



Solução Sólida e Fases

Solução sólida

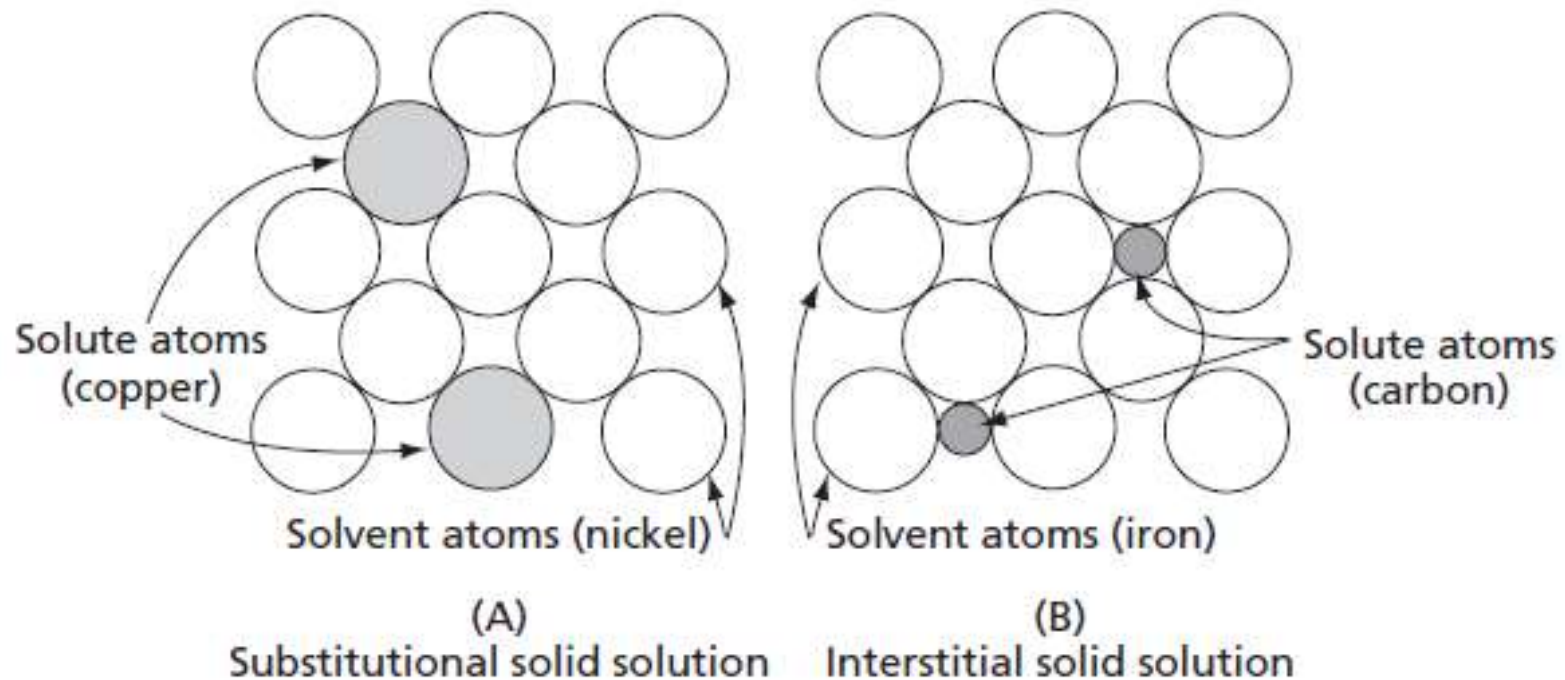


FIG. 9.1 The two basic forms of solid solutions. Note: In the interstitial example on the right, carbon is dissolved interstitially in the body-centered cubic form of iron. For the substitutional solid solution shown on the left, the nickel atoms replace copper atoms

Carbono na ferrita

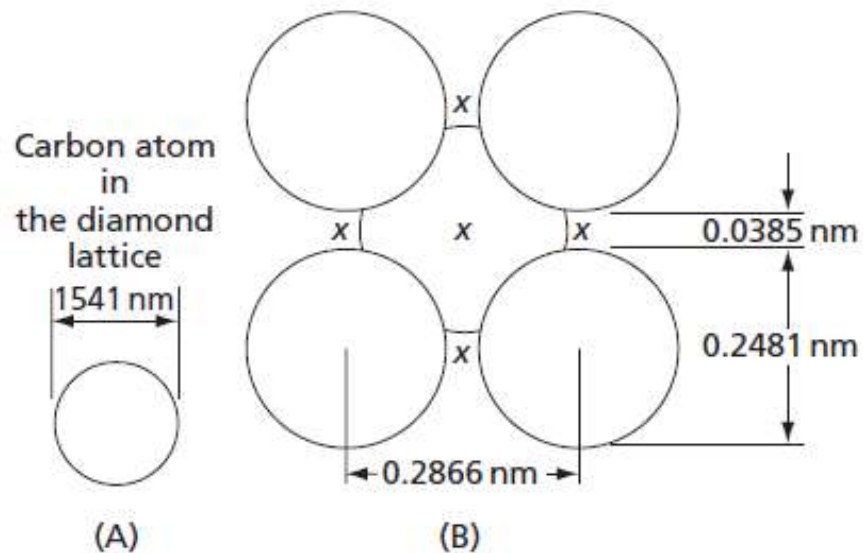


FIG. 9.2 The interstitial positions in the body-centered cubic iron unit cell that may be occupied by carbon atoms

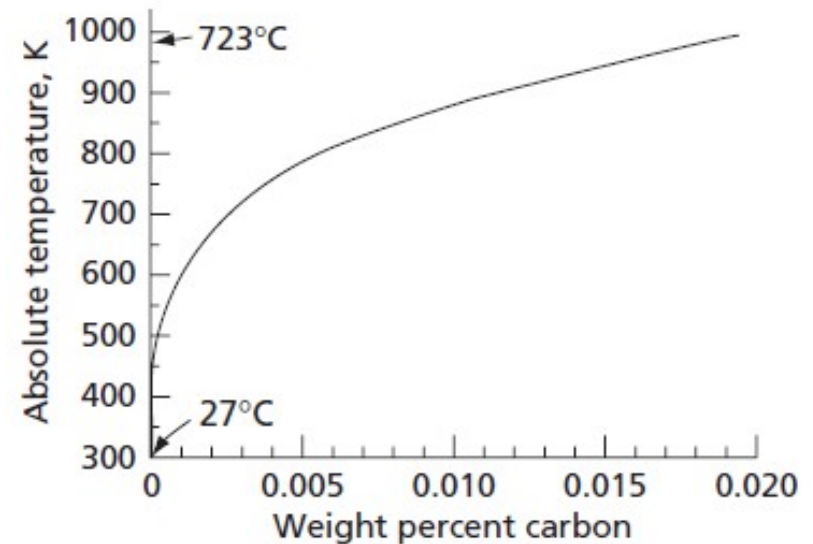


FIG. 9.3 Solubility of carbon in alpha-iron (body-centered cubic iron)

$$C = Be^{-Q_c/RT}$$

Regras de Hume-Rothery para SS substitucional

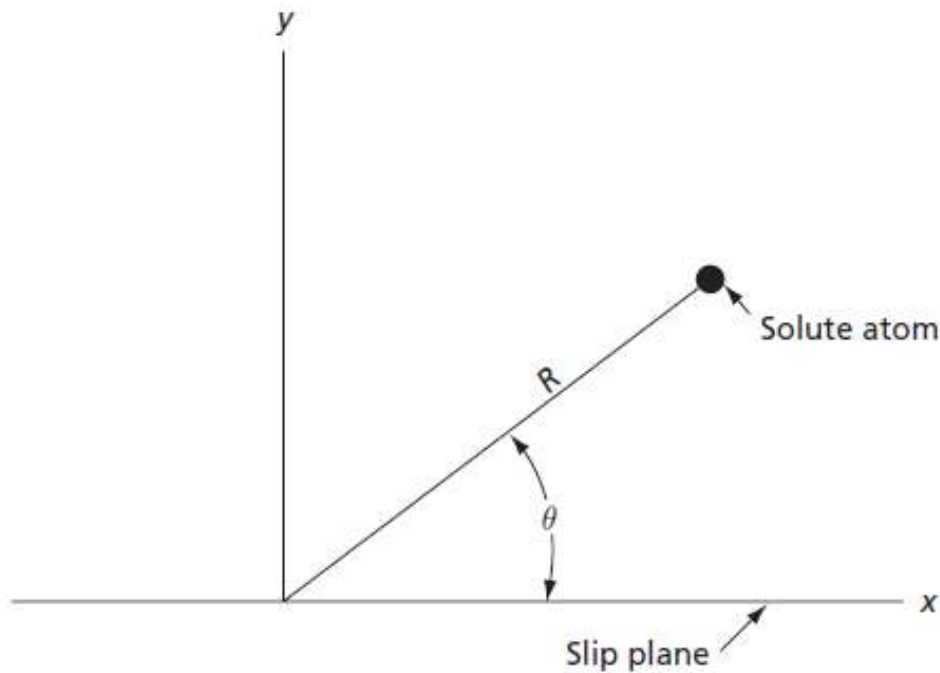
1- Tamanho atômico: Quanto **maior** for a diferença entre os tamanhos dos átomos do soluto e do solvente, **menor** é a faixa de soluções. Se os raios diferem mais de 15%, a solubilidade é pequena. Em outras palavras, o raio do átomo de soluto deve ser menor do que 0,59 do raio do átomo do solvente.

2- Estrutura cristalina: o tipo de estrutura cristalina deve ser o mesmo.

3- Valência química: O metal de **menor valência** (soluto) provavelmente se dissolverá no metal de **maior valência** (solvente). Esta regra é válida para as ligas de cobre (Cu), prata (Ag) e ouro (Au) com metais de maior valência. Para ocorrer extensa faixa de solubilidade, as valências dos dois elementos não devem diferir de mais de uma unidade.

4 - Eletronegatividade: as eletronegatividades devem ser quase iguais; quanto mais eletropositivo for um componente e mais eletronegativo o outro, **maior** será a tendência à formação de compostos entre eles e menor será a solubilidade.

Atmosferas de solutos em linhas de discordâncias



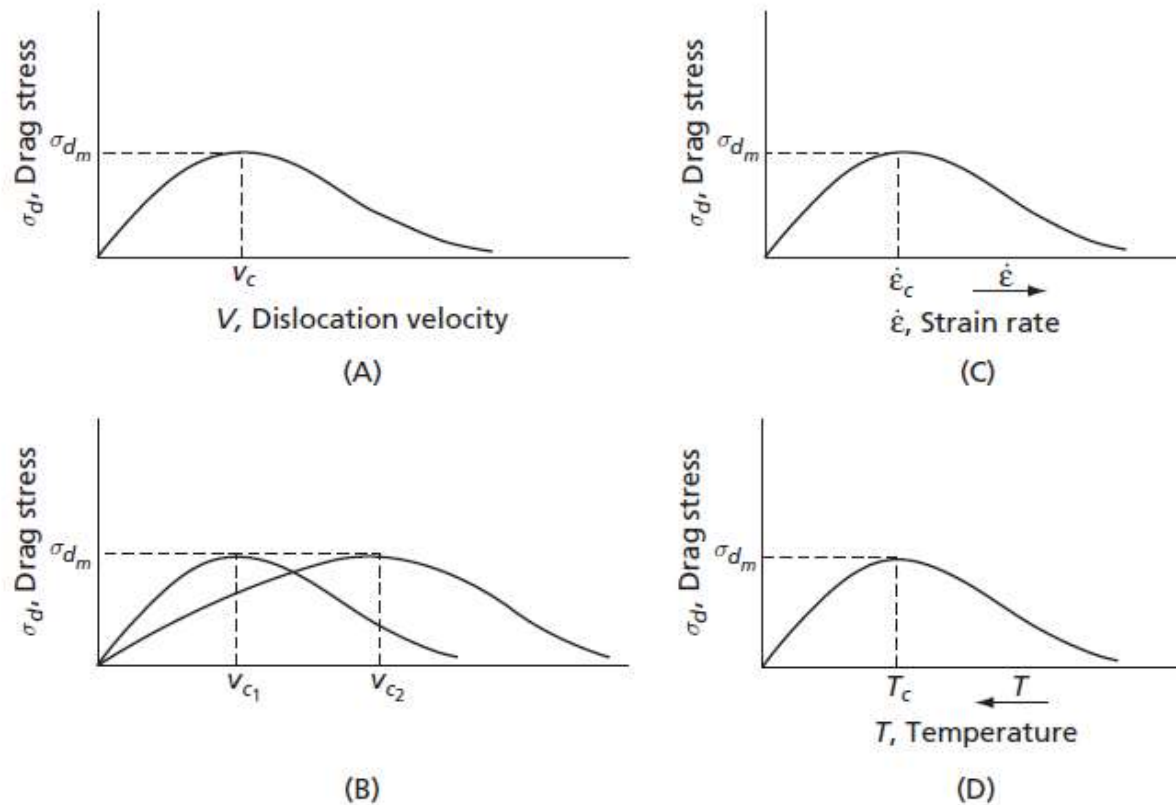
$$\varepsilon = \frac{r' - r}{r}$$

$$U = \frac{A \sin \theta}{R}$$

$$A = \frac{4(1 + \nu)}{3(1 - \nu)} \mu b \varepsilon r^3$$

FIG. 9.5 A figure defining the polar coordinate variables R and θ

Ancoragem das discordâncias pelas atmosferas



$$\dot{\gamma} = \rho b \bar{v}$$

Concentrações de C para atmosferas de Cottrell na ferrita:

Recozido:

$$\frac{n_c}{n_c + n_{Fe}} \approx \frac{n_c}{n_{Fe}} = \frac{4 \times 10^{15}}{10^{23}} = 4 \times 10^{-8}$$

Deformado:

$$\frac{n_c}{n_{Fe}} = 4 \times 10^{-4}$$

FIG. 9.6 Variation of the drag-stress with, (A) the dislocation velocity, (B) the dislocation velocity at two different temperatures, (C) the strain rate, and (D) the temperature at constant strain rate

Tensão de escoamento definida e as bandas de Lüders

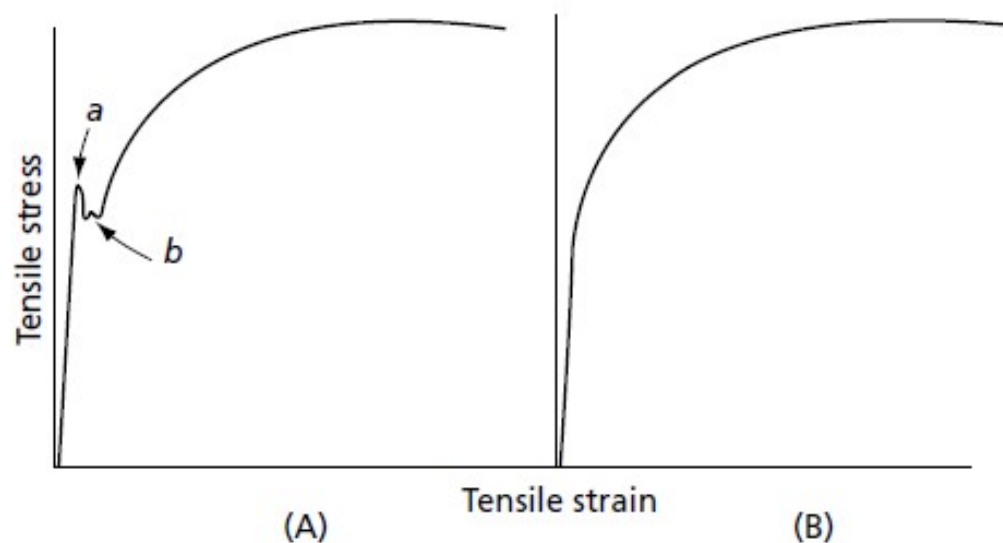


FIG. 9.7 (A) Tensile stress-strain curve for a metal exhibiting a sharp yield point. **(B)** Stress-strain curve for a metal that does not exhibit a sharp yield point

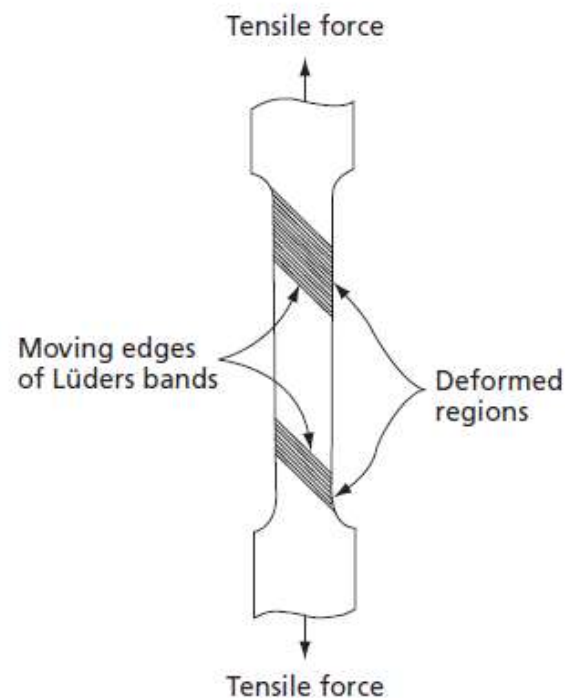


FIG. 9.8 Lüders bands in a tensile-test specimen

Envelhecimento por deformação

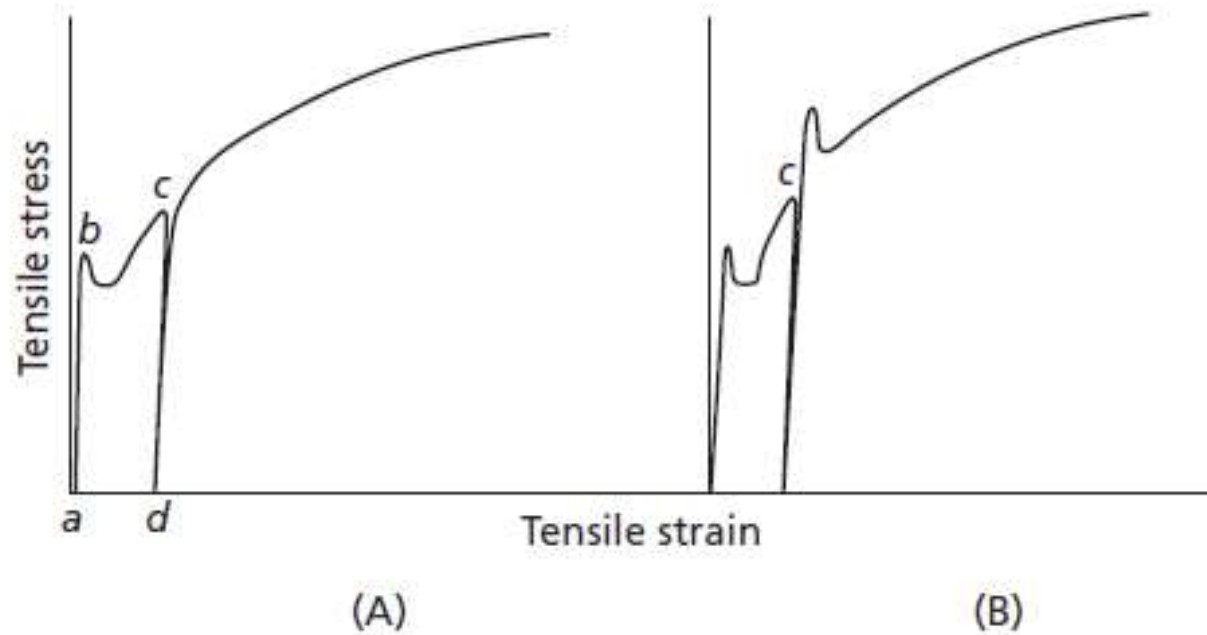
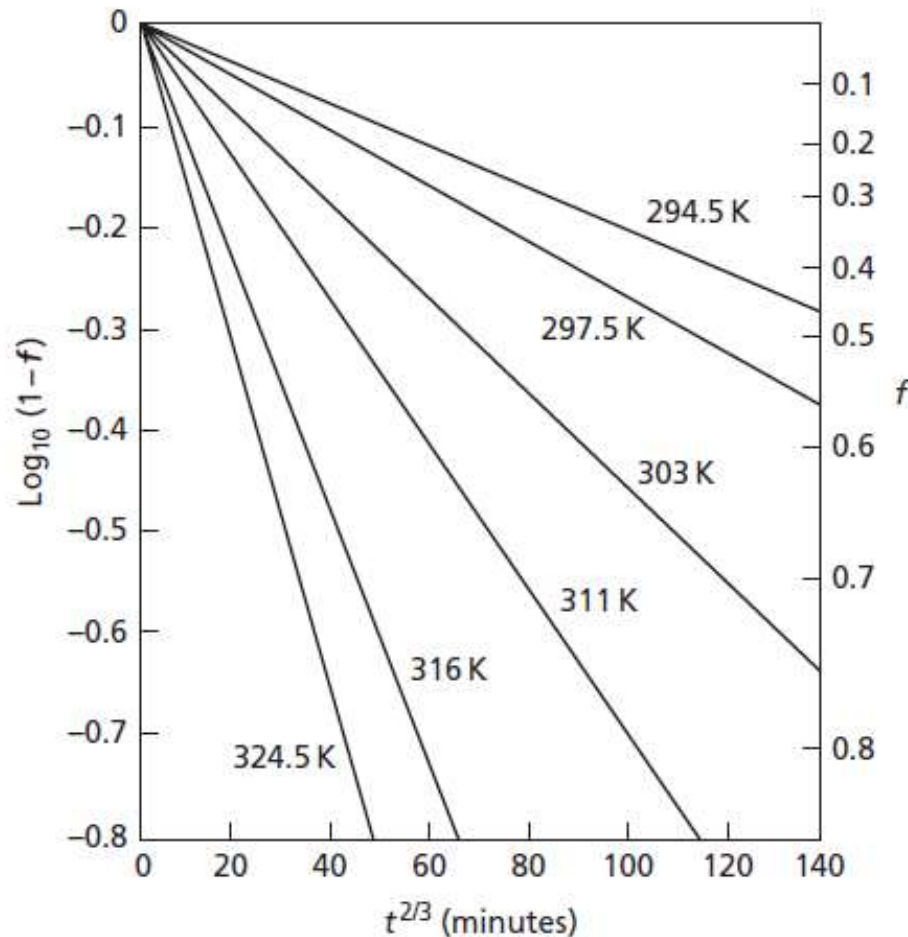


FIG. 9.9 Strain aging. **(A)** Load removed from specimen at point *c* and specimen reloaded within a short period of time (hours). **(B)** Load removed at point *c* and specimen reloaded after a long period of time (months)

Tempo para o envelhecimento



Equação de Harper

$$f = 1 - \exp[-\alpha\rho(ADt/kT)^{2/3}]$$

FIG. 9.11 Harper's plot showing that his equation is able to describe the time dependence of the flow of solute to the dislocation atmospheres. Cold-worked iron wire specimens with carbon in solid solution were used

Envelhecimento dinâmico

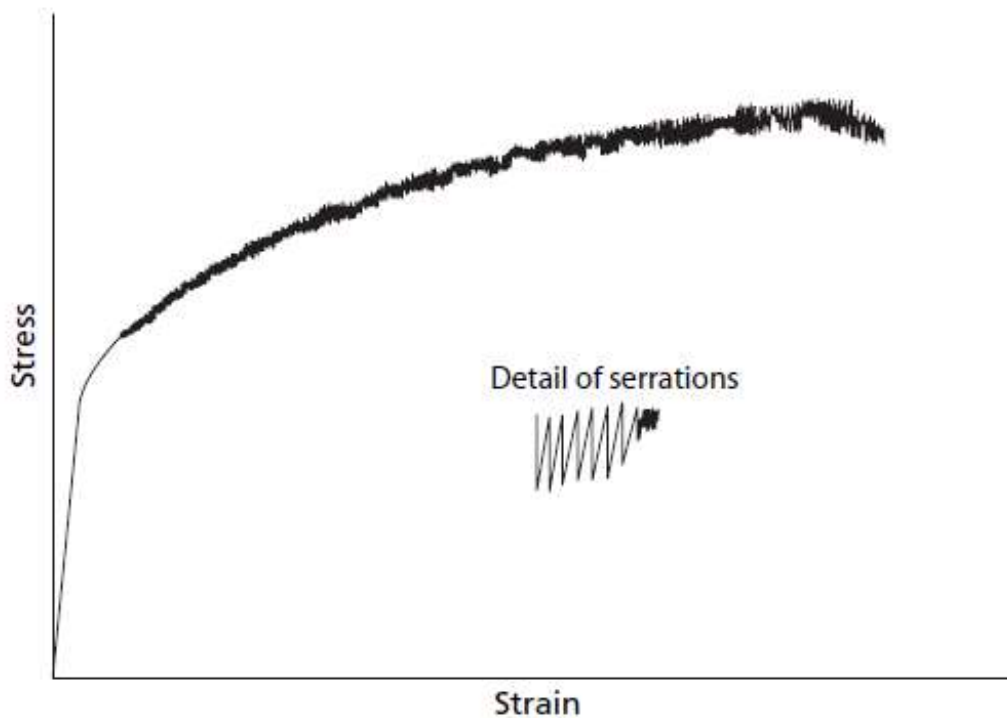


FIG. 9.16 Discontinuous plastic flow is a common aspect of dynamic strain aging. This diagram indicates one form of serrations that may be observed

$$\frac{\sigma_2}{\sigma_1} = \left(\frac{\dot{\epsilon}_2}{\dot{\epsilon}_1} \right)^n$$



Fases - considerações iniciais

- Definir termos e conceitos fundamentais

TABLE 10.1 Phases of Pure Iron.

Stable Temperature Range K	Form of Matter	Phase	Identification Symbol of Phase
Above 3013	gaseous	gas	gas
1812 to 3013	liquid	liquid	liquid
1673 to 1812	solid	body-centered cubic	(delta)
1183 to 1673	solid	face-centered cubic	(gamma)
Below 1183	solid	body-centered cubic	(alpha)



Equilíbrio termodinâmico de fases

$$\bar{G}_A^\alpha = \bar{G}_A^\beta = \bar{G}_A^\gamma = \dots = \bar{G}_A^\mu$$

$$\bar{G}_B^\alpha = \bar{G}_B^\beta = \bar{G}_B^\gamma = \dots = \bar{G}_B^\mu$$

$$\bar{G}_C^\alpha = \bar{G}_C^\beta = \bar{G}_C^\gamma = \dots = \bar{G}_C^\mu$$

$$\vdots \qquad \dots \qquad \vdots$$

$$\bar{G}_M^\alpha = \bar{G}_M^\beta = \bar{G}_M^\gamma = \dots = \bar{G}_M^\mu$$

Estabilidade termodinâmica de fases

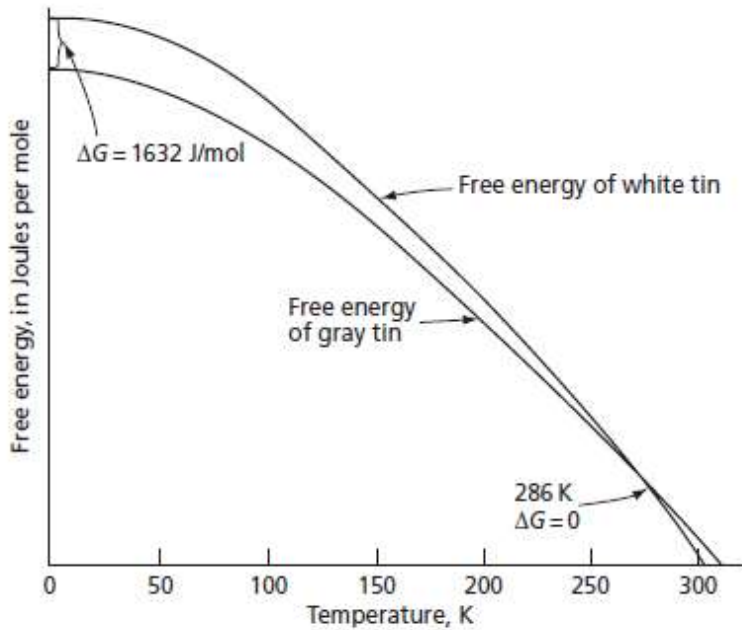


FIG. 10.2 Temperature-free energy curves for two solid forms of tin

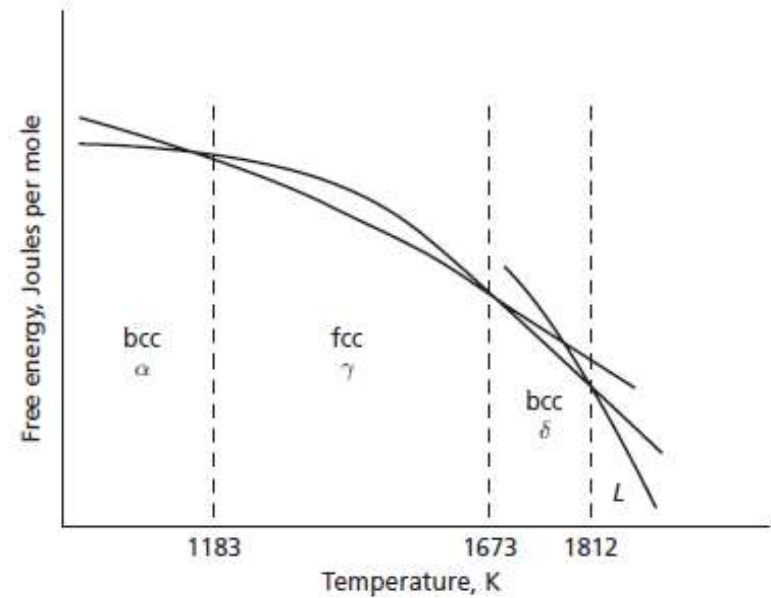


FIG. 10.4 Free energies of bcc, fcc, and liquid iron versus temperature



Solução ideal

$$G = N_A \bar{G}_A + N_B \bar{G}_B$$

$$\bar{G}_A = G_A^0 + RT \ln N_A$$

$$\bar{G}_B = G_B^0 + RT \ln N_B$$

$$\Delta \bar{G}_A = \bar{G}_A - G_A^0 = RT \ln N_A$$

$$\Delta \bar{G}_B = \bar{G}_B - G_B^0 = RT \ln N_B$$

Solução não ideal

$$\begin{aligned}\overline{\Delta G}_A &= RT \ln a_A \\ \overline{\Delta G}_B &= RT \ln a_B\end{aligned}$$

$$\gamma_A = \frac{a_A}{N_A} \quad \text{and} \quad \gamma_B = \frac{a_B}{N_B}$$

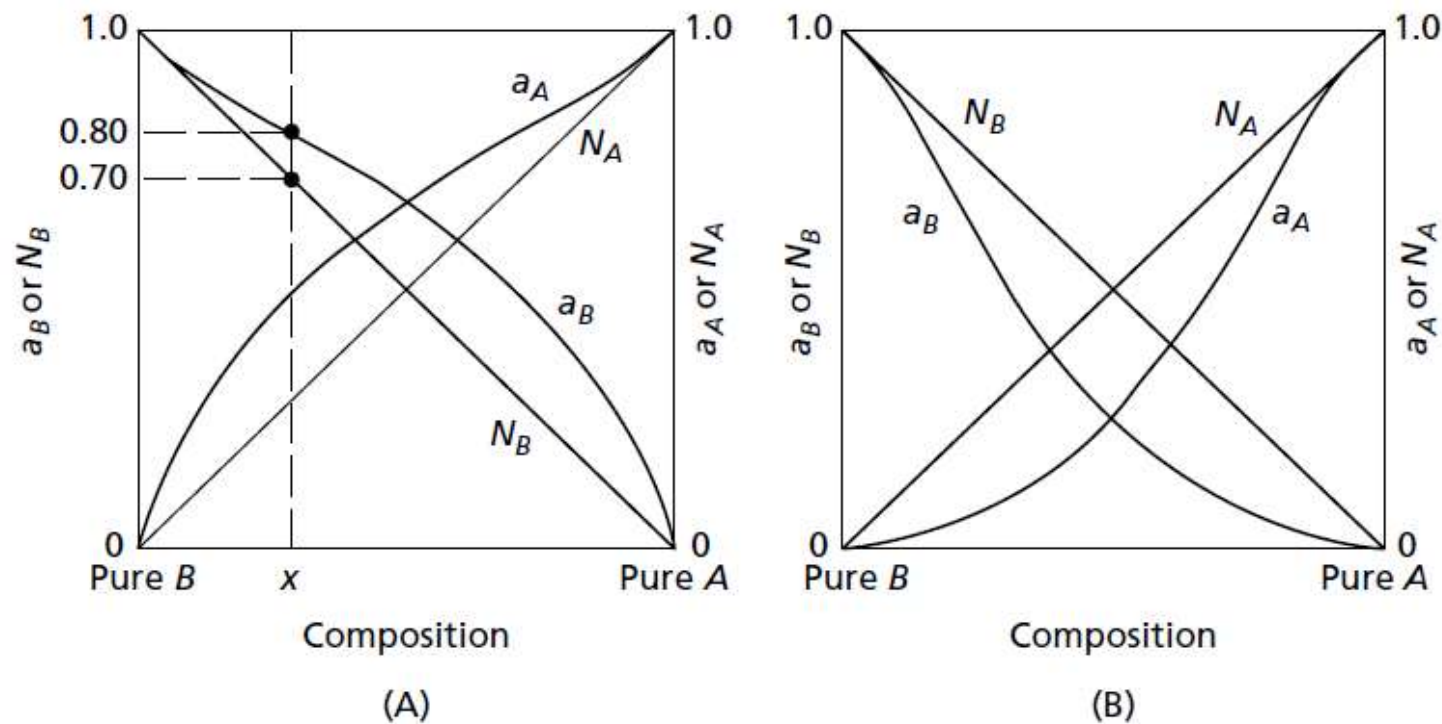


FIG. 10.5 Variation of the activities with concentration: (A) positive deviation, and (B) negative deviation

Energia livre de mistura

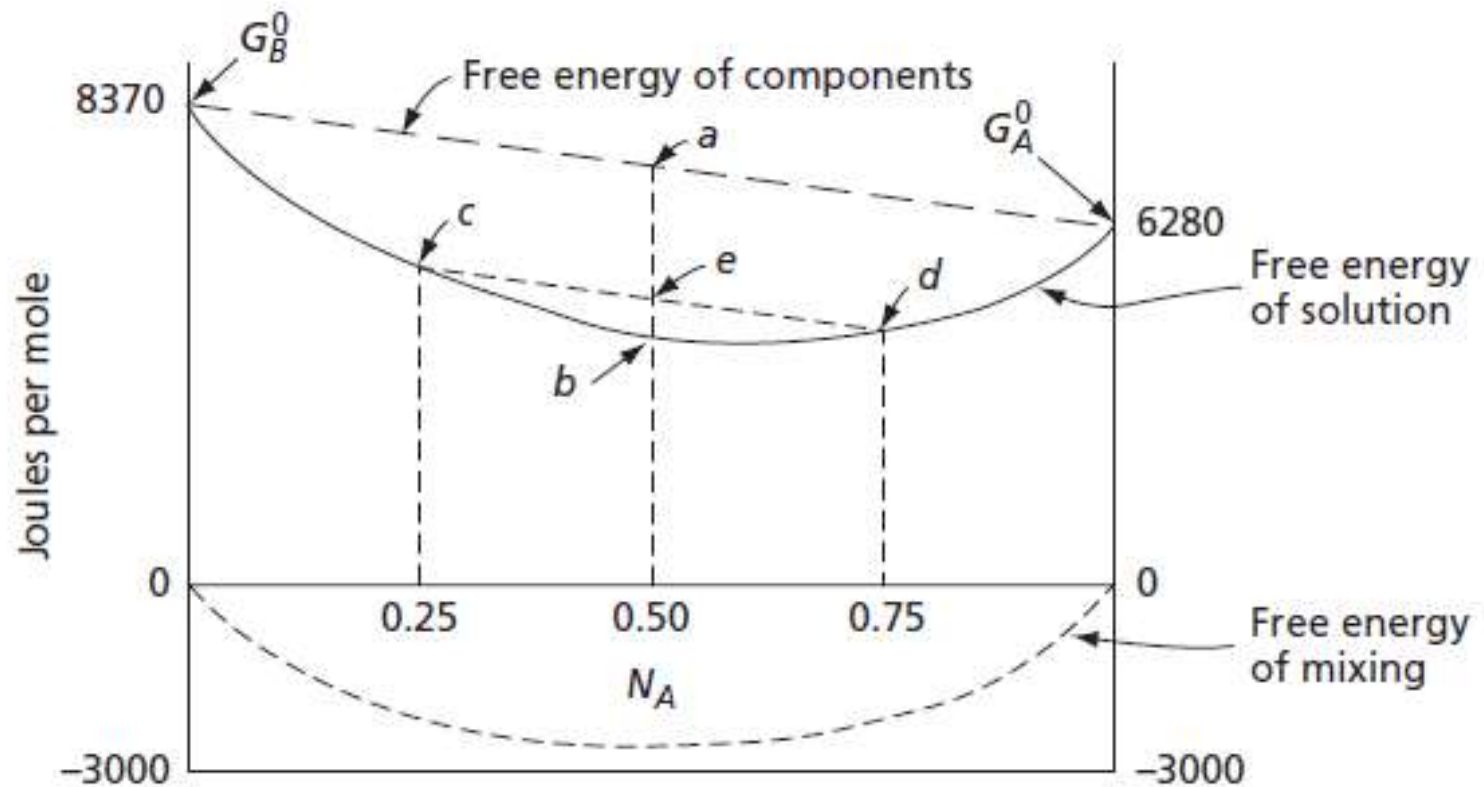
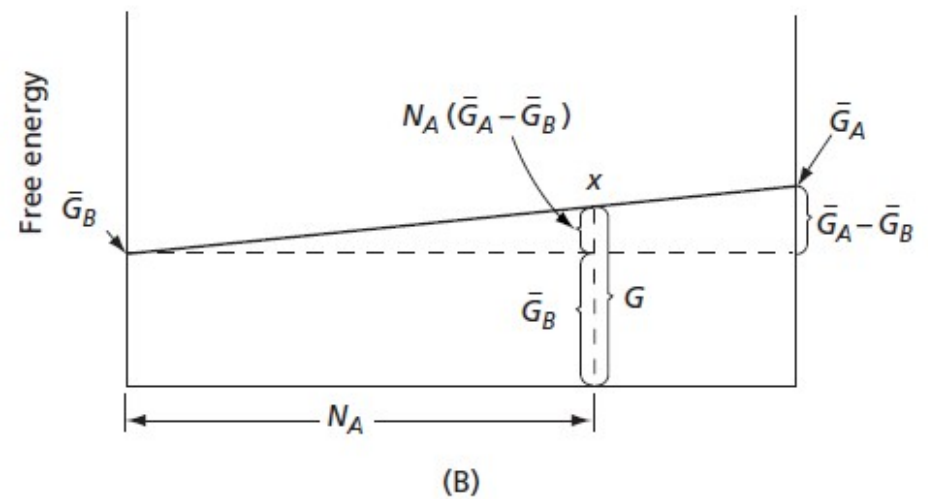
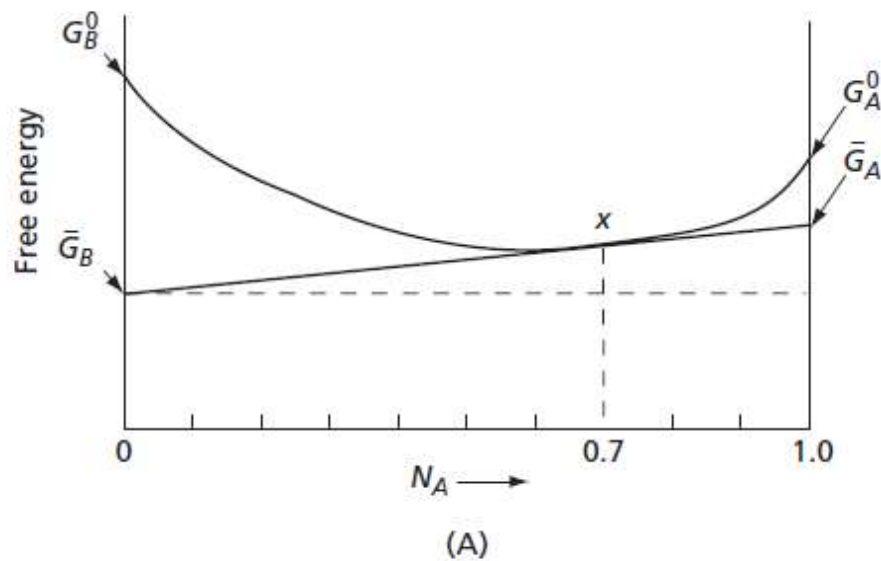


FIG. 10.7 Hypothetical free energy of an ideal solution

Energia livre parcial molar

$$G = N_A \bar{G}_A + N_B \bar{G}_B$$



Equilíbrio de fases

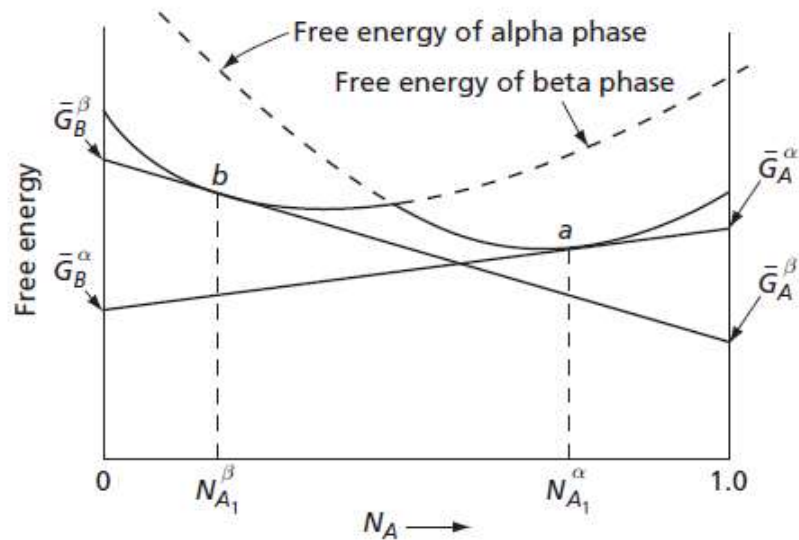


FIG. 10.9 Two phases having compositions of N_{A1}^α and N_{A1}^β , respectively, cannot be in equilibrium

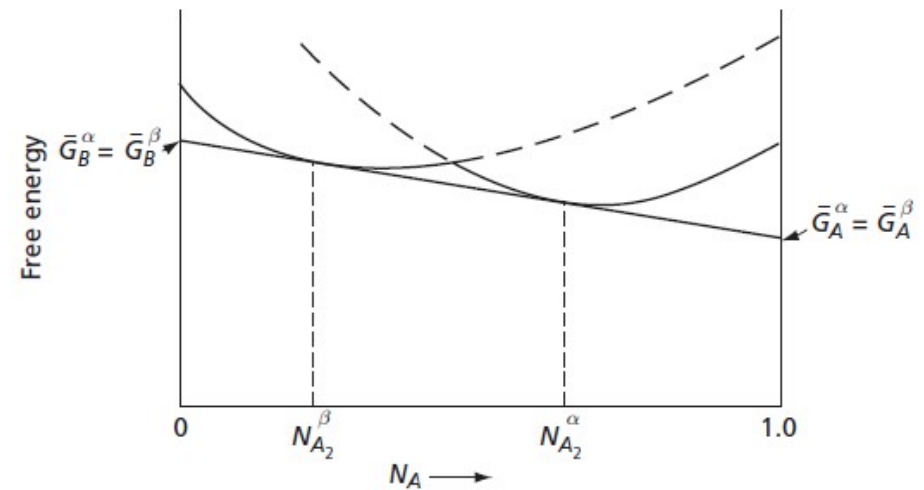


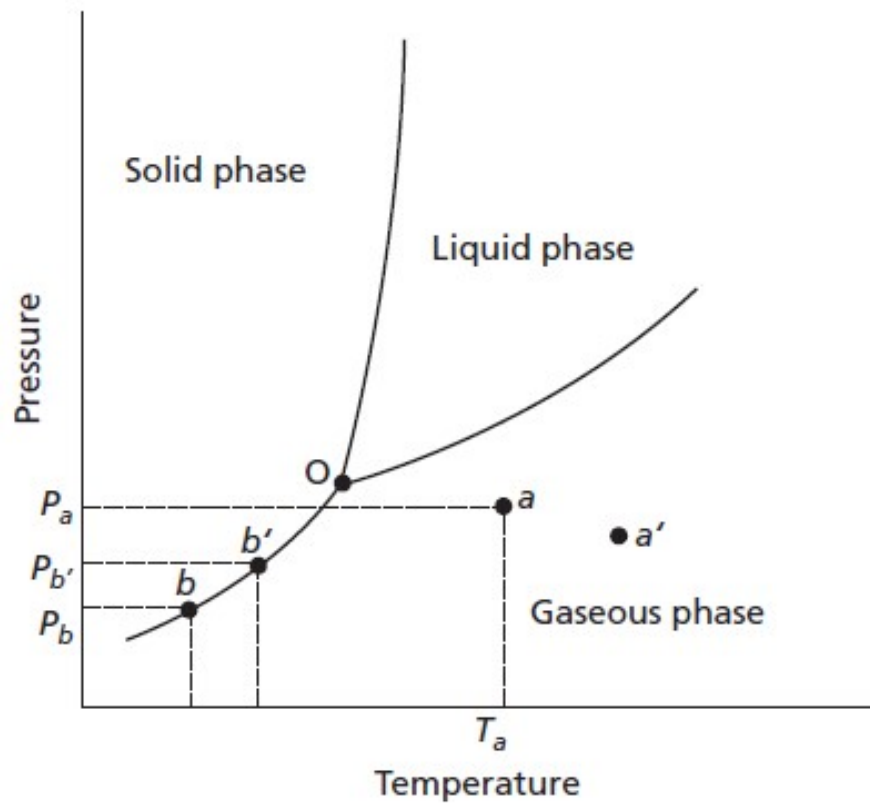
FIG. 10.10 Two phases in equilibrium

Dois componentes e três fases em equilíbrio

TABLE 10.3 Types of Three-Phase Transformations That Can Occur in Binary Systems.

Type of Transformation	Nature of the Phase Transformation		
	Phase A	Phase B	Phase C
Eutectic	Liquid	\rightleftharpoons Solid Solution	+ Solid Solution
Eutectoid	Solid Solution	\rightleftharpoons Solid Solution	+ Solid Solution
Peritectic	Liquid Solution	+ Solid Solution	\rightleftharpoons Solid Solution
Monotectic	Liquid Solution	\rightleftharpoons Liquid Solution	+ Solid Solution

A regra das fases de Gibbs



$$P + F = C + 2$$

FIG. 10.11 A single-component phase diagram