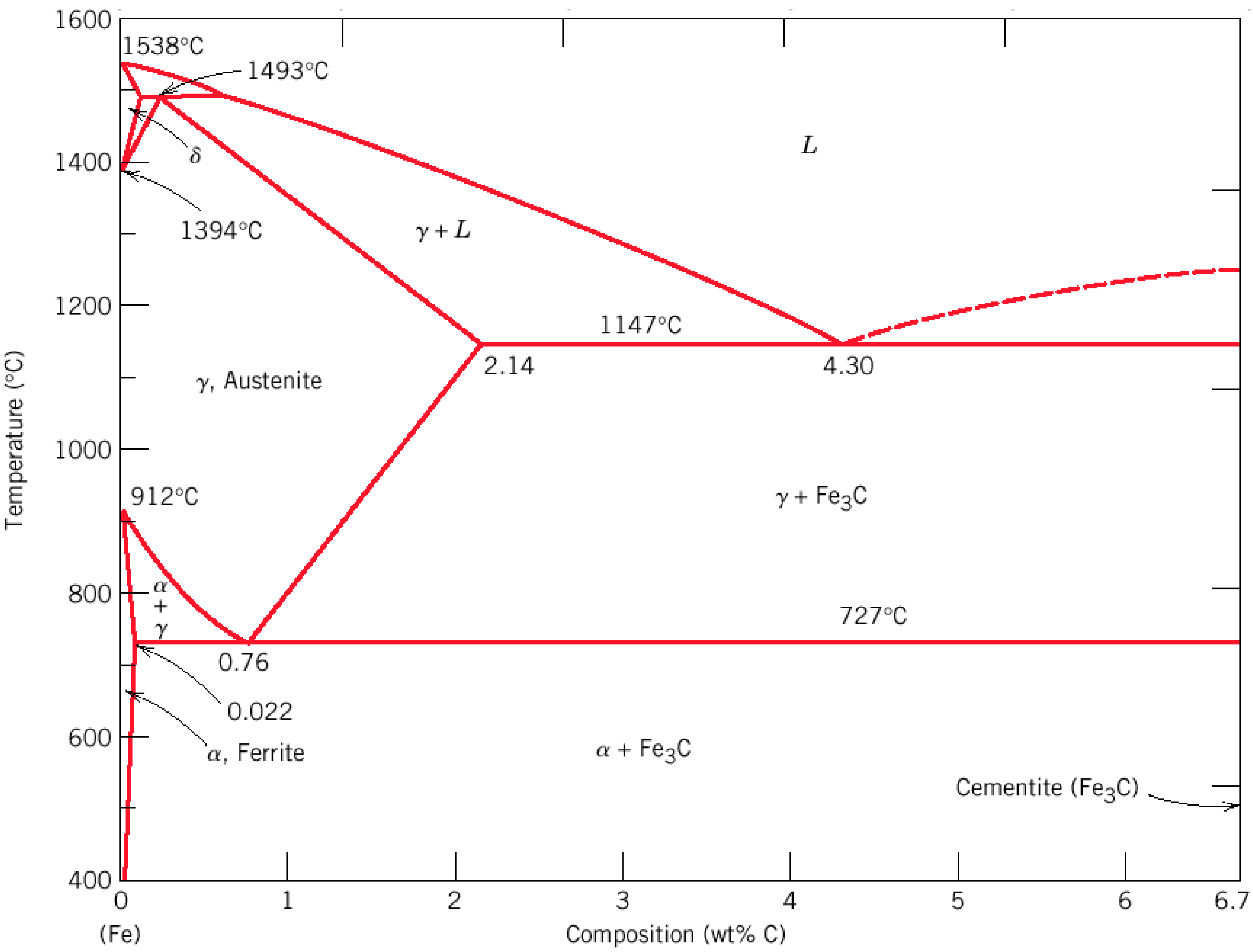
Iron-Carbon Phase Diagram (a review) see Callister Chapter 9

The Iron–Iron Carbide (Fe–Fe_3C) Phase Diagram

In their simplest form, steels are alloys of Iron (Fe) and Carbon (C). The Fe-C phase diagram is a fairly complex one, but we will only consider the steel part of the diagram, up to around 7% Carbon.



Phases in Fe–Fe_3C Phase Diagram

- **α-ferrite - solid solution of C in BCC Fe**
  - Stable form of iron at room temperature.
  - The maximum solubility of C is 0.022 wt%
  - Transforms to FCC γ-austenite at 912 °C

- **γ-austenite - solid solution of C in FCC Fe**
  - The maximum solubility of C is 2.14 wt %.
  - Transforms to BCC δ-ferrite at 1395 °C
  - Is not stable below the eutectic temperature (727 ° C) unless cooled rapidly (Chapter 10)

- **δ-ferrite solid solution of C in BCC Fe**
  - The same structure as α-ferrite
  - Stable only at high T, above 1394 °C
  - Melts at 1538 °C

- **Fe_3C (iron carbide or cementite)**
  - This intermetallic compound is metastable, it remains as a compound indefinitely at room T, but decomposes (very slowly, within several years) into α-Fe and C (graphite) at 650 - 700 °C

- **Fe-C liquid solution**

A few comments on Fe–Fe_3C system

C is an interstitial impurity in Fe. It forms a solid solution with α, γ, δ phases of iron

Maximum solubility in BCC α-ferrite is limited (max. 0.022 wt% at 727 °C) - BCC has relatively small interstitial positions

Maximum solubility in FCC austenite is 2.14 wt% at 1147 °C - FCC has larger interstitial positions

Mechanical properties: Cementite is very hard and brittle - can strengthen steels. Mechanical properties also depend on the microstructure, that is, how ferrite and cementite are mixed.

Magnetic properties: α -ferrite is magnetic below 768 °C, austenite is non-magnetic

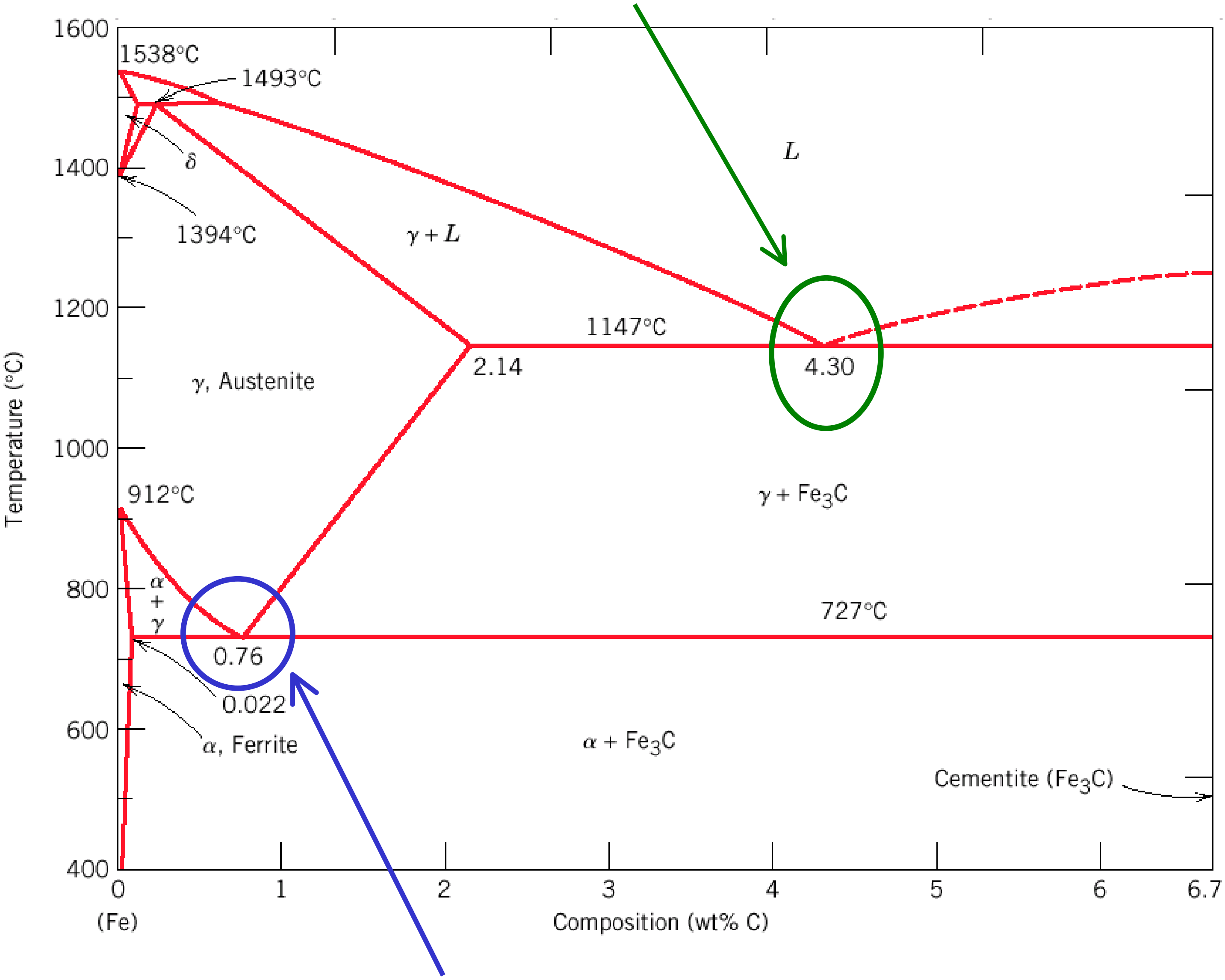
Classification. Three types of ferrous alloys:

- Iron: less than 0.008 wt % C in α–ferrite at room T
- Steels: 0.008 - 2.14 wt % C (usually < 1 wt %)
  α-ferrite + Fe_3C at room T (Chapter 12)
- Cast iron: 2.14 - 6.7 wt % (usually < 4.5 wt %)

Eutectic and eutectoid reactions in $Fe–Fe_3C$

Eutectic: 4.30 wt% C, 1147 °C

$L \leftrightarrow \gamma + Fe_3C$



Eutectoid: 0.76 wt%C, 727 °C

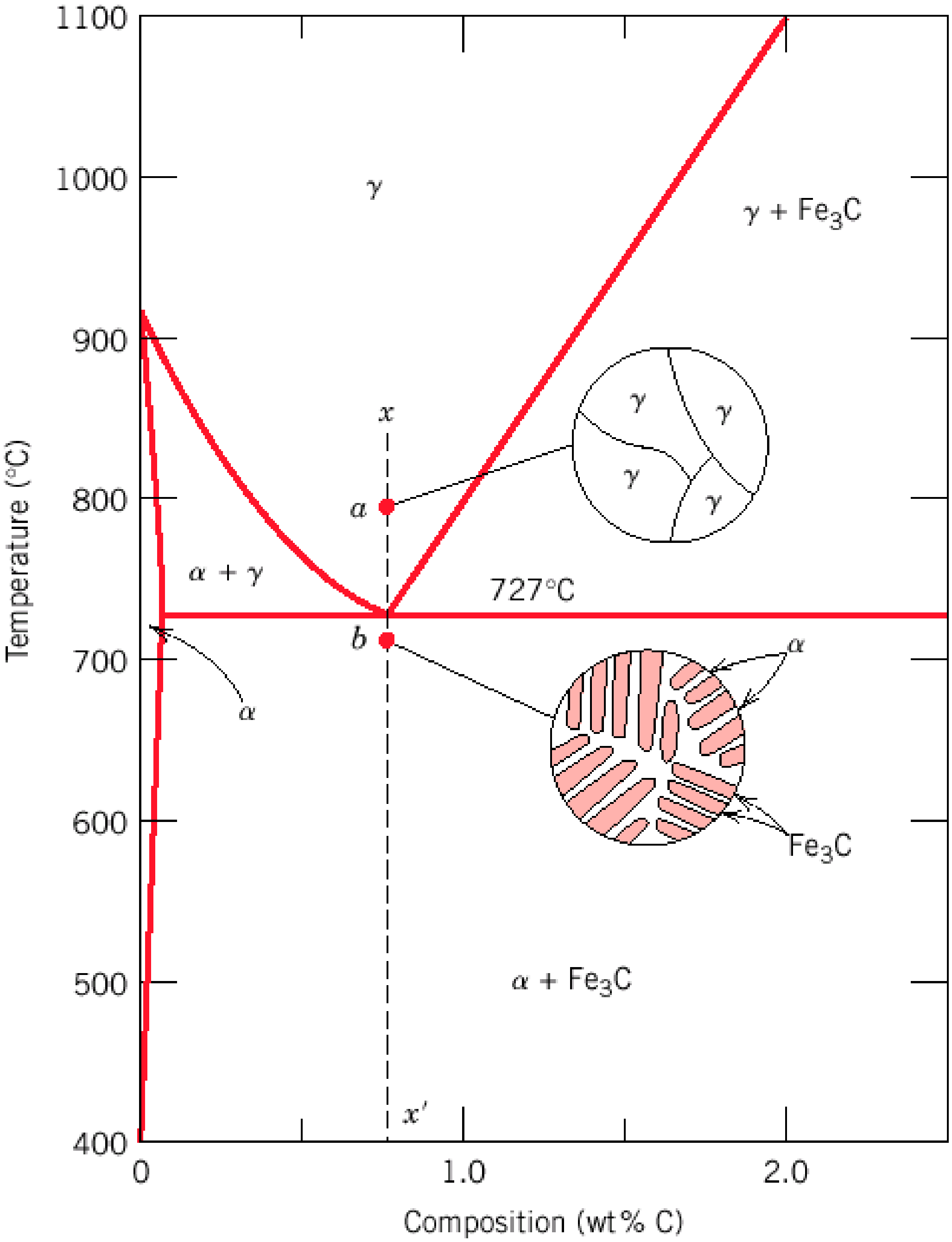
γ(0.76 wt% C) $\leftrightarrow$ α (0.022 wt% C) + Fe_3C

Eutectic and eutectoid reactions are very important in heat treatment of steels

Development of Microstructure in Iron - Carbon alloys

Microstructure depends on composition (carbon content) and heat treatment. In the discussion below we consider slow cooling in which equilibrium is maintained.

Microstructure of eutectoid steel (I)

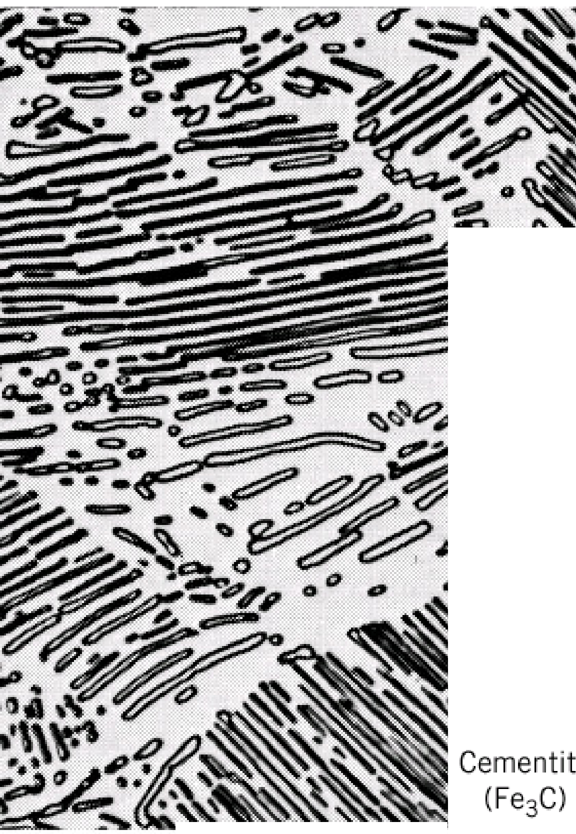


Microstructure of eutectoid steel (II)

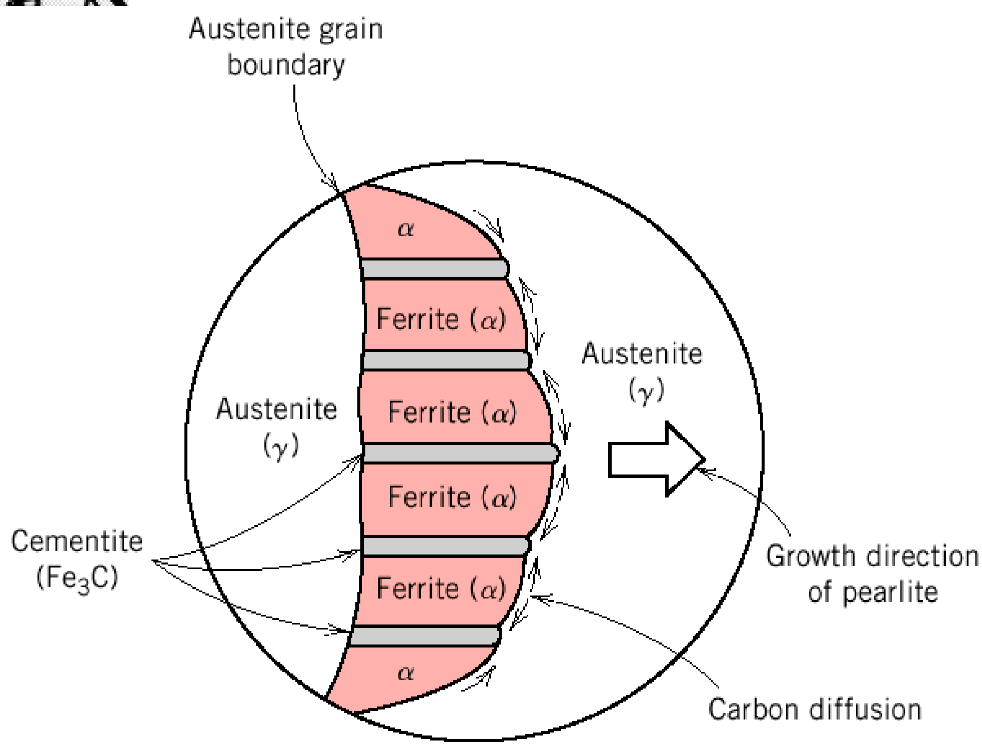
When alloy of eutectoid composition (0.76 wt % C) is cooled slowly it forms **perlite**, a lamellar or layered structure of two phases: α-ferrite and cementite (Fe_3C)

The layers of alternating phases in pearlite are formed for the same reason as layered structure of eutectic structures: redistribution C atoms between ferrite (0.022 wt%) and cementite (6.7 wt%) by atomic diffusion.

Mechanically, pearlite has properties intermediate to soft, ductile ferrite and hard, brittle cementite.



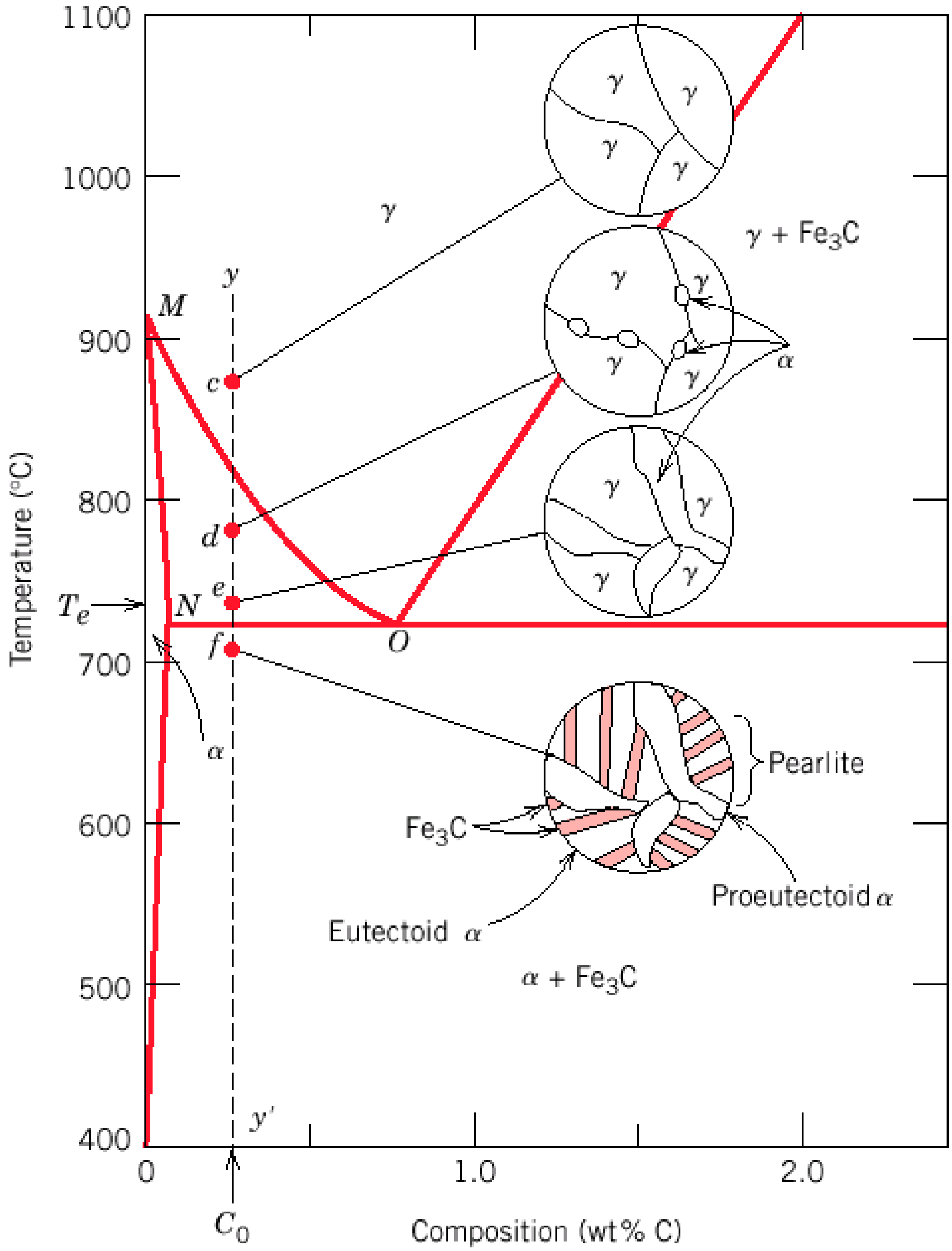
In the micrograph, the dark areas are Fe_3C layers, the light phase is α-ferrite



Microstructure of hypoeutectoid steel (I)

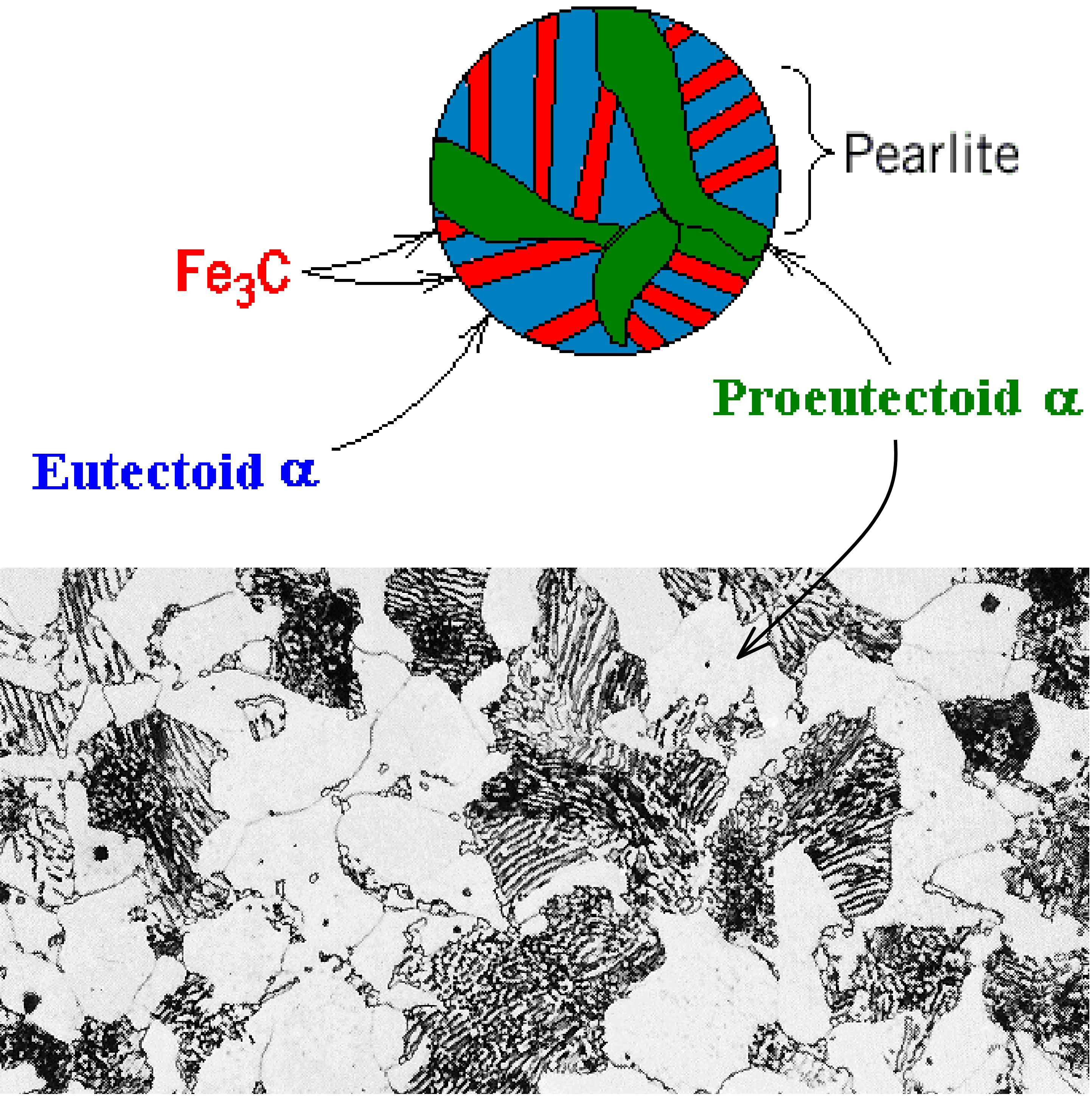
Compositions to the left of eutectoid (0.022 - 0.76 wt % C)
hypoeutectoid (*less than eutectoid* -Greek) alloys.

$$\gamma \rightarrow \alpha + \gamma \rightarrow \alpha + Fe_3C$$



Microstructure of hypoeutectoid steel (II)

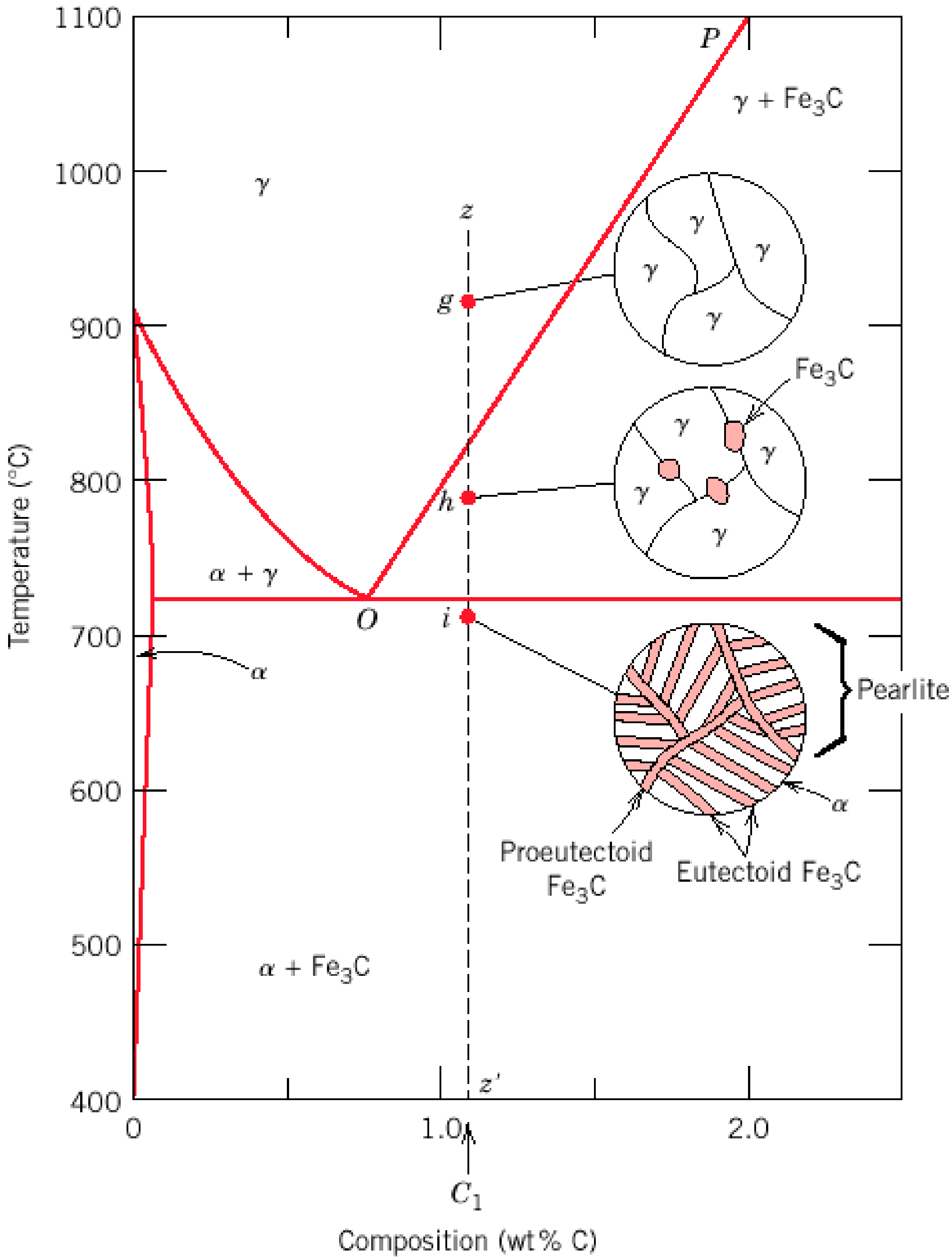
Hypoeutectoid alloys contain proeutectoid ferrite (formed above the eutectoid temperature) plus the eutectoid perlite that contain eutectoid ferrite and cementite.



Microstructure of hypereutectoid steel (I)

Compositions to the right of eutectoid (0.76 - 2.14 wt % C) **hypereutectoid** (*more than eutectoid* -Greek) alloys.

$$\gamma \rightarrow \gamma + Fe_3C \rightarrow \alpha + Fe_3C$$



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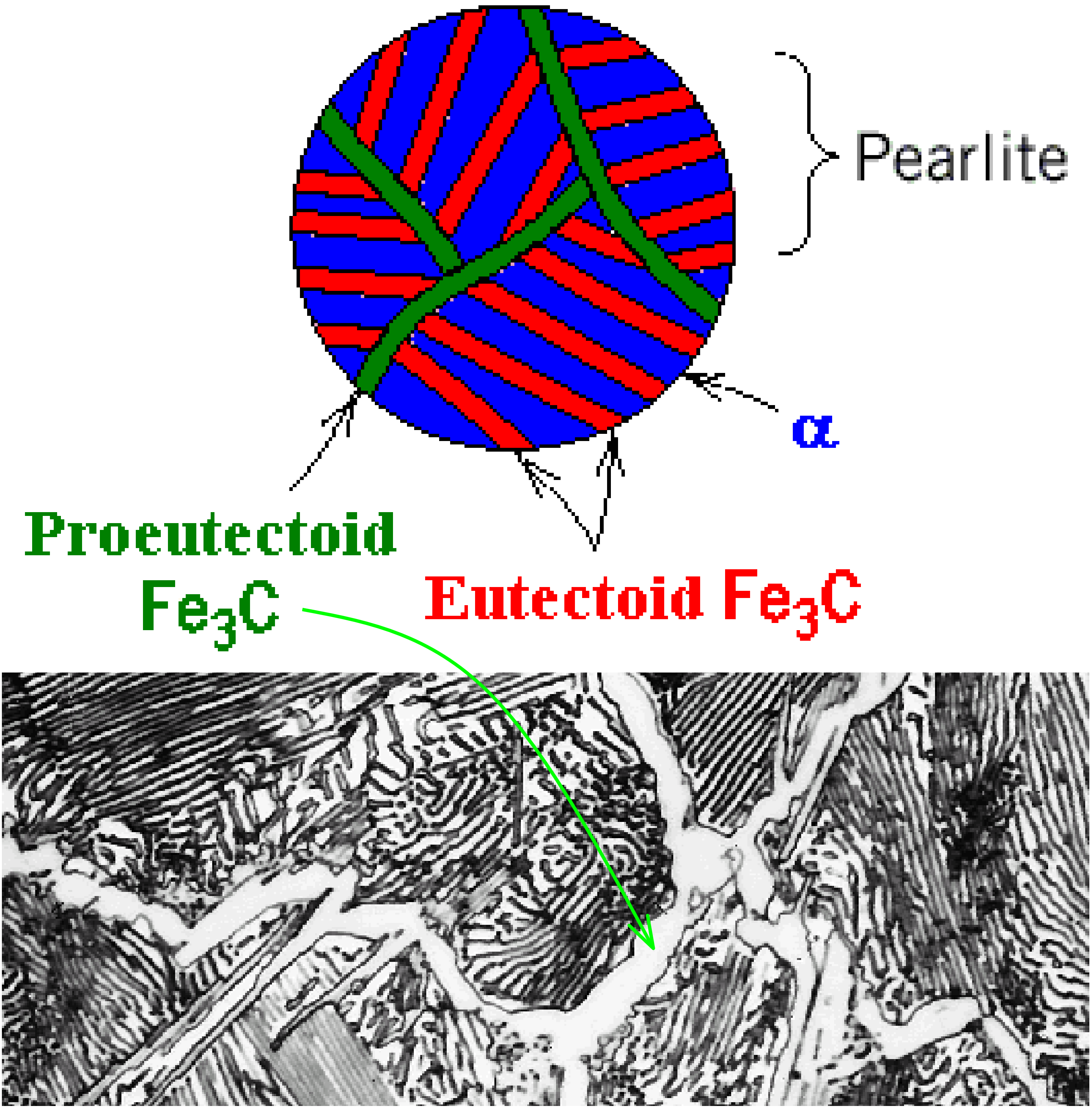
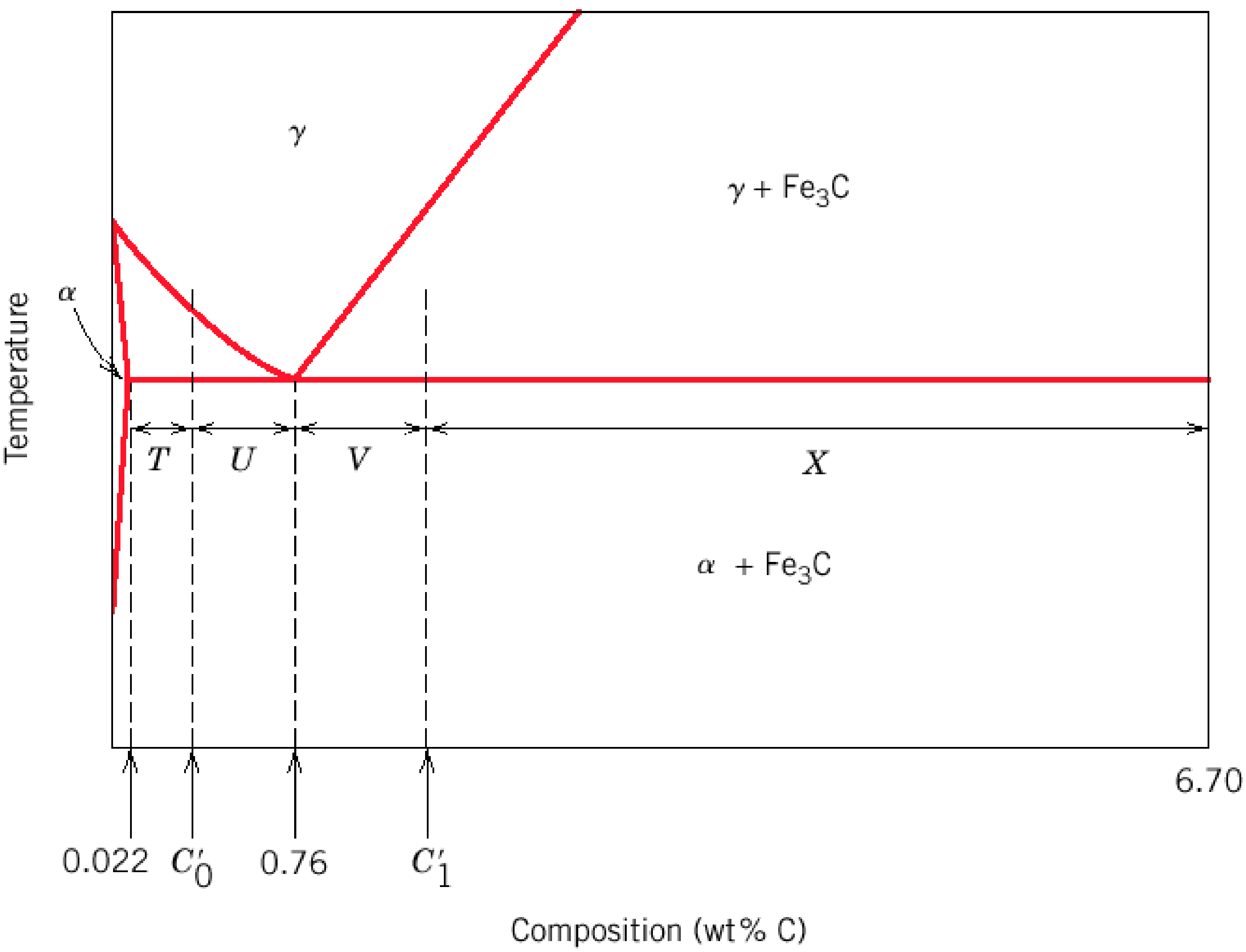
Microstructure of hypereutectoid steel (II)

Hypereutectoid alloys contain proeutectoid cementite (formed above the eutectoid temperature) plus perlite that contain eutectoid ferrite and cementite.



How to calculate the relative amounts of proeutectoid phase (α or Fe_3C) and pearlite?

Application of the lever rule with tie line that extends from the eutectoid composition (0.76 wt% C) to α – (α + Fe_3C) boundary (0.022 wt% C) for hypoeutectoid alloys and to (α + Fe_3C) – Fe_3C boundary (6.7 wt% C) for hypereutectoid alloys.



Fraction of α phase is determined by application of the lever rule across the entire (α + Fe_3C) phase field: