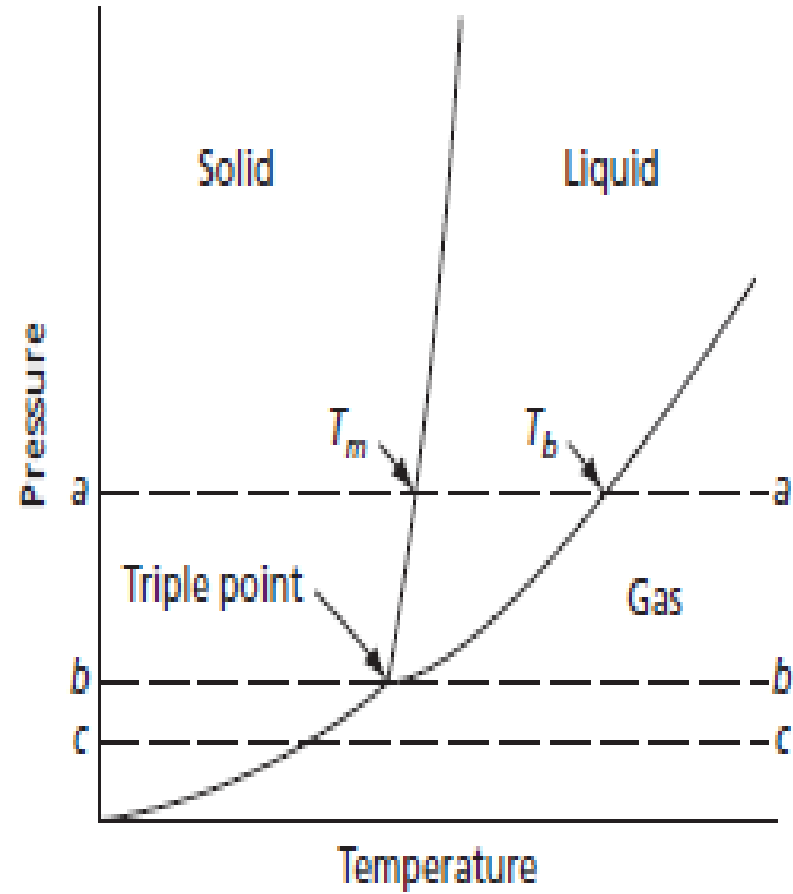


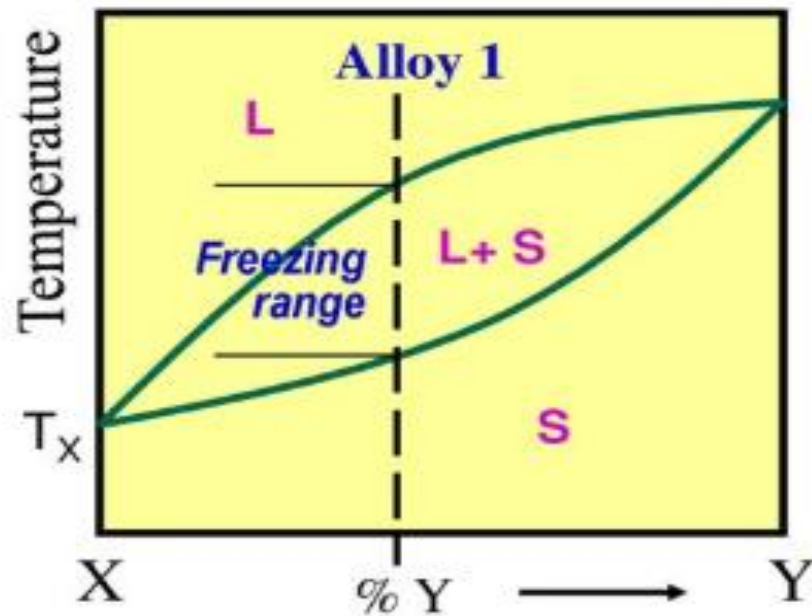
# دیاگرام های فازی



**FIG. 14.2** Same as Fig. 14.1, but showing the isobars considered in Fig. 14.3

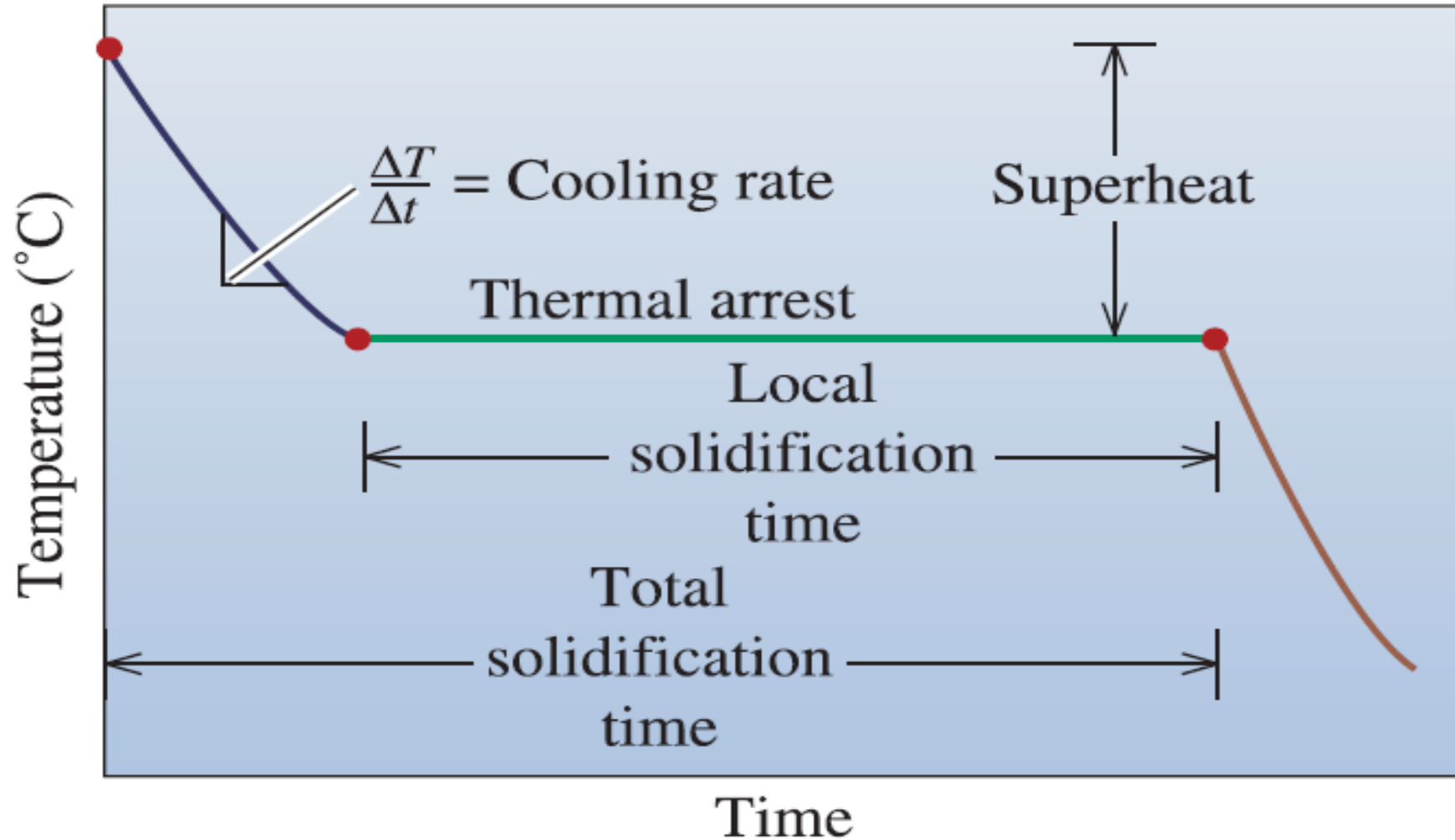
## The Cooling Curve

- ❑ Cooling curve indicates the gradual change in temperature with time during cooling of alloy



# سرعت سرد شدن- زمان انجماد

3



# انجماد فلز خالص مس

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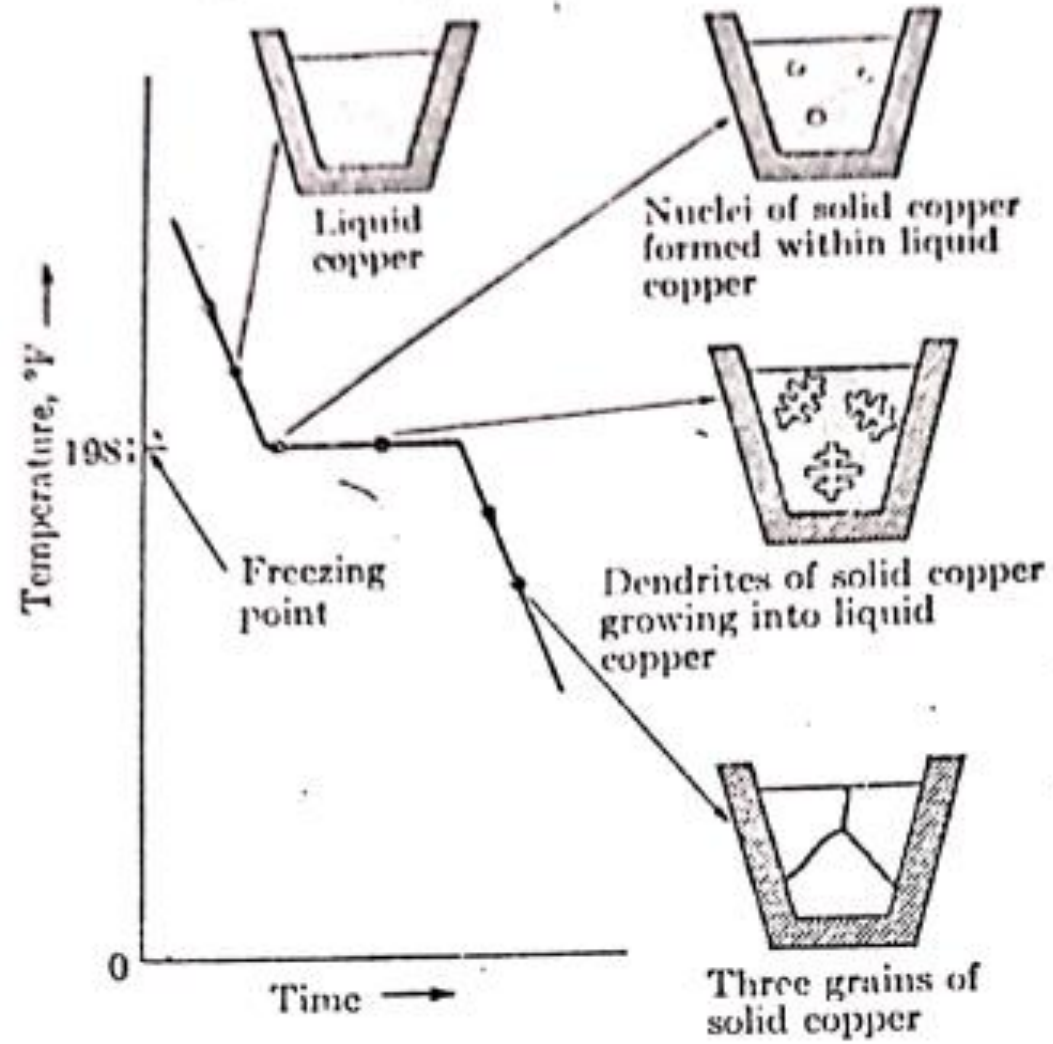


FIG. 6-2. Time-temperature curve for the solidification of a small crucible of liquid copper.

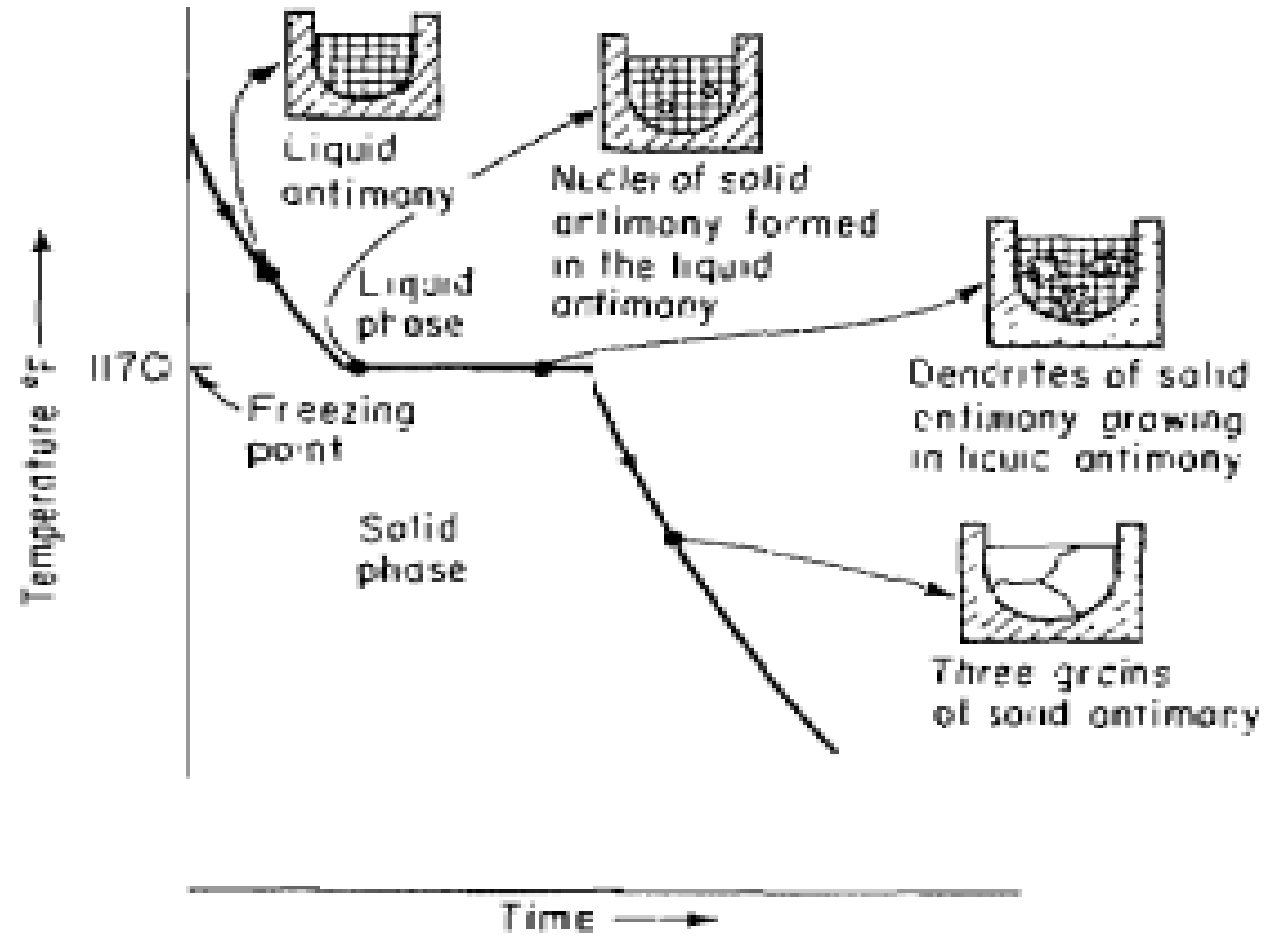


Fig. 5-1 Time-temperature cooling curve for the solidification of a small crucible of liquid antimony.

## Cooling Curves

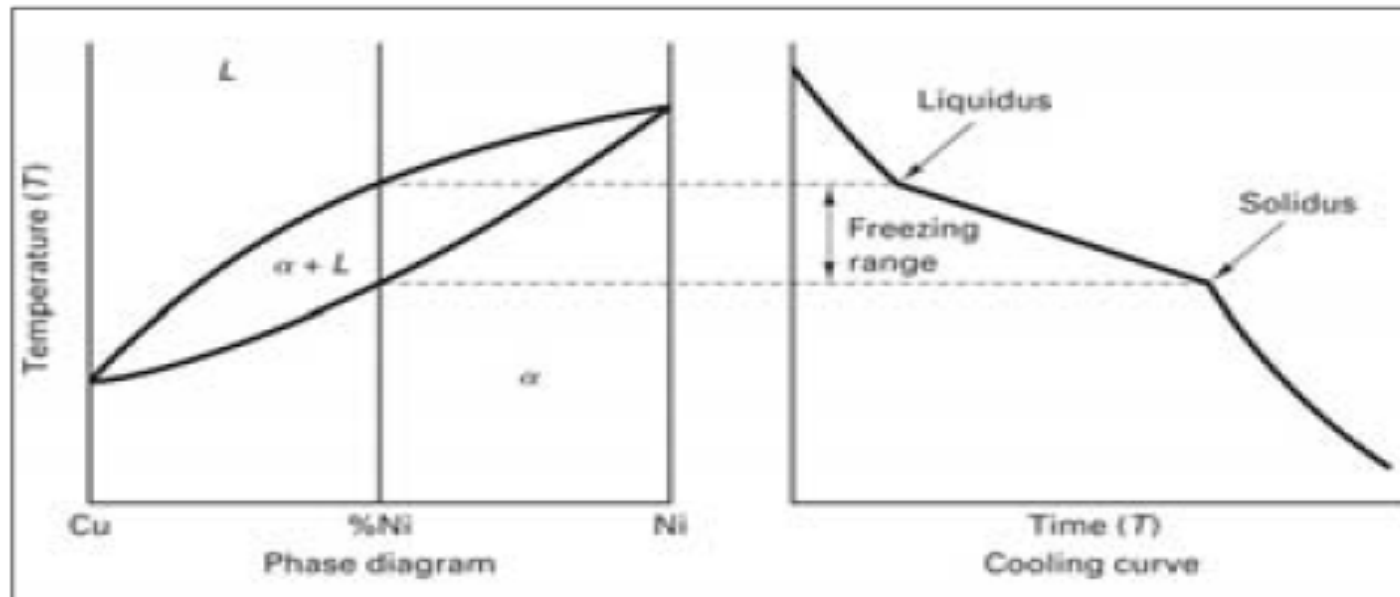


Figure 11-4 Phase diagram and companion cooling curve for an alloy with a freezing range. The slope changes indicate the onset and termination of solidification.



# منحنی سرد شدن الیاژ مس-نیکل

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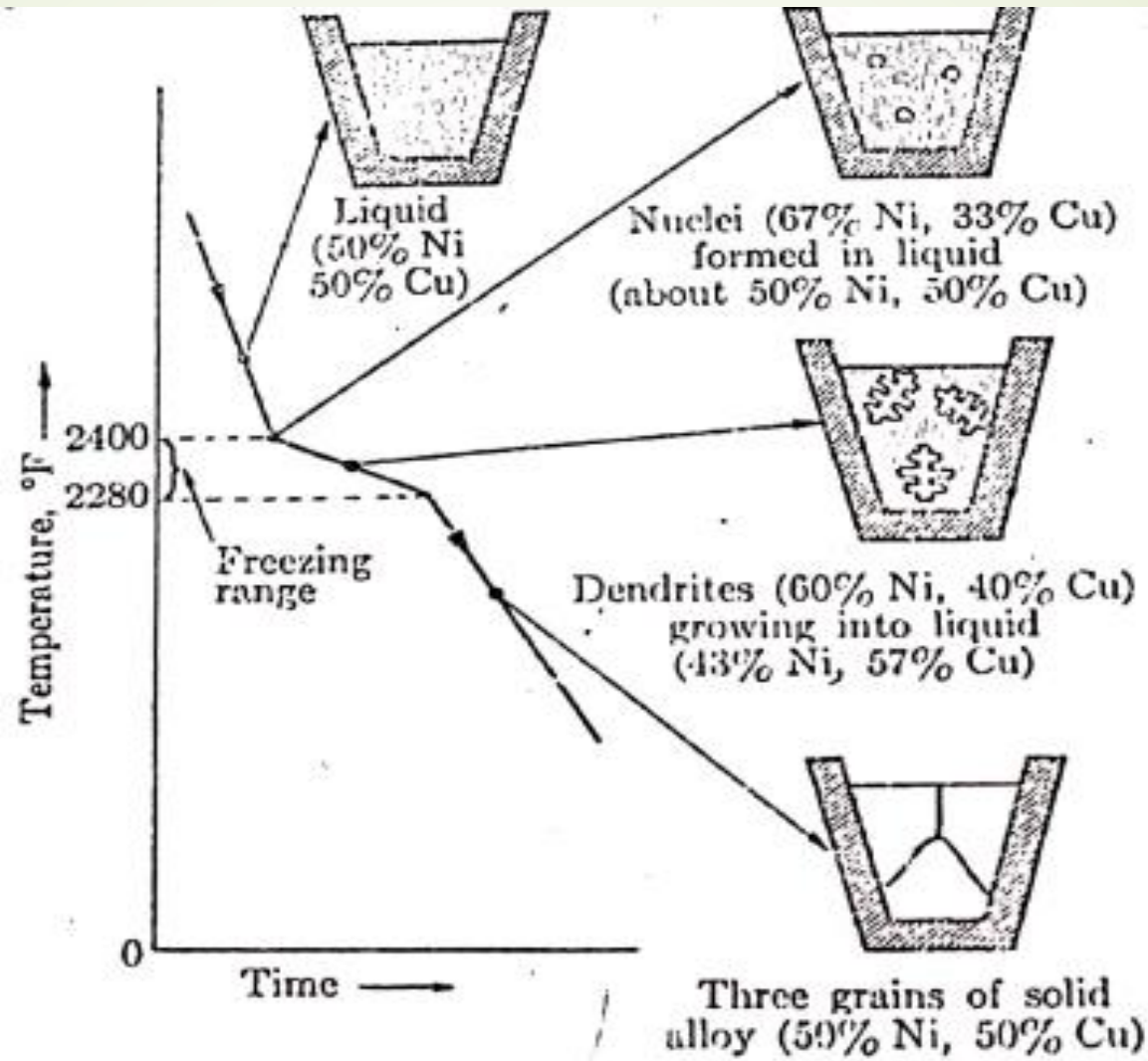
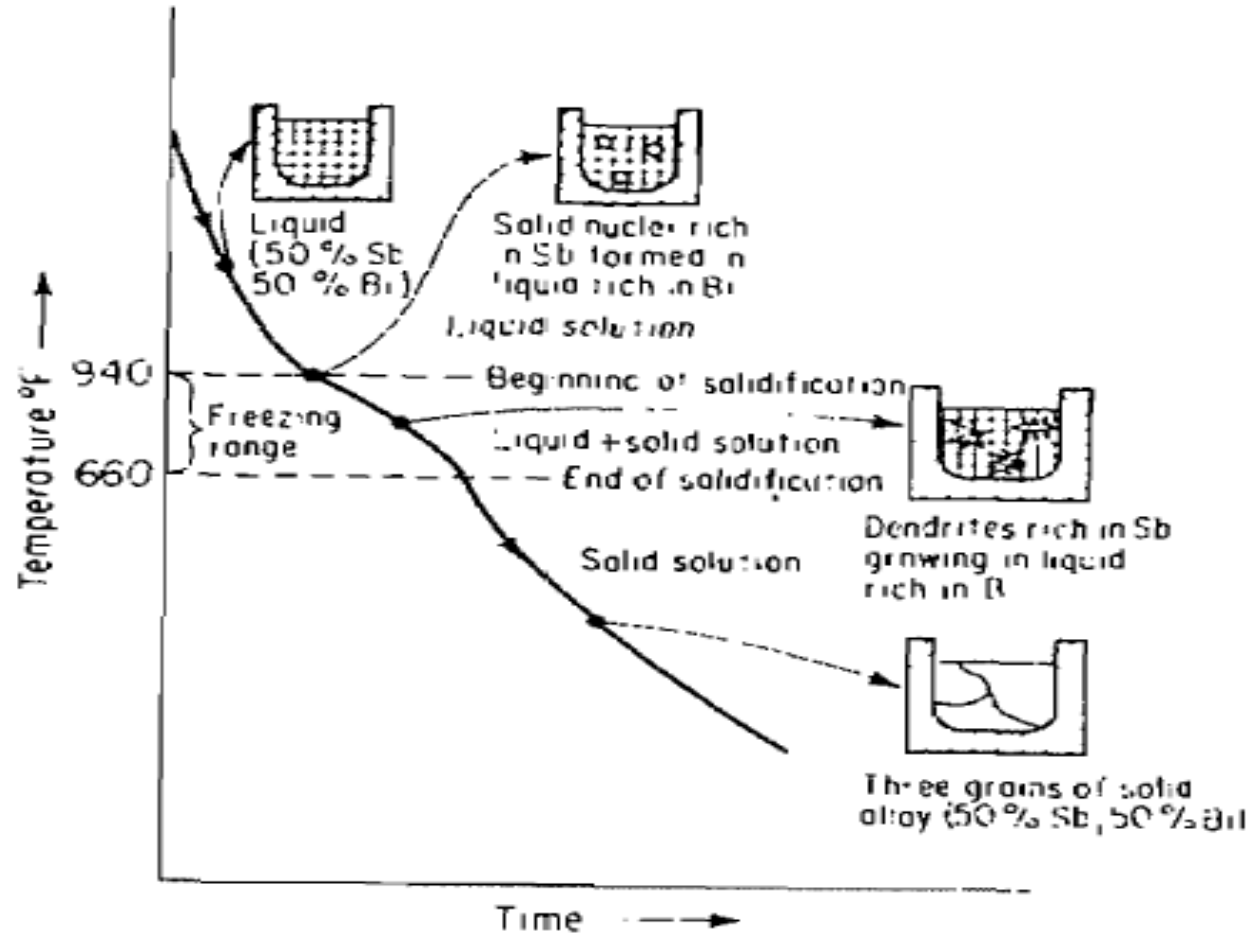
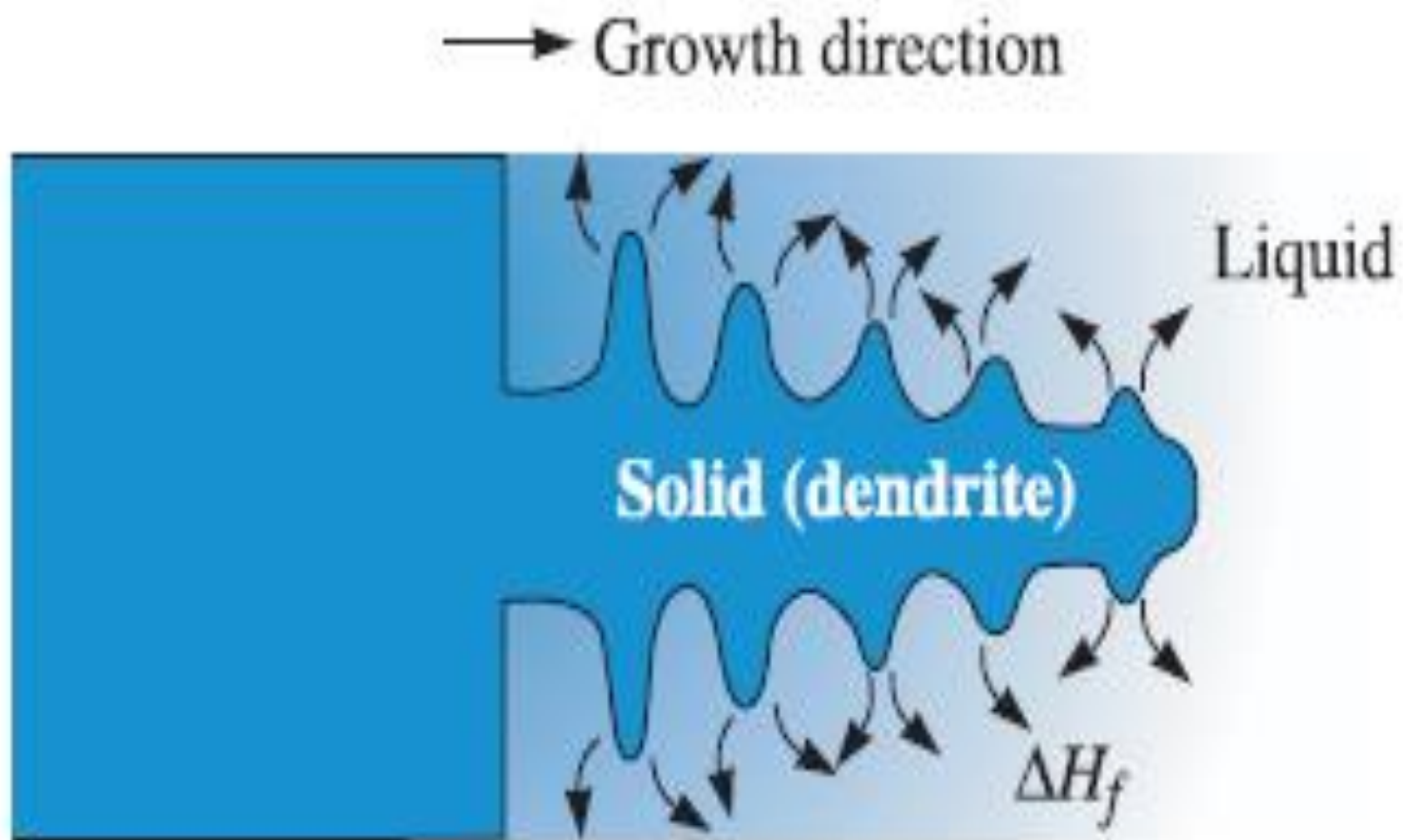


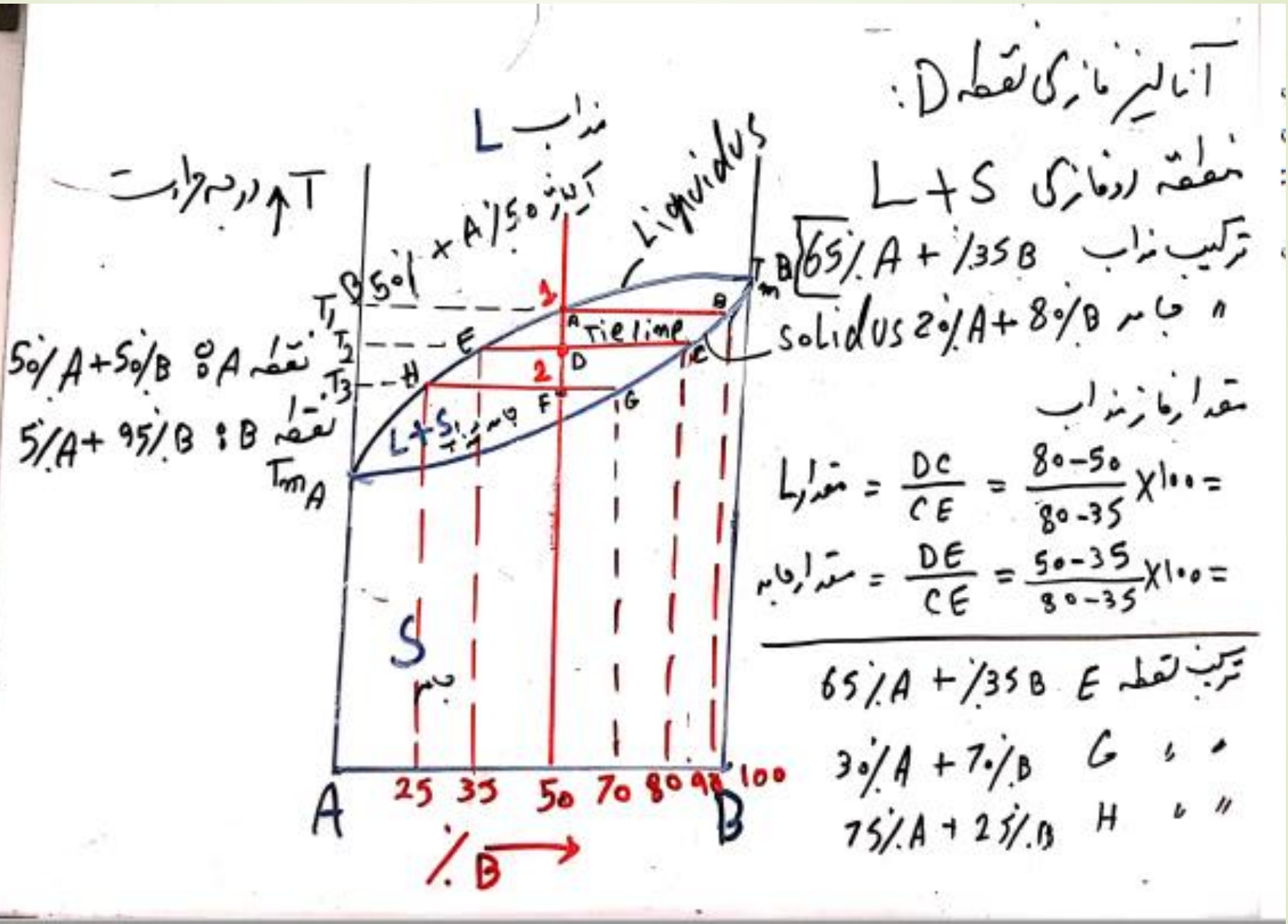
FIG. 6-3. Time-temperature curve for the solidification of a small crucible of 50% copper-50% nickel alloy.



**Fig. 5-2** Time-temperature cooling curve for the solidification of a small crucible of 50 percent antimony, 50 percent bismuth alloy.







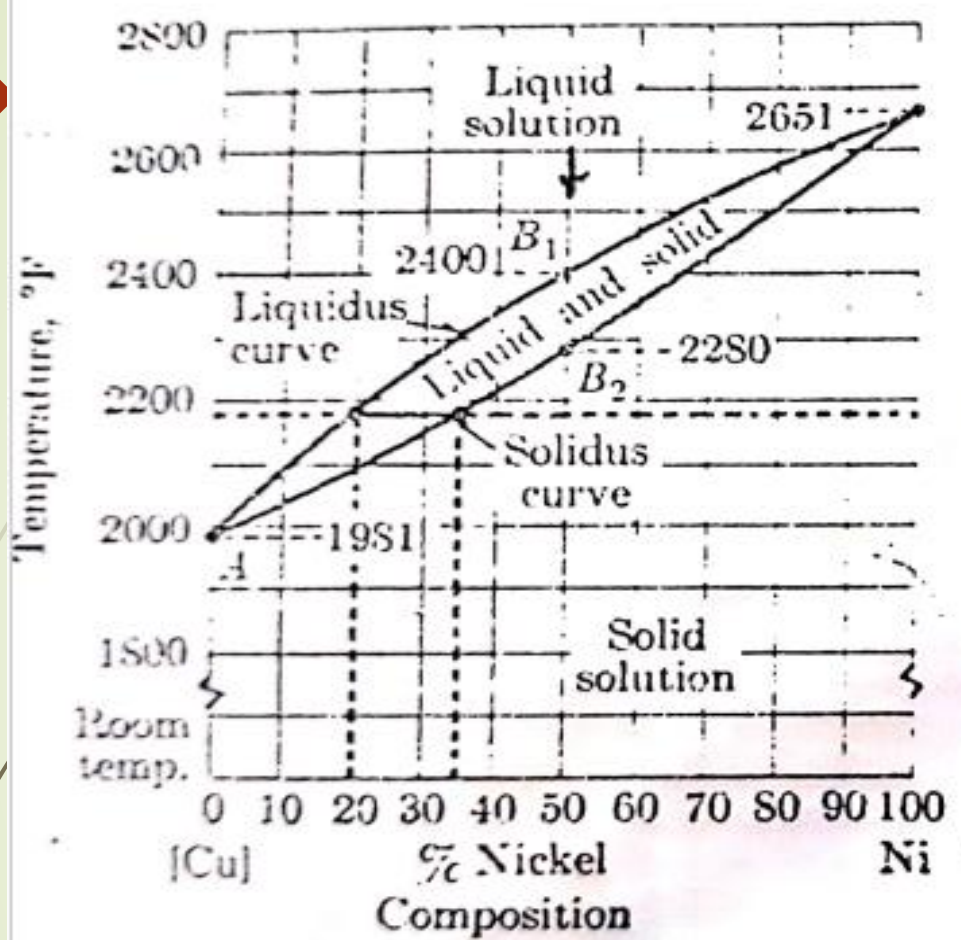


FIG. 6-4. The copper-nickel equilibrium diagram. Points A, B<sub>1</sub>, and B<sub>2</sub> show how the diagram is constructed from time-temperature curve data.

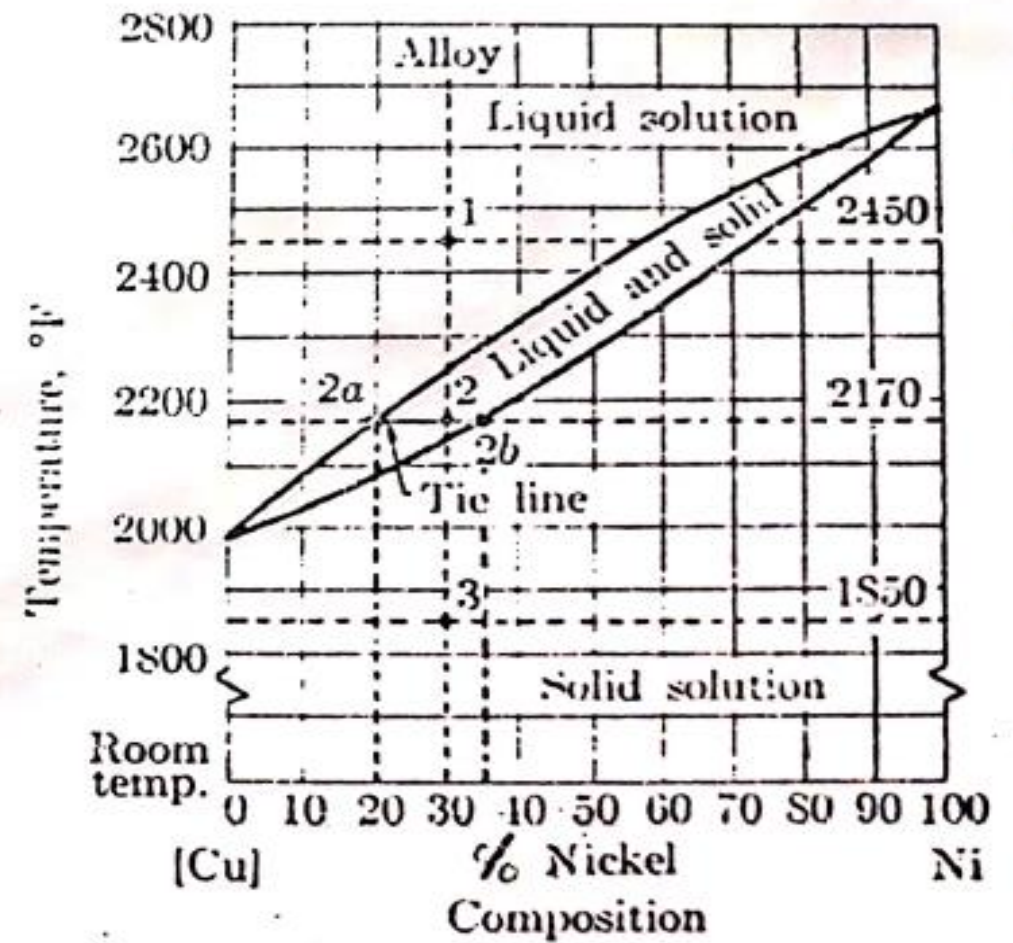
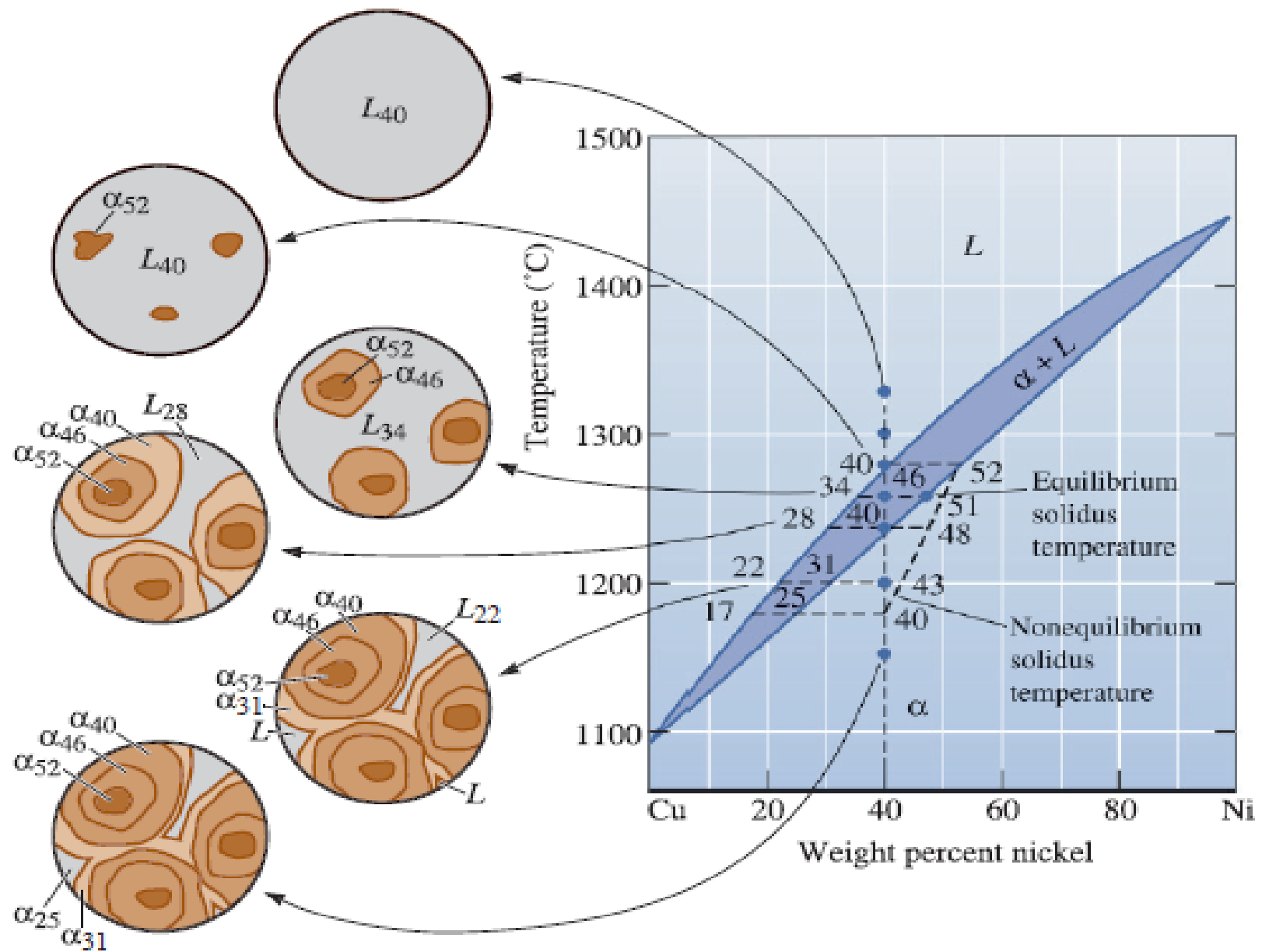


FIG. 6-5. The equilibrium conditions of a 30% nickel alloy at three different temperatures.







**Figure 10-17** The change in structure of a Cu-40% Ni alloy during nonequilibrium solidification. Insufficient time for diffusion in the solid produces a segregated structure. Notice the nonequilibrium solidus curve.

### Example 10-11 Nonequilibrium Solidification of Cu-Ni Alloys

Calculate the composition and amount of each phase in a Cu-40% Ni alloy that is present under the nonequilibrium conditions shown in Figure 10-17 at 1300°C, 1280°C, 1260°C, 1240°C, 1200°C, and 1150°C. Compare with the equilibrium compositions and amounts of each phase.

### SOLUTION

We use the tie line to the equilibrium solidus temperature to curve to calculate compositions and percentages of phases as per the lever rule. Similarly, the nonequilibrium solidus temperature curve is used to calculate percentages and concentrations of different phases formed under nonequilibrium conditions.

Temperature	Equilibrium	Nonequilibrium
1300°C	L: 40% Ni 100% L	L: 40% Ni 100% L
1280°C	L: 40% Ni 100% L	L: 40% Ni 100% L
1260°C	L: 34% Ni $\frac{46 - 40}{46 - 34} = 50\%$ L $\alpha$ : 46% Ni $\frac{40 - 34}{46 - 34} = 50\%$ $\alpha$	L: 34% Ni $\frac{51 - 40}{51 - 34} = 65\%$ L $\alpha$ : 51% Ni $\frac{40 - 34}{51 - 34} = 35\%$ $\alpha$
1240°C	L: 28% Ni ~ 0% L $\alpha$ : 40% Ni 100% $\alpha$	L: 28% Ni $\frac{48 - 40}{48 - 28} = 40\%$ L $\alpha$ : 48% Ni $\frac{40 - 28}{48 - 28} = 60\%$ $\alpha$
1200°C	$\alpha$ : 40% Ni 100% $\alpha$	L: 22% Ni $\frac{43 - 40}{43 - 22} = 14\%$ L $\alpha$ : 43% Ni $\frac{40 - 22}{43 - 22} = 86\%$ $\alpha$
1150°C	$\alpha$ : 40% Ni 100% $\alpha$	$\alpha$ : 40% Ni 100% $\alpha$

# دياگرام محلول جامد (درصد جامد و مذاب)

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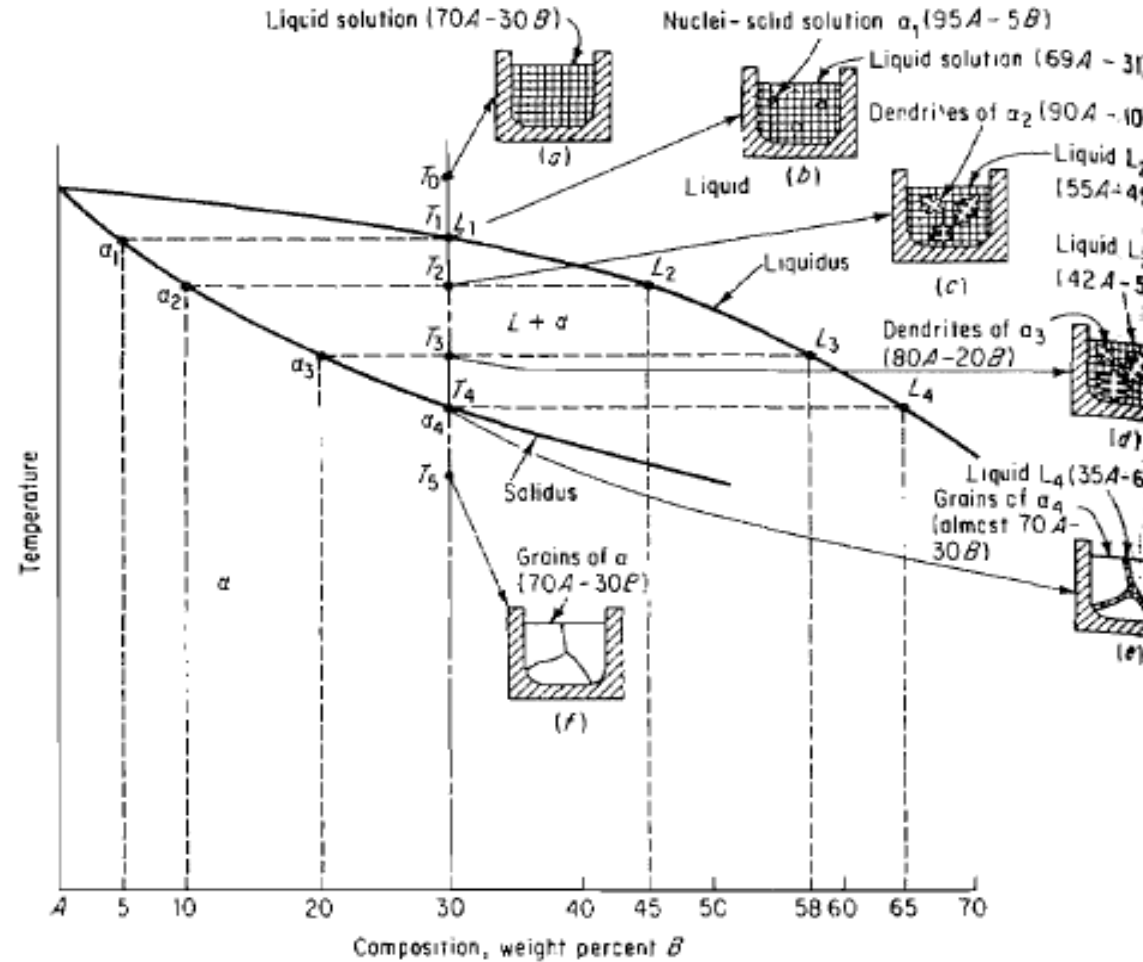
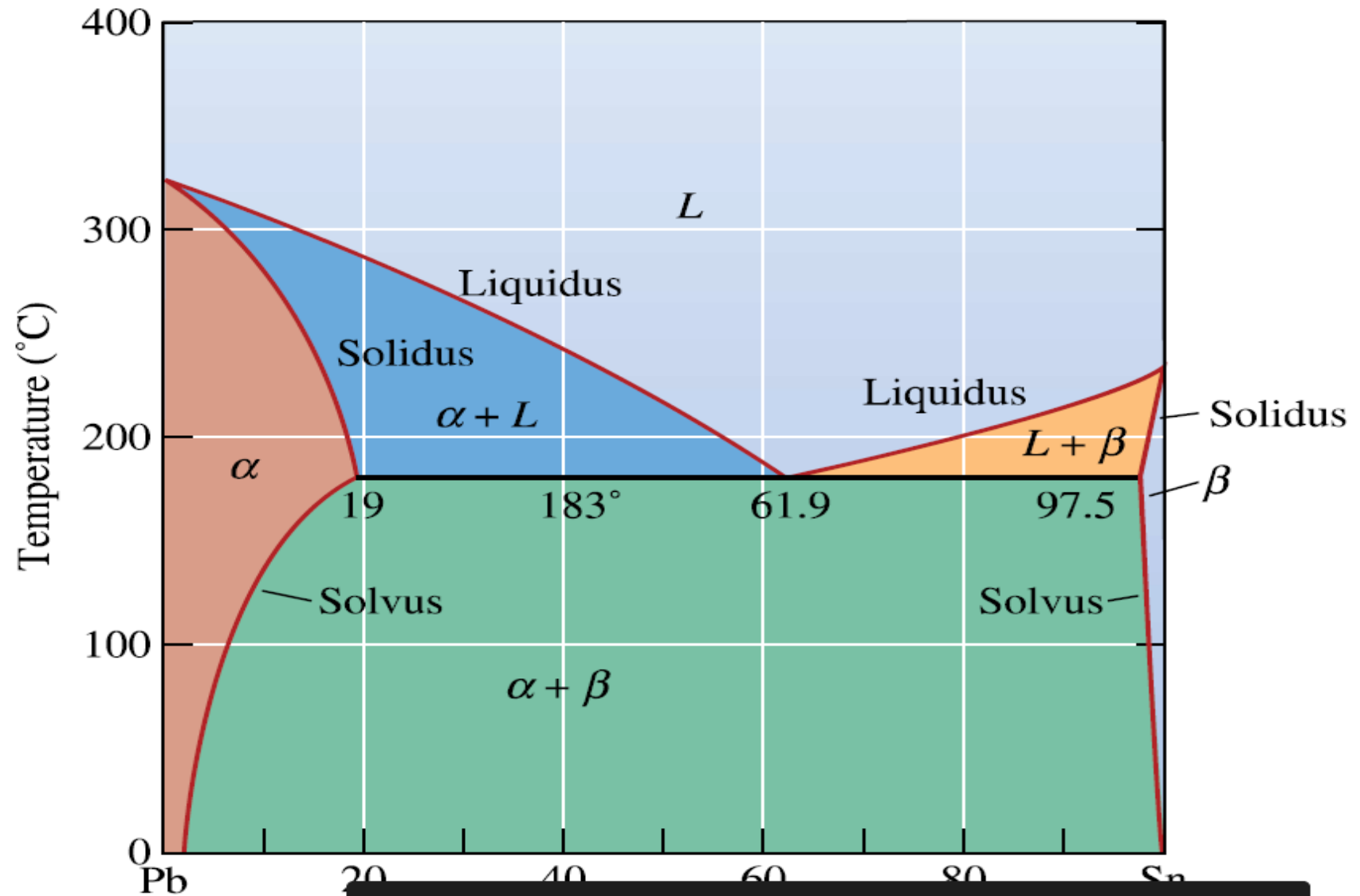


Fig. 6-5 The slow cooling of a 70A-30B alloy, showing the microstructure at various points during solidification.



# دیاگرام یوتکتیک

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# سه الياژ با تركيب متفاوت

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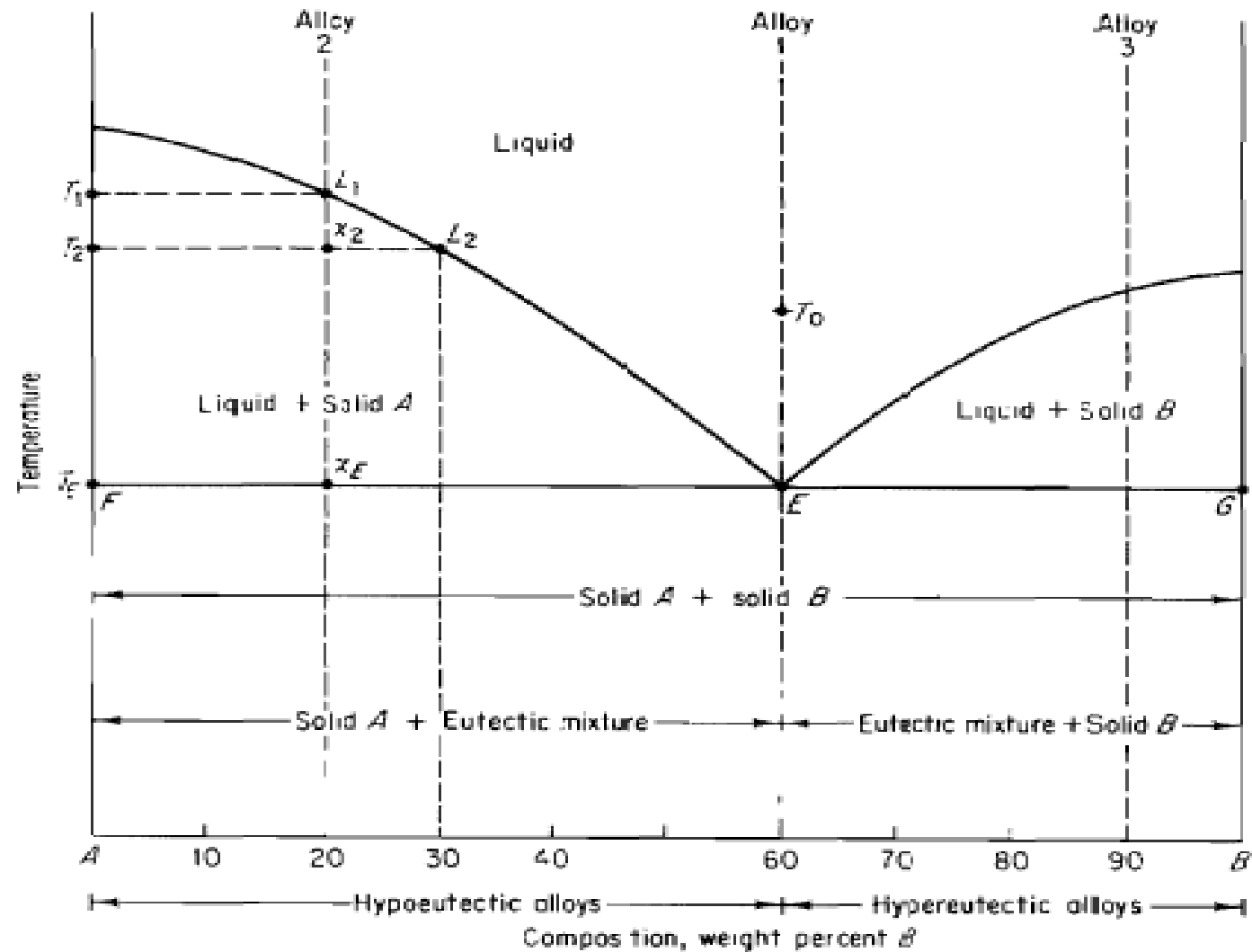
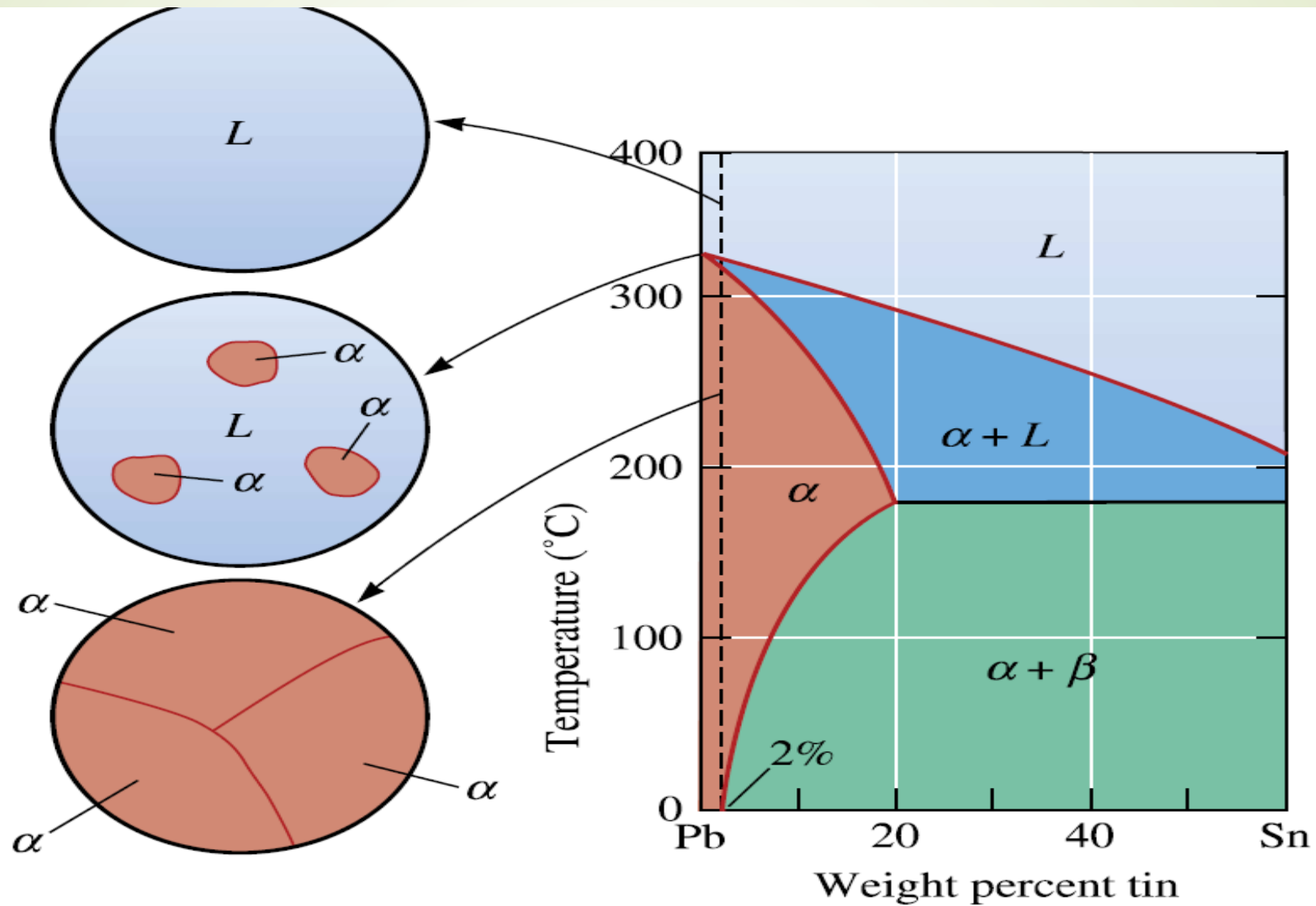


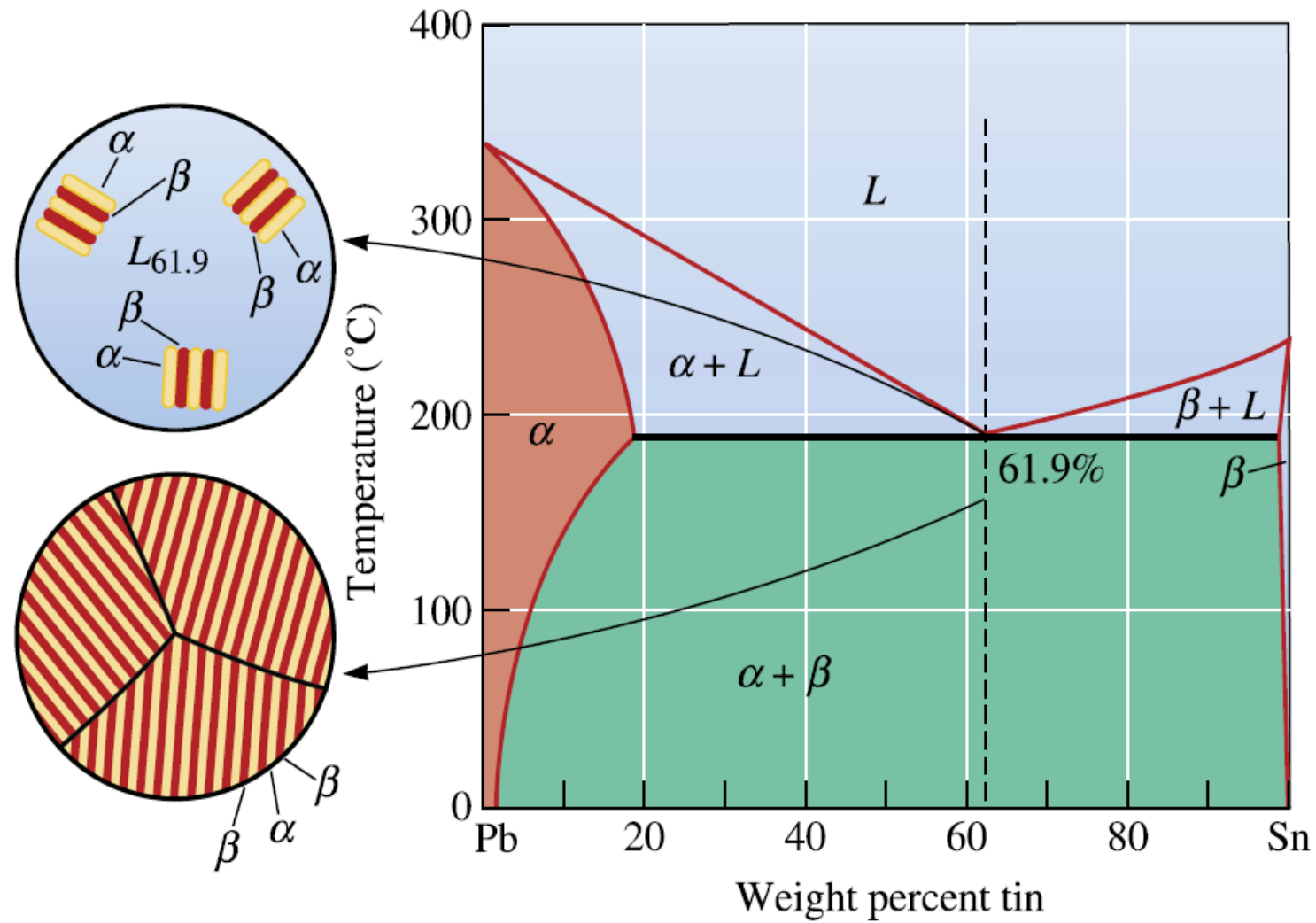
Fig. 6-17 Eutectic-type phase diagram.

# دیاگرام یوتکتیک محلول جامد تک فاز

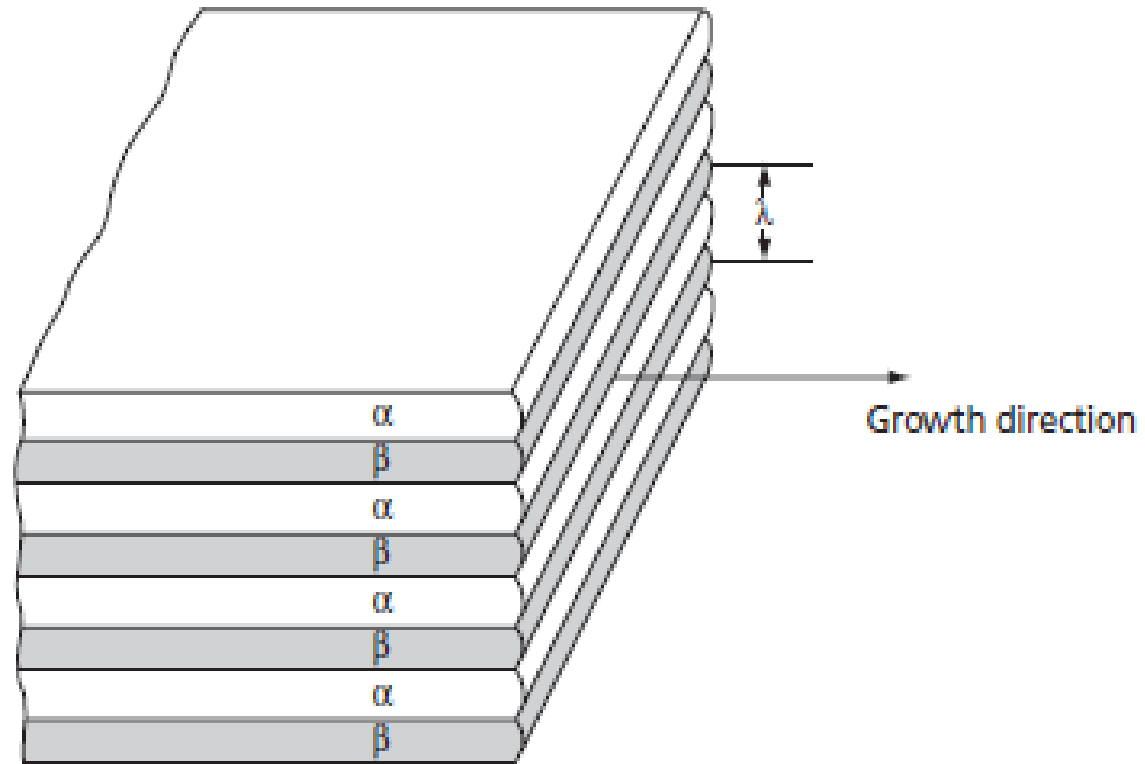
17



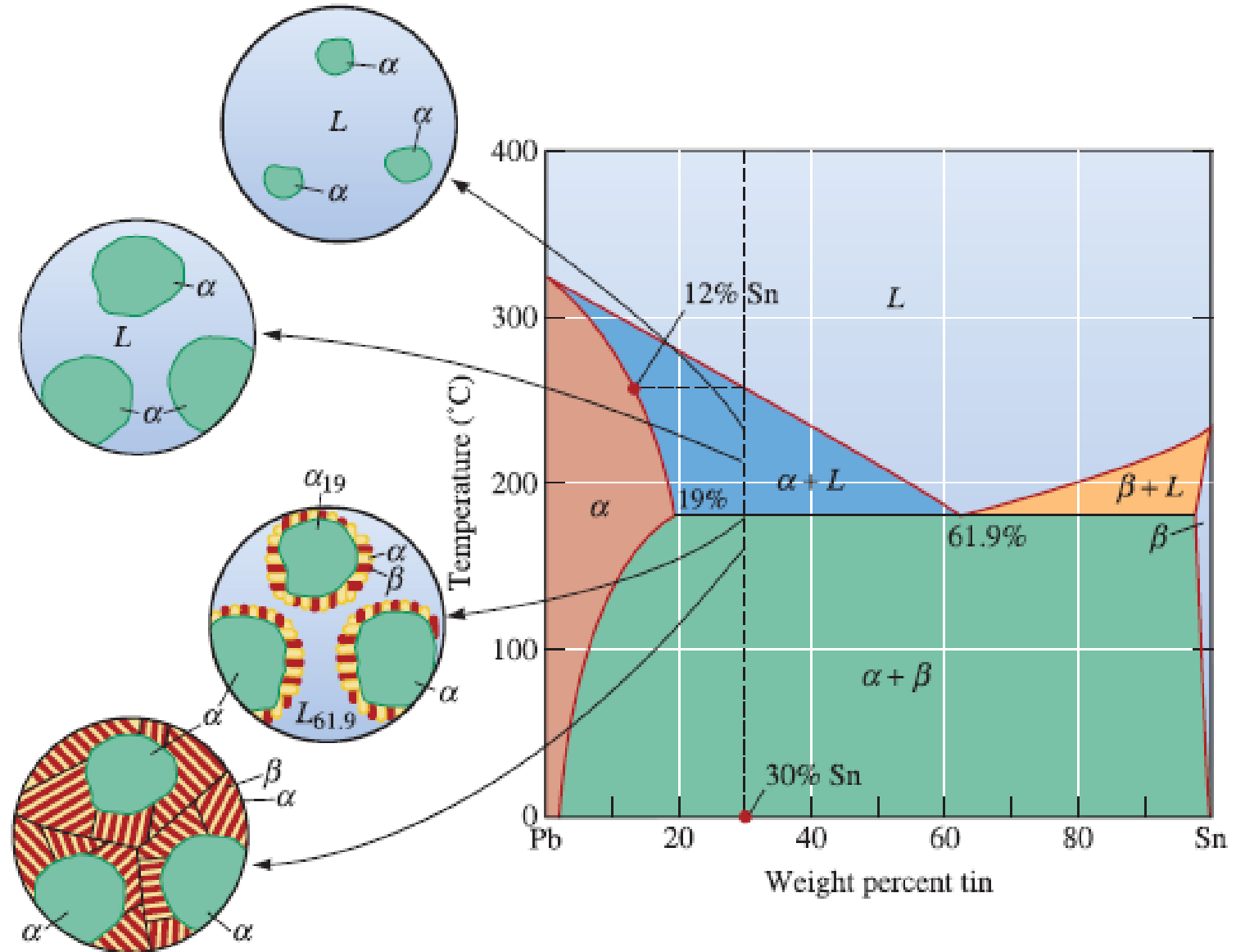
**Figure 11-7** Solidification and microstructure of a Pb-2% Sn alloy. The alloy is a single-phase solid solution.



**Figure 11-9** Solidification and microstructure of the eutectic alloy Pb-61.9% Sn.



**FIG. 14.43** Simple plate-like lamellar eutectic with an interlam spacing  $\lambda$



**Figure 11-13** The solidification and microstructure of a hypoeutectic alloy (Pb-30% Sn).



### Example 11-4 *Determination of Phases and Amounts in a Pb-30% Sn Hypoeutectic Alloy*

For a Pb-30% Sn alloy, determine the phases present, their amounts, and their compositions at 300°C, 200°C, 184°C, 182°C, and 0°C.

#### SOLUTION

Temperature (°C)	Phases	Compositions	Amounts
300	$L$	$L$ : 30% Sn	$L = 100\%$
200	$\alpha + L$	$L$ : 55% Sn	$L = \frac{30 - 18}{55 - 18} \times 100 = 32\%$
		$\alpha$ : 18% Sn	$\alpha = \frac{55 - 30}{55 - 18} \times 100 = 68\%$
184	$\alpha + L$	$L$ : 61.9% Sn	$L = \frac{30 - 19}{61.9 - 19} \times 100 = 26\%$
		$\alpha$ : 19% Sn	$\alpha = \frac{61.9 - 30}{61.9 - 19} \times 100 = 74\%$
182	$\alpha + \beta$	$\alpha$ : 19% Sn	$\alpha = \frac{97.5 - 30}{97.5 - 19} \times 100 = 86\%$
		$\beta$ : 97.5% Sn	$\beta = \frac{30 - 19}{97.5 - 19} \times 100 = 14\%$
0	$\alpha + \beta$	$\alpha$ : 2% Sn	$\alpha = \frac{100 - 30}{100 - 2} \times 100 = 71\%$
		$\beta$ : 100% Sn	$\beta = \frac{30 - 2}{100 - 2} \times 100 = 29\%$

# 60A-40B دیاگرام یوتکتیک الیاژ درصد فازها

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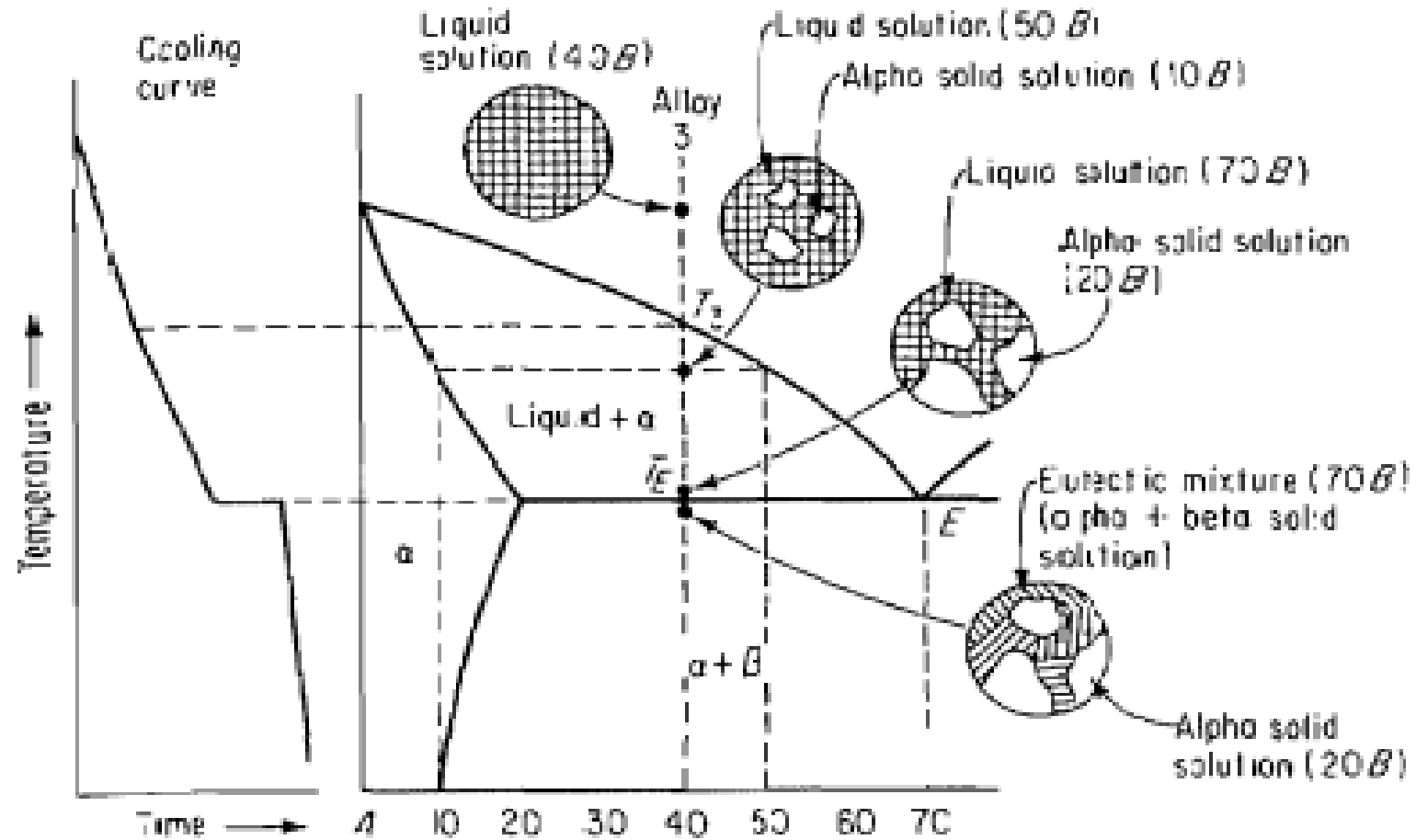


Fig. 6-27 The cooling curve and microstructure at various temperatures during solidification of a 60A-40B alloy.

# دیاگرام یوتکتیک الیاژ درصد فازها برای سه الیاژ ۱ و ۲ و ۳

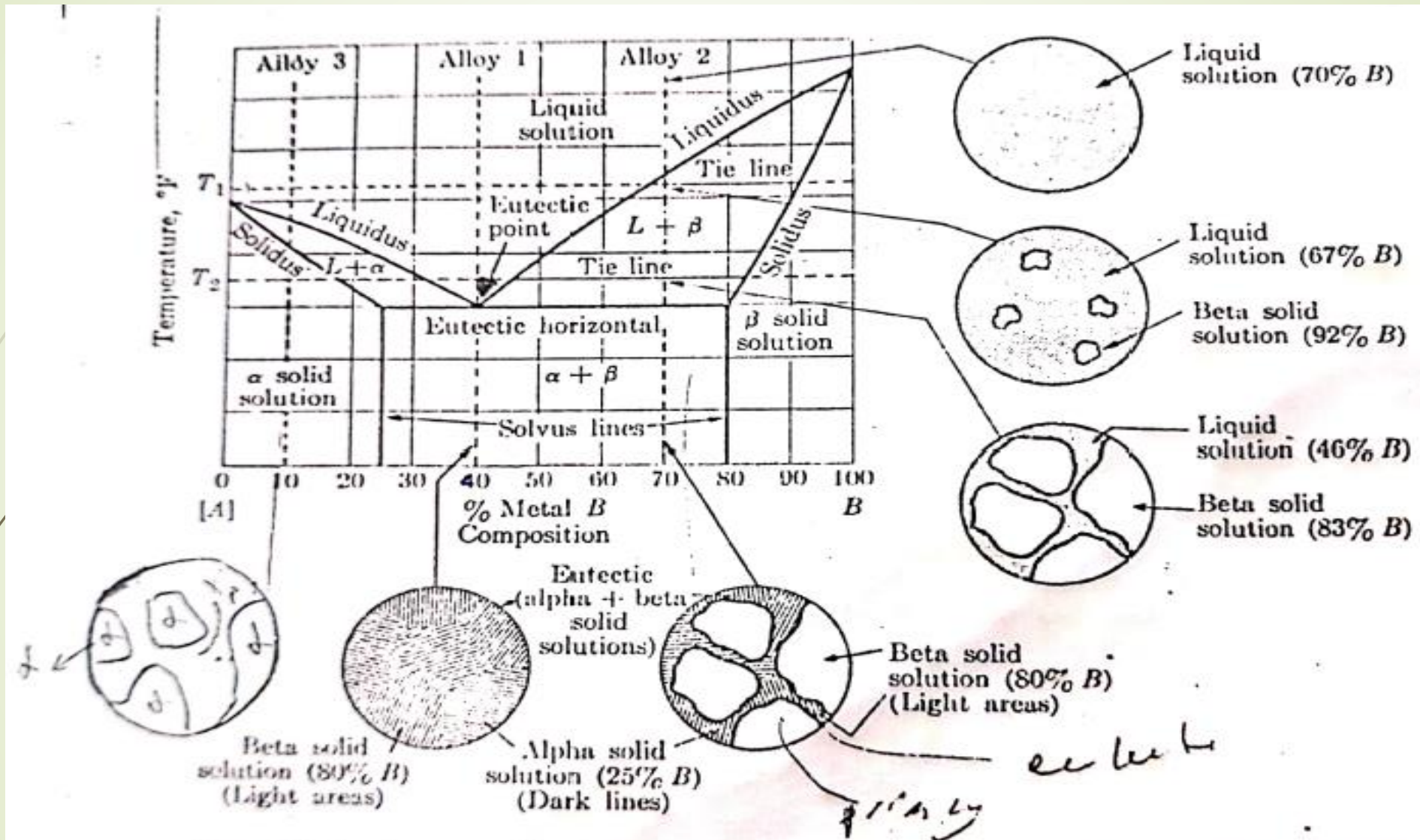
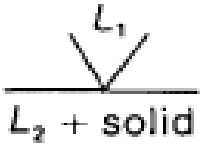
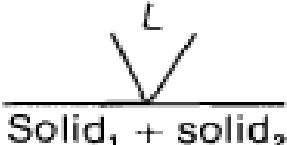
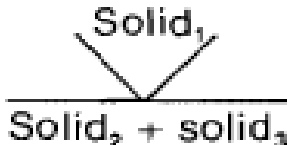
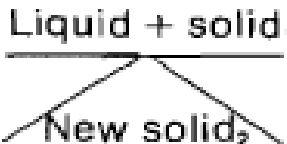
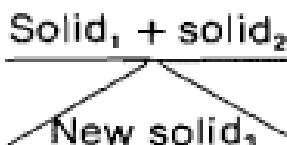


FIG. 6-12. A generalized eutectic equilibrium diagram involving the hypothetical metals A and B. The solidification processes of alloy 1 (eutectic composition) and of alloy 2 are indicated.

# واکنش‌های دیاگرام‌های فازی

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TABLE 6-4 Equilibrium-diagram Reactions

NAME OF REACTION	GENERAL EQUATION	APPEARANCE ON DIAGRAM
Monotectic	$L_1 \xrightleftharpoons[\text{heating}]{\text{cooling}} L_2 + \text{solid}$	
Eutectic	$\text{Liquid} \xrightleftharpoons[\text{heating}]{\text{cooling}} \text{solid}_1 + \text{solid}_2$	
Eutectoid	$\text{Solid}_1 \xrightleftharpoons[\text{heating}]{\text{cooling}} \text{solid}_2 + \text{solid}_3$	
Peritectic	$\text{Liquid} + \text{solid}_1 \xrightleftharpoons[\text{heating}]{\text{cooling}} \text{new solid}_2$	
Peritectoid	$\text{Solid}_1 + \text{solid}_2 \xrightleftharpoons[\text{heating}]{\text{cooling}} \text{new solid}_3$	

Eutectic	$L \rightarrow \alpha + \beta$	
Peritectic	$\alpha + L \rightarrow \beta$	
Monotectic	$L_1 \rightarrow L_2 + \alpha$	
Eutectoid	$\gamma \rightarrow \alpha + \beta$	
Peritectoid	$\alpha + \beta \rightarrow \gamma$	

**Figure 11-4** The five most important three-phase reactions in binary phase diagrams.

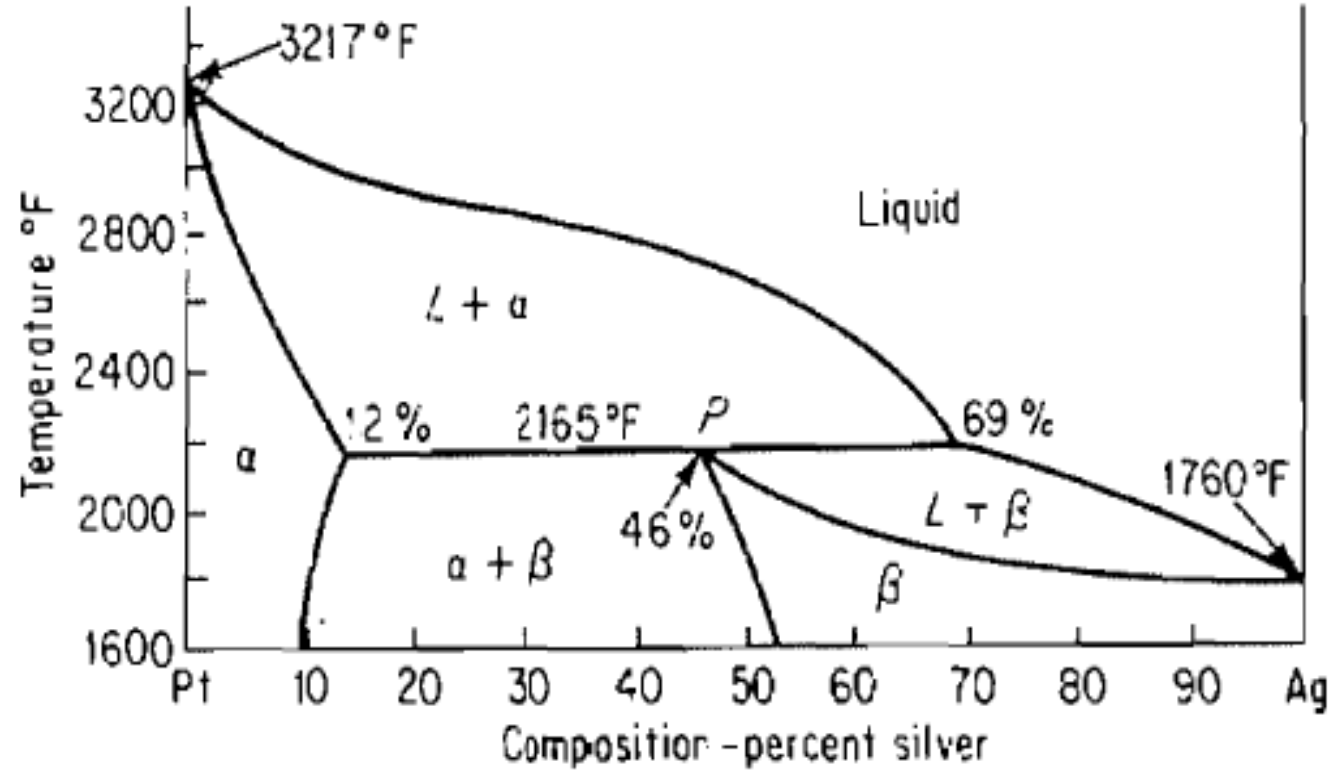


Fig. 6-39 Silver-platinum alloy system showing the formation of a terminal solid solution by a peritectic reaction.



# دیاگرام پری تکتیک نقره پلاتین فازها و درصد فازها

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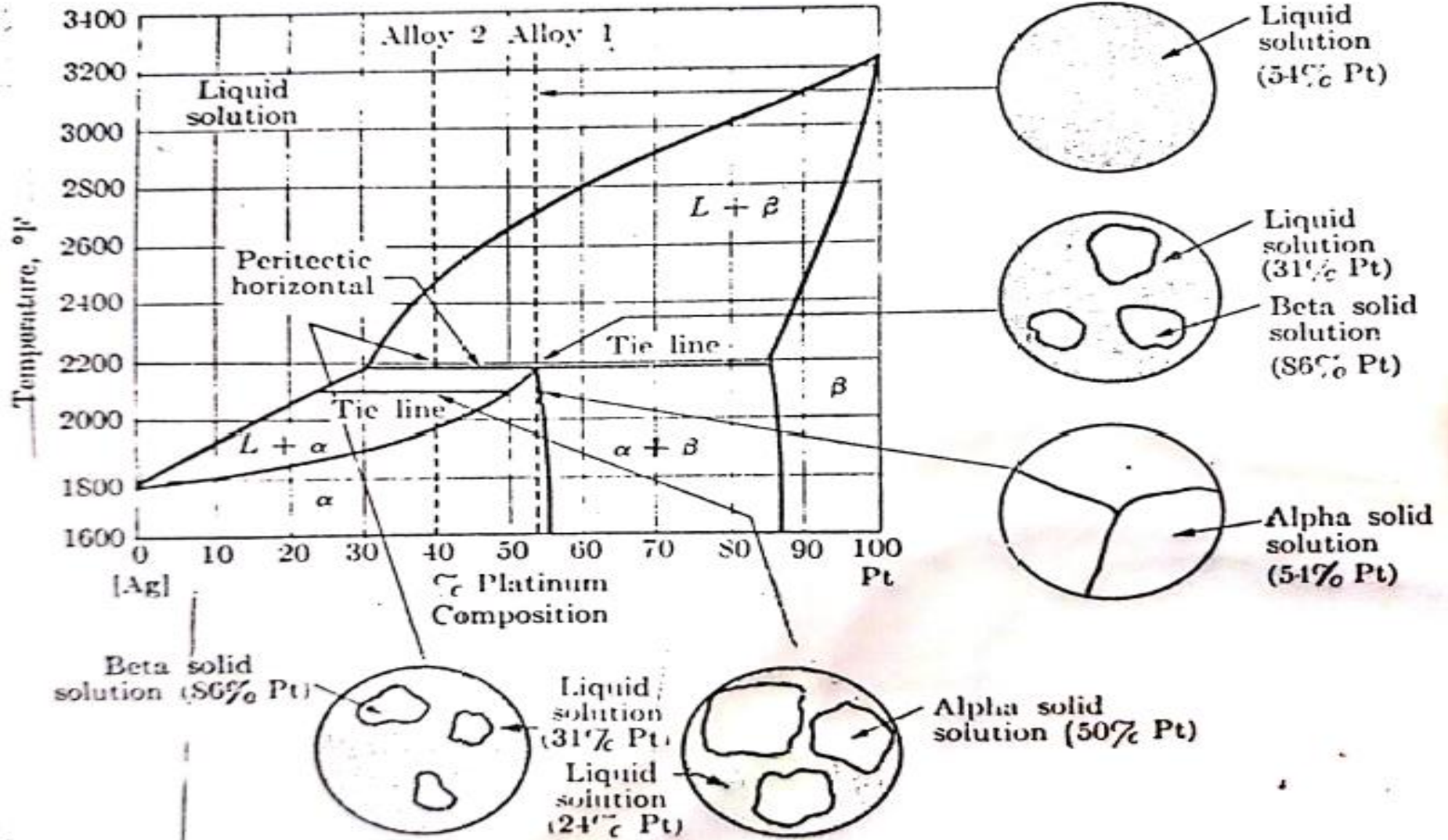
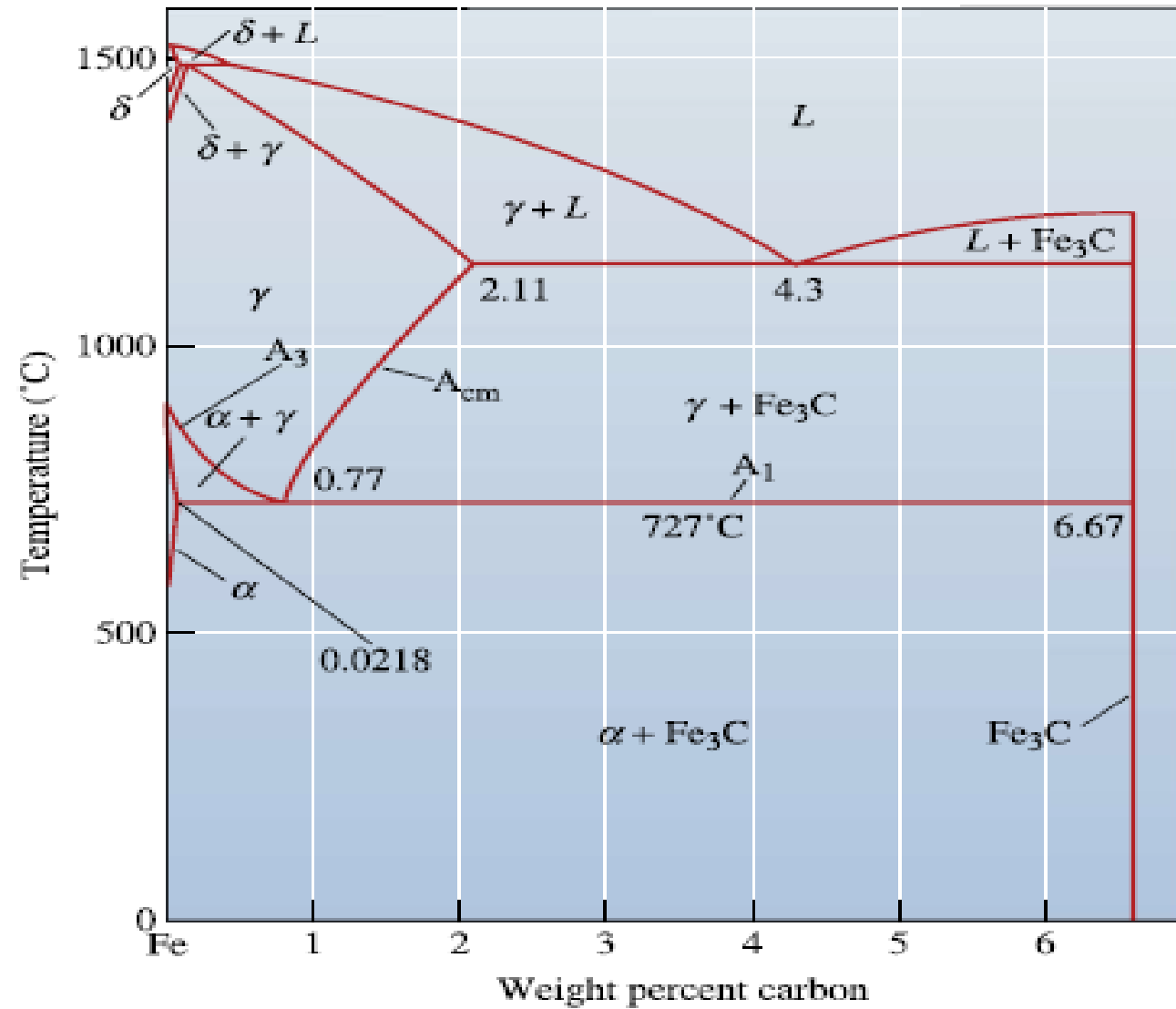


FIG. 6-17. Simplified silver-platinum diagram showing the peritectic reaction.

# دیاگرام آهن کربن

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**Figure 12-14** The Fe-Fe<sub>3</sub>C phase diagram (a portion of the Fe-C diagram). The vertical line at 6.67% C is the stoichiometric compound Fe<sub>3</sub>C.

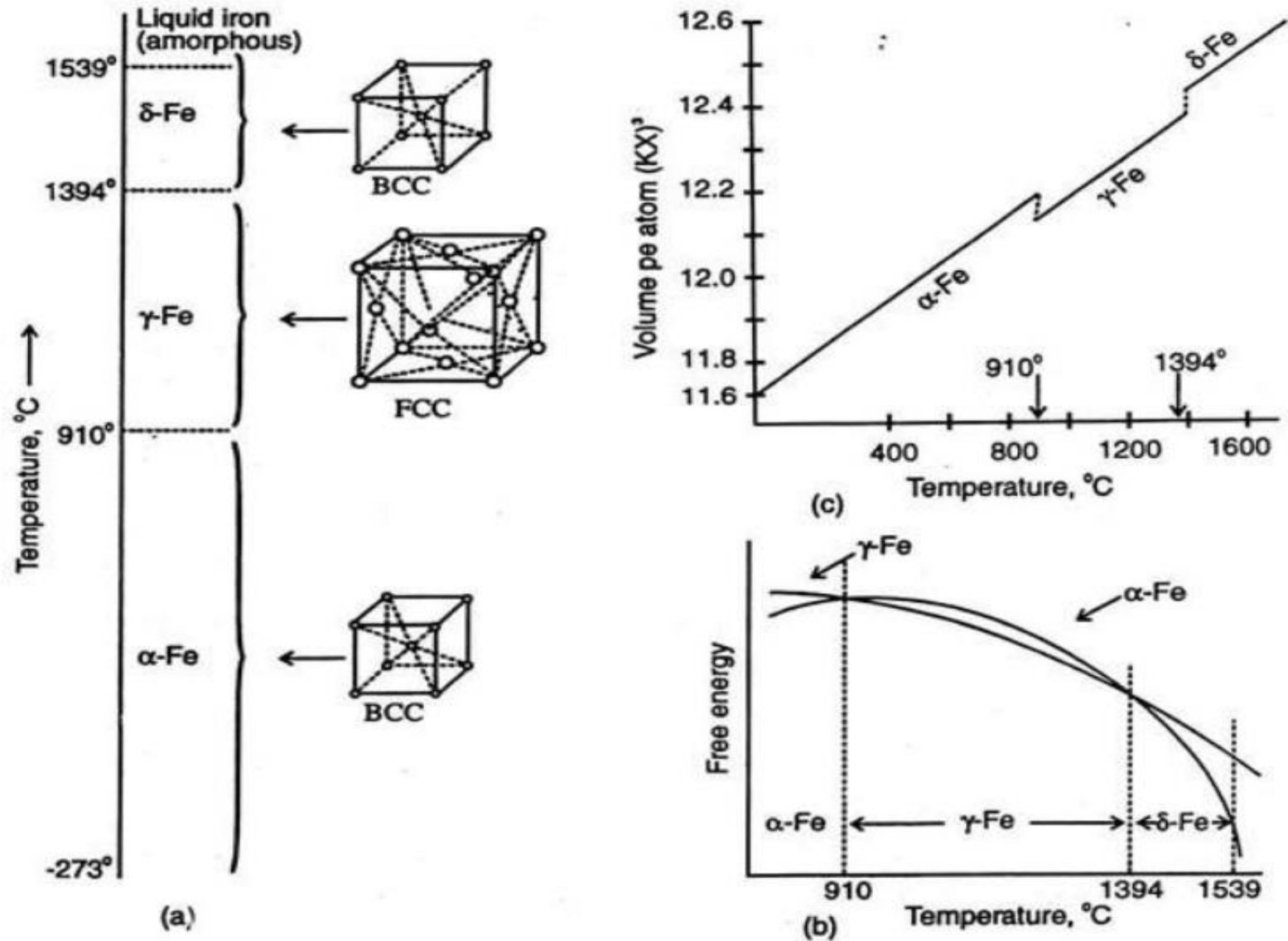
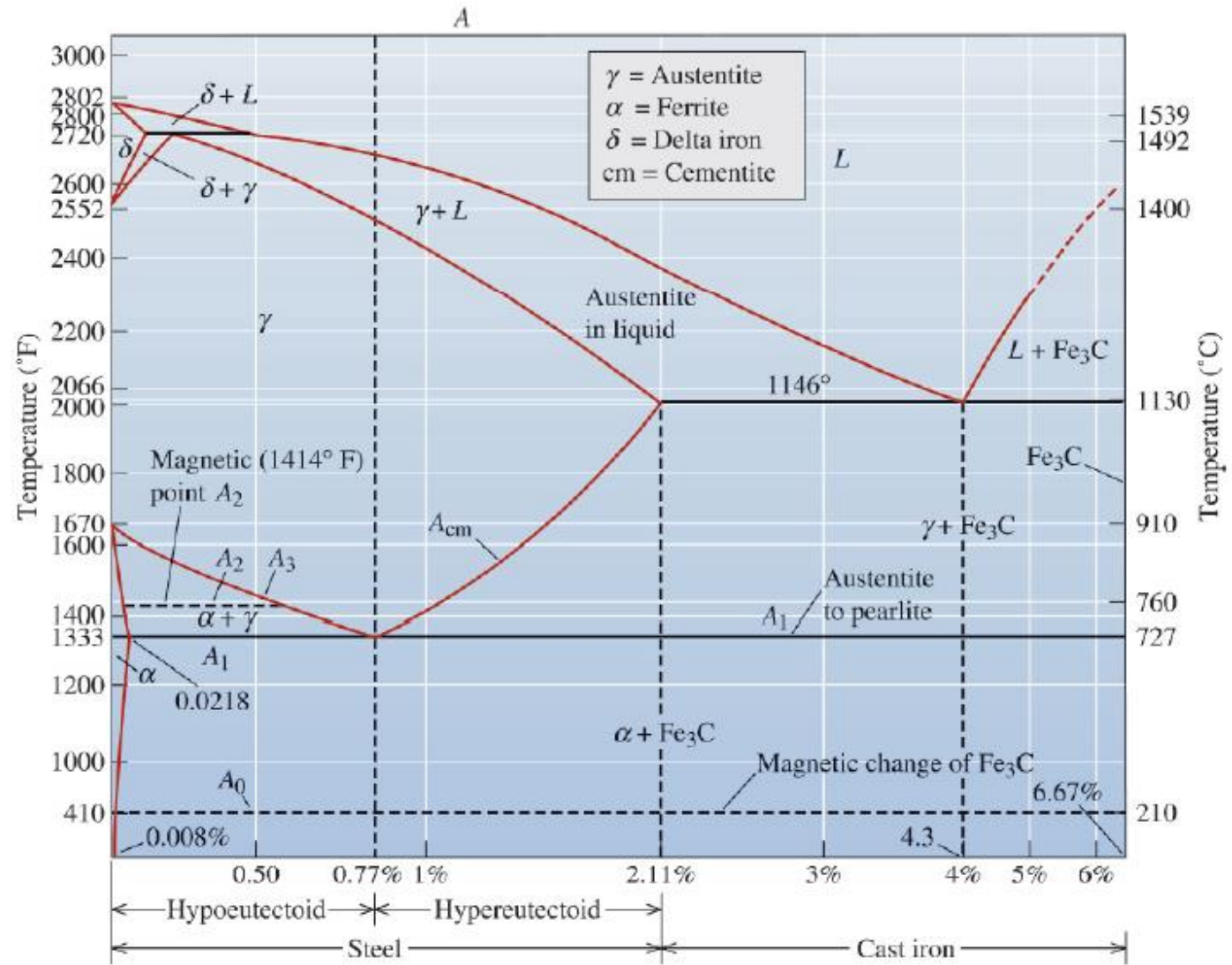


Fig. 1.44. Allotropic changes in iron: (a) Temperature ranges of stability of different allotropes; (b) Free energy-temperature curves for different allotropes; (c) Volume change-temperature curve for different allotropes.



(a)

## Solid Solutions

Iron goes through two allotropic transformations (Chapter 3) during heating or cooling. Immediately after solidification, iron forms a BCC structure called  $\delta$ -ferrite. On further cooling, the iron transforms to a FCC structure called  $\gamma$ , or austenite. Finally, iron transforms back to the BCC structure at lower temperatures; this structure is called  $\alpha$ , or ferrite. Both of the ferrites ( $\alpha$  and  $\delta$ ) and the austenite are solid solutions of interstitial carbon atoms in iron. Normally, when no specific reference is made, the term ferrite refers to the  $\alpha$  ferrite, since this is the phase we encounter more often during the heat treatment of steels. Certain ceramic materials used in magnetic applications are also known as ferrites (Chapter 20) but are not related to the ferrite phase in the Fe-Fe<sub>3</sub>C system.

Because interstitial holes in the FCC crystal structure are somewhat larger than the holes in the BCC crystal structure, a greater number of carbon atoms can be accommodated in FCC iron. Thus, the maximum solubility of carbon in austenite is 2.11% C, whereas the maximum solubility of carbon in BCC iron is much lower (i.e.,  $\sim 0.0218\%$  C in  $\alpha$  and 0.09% C in  $\delta$ ). The solid solutions of carbon in iron are relatively soft and ductile, but are stronger than pure iron due to solid-solution strengthening by the carbon.



# دیاگرام آهن-کربن واکنش یوتکتیک ویوتکتوئید

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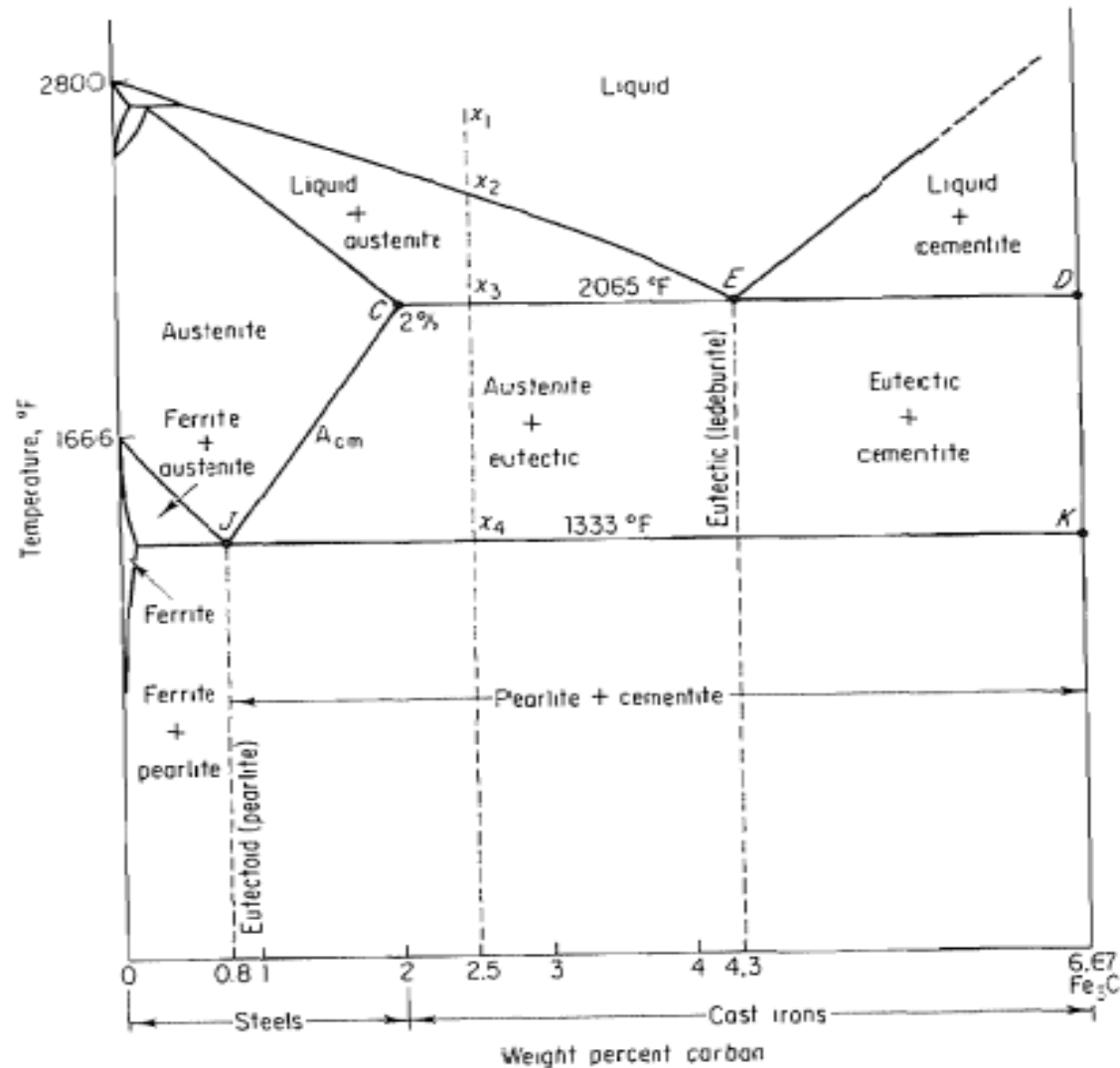


Fig. 11-1 The metastable iron-iron carbide phase diagram.



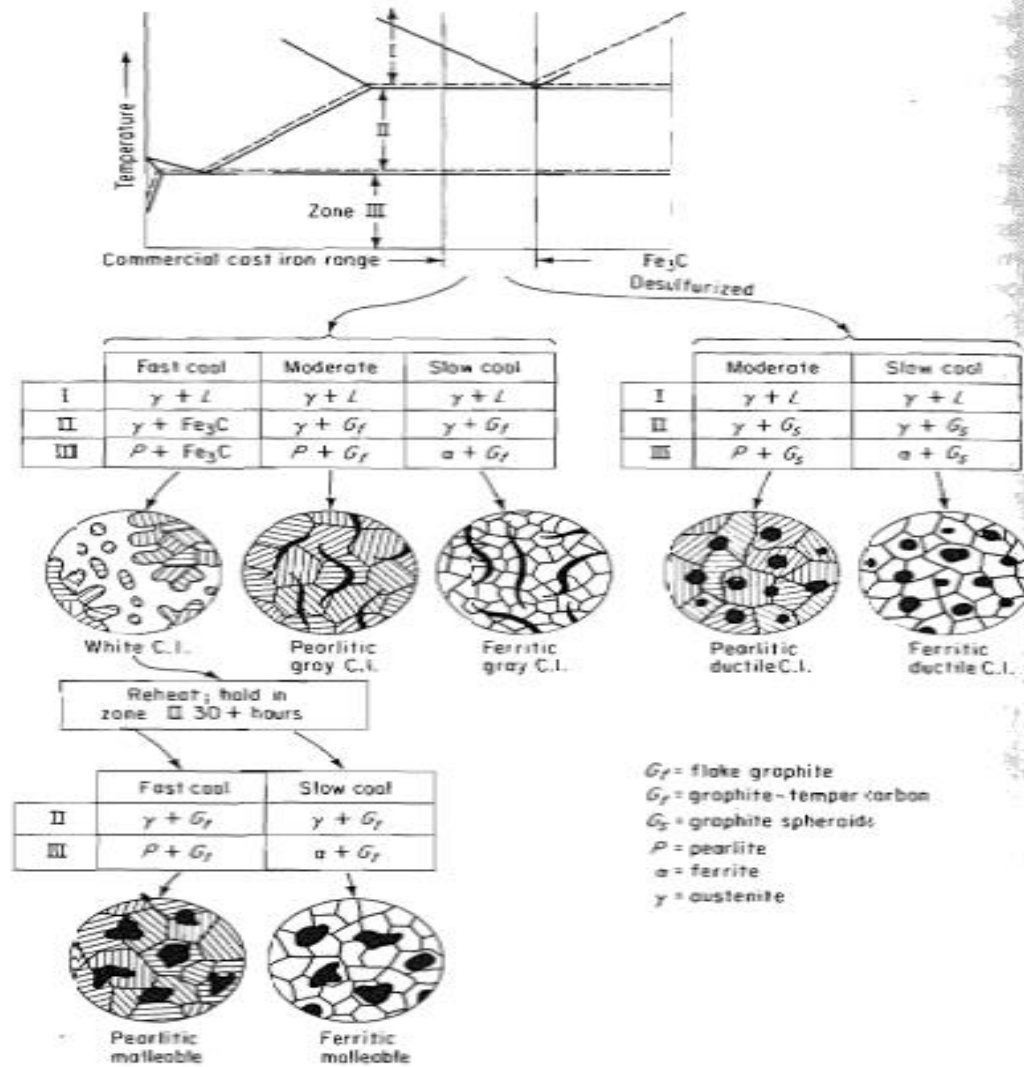
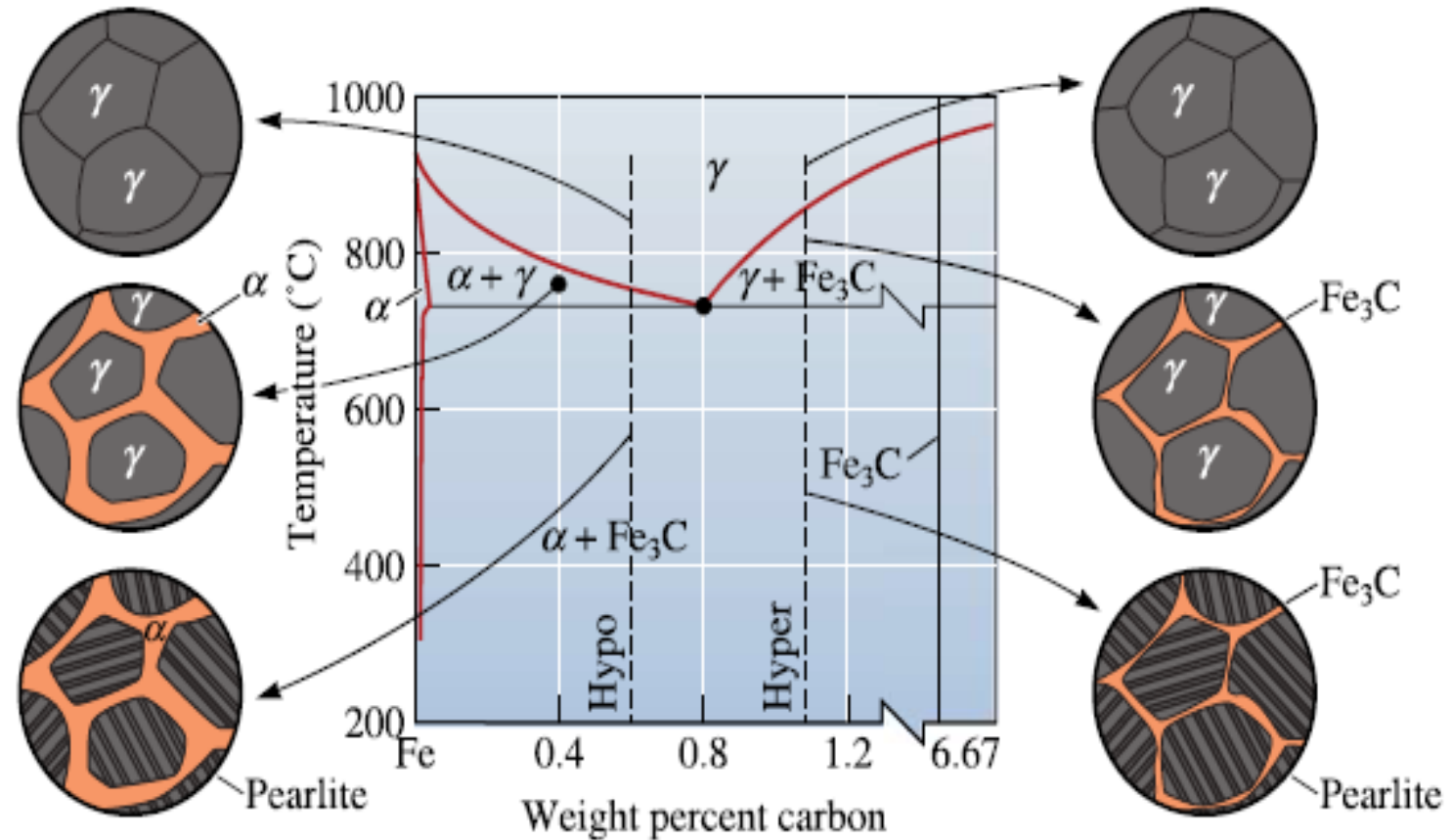
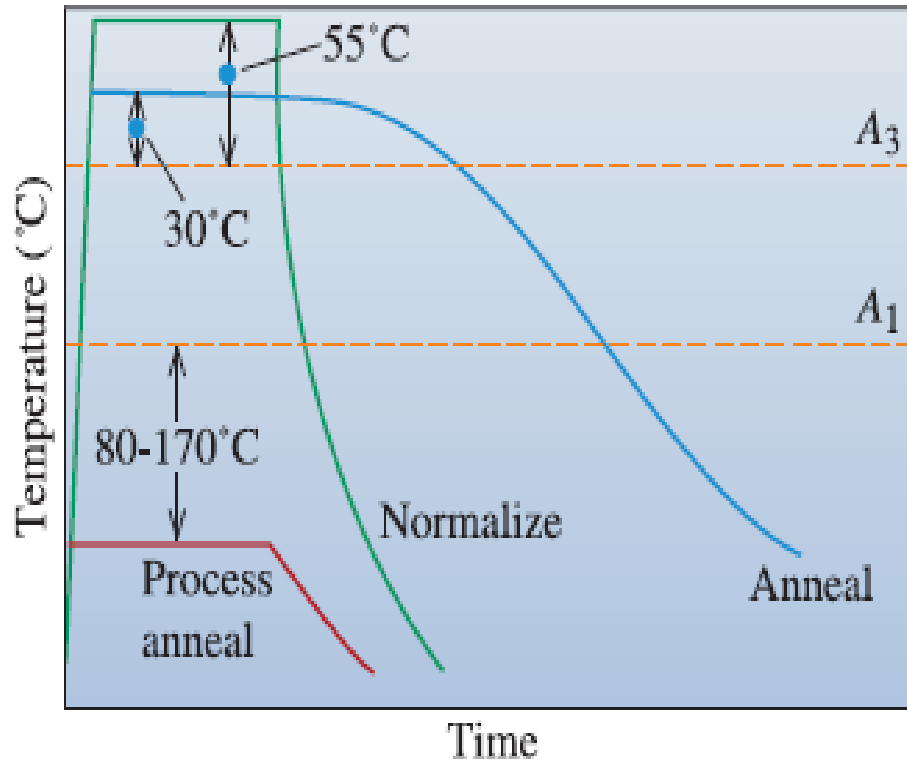


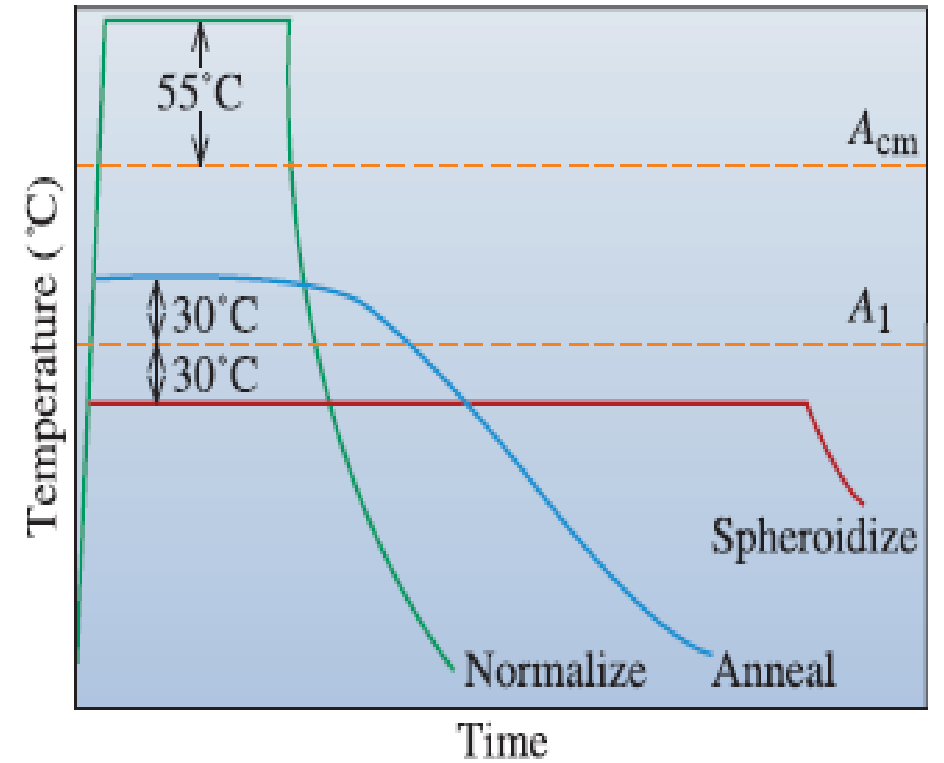
Fig. 11-24 Summary of cast-iron microstructures and the phases coexisting at various temperatures. (From Moffatt, Pearsall, and Wulff, "The Structure and Properties of Materials," John Wiley & Sons, Inc., New York, 1964.)



**Figure 12-16** The evolution of the microstructure of hypoeutectoid and hypereutectoid steels during cooling, in relationship to the Fe-Fe<sub>3</sub>C phase diagram.

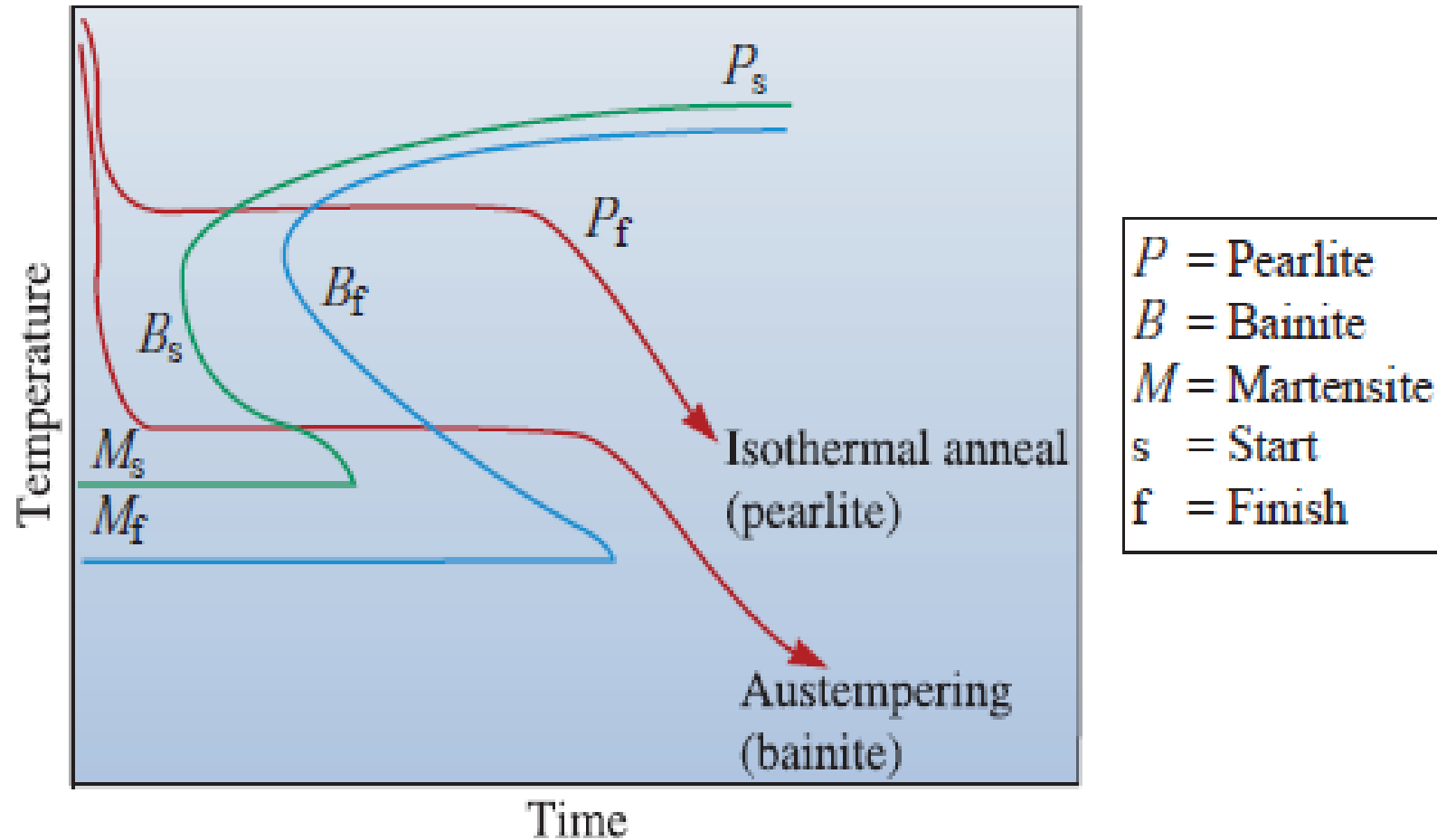


(a) Hypoeutectoid

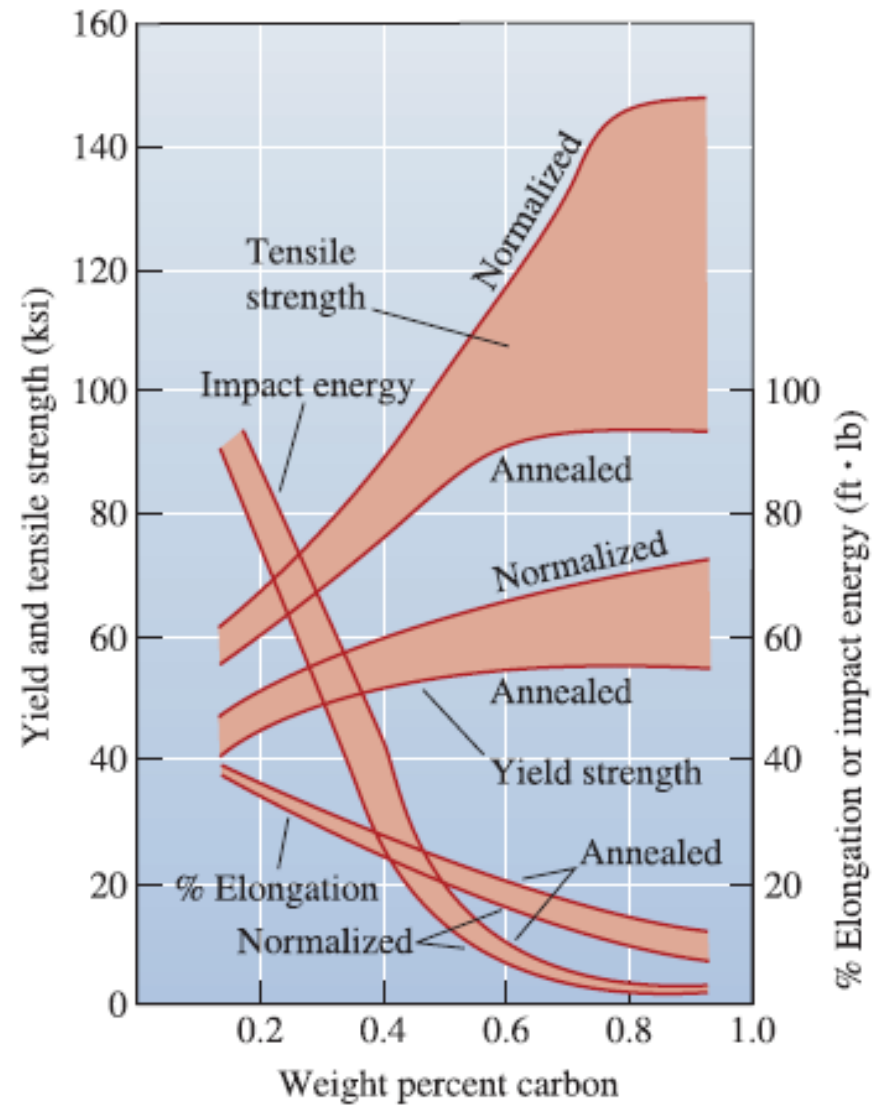


(b) Hypereutectoid

**Figure 13-3** Schematic summary of the simple heat treatments for (a) hypoeutectoid steels and (b) hypereutectoid steels.

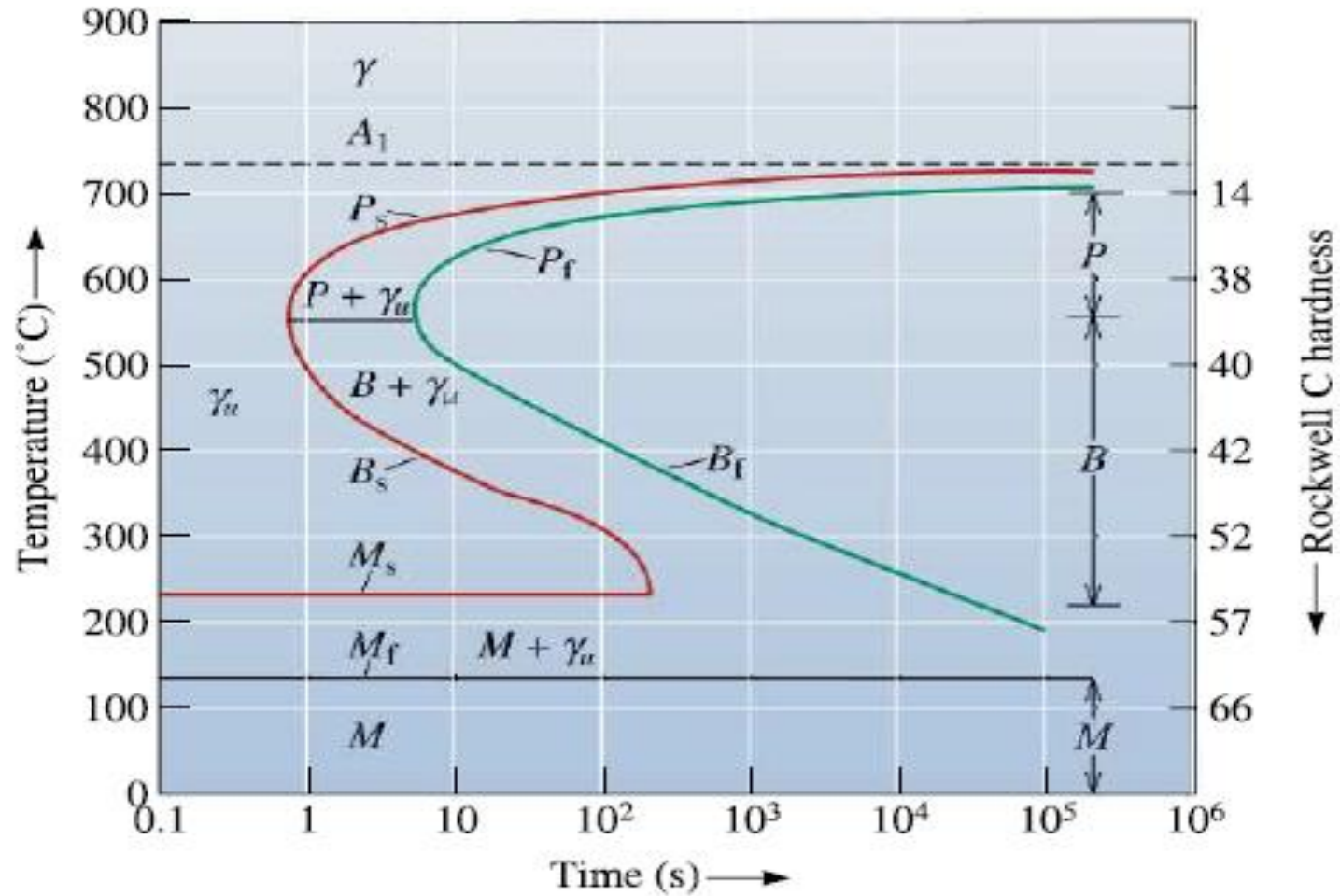


**Figure 13-6** The austempering and isothermal anneal heat treatments in a 1080 steel.



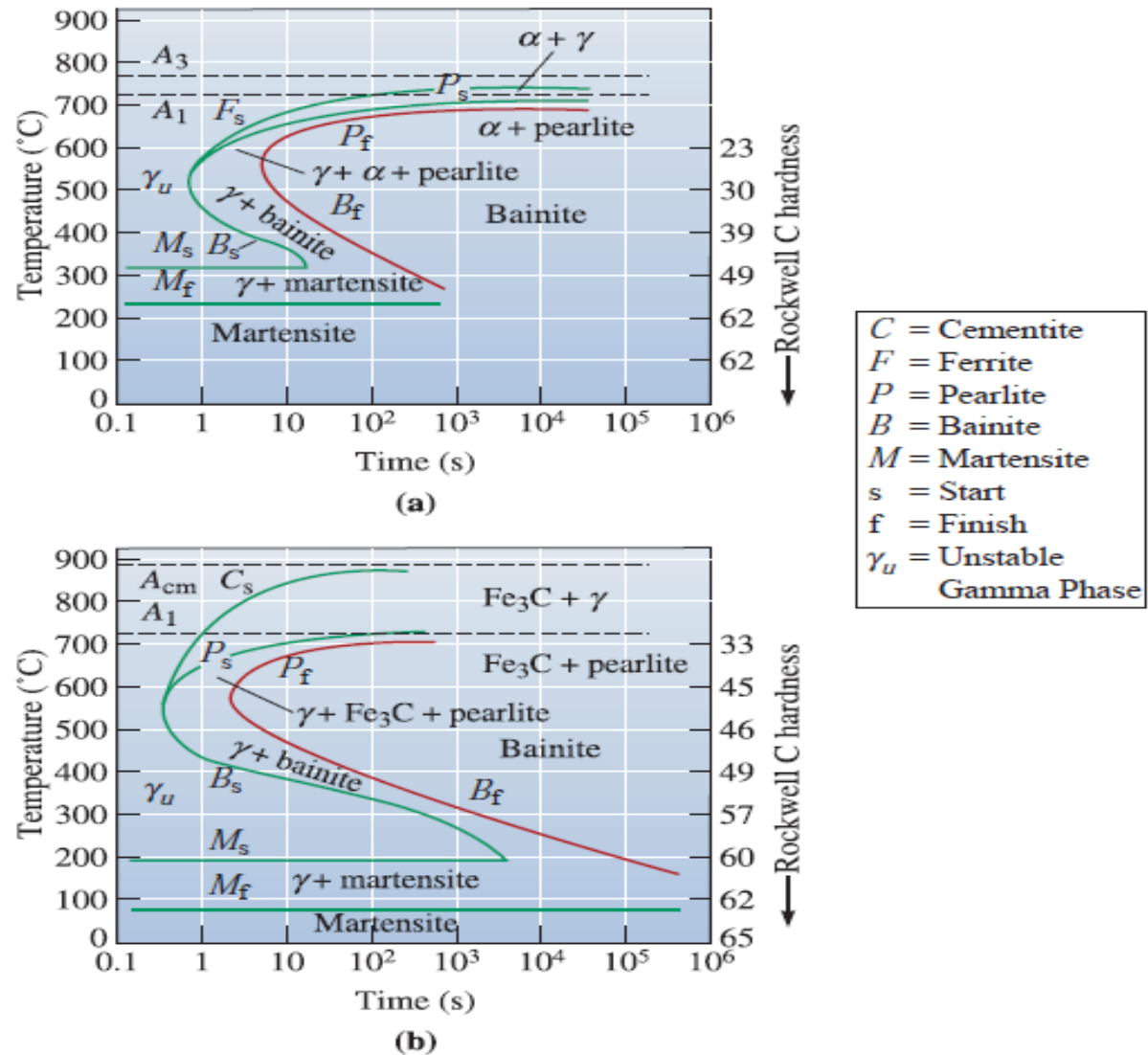
**Figure 13-4**

The effect of carbon and heat treatment on the properties of plain carbon steels.

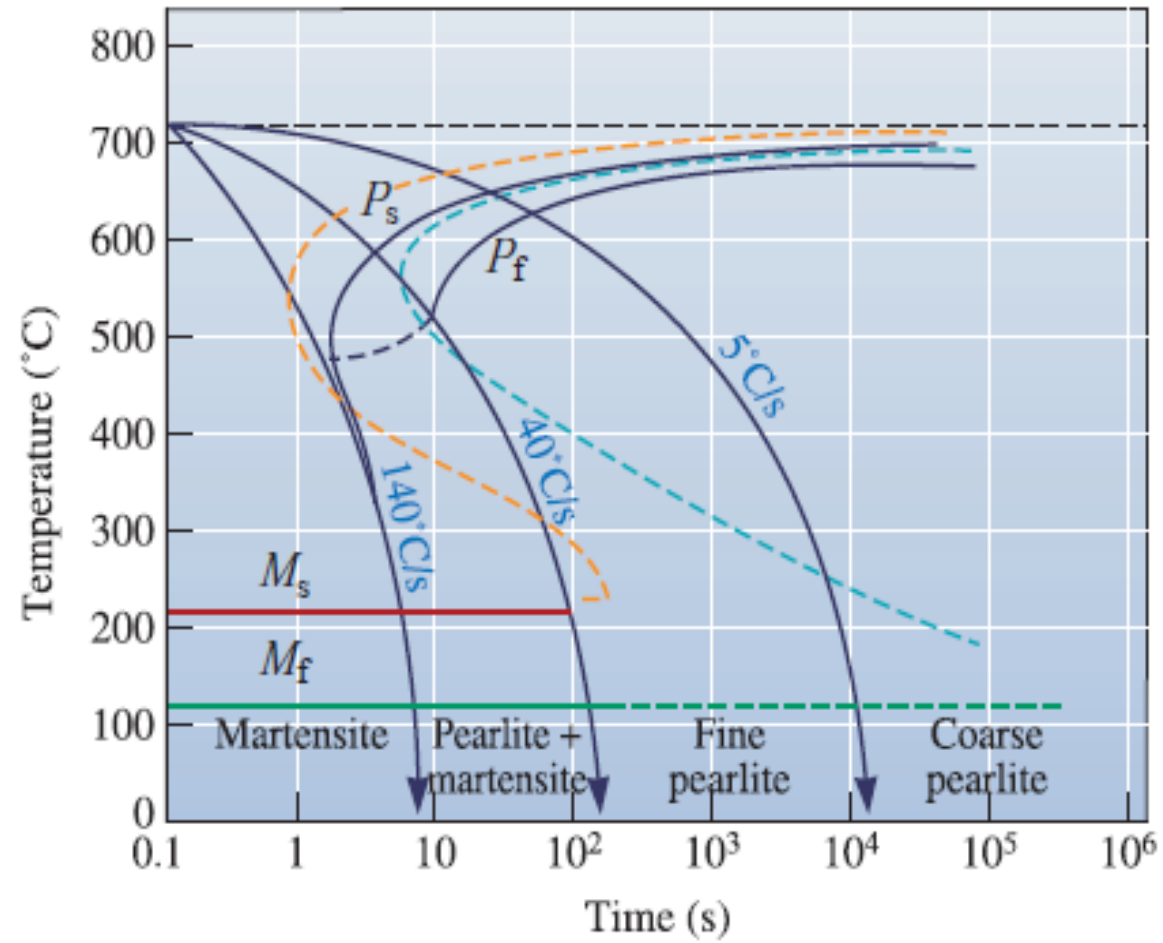


**Figure 12-20** The time-temperature-transformation (TTT) diagram for a eutectoid steel, where  $P$  = Pearlite,  $B$  = Bainite, and  $M$  = Martensite. The subscripts "s" and "f" indicate the start and finish of a transformation.  $\gamma_u$  is unstable austenite.

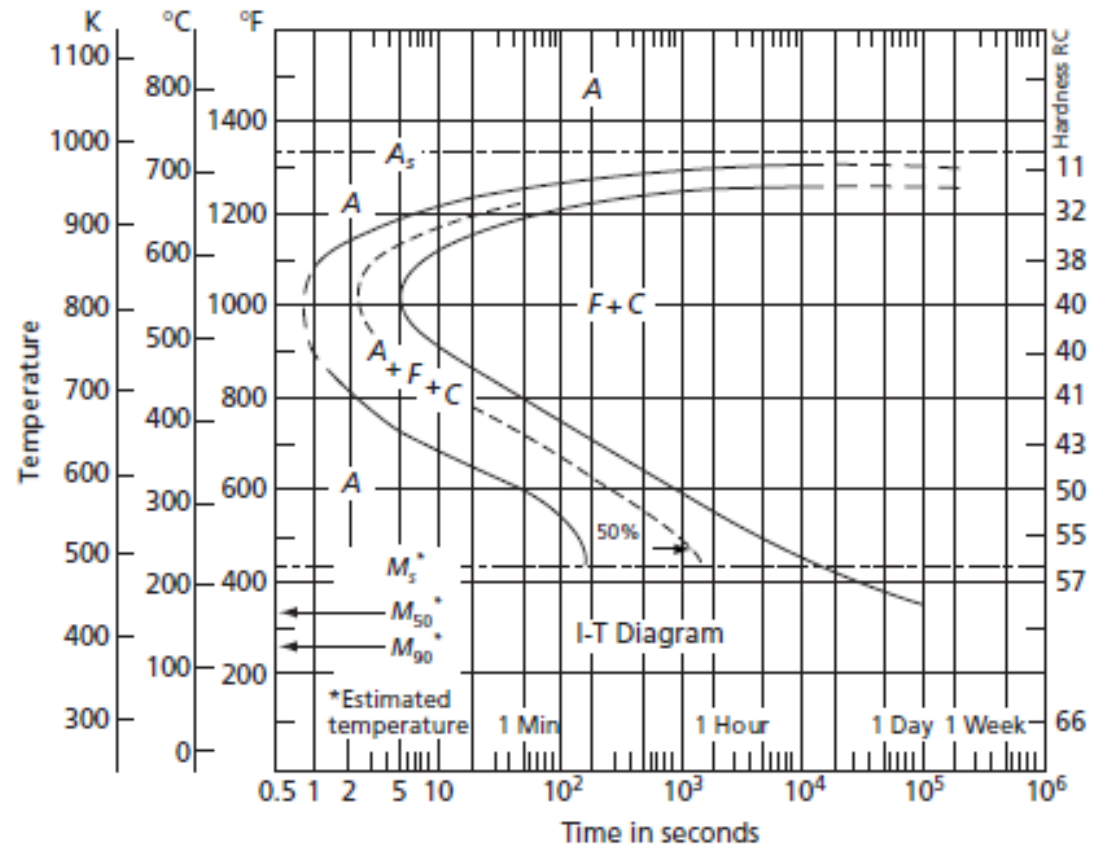




**Figure 13-7** The TTT diagrams for (a) a 1050 and (b) a 10110 steel. Note  $\gamma_u$  = unstable austenite.



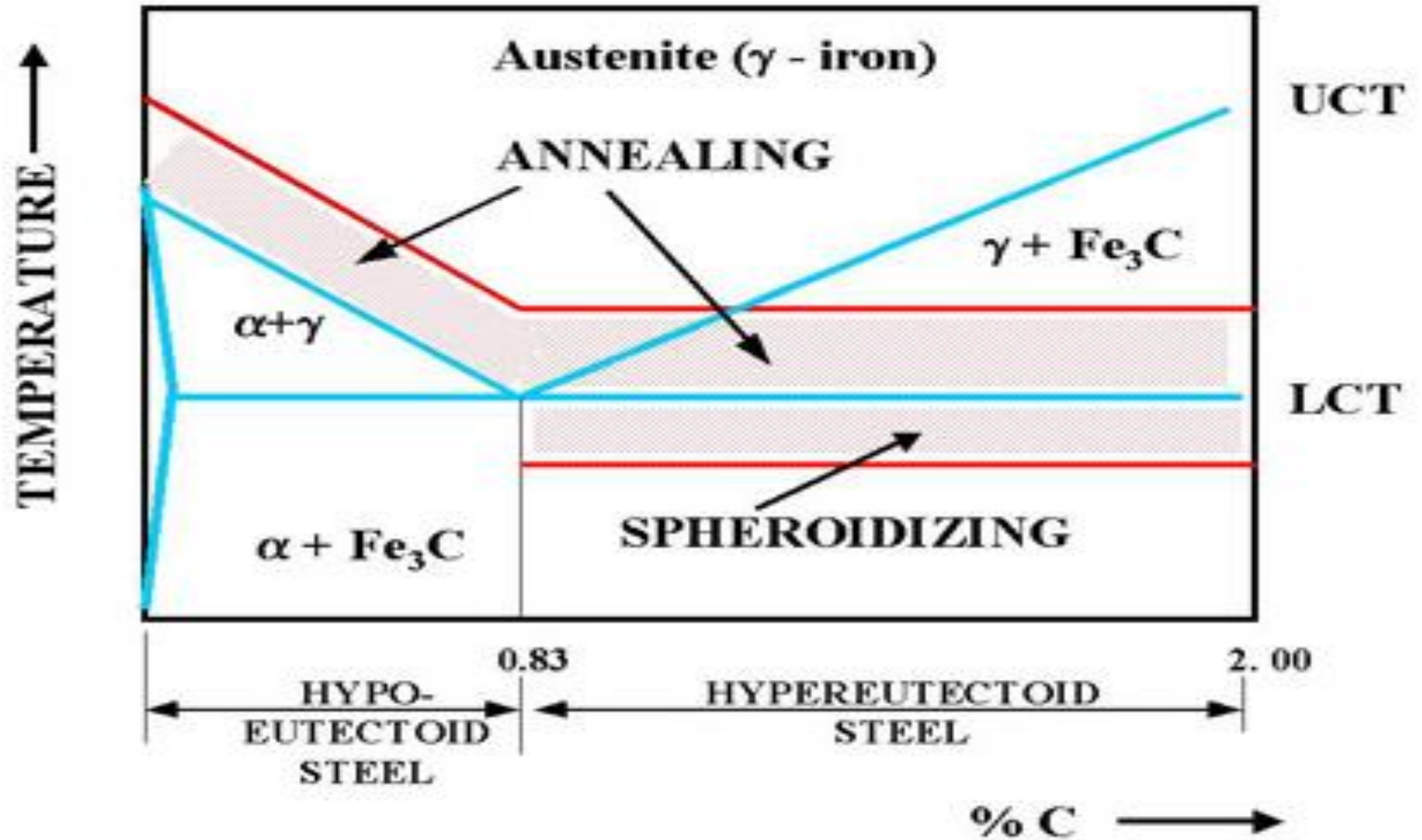
**Figure 13-14** The CCT diagram (solid lines) for a 1080 steel compared with the TTT diagram (dashed lines).



**FIG. 18.30** The complete isothermal transformation diagram for an eutectoid steel. Notice that this steel is not a high-purity iron-carbon alloy, but a commercial steel (AISI 1080) containing 0.79 percent carbon and 0.76 percent manganese. The effect of the manganese will be discussed in Chapter 19. Note that the temperature is given in Centigrade, Fahrenheit, and Kelvin on the left and the hardness of the isothermally transformed specimens is shown on the right. In this figure  $A$  = austenite,  $F$  = ferrite,  $C$  = cementite, and  $M$  = martensite. (From *Atlas of Isothermal Transformation and Continuous Cooling Diagrams*, American Society for Metals, Metals Park, 1977. Reprinted with permission of AMS International (R). All rights reserved. [www.asminternational.org](http://www.asminternational.org))

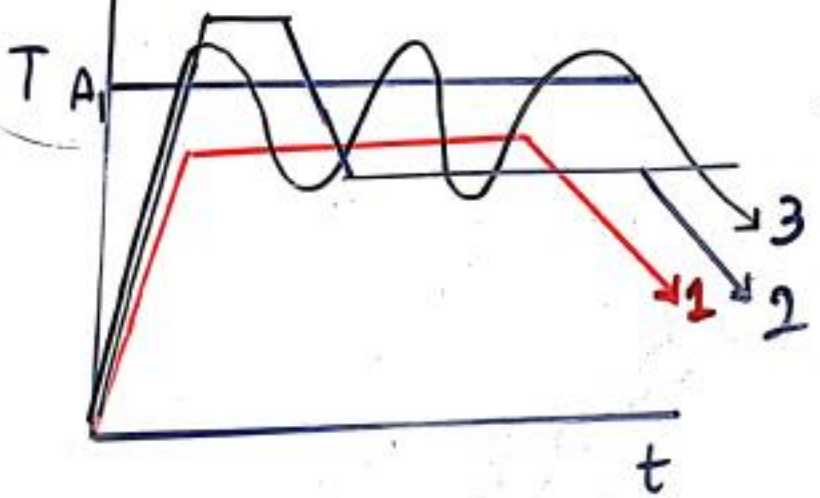
# عملیات حرارتی انیل-نرماله-کروی کردن

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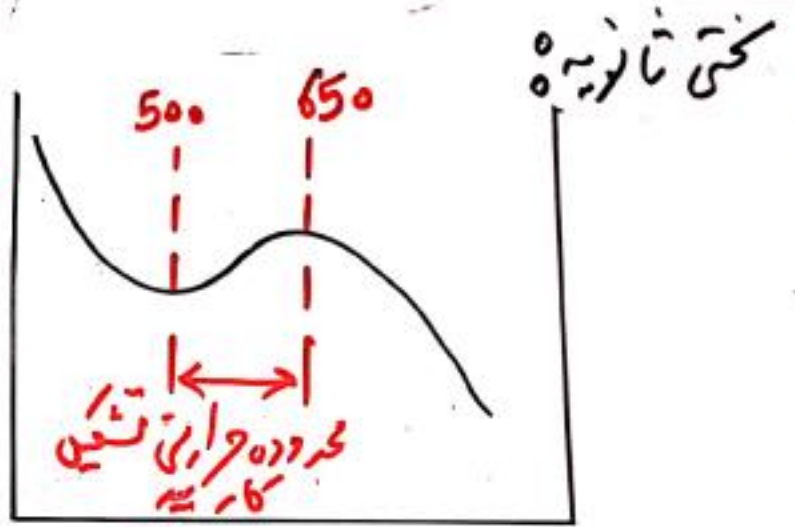




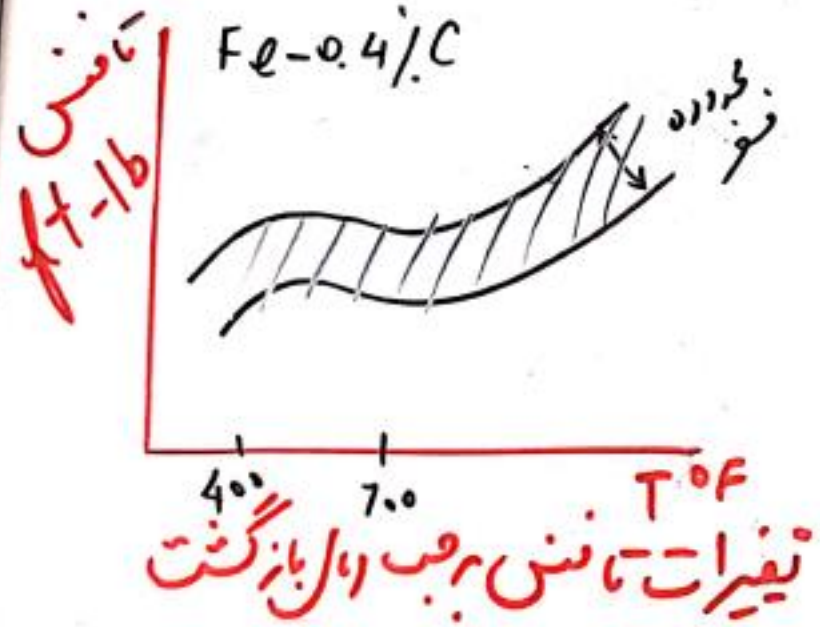
سیکل های عملیات حرارتی کروم کروم

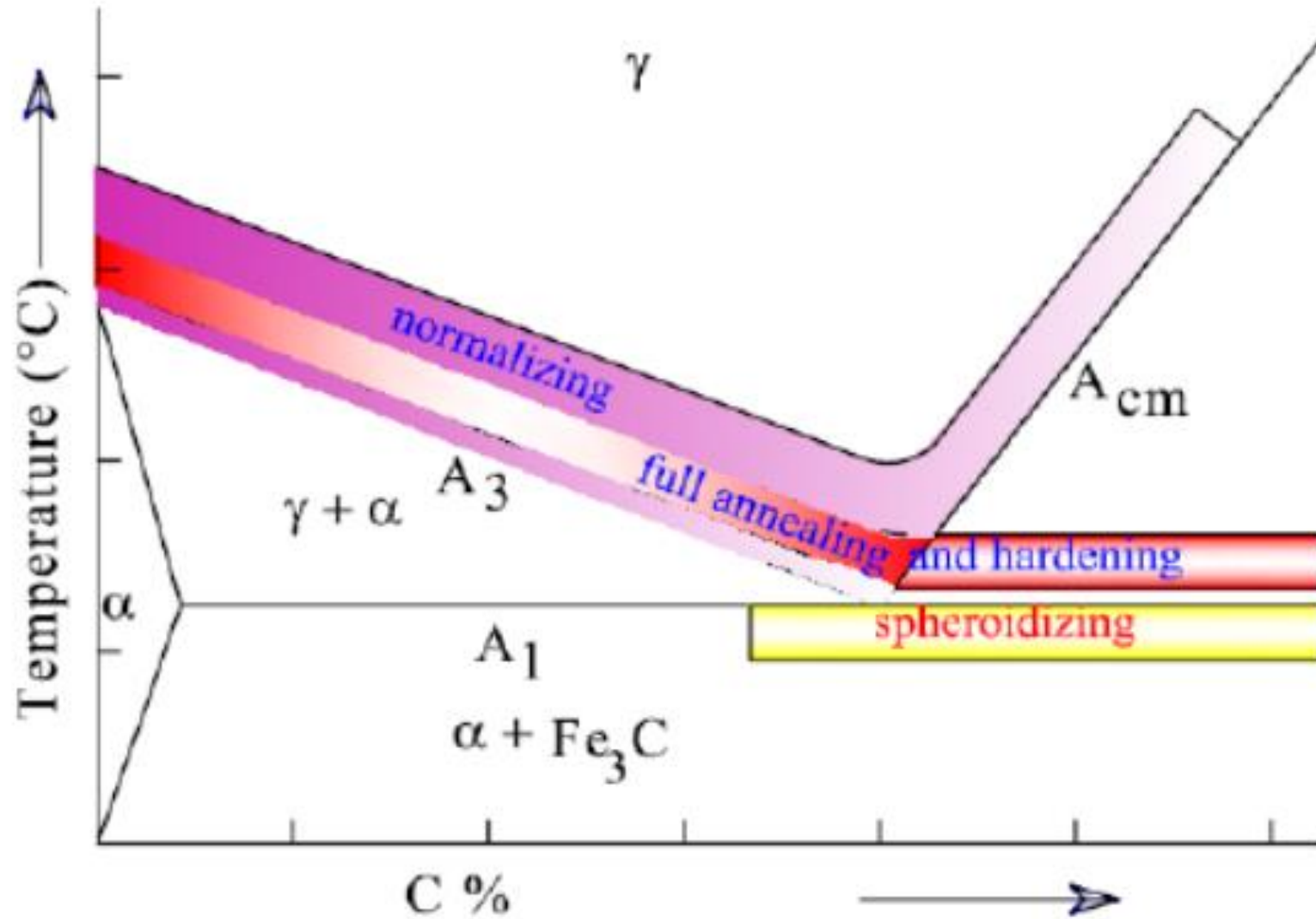


سختی

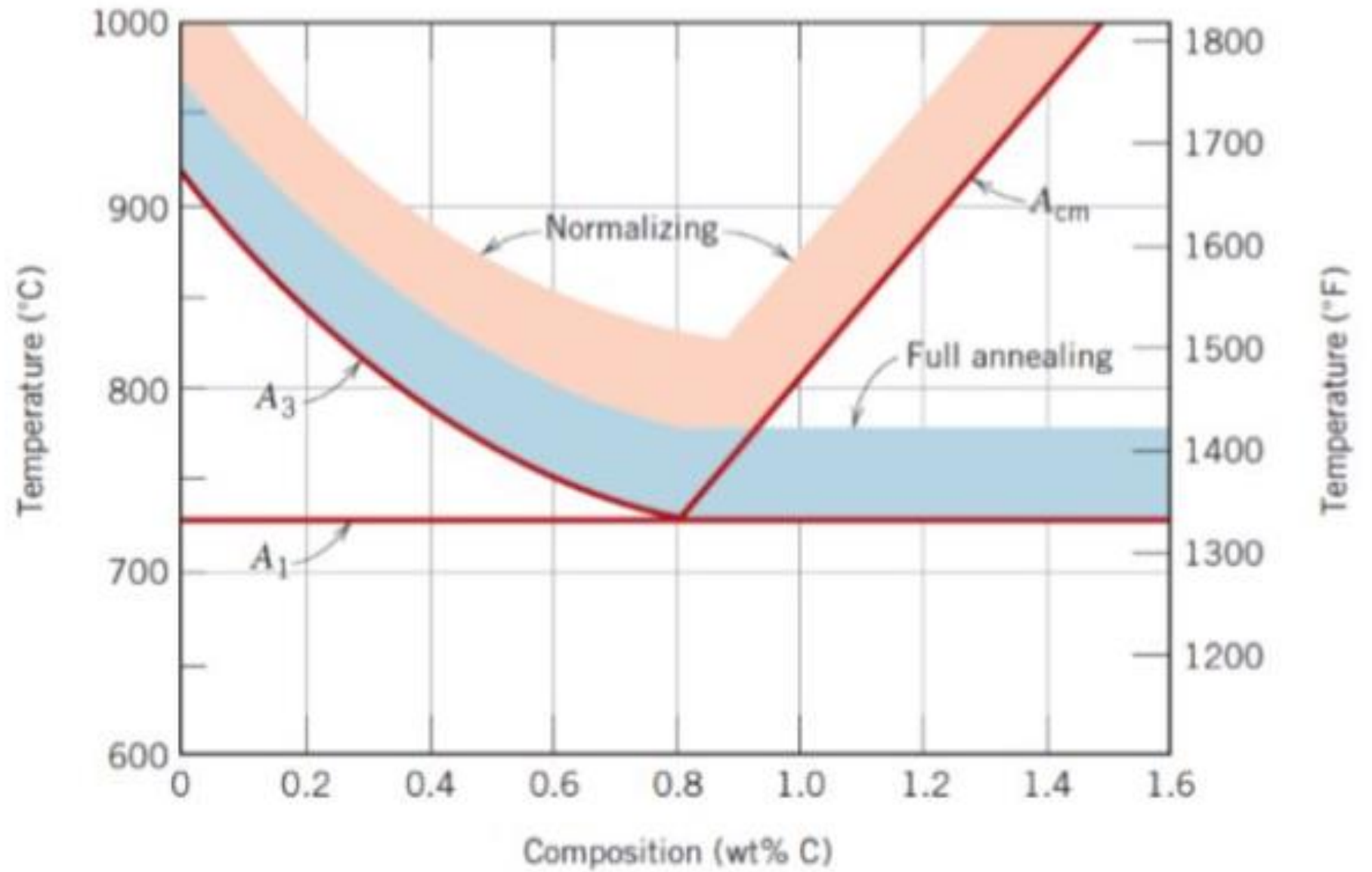


درجه حرارت بازگشت

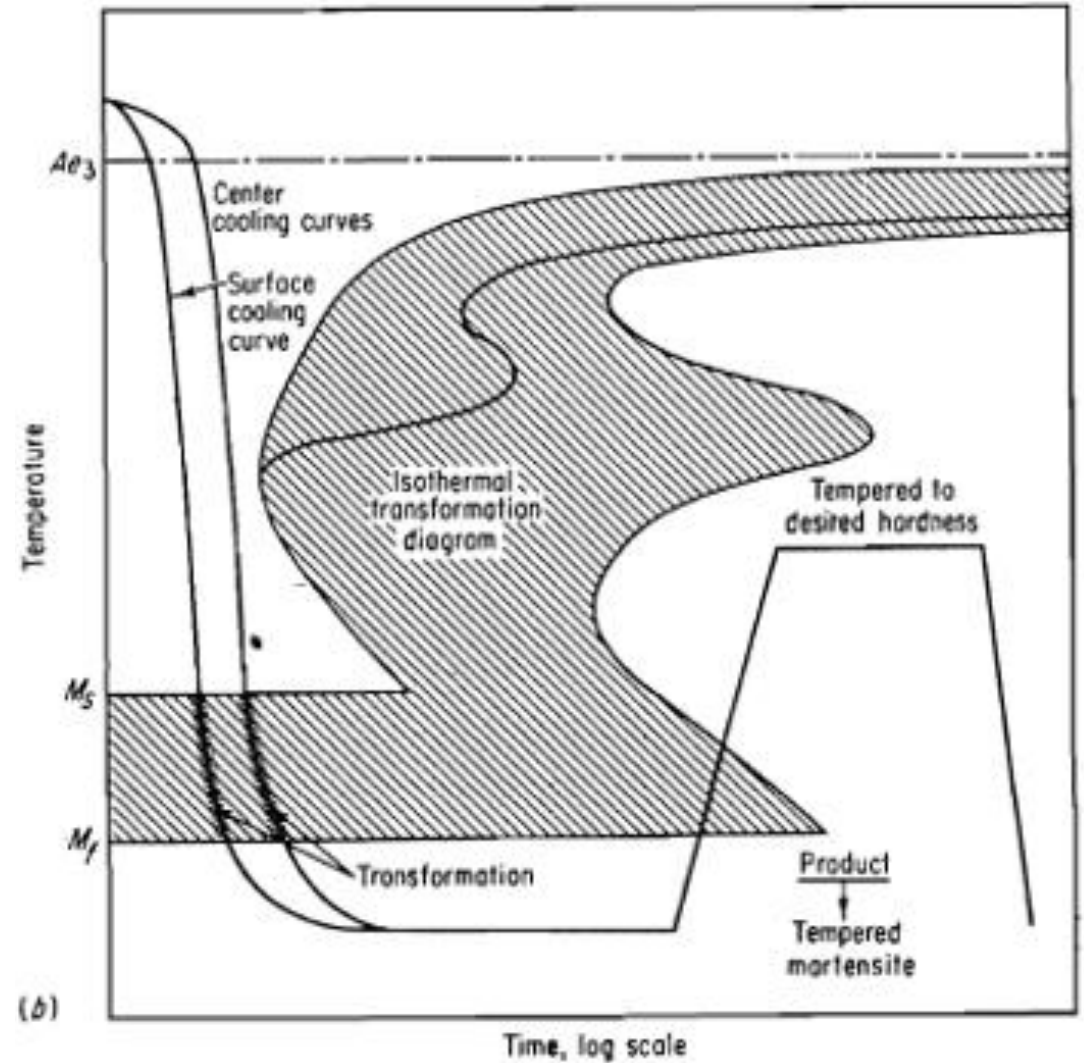
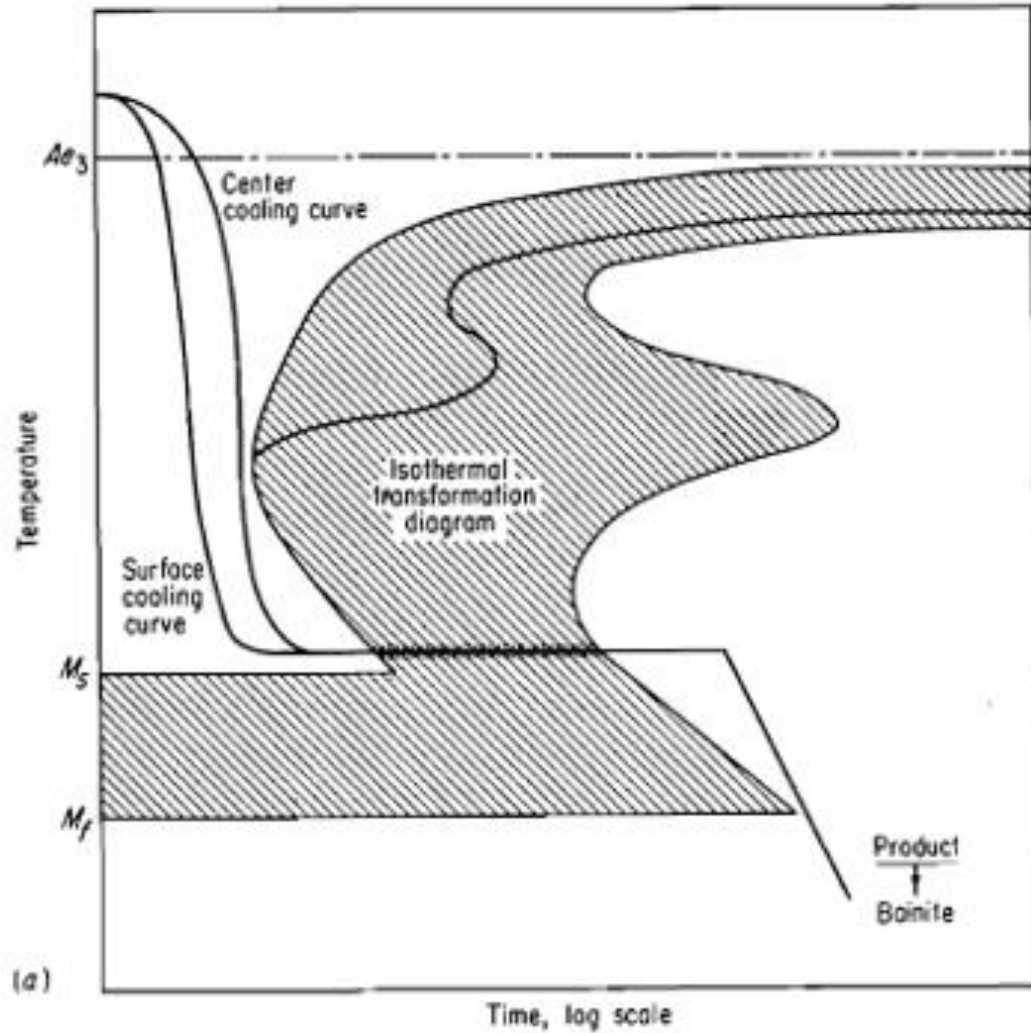








# عملیات حرارتی استمپرینگ و کوانچ و تمپر



# عملیات حرارتی مارتمپرینگ یا مار کوانچینگ

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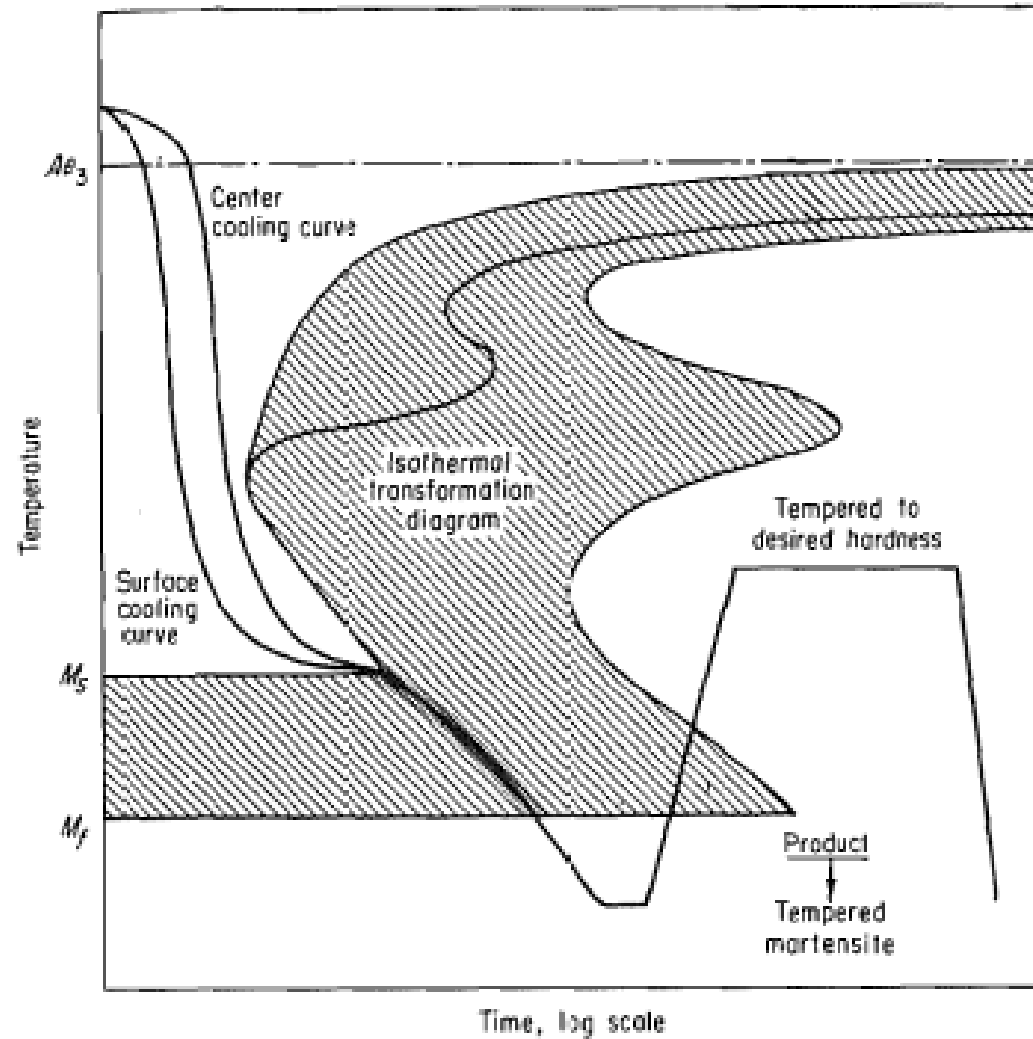


Fig. 8-86 Schematic transformation diagram illustrating martempering or marquenching. (From "U.S.S. Carilloy Steels." U.S. Steel Corporation.)



# انواع مختلف فرایند های کوانچ

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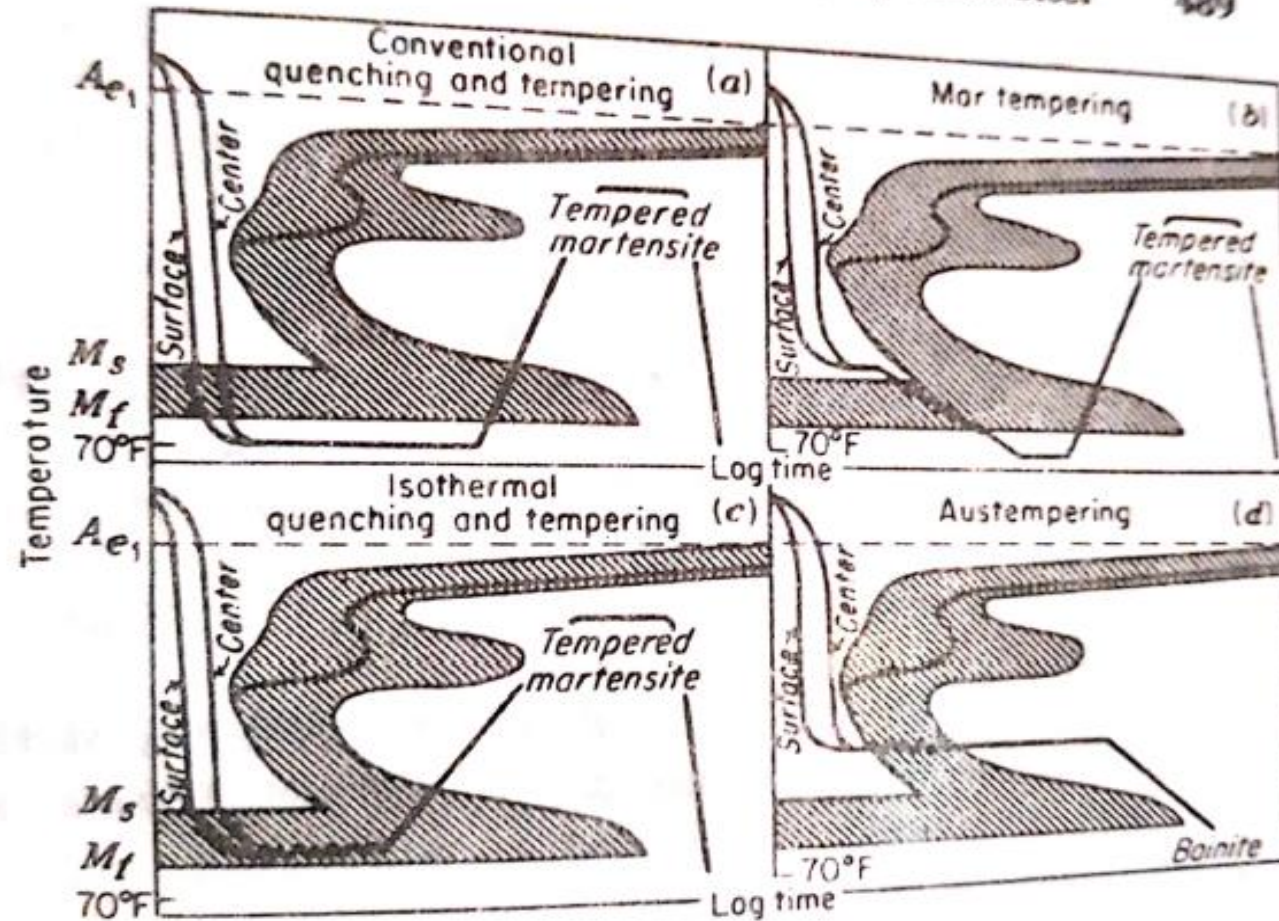


Fig. 17.15 Various types of quenching processes. (Courtesy of Steel Founders' Society of America.)

# منحنی های سرد کردن

49

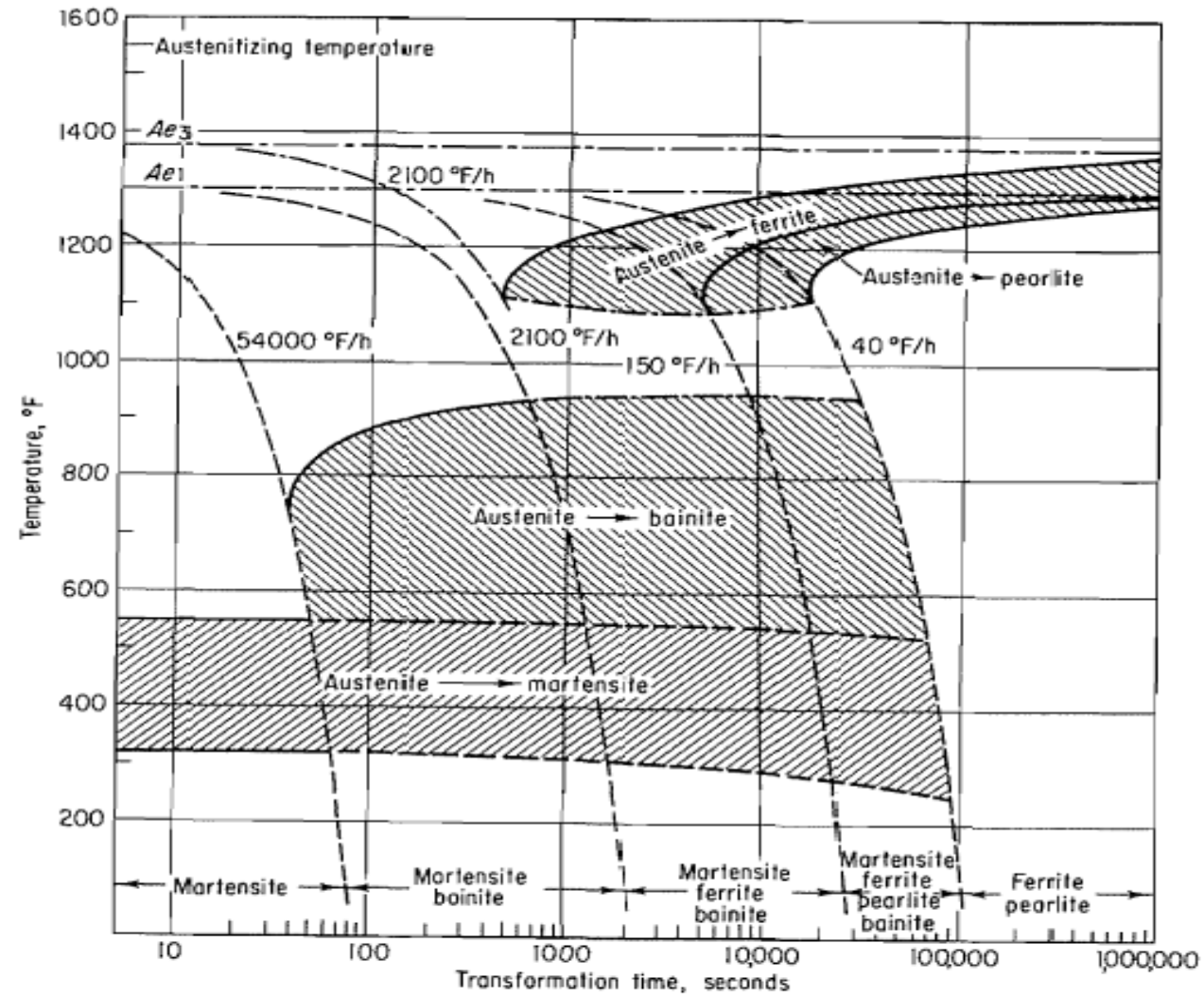
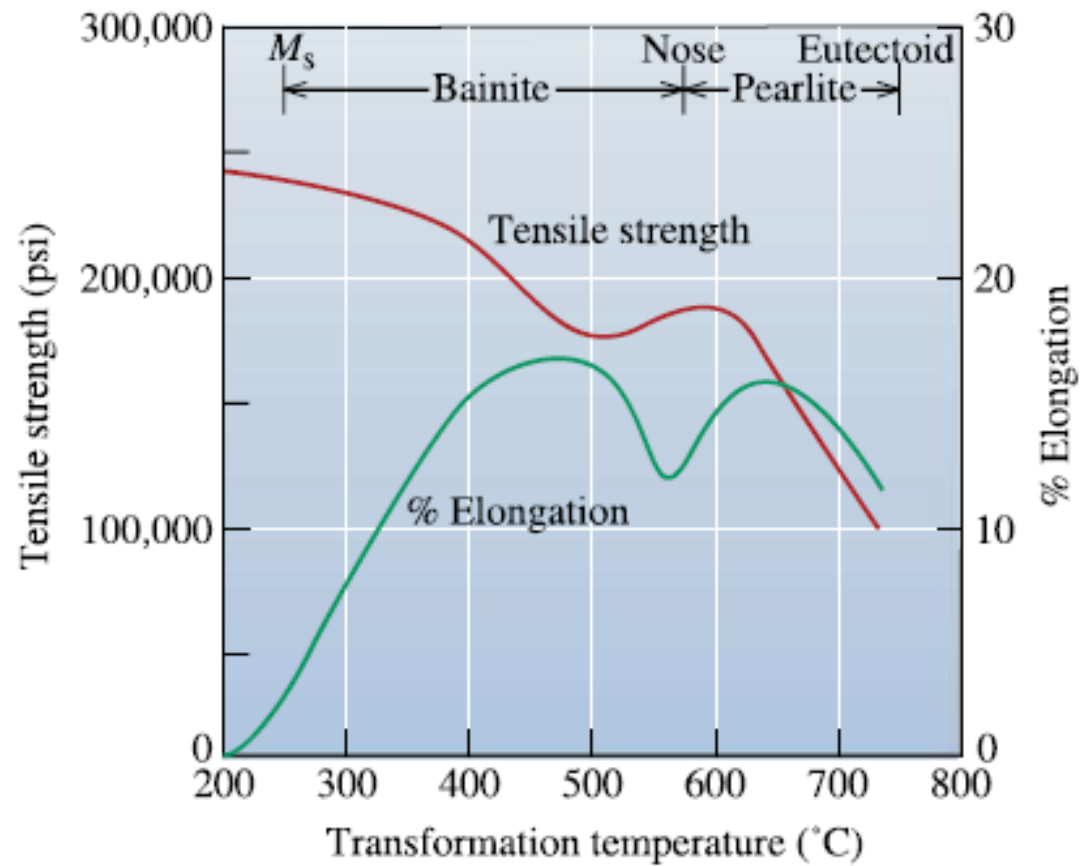


Fig. 8-26 C-T diagram of a triple-alloy steel (4340): 0.42 percent carbon, 0.78 percent manganese, 1.79 percent nickel, 0.80 percent chromium, 0.33 percent molybdenum. (From "U.S.S. Carilloy Steels," U.S. Steel Corporation.)



**Figure 12-23**  
The effect of transformation temperature on the properties of a eutectoid steel.



# داگرام بوتکتیک

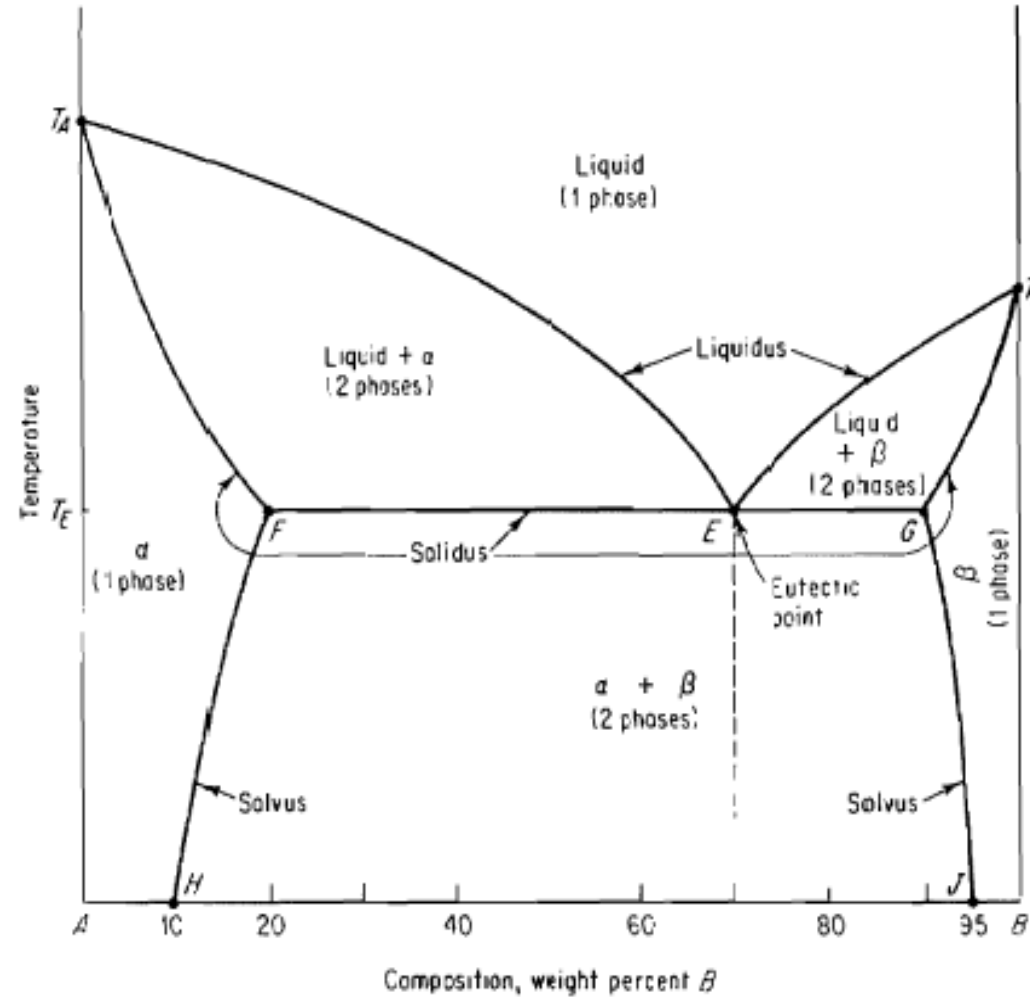


Fig. 6-23 Phase diagram illustrating partial solid solubility.

## Understanding of Fe –C Phase Equilibrium - 1946

Tool Available at the time:

- \*X-ray Diffraction
- \*Optical Metallography
- \*Thermocouples

Delta – BCC

Austenite – FCC

Ferrite – BCC

Cementite -  
Orthorhombic

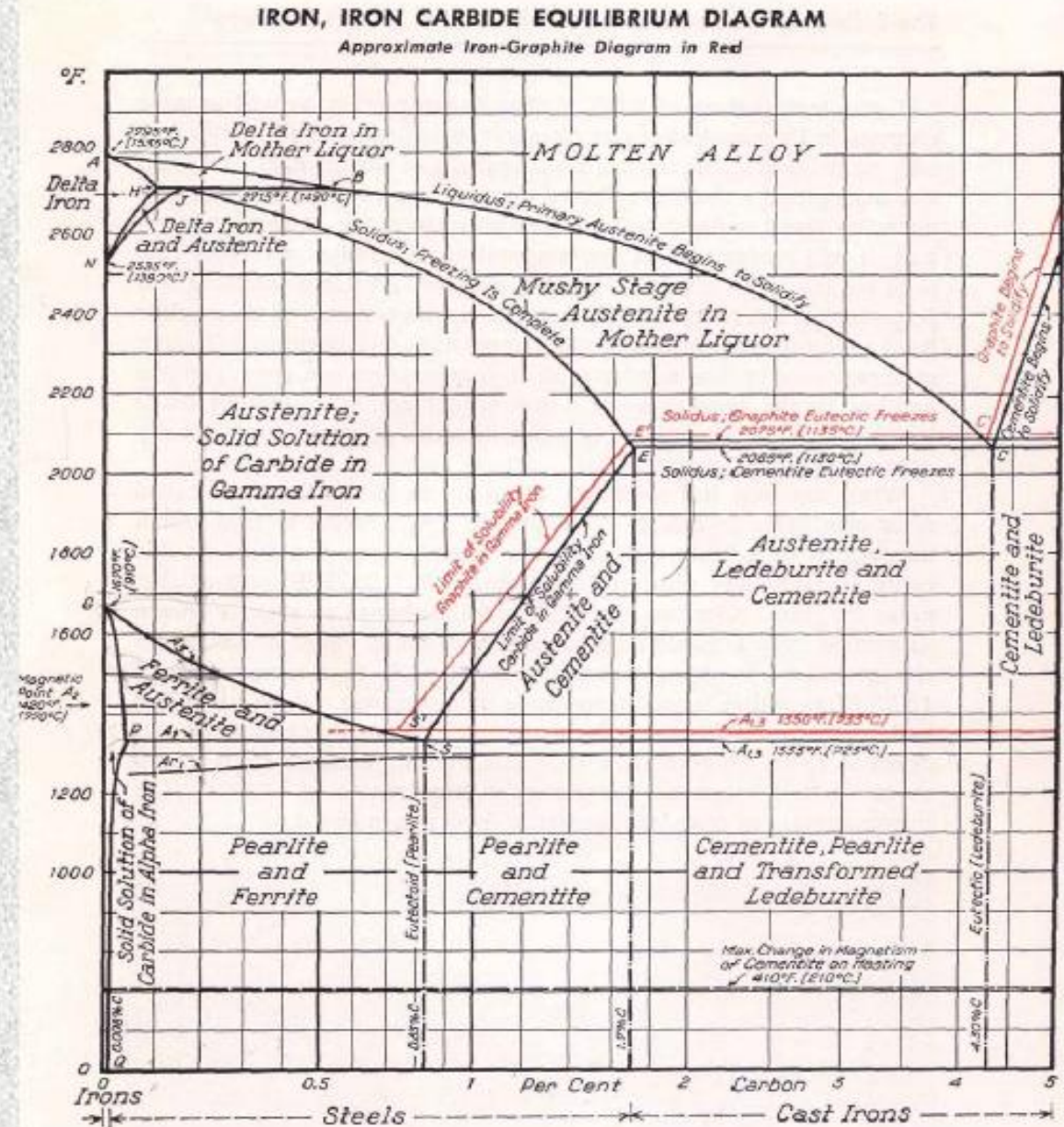
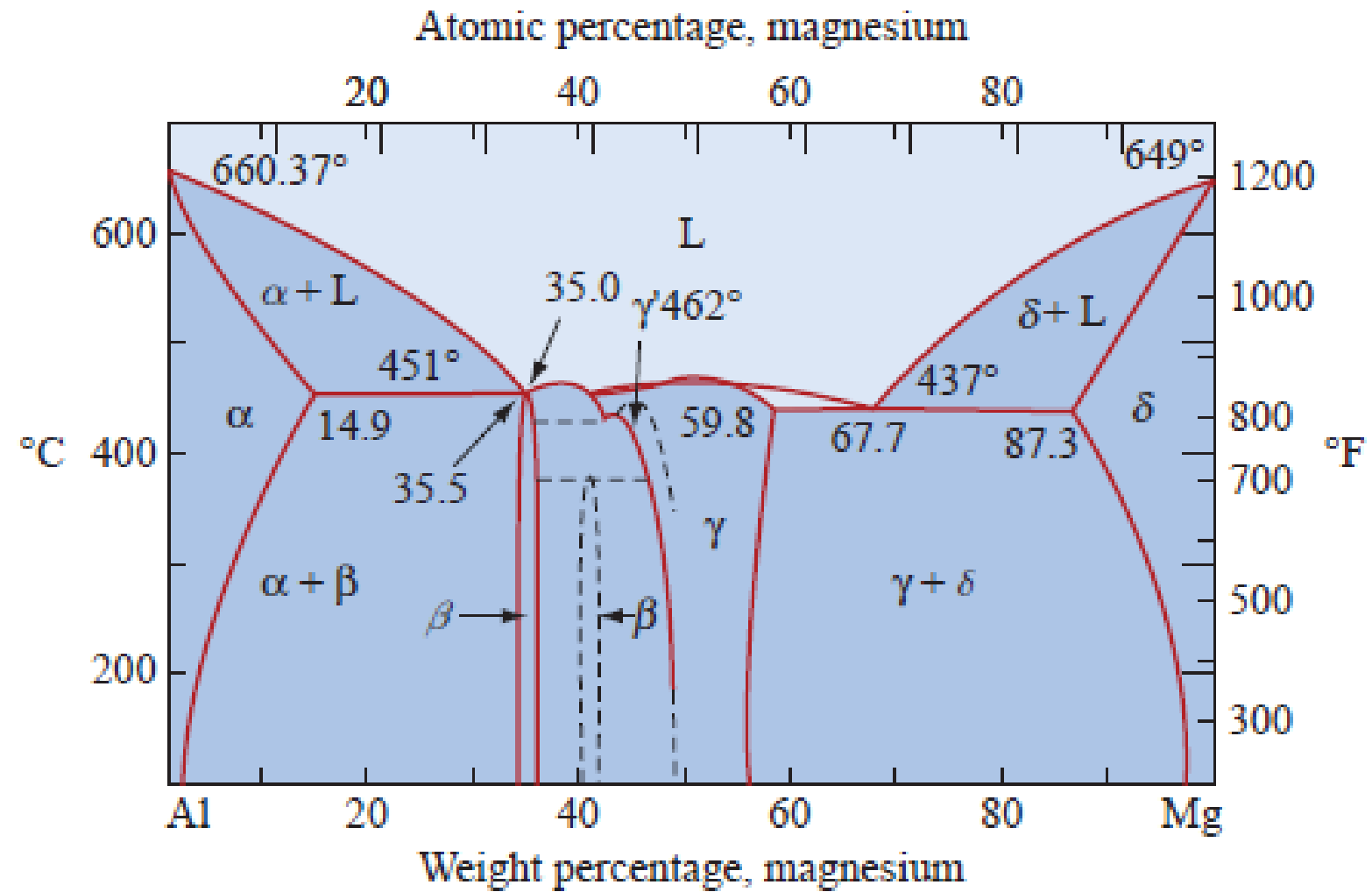


Fig. 3—The Iron-Carbon Equilibrium Diagram (Metal Progress July, 1946)



**Figure 12-10** The aluminum-magnesium phase diagram.