IRON IRON-CARBON DIAGRAM

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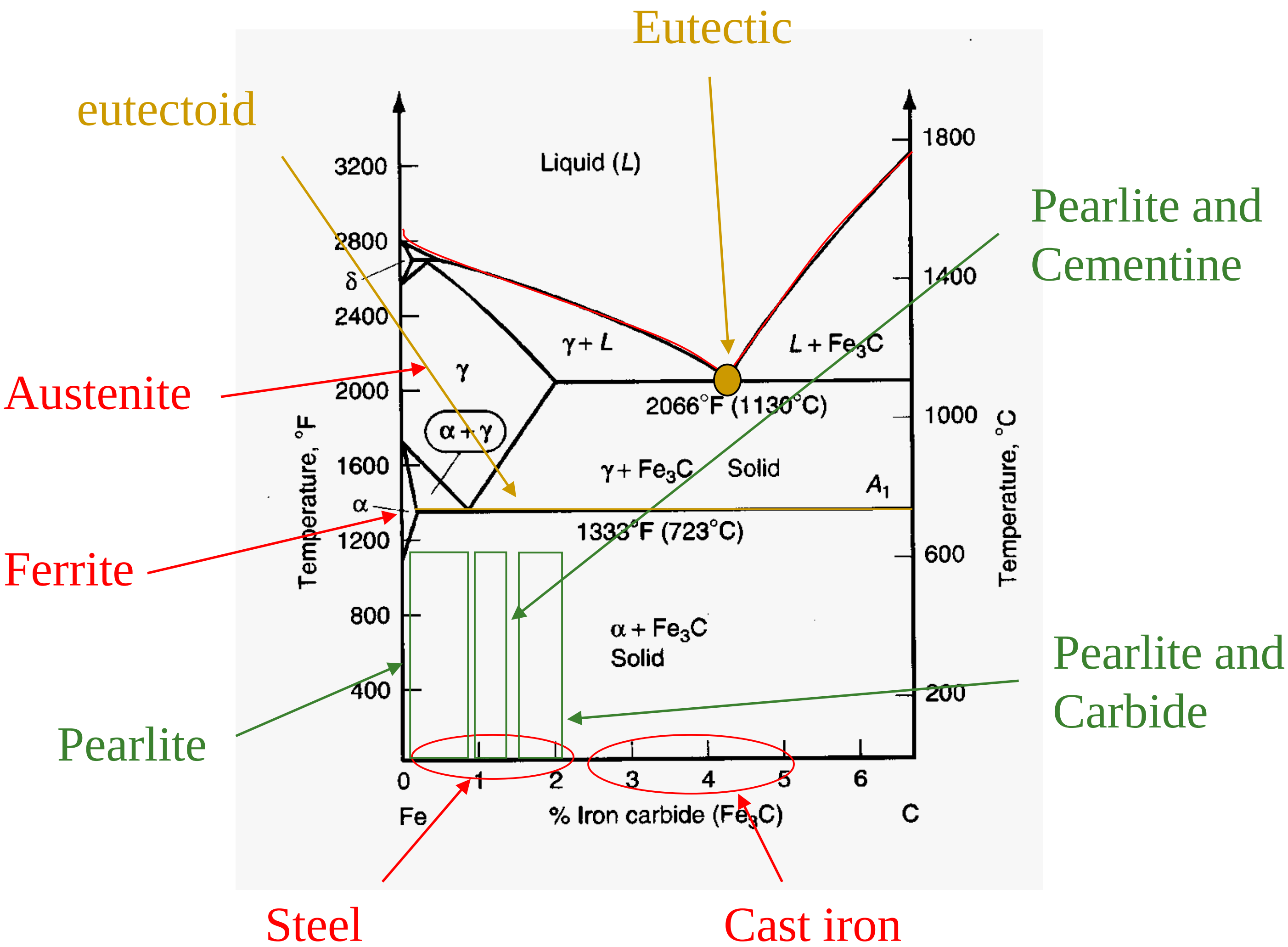
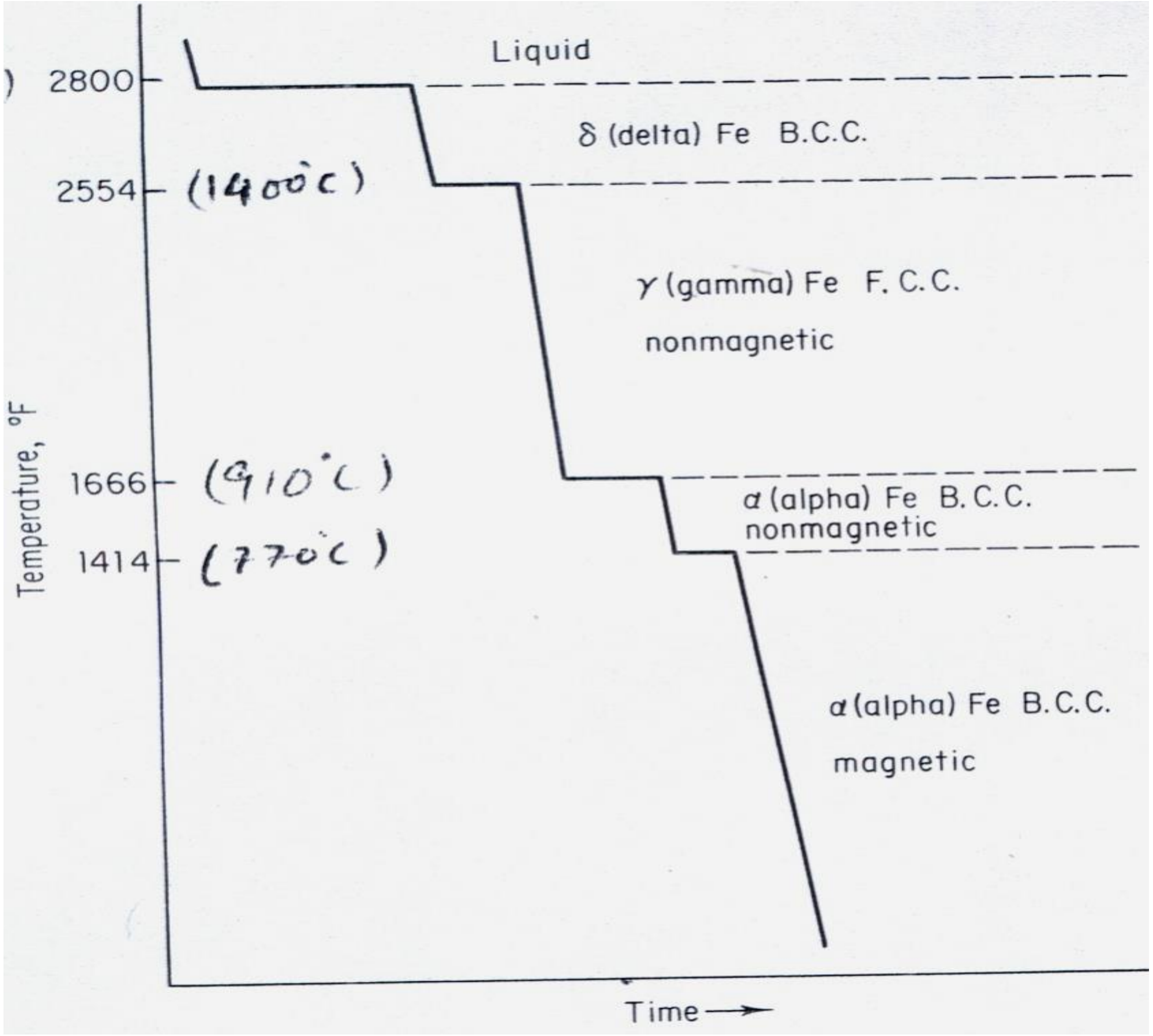


Outline

- Introduction
- Cooling curve for pure iron
- Definition of structures
- Iron-Carbon equilibrium phase diagram – Sketch
- The Iron-Iron Carbide Diagram - Explanation
- The Austenite to ferrite / cementite transformation
- Nucleation & growth of pearlite
- Effect of C %age on the microstructure of steel
- Relationship b/w C %age & mechanical properties of steel

Cooling curve for pure iron

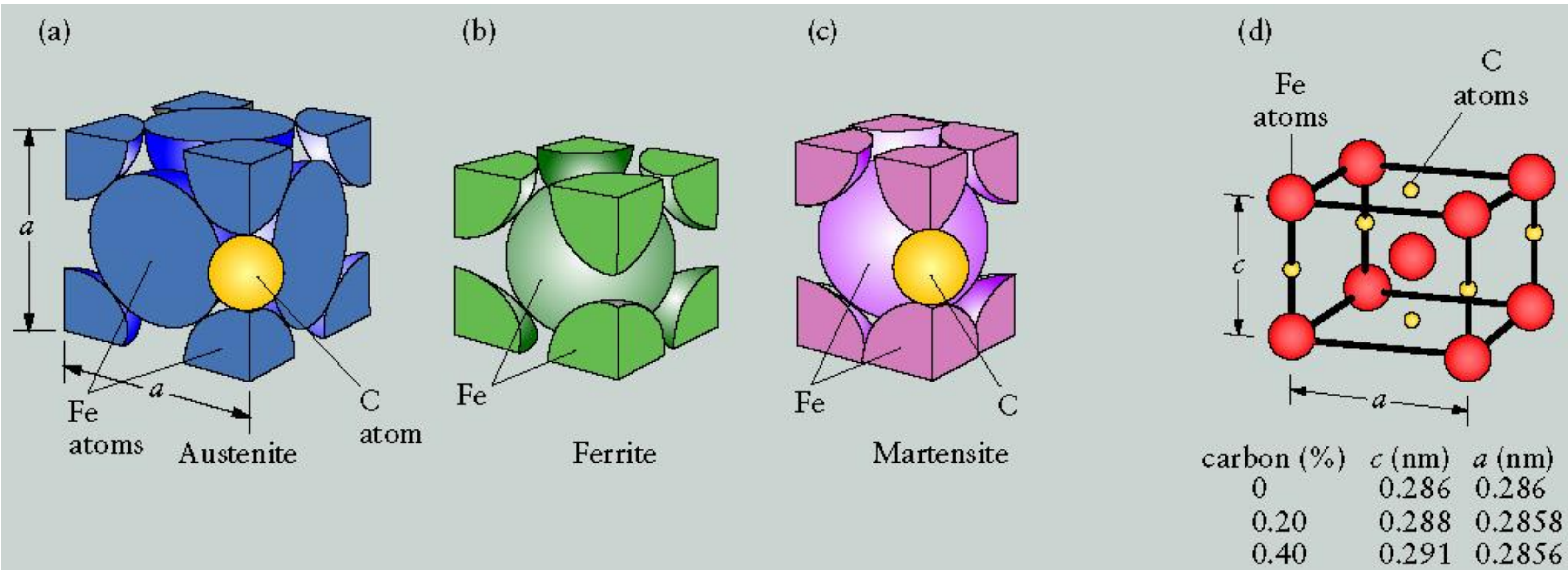


Definition of structures

Various phases that appear on the Iron-Carbon equilibrium phase diagram are as under:

- Austenite
- Ferrite
- Pearlite
- Cementite
- Martensite*
- Ledeburite

Unit Cells of Various Metals



- FIGURE - The unit cell for (a) austentite, (b) ferrite, and (c) martensite. The effect of the percentage of carbon (by weight) on the lattice dimensions for martensite is shown in (d). Note the interstitial position of the carbon atoms and the increase in dimension *c* with increasing carbon content. Thus, the unit cell of martensite is in the shape of a rectangular prism.

Microstructure of different phases of steel

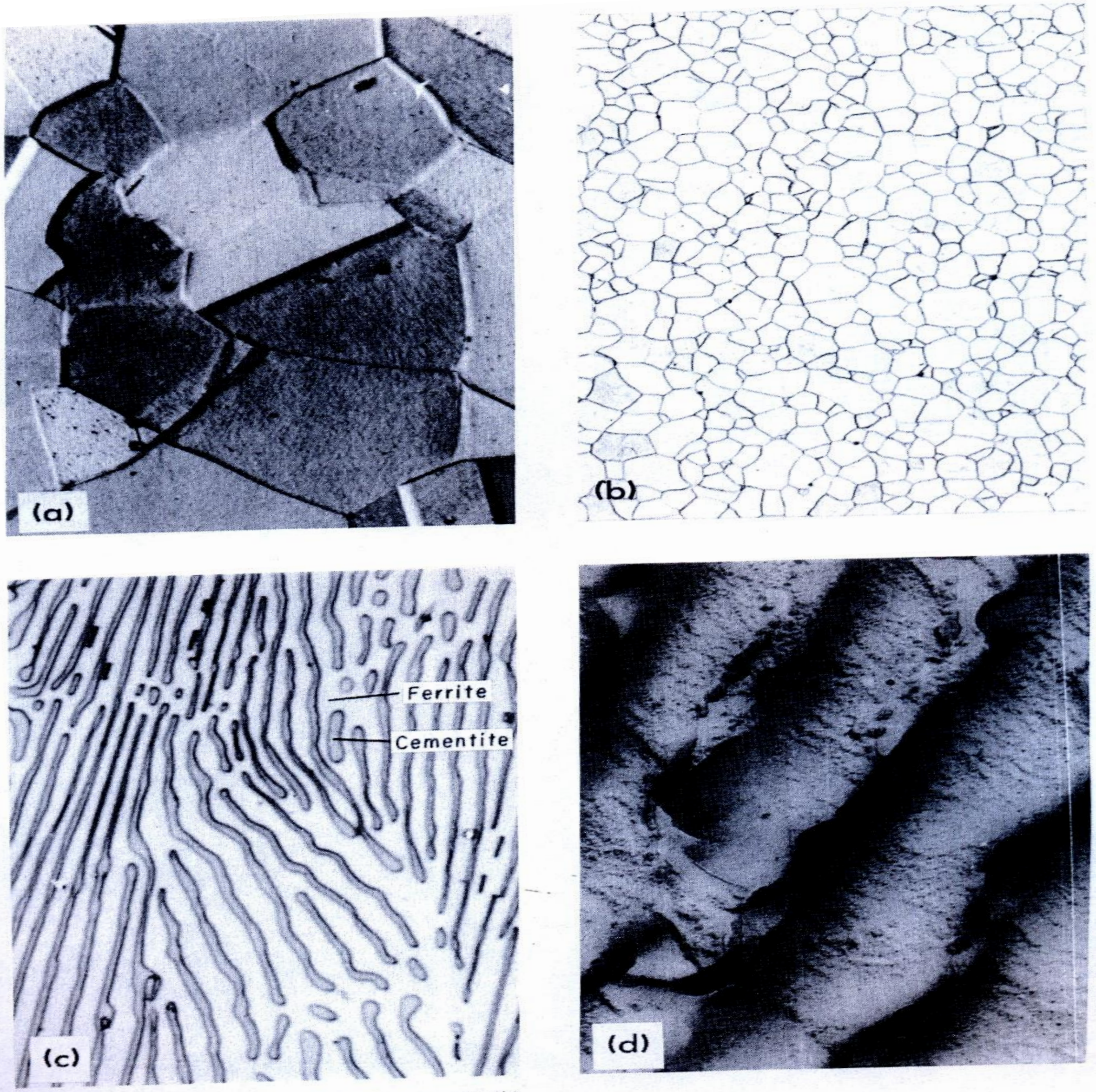


Fig. 7·8 The microstructure of (*a*) austenite, 500X; (*b*) ferrite, 100X; (*c*) pearlite, 2,500X; (*d*) pearlite, electron micrograph, 17,000X; enlarged 3X in printing. (*a*, *b*, and *c*, Research Laboratory, U.S. Steel Corporation.)

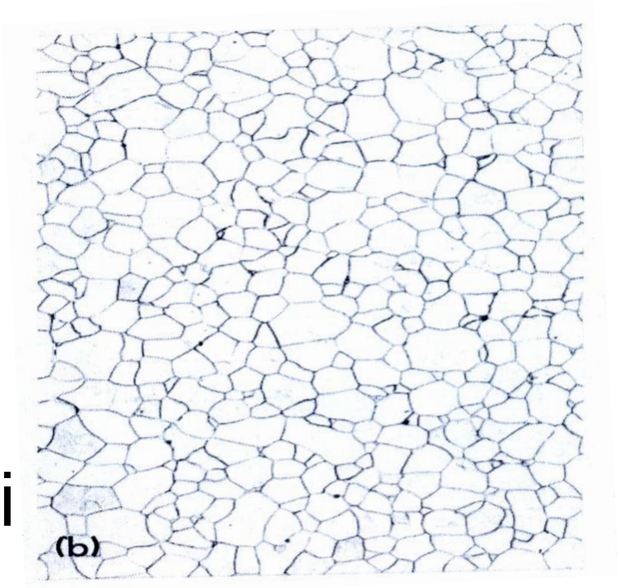
Definition of structures

- **Ferrite** is known as *α* solid solution.
- It is an interstitial solid solution of a small amount of carbon dissolved in *α* (BCC) iron.
- stable form of iron below 912 deg.C
- The maximum solubility is 0.025 % C at 723°C and it dissolves only 0.008 % C at room temperature.
- It is the softest structure that appears on the diagram.

Definition of structures

Ferrite

- Average properties are:
  - Tensile strength = 40,000 psi
  - Elongation = 40 % in 2 in;
  - Hardness > Rockwell C 0 or > Rockwell B 90



Definition of structures

- **Pearlite** is the eutectoid mixture containing 0.80 % C and is formed at 723°C on very slow cooling.
- It is a very fine platelike or lamellar mixture of ferrite and cementite.
- The white ferritic background or matrix contains thin plates of cementite (dark).

Definition of structures

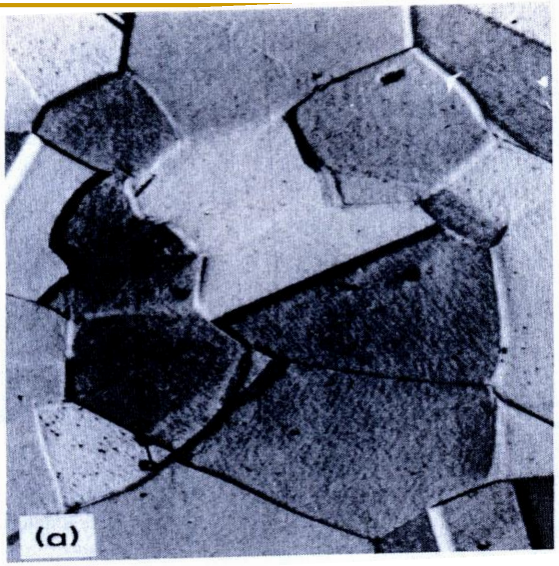
Pearlite

- Average properties are:
  - Tensile strength = 120,000 psi;
  - Elongation = 20 % in 2 in.;
  - Hardness = Rockwell C 20, Rockwell B 95-100, or BHN 250-300.

Definition of structures

- **Austenite** is an interstitial solid solution of Carbon dissolved in γ (F.C.C.) iron.
- Maximum solubility is 2.0 % C at 1130°C.
- High formability, most of heat treatments begin with this single phase.
- It is normally not stable at room temperature. But, under certain conditions it is possible to obtain austenite at room temperature.

Definition of structures



Austenite

- Average properties are:
  - Tensile strength = 150,000 psi;
  - Elongation = 10 percent in 2 in.;
  - Hardness = Rockwell C 40, approx; and
  - toughness = high

Definition of structures

- **Cementite** or iron carbide, is very hard, brittle intermetallic compound of iron & carbon, as Fe_3C, contains 6.67 % C.
- It is the hardest structure that appears on the diagram, exact melting point unknown.
- Its crystal structure is orthorhombic.
- It is has
  - low tensile strength (approx. 5,000 psi), but
  - high compressive strength.

Definition of structures

- **Ledeburite** is the eutectic mixture of austenite and cementite.
- It contains 4.3 percent C and is formed at 1130°C.

Definition of structures

- **Martensite** - a super-saturated solid solution of carbon in ferrite.
- It is formed when steel is cooled so rapidly that the change from austenite to pearlite is suppressed.
- The interstitial carbon atoms distort the BCC ferrite into a BC-tetragonal structure (BCT).; responsible for the hardness of quenched steel

The Iron-Iron Carbide Diagram

- A map of the temperature at which different phase changes occur on very slow heating and cooling in relation to Carbon, is called Iron- Carbon Diagram.
- Iron- Carbon diagram shows
  - the type of alloys formed under very slow cooling,
  - proper heat-treatment temperature and
  - how the properties of steels and cast irons can be radically changed by heat-treatment.

Various Features of Fe-C diagram

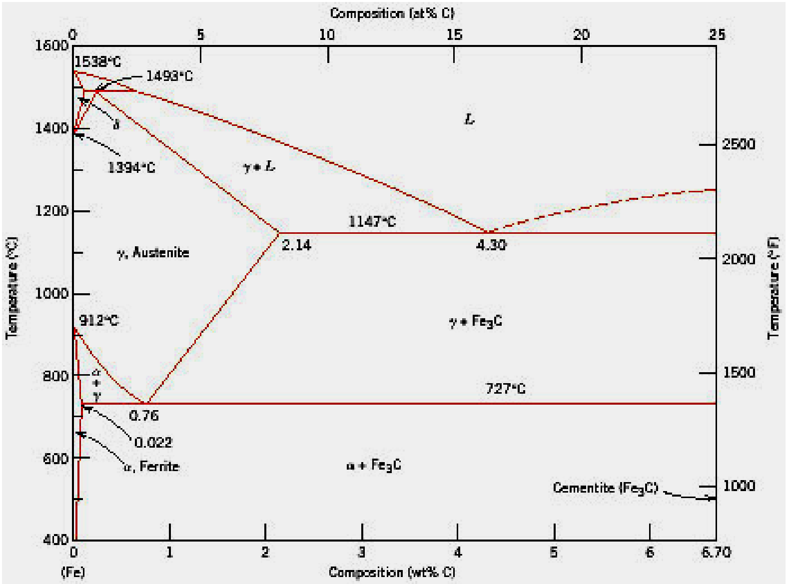


FIGURE 9.22 The iron–iron carbide phase diagram. (Adapted from *Binary Alloy Phase Diagrams*, 2nd edition, Vol. 1, T. B. Massalski, Editor-in-Chief, 1990. Reprinted by permission of ASM International, Materials Park, OH.)

Phases present

L

δ
BCC structure
Paramagnetic

α ferrite
BCC structure
Ferromagnetic
Fairly ductile

γ austenite
FCC structure
Non-magnetic
ductile

Fe_3C cementite
Orthorhombic
Hard
brittle

Reactions

Peritectic $L + \delta = \gamma$

Eutectic $L = \gamma + Fe_3C$

Eutectoid $\gamma = \alpha + Fe_3C$

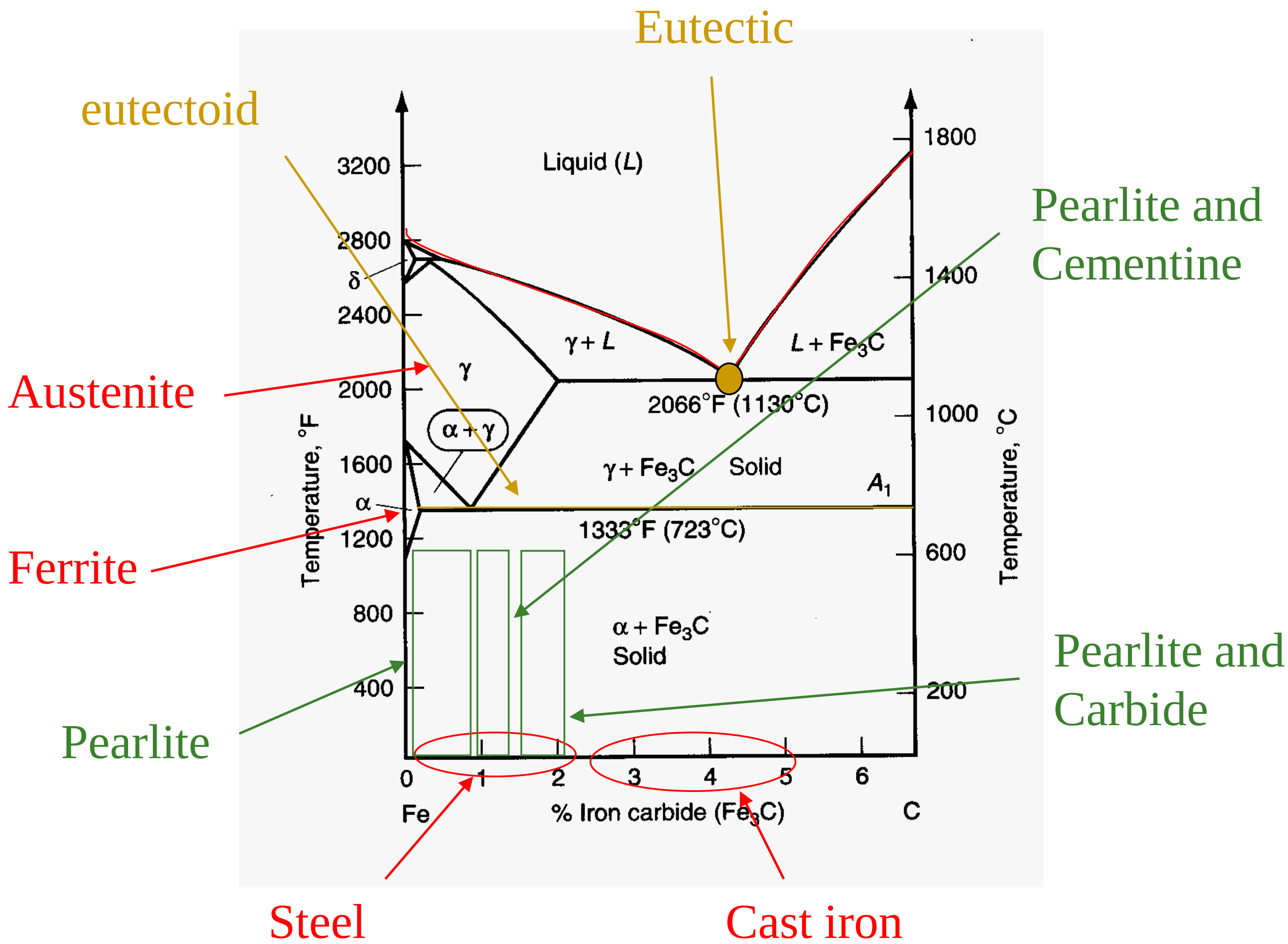
Max. solubility of C in ferrite=0.022%

Max. solubility of C in austenite=2.11%

Three Phase Reactions

- Peritectic, at 1490 deg.C, with low wt% C alloys (almost no engineering importance).
- Eutectic, at 1130 deg.C, with 4.3wt% C, alloys called cast irons.
- Eutectoid, at 723 deg.C with eutectoid composition of 0.8wt% C, two-phase mixture (ferrite & cementite). They are steels.

How to read the Fe-C phase diagram



The Iron-Iron Carbide Diagram

The diagram shows three horizontal lines which indicate isothermal reactions (on cooling / heating):

- First horizontal line is at 1490°C, where peritectic reaction takes place:

  Liquid + δ ↔ austenite

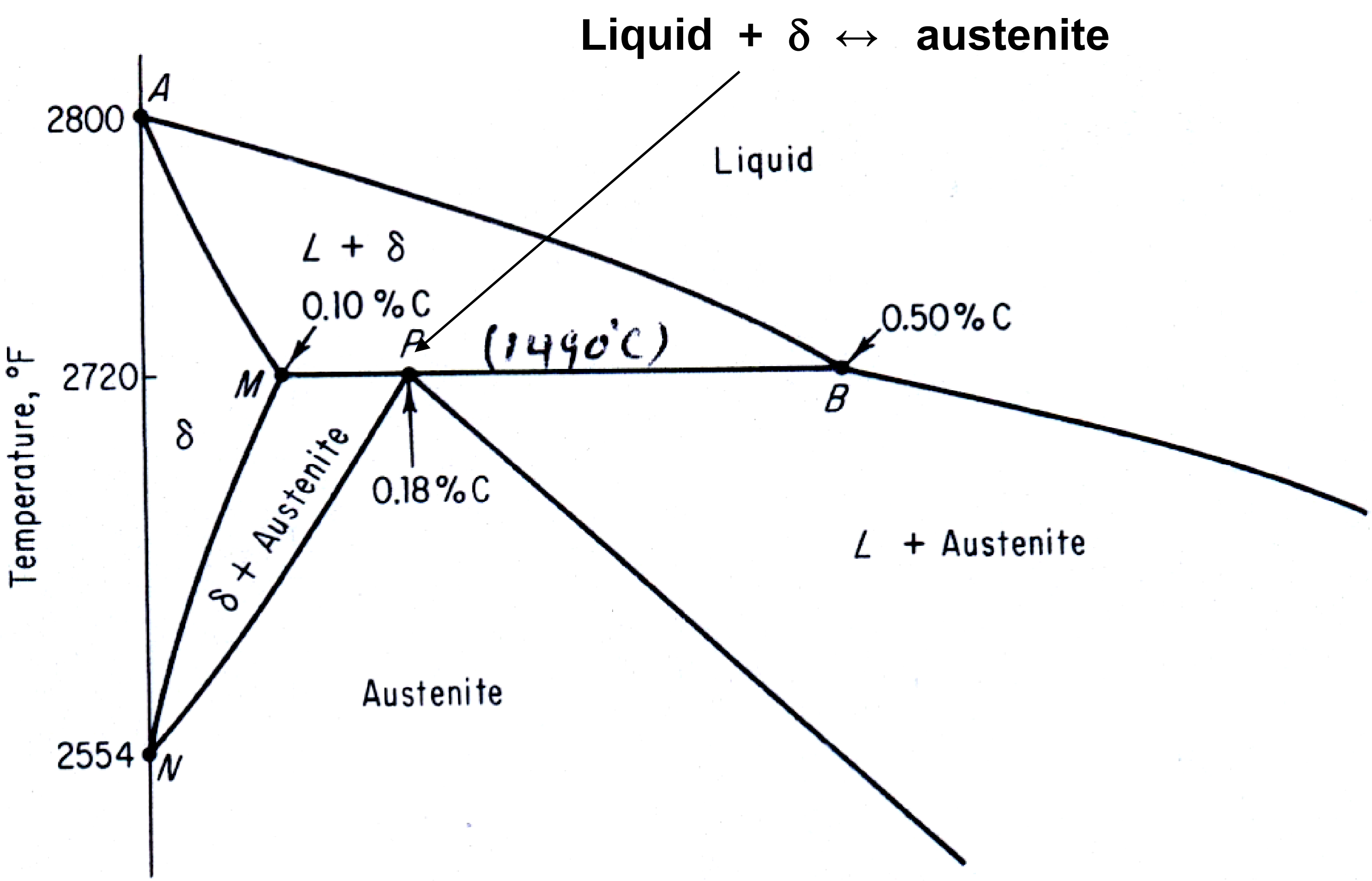
- Second horizontal line is at 1130°C, where eutectic reaction takes place:

  liquid ↔ austenite + cementite

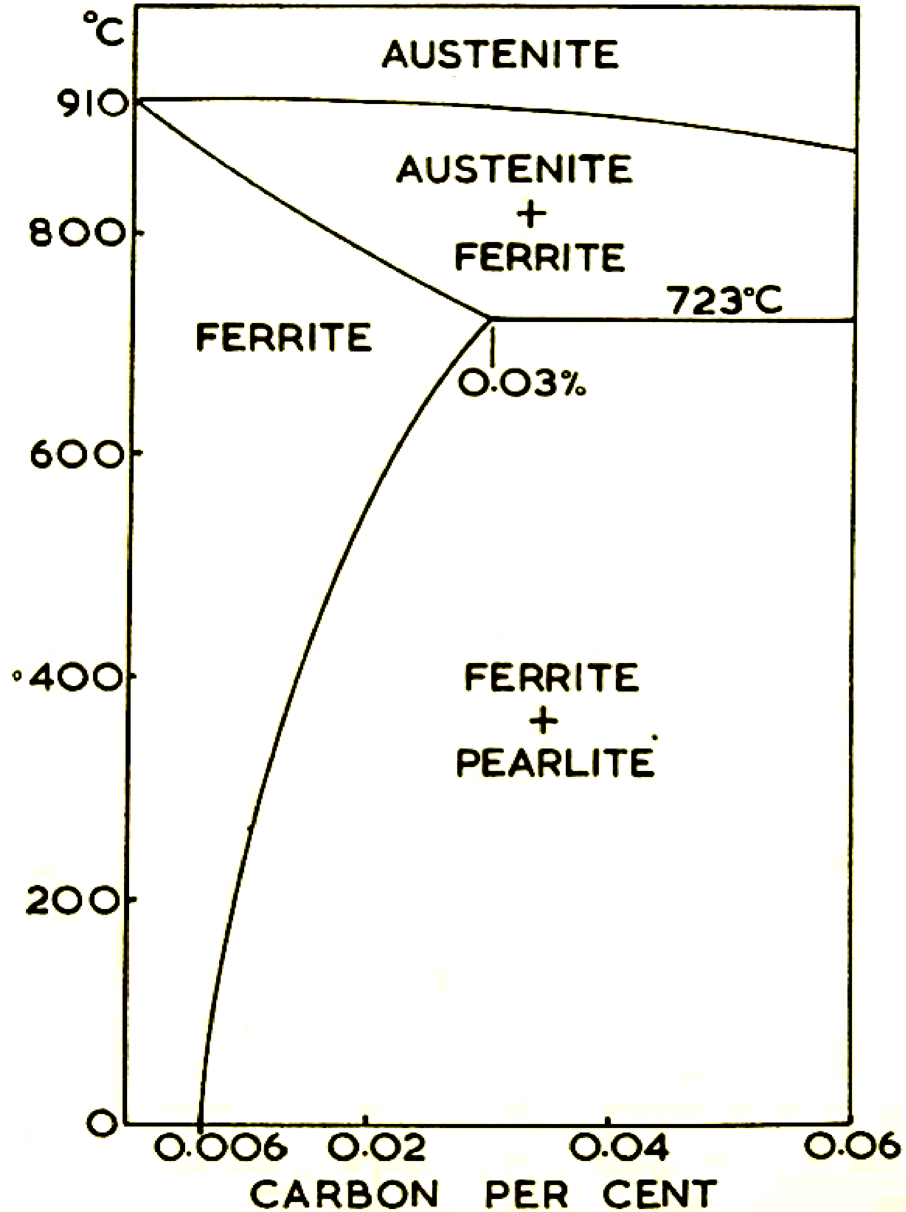
- Third horizontal line is at 723°C, where eutectoid reaction takes place:

  austenite ↔ pearlite (mixture of ferrite & cementite)

Delta region of Fe-Fe carbide diagram

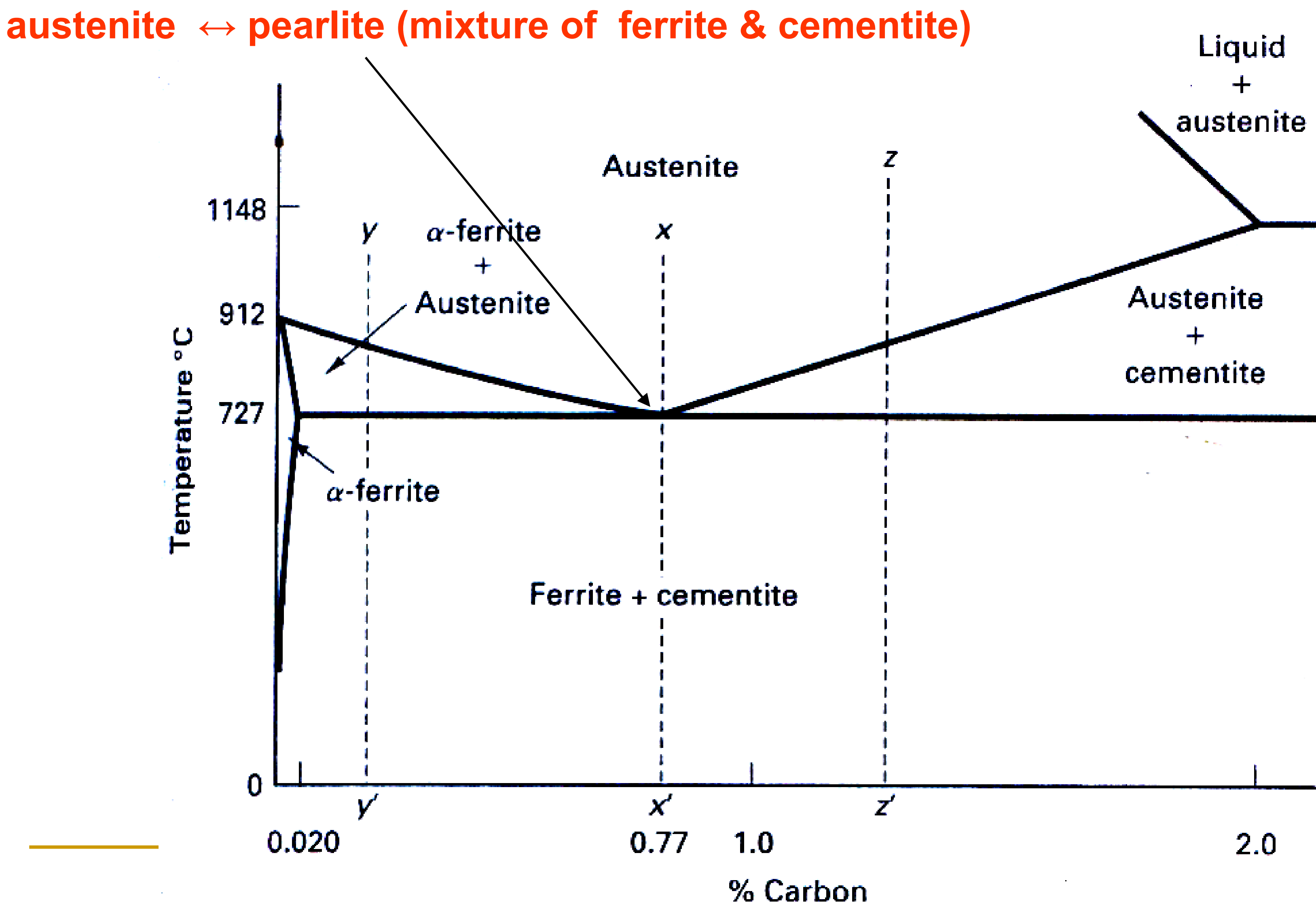


Ferrite region of Fe-Fe Carbide diagram



2.—The "Ferrite Area" of the Iron–Carbon Equilibrium Diagram, Showing the Extent to Which Carbon is Soluble in α Iron.

Simplified Iron-Carbon phase diagram



The Austenite to ferrite / cementite transformation in relation to Fe-C diagram

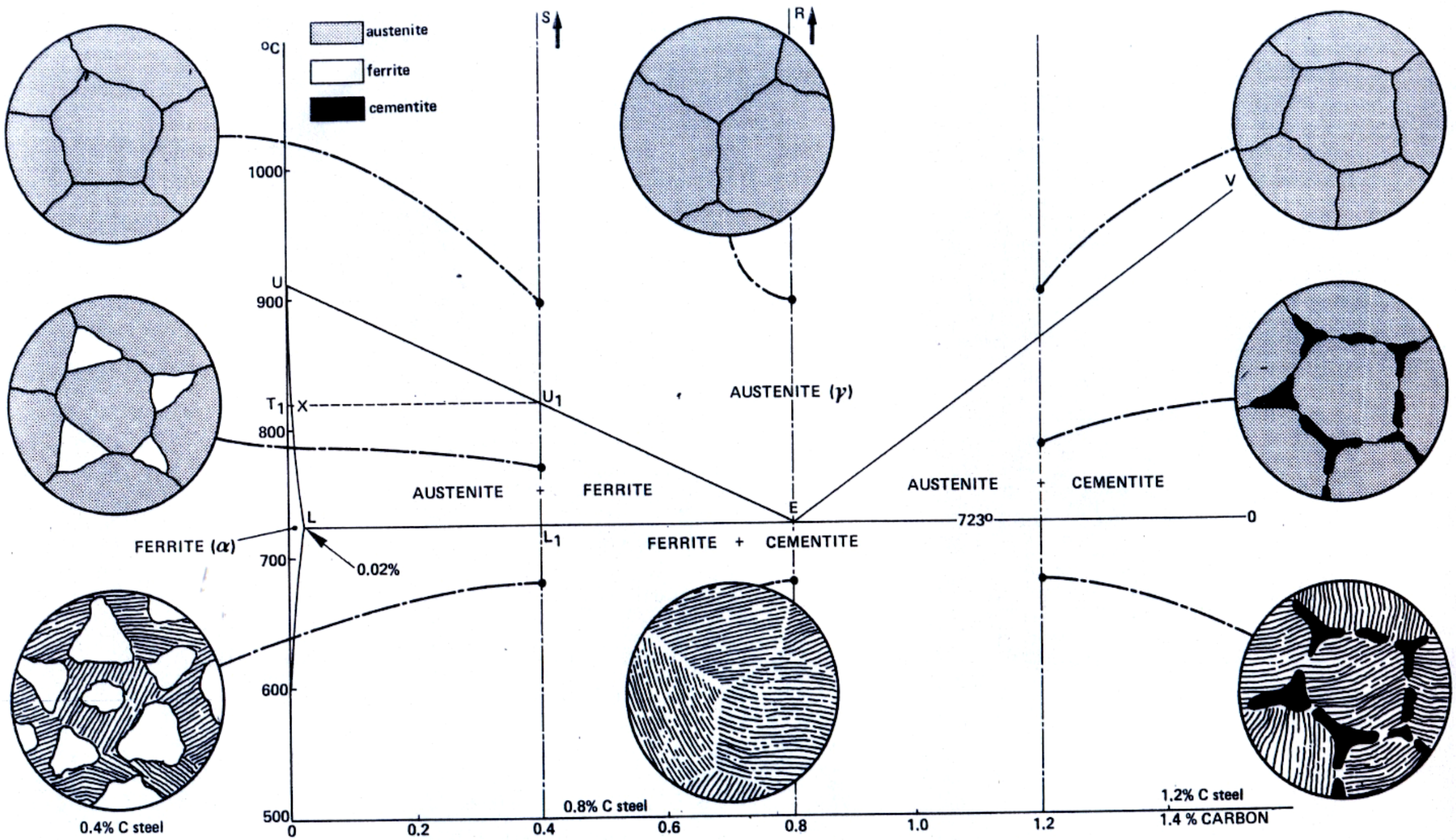


Fig. 9.3—The austenite → ferrite/cementite transformation in relation to the iron–carbon diagram.

The Austenite to ferrite / cementite transformation in relation to Fe-C diagram

In order to understand the transformation processes, consider a steel of the eutectoid composition. 0.8% carbon, being slow cooled along line *x-x'.*

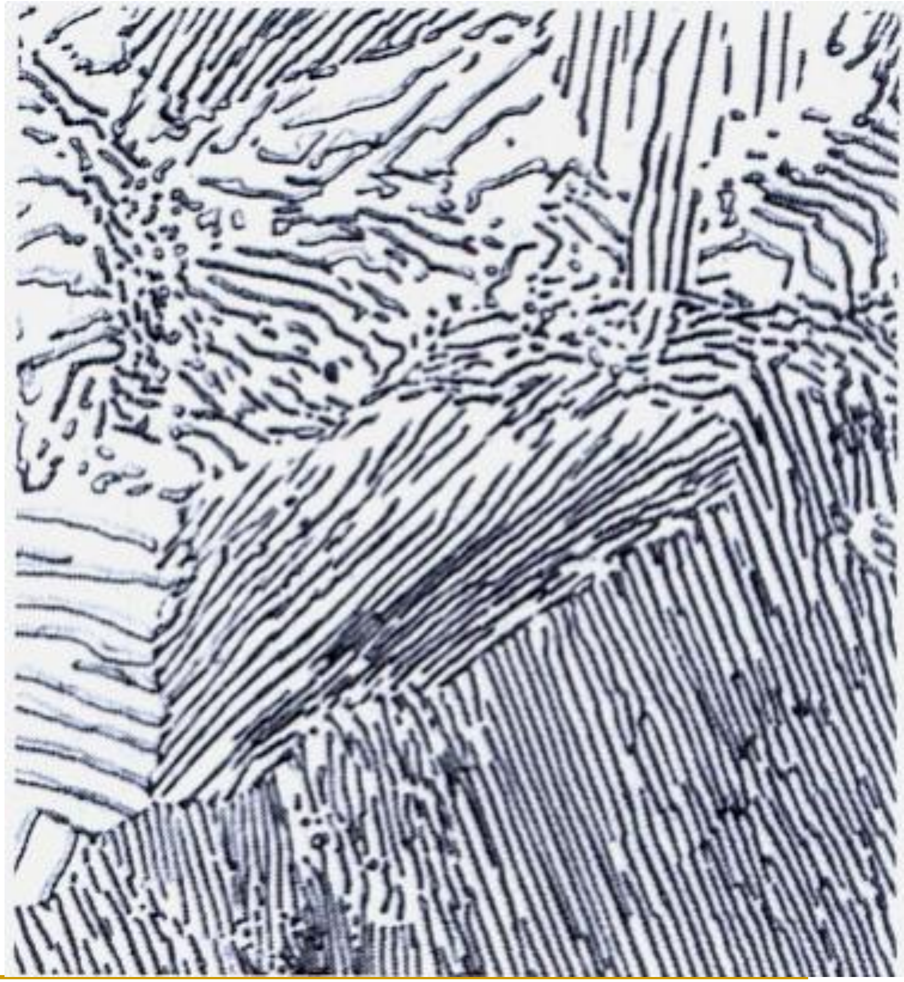
- At the upper temperatures, only austenite is present, with the 0.8% carbon being dissolved in solid solution within the FCC. When the steel cools through 723°C, several changes occur simultaneously.

The Austenite to ferrite / cementite transformation in relation to Fe-C diagram

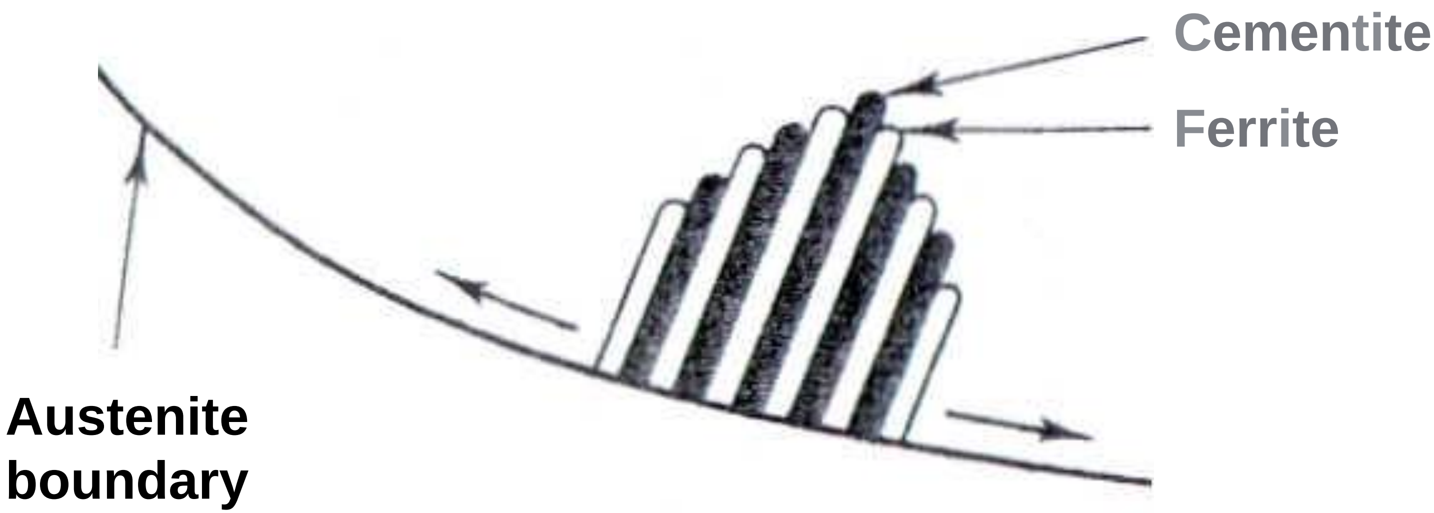
- The iron wants to change crystal structure from the FCC austenite to the BCC ferrite, but the ferrite can only contain 0.02% carbon in solid solution.
- The excess carbon is rejected and forms the carbon-rich intermetallic known as cementite.

Pearlitic structure

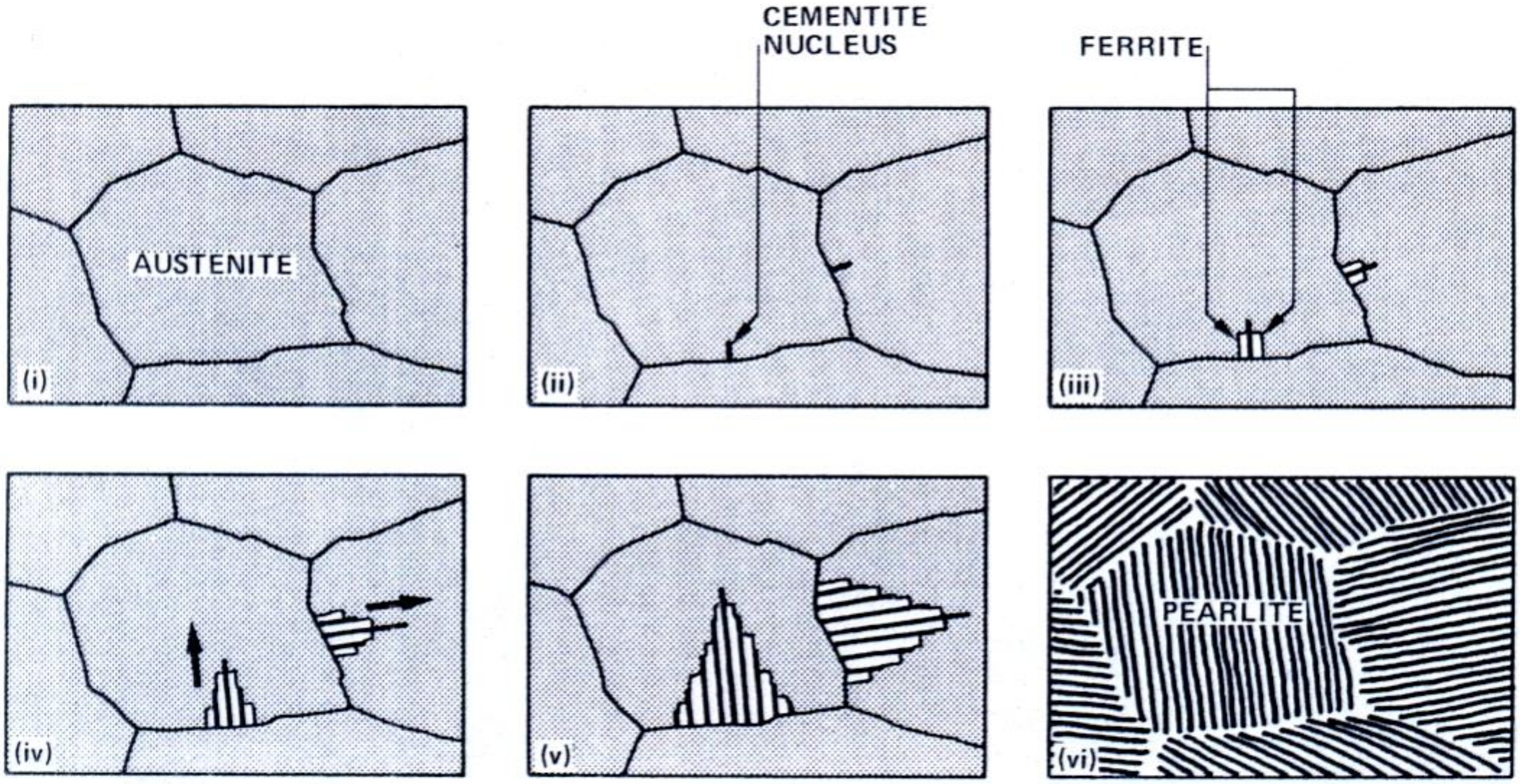
- The net reaction at the eutectoid is the formation of pearlitic structure.
- Since the chemical separation occurs entirely within crystalline solids, the resultant structure is a fine mixture of ferrite and cementite.



Schematic picture of the formation and growth of pearlite



Nucleation & growth of pearlite

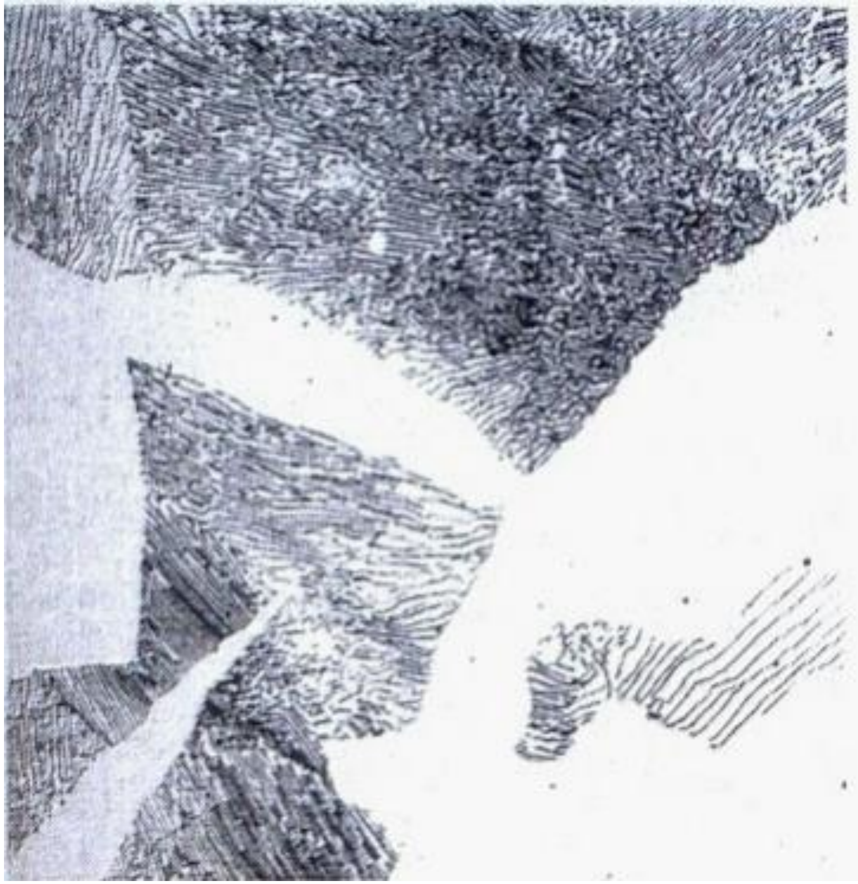


The Austenite to ferrite / cementite transformation in relation to Fe-C diagram

- **Hypo-eutectoid steels:** Steels having less than 0.8% carbon are called *hypo-eutectoid steels* (*hypo* means "less than").
- Consider the cooling of a typical hypo-eutectoid alloy along line *y-y'.*
- At high temperatures the material is entirely austenite.
- Upon cooling it enters a region where the stable phases are ferrite and austenite.
- The low-carbon ferrite nucleates and grows, leaving the remaining austenite richer in carbon.

The Austenite to ferrite / cementite transformation in relation to Fe-C diagram

- **Hypo-eutectoid steels-**
  At *723°C*, the remaining austenite will have assumed the eutectoid composition *(0.8%* carbon), and further cooling transforms it to pearlite.



- The resulting structure, is a mixture of *primary* or *pro-eutectoid ferrite* (ferrite that forms before the eutectoid reaction) and regions of pearlite.

The Austenite to ferrite / cementite transformation in relation to Fe-C diagram

- **Hyper-eutectoid steels** (*hyper* means "greater than") are those that contain more than the eutectoid amount of Carbon.
- When such a steel cools, as along line *z-z'* , the process is similar to the hypo-eutectoid steel, except that the primary or pro-eutectoid phase is now cementite instead of ferrite.

The Austenite to ferrite / cementite transformation in relation to Fe-C diagram

- As the carbon-rich phase nucleates and grows, the remaining austenite decreases in carbon content, again reaching the eutectoid composition at 723°C.
- This austenite transforms to pearlite upon slow cooling through the eutectoid temperature.
- The resulting structure consists of primary cementite and pearlite.
- The continuous network of primary cementite will cause the material to be extremely brittle.

The Austenite to ferrite / cementite transformation in relation to Fe-C diagram

Hypo-eutectoid steel showing primary cementite along grain boundaries pearlite

The Austenite to ferrite / cementite transformation in relation to Fe-C diagram

- It should be noted that the transitions as discussed, are for equilibrium conditions, as a result of slow cooling.
- Upon slow heating the transitions will occur in the reverse manner.

The Austenite to ferrite / cementite transformation in relation to Fe-C diagram

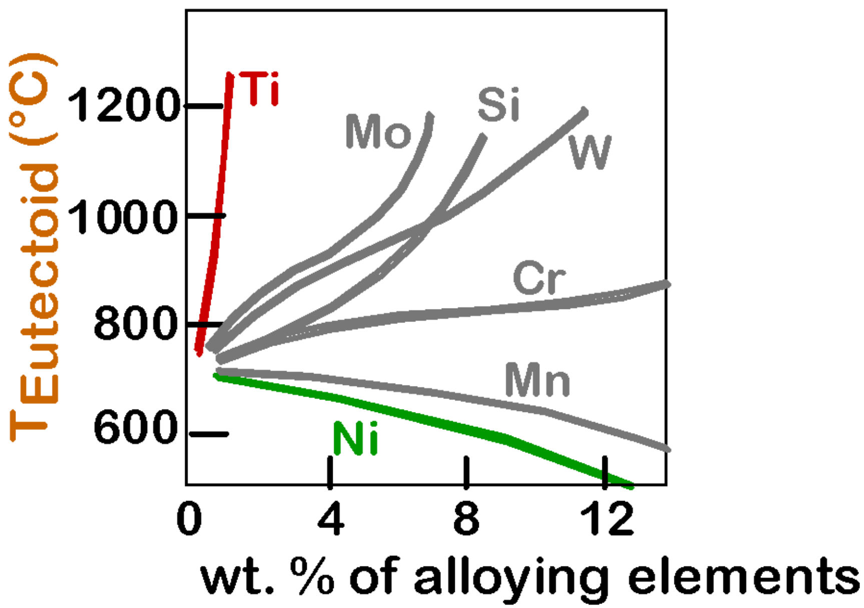
- When the alloys are cooled rapidly, entirely different results are obtained, since sufficient time may not be provided for the normal phase reactions to occur.
- In these cases, the equilibrium phase diagram is no longer a valid tool for engineering analysis.
- Rapid-cool processes are important in the heat treatment of steels and other metals (to be discussed later in H/T of steels).

Principal phases of steel and their Characteristics

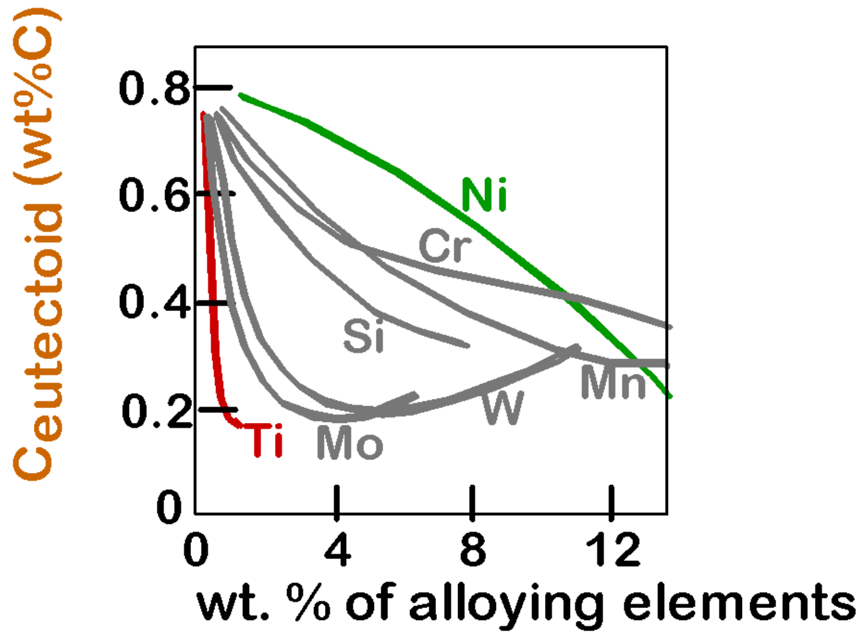
Phase	Crystal structure	Characteristics
Ferrite	BCC	Soft, ductile, magnetic
Austenite	FCC	Soft, moderate strength, non-magnetic
Cementite	Compound of Iron & Carbon Fe_3C	Hard &brittle

Alloying Steel with more Elements

- $T_{eutectoid}$ changes:



- $C_{eutectoid}$ changes:

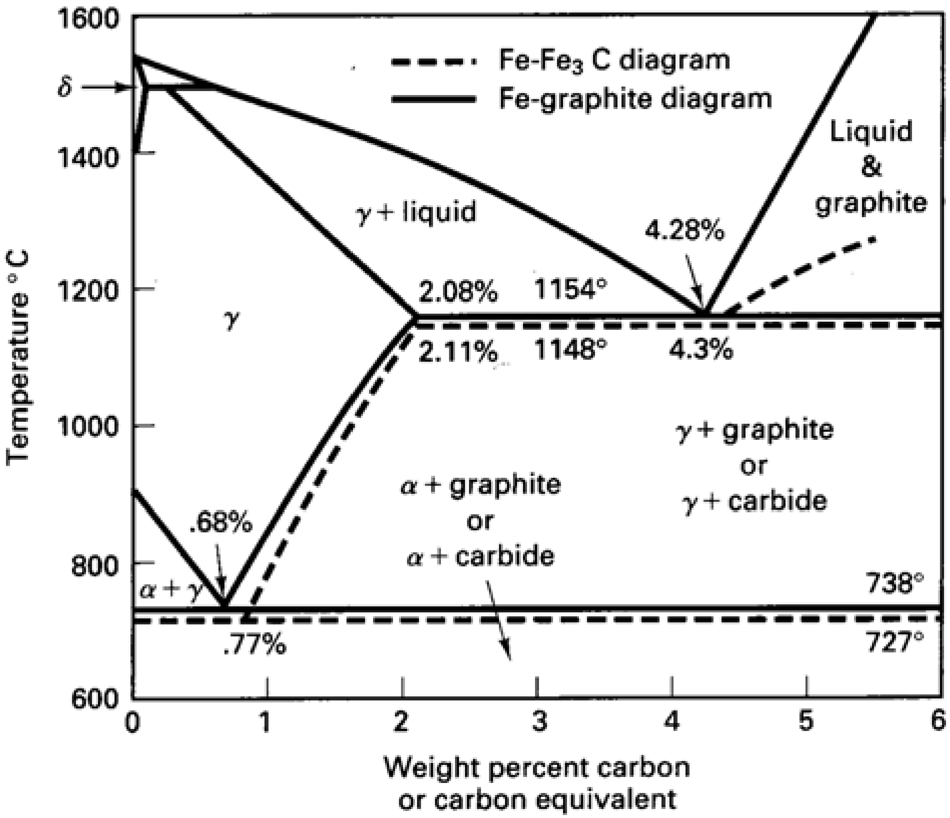


Cast Irons

-Iron-Carbon alloys of 2.11%C or more are cast irons.

-Typical composition: 2.0-4.0%C,0.5-3.0% Si, less than 1.0% Mn and less than 0.2% S.

-Si-substitutes partially for C and promotes formation of graphite as the carbon rich component instead Fe_3C.



Applications

- It is used tailor properties of steel and to heat treat them.
- It is also used for comparison of crystal structures for metallurgists in case of rupture or fatigue