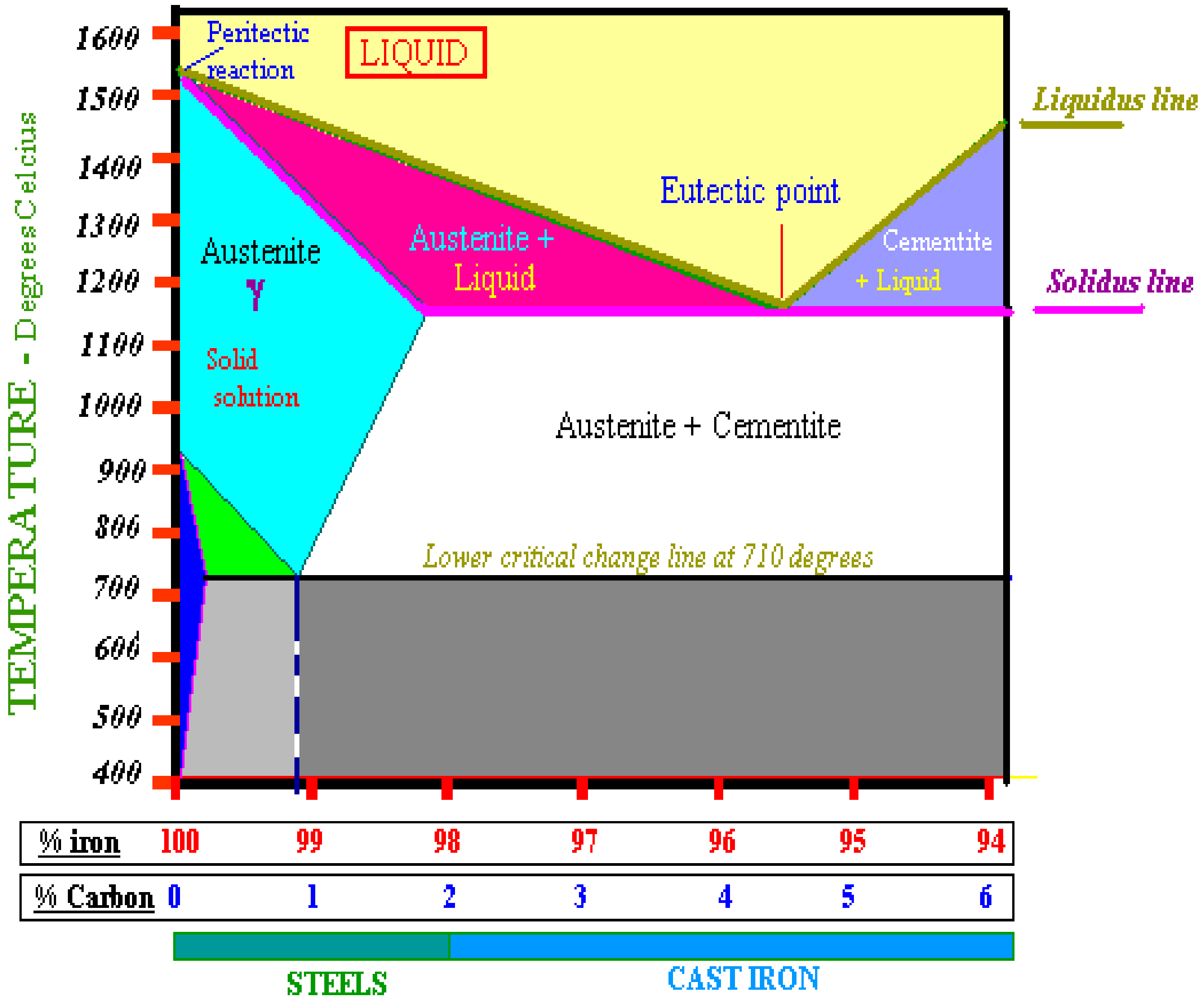
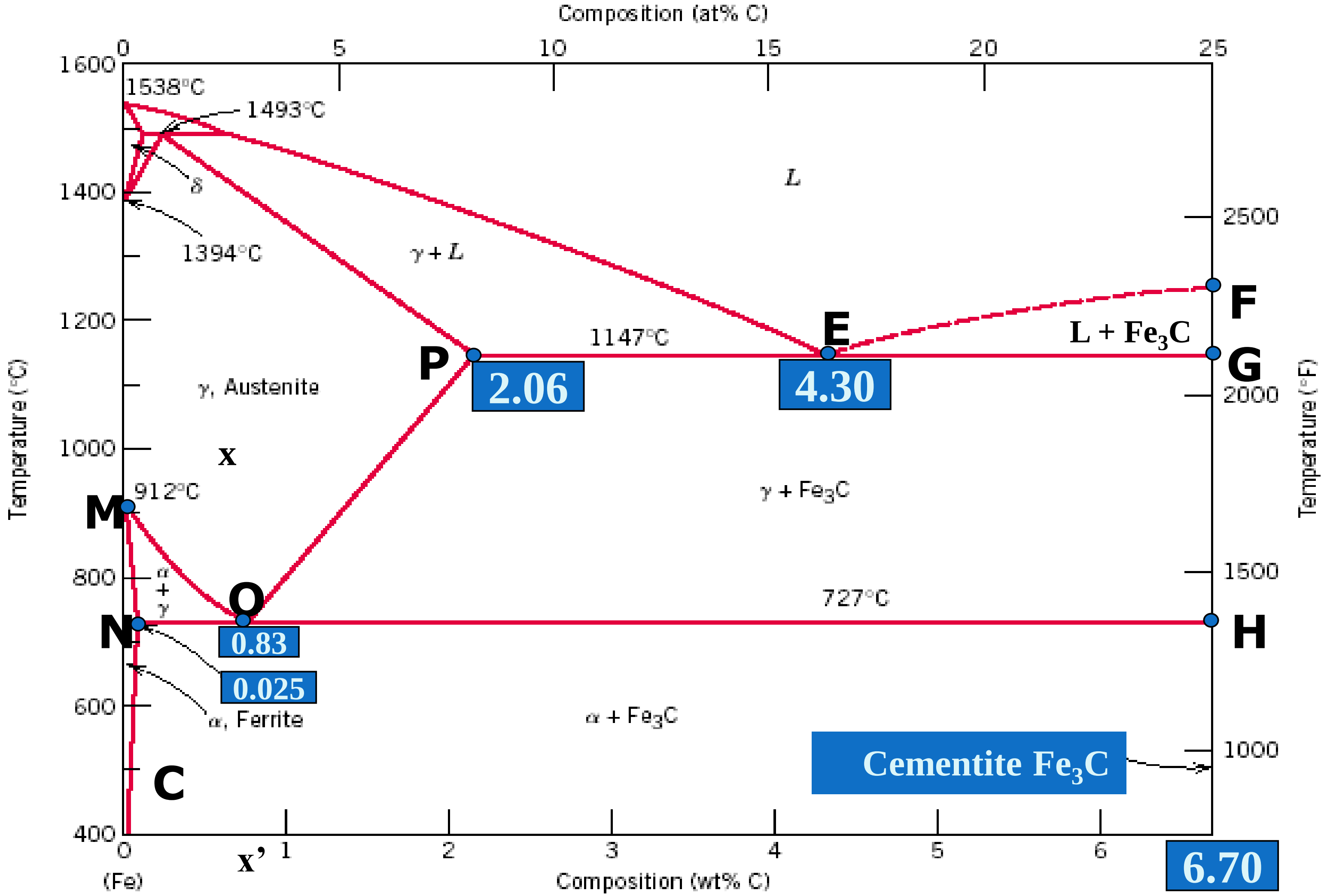
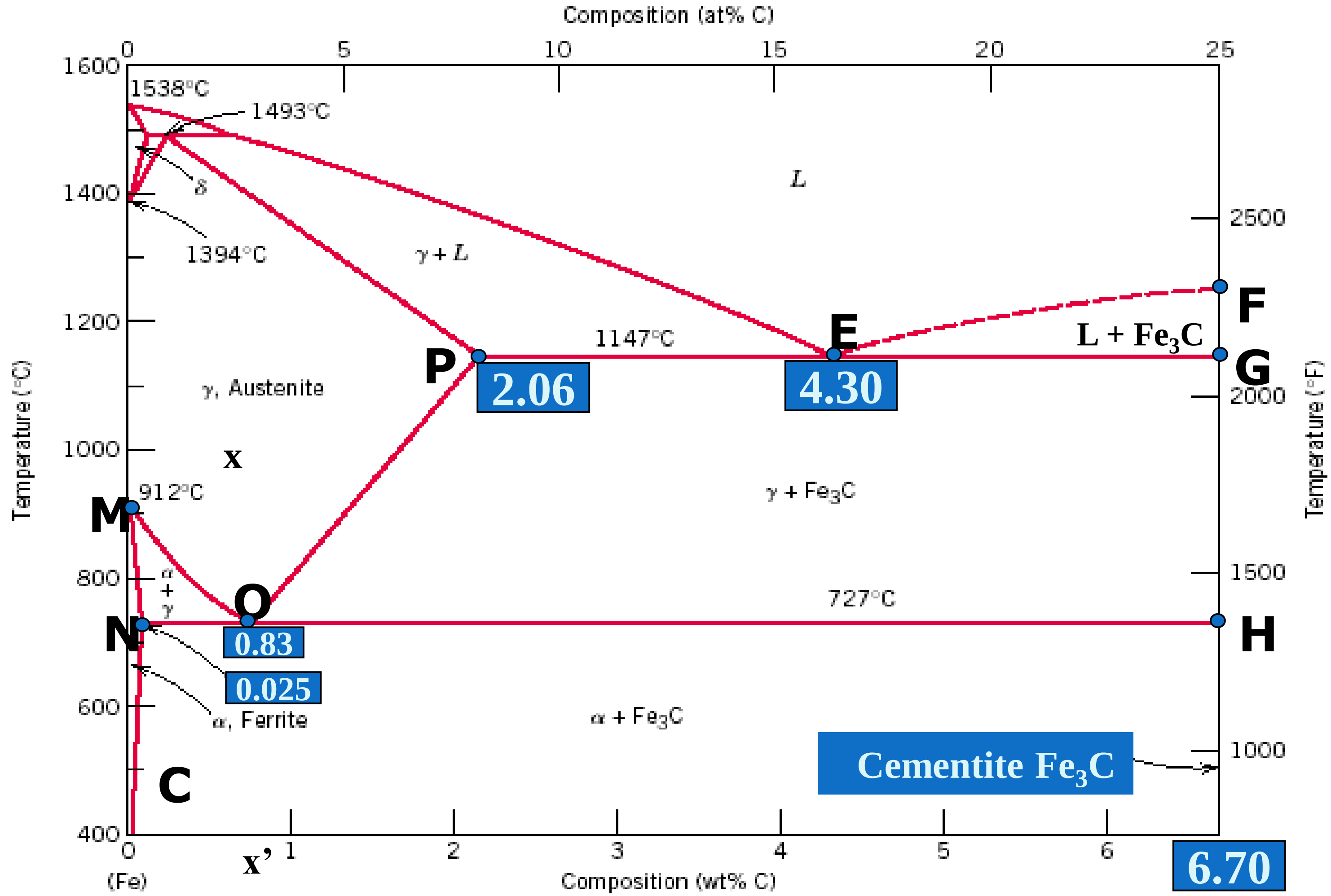
Fe-C Diagram

Fe-Carbon Diagram

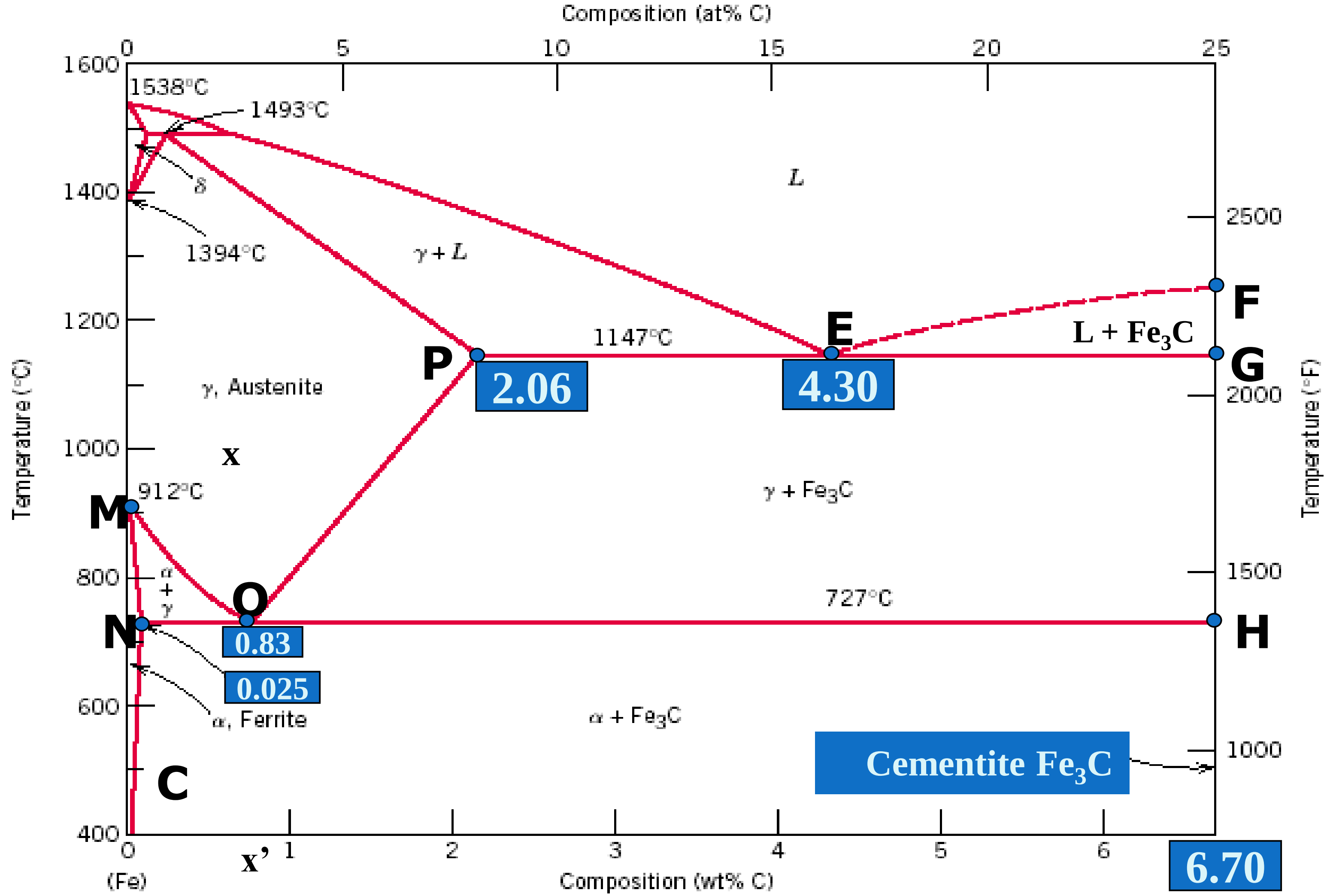




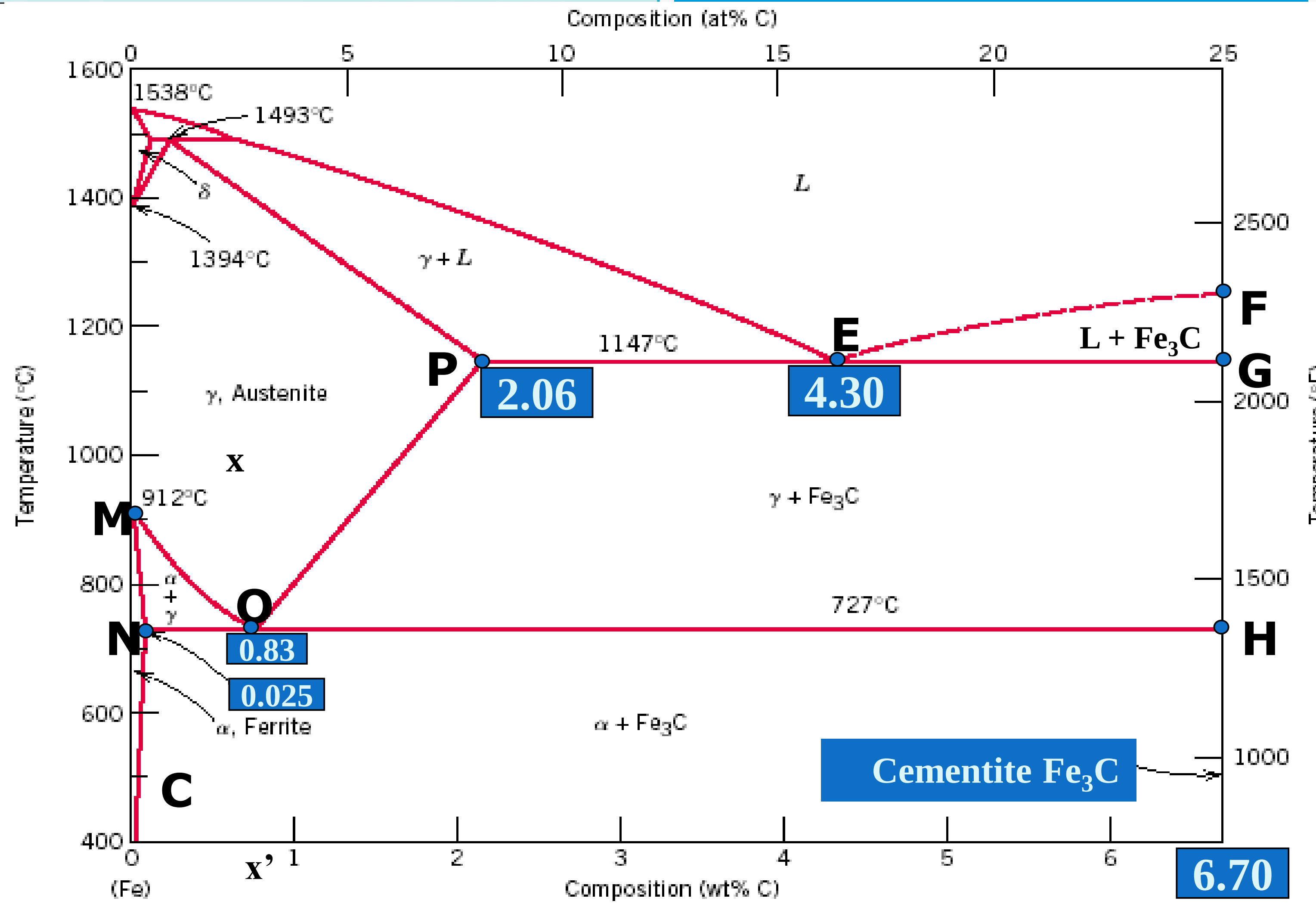
❖ δ-ferrite – Solid solution of carbon in iron. Maximum concentration of carbon in δ-ferrite is 0.09% at 2719 ºF (1493ºC) – temperature of the peritectic transformation. The crystal structure of δ-ferrite is BCC (cubic body centered).



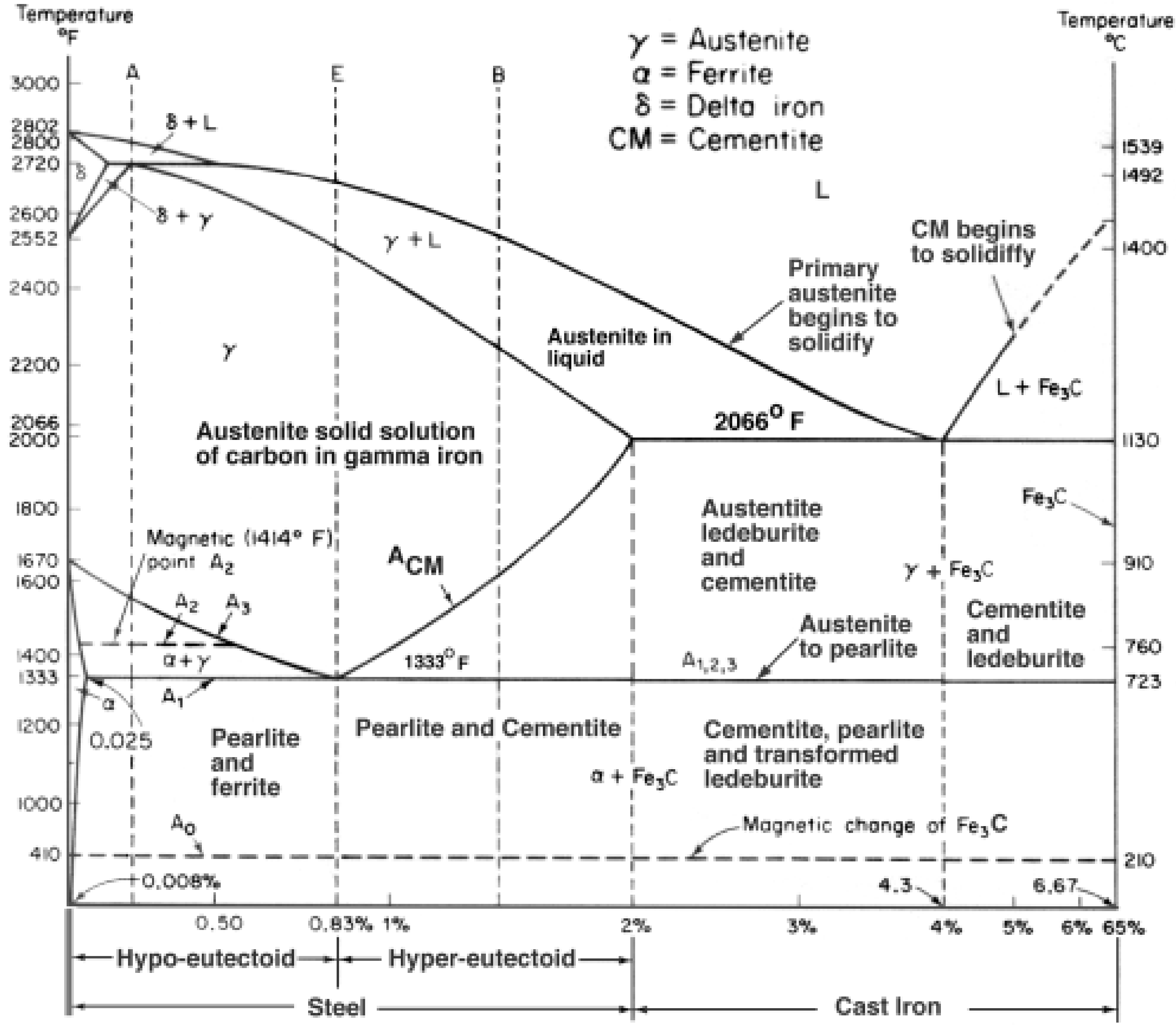
❖ Austenite – interstitial solid solution of carbon in γ-iron. Austenite has FCC (cubic face centered) crystal structure, permitting high solubility of carbon – up to 2.06% at 2097 ºF (1147 ºC). Austenite does not exist below 1333 ºF (727ºC) and maximum carbon concentration at this temperature is 0.83%.



❖ α-ferrite – solid solution of carbon in α-iron. α-ferrite has BCC crystal structure and low solubility of carbon – up to 0.25% at 1333 ºF (727ºC). α-ferrite exists at room temperature.

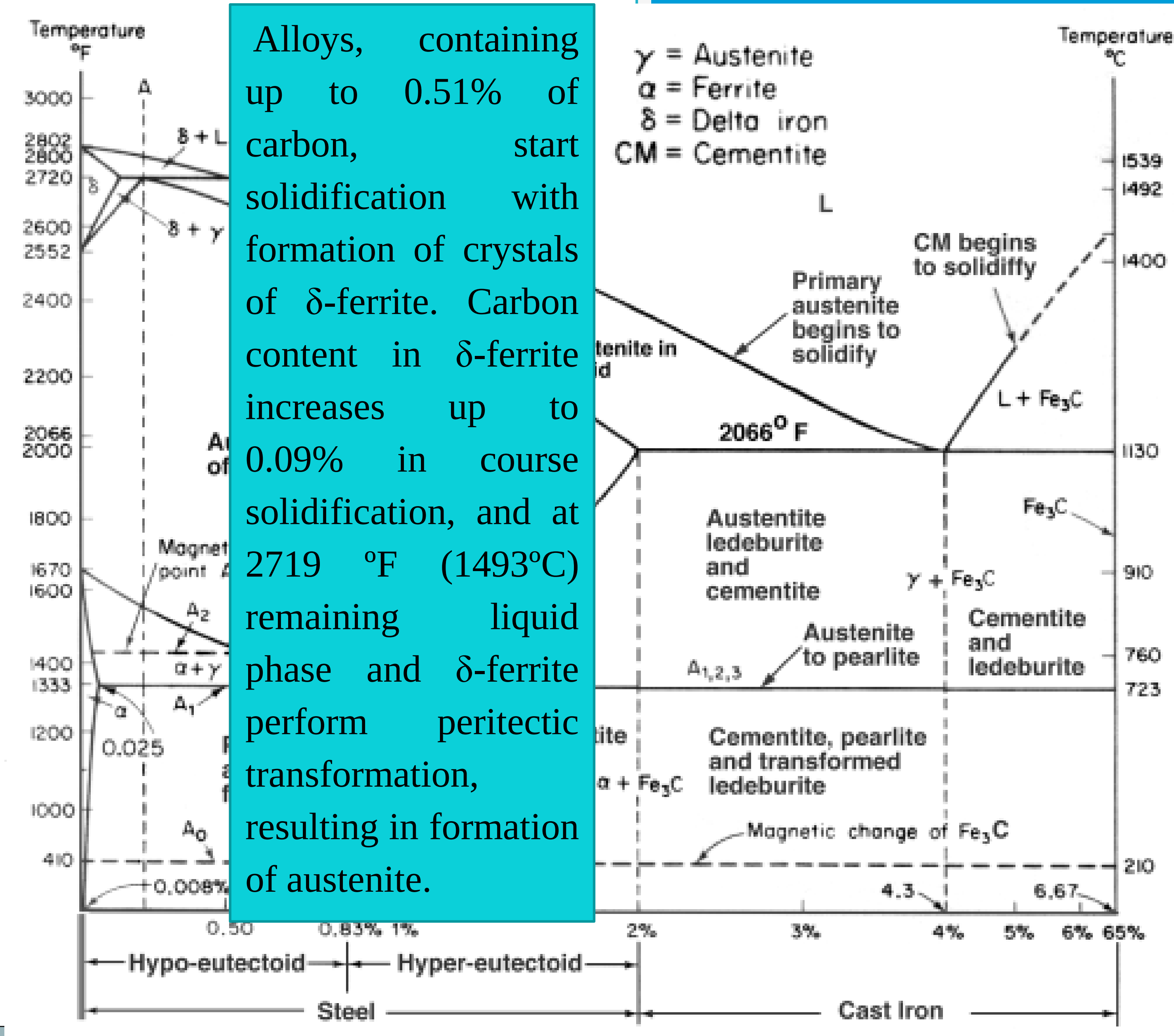


❖ Cementite – iron carbide, intermetallic compound, having fixed composition Fe_3C.



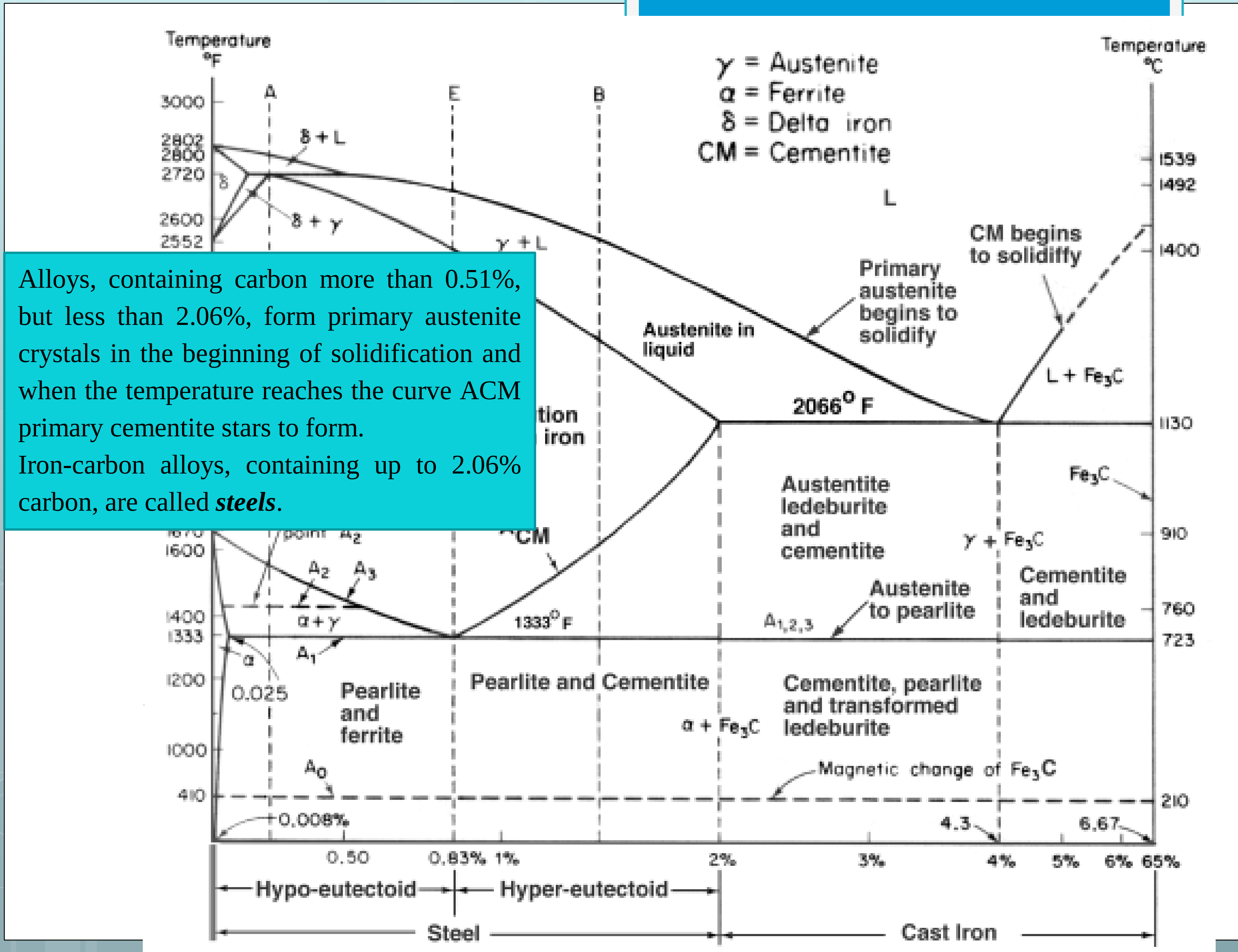
IRON CARBON CONSTITUTIONAL DIAGRAM-II

Alloys, containing up to 0.51% of carbon, start solidification with formation of crystals of δ-ferrite. Carbon content in δ-ferrite increases up to 0.09% in course solidification, and at 2719 ºF (1493ºC) remaining liquid phase and δ-ferrite perform peritectic transformation, resulting in formation of austenite.



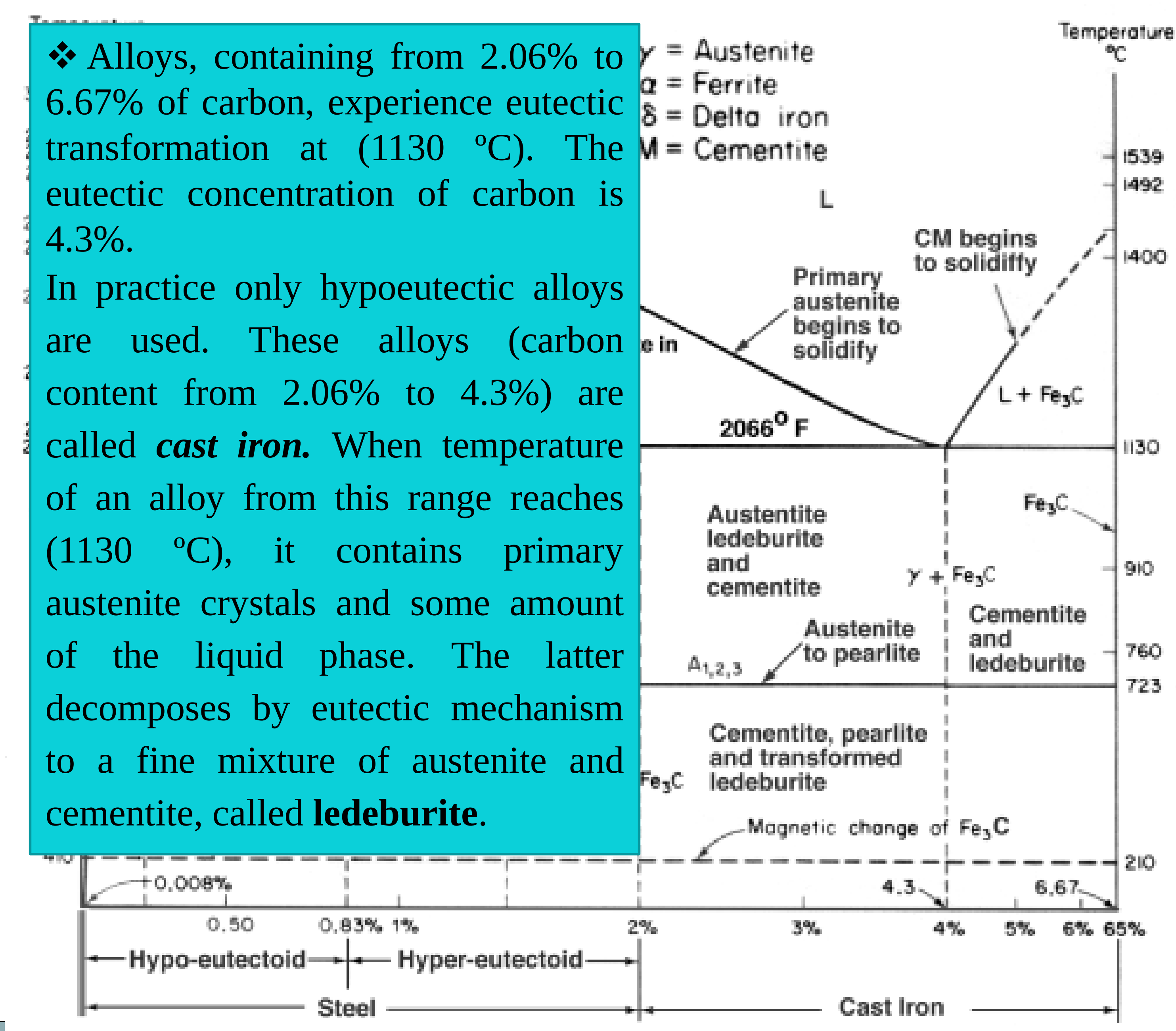
Alloys, containing carbon more than 0.51%, but less than 2.06%, form primary austenite crystals in the beginning of solidification and when the temperature reaches the curve ACM primary cementite stars to form.

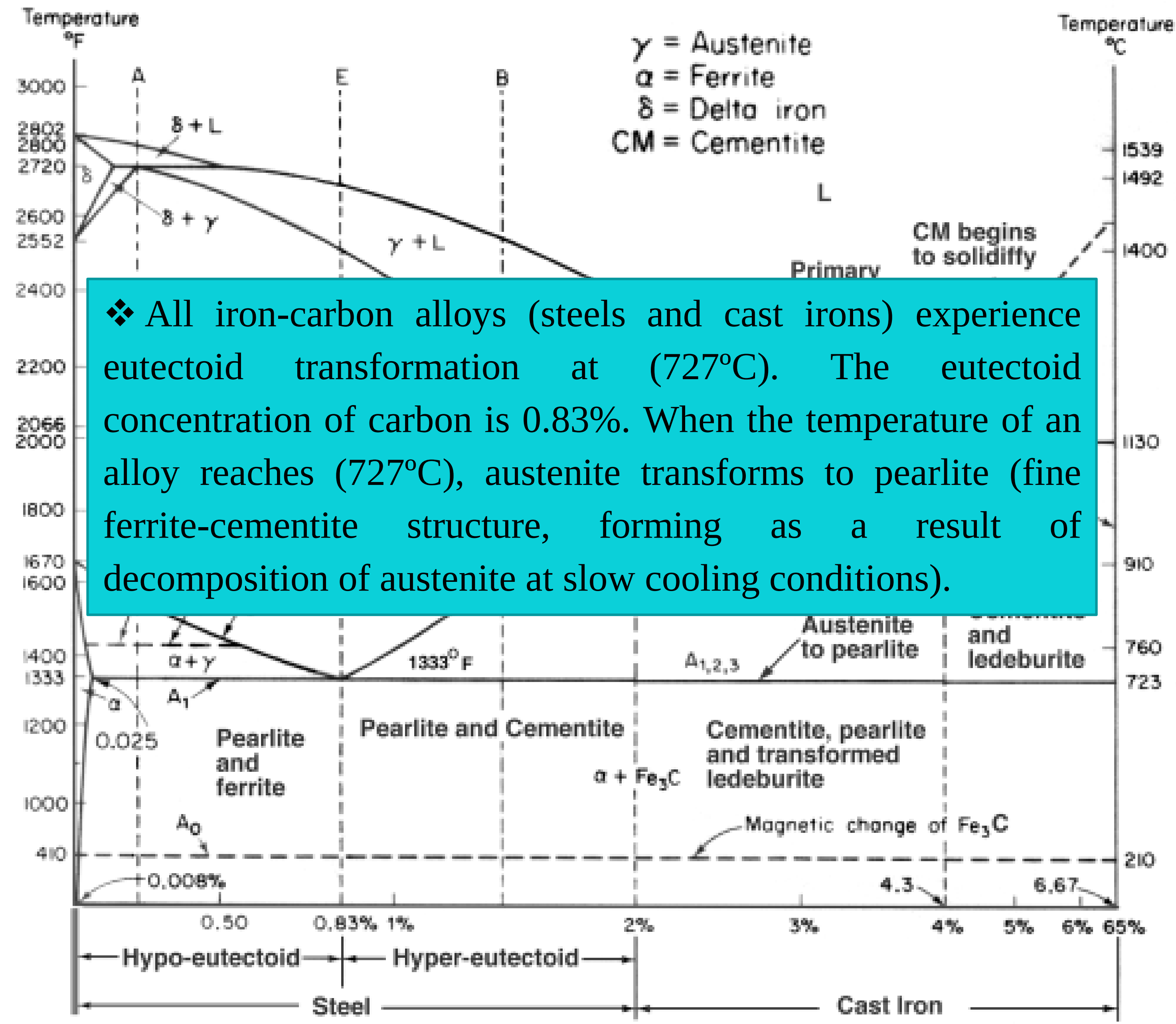
Iron-carbon alloys, containing up to 2.06% carbon, are called ***steels***.



❖ Alloys, containing from 2.06% to 6.67% of carbon, experience eutectic transformation at (1130 ºC). The eutectic concentration of carbon is 4.3%.

In practice only hypoeutectic alloys are used. These alloys (carbon content from 2.06% to 4.3%) are called ***cast iron.*** When temperature of an alloy from this range reaches (1130 ºC), it contains primary austenite crystals and some amount of the liquid phase. The latter decomposes by eutectic mechanism to a fine mixture of austenite and cementite, called **ledeburite**.





❖ All iron-carbon alloys (steels and cast irons) experience eutectoid transformation at (727ºC). The eutectoid concentration of carbon is 0.83%. When the temperature of an alloy reaches (727ºC), austenite transforms to pearlite (fine ferrite-cementite structure, forming as a result of decomposition of austenite at slow cooling conditions).

CRITICAL TEMPERATURE

❖ **Upper critical temperature (point)** A_3 is the temperature, below which ferrite starts to form as a result of ejection from austenite in the hypoeutectoid alloys.

❖ **Upper critical temperature (point)** A_{CM} is the temperature, below which cementite starts to form as a result of ejection from austenite in the hypereutectoid alloys.

❖ **Lower critical temperature (point)** A_1 is the temperature of the austenite-to-pearlite eutectoid transformation. Below this temperature austenite does not exist.

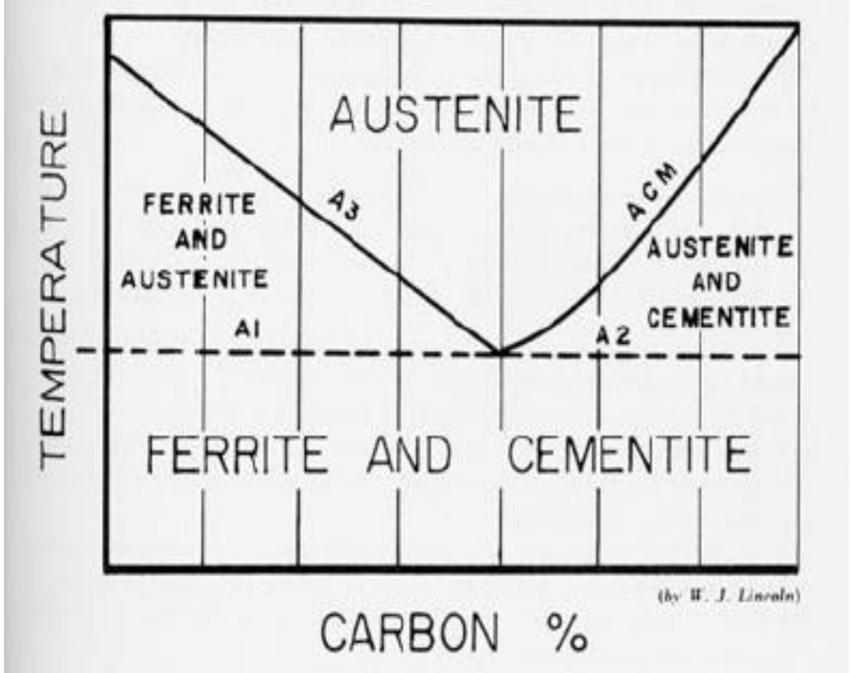
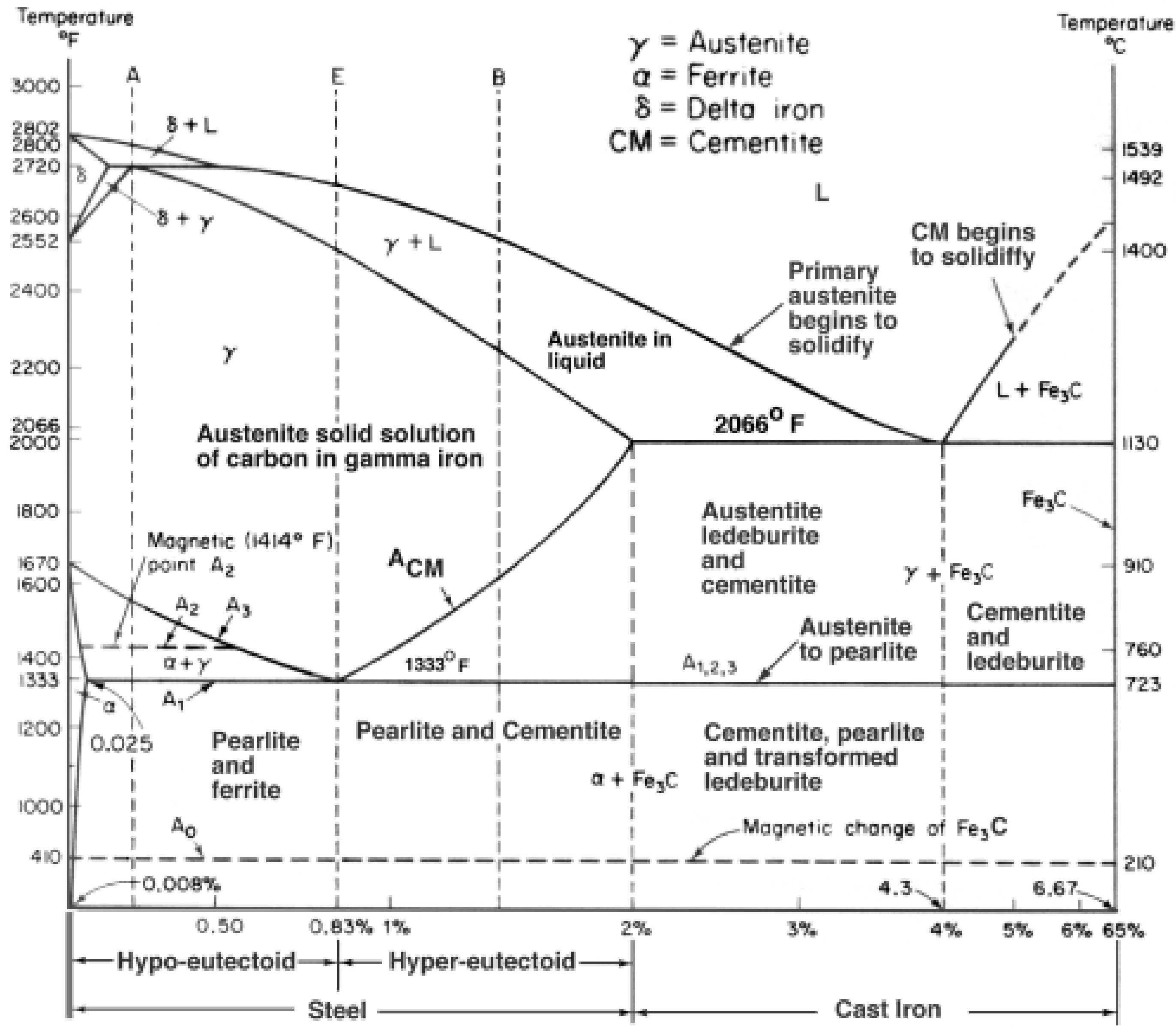


Figure 73. Schematic iron-carbon diagram showing areas important in heat treatment.



IRON CARBON CONSTITUTIONAL DIAGRAM-II

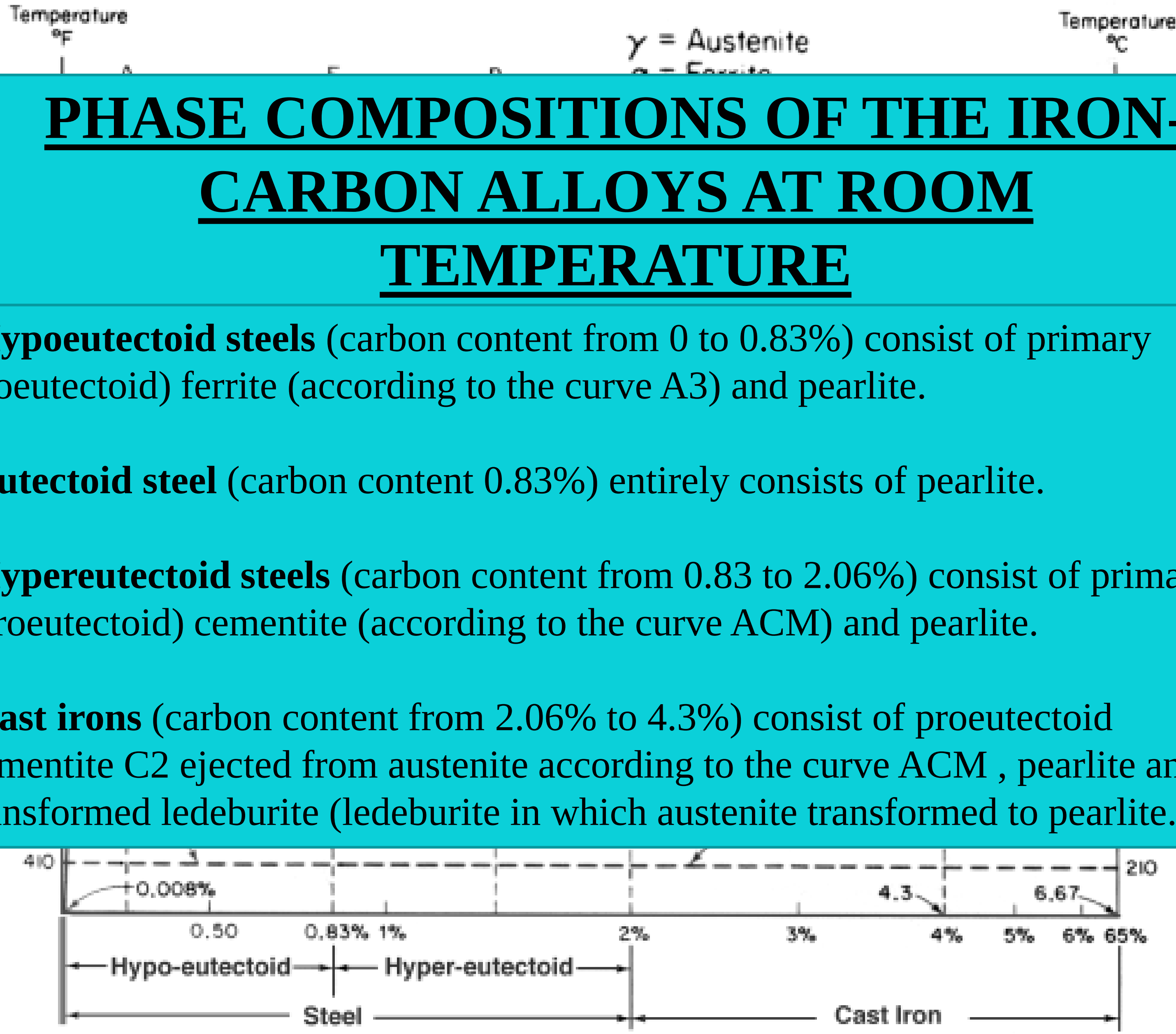
PHASE COMPOSITIONS OF THE IRON-CARBON ALLOYS AT ROOM TEMPERATURE

Hypoeutectoid steels (carbon content from 0 to 0.83%) consist of primary proeutectoid) ferrite (according to the curve A3) and pearlite.

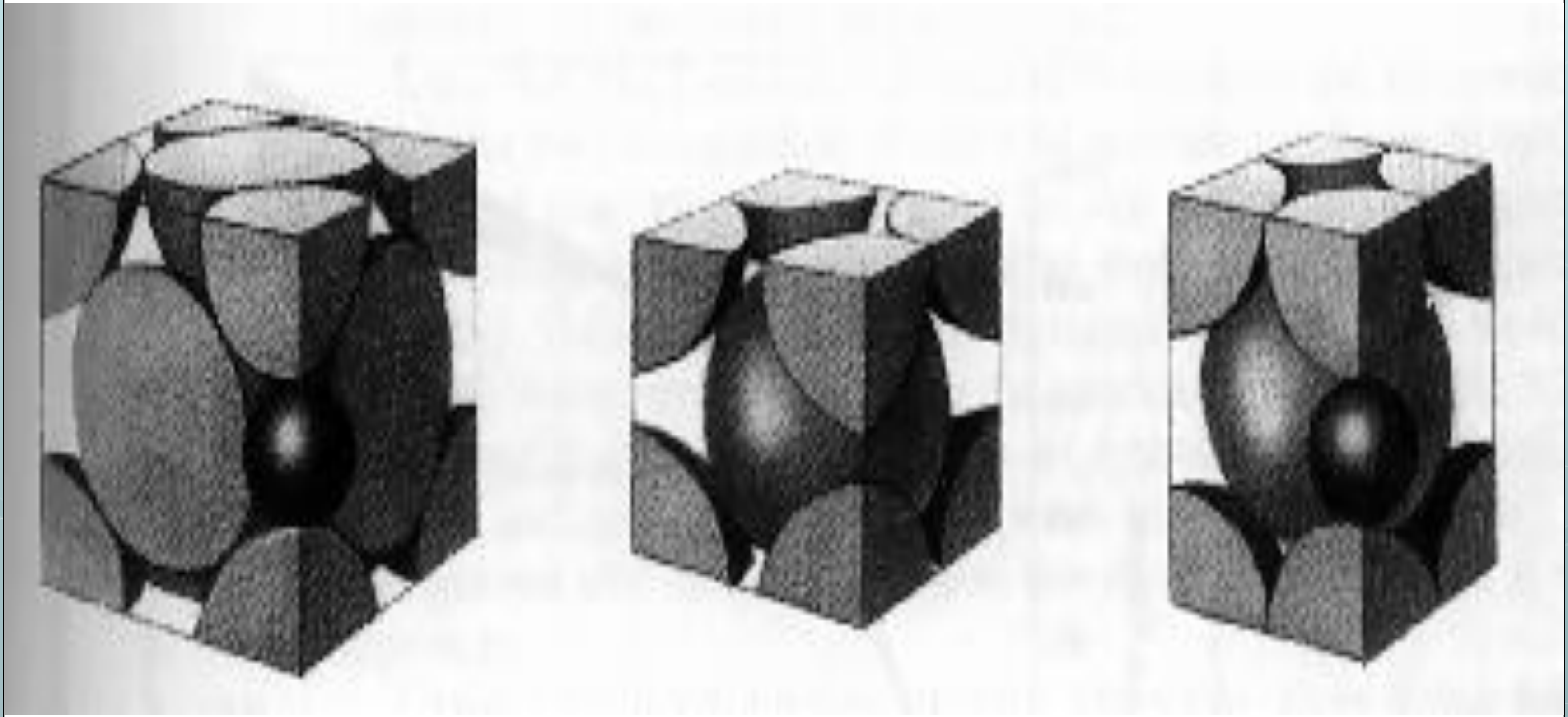
Eutectoid steel (carbon content 0.83%) entirely consists of pearlite.

Hypereutectoid steels (carbon content from 0.83 to 2.06%) consist of primary (proeutectoid) cementite (according to the curve ACM) and pearlite.

Cast irons (carbon content from 2.06% to 4.3%) consist of proeutectoid cementite C2 ejected from austenite according to the curve ACM , pearlite and transformed ledeburite (ledeburite in which austenite transformed to pearlite.)

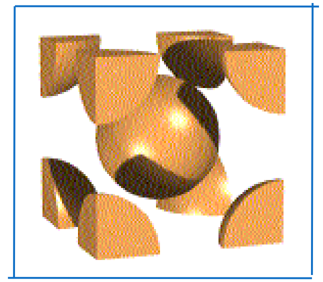


PHASES OF IRON

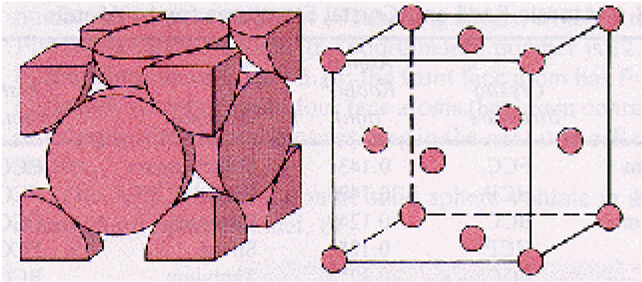


FCC (Austenite) BCC (Ferrite) HCP (Martensite)

- Alpha
  - “Ferrite”, BCC Iron
  - Room Temperature

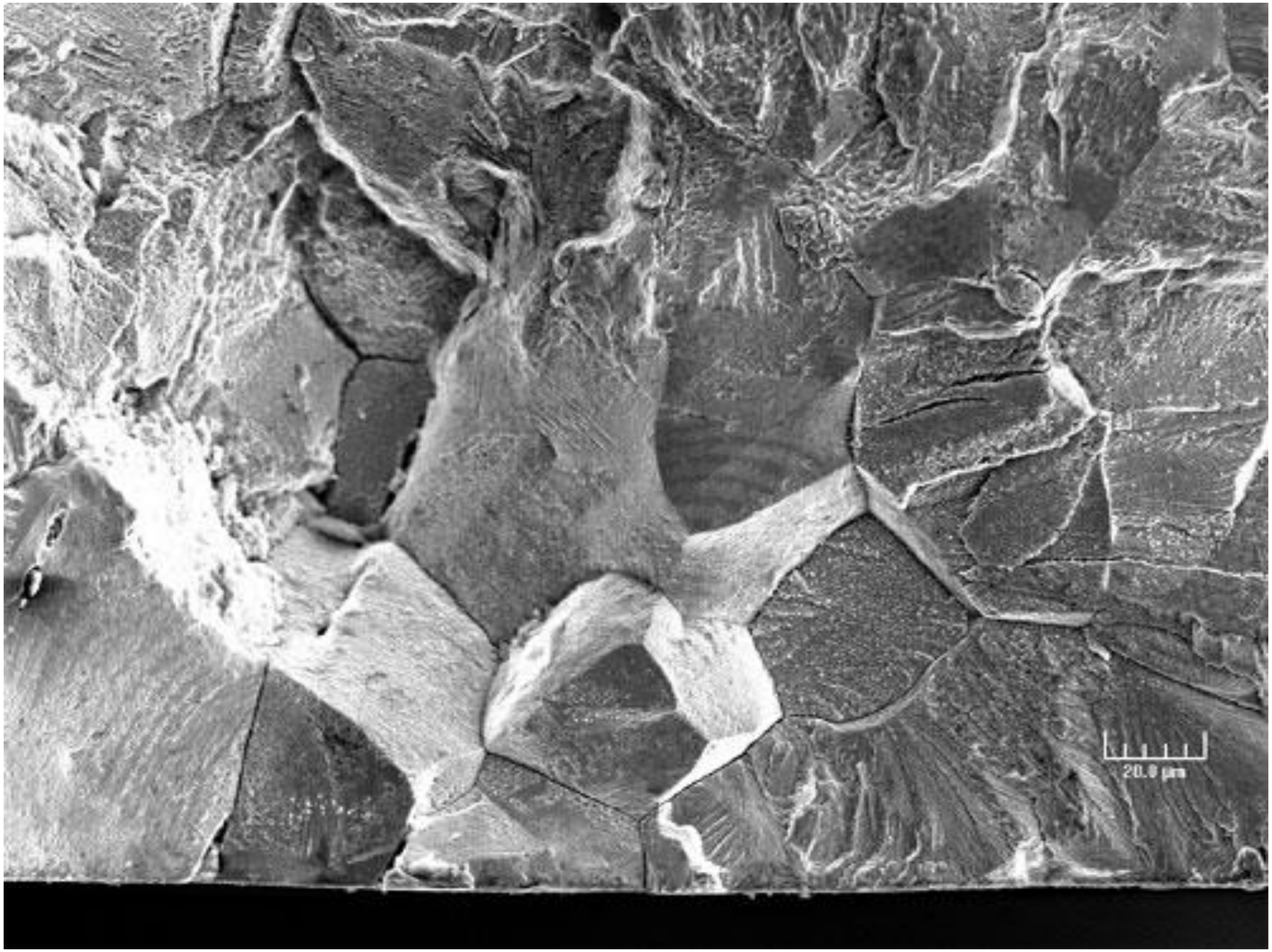


- Gamma
  - “Austenite”, FCC Iron
  - Elevated Temperatures

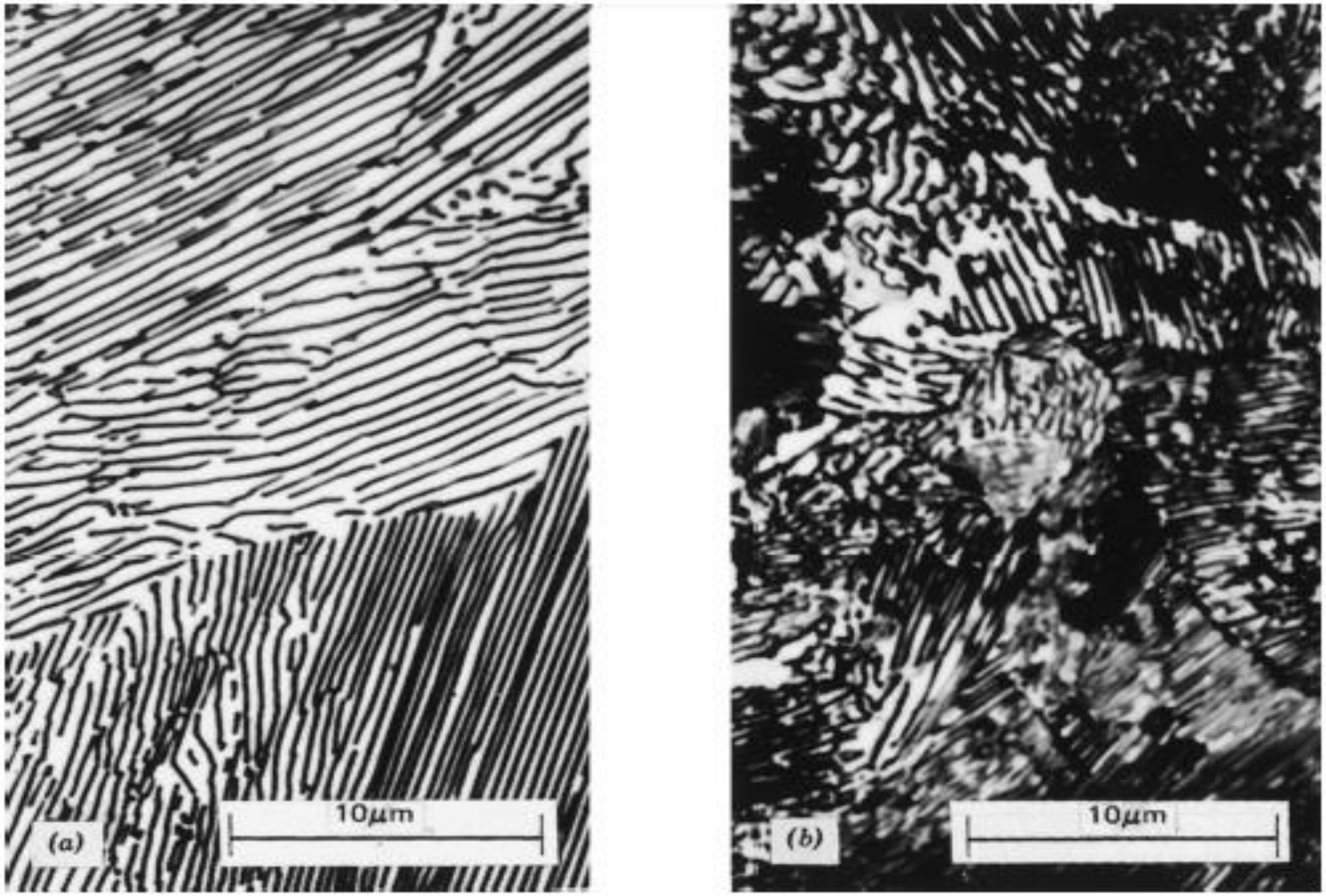


These are PHASES of iron. Adding carbon changes the phase transformation temperature.

MICROSTRUCTURE OF AUSTENITE

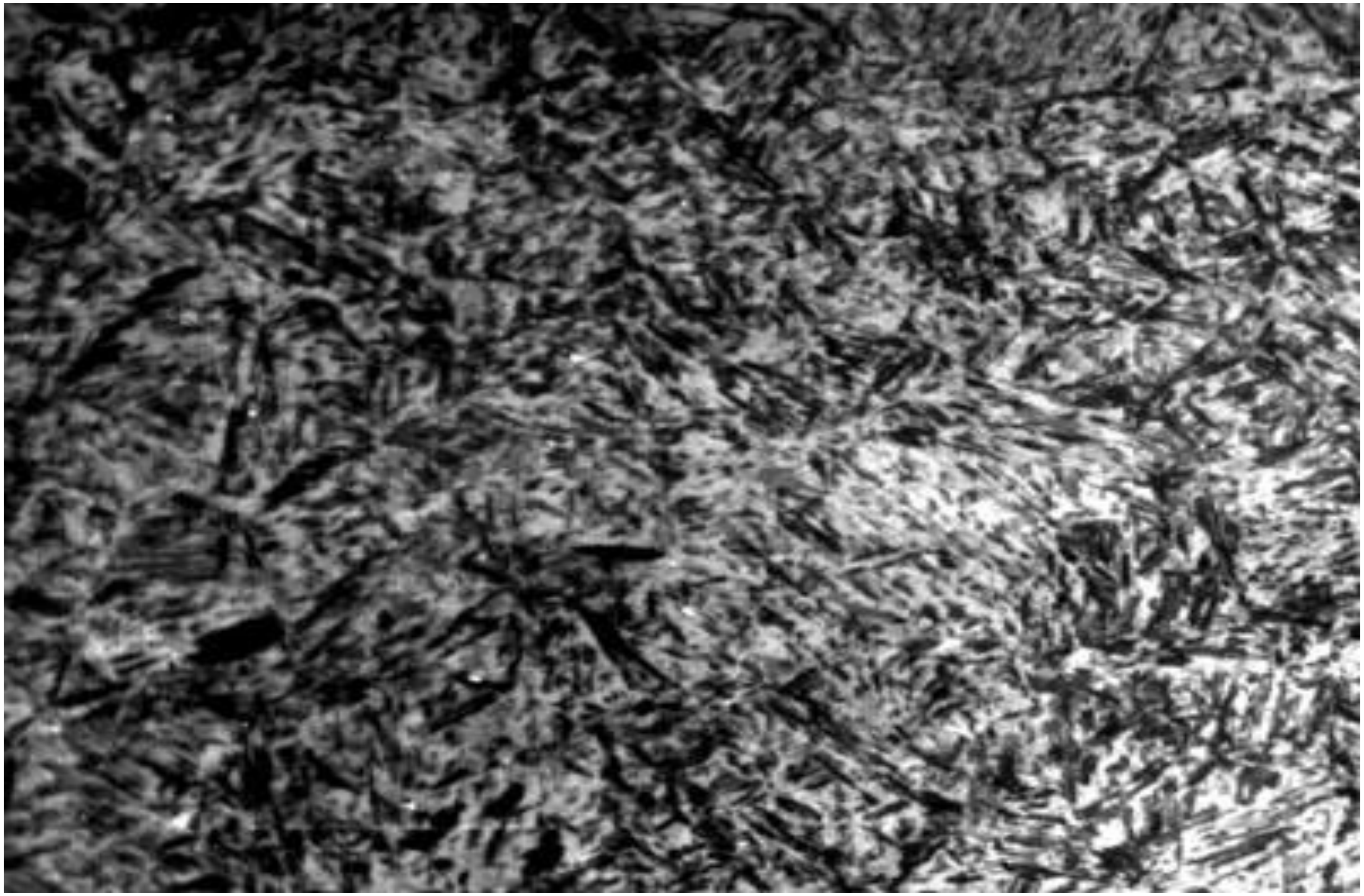


MICROSTRUCTURE OF PEARLITE



Photomicrographs of (a) coarse pearlite and (b) fine pearlite. 3000X

MICROSTRUCTURE OF MARTENSITE



IRON-CARBON (Fe-C) PHASE DIAGRAM (EXAMPLE 1)

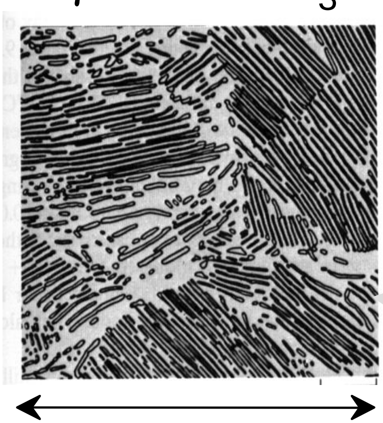
2 important points

- Eutectic (A)

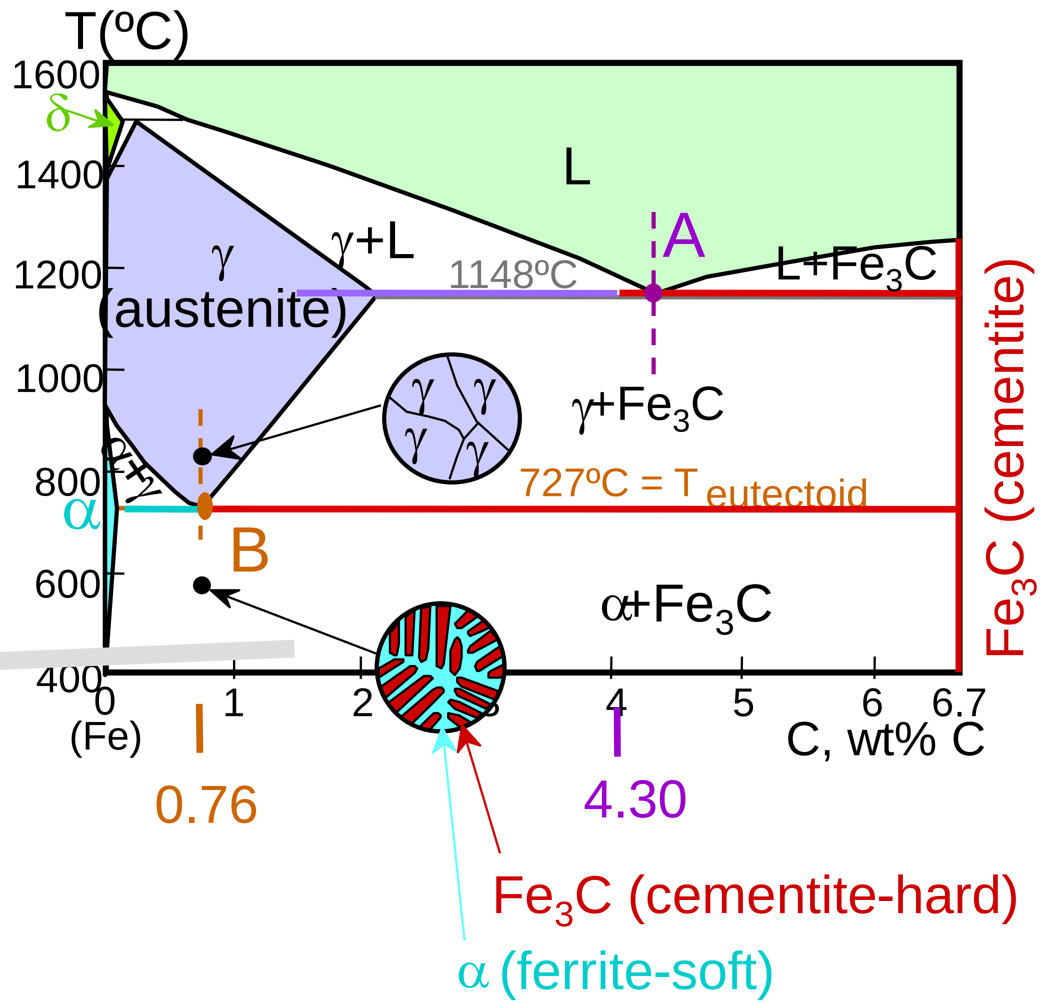
$L \Rightarrow \gamma + Fe_3C$

- Eutectoid (B)

$\gamma \Rightarrow \alpha + Fe_3C$



Result: Pearlite = alternating layers of α and Fe_3C phases



EXAMPLE 1

- An alloy of eutectoid composition (0.83 wt% C) as it is cooled down from a temperature within the γ-phase region (e.g., at 800 ºC).
- Initially the alloy is composed entirely of the austenitic phase having a composition of 0.83 wt% C
- As the alloy is cooled, no changes will occur until the eutectoid temperature (727 ºC).
- Upon crossing this temperature to point B, the austenite transforms according to:

Eutectoid (B):

$$\gamma\ (0.83\ \text{wt\% C}) \Rightarrow \alpha\ (0.025\ \text{wt\% C}) + Fe_3C\ (6.7\ \text{wt\% C})$$

EXAMPLE 1 (cont.)

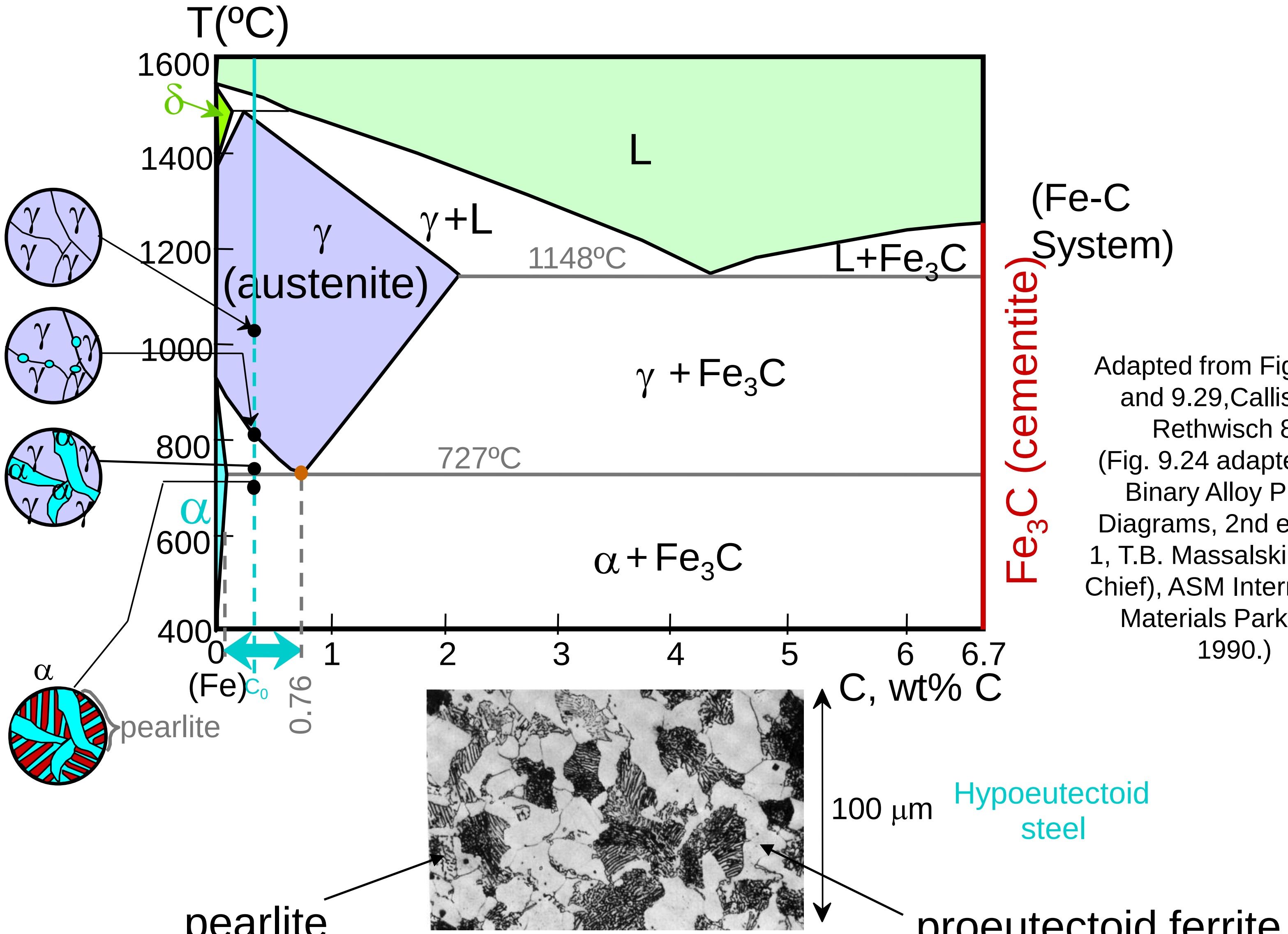
- The microstructure for this eutectoid steel is slowly cooled through the eutectoid temperature consists of alternating layers or lamellar of the two phases (α and Fe_3C) that form simultaneously during the transformation.
- Point B is called **pearlite**.
- Mechanically, pearlite has properties intermediate between the soft, ductile ferrite and the hard, brittle cementite.

EXAMPLE 1 (cont.)

- The alternating α and Fe_3C layers in pearlite form as such for the same reason that the eutectic structure forms because the composition of austenite (0.83 %wt C) is different from either of ferrite (0.025 wt% C) and cementite (6.70 wt% C), and the phase transformation requires that there be a redistribution of the carbon by diffusion.

- Subsequent cooling of the pearlite from point B will produce relatively insignificant microstructural changes.

Hypoeutectoid Steel (EXAMPLE 2)



Adapted from Figs. 9.24 and 9.29,Callister & Rethwisch 8e. (Fig. 9.24 adapted from Binary Alloy Phase Diagrams, 2nd ed., Vol. 1, T.B. Massalski (Ed.-in-Chief), ASM International, Materials Park, OH, 1990.)

Adapted from Fig. 9.30, Callister & Rethwisch 8e.

EXAMPLE 2 (cont.)

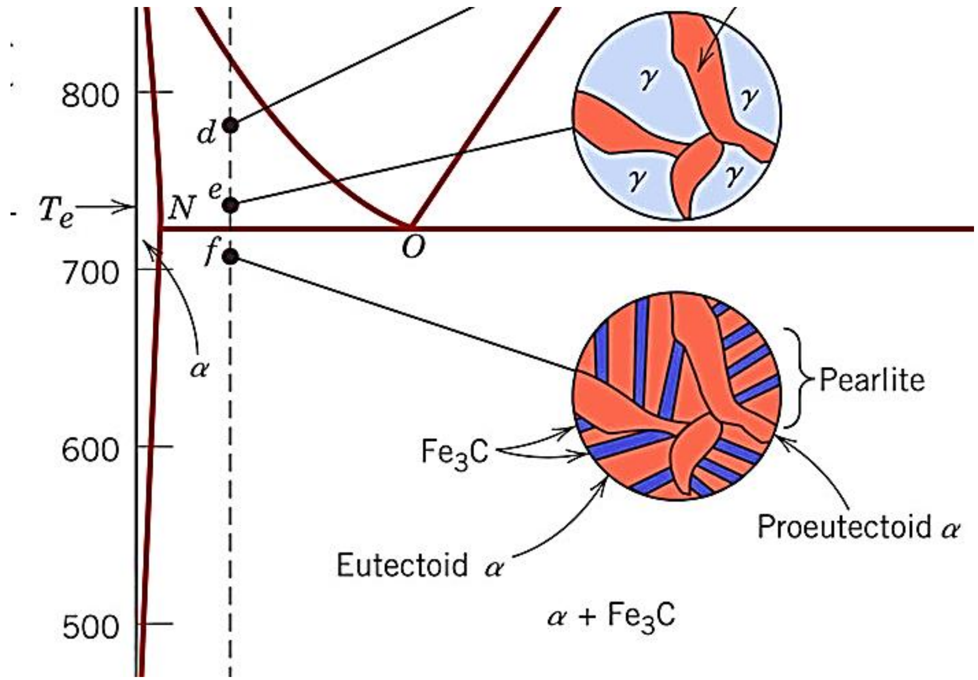
- Within the $\alpha + \gamma$ region, most of the α particles will form along the original γ grain boundaries.
- The particles will grow larger just above the eutectoid line. As the temperature is lowered below T_e, all the γ phase will transform to pearlite according to:

$$\gamma \Rightarrow \alpha + Fe_3C$$

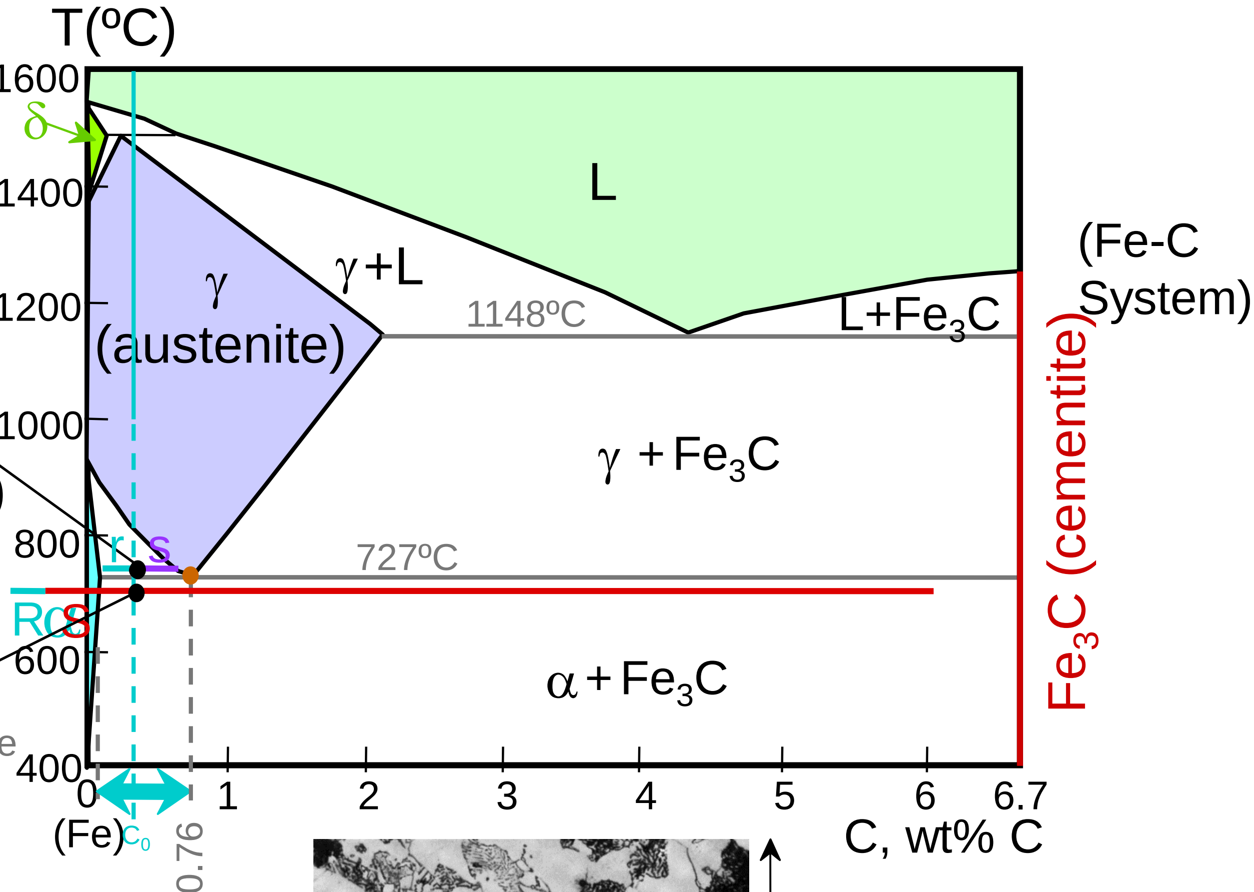
- There will be virtually no change in the α phase that existed just above the $T_{e.}$
- This α that is formed above T_e is called **proeutectoid** (pro=pre=before eutectoid) ferrite.

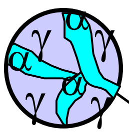
EXAMPLE 2 (cont.)

- The ferrite that is present in the pearlite is called **eutectoid ferrite**.
- As a result, two microconstituents are present in the last micrograph (the one below T_e): proeutectoid ferrite and pearlite



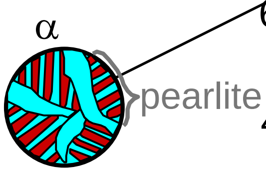
EXAMPLE 2





$W_{\alpha} = s/(r+s)$

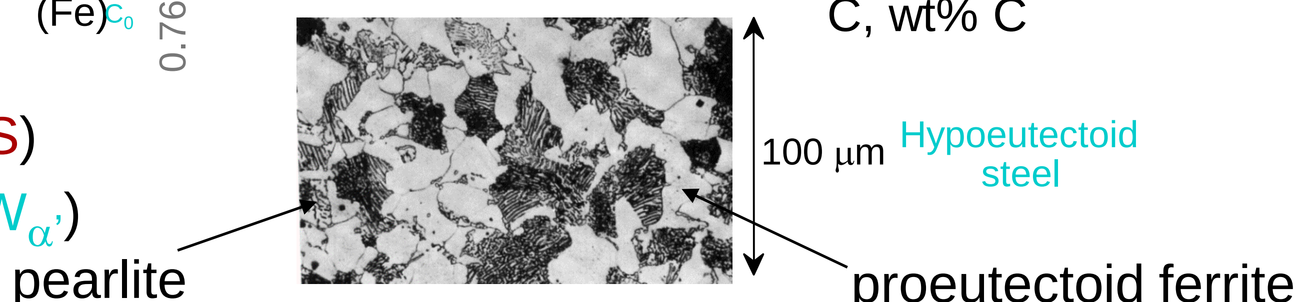
$W_{\gamma} = (1 - W_{\alpha})$



$W_{pearlite} = W_{\gamma}$

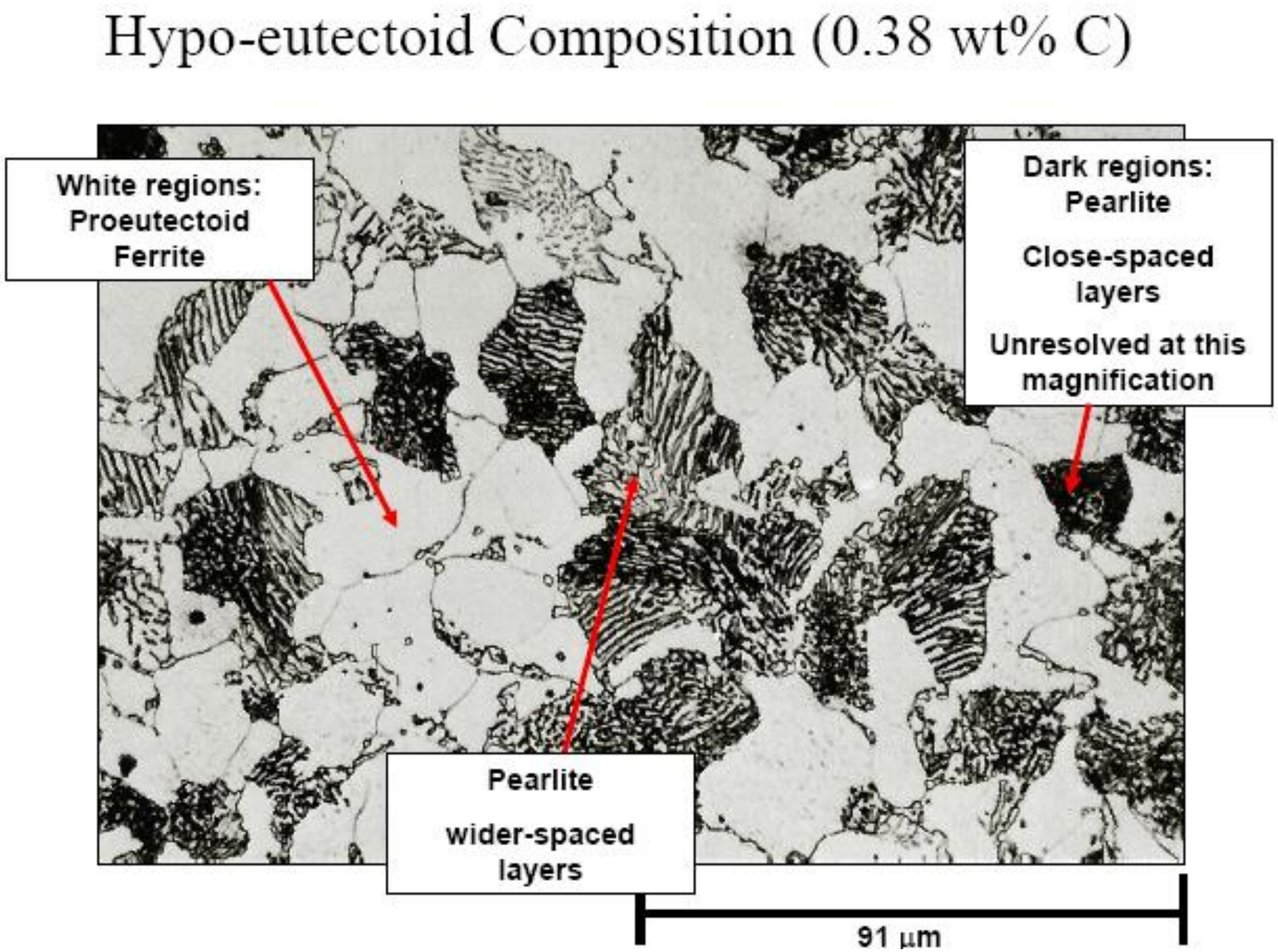
$W_{\alpha'} = S/(R+S)$

$W_{Fe_3C} = (1 - W_{\alpha'})$

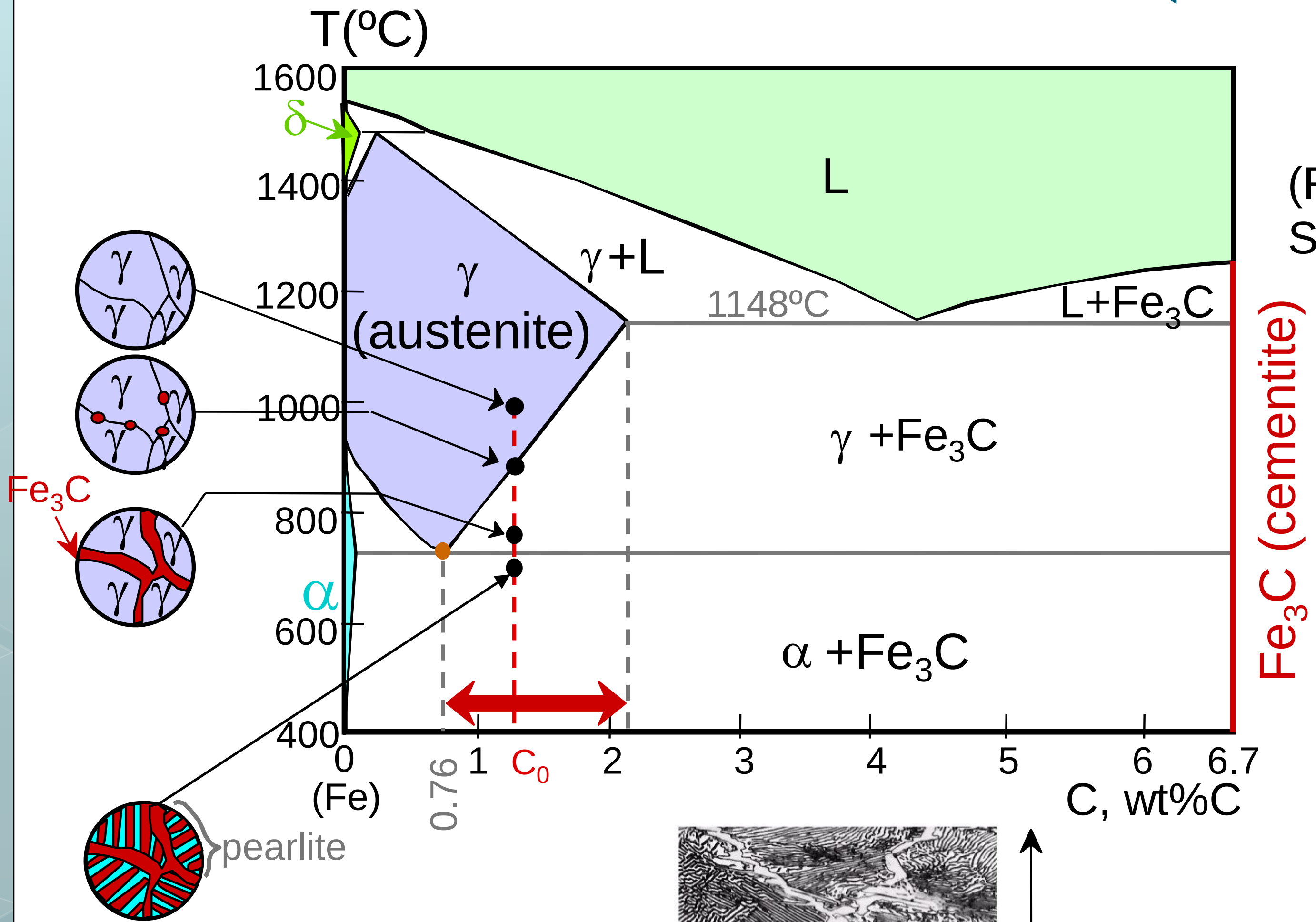


Adapted from Fig. 9.30, Callister & Rethwisch 8e.

MICROSTRUCTURE OF HYPO-EUTECTOID

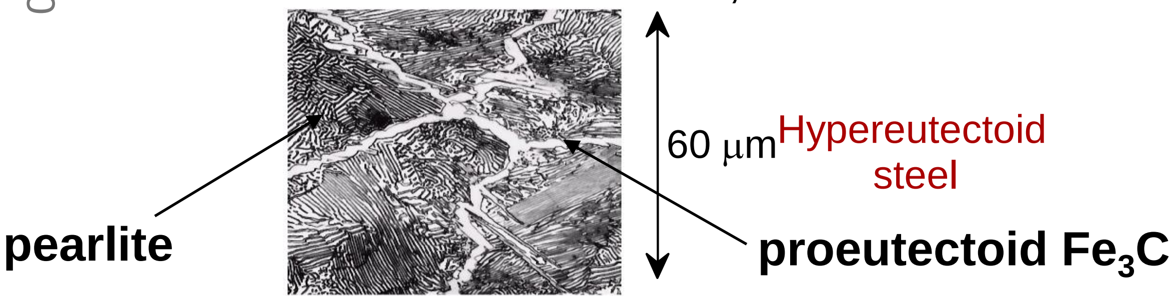


HYPEREUTECTOID STEEL (EXAMPLE 3)



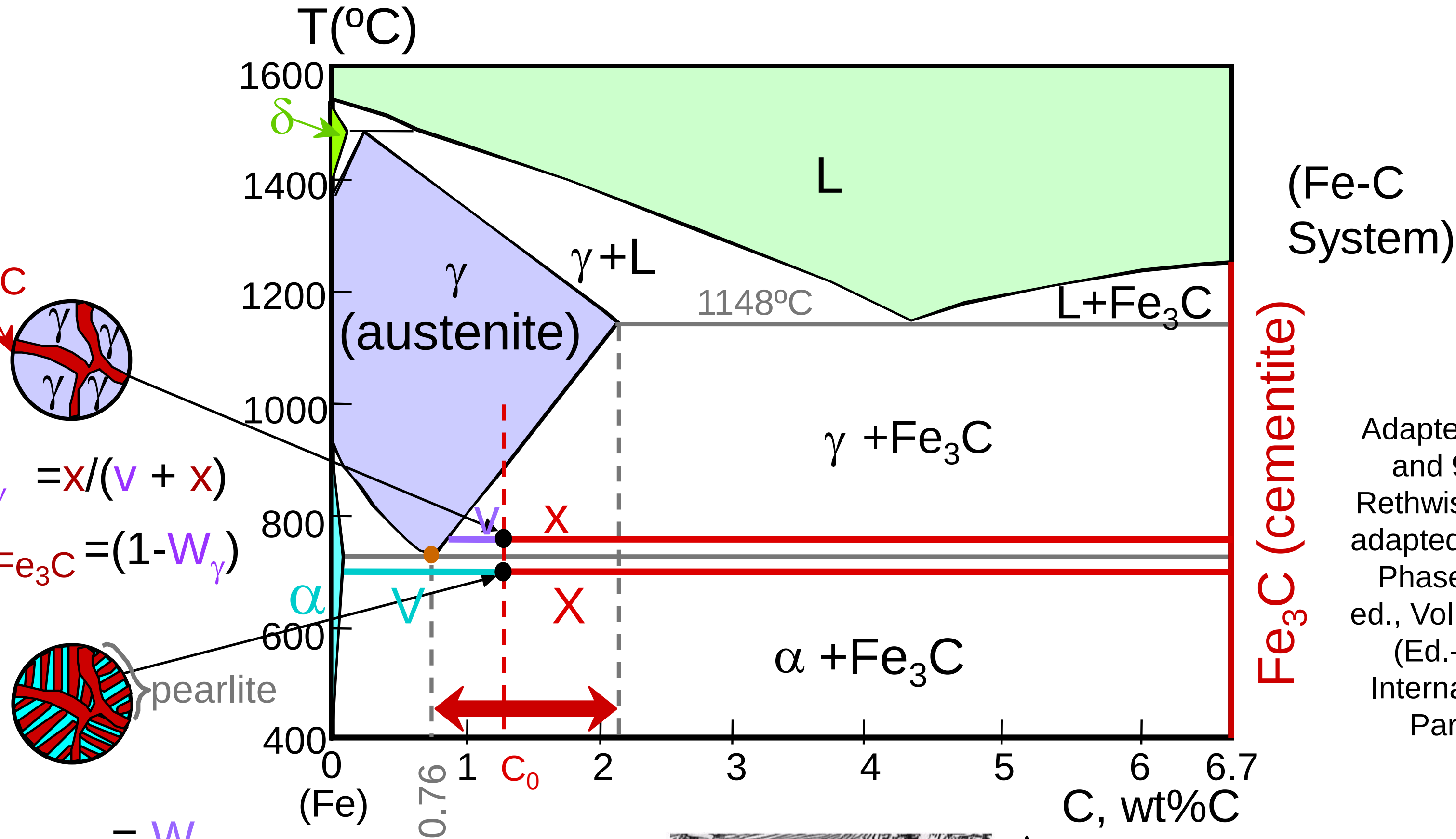
(Fe-C System)

Adapted from Figs. 9.24 and 9.32,Callister & Rethwisch 8e. (Fig. 9.24 adapted from Binary Alloy Phase Diagrams, 2nd ed., Vol. 1, T.B. Massalski (Ed.-in-Chief), ASM International, Materials Park, OH, 1990.)



Adapted from Fig. 9.33, Callister & Rethwisch 8e.

EXAMPLE 3 (cont.)



$W_\gamma = x/(v + x)$

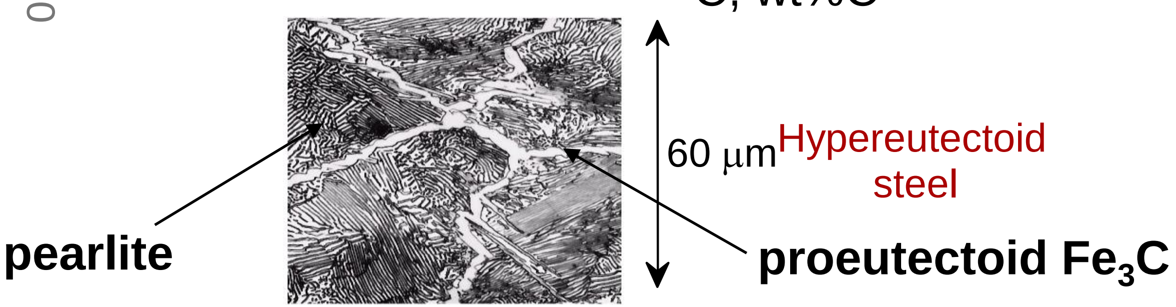
$W_{Fe_3C} = (1 - W_\gamma)$

$W_{pearlite} = W_\gamma$

$W_\alpha = X/(V + X)$

$W_{Fe_3C'} = (1 - W_\alpha)$

Adapted from Figs. 9.24 and 9.32,Callister & Rethwisch 8e. (Fig. 9.24 adapted from Binary Alloy Phase Diagrams, 2nd ed., Vol. 1, T.B. Massalski (Ed.-in-Chief), ASM International, Materials Park, OH, 1990.)

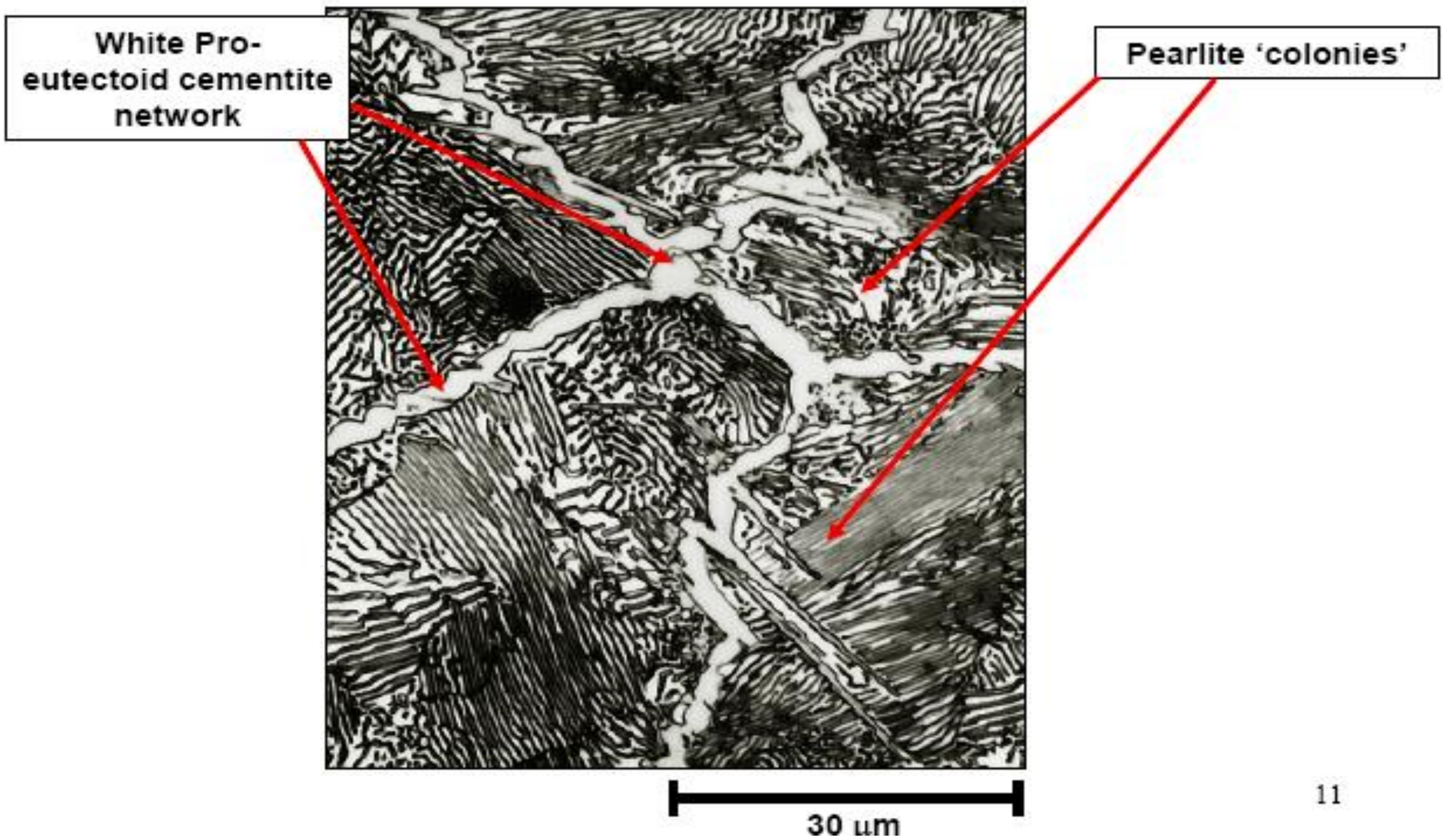


Hypereutectoid steel

Adapted from Fig. 9.33, Callister & Rethwisch 8e.

MICROSTRCTURE OF HYPER-EUTECTOID

Hyper-eutectoid Composition (1.40 wt% C)



Example: Phase Equilibria

For a 99.6 wt% Fe-0.40 wt% C at a temperature just below the eutectoid, determine the following

a) composition of Fe_3C and ferrite (α)
b) the amount of carbide (cementite) in grams that forms per 100 g of steel
c) the amount of pearlite and proeutectoid ferrite (α)

Solution:

a) composition of Fe_3C and ferrite (α)

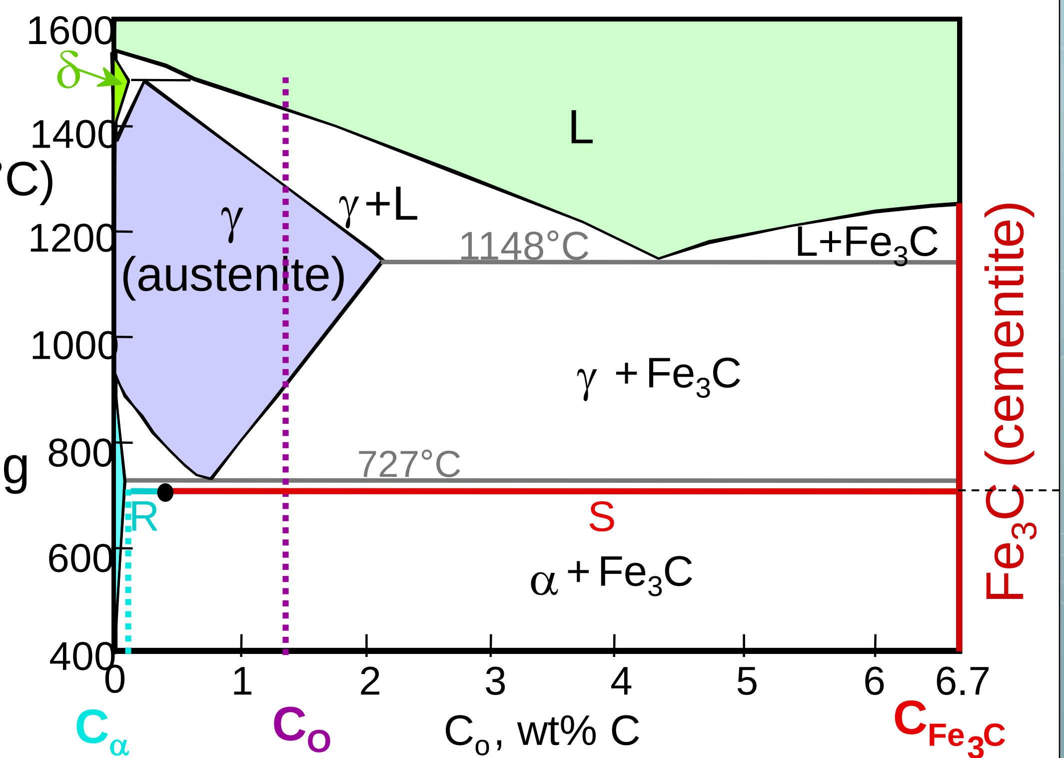
b) the amount of carbide (cementite) in grams that forms per 100 g of steel

C_O = 0.40 wt% C
C_α = 0.022 wt% C
C_{Fe_3C} = 6.70 wt% C

$$\frac{Fe_3C}{Fe_3C + \alpha} = \frac{C_o - C_\alpha}{C_{Fe_3C} - C_\alpha} \text{x}100$$

$$= \frac{0.4 - 0.022}{6.7 - 0.022} x\,100 = 5.7\text{g}$$

$Fe_3C = 5.7$ g
$\alpha = 94.3$ g

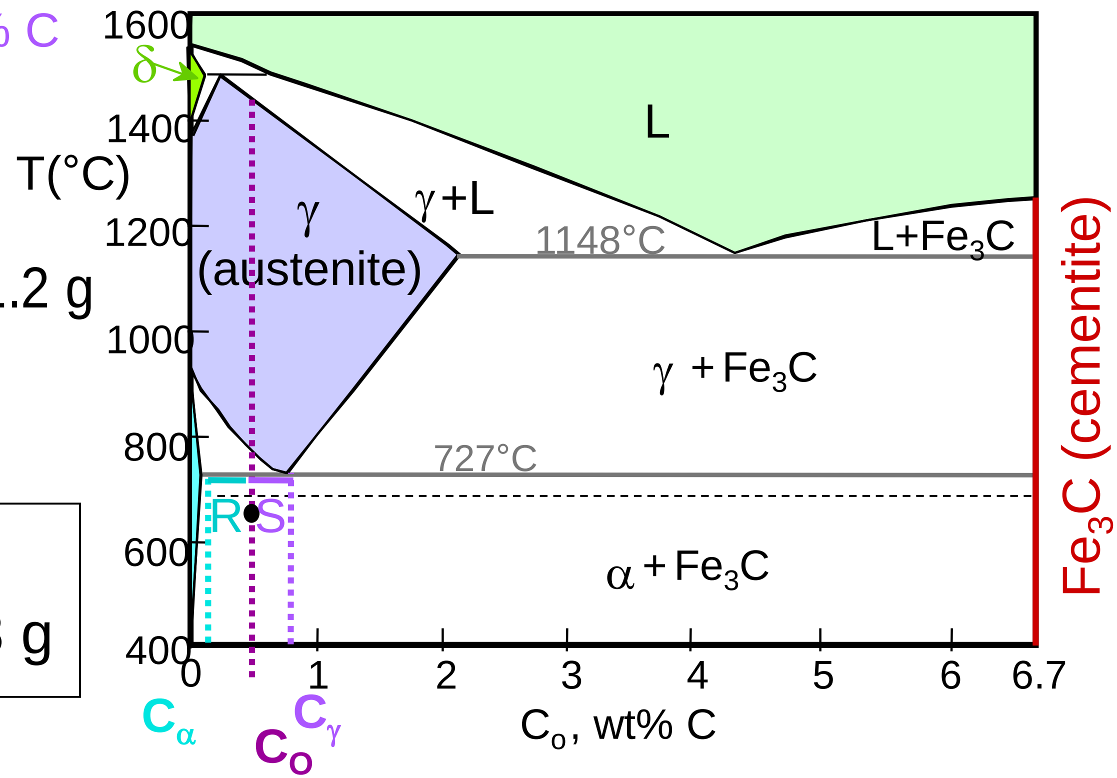


c. the amount of pearlite and proeutectoid ferrite (α)
note: amount of pearlite = amount of γ just above T_E

C_o = 0.40 wt% C
C_α = 0.022 wt% C
$C_{pearlite} = C_\gamma$ = 0.76 wt% C

$$\frac{\gamma}{\gamma+\alpha} = \frac{C_O - C_\alpha}{C_\gamma - C_\alpha} \times 100 = 51.2 \text{ g}$$

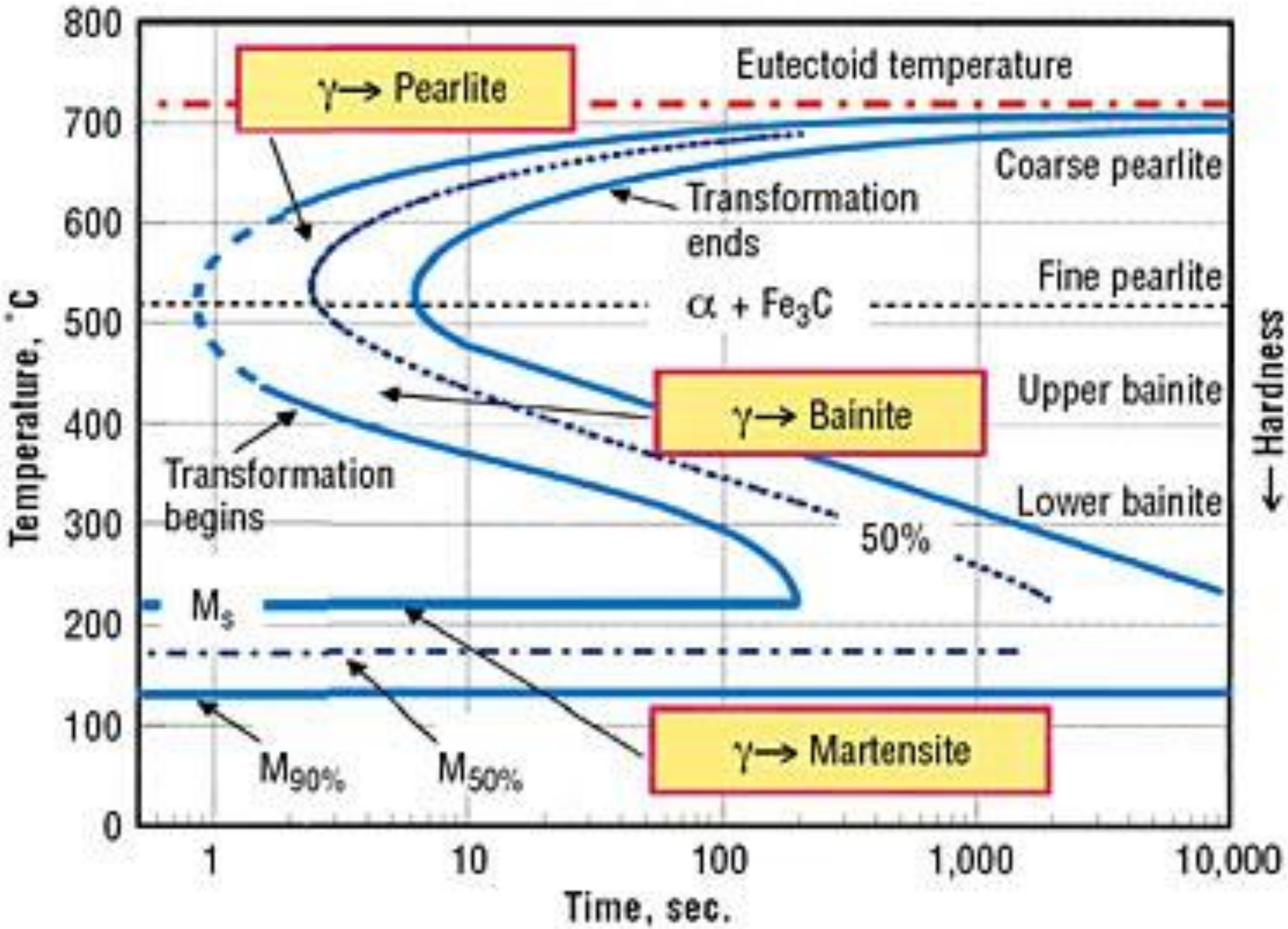
pearlite = 51.2 g
proeutectoid α = 48.8 g



TTT DIAGRAM

T (Time) T(Temperature) T(Transformation) diagram is a plot of temperature versus the logarithm of time for a steel alloy of definite composition. It is used to determine when transformations begin and end for an isothermal (constant temperature) heat treatment of a previously austenitized alloy. When austenite is cooled slowly to a temperature below LCT (Lower Critical Temperature), the structure that is formed is Pearlite. As the cooling rate increases, the pearlite transformation temperature gets lower. The microstructure of the material is significantly altered as the cooling rate increases. By heating and cooling a series of samples, the history of the austenite transformation may be recorded. TTT diagram indicates when a specific transformation starts and ends and it also shows what percentage of transformation of austenite at a particular temperature is achieved.

TTT DIAGRAM



800
700
600
500
400
300
200
100
0
Temperature, °C
γ→ Pearlite
Eutectoid temperature
Coarse pearlite
Transformation ends
Fine pearlite
α + Fe3C
Upper bainite
γ→ Bainite
Lower bainite
Transformation begins
50%
Ms
M90%
M50%
γ→ Martensite
← Hardness
1
10
100
1,000
10,000
Time, sec.

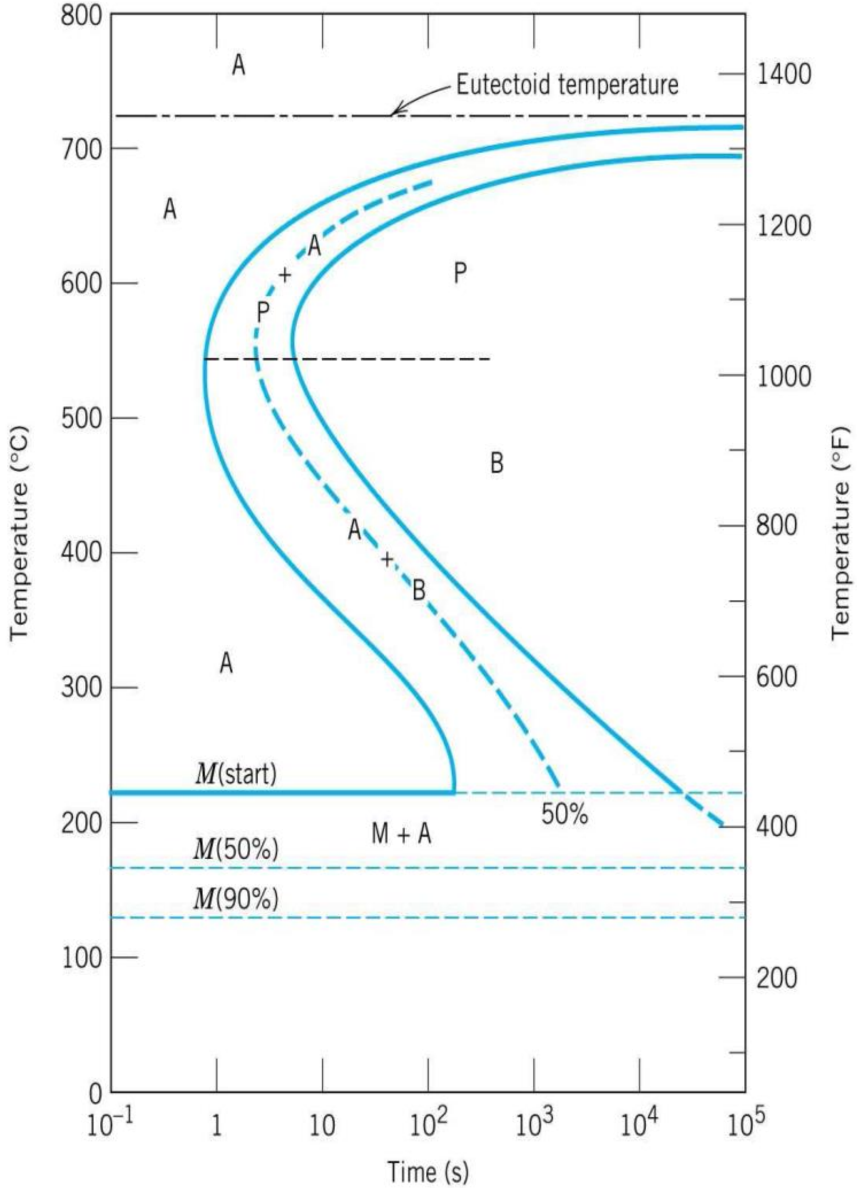
AUSTENITE

PEARLITE

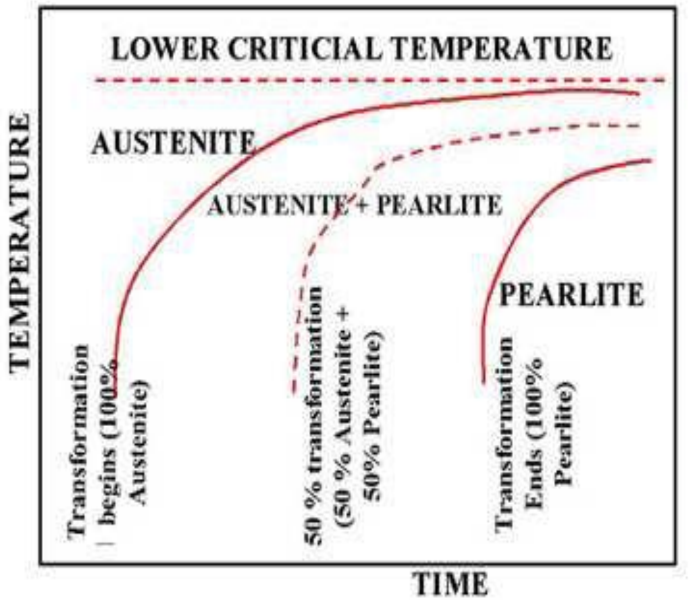
AUSTENITE

Austenite is stable at temperatures above LCT but unstable below LCT. Left curve indicates the start of a transformation and right curve represents the finish of a transformation. The area between the two curves indicates the transformation of austenite to different types of crystal structures. (Austenite to pearlite, austenite to martensite, austenite to bainite transformation.) Isothermal Transform Diagram shows that γ to transformation (a) is rapid! at speed of sound; (b) the percentage of transformation depends on Temperature only.

FIGURE 10.13 The complete isothermal transformation diagram for an iron–carbon alloy of eutectoid composition: A, austenite; B, bainite; M, martensite; P, pearlite.

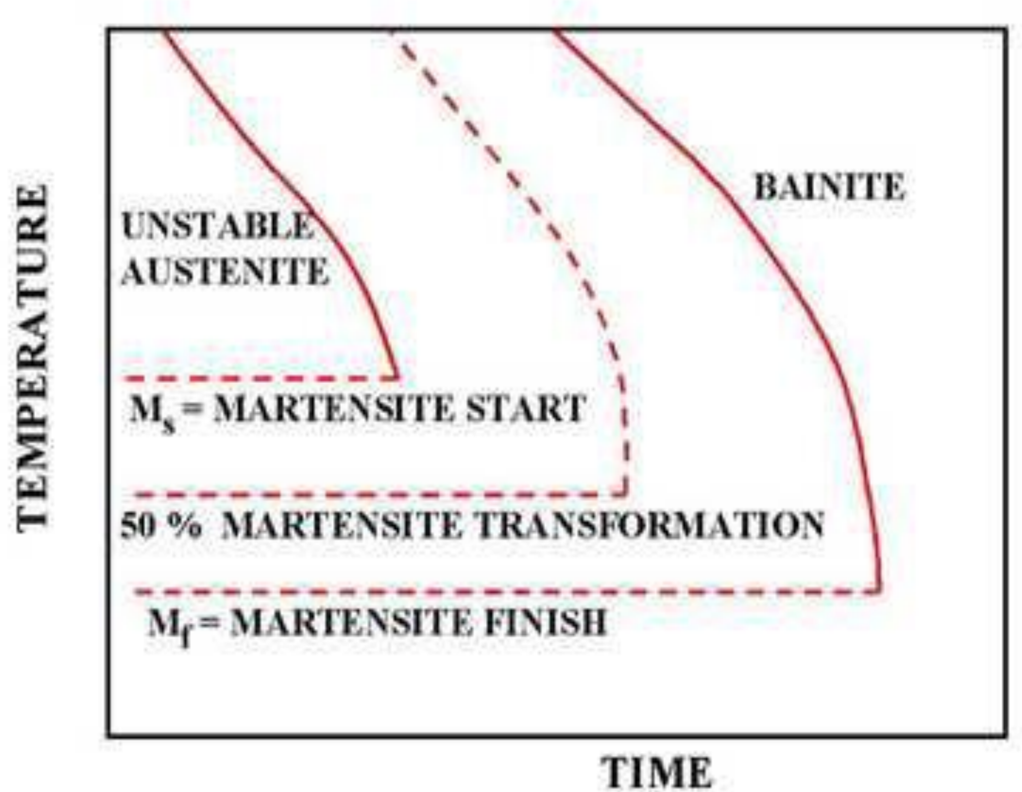


As indicated when is cooled to temperatures below LCT, it transforms to other crystal structures due to its unstable nature. A specific cooling rate may be chosen so that the transformation of austenite can be 50 %, 100 % etc. If the cooling rate is very slow such as annealing process, the cooling curve passes through the entire transformation area and the end product of this the cooling process becomes 100% Pearlite. In other words, when slow cooling is applied, all the Austenite will transform to Pearlite. If the cooling curve passes through the middle of the transformation area, the end product is 50 % Austenite and 50 % Pearlite, which means that at certain cooling rates we can retain part of the Austenite, without transforming it into Pearlite.



Upper half of TTT Diagram(Austenite-Pearlite Transformation Area)

If a cooling rate is very high, the cooling curve will remain on the left hand side of the Transformation Start curve. In this case all Austenite will transform to Martensite. If there is no interruption in cooling the end product will be martensite.



Lower half of TTT Diagram (Austenite-Martensite and Bainite Transformation Areas)