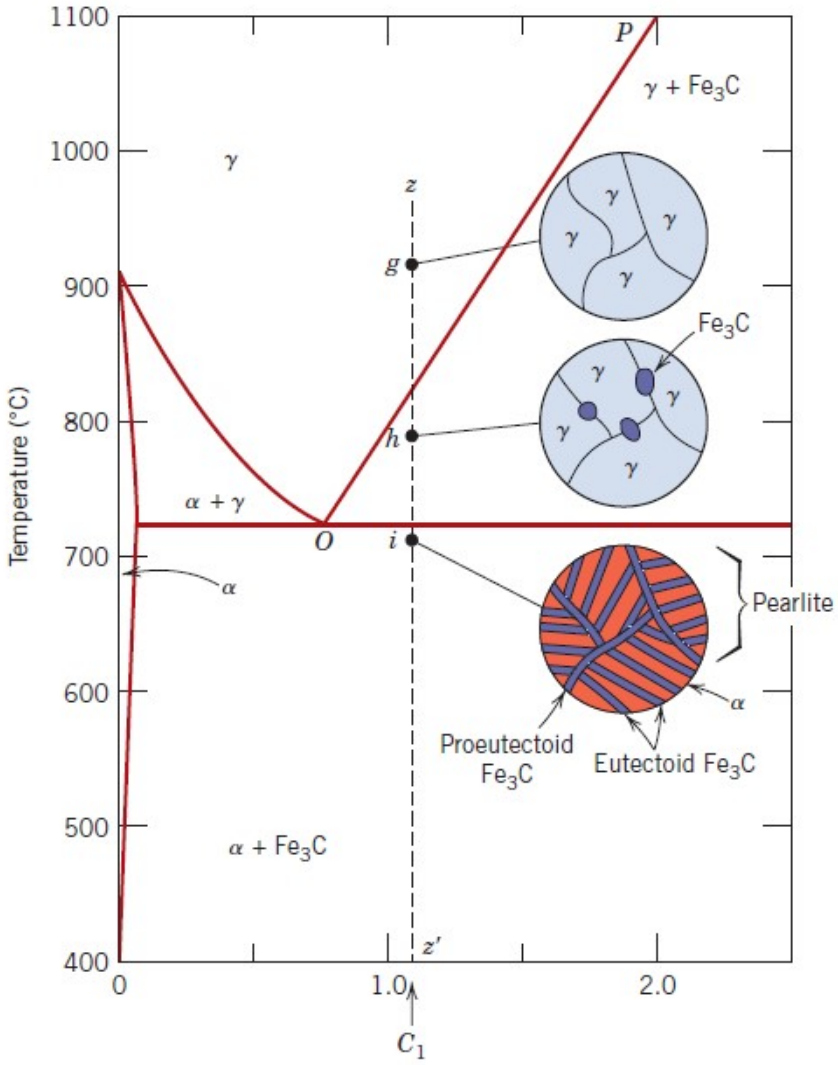


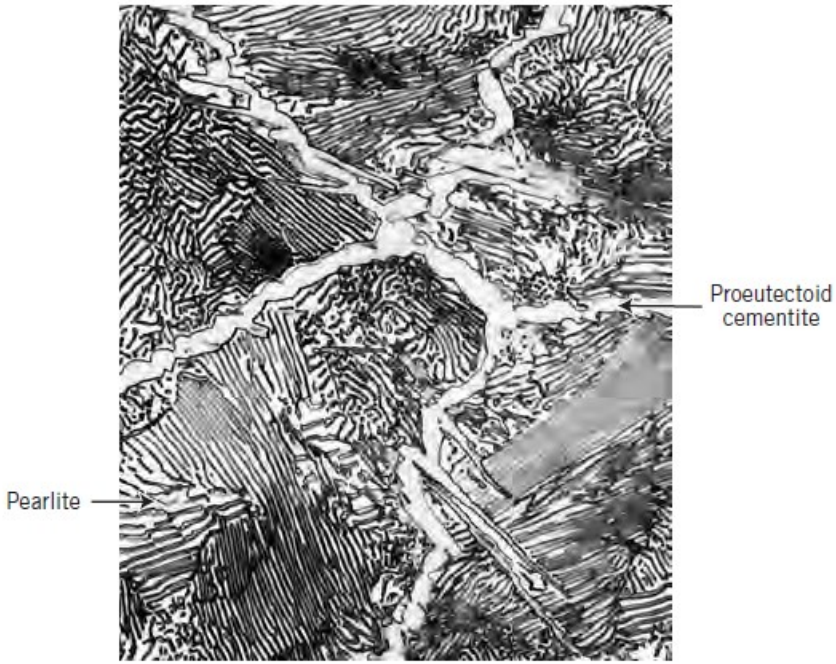
Microestrutura hipoeutetóide



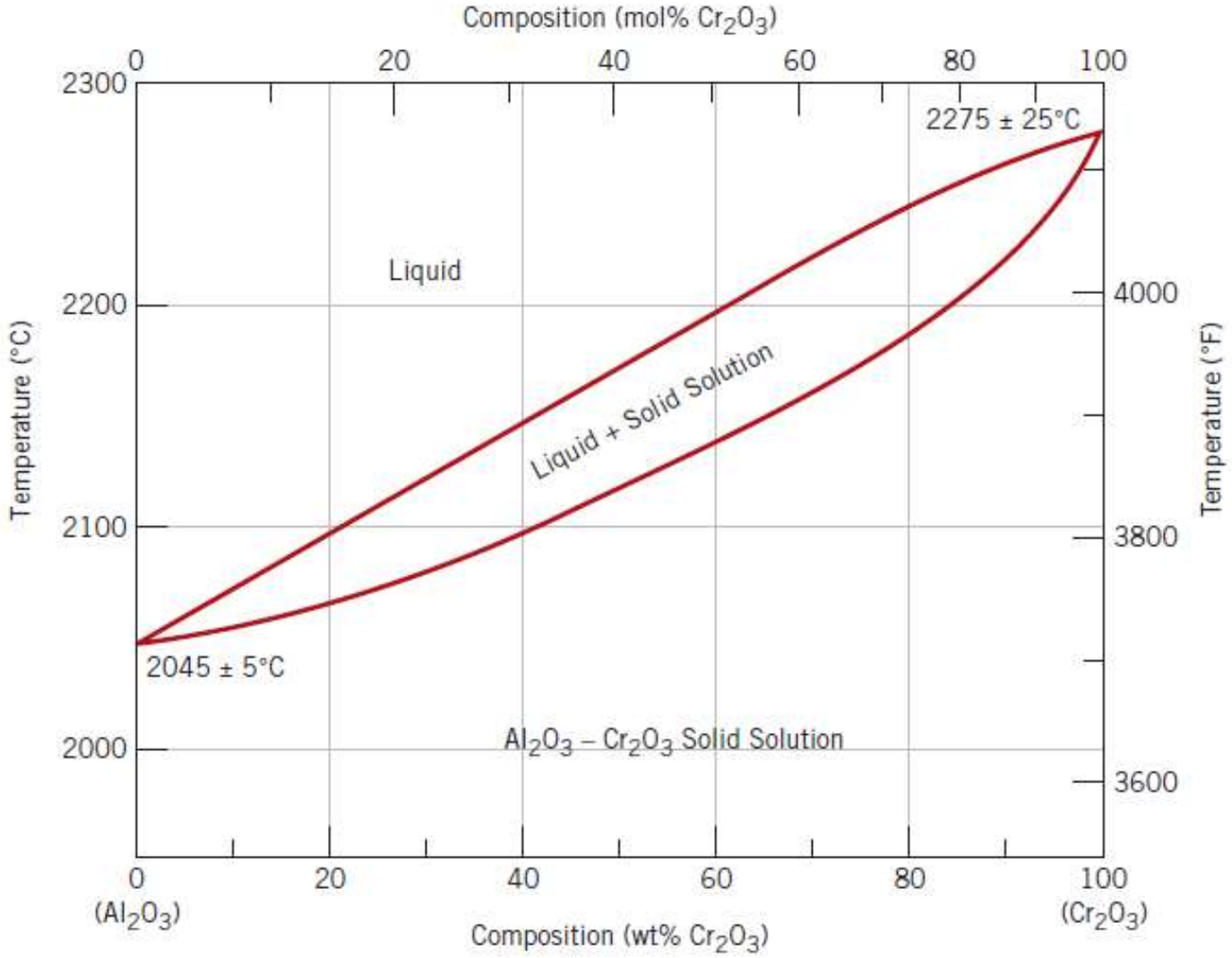


Microestrutura Hipereutetóide

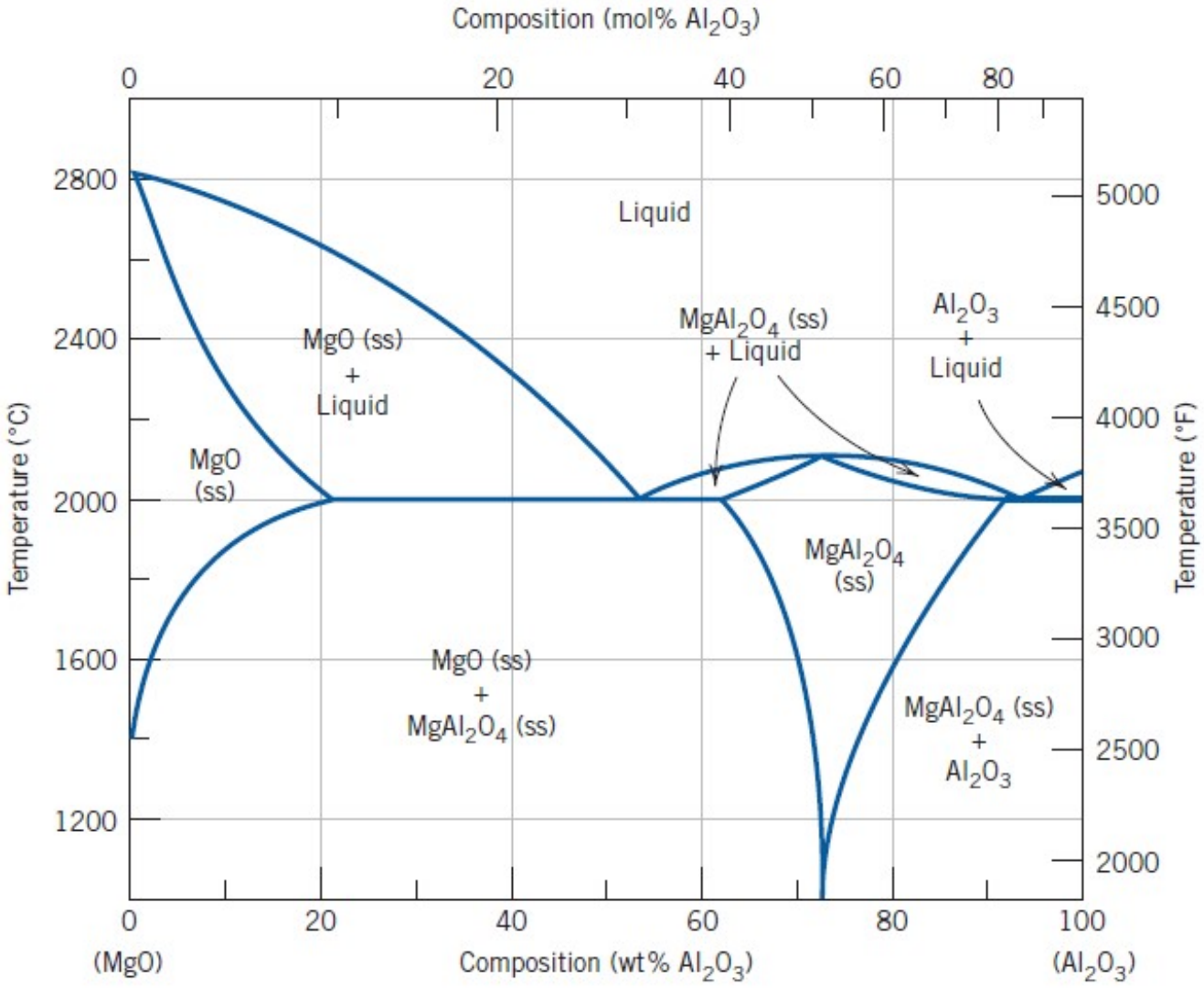




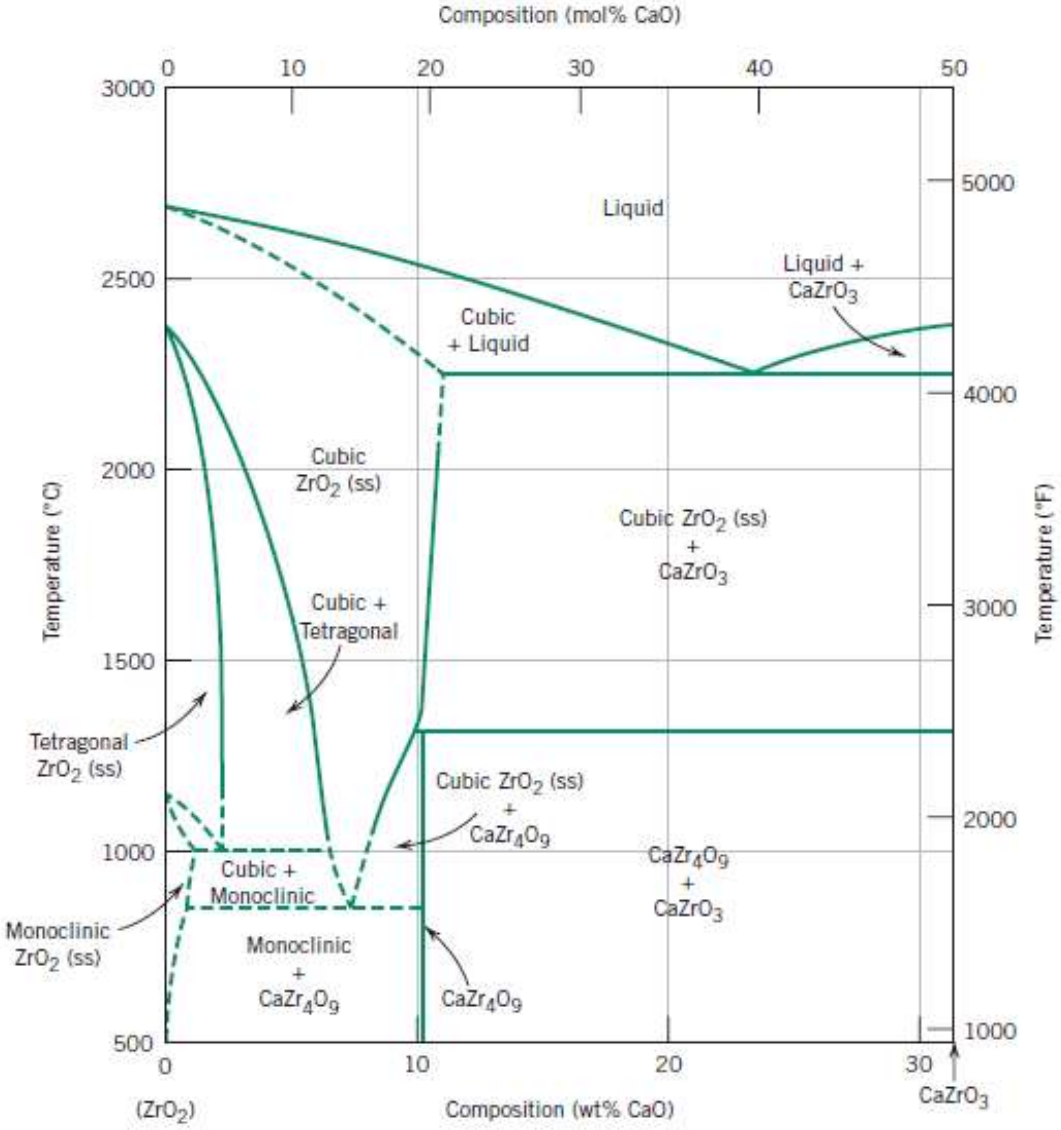
Diagramas cerâmicos



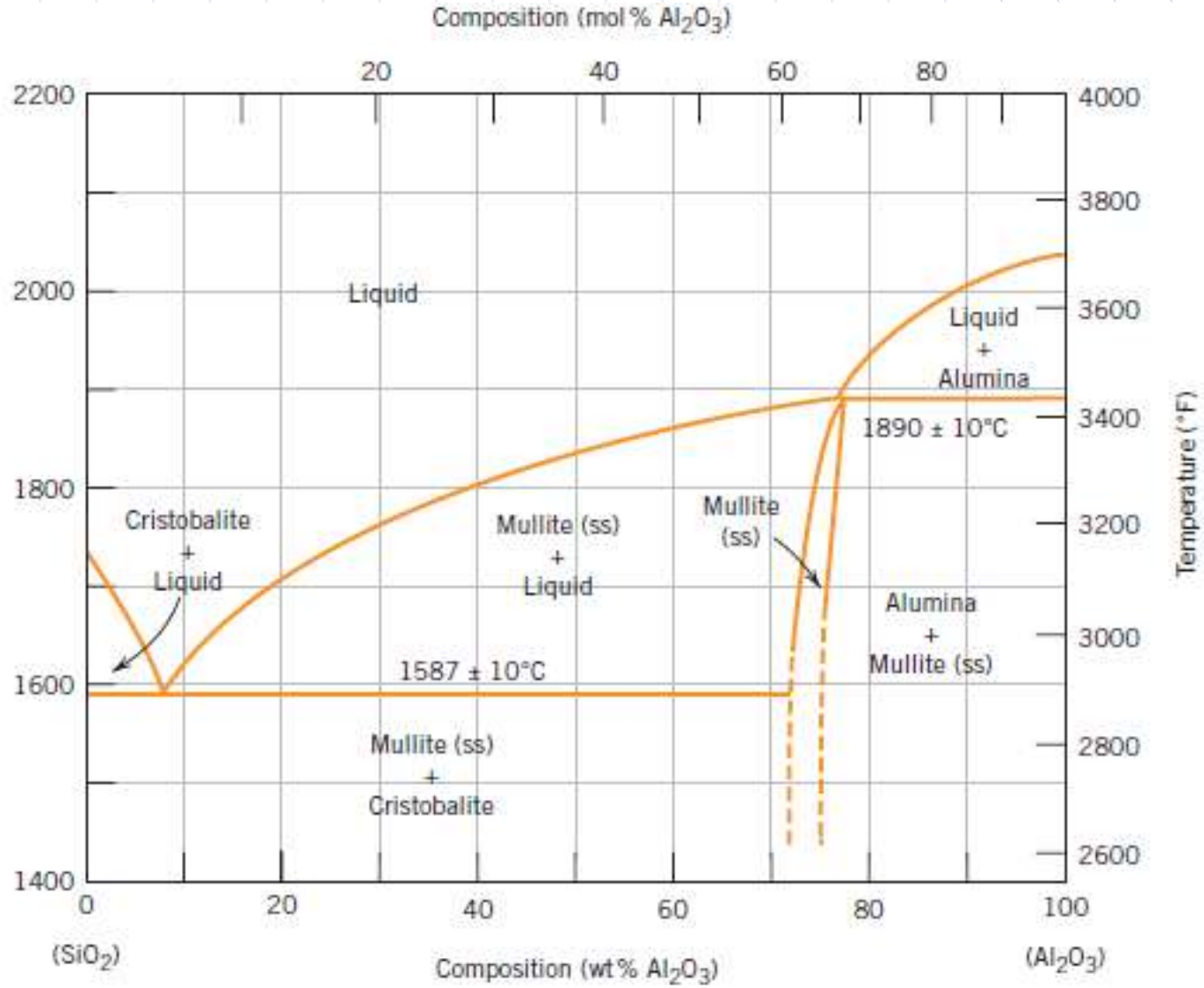
Diagramas cerâmicos



Diagramas cerâmicos



Diagramas cerâmicos



Diagramas Ternários