

Diagramas de fases:

- Limite de solubilidade

- Microestrutura

- Diagramas em sistemas metálicos monocomponentes

- Diagramas em sistemas binários

- Nucleação

- Crescimento e segregação de fases

- Transformação de fases em metais

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 - Diagramas em sistemas binários
 - Nucleação
 - Crescimento e segregação de fases
 - **Transformação de fases em metais**

Diagramas de fases:

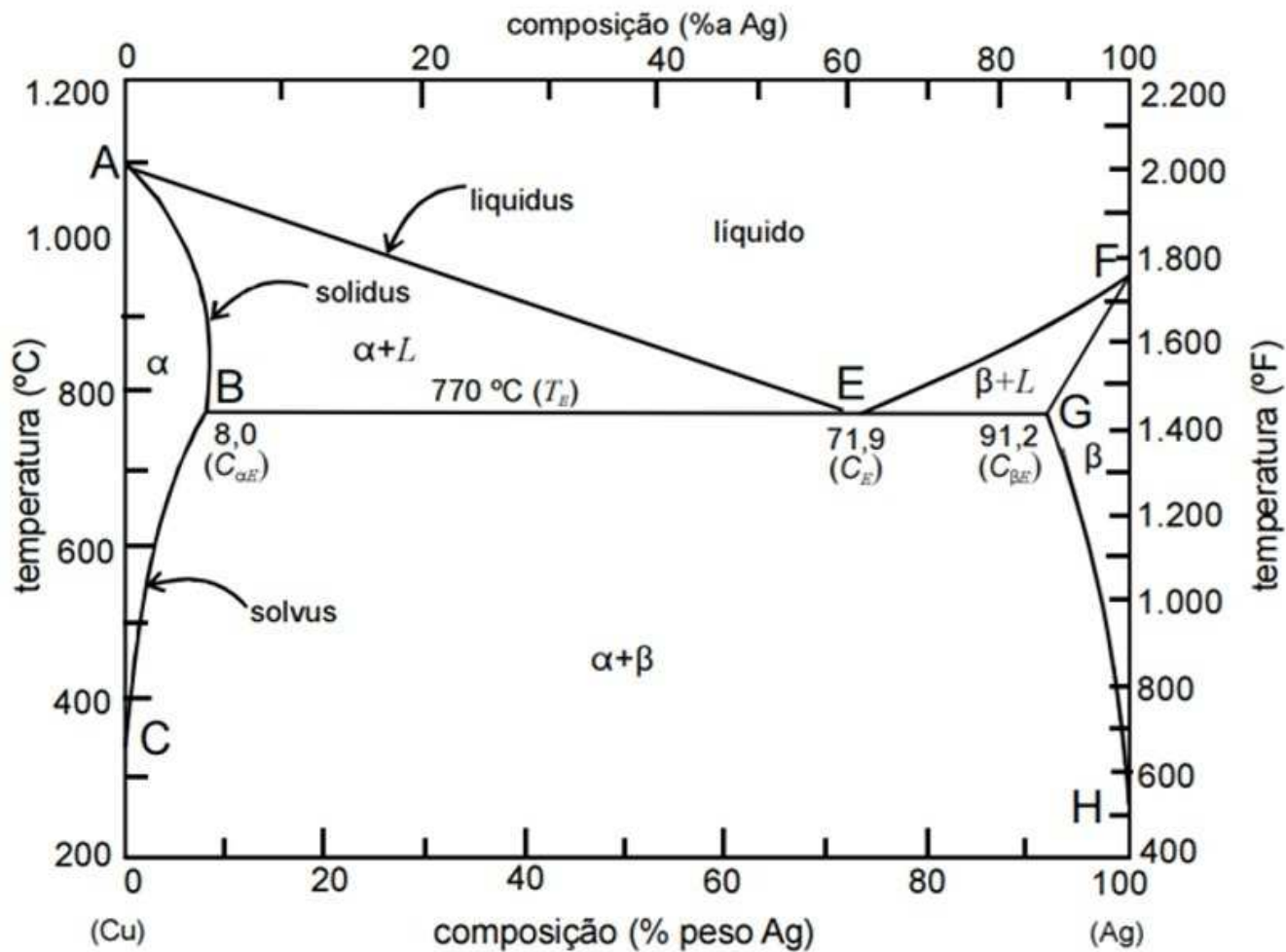
- Limite de solubilidade
- Microestrutura

- Diagramas em sistemas metálicos monocomponentes
- **Diagramas em sistemas binários**

Sistemas eutéticos binários

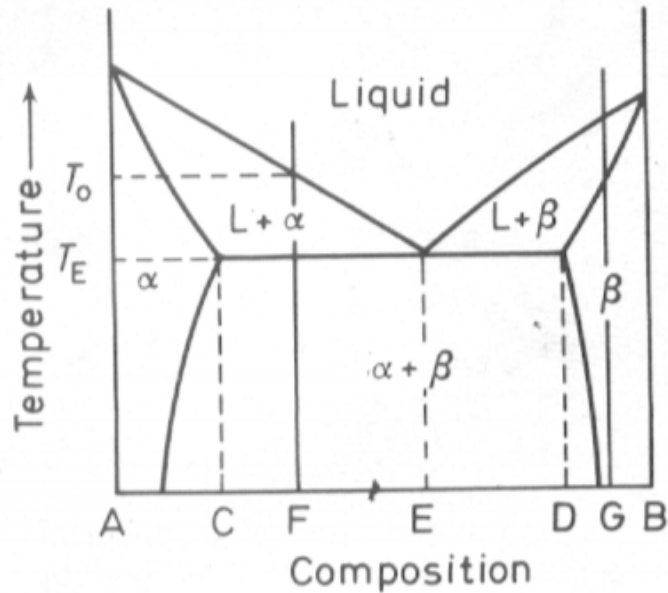
Tem apenas duas fases sólidas, α e β , que existem em faixas de composições próximas as extremidades de concentração do diagrama de fases (*soluções sólidas terminais*).

Diagrama de fases eutético binário

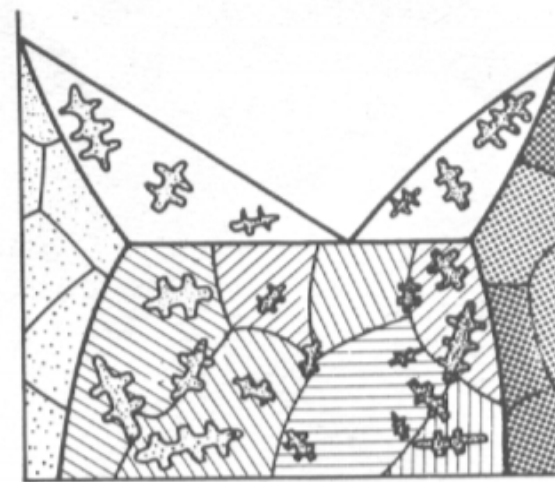


- ◆ Três regiões monofásicas: α , β e líquido (L).
- ◆ Fase α : Cu (solvente) e Ag (soluto), estrutura CFC.
- ◆ Fase β : Ag (solvente) e Cu (soluto), estrutura CFC.
- ◆ Solubilidade limitada da Ag no Cu e vice-versa.
- ◆ Três regiões bifásicas: $\alpha + \beta$, $\alpha + L$ e $\beta + L$.
- ◆ Ponto invariante eutético, E.
- ◆ Linha *liquidus*: separa as regiões L/($\alpha + L$) e L/($\beta + L$).
- ◆ Linha *solidus*: separa as regiões ($\alpha + L$)/ α e ($\beta + L$)/ β .
- ◆ Linha *solvus*: separa os campos α /($\alpha + \beta$) e β /($\alpha + \beta$).

Solidificação eutética

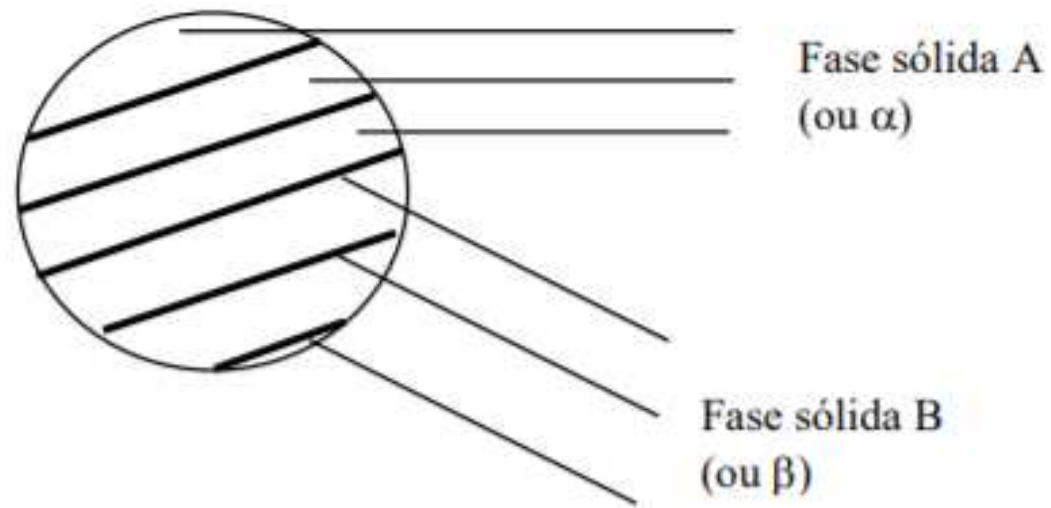


(a)



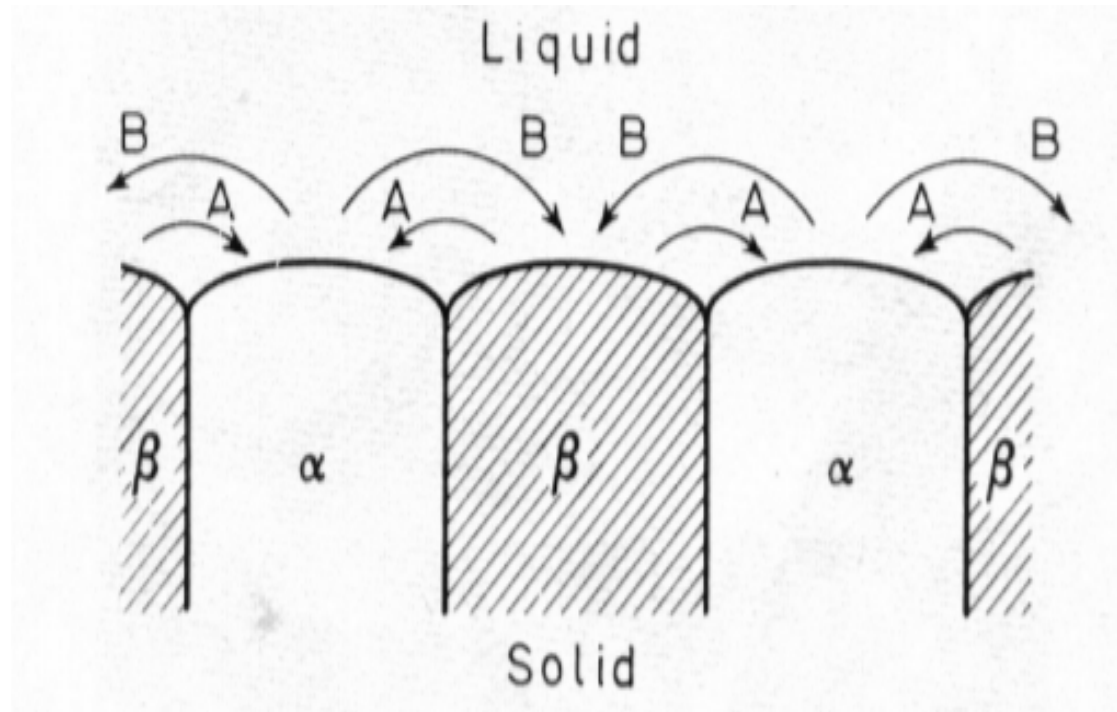
(b)

- (a) Digrama de equilíbrio eutético com todos campos de fases marcados
(b) Desenho esquemático do desenvolvimento das diferentes morfologias de todas as ligas através do diagrama de fases (equilíbrio).



Representação esquemática da microestrutura lamelar típica de um constituinte eutético

Difusão entre interfaces

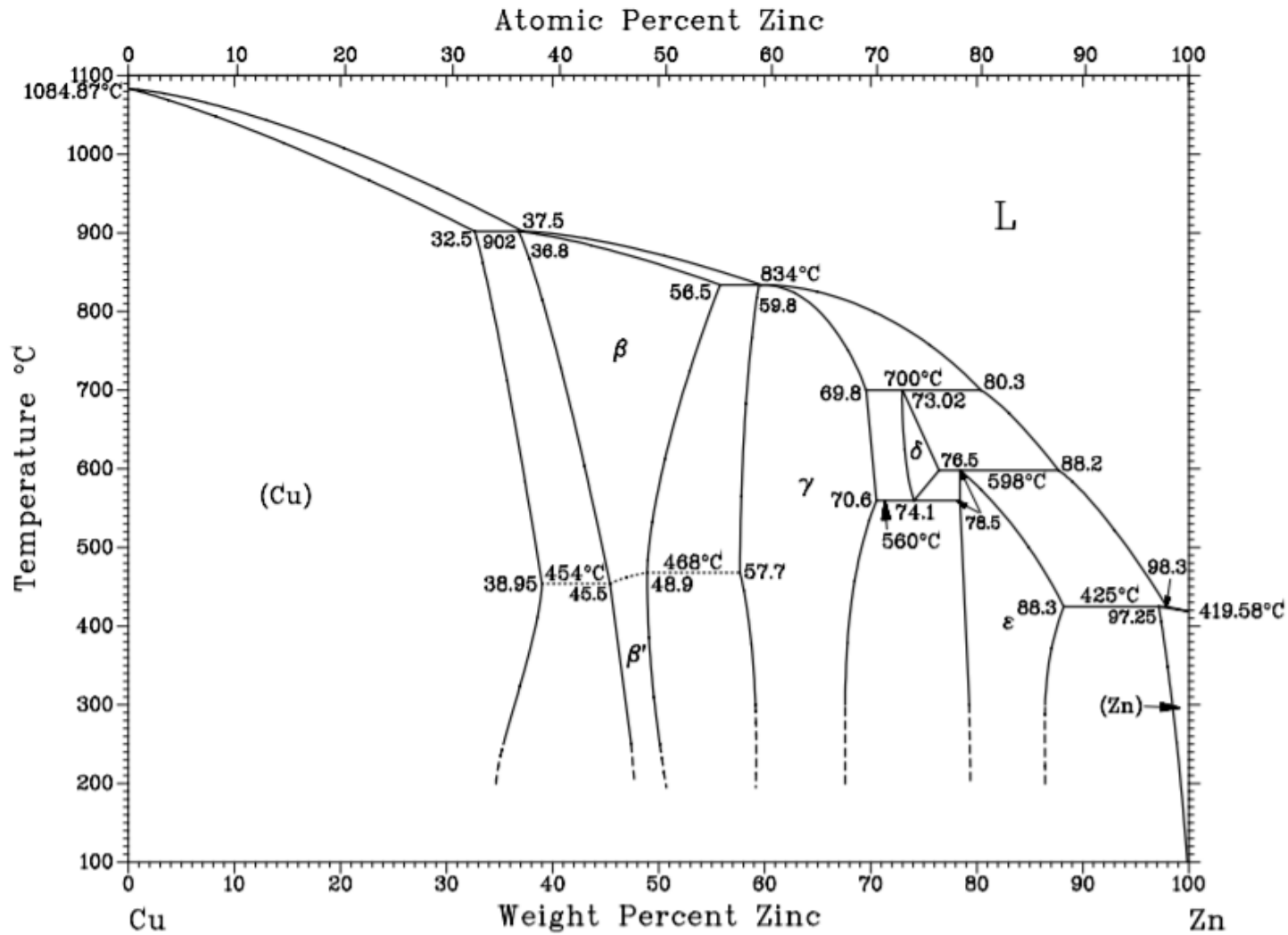


Forma idealizada da interface eutética sólido-líquido mostrando a inter-difusão do soluto acima da interface.

Reações eutetoides e peritéticas

Além do eutético, formam-se outros pontos invariantes envolvendo três fases diferentes. A formação de soluções sólidas intermediárias (ou fases intermediárias).

Diagrama de fases Cu – Zn

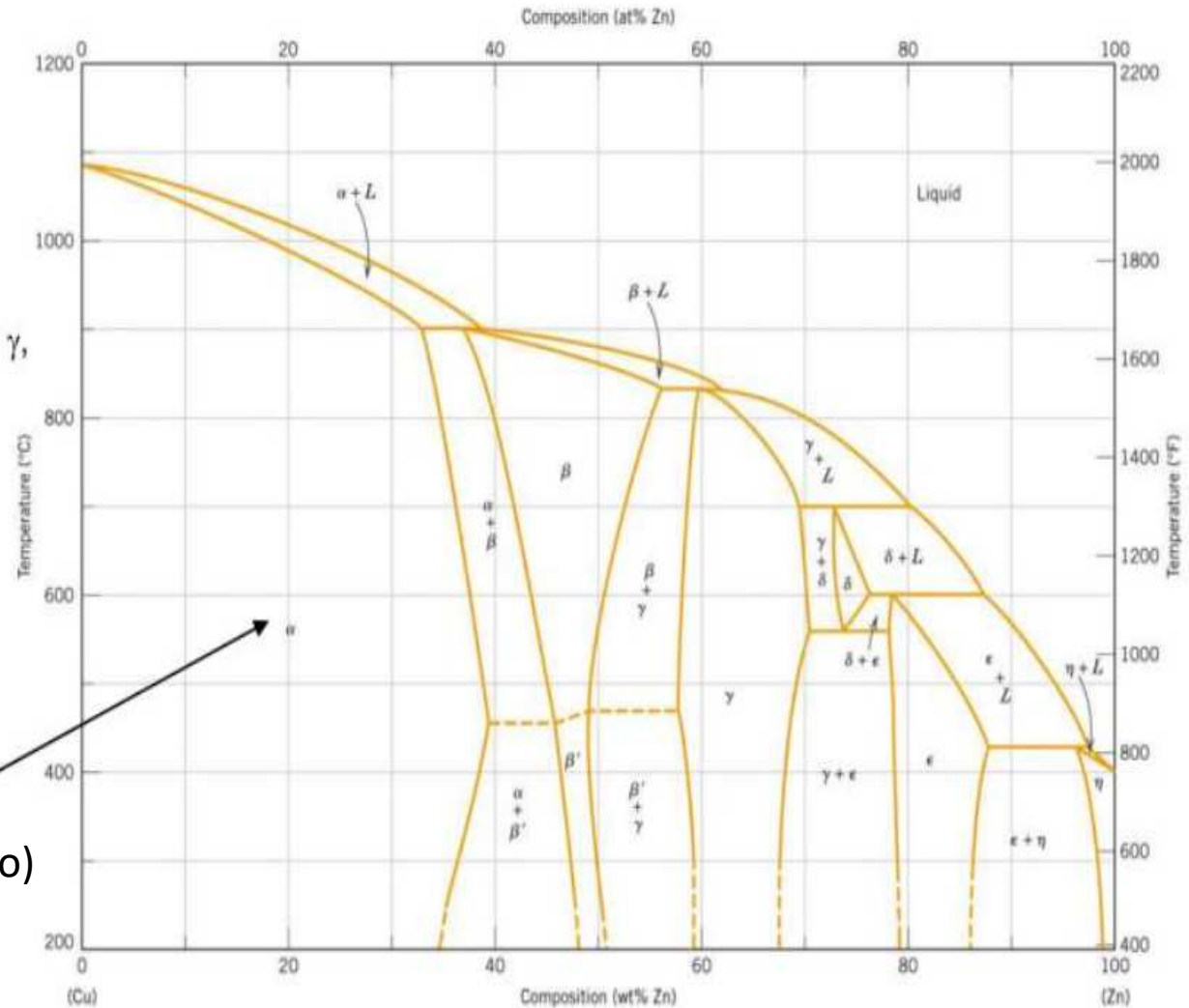


Sistema Cu-Zn

Duas soluções terminais α e η .

Quatro soluções intermediárias β , γ , δ e ϵ . β' é uma fase ordenada

Latão
(5 a 50 % de zinco)



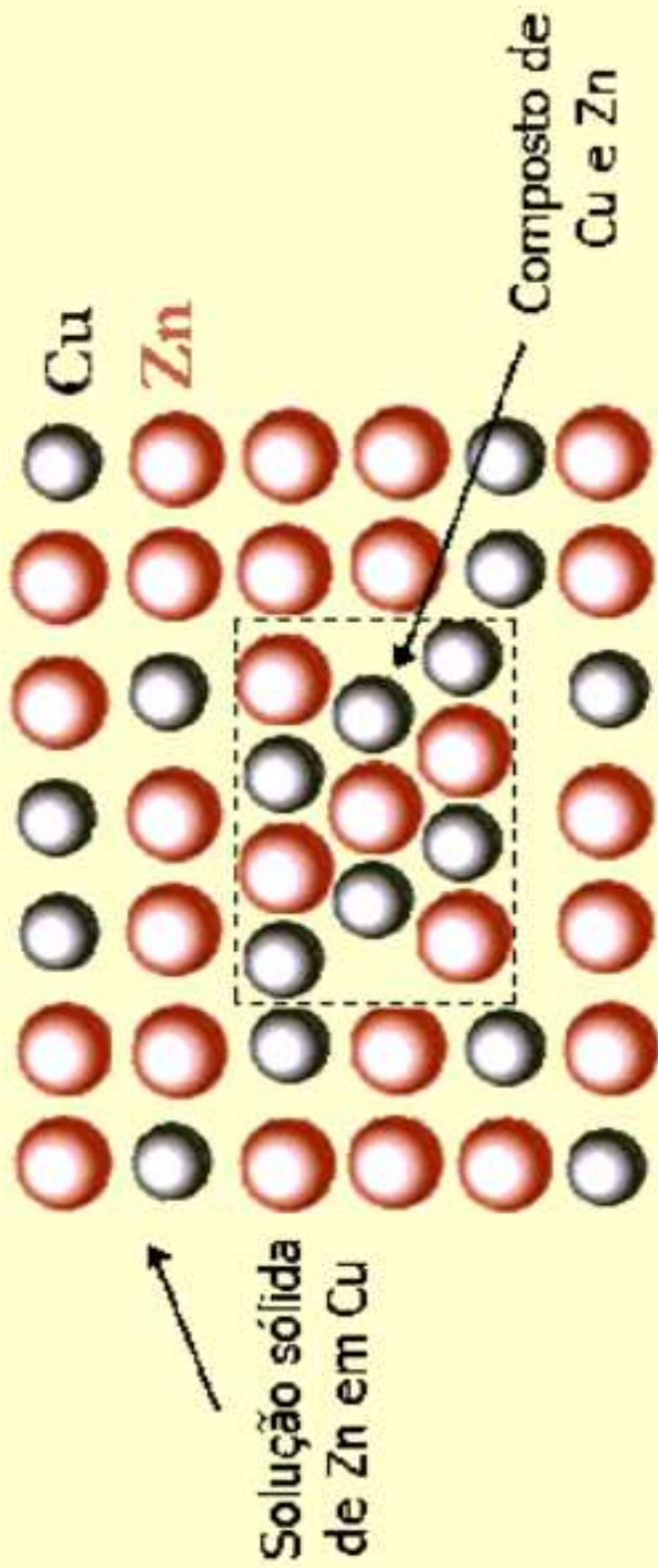
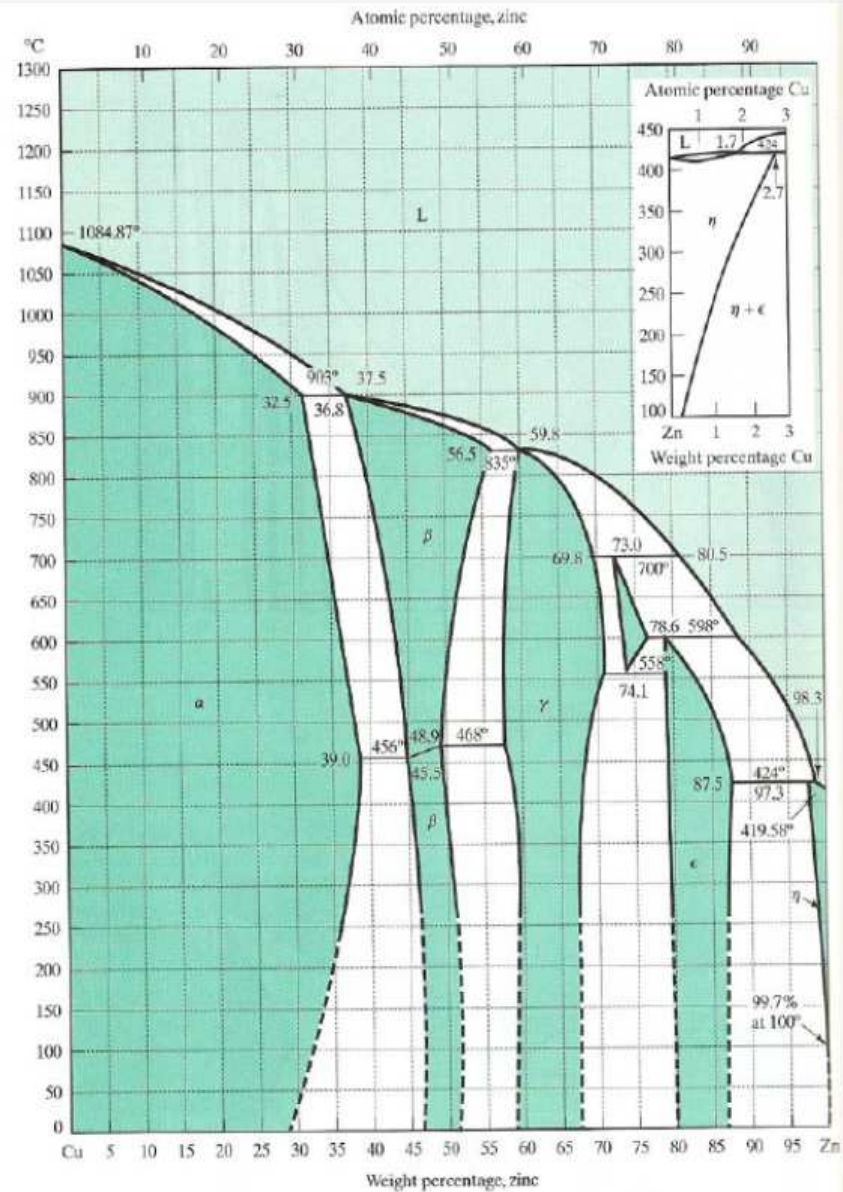
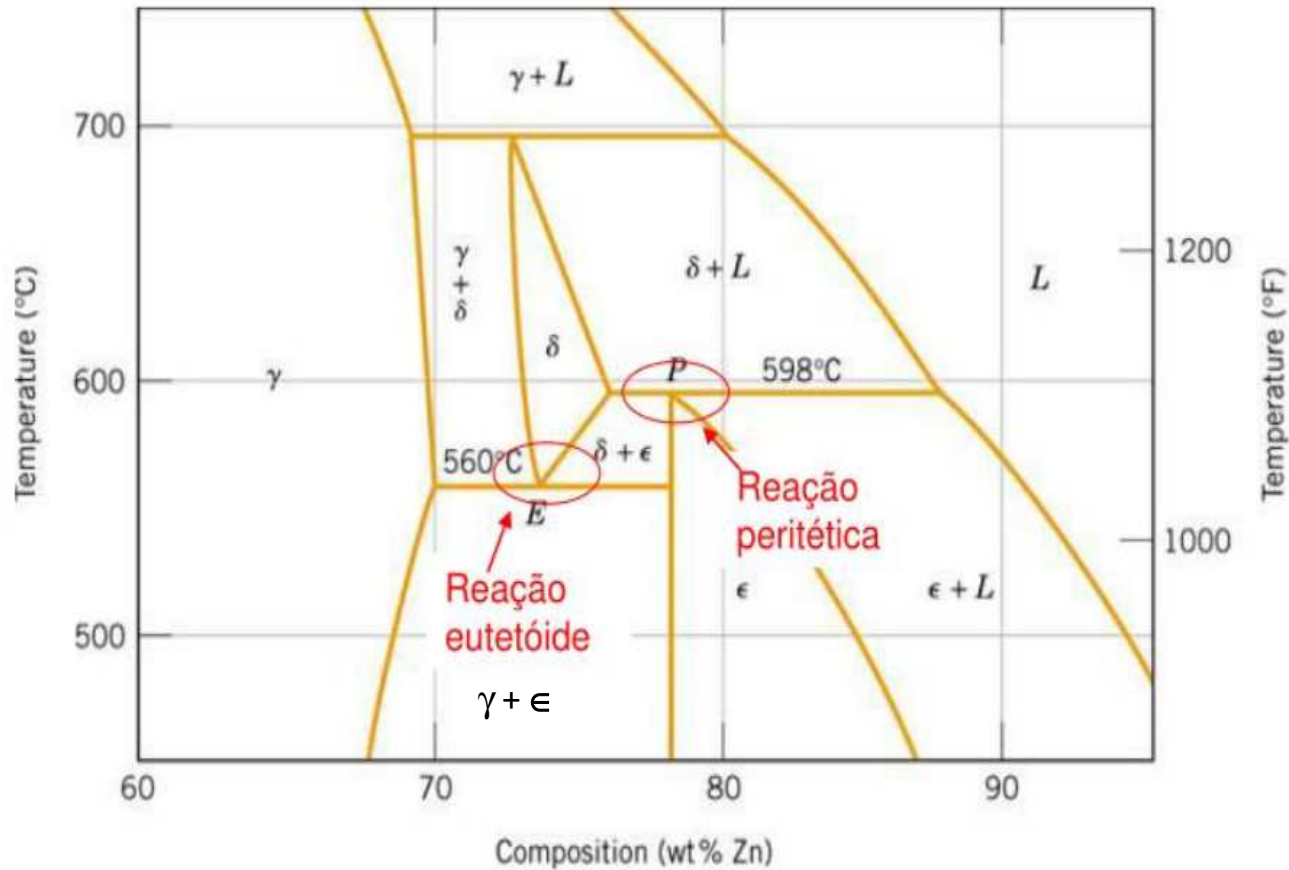


Figura 4 - Solubilidade sólida limitada Cu-Zn.

Diagrama de fases Cu – Zn:
 destaque para as
 soluções sólidas
 α , β , γ , δ , ϵ , η



Sistema Cu-Zn



Reação eutetóide (E):

560 °C, 74 % p Zn e 26 % p Cu

resfriamento

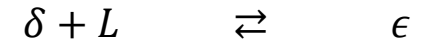


aquecimento

Reação peritética (P):

598 °C, 78,6 % p Zn e 21,4 % p Cu

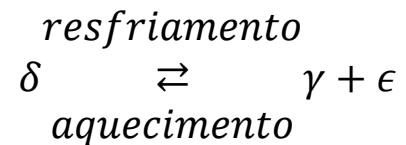
resfriamento



aquecimento

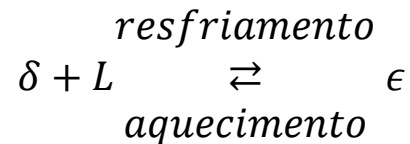
Reação eutetóide:

A *reação inversa de aquecimento* é chamad de *reação eutetóide*, o ponto invariante **E** é denominado de *eutetóide* e a isoterma é denominada de *isoterma eutetóide*:

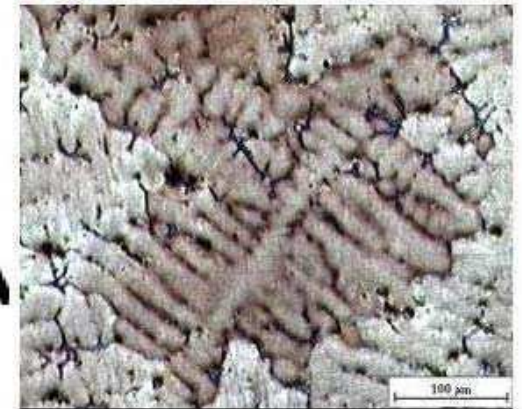
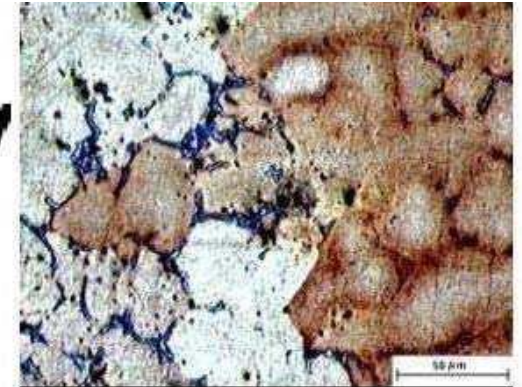
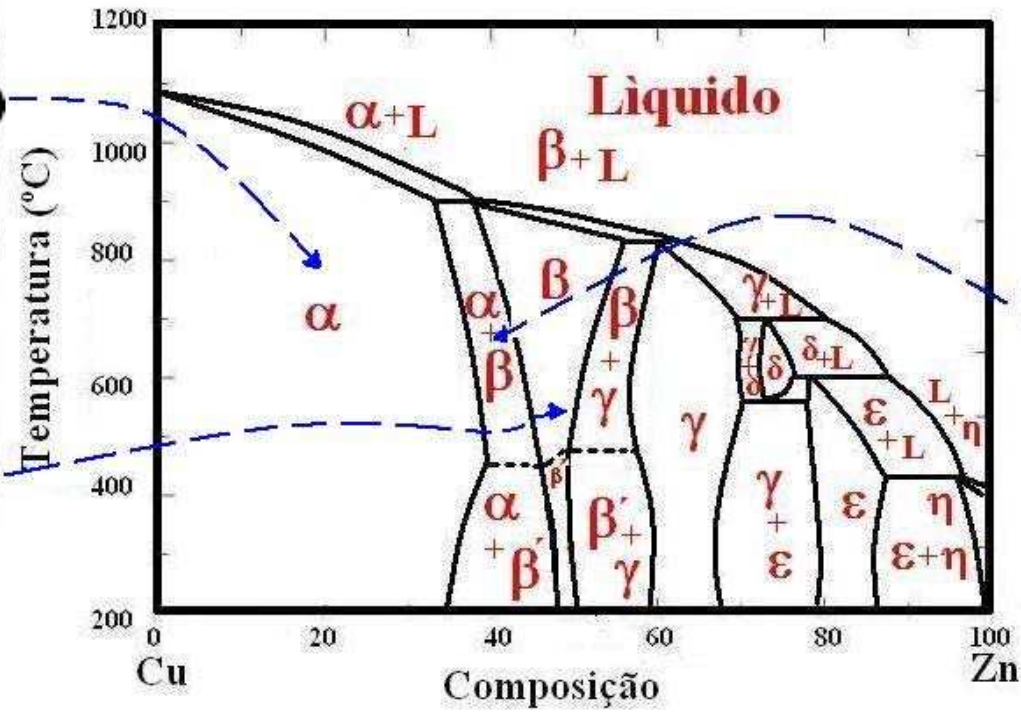


Reação peritética:

A *reação inversa de aquecimento* é chamad de *reação peritética*, o ponto invariante **P** é denominado de *peritéticou* e a isoterma é denominada de *isoterma peritetóide*.



Cu – Zn



Influência do Zinco na liga Cu – Zn:

- ◆ Aumenta a resistência mecânica;
- ◆ Baixa o ponto de fusão;
- ◆ Baixa o custo.

- ◆ Fase α \rightarrow CFC, dúctil e tenaz;
- ◆ Fase β \rightarrow CCC, mais resistente.

- ◆ A resistência à tração aumenta com o aumento do teor de Zn e a resistência à corrosão diminui;
- ◆ A partir de 30 % de Zn a ductilidade começa a diminuir;
- ◆ Até 37 % de Zn → fase α (latões α);
- ◆ 37 – 45 % de Zn → fases α e β (latões $\alpha + \beta$);
- ◆ 46 – 50 % de Zn → fase β (latões β);
- ◆ Acima de 50 % de Zn começa a precipitar a fase γ que é quebradiça.

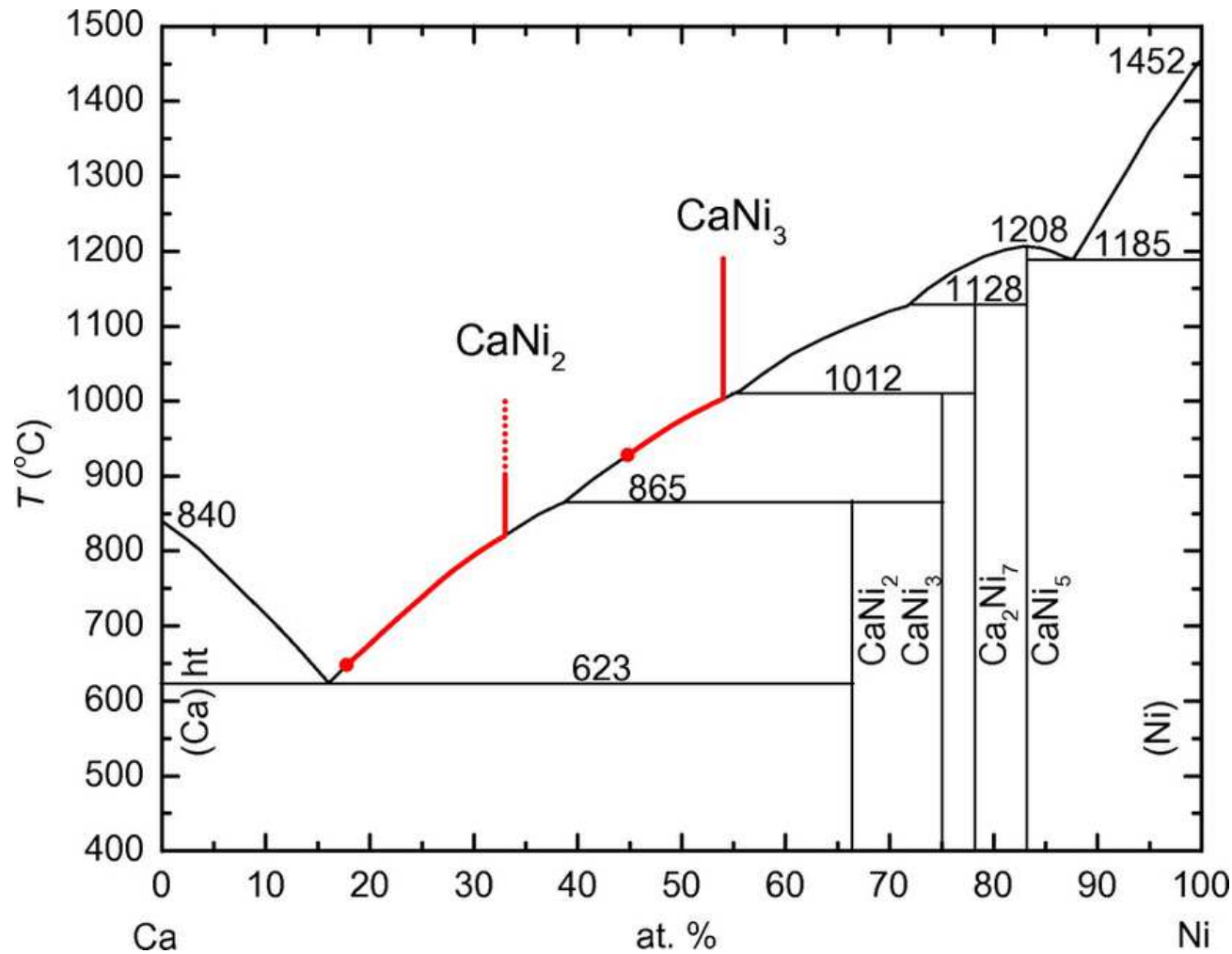
Aplicações do Latão

- Esta liga é utilizada em moedas, medalhas, bijuterias, radiadores de automóvel, ferragens, cartuchos, diversos componentes estampados e conformados etc.



Transformações de fases congruentes

Diagrama de fase: cálcio – níquel



Contém os compostos intermediários, $CaNi_2$, $CaNi_3$, Ca_2Ni_7 e $CaNi_5$. O composto intermetálico $CaNi_5$ é dito ser um *composto que se fundem congruentemente*, uma vez que mantém sua composição como a do ponto de fusão. Os outros compostos são ditos *compostos que se fundem incongruentemente*

Diagrama de fases Mg – Pb

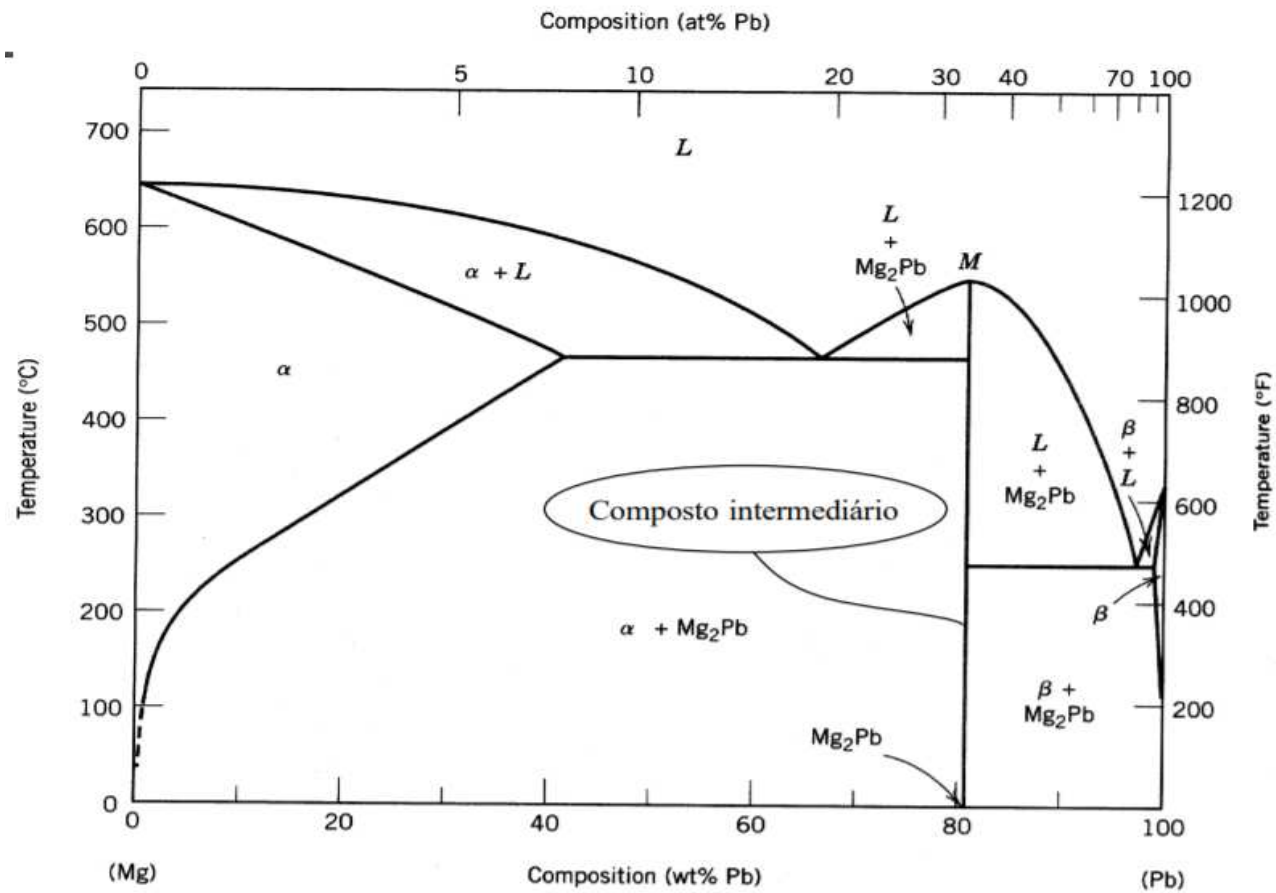
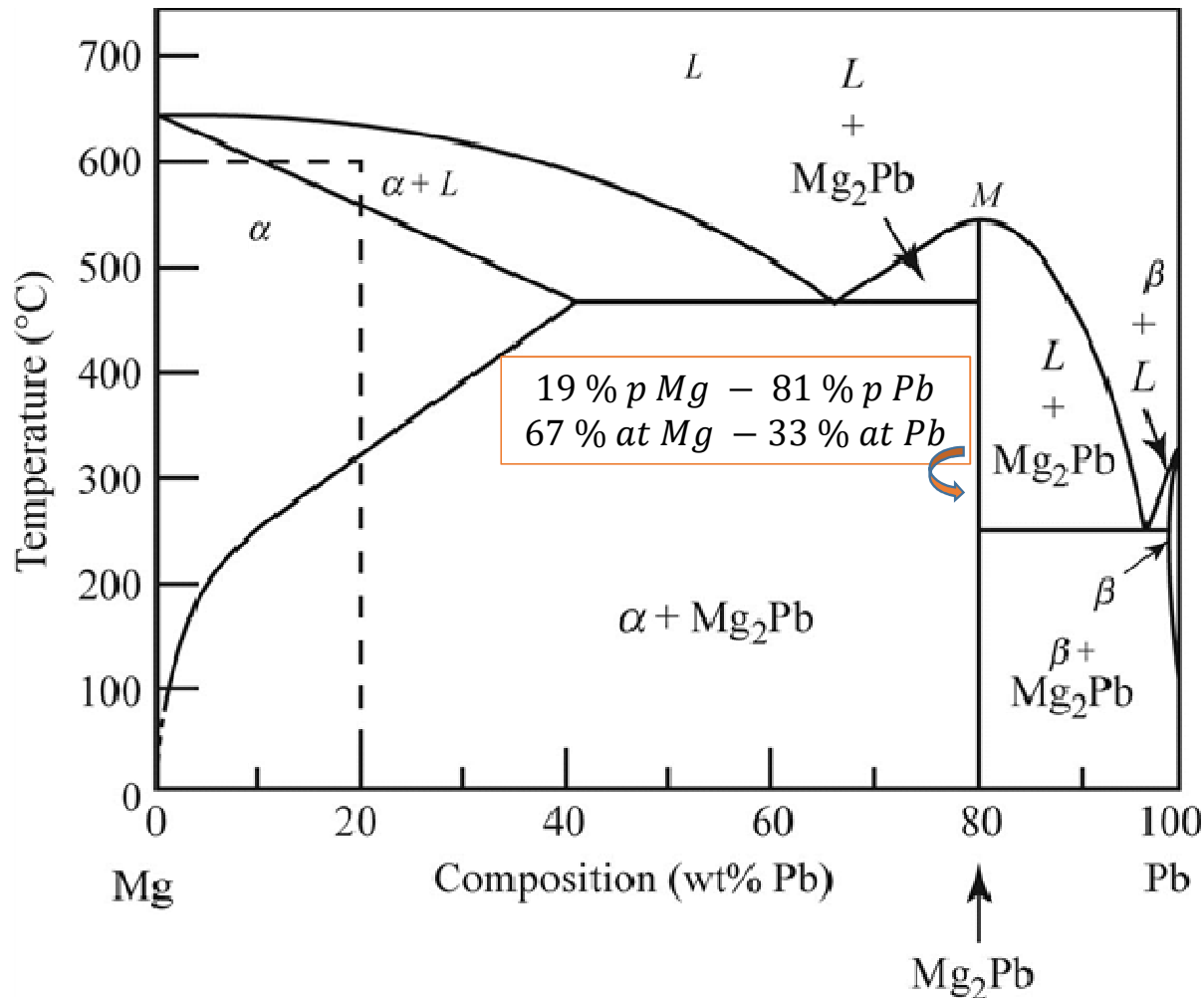


Diagrama de fases magnésio – chumbo



Os compostos intermetálicos formam uma linha no diagrama de fases, não uma região, devido a composição exata.

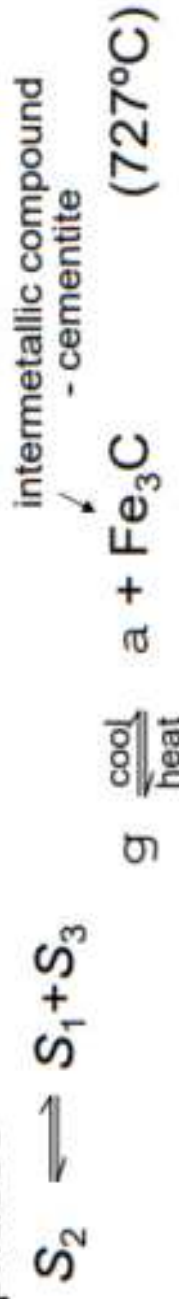
Observa-se do diagrama que se forma o composto intermetálico, Mg_2Pb , que se funde congruentemente em M

Eutectoid & Peritectic

- **Eutectic** - liquid in equilibrium with two solids



- **Eutectoid** - solid phase in equation with two solid phases



- **Peritectic** - liquid + solid 1 \rightarrow solid 2 (Fig 9.21)

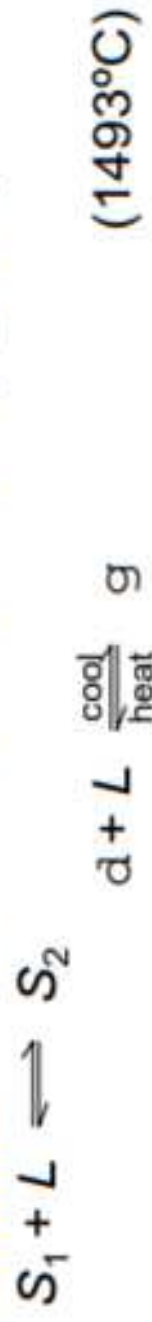
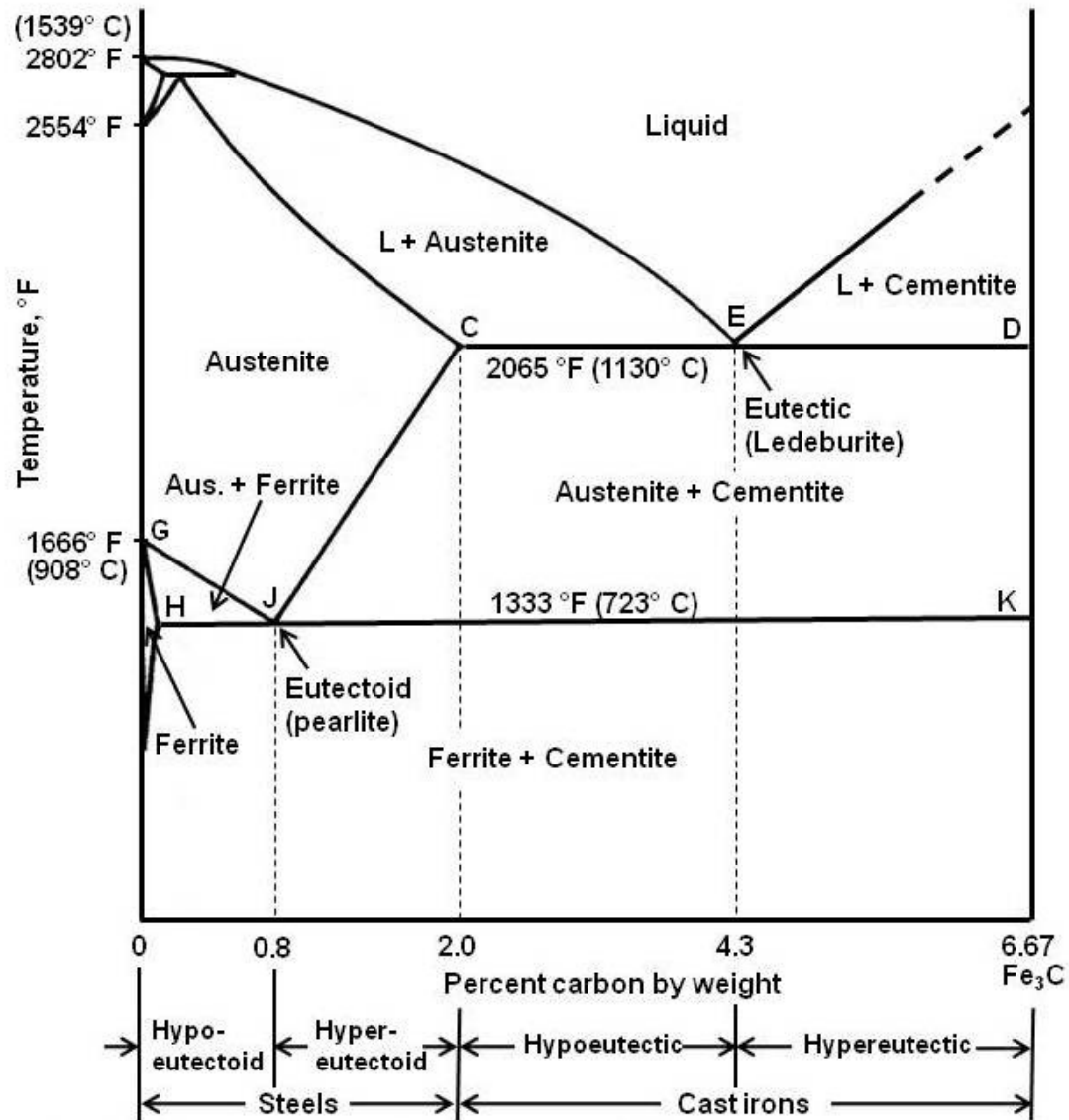


Diagrama de fases
ferro – carbono (carbeto de ferro)
($Fe - Fe_3C$)

Diagrama de fases
Fe – carbeto de ferro



The iron-iron carbide equilibrium diagram labeled with common names

Diagrama de fases Fe – carbeto de ferro

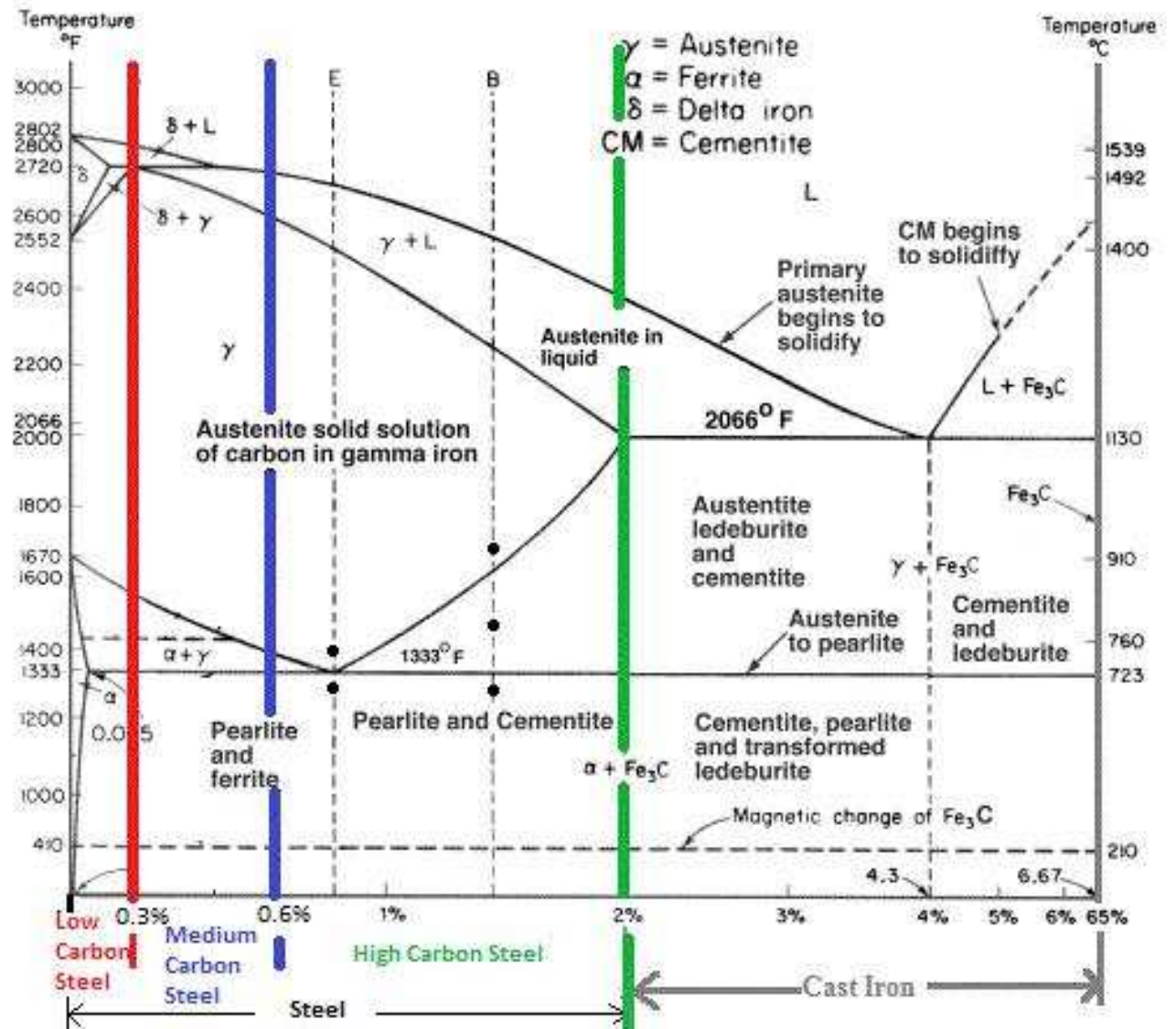
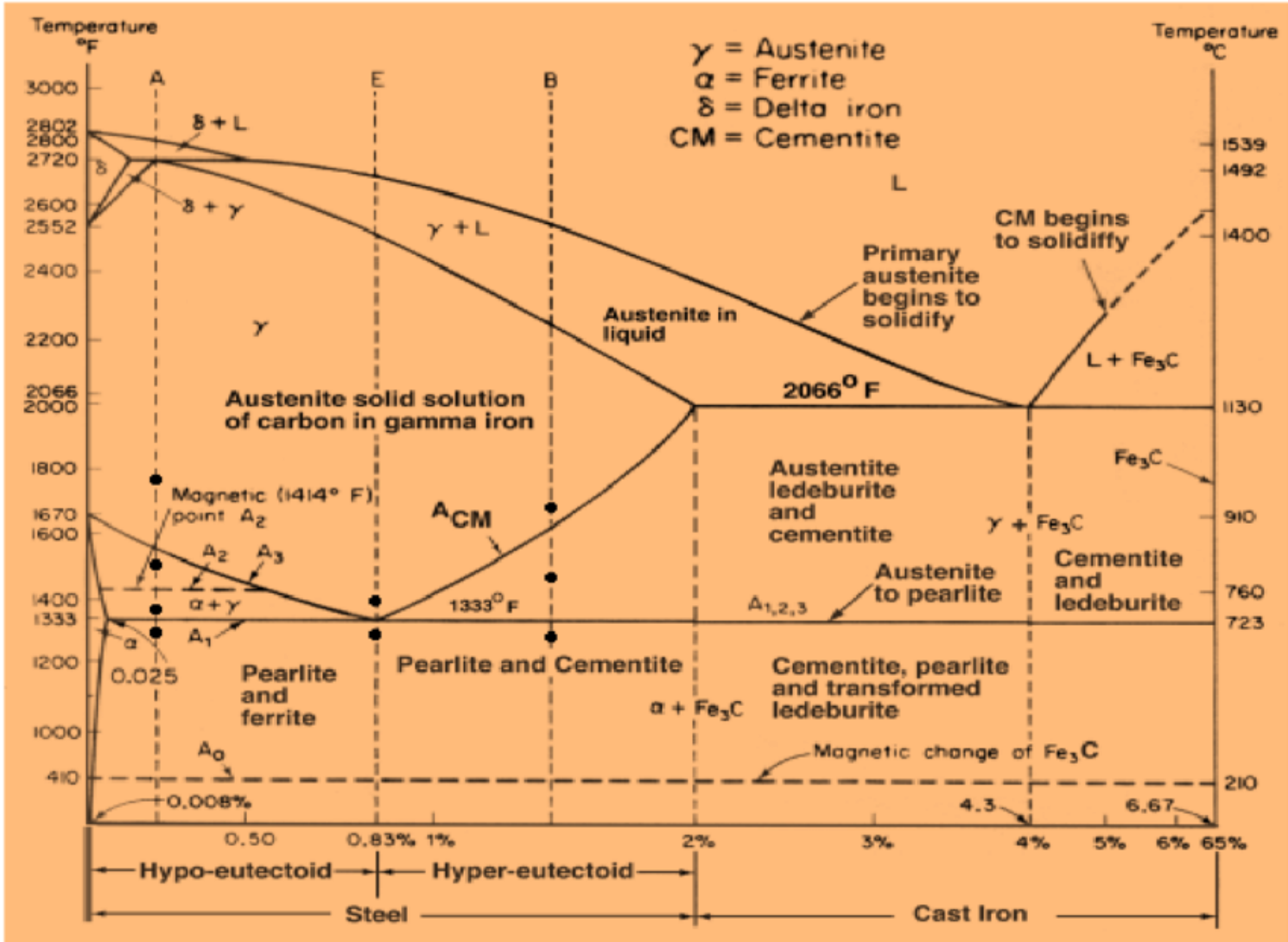


Diagrama de fases
Fe – carbeto
de ferro



Carbon steel, Fe-C phase diagram

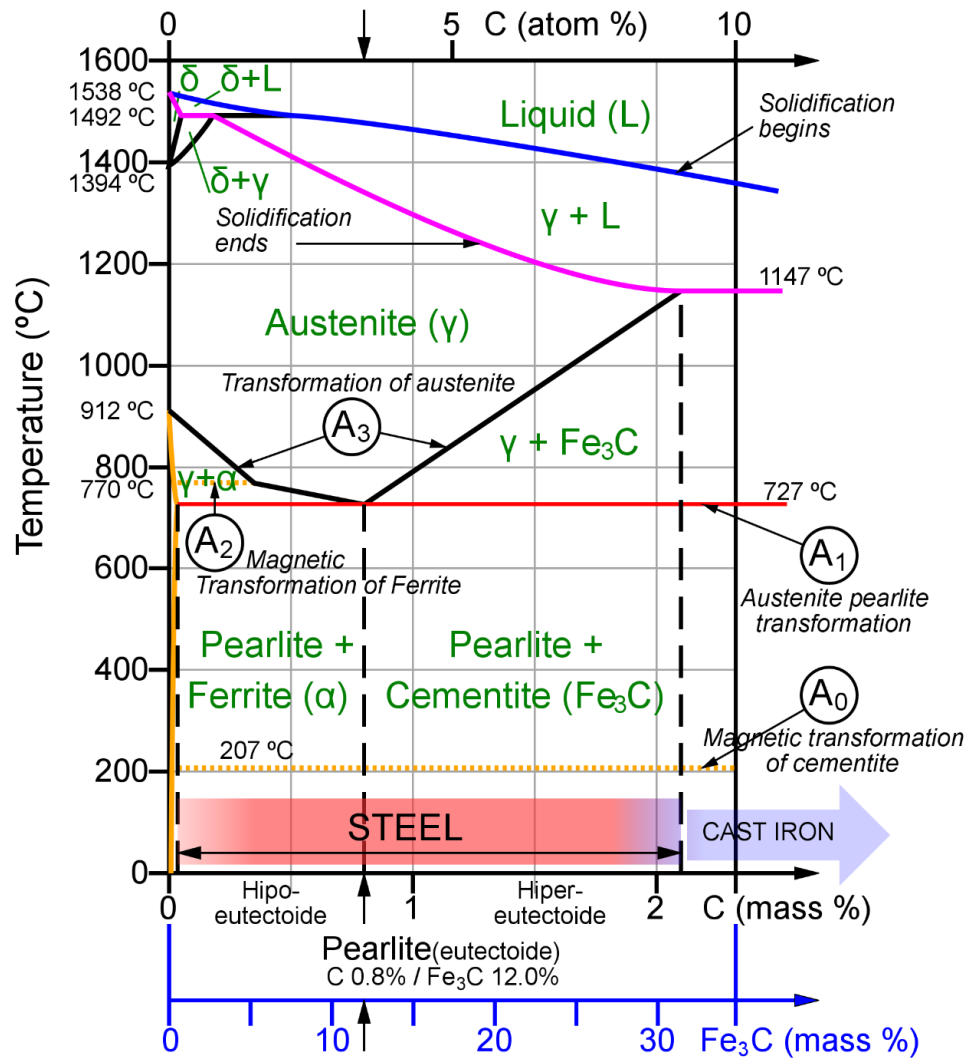


Diagrama de fases Fe – carbeto de ferro

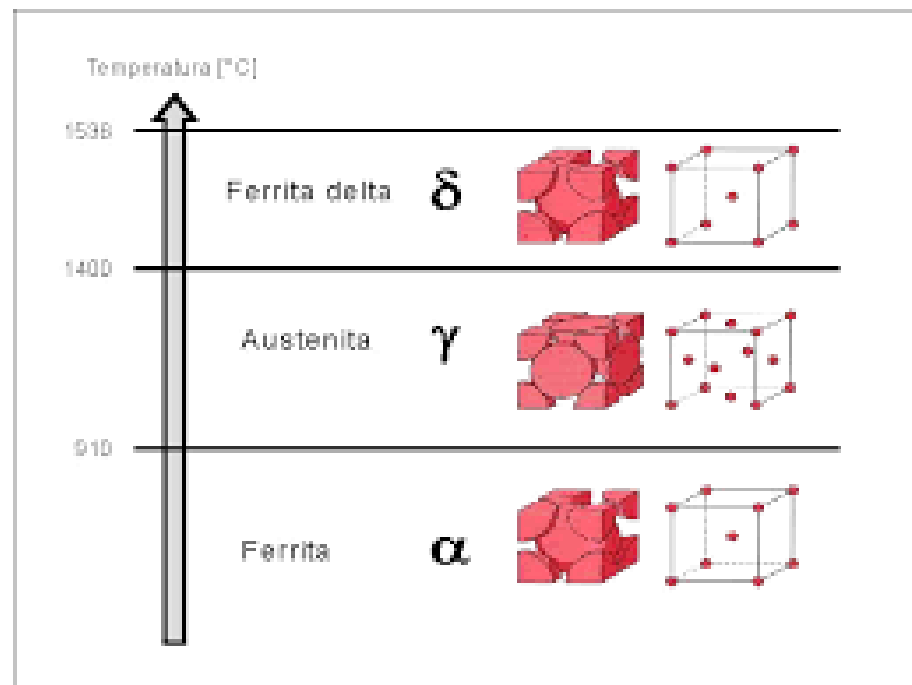
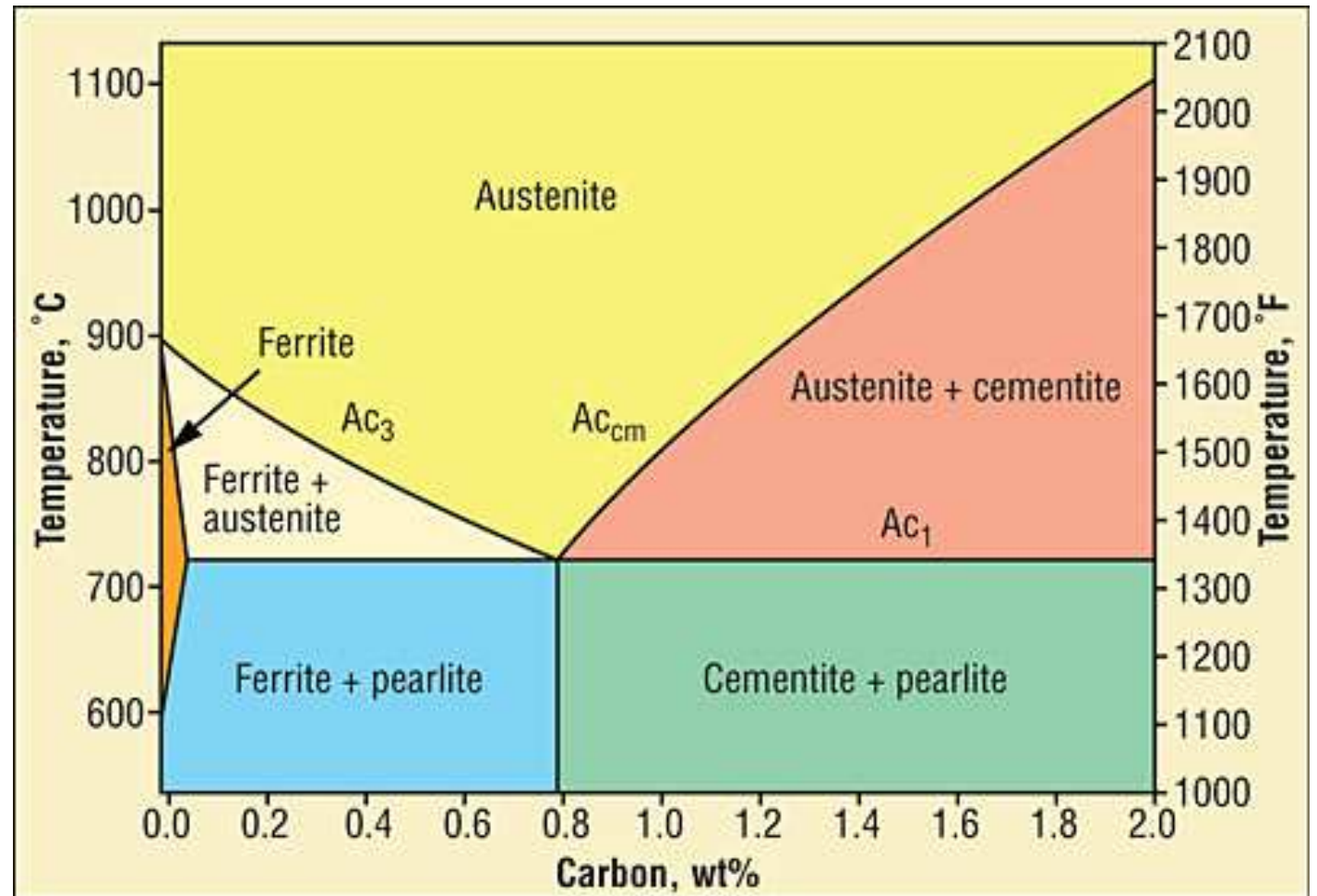
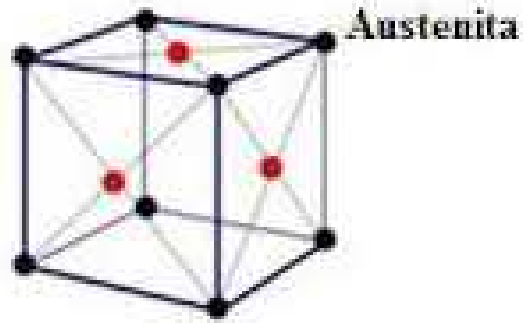
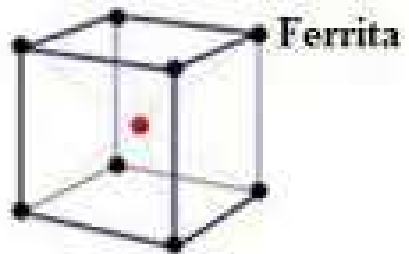


Diagrama de
fases Fe – carbeto
de ferro

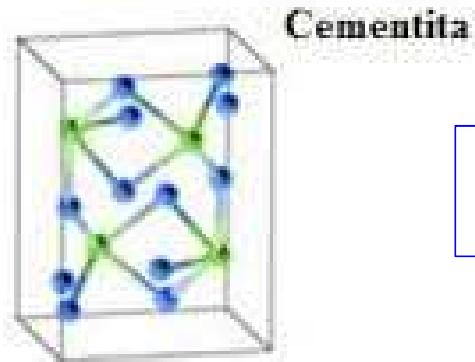




γ



α



Fe_3C

Diagrama de fases Fe – carbeto de ferro

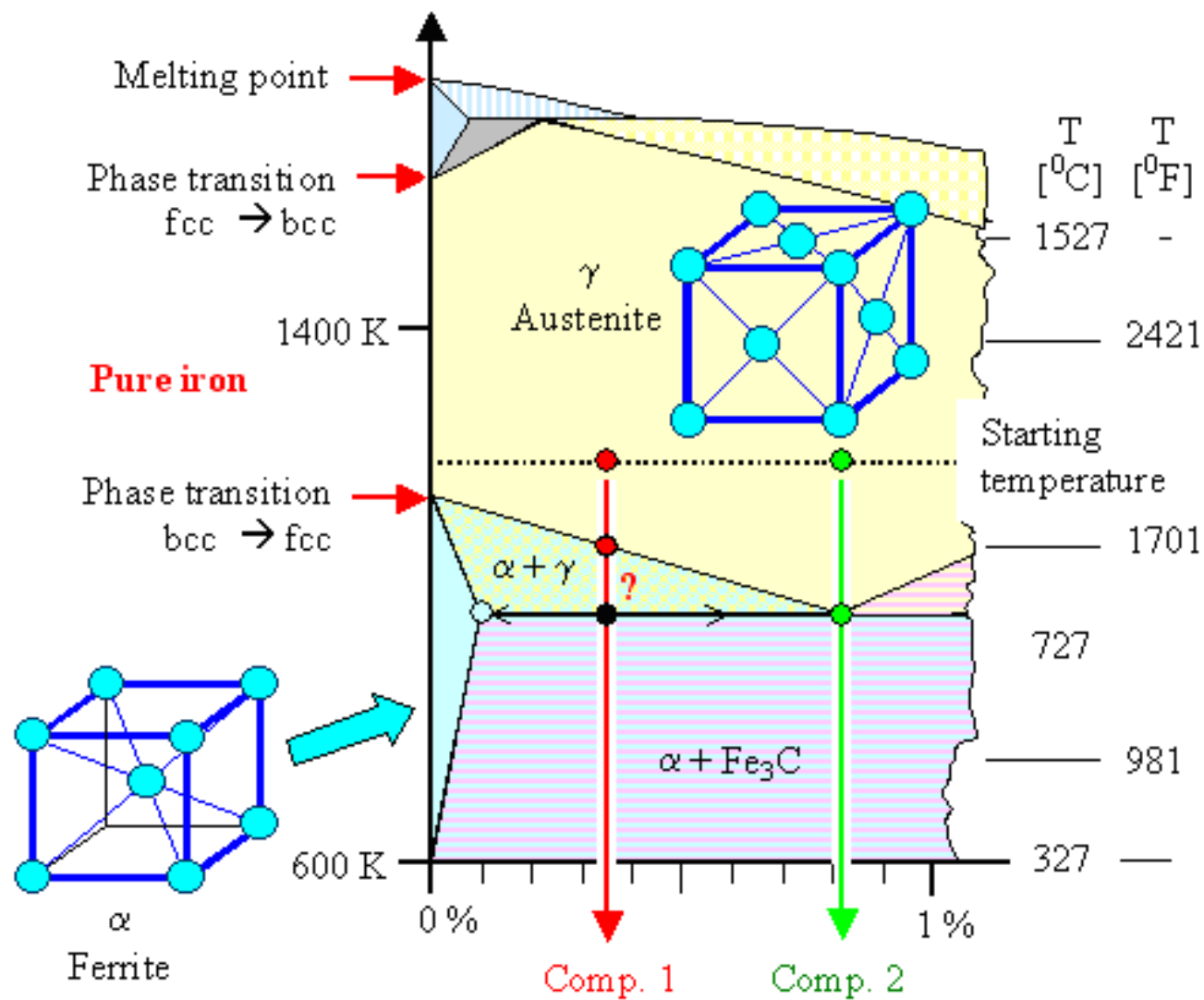
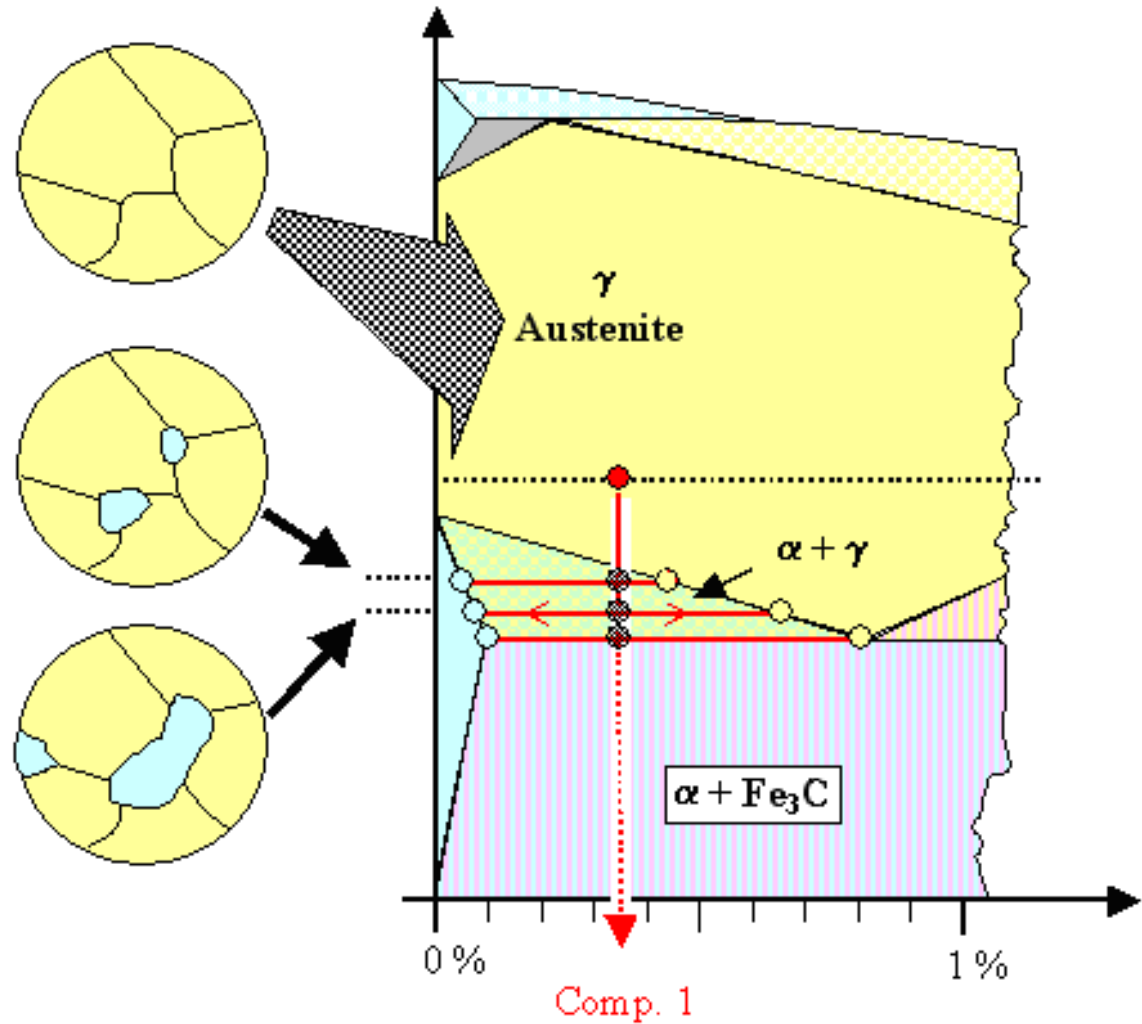
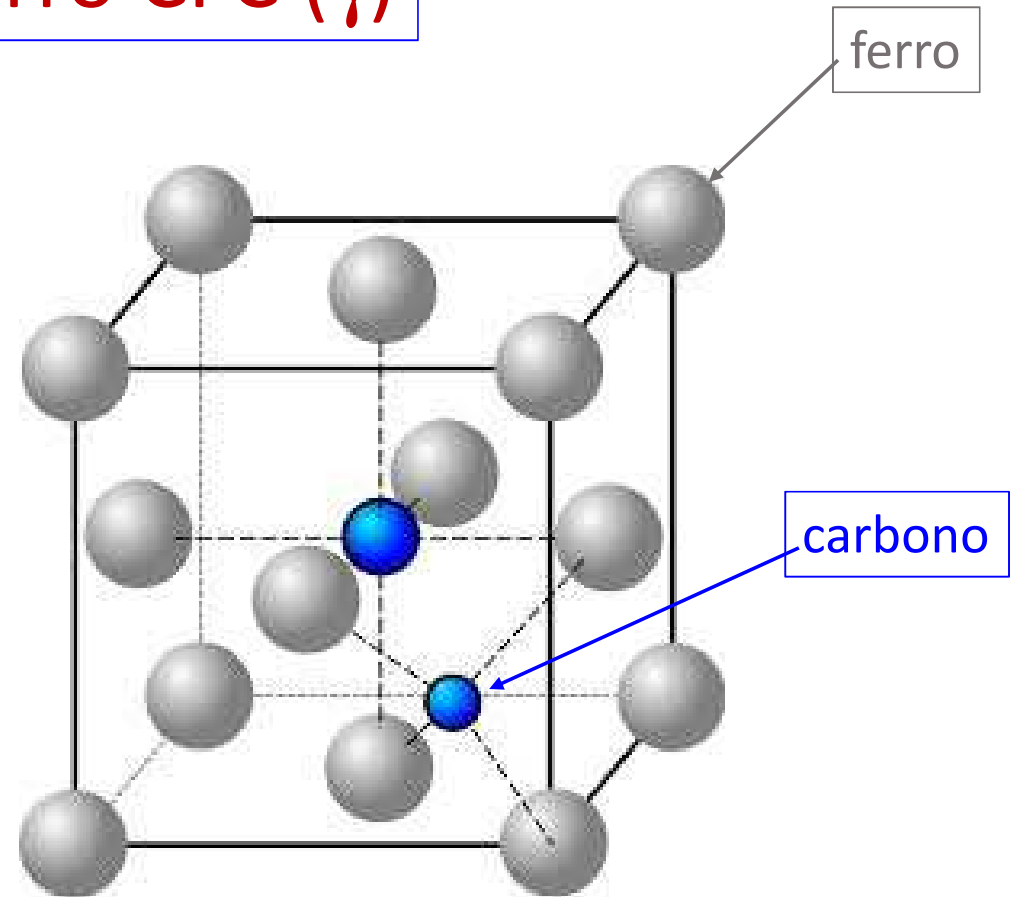
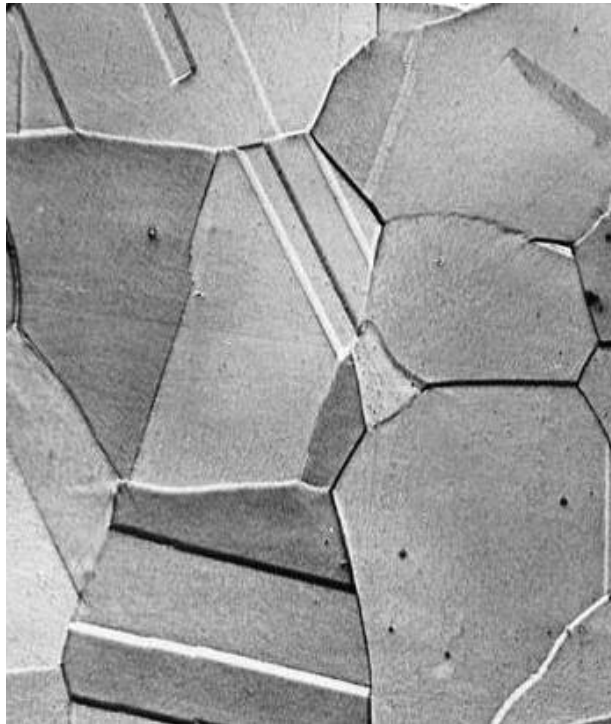


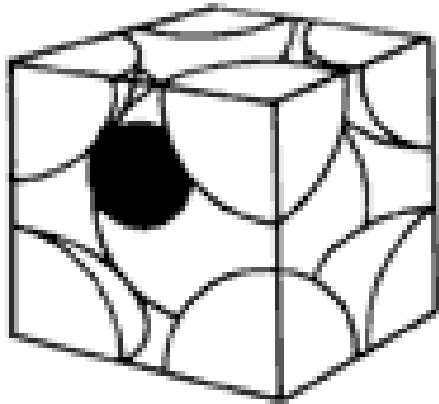
Diagrama de fases
Fe – carbeto de ferro



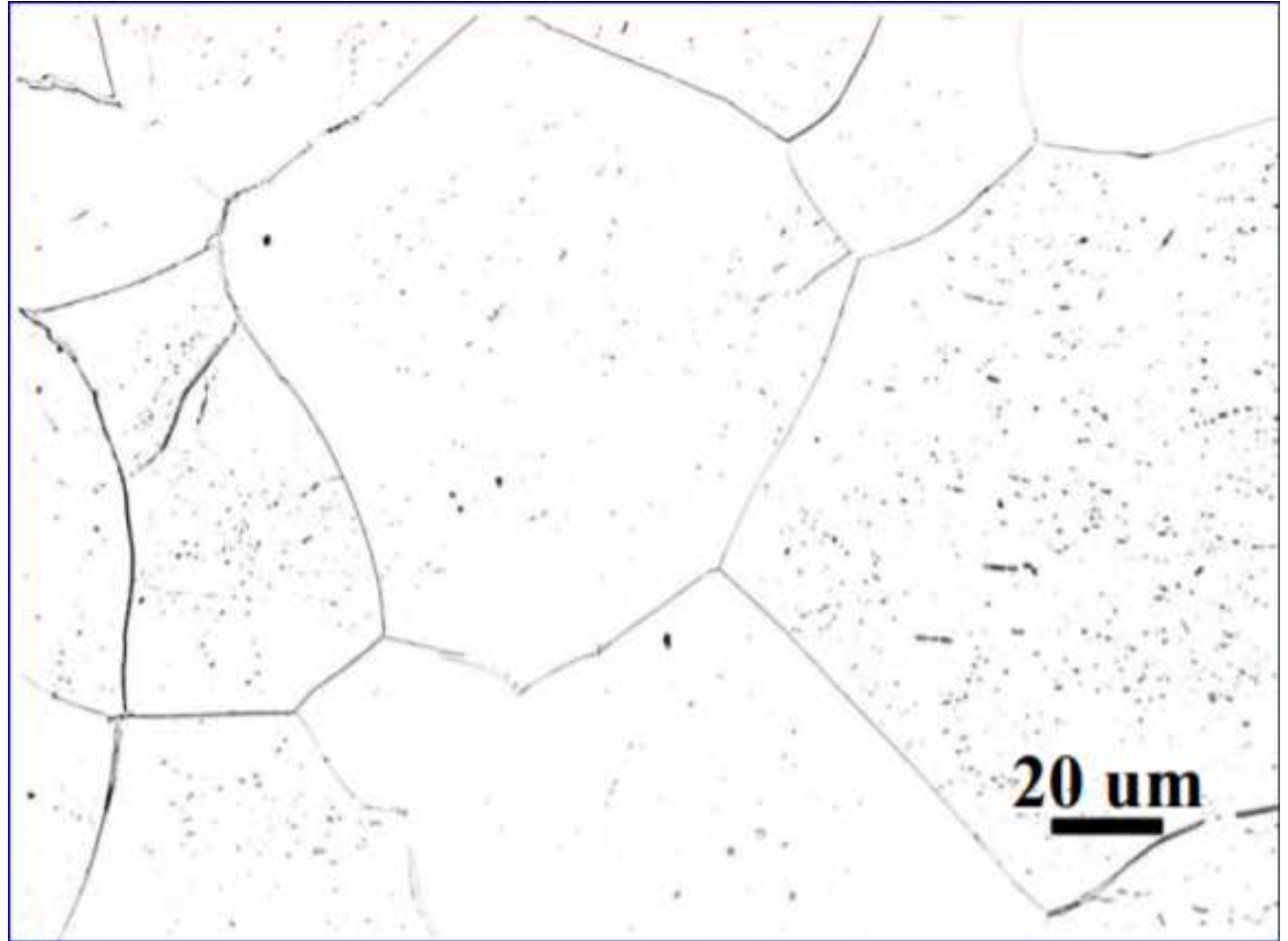
Austenita – ferro CFC (γ)



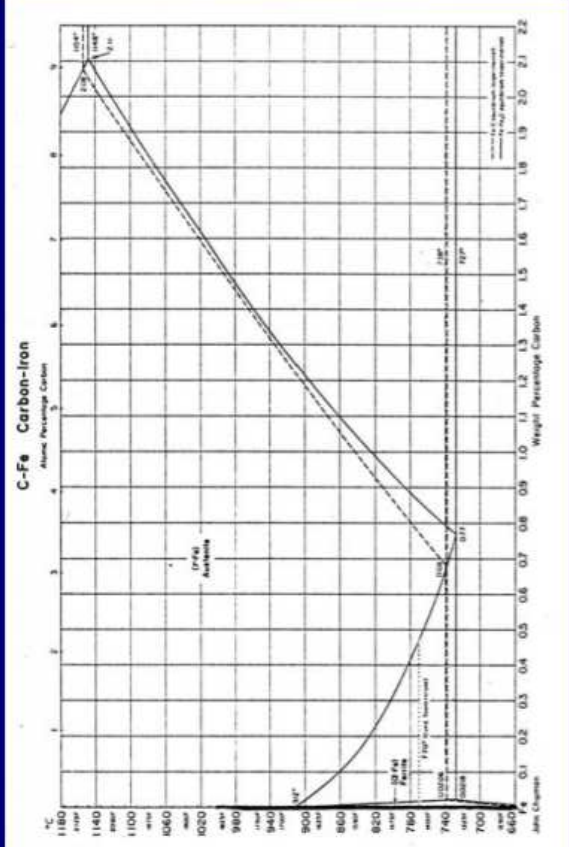
Fe – 0,003 % C
ferrita (α)



FERRITA

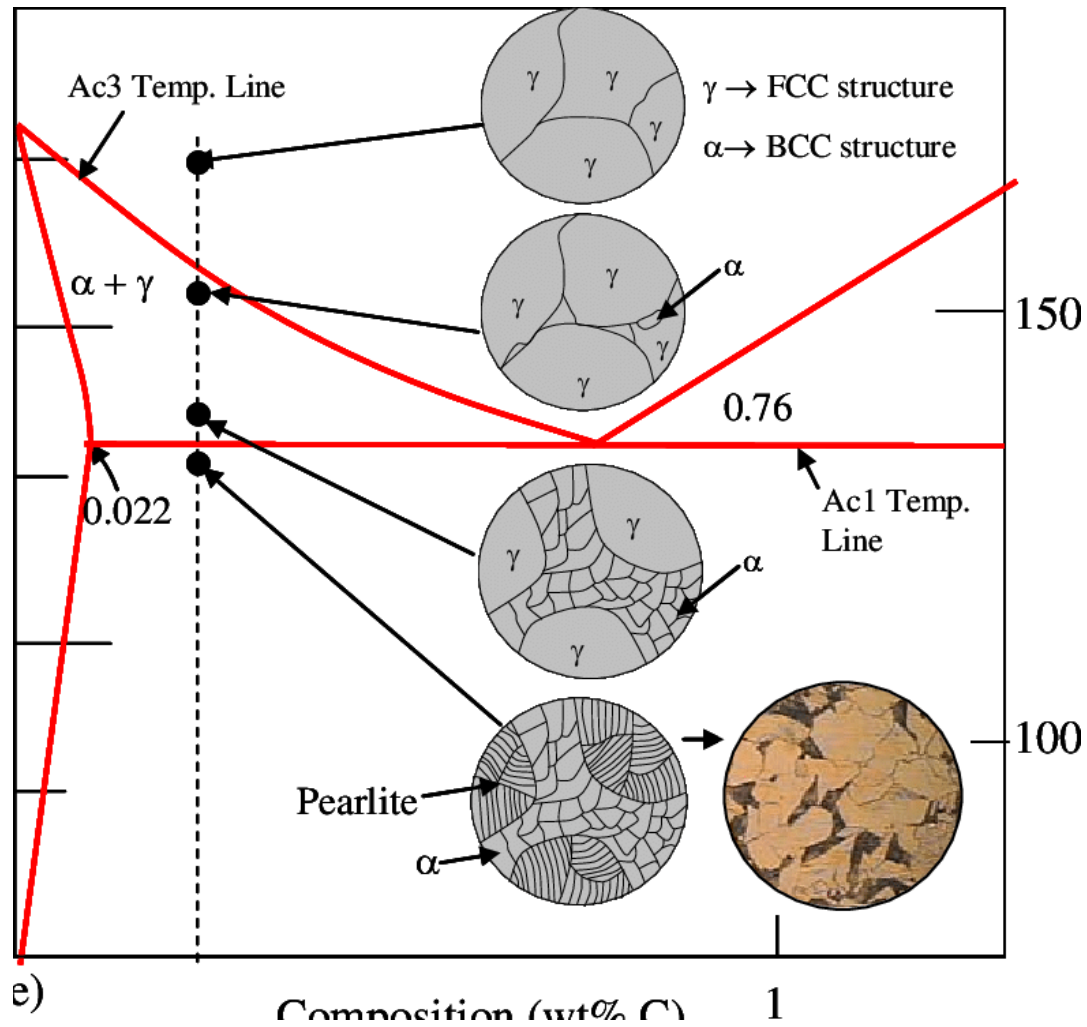
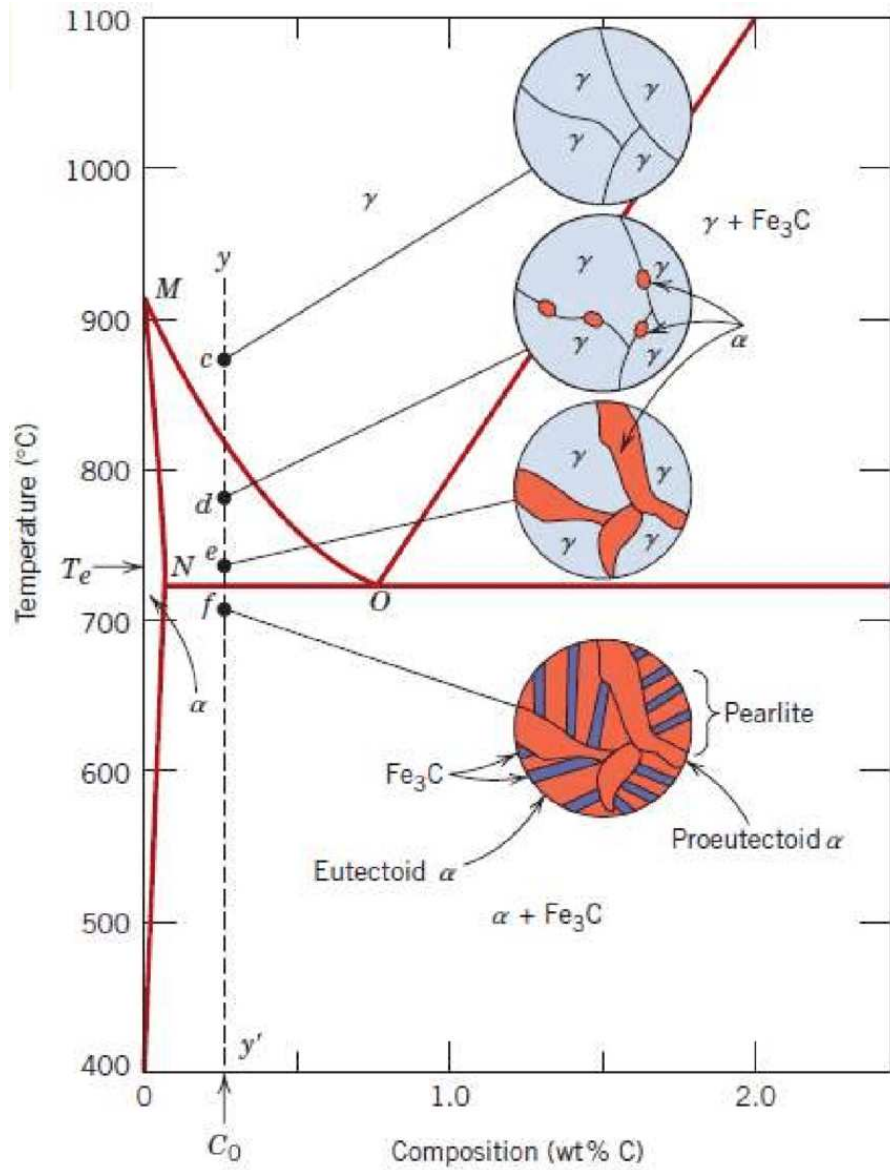


Fe – C Equilibrium Phase Diagram

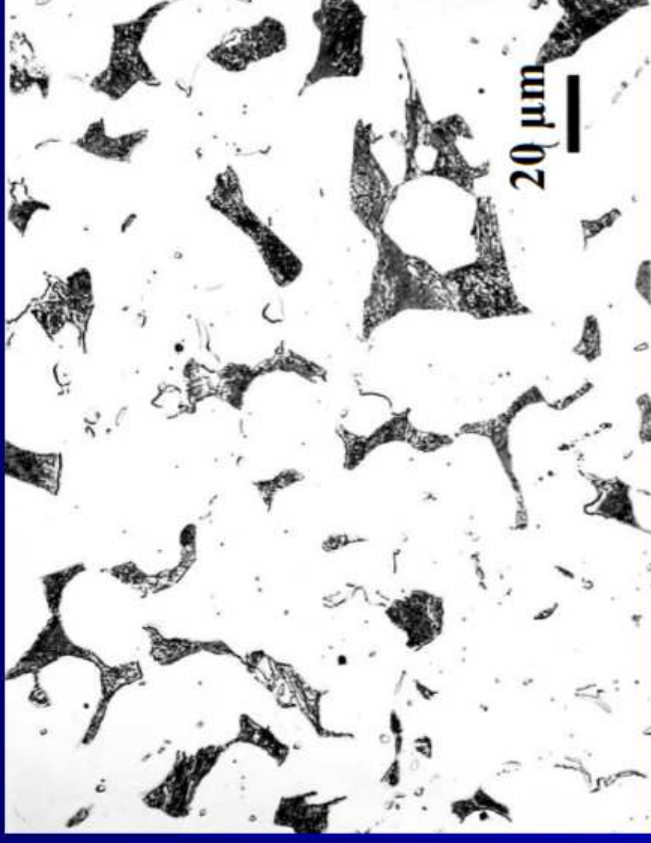
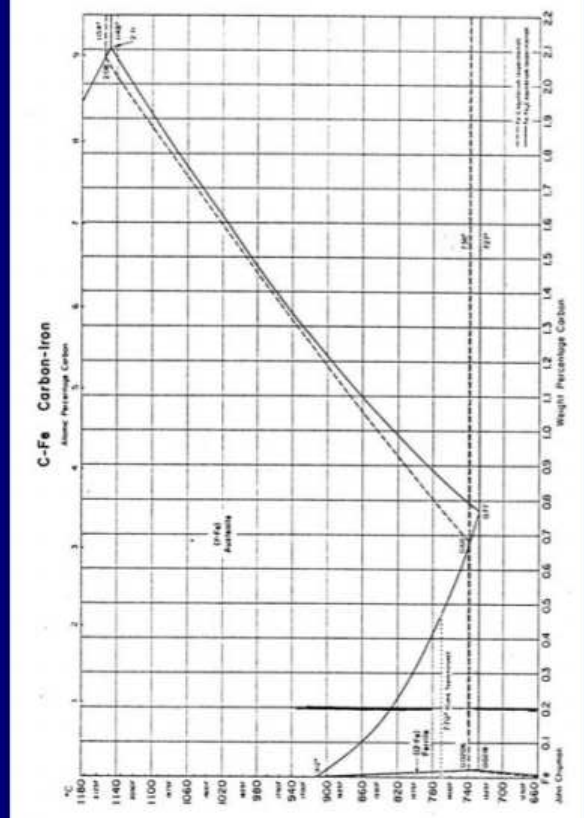


Fe – 0.003% C, diagram and microstructure (2% nital).

Diagrama de fases Fe – carbeto de ferro

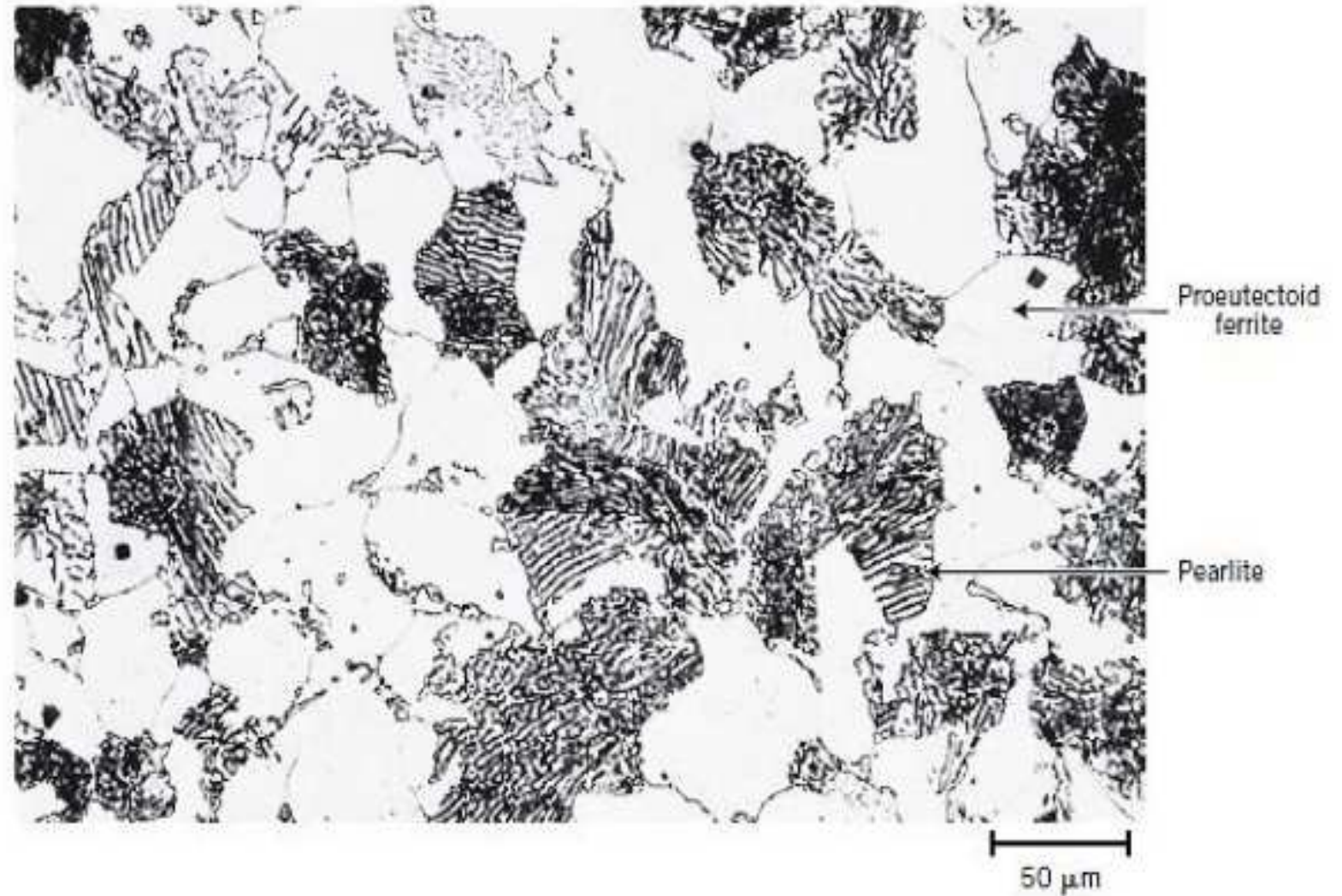


Fe – C Equilibrium Phase Diagram

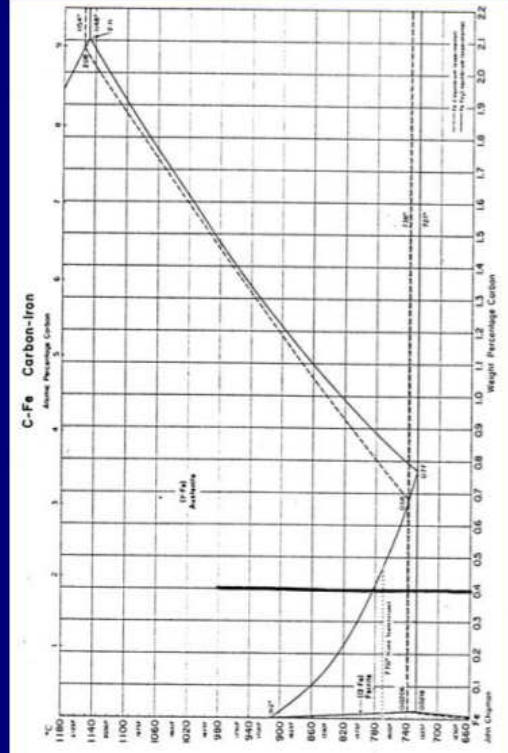


Fe - 0.20% C, diagram and microstructure (4% picral).

*Aço 1034
(0,34 % C)
Hipo-eutetóide*

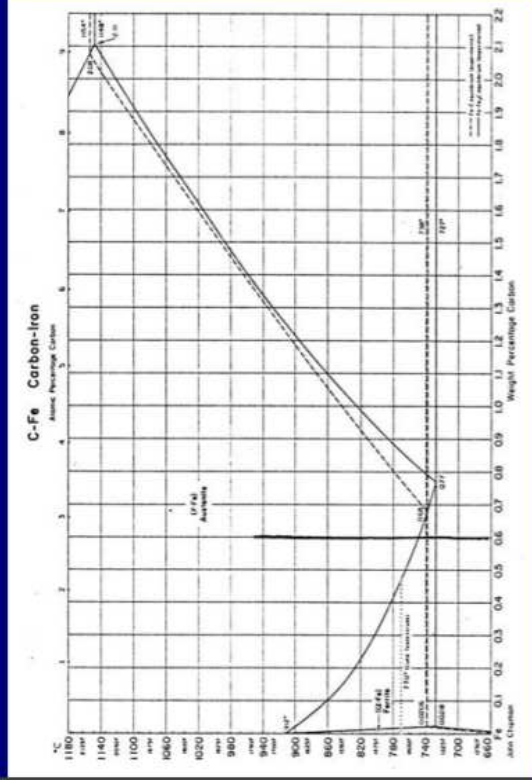


Fe – C Equilibrium Phase Diagram



Fe – 0.40% C, diagram and microstructure, 4% picral.

Fe – C Equilibrium Phase Diagram



Fe – 0.60% C, diagram and microstructure, 4% picral.

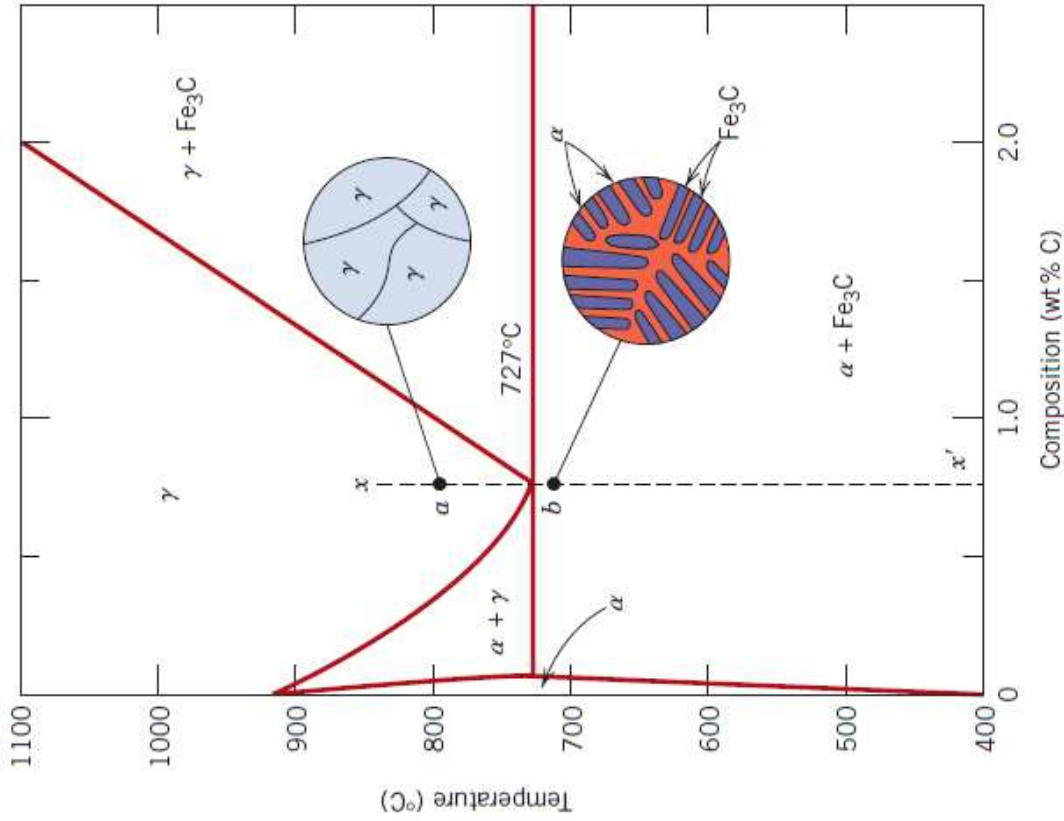
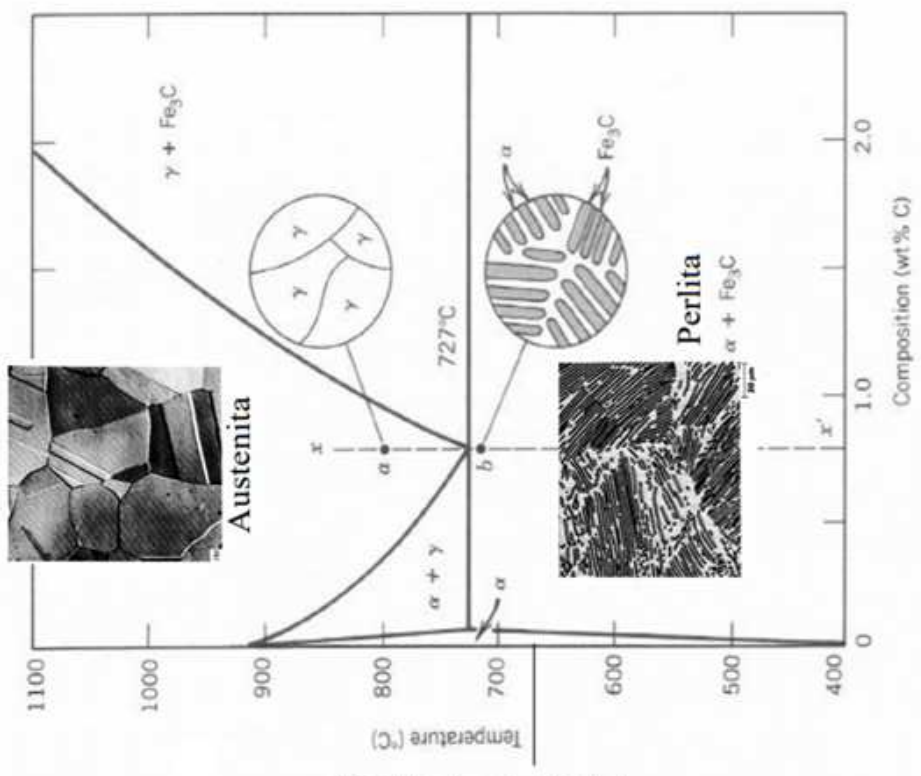
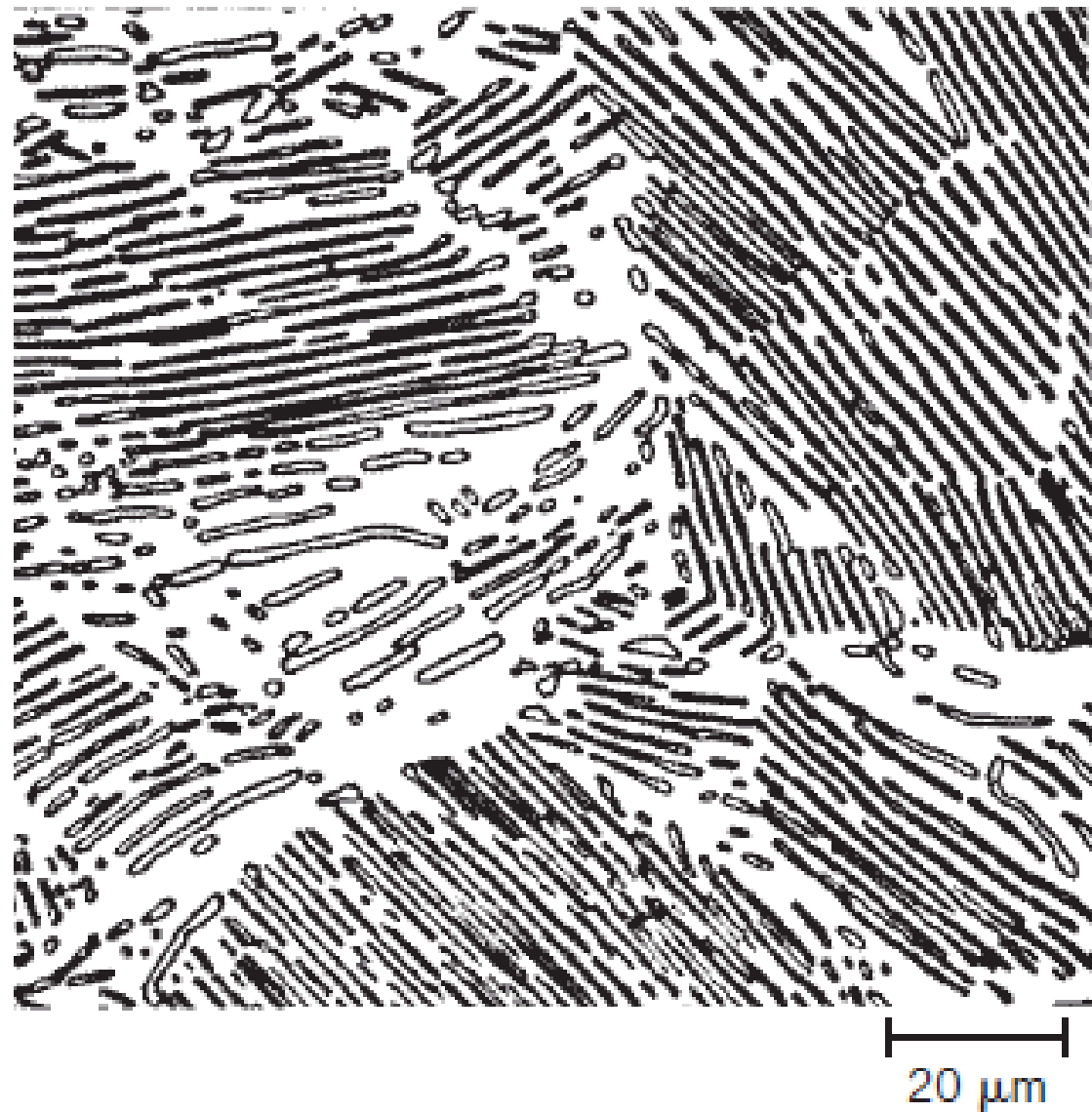


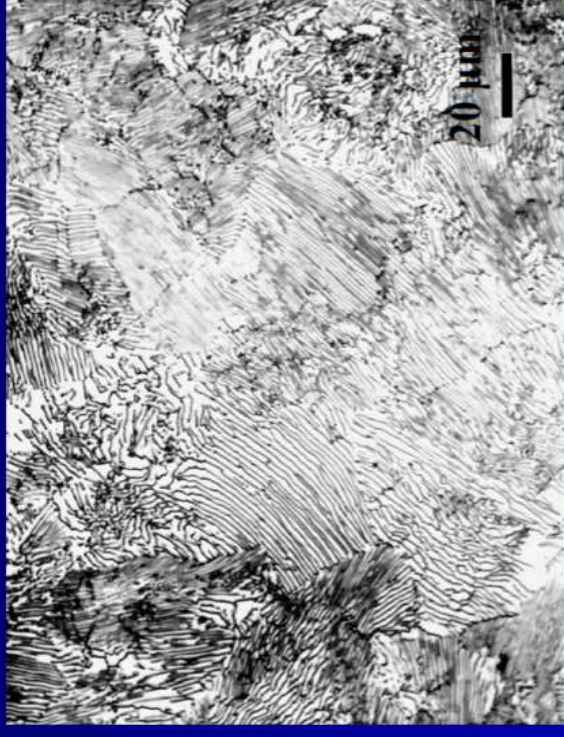
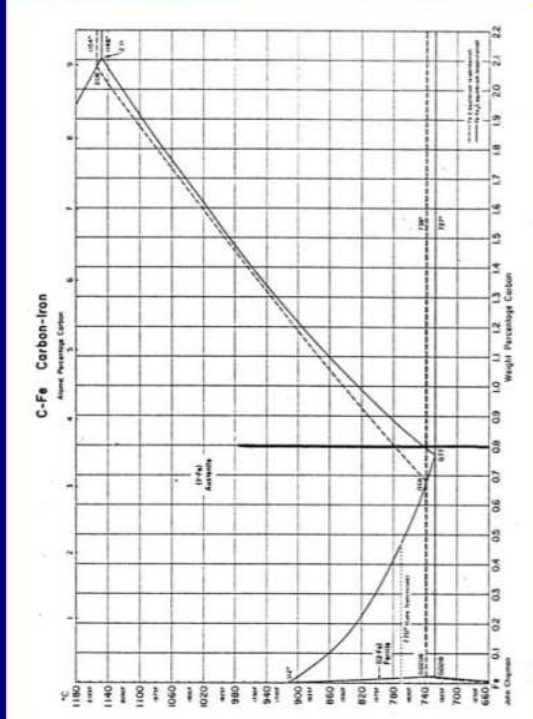
Diagrama Eutetóide



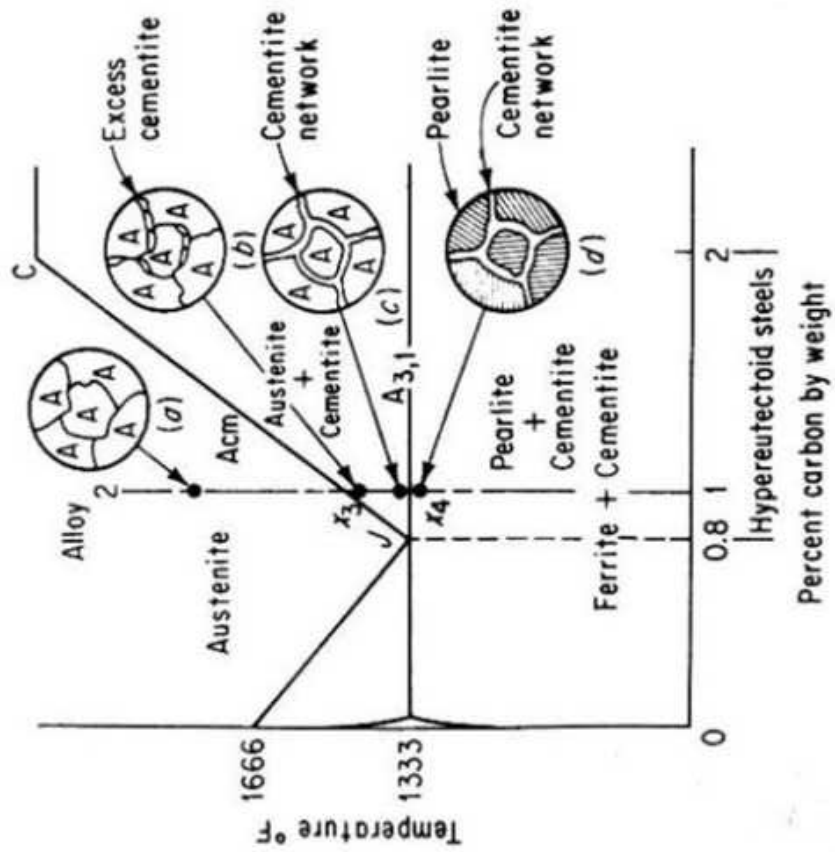
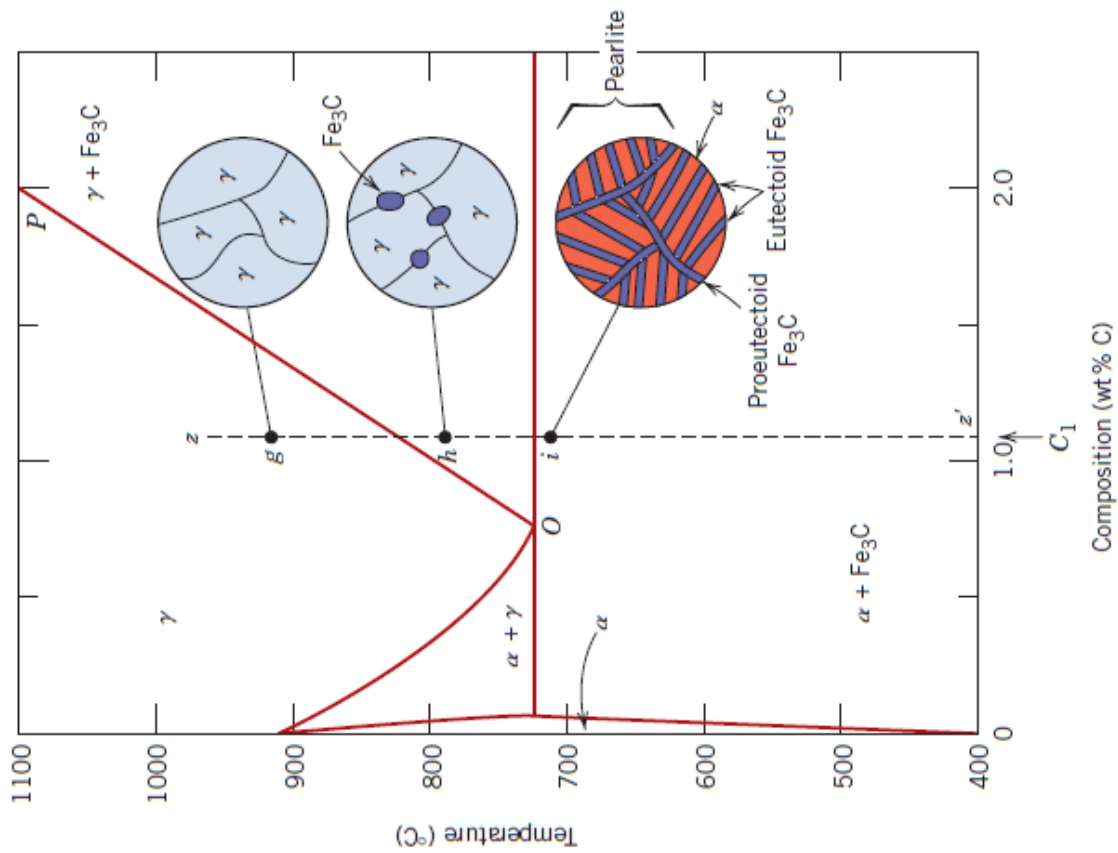
*Aço 1080
(0,80 % C)
Eutetoide*



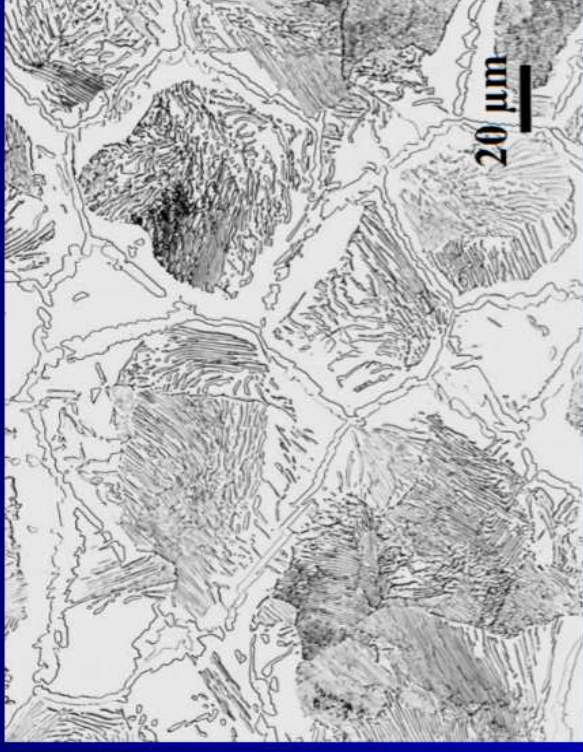
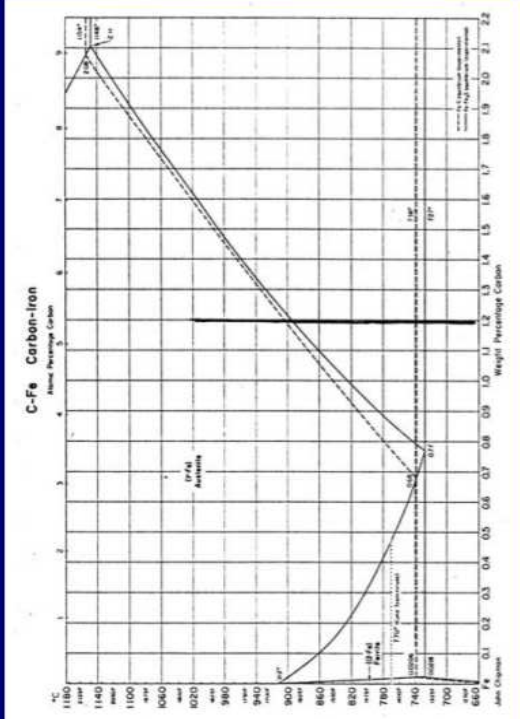
Fe – C Equilibrium Phase Diagram



Fe – 0.80% C, diagram and microstructure, 4% picral.



Fe – C Equilibrium Phase Diagram



Fe – 1.20% C, diagram and microstructure, 4% picral.

Aço 1140
(1,4 % C)
Hiper-eutetóide

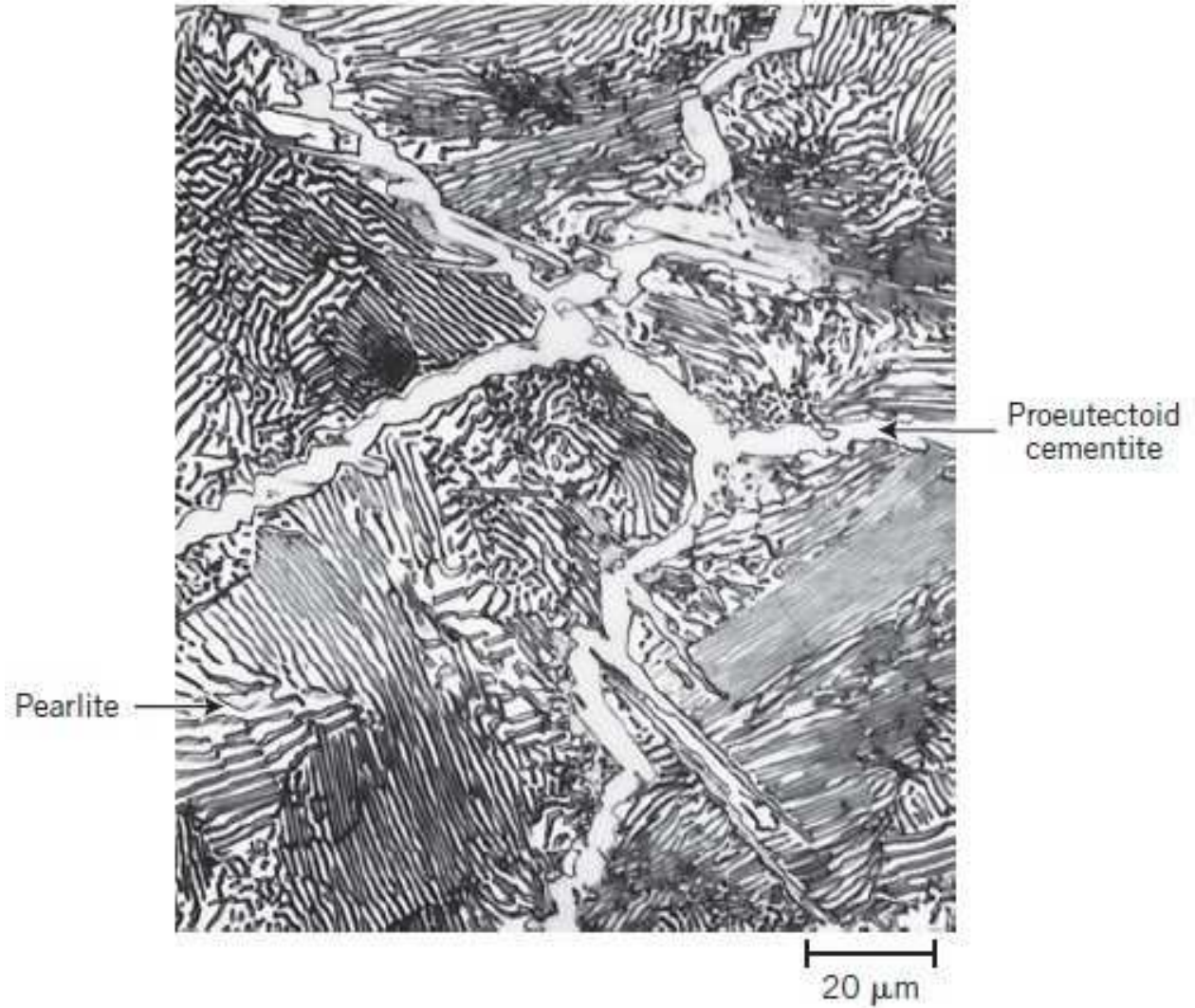


Diagrama de fases Fe – carbeto de ferro de ferro

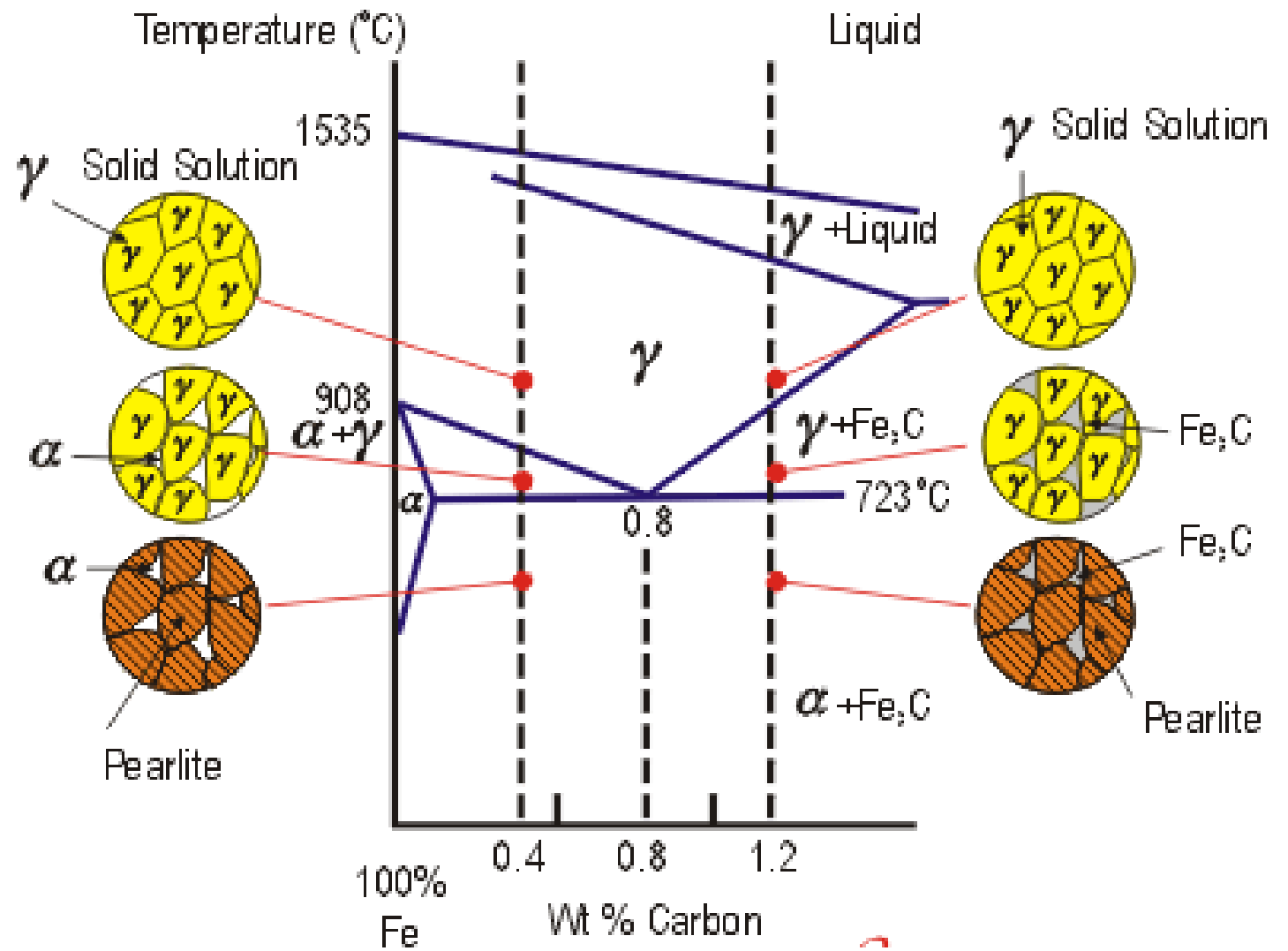
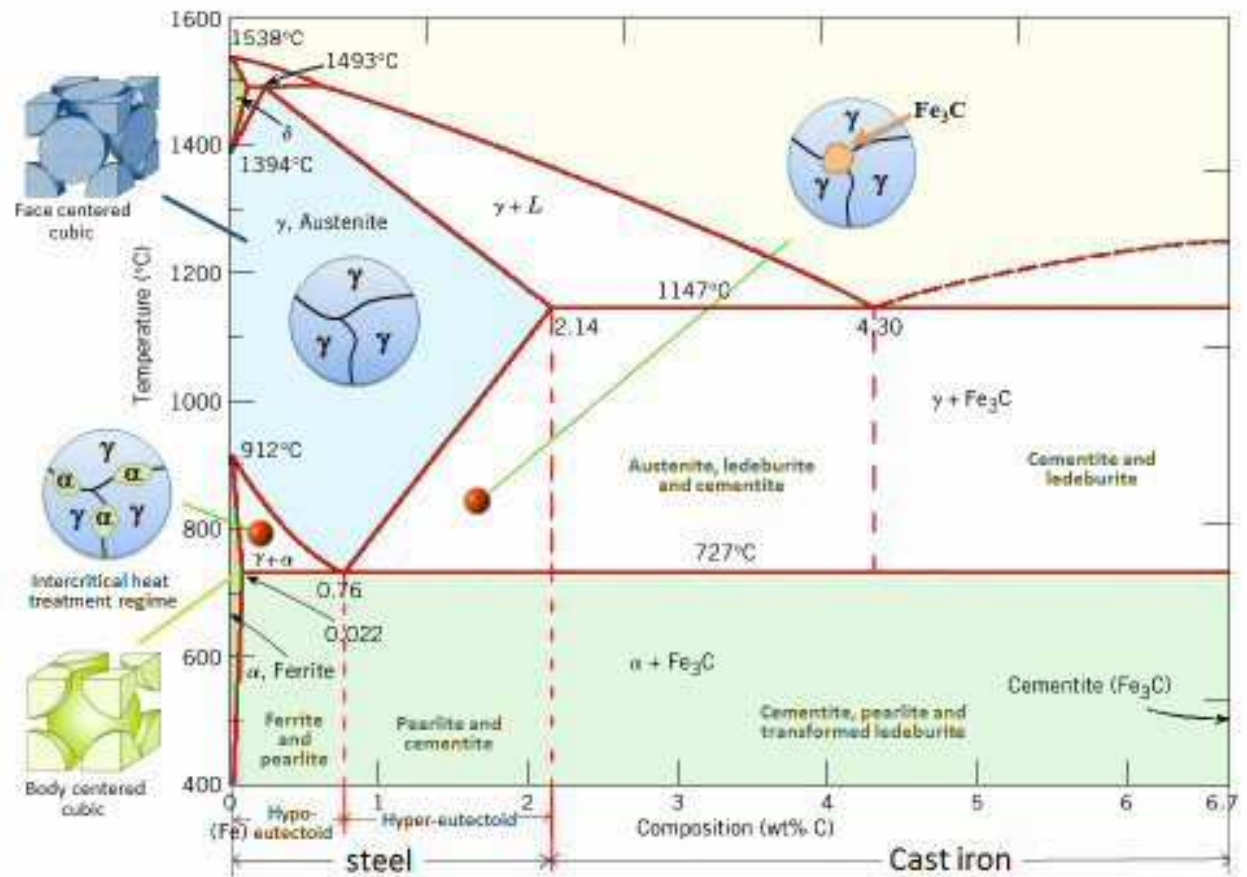
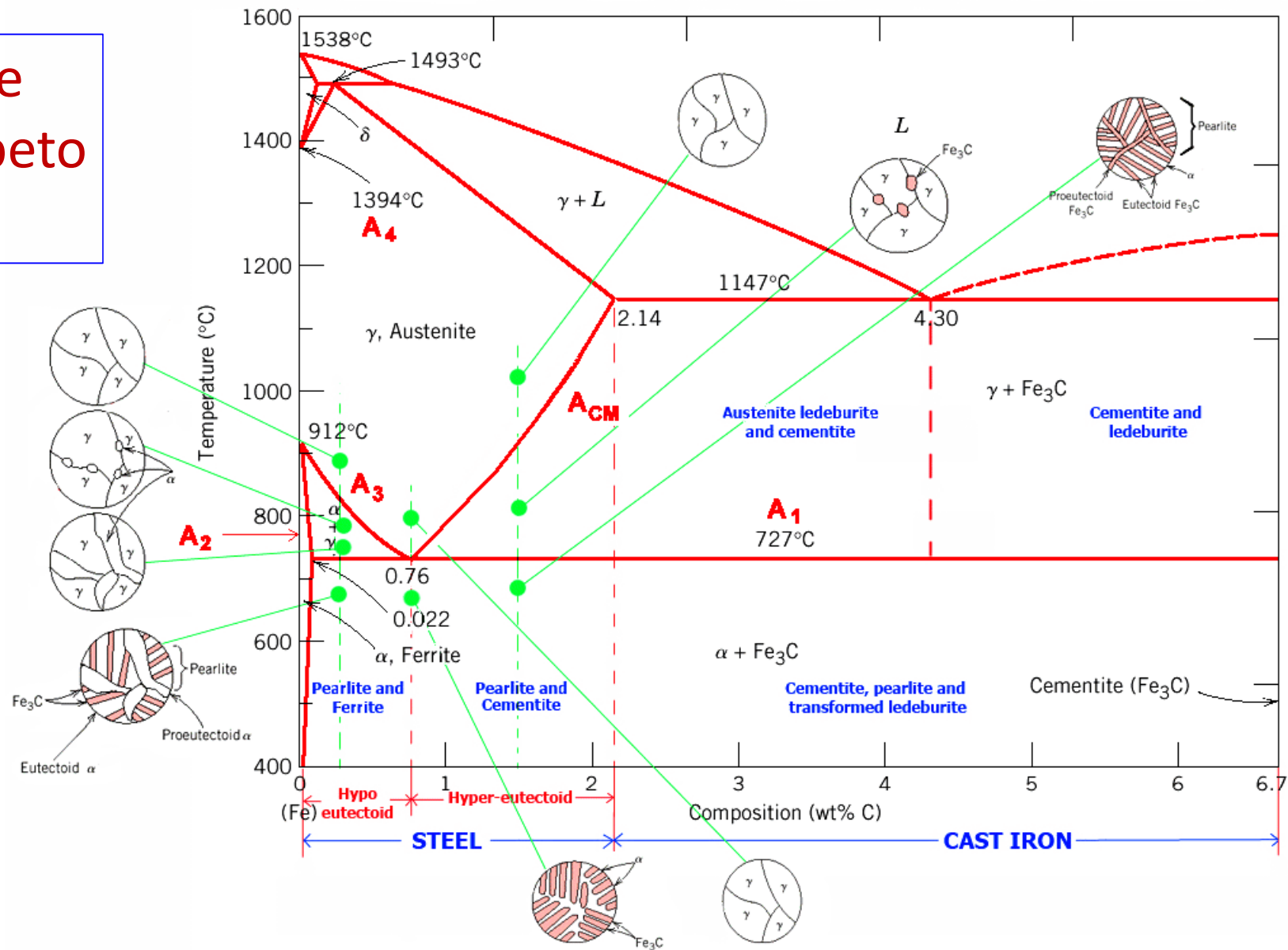


Diagrama de fases Fe – carbeto de ferro



- A_1 : Eutectoid temperature, minimum temperature of austenite
- A_3 : Lower-temperature border of austenite region at low carbon contents; i.e. gamma / gamma + ferrite border
- A_{c1} : Temperature at which austenite begins to form during heating
- A_{c3} : Temperature at which transformation of ferrite to austenite is completed during heating
- A_{r1} : Temperature at which transformation of austenite to ferrite or to ferrite plus cementite is completed during cooling
- A_{r3} : Temperature at which austenite begins to transform to ferrite during cooling

Diagrama de fases Fe – carbeto de ferro



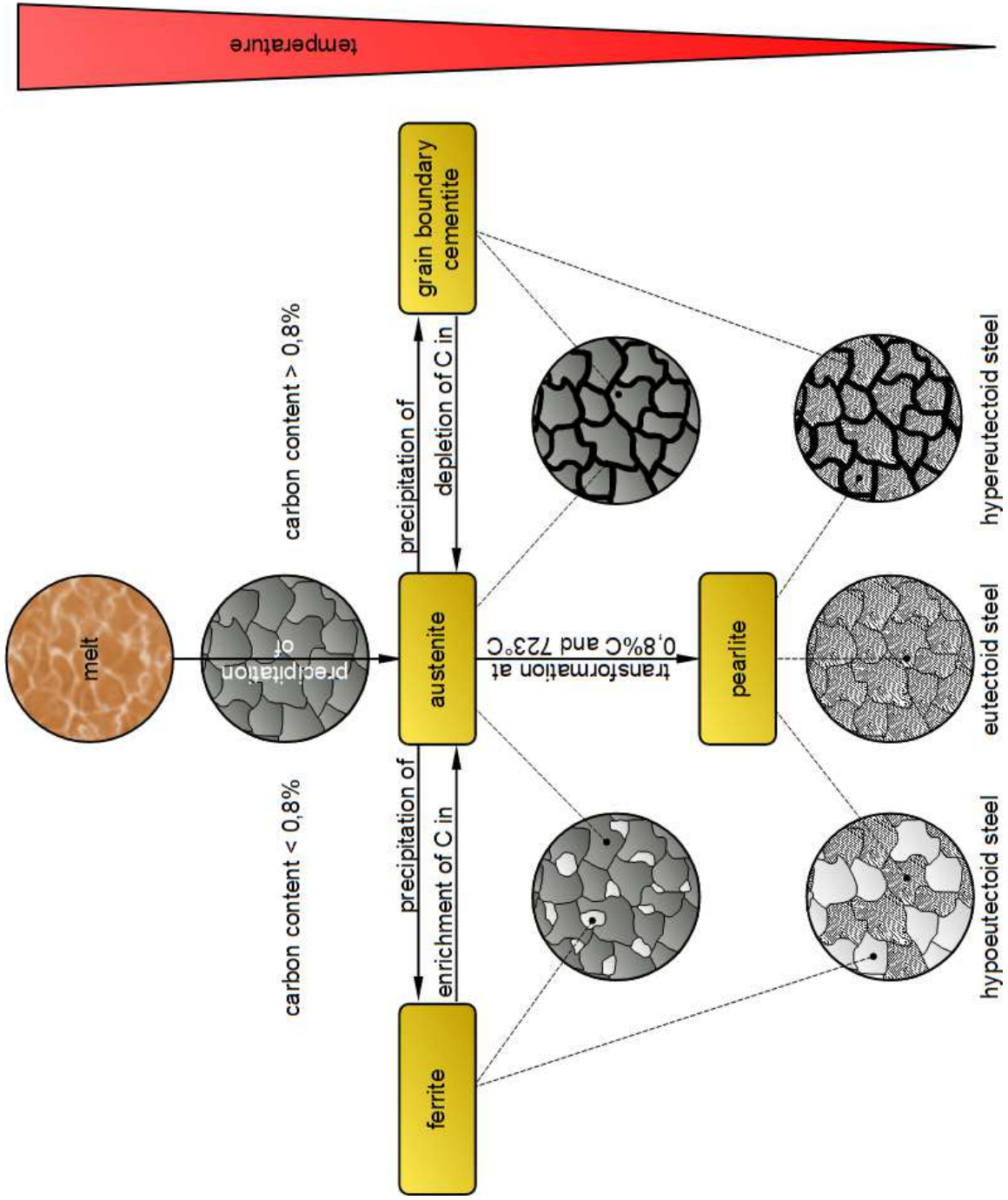


Diagrama de fases Fe – carbeto de ferro

transformation in relation to Fe-C diagram

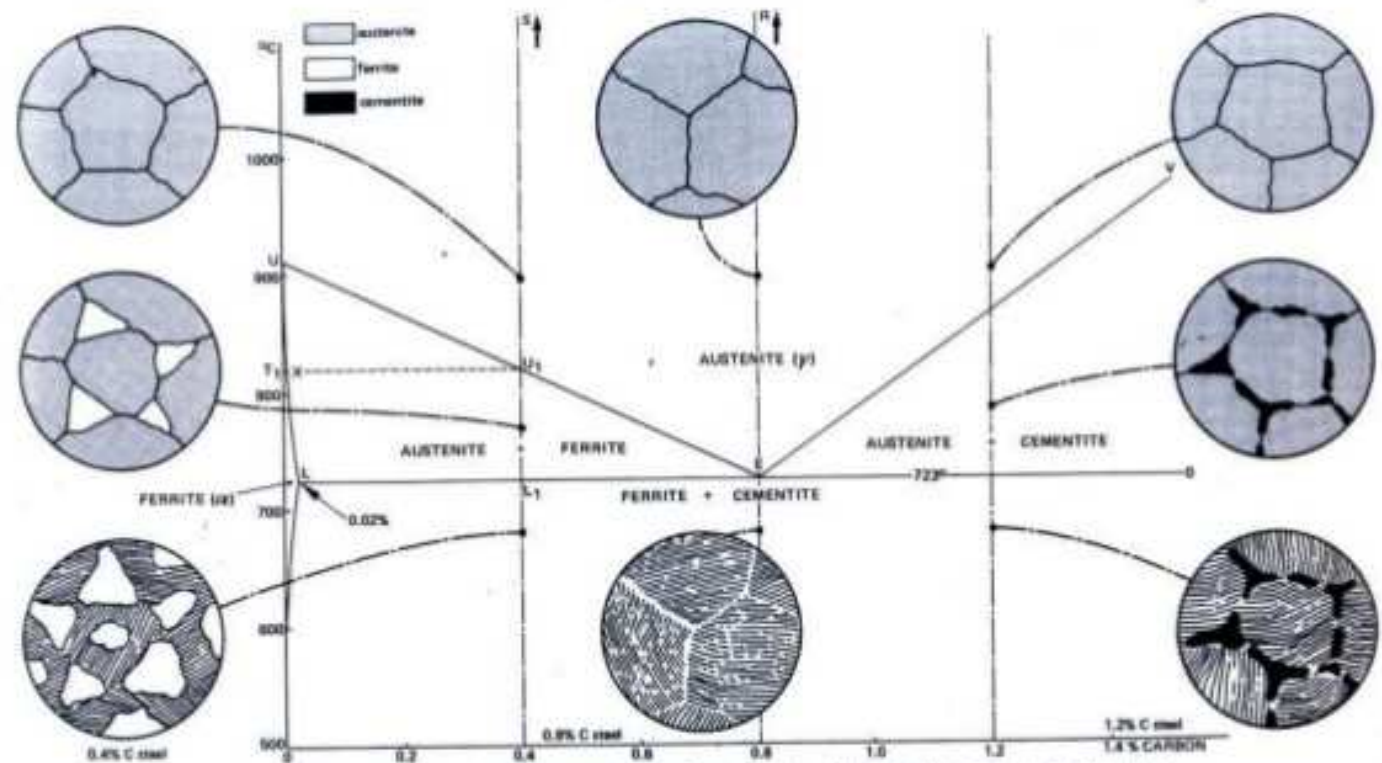
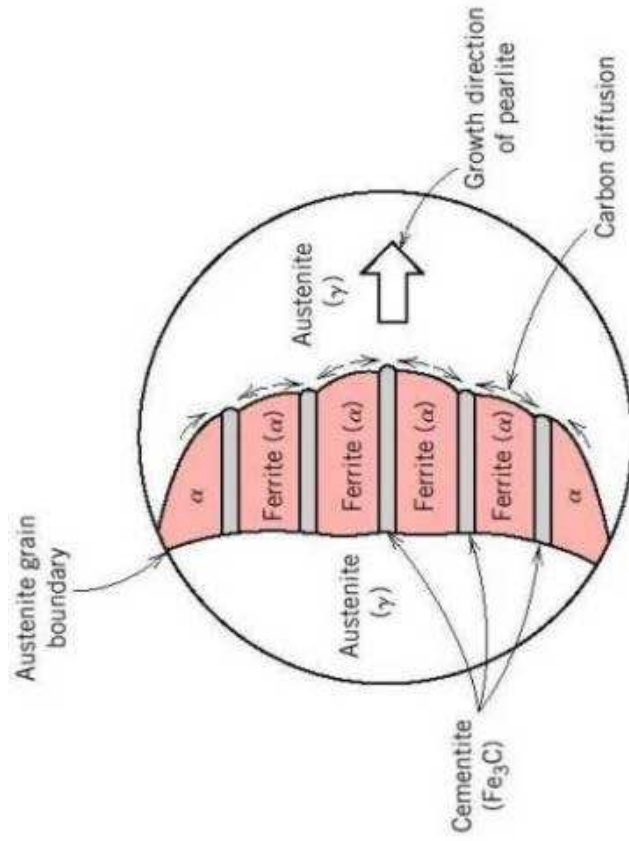


Fig. 9.3—The austenite → ferrite/cementite transformation in relation to the iron-carbon diagram.

Propriedades mecânicas vs. microestrutura (aços recozidos)

Microconstituente	Dureza (HV)
Ferrita (Fe – α)	90
Cementita (Fe_3C)	1050
Perlita ($\alpha + Fe_3C$)	230

Solidificação eutética



Formation and Growth of Pearlite

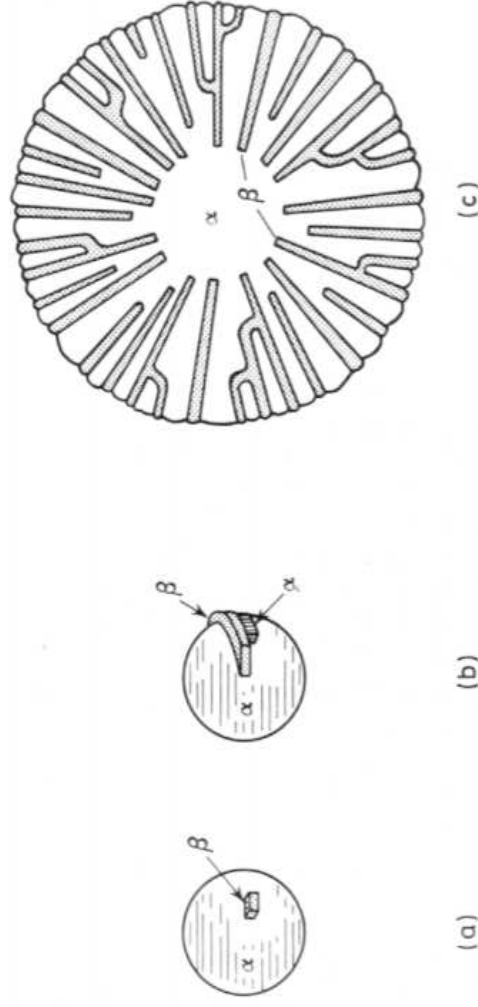
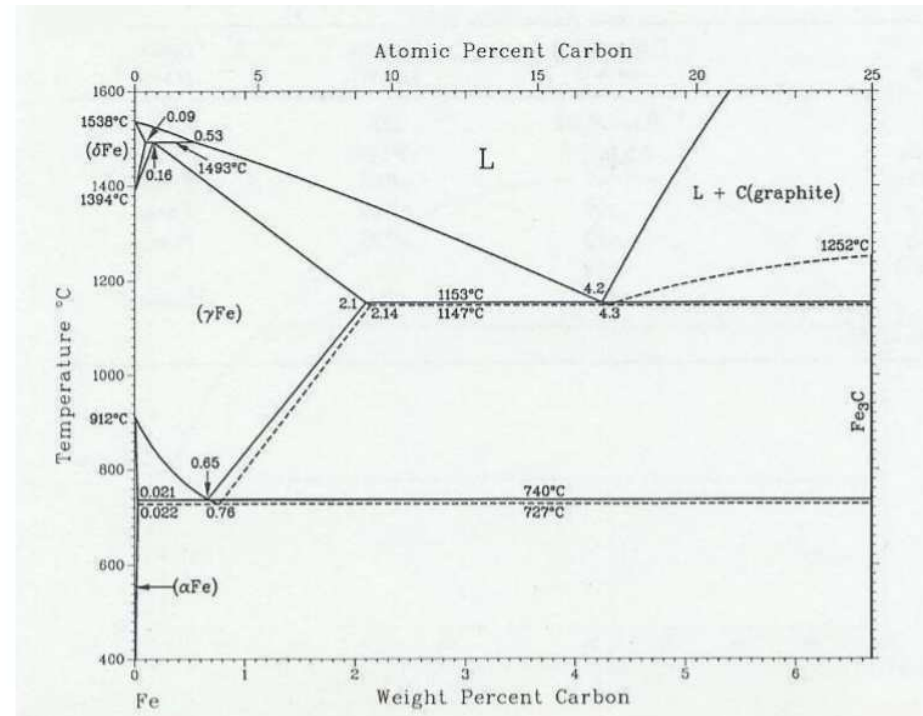


Figure 4.43 Schematic drawing of nucleation and multiplication of lamellae in a eutectic nodule. (a) Primary nucleus of α -phase and heterogeneous nucleation of β -phase; (b) growth of β -phase succeeded by bridging and branching of both phases; (c) growth on a spherical growth front necessitates frequent lamellar multiplication

Diagrama de fases Fe – carbeto de ferro



Phase	Composition, wt% C
(δFe)	0 to 0.09
(γFe)	0 to 2.1
(αFe)	0 to 0.021
(C)	100

Figura 21 – Diagrama de equilibrio Fe-C (ASM Handbook, H. Okamoto, 1992).

