

## 第三节 二元系相图

有两个组元,系统有3个独立变量,比单元系统多了一个,即组元浓度的变化,而两个组元中只有一个组元的浓度作独立变量。通常范围内压力对凝聚系统相平衡的影响可忽略,相律的数学表达式可变为:  $f = c - p + 1$ , 这样二元系统f最大取2, 为温度T和成分X。

# 一.二元系相图的建立：实验测定，理论计算

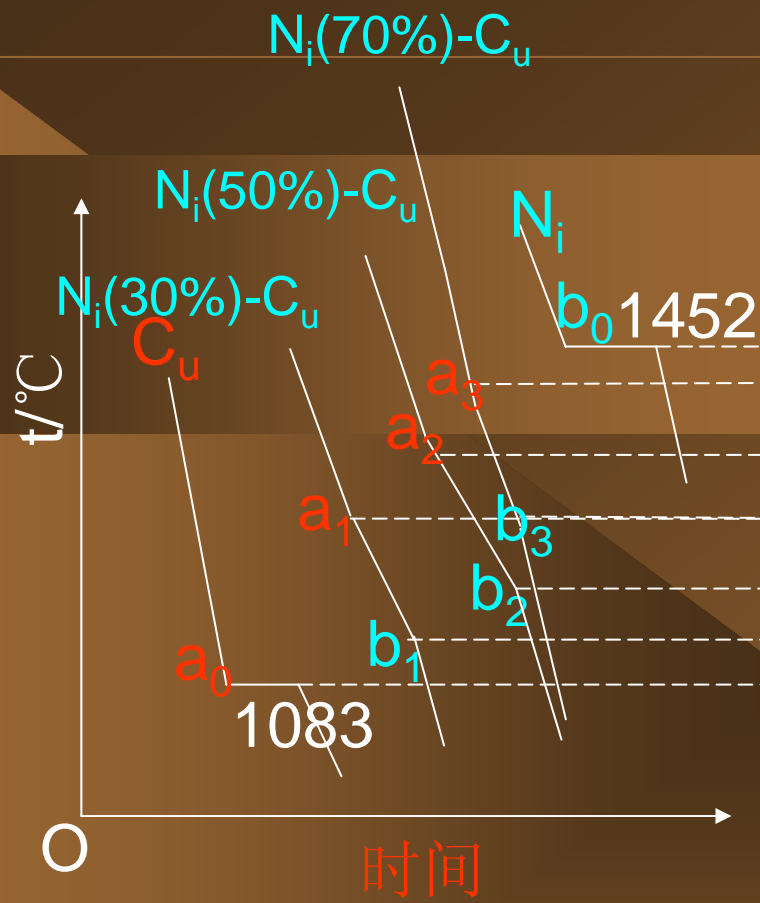
## 相变临界点

决定系统状况的温度、压力、浓度等变数连续变化，并保持相数目和特点不变，则整个系统性质的变化即为连续的；若系统中有了新相产生或旧相消失，则整个系统的性质将发生跳跃式变化，发生跳跃的奇异点即为相变的临界点。

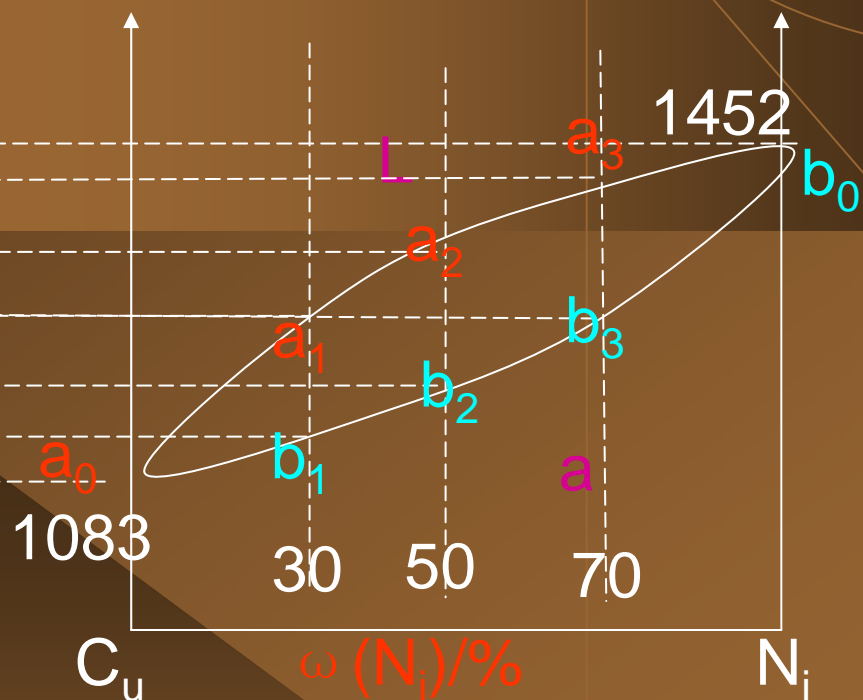
相图即是根据临界点特征建立的。

临界点测定方法：热分析法、金相法、膨胀法、磁性法、电阻法、X射线结构分析法等。

步冷曲线



(a)



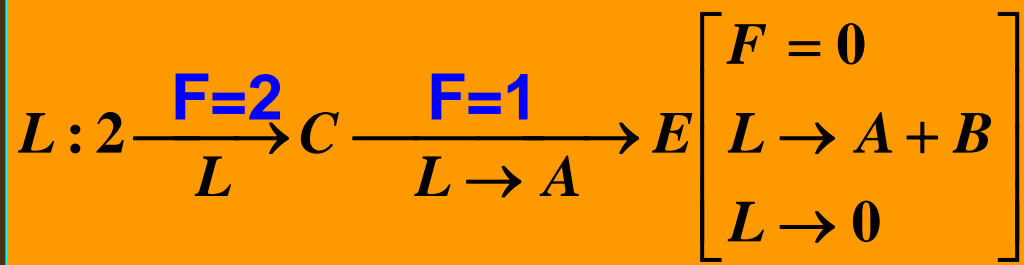
(b)

热分析法建立 $\text{Cu-Ni}$ 相图

(a).冷却曲线; (b).相图

# 三.二元相图的类型

析晶分析



S: D → → → → G → K → N

相对含量的变化:

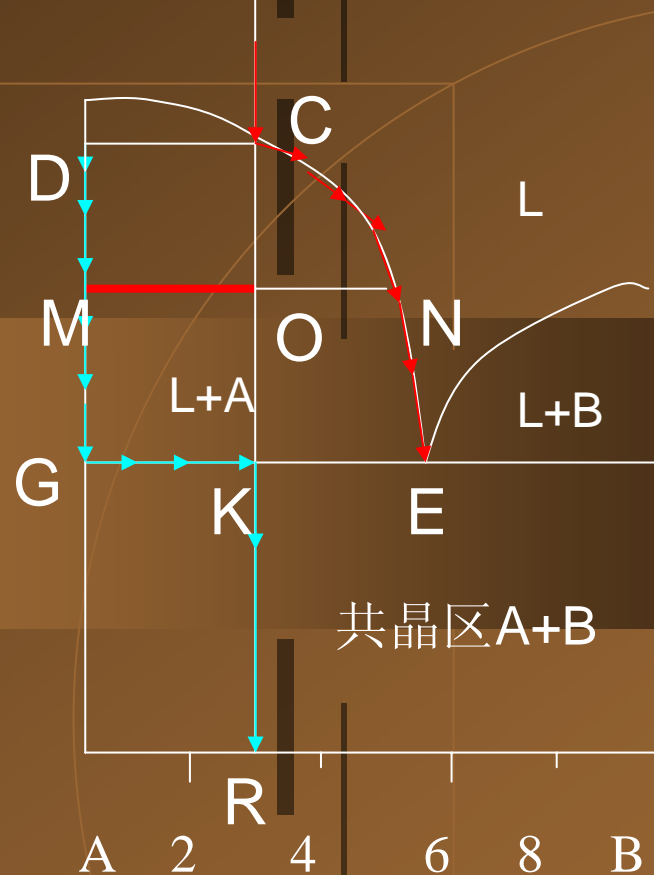
O: 刚到E

E结束

$$\frac{L}{S} = \frac{MO}{NO}$$

$$\frac{L}{S} = \frac{GK}{EK}$$

$$\frac{A}{B} = \frac{KH}{GK}$$



# 具有一个化合物的二元相图

AmBn是一个稳定化合物

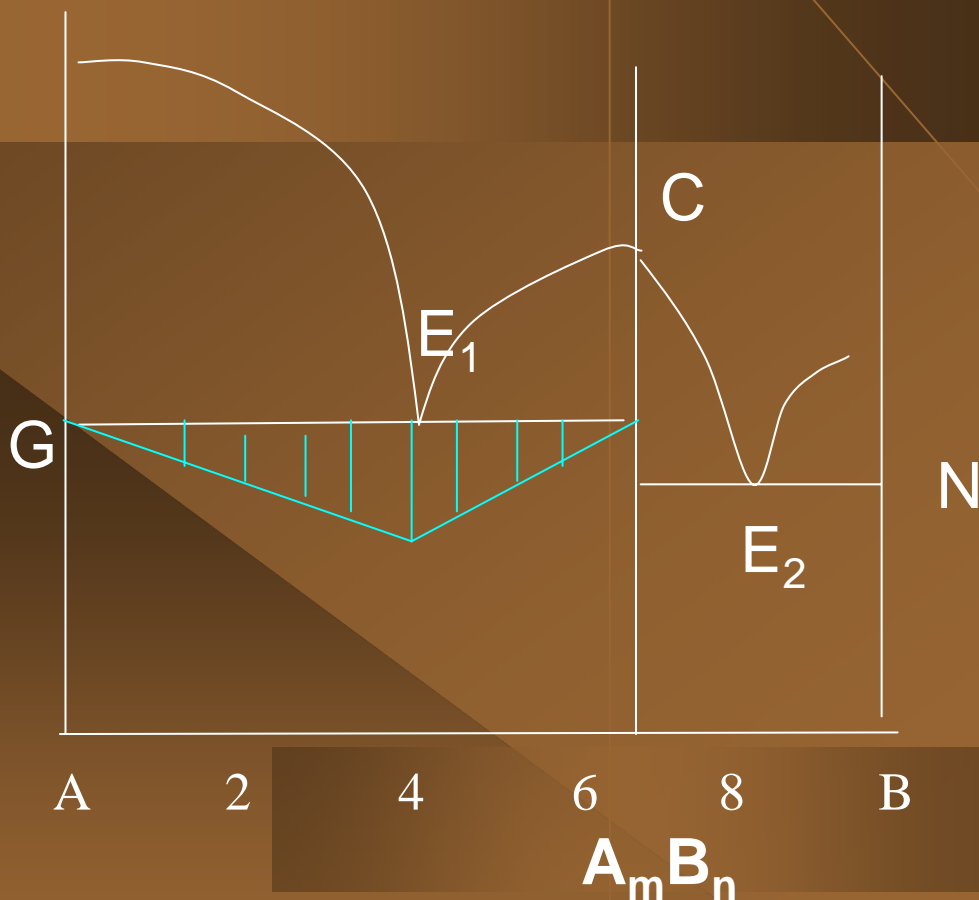
1) C点:  $C=1$ ,  $P=2$ ,  
 $F = C - P + 1 = 0$

**呆性点:** 使平衡两相（液相和固相）为相同组成而使体系消失一个自由度的点

2) 可分解为两个简单相图

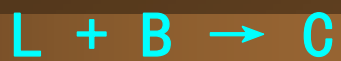
3) 稳定性 化合物液相线越平缓, 该化合物稳定性越差

4) 台曼三角形

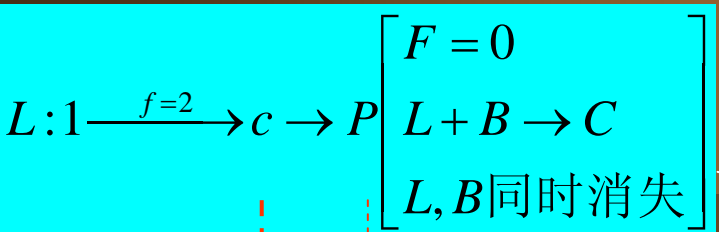


# 生成不一致熔融化合物的二元相图

$T_p$ : 转熔点



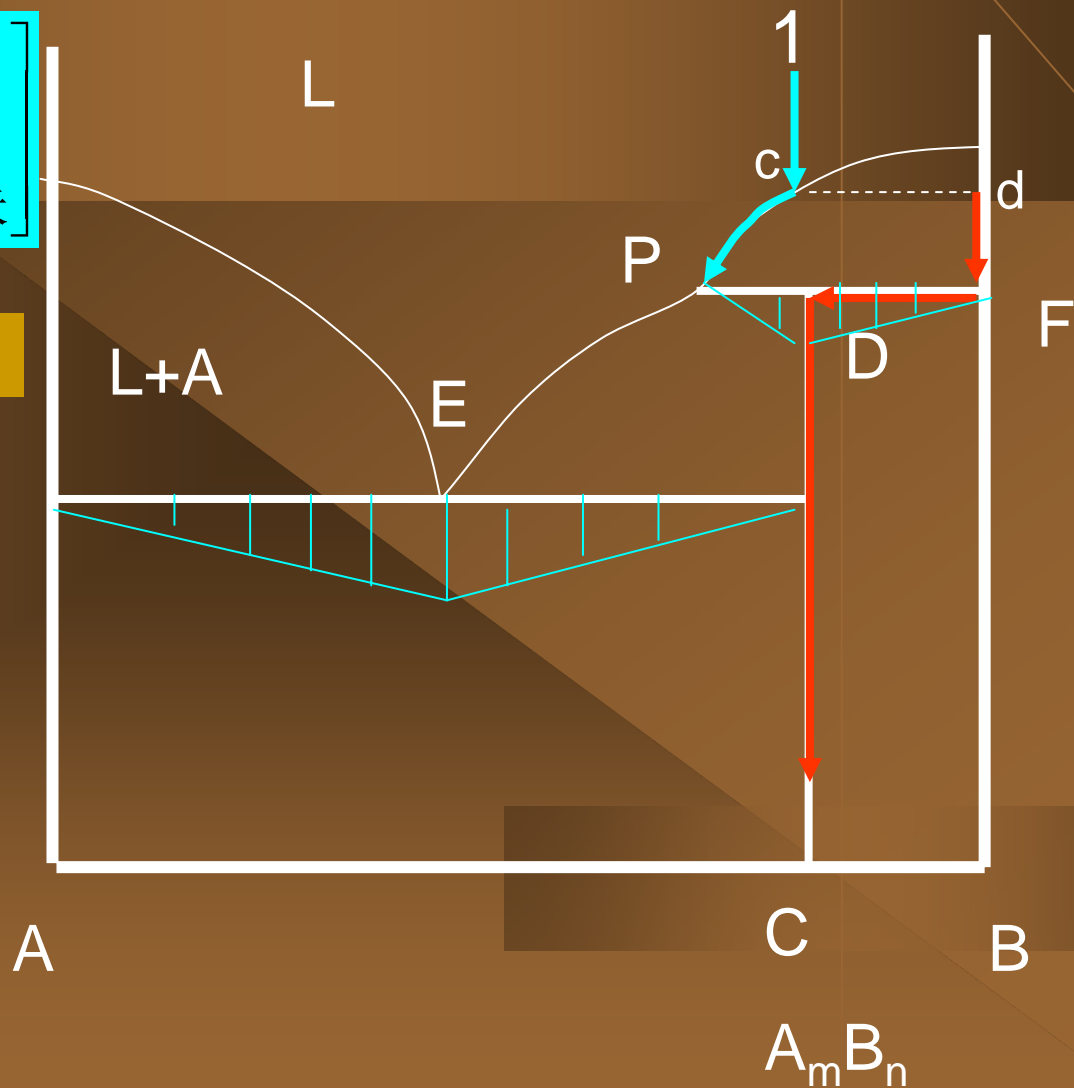
$$F = C - P + 1 = 2 - 3 + 1 = 0$$



刚到P点:

$$\frac{L}{S} = \frac{FD}{DP}$$

产物: C



## 二. 杠杆定律

### 杠杆定律的证明

设合金C的总质量为1，液相的质量为 $\omega_L$ ，固相的质量为 $\omega_a$

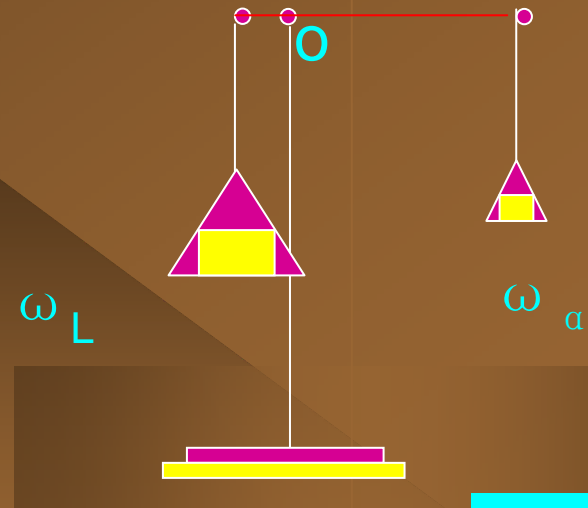
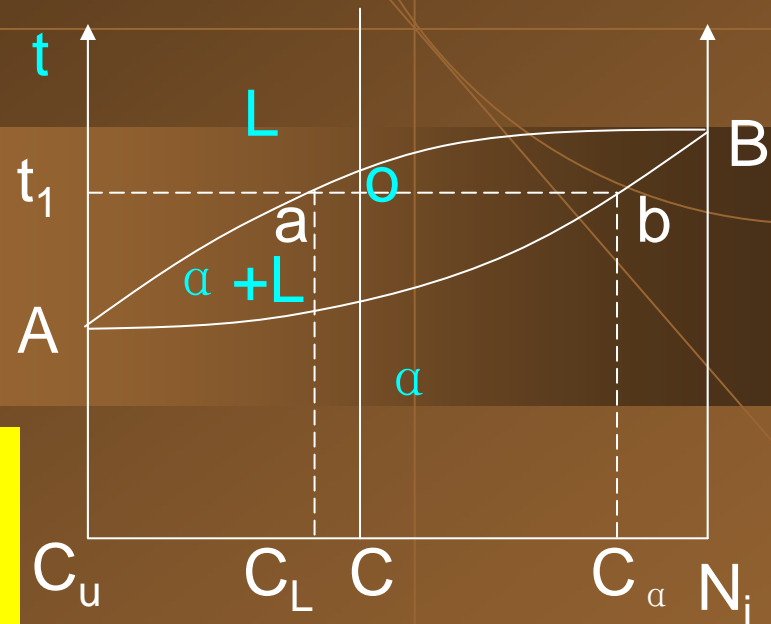
$$\omega_L + \omega_a = 1$$

$$\omega_L C_L + \omega_a \cdot C_a = 1 \cdot C$$

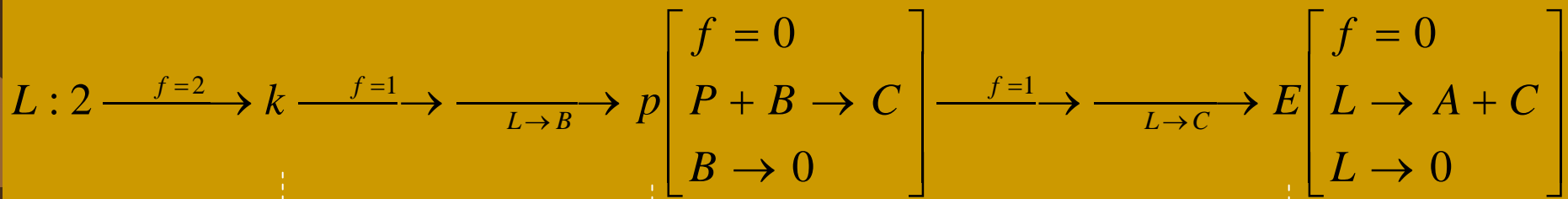
由以上两式可得 $\omega_L C_L + (1 - \omega_L) C_a = C$

$$\omega_L = \frac{C_a - C}{C_a - C_L} = \frac{bo}{ba}, \text{同理 } \omega_a = \frac{ao}{ab}$$

o视为支点， $\omega_a$ 和 $\omega_L$ 看为作用于a，b两点的力，则由力学中杠杆原理可得上式，故上式称杠杆定律。



$$\frac{\omega_L}{\omega_a} = \frac{ob}{ao}$$



S:  $e \longrightarrow F \longrightarrow D \longrightarrow N \longrightarrow H$

刚到P

$$\frac{L}{B} = \frac{hF}{hP}$$

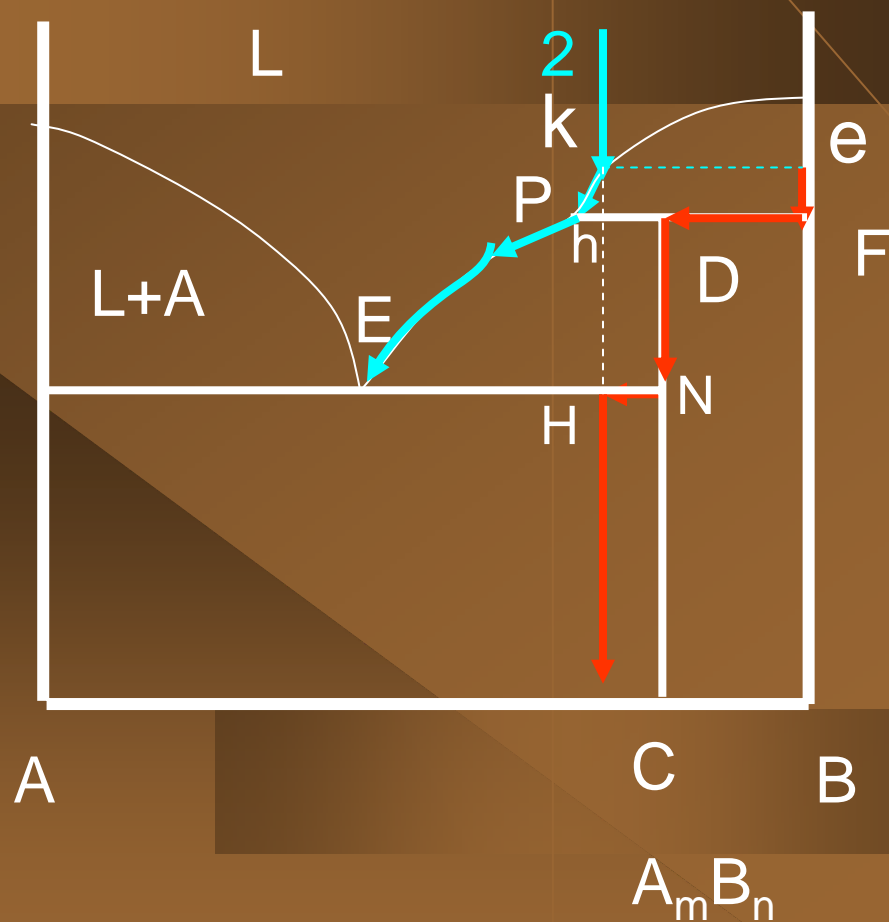
离开P

$$\frac{L}{C} = \frac{hD}{hP}$$

刚到E

$$\frac{L}{C} = \frac{HN}{HE}$$

产物:  $A+C$



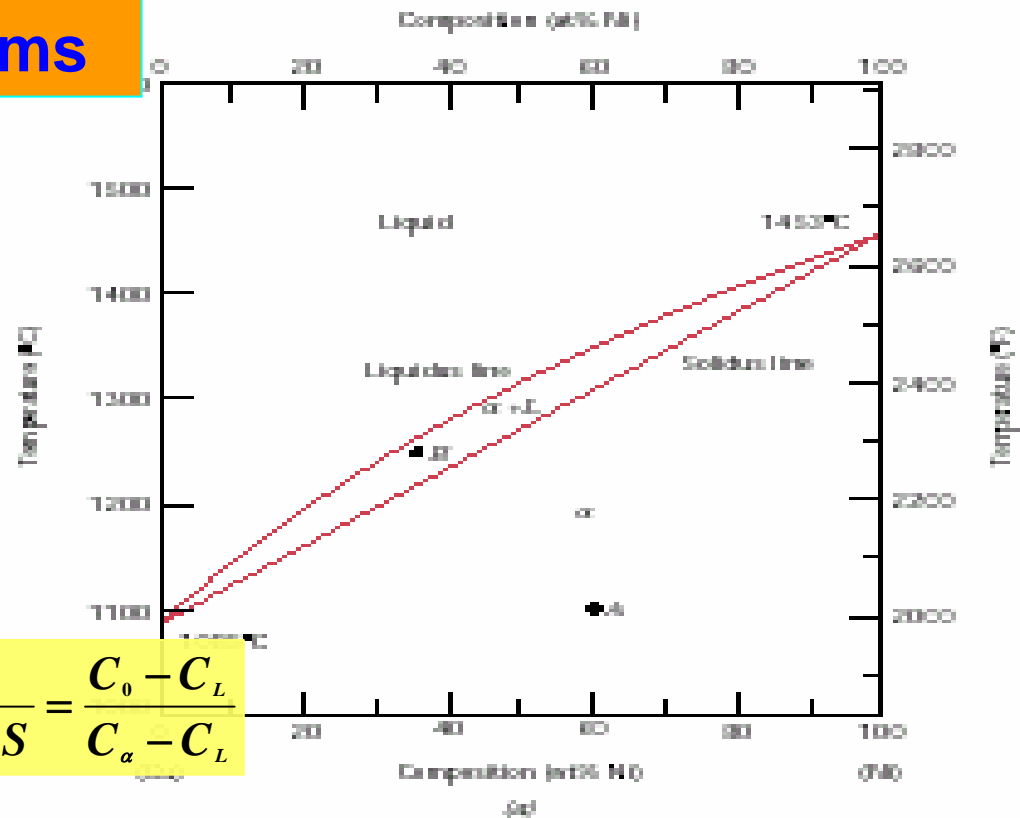




# Binary isomorphous systems

From *Phase Diagrams of Binary Nickel Alloys*,  
P. Nash, Editor, 1991.

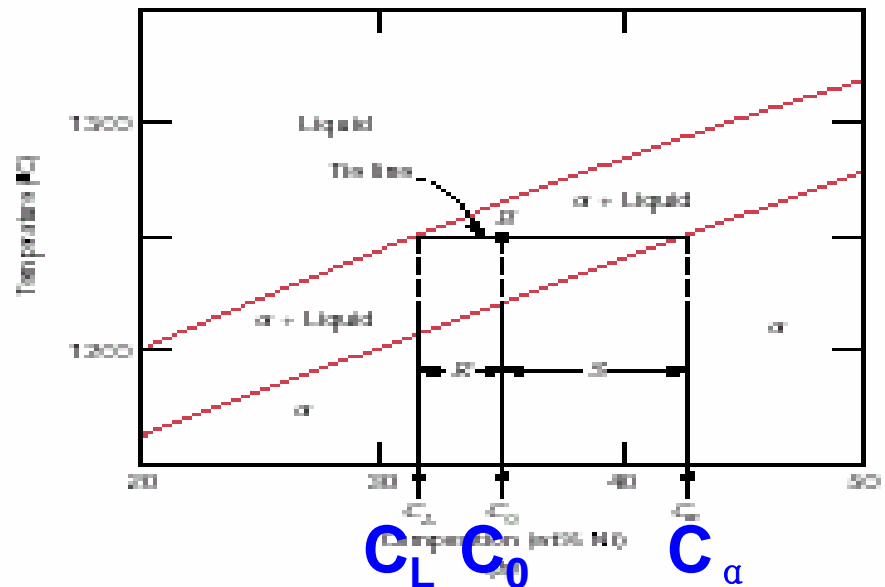
Reprinted by permission of ASM International, Materials Park, OH.) (b) A portion of the copper-nickel phase diagram for which compositions and phase amounts are determined at point B.



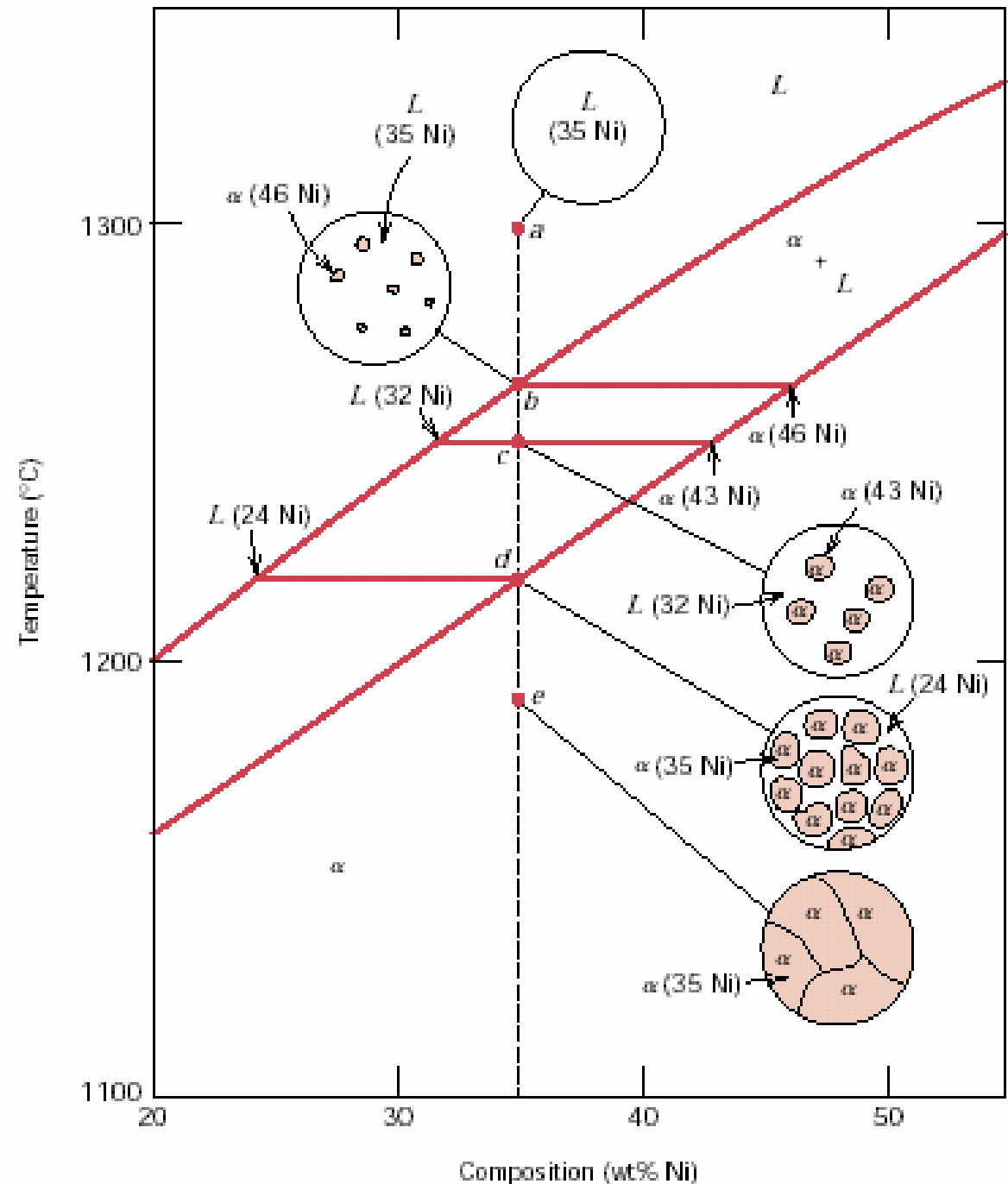
$$W_{\alpha} = \frac{R}{R+S} = \frac{C_0 - C_L}{C_{\alpha} - C_L}$$

$$W_L = \frac{S}{R+S} = \frac{C_{\alpha} - C_0}{C_{\alpha} - C_L}$$

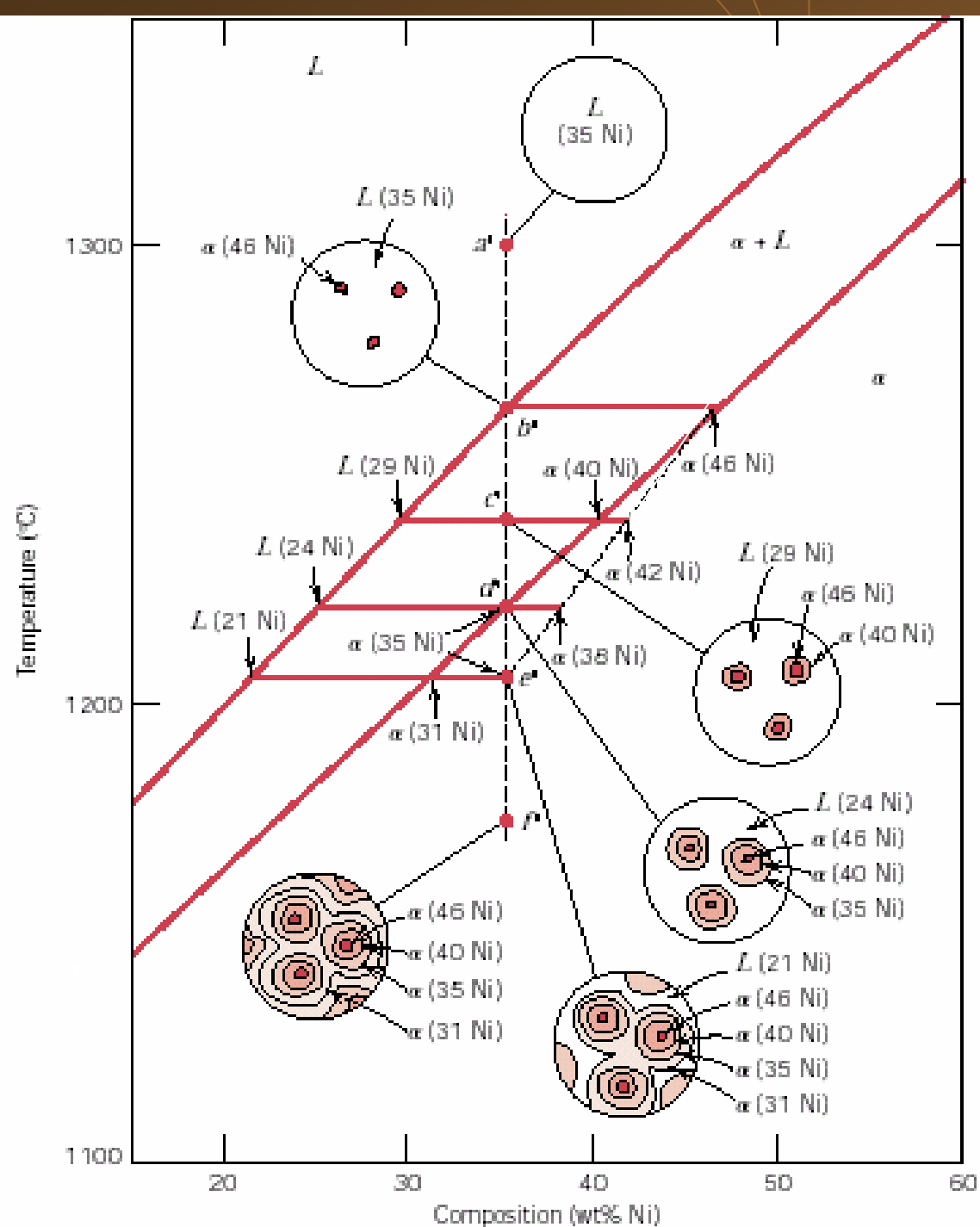
$$W_{\alpha} = \frac{R}{R+S} = \frac{C_0 - C_L}{C_{\alpha} - C_L}$$



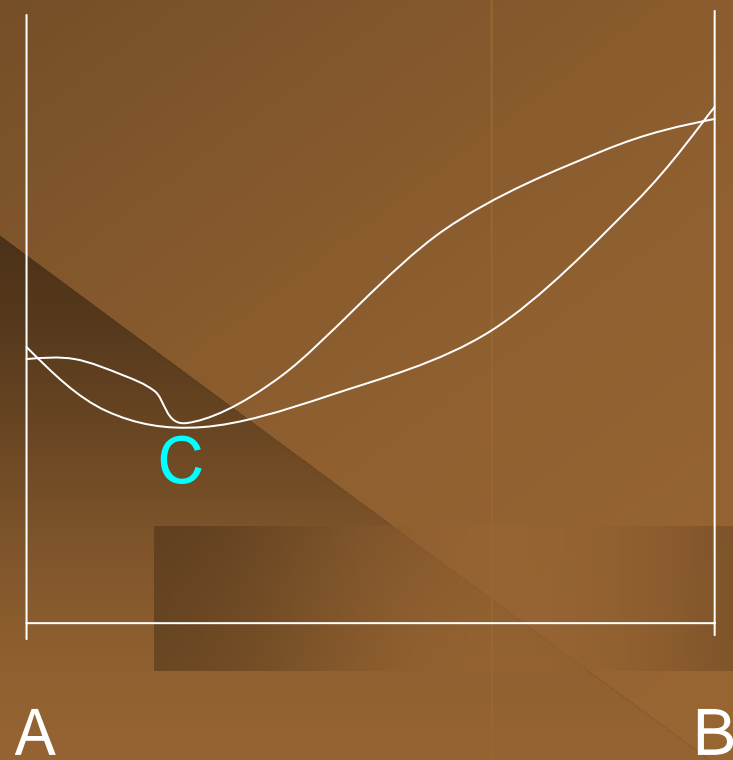
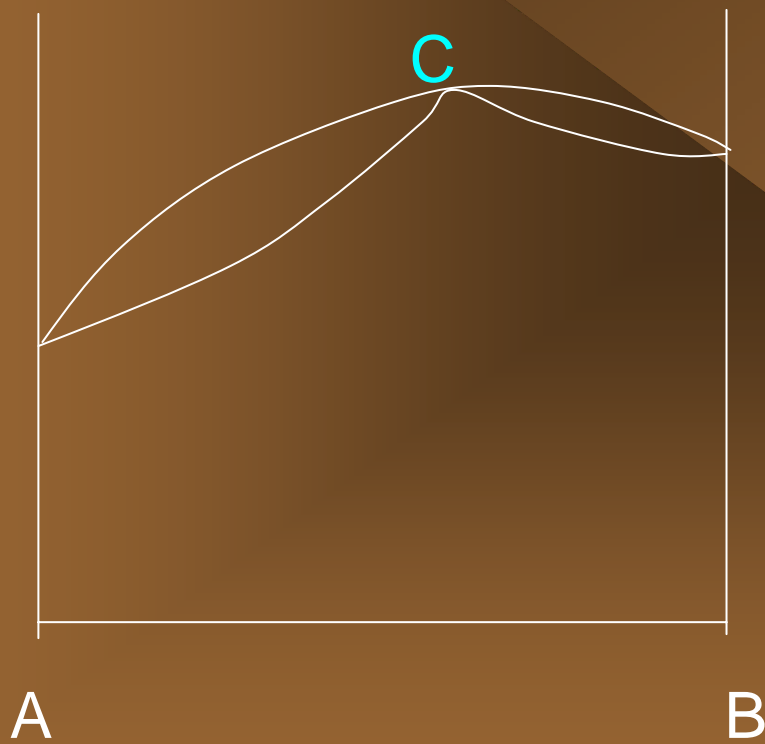
**FIGURE 10.3** Schematic representation of the development of microstructure during the equilibrium solidification of a 35 wt% Ni–65 wt% Cu alloy.



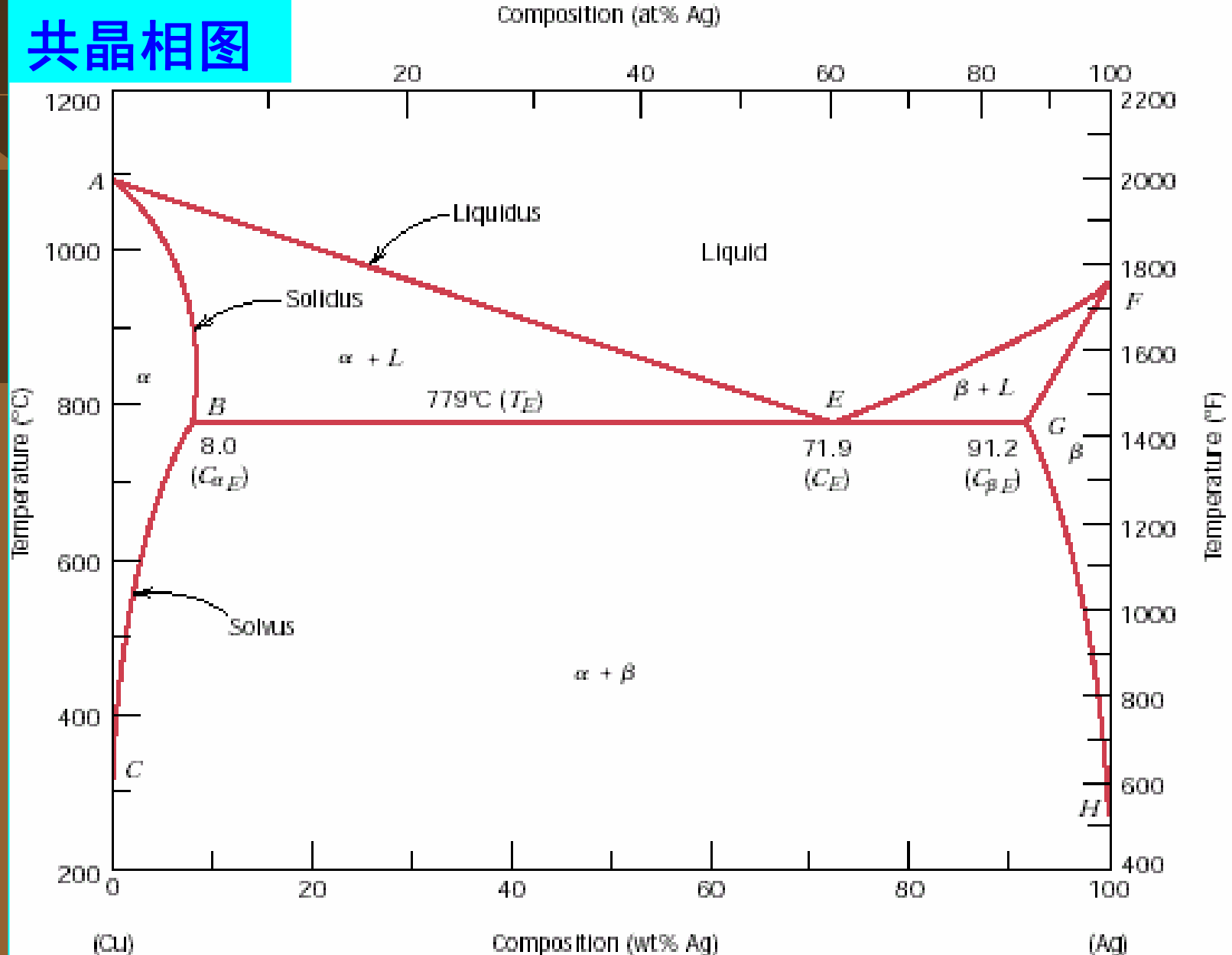
**FIGURE 10.4** Schematic representation of the development of microstructure during the nonequilibrium solidification of a 35 wt% Ni–65 wt% Cu alloy.



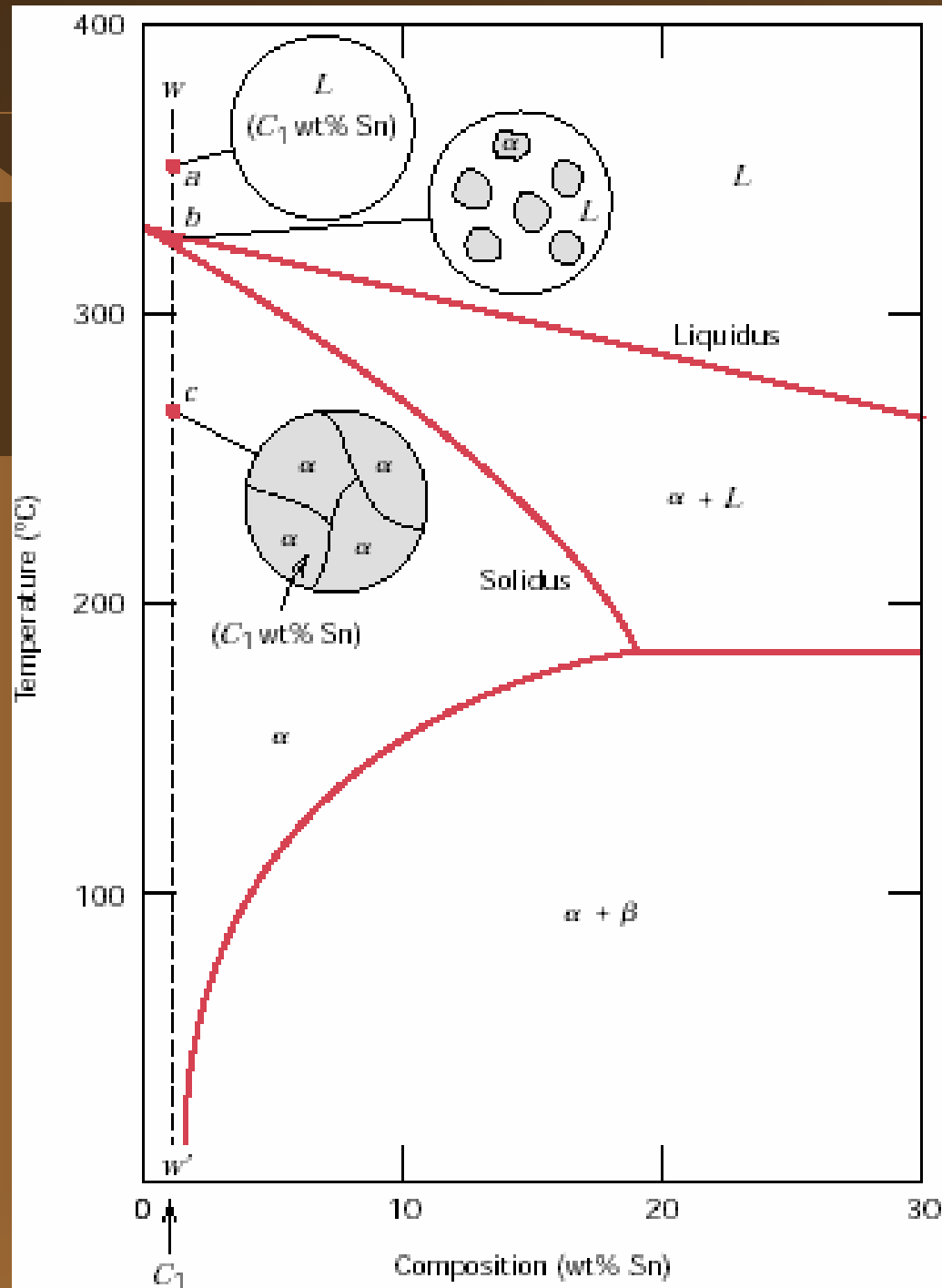
# 有极值的匀晶相图



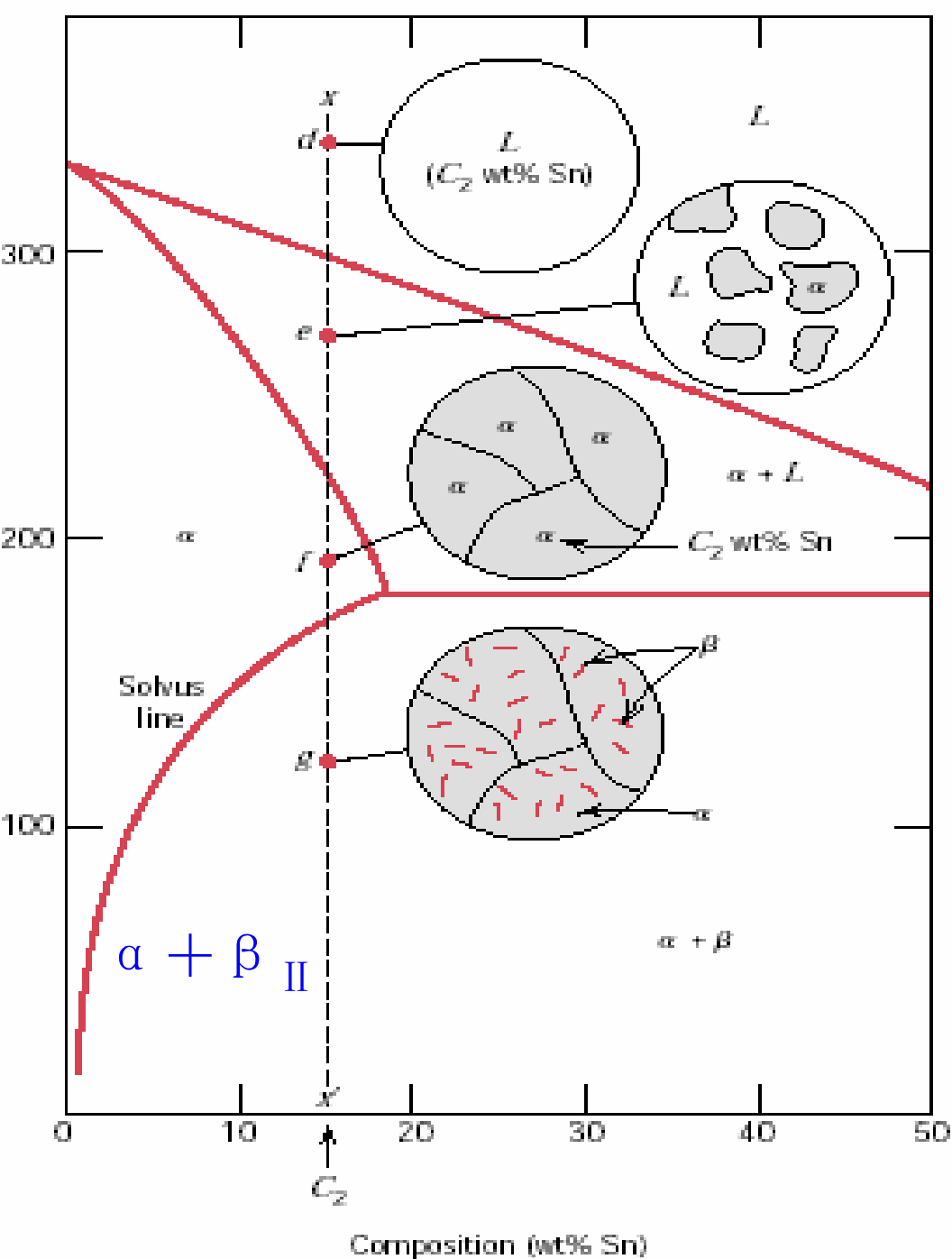
# 共晶相图



**FIGURE 10.6** The copper-silver phase diagram. (Adapted from *Binary Alloy Phase Diagrams*, 2nd edition, Vol. 1, T. B. Massalski, Editor-in-Chief, 1990. Reprinted by permission of ASM International, Materials Park, OH.)



**FIGURE 10.9** Schematic representations of the equilibrium microstructures for a lead-tin alloy of composition  $C_1$  as it is cooled from the liquid-phase region.

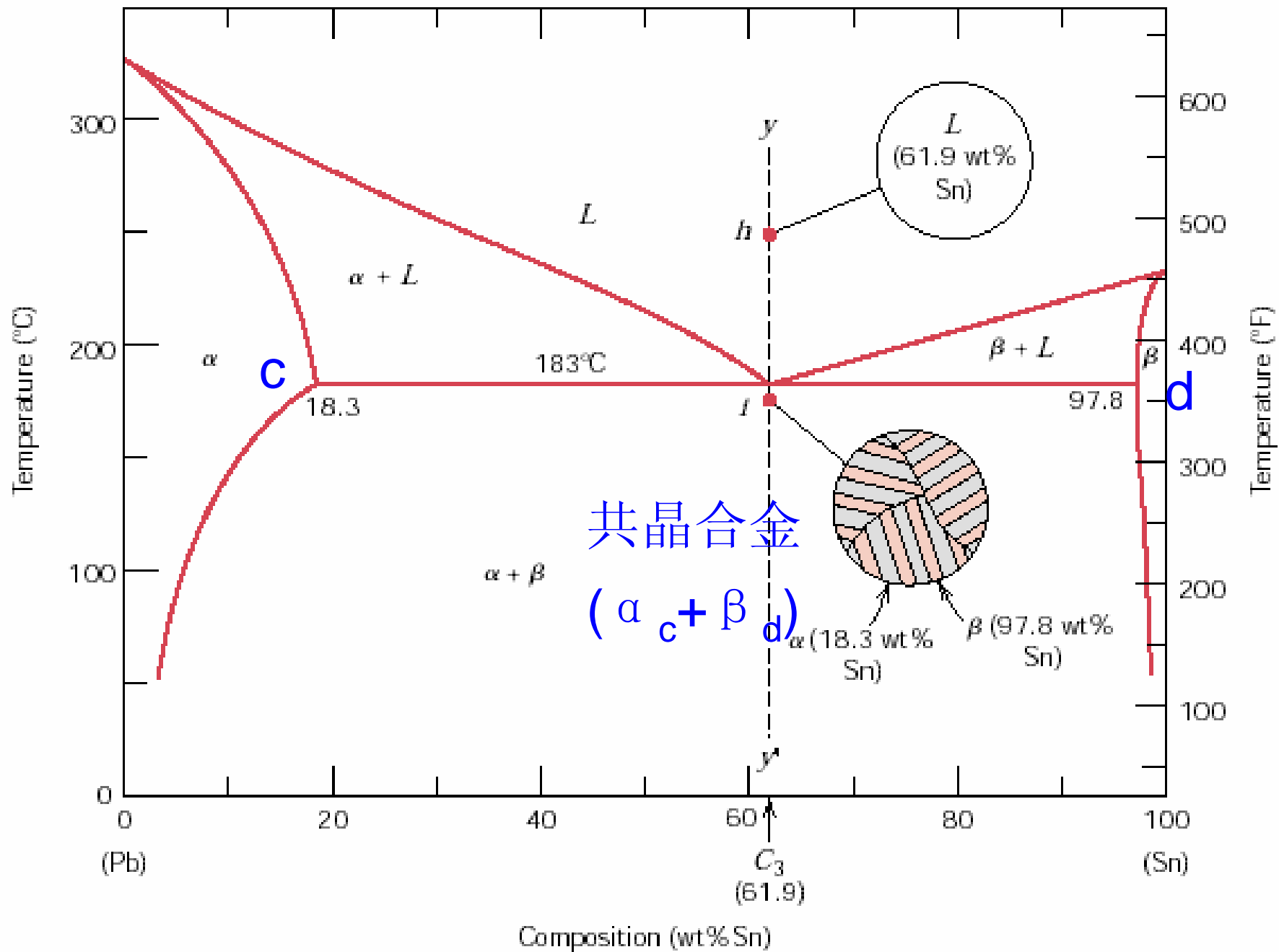


**FIGURE 10.10** Schematic representations of the equilibrium microstructures for a lead-tin alloy of composition  $C_2$  as it is cooled from the liquid-phase region.

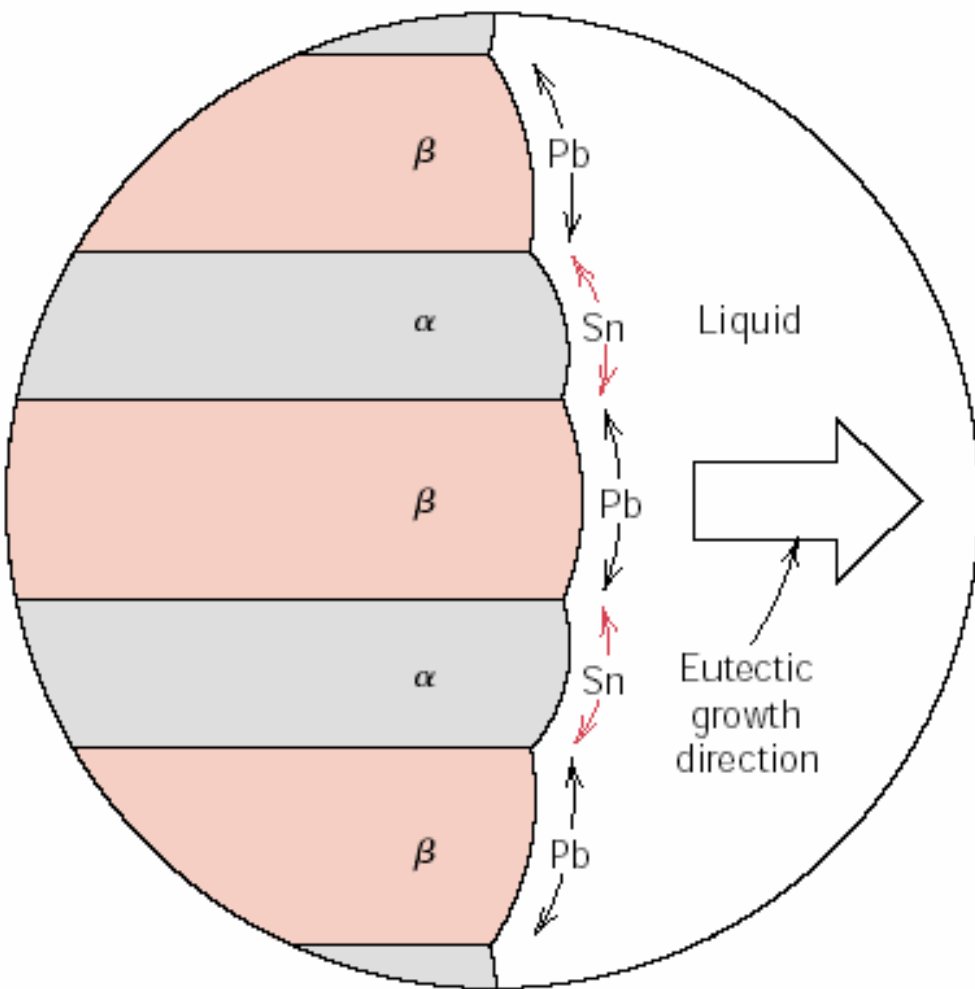
脱溶：从一个固相中析出另一个固相

过饱和固溶体的分解，称二次结晶，次生相  $\beta_{II}$

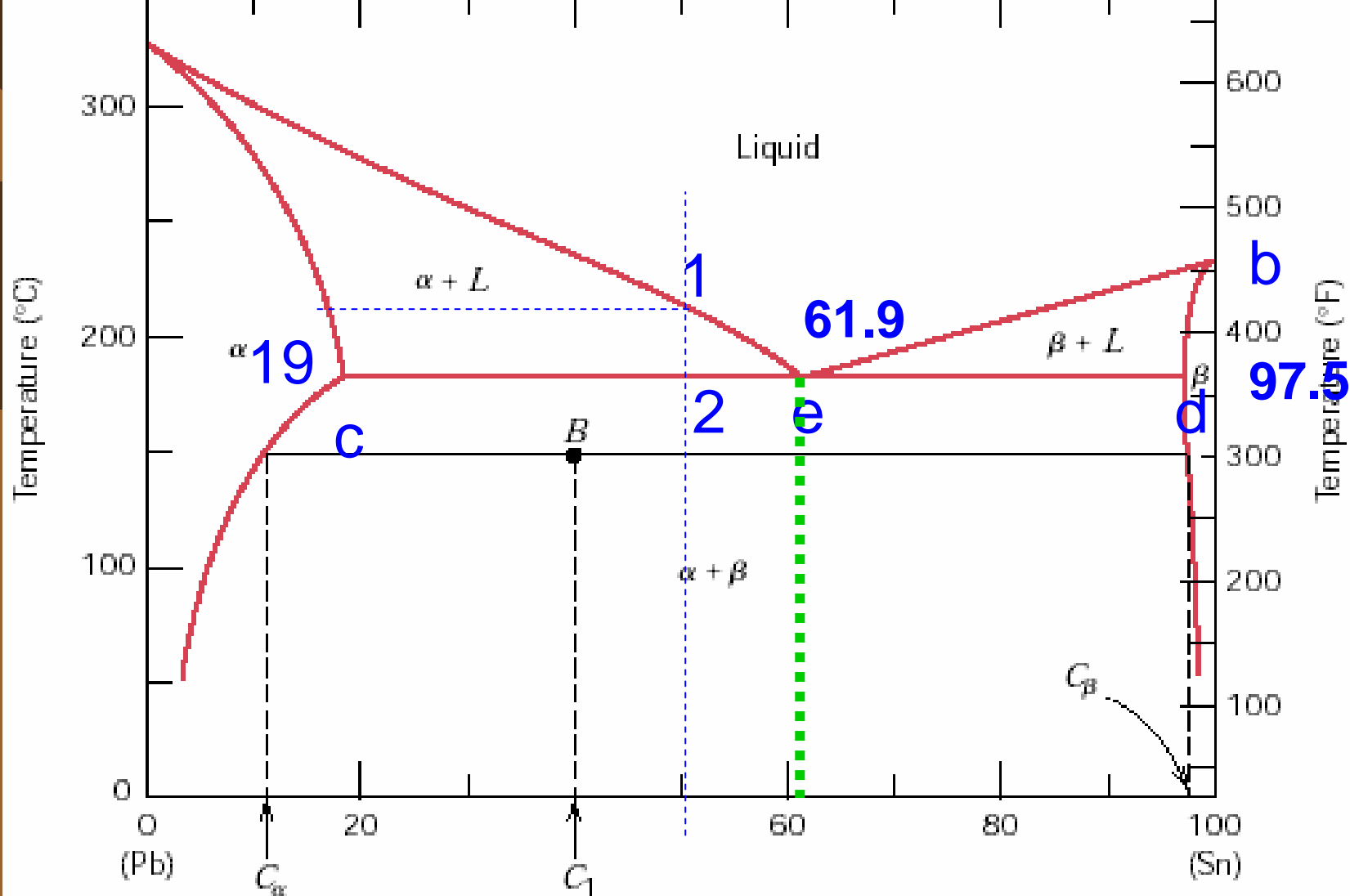




共晶组织( $\alpha_c + \beta_d$ )就是共晶转变前剩余液相的含量



**FIGURE 10.13** Schematic representation of the formation of the eutectic structure for the lead–tin system. Directions of diffusion of tin and lead atoms are indicated by colored and black arrows, respectively.



组织组成

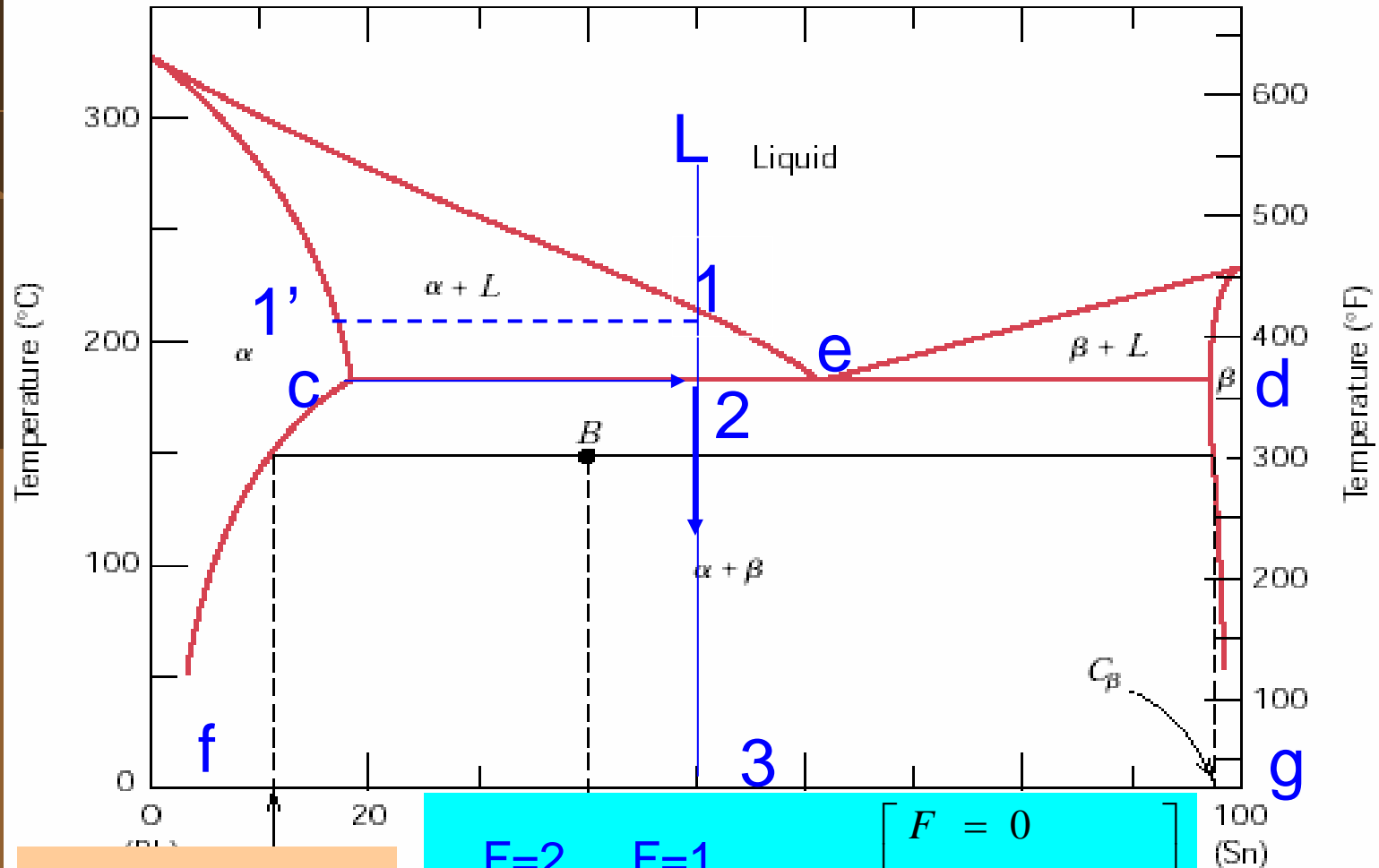
$$\omega_{\alpha} = \frac{2e}{ce} = \frac{61.9 - 50}{61.9 - 19} = 27.8\%$$

$\omega(\alpha + \beta)$  共晶组织

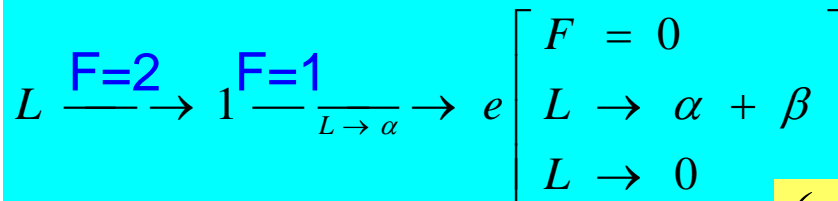
相组成

$$\omega_{\alpha} = \frac{2d}{cd} = \frac{97.5 - 50}{97.5 - 19}$$

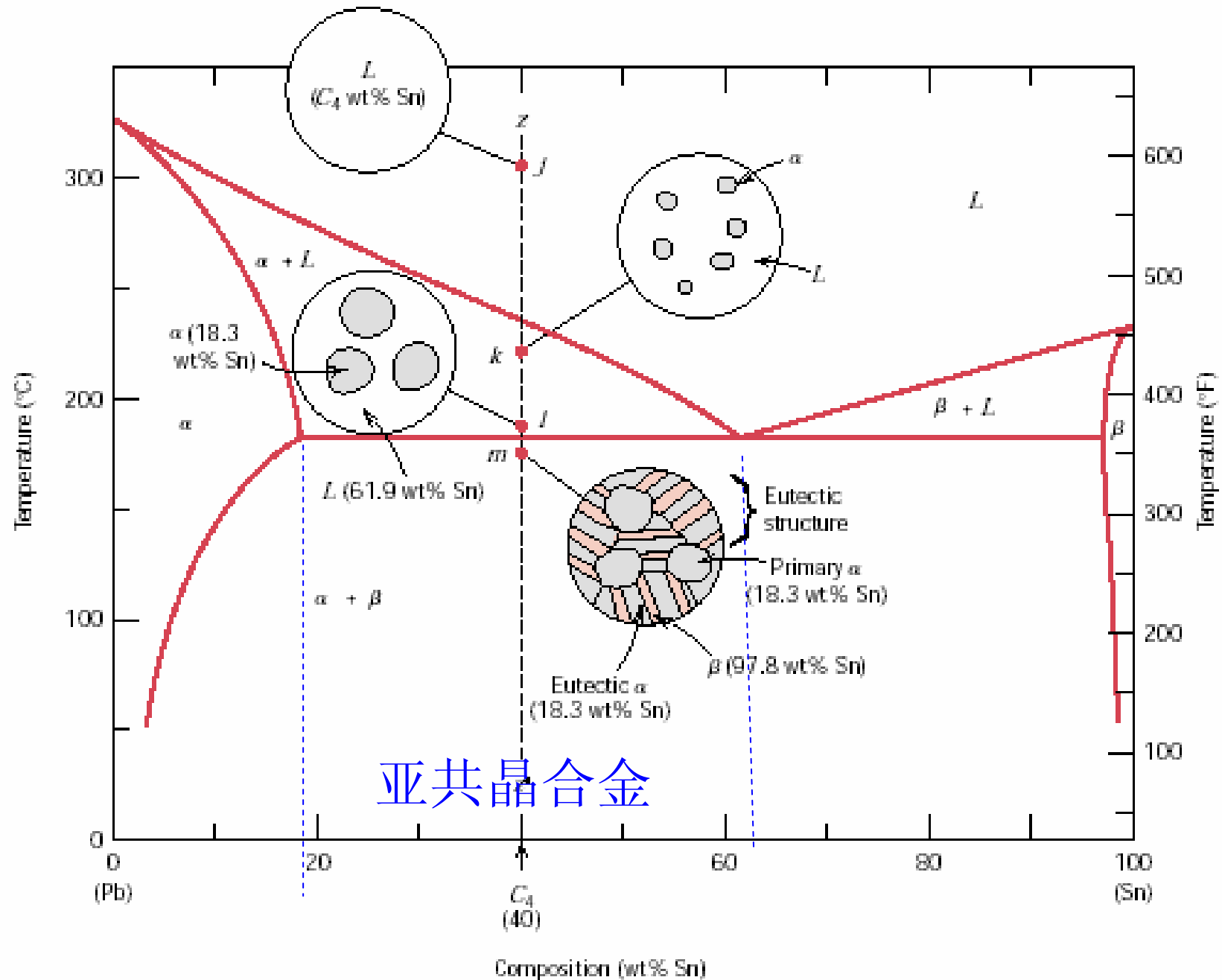
$\omega_{\beta}$  另一相



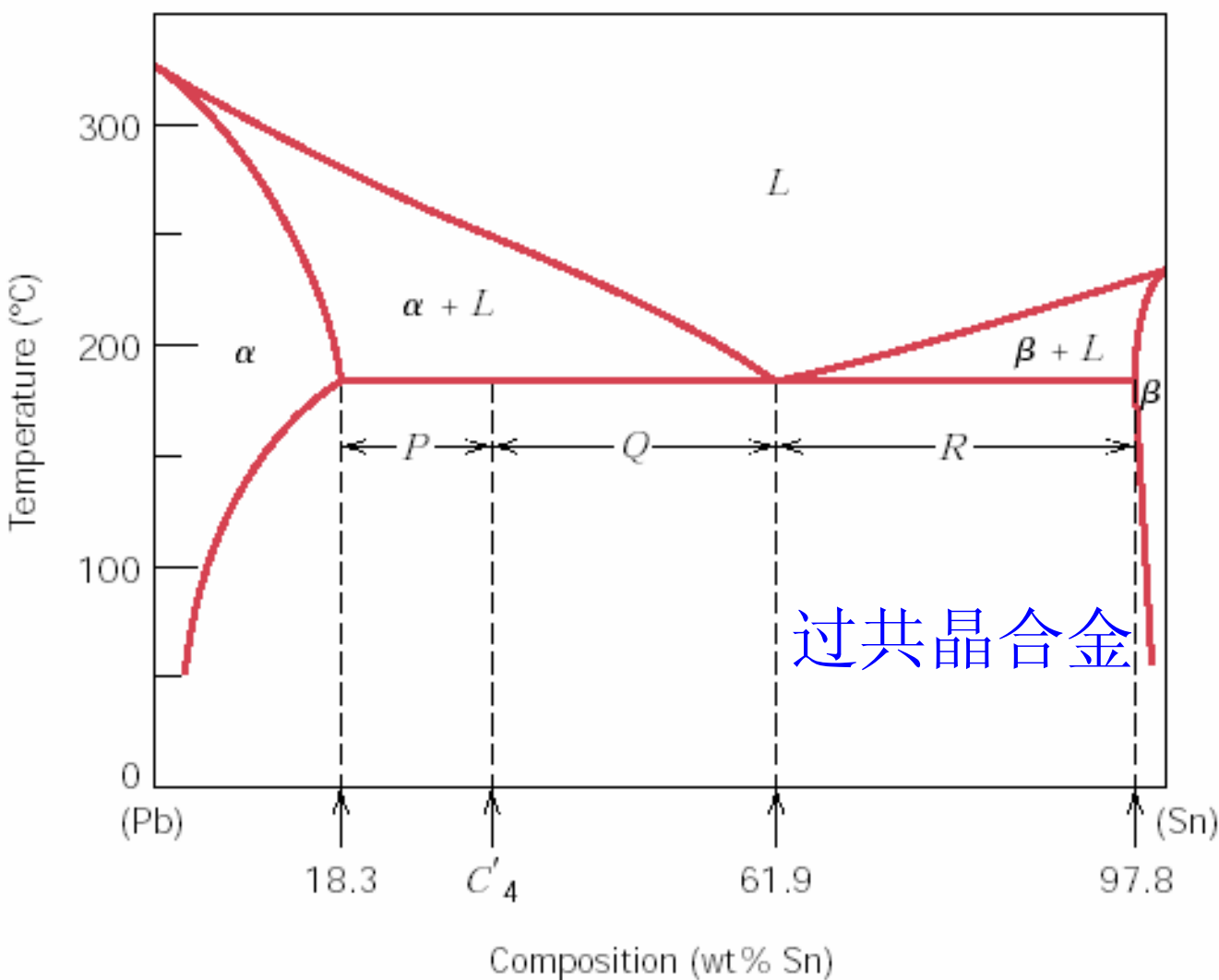
析晶路线:



**FIGURE 10.8** The lead-tin phase diagram. For a 40 wt% Sn alloy at 150°C (point *B*), phase transformations are: **S:**  $1' \rightarrow c \rightarrow 2 \rightarrow 3$   $\left( \begin{array}{l} c \rightarrow f \\ d \rightarrow g \end{array} \right)$  **3**

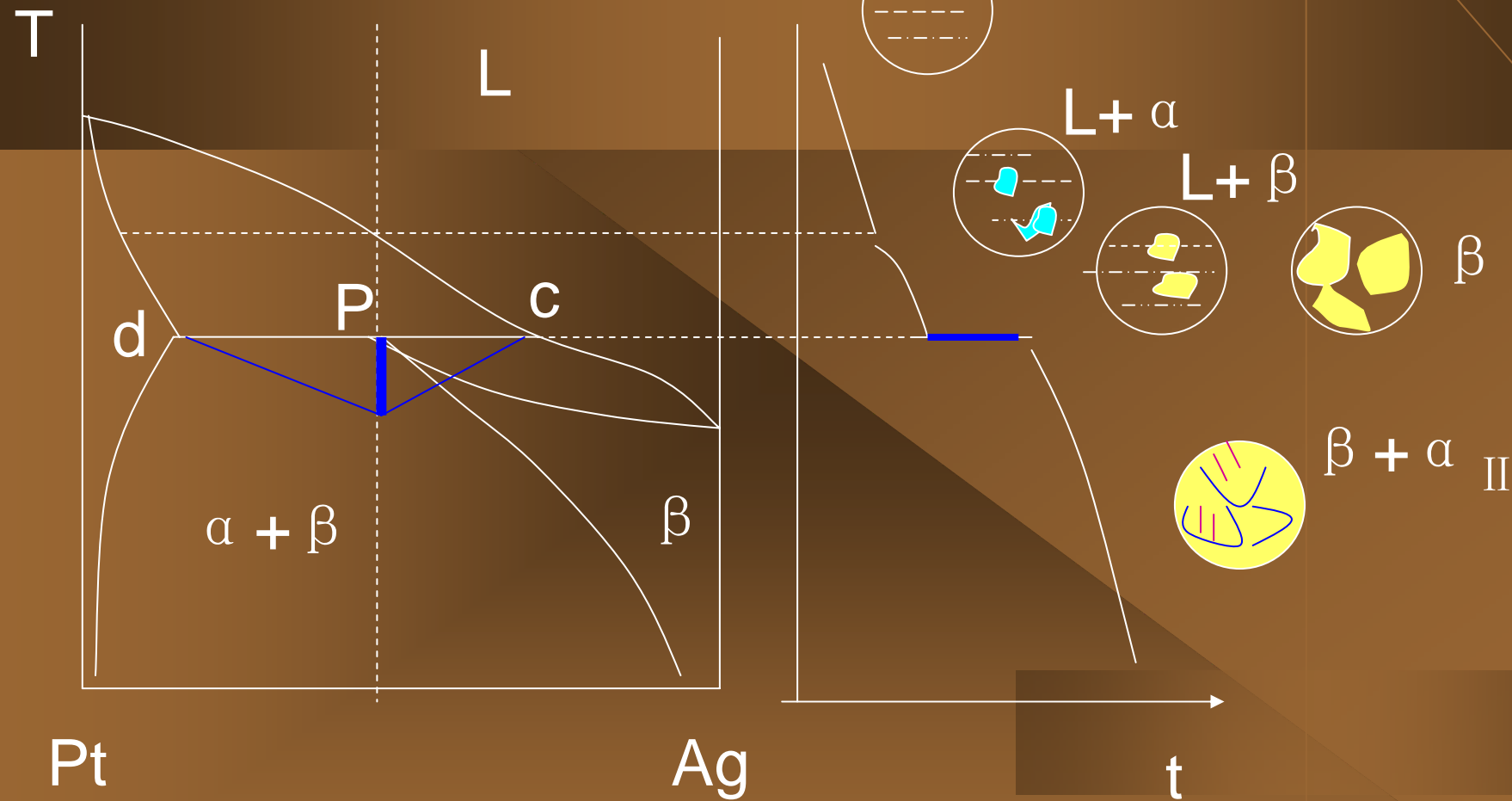
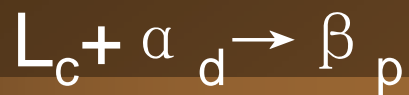


**FIGURE 10.14** Schematic representations of the equilibrium microstructures for a lead-tin alloy of composition  $C_4$  as it is cooled from the liquid-phase region.



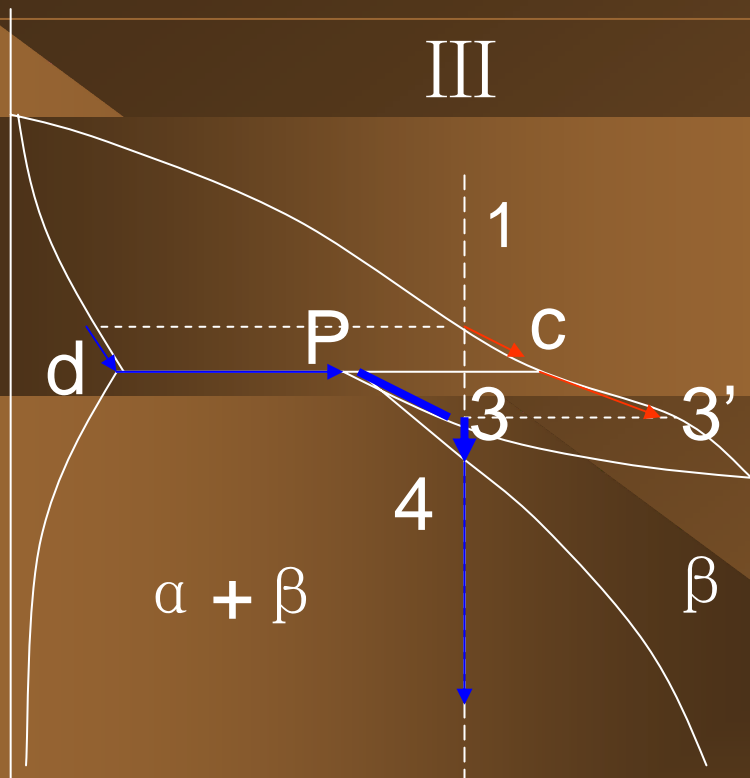
**FIGURE 10.16** The lead-tin phase diagram used in computations for relative amounts of primary  $\alpha$  and eutectic microconstituents for an alloy of composition  $C'_4$ .

# 包晶相图

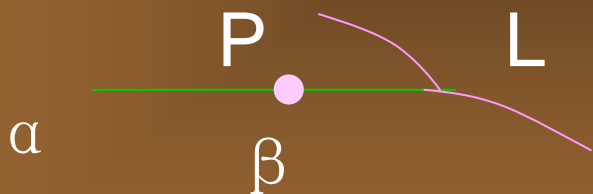








合金:  $\beta + \alpha_{II}$



转熔 (包晶)

$L +$

$\alpha \rightarrow \beta$

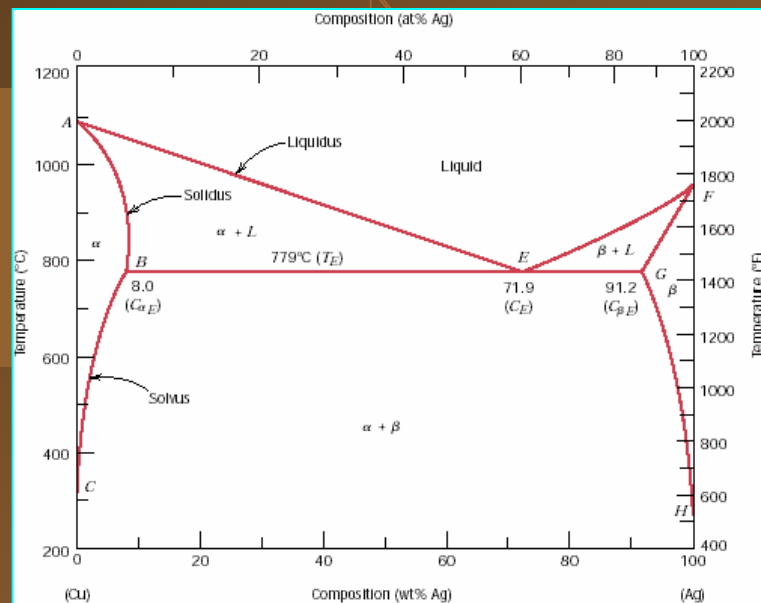
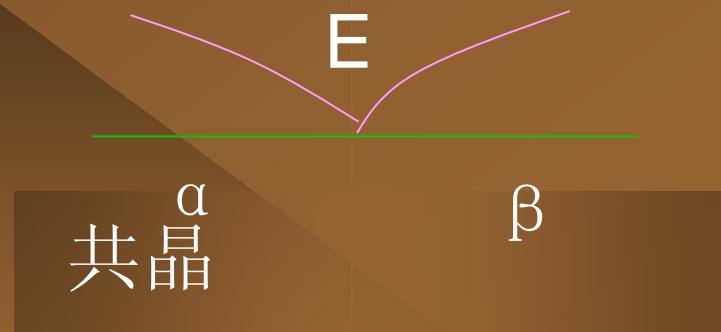


FIGURE 10.6 The copper-silver phase diagram. (Adapted from *Binary Alloy Phase Diagrams*, 2nd edition, Vol. 1, T. B. Massalski, Editor-in-Chief, 1990. Reprinted by permission of ASM International, Materials Park, OH.)



$L \rightarrow \alpha + \beta$

## 4.形成化合物的相图

(1)稳定化合物

(2)不稳定化合物

## 5.液相分层相图

(1)具有偏晶转变的相图

$$L_d = L_c + \alpha$$

(2)具有合晶转变的相图

$$L_d + L_c = \gamma$$

6.熔晶相图:一个已经结晶的固相转变为一个液相和另一个固相

## 四.二元相图的几何规律

由热力学基本原理，二元系相图在相律约束下，  
有以下几何规律：

- 1.两单相区只能交于一点，而不能交成直线；
- 2.两单相区之间，必是一由此两单相构成的两相区；
- 3.三相共存区，必是一与由此三相组和而成的3个两相区相邻的水平线；
- 4.如两恒温转变中有两个是相同的相，则这两条水平线之间必是由此两相组成的两相区；
5. 两相区与单相区分界线与三相等温水平线相交，则分界线的延长线应进入另一两相区，不进入单相区。

# 二元相图各类恒温转变类型、反应式和相图特征

恒温转变类型		反应式	相图特征
分解型	共晶转变	$L \rightleftharpoons \alpha + \beta$	
	共析转变	$\gamma \rightleftharpoons \alpha + \beta$	
	偏晶转变	$L_1 \rightleftharpoons L_2 + \alpha$	
	熔晶转变	$\delta \rightleftharpoons L + \gamma$	
合成型	包晶转变	$L + \beta \rightleftharpoons \alpha$	
	包析转变	$\gamma + \beta \rightleftharpoons \alpha$	
	合晶转变	$L_1 + L_2 \rightleftharpoons \alpha$	