FUNDAMENTALS OF METAL ALLOYS, EQUILIBRIUM DIAGRAMS

Chapter 5

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5.2 What is a Phase?

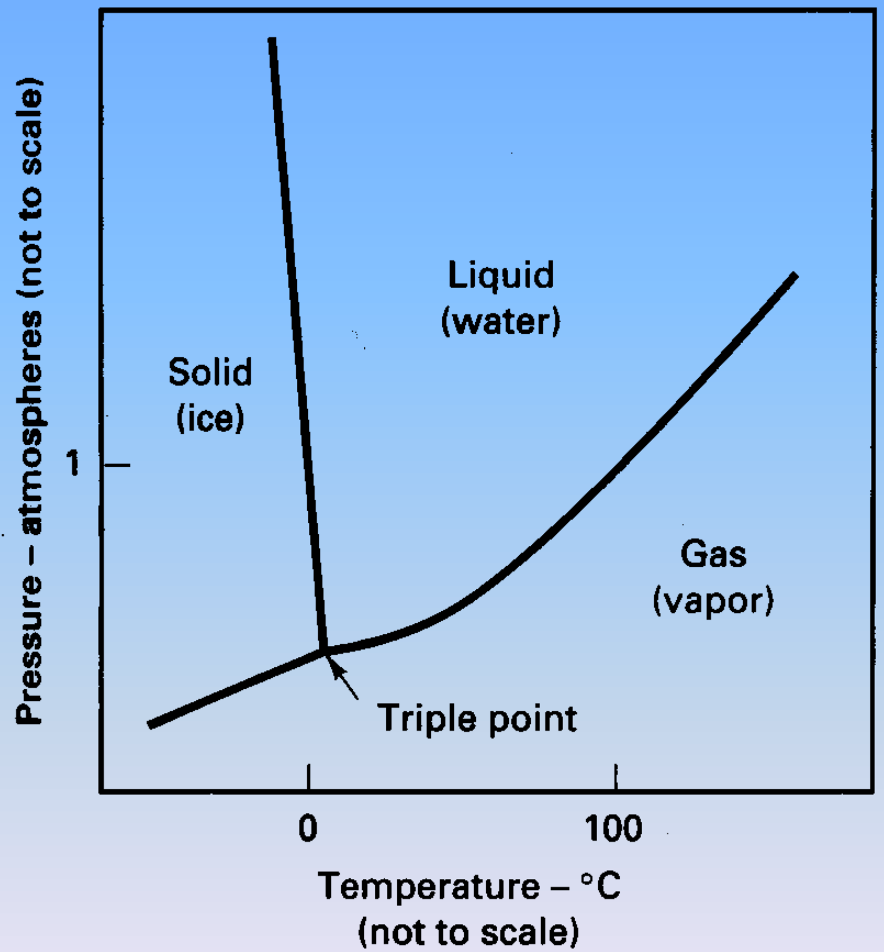
- Phase is a form of material having characteristic structure and properties.
- More precisely: form of material with identifiable composition (chemistry), definable structure, and distinctive boundaries (interfaces) which separate it from other phases.

5.2 Phases

- Phase can be continuous (air in the room) or discontinuous (salt grains in the shaker).
- Gas, liquid or solid.
- Pure substance or solution (uniform structure throughout).

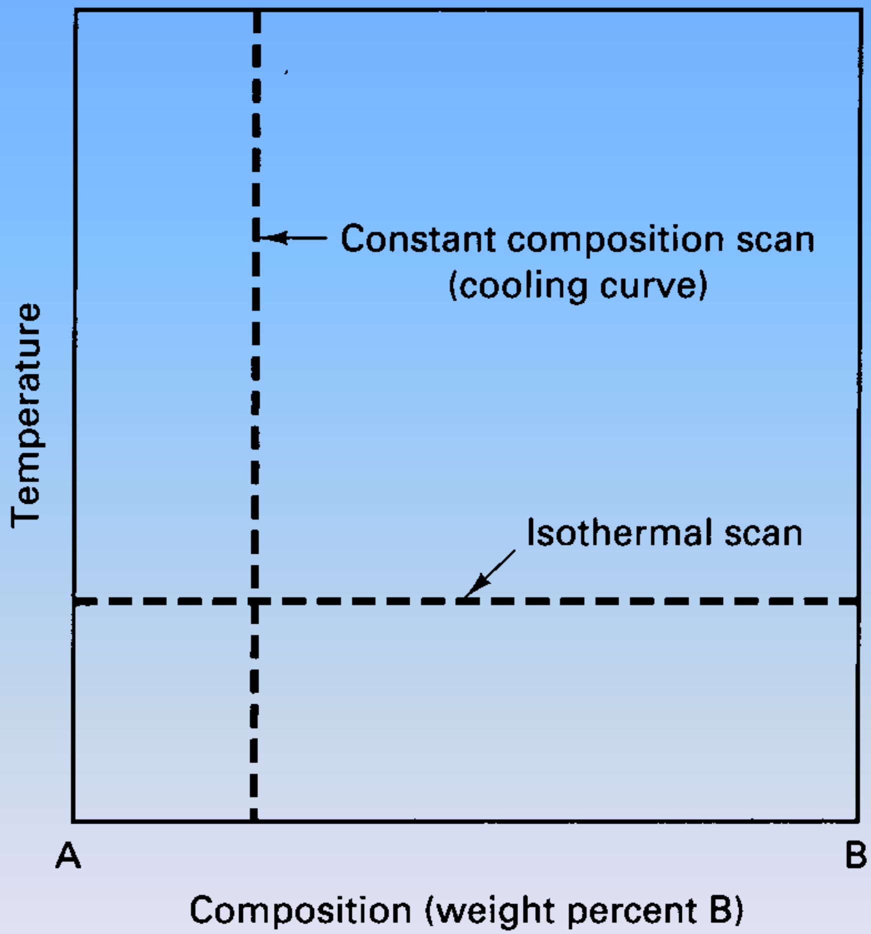
5.3 Equilibrium Phase Diagrams

- Graphic mapping of the natural tendencies of a material or a material system (equilibrium for all possible conditions).
- Primary variables: temperature, pressure and composition.
- P-T diagram (the simplest).



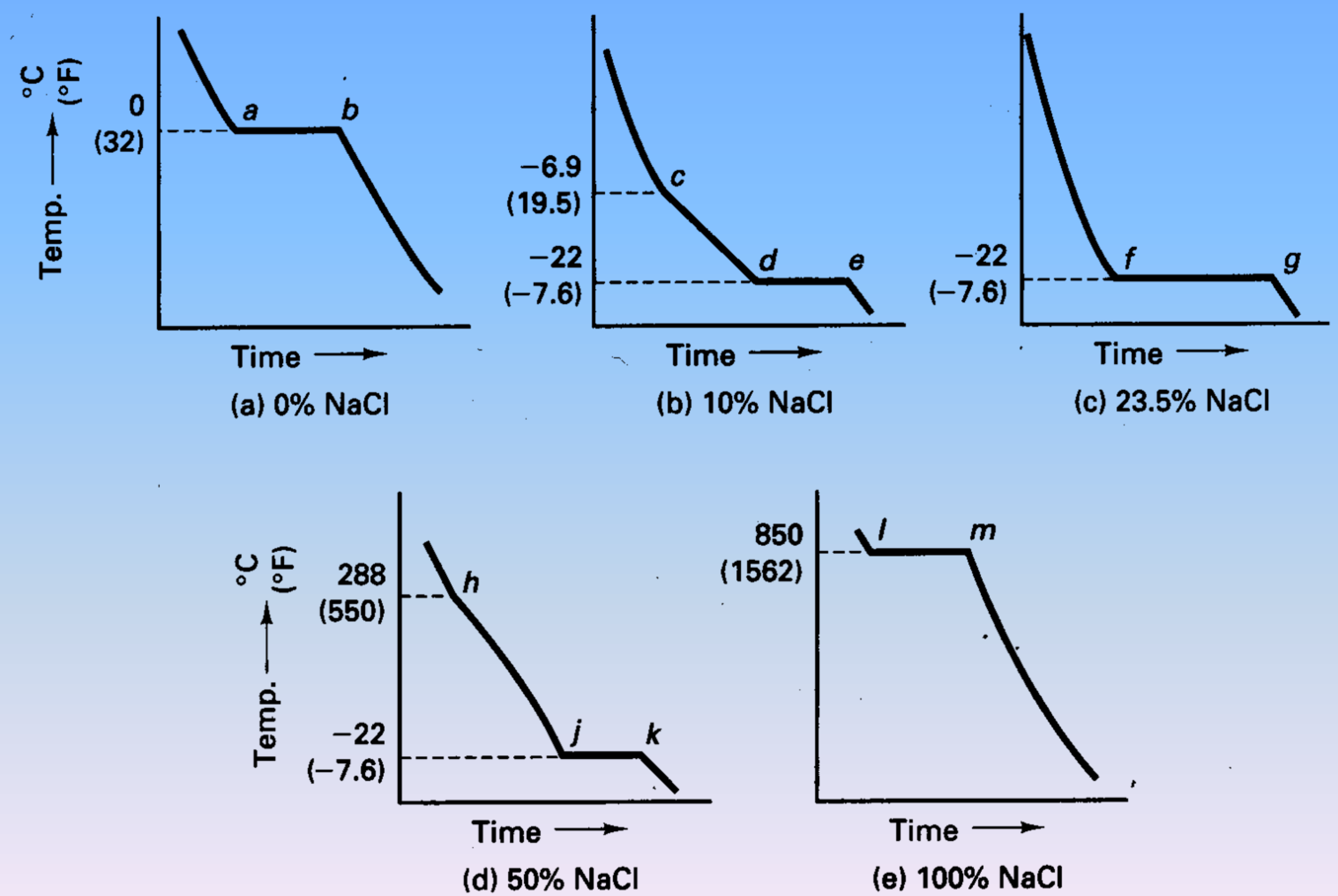
5.3 Temperature-Composition Diagrams

- Engineering processes conducted at atmospheric pressure (P/T variations).
- The most common: temperature-composition phase diagrams.



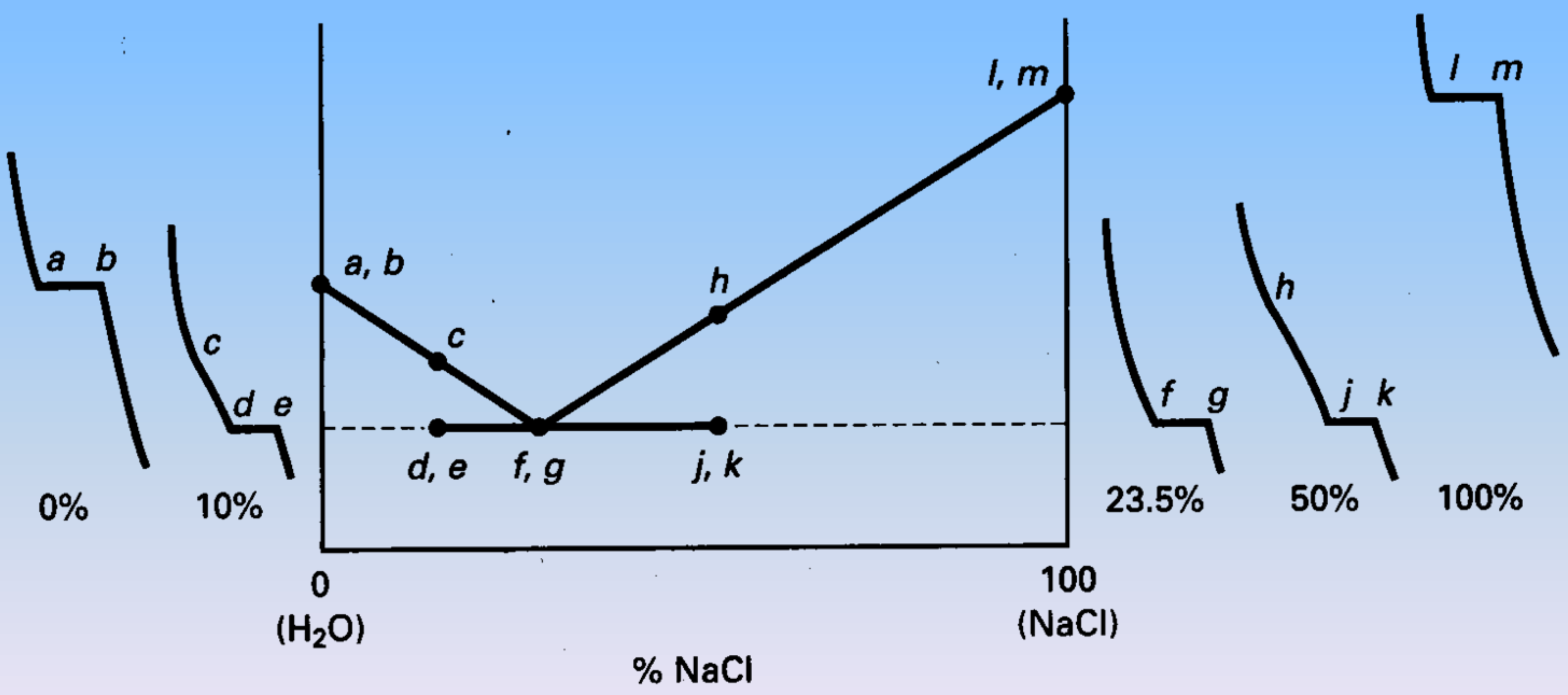
5.3 Cooling Curves

- Cooling curves for NaCl-H20 combinations:



5.3 Cooling Curves

- Partial equilibrium diagram of NaCl-H20 system

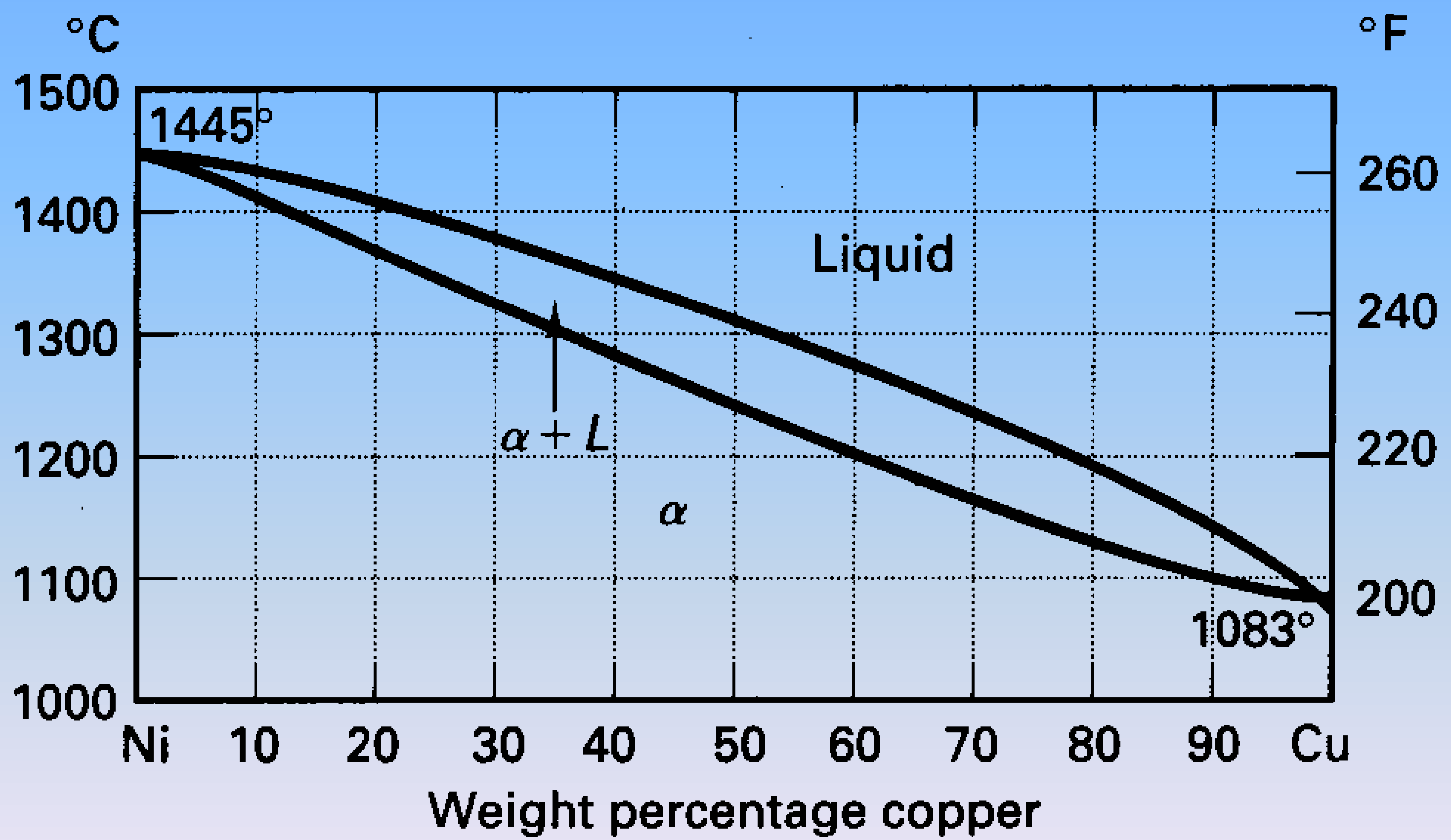


5.3 Solubility

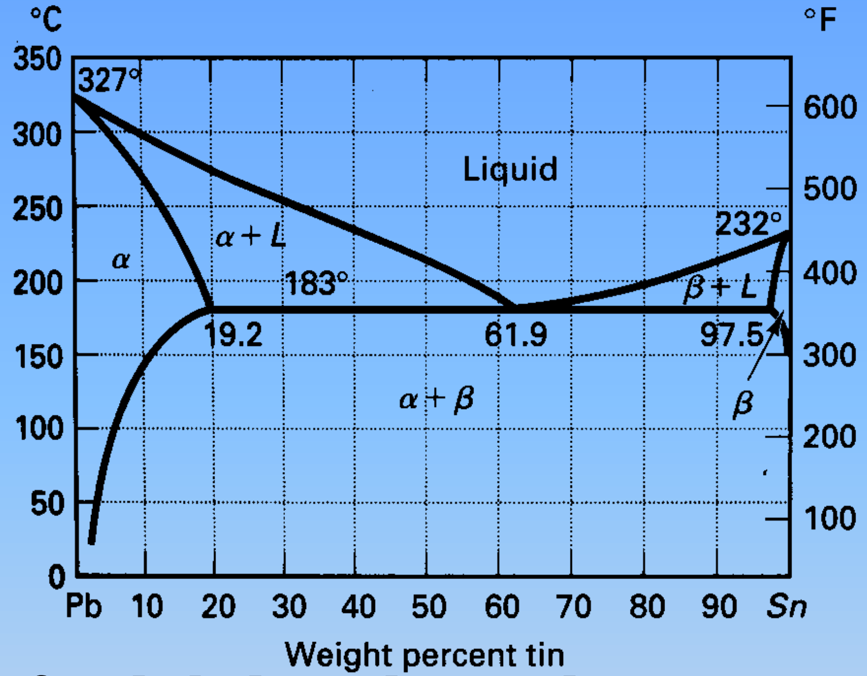
- Solubility limits.
- Degree of solubility determines properties.
- I-Two metals completely soluble in each other.
- II- Two metals soluble in liquid state and insoluble in solid state.
- III-Two metals soluble in liquid state and partially soluble in solid state.

5.3 Complete Solubility

- Copper-Nickel equilibrium diagram



5.3 Partial Solid Solubility

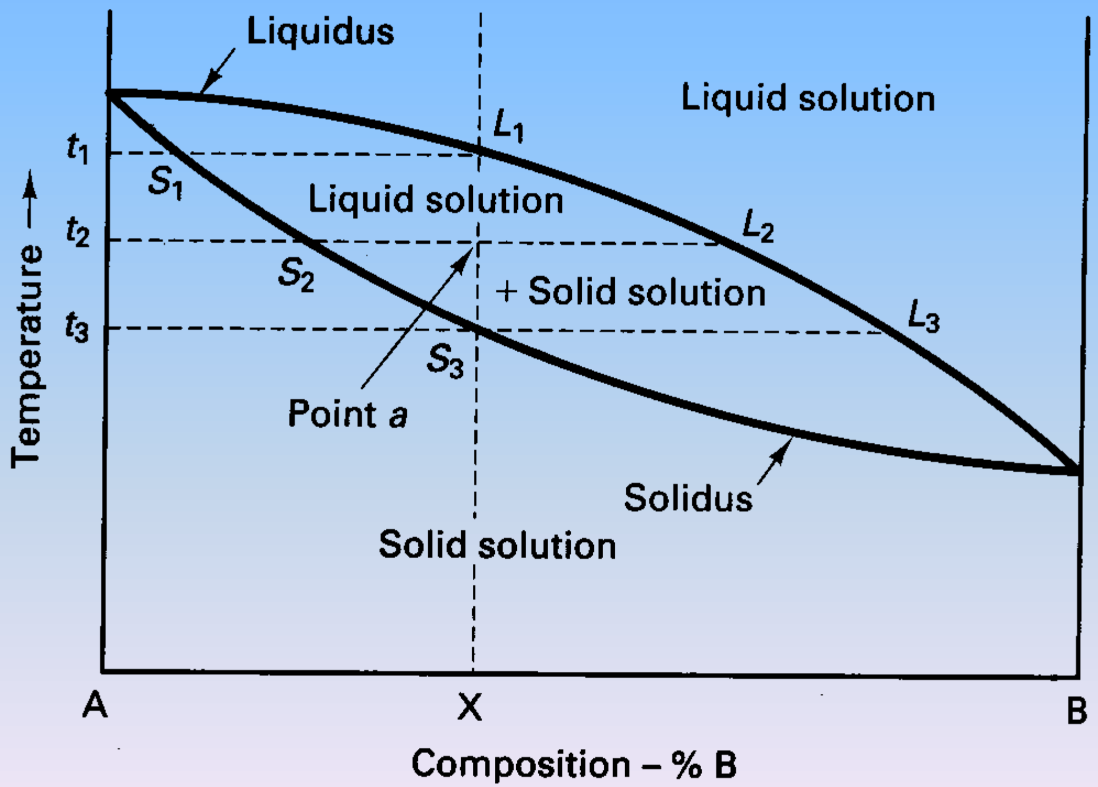


- Degree of solubility depends on temperature
- At max. solubility, 183℃: lead holds up to 19.2 wt% tin in a single phase solution, and tin holds up to 2.5wt% lead and still be a single phase.

5.3 Utilization of Diagrams

$$Liquid\ \ phase\ amount = \frac{a - S_2}{L_2 - S_2} \times 100\% = \%\ by\ mas$$

$$Solid\ \ phase\ amount = \frac{L_2 - a}{L_2 - S_2} \times 100\% = \%\ by\ mass$$



5.3 Example problem

$Given\ data:$

$X = 36\%\ of\ B$

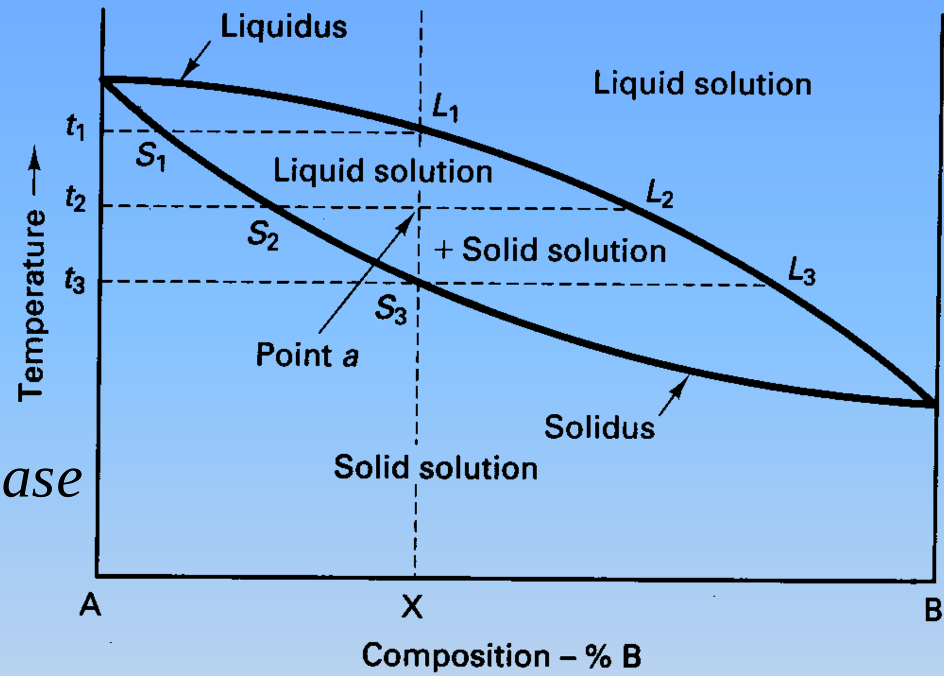
$a = 36\%\ of\ B$

$L_2 = 72\%\ of\ B$

$S_2 = 18\%\ of\ B$

$Compute\ liquid\ phase\ and\ solid\ phase$

$\%\ amounts\ by\ mass.$



$$Liquid\ phase\ amount = \frac{36-18}{72-18} \times 100\% = 33.33\ \%\ by\ mass$$

$$Solid\ phase\ amount = \frac{72-36}{72-18} \times 100\% = 66.67\ \%\ by\ mass$$

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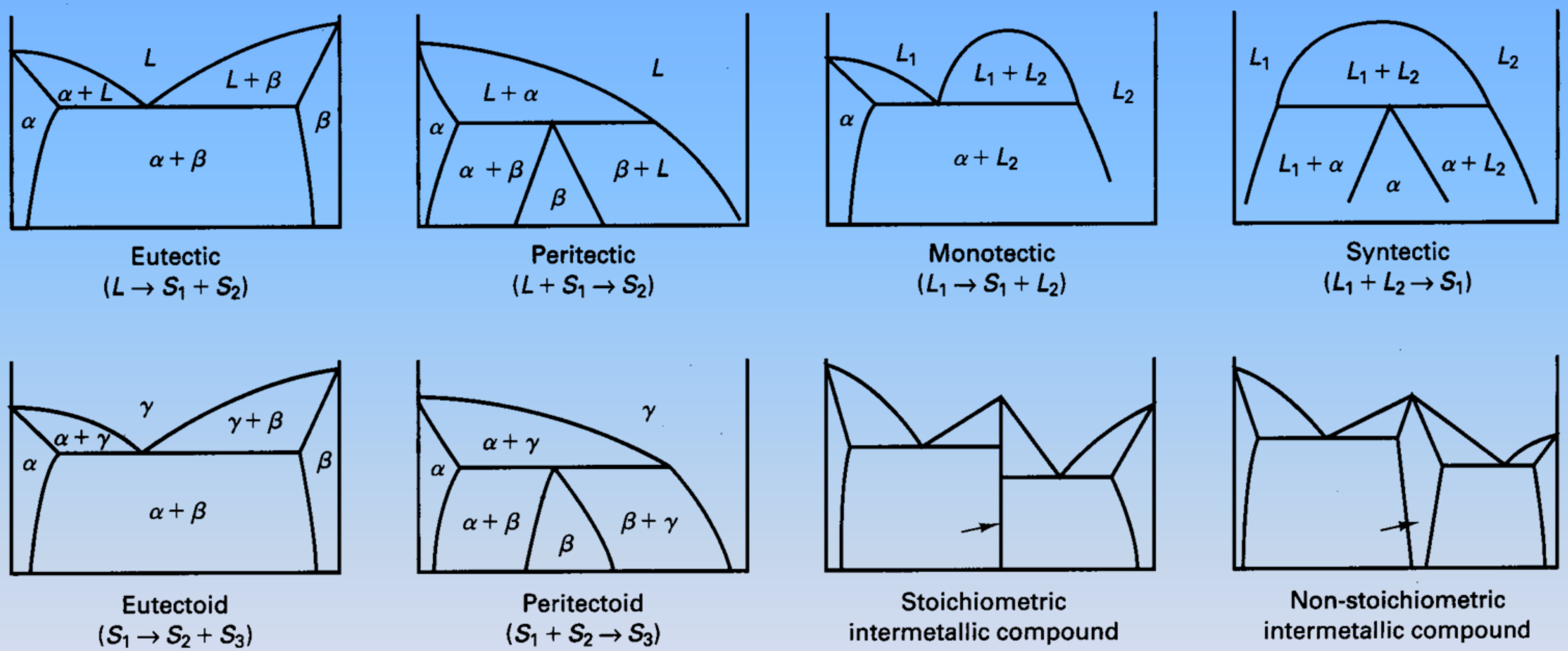
5.3 Utilization of Diagrams

- The phases present.
- Composition of each phase (single phase region or two phase region).
- In two phase region a tie-line should be constructed.
- The amount of each phase present: lever-law calculation using a tie-line.

5.3 Three Phase Reactions



Intermetallic Compounds

- If two components in a compound can only exist at one atomic ratio, the compound is known as a stoichiometric intermetallic compound
- Appears as a single vertical line in the equilibrium phase diagram
- If some degree of variability is tolerable, then the vertical line will extend into a single phase region

5.4 Iron-Carbon Equilibrium Diagram

4 Single Phase solids:
• 3 in pure Fe and one Fe-carbide inter-metallic

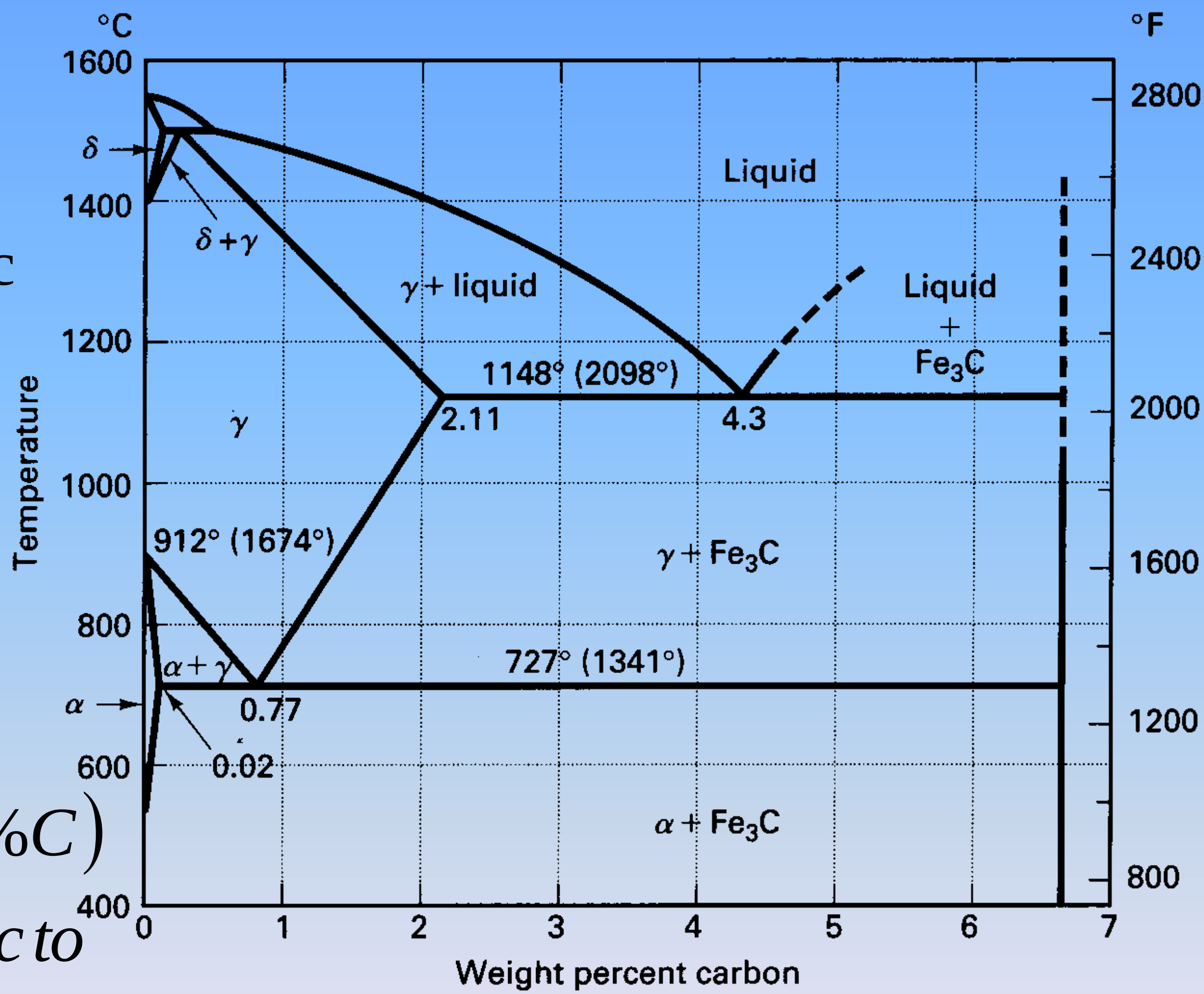
α, *ferrite* (*BCC*)

γ, *austenite* (*FCC*)

$\delta, \delta -$ *ferrite* (*BCC*)

Fe_3C, *cementite* (6.67%*C*)

Curie po. nonmagnetic to magnetic transition



5.4 Iron-Carbon Equilibrium Diagram

- $\delta - ferrite$ (present only at extreme temperatures)
- Austenite, (FCC, high formability, high solubility of C, over 2%C can be dissolved in it, most of heat treatments begin with this single phase).
- Ferrite, BCC, stable form of iron below 912 deg.C, only up to 0.02 wt% C in solid solution and leads to two phase mixture in most of steels.
- Cementite (iron-carbide), stoichiometric intermetalic compound, hard, brittle, exact melting point unknown.
- Currie point (770 deg. C), atomic level nonmagnetic-to-magnetic transition.

5.4 Key Points of Fe-C Diagram

Phases:

- Liquid Fe-T-min=1148C @ 4.3%C
- 1394 C<δ-Fe-<1538C
- α-Ferrite (Ferrite)<912C; <0.02%C
- Magnetic-nonmagnetic-770C
- Cementite Fe_3C=6.67weight %C
- Austenite-727 C<T<1495 C; 0<%C<2.11

5.4 Phase Transformations

Liquid to Austenite

- Eutectic transformation-1148C,
- C-2.11%-4.3%
- Eutectic transformation-4.3% C, 1148C
- Eutectic transformation L-γ+ Fe_3C (fast)
- Eutectic trans L-γ+C (graphite) (slow)

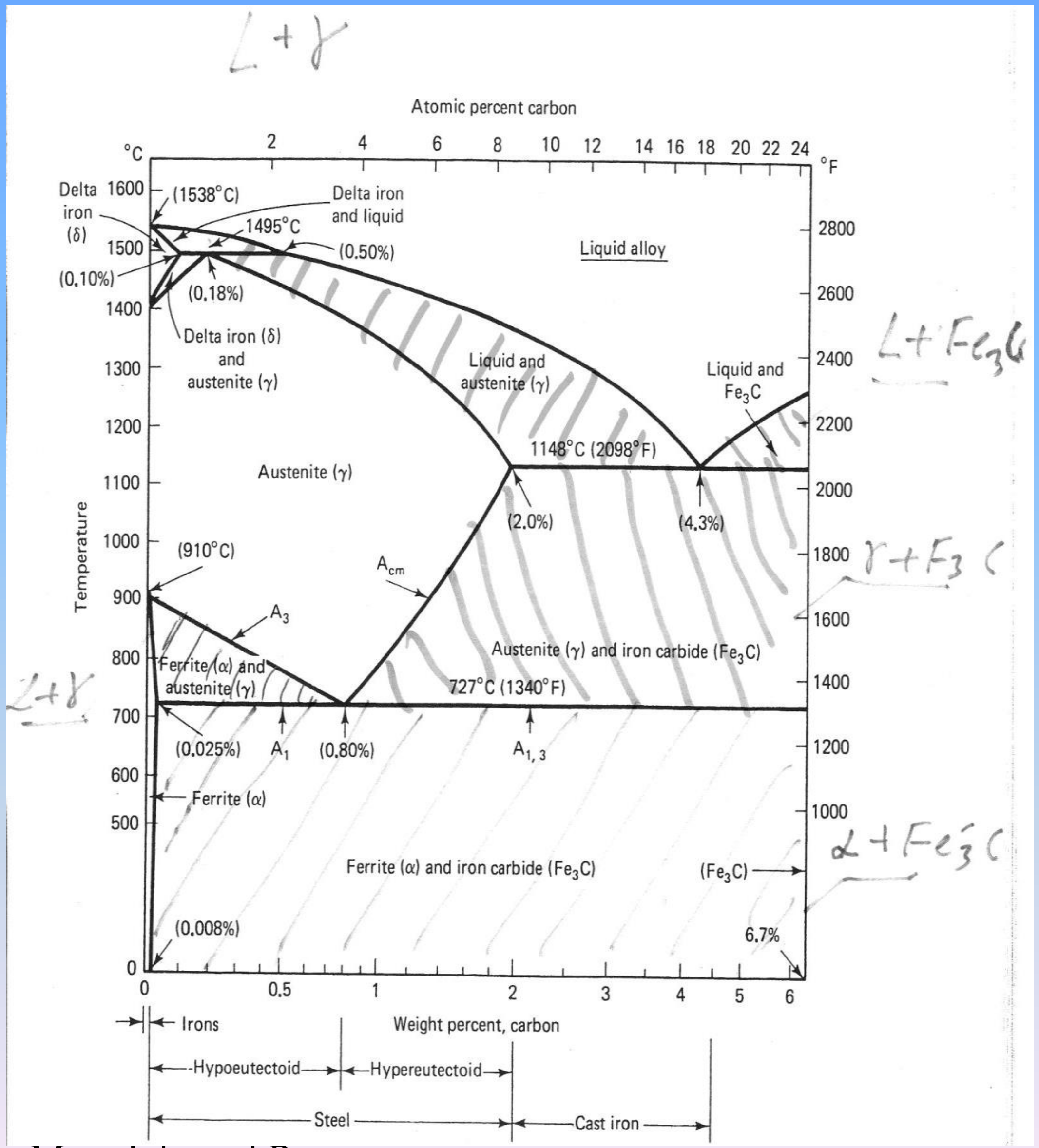
5.4 Eutectoid Transformation

- γ→pearlite (ferrite+ Fe_3C)
- 727 C, 077 % C eutectic point

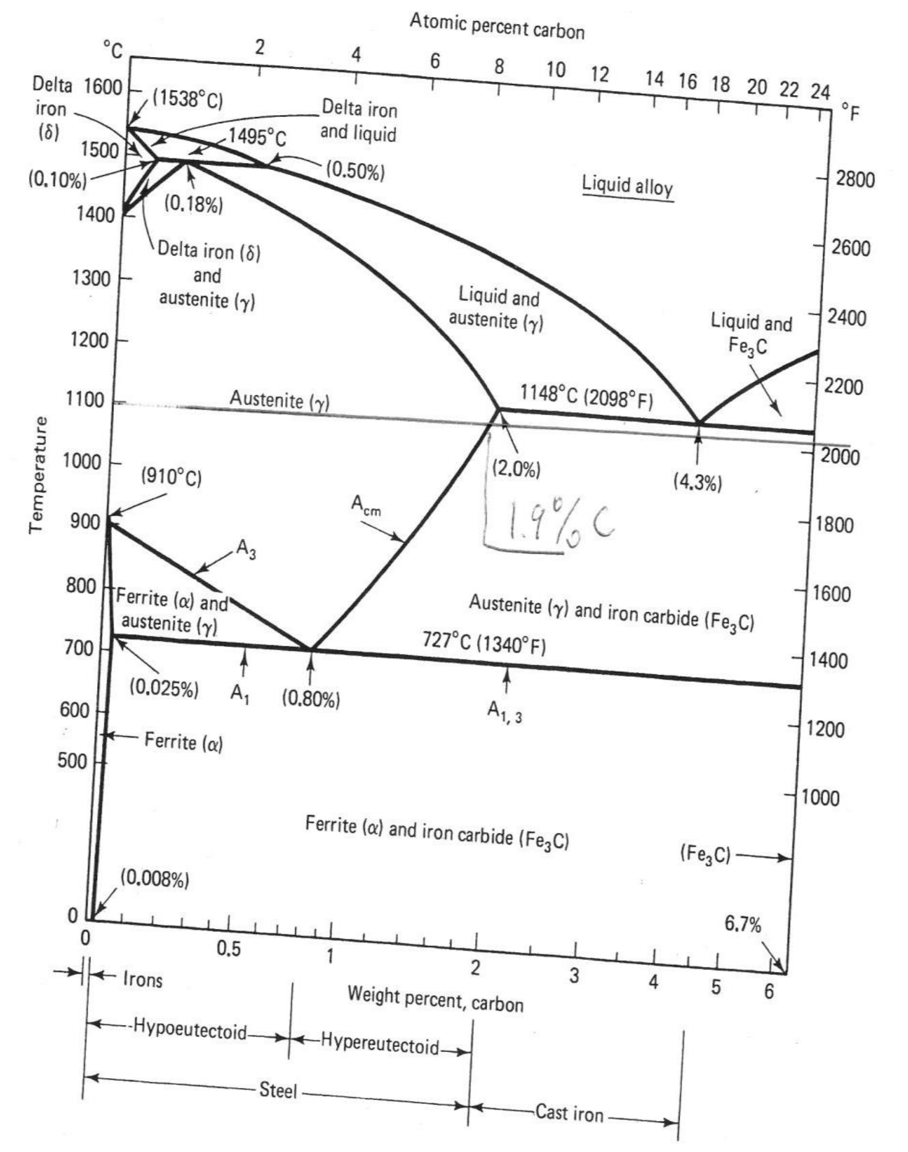
5.4 Three Phase Reactions

- Peritectic, at 1495 deg.C, with low wt% C alloys (almost no engineering importance).
- Eutectic, at 1148 deg.C, with 4.3wt% C, happens to all alloys of more than 2.11wt% C and they are called cast irons.
- Eutectoid, at 727 deg.C with eutectoid composition of 0.77wt% C, alloys bellow 2.11%C miss the eutectic reaction to create two-phase mixture. They are steels.

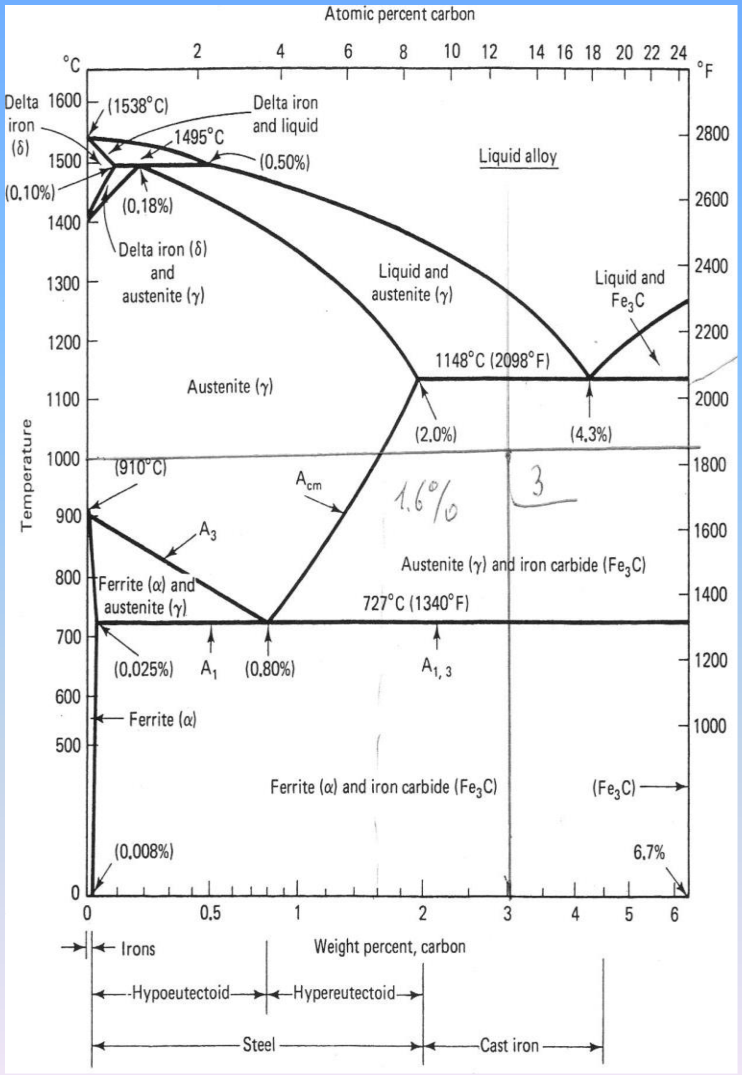
5.4 Iron-Carbon Equilibrium Diagram



5.4 Iron-Carbon Equilibrium Diagram



5.4 Iron-Carbon Equilibrium Diagram

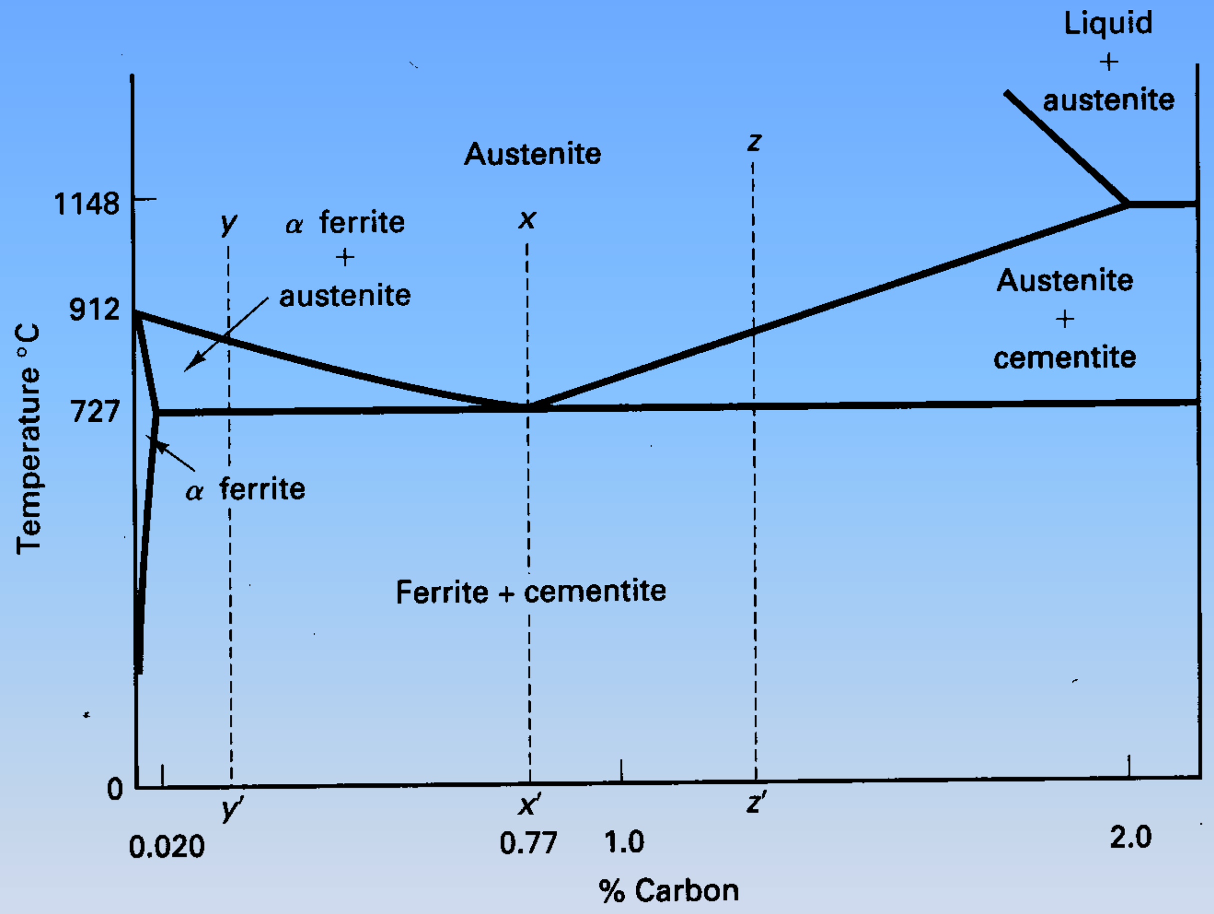


$$\% \, Austenite = \frac{6.67-3}{6.67-1.75} \times 100\% = 74.74 \ \% \ by \ mass$$

5.5 Steels and the Simplified Iron-Carbon Diagram

- Steels having less than the eutectoid amount of carbon are hypoeutectoid steels
- Steels having more than the eutectoid amount of carbon are called hypereutectoid steels
- Transitions occur both in slow heating and cooling

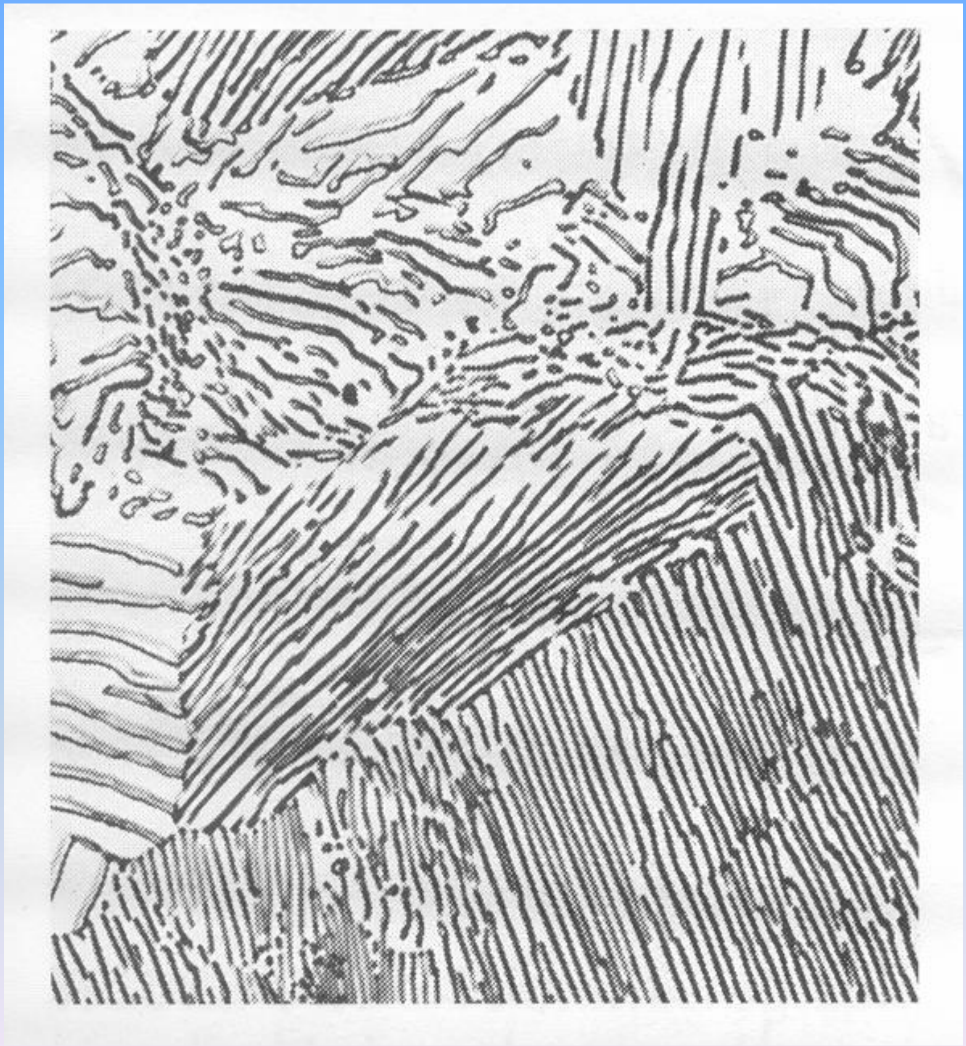
5.5 Steels



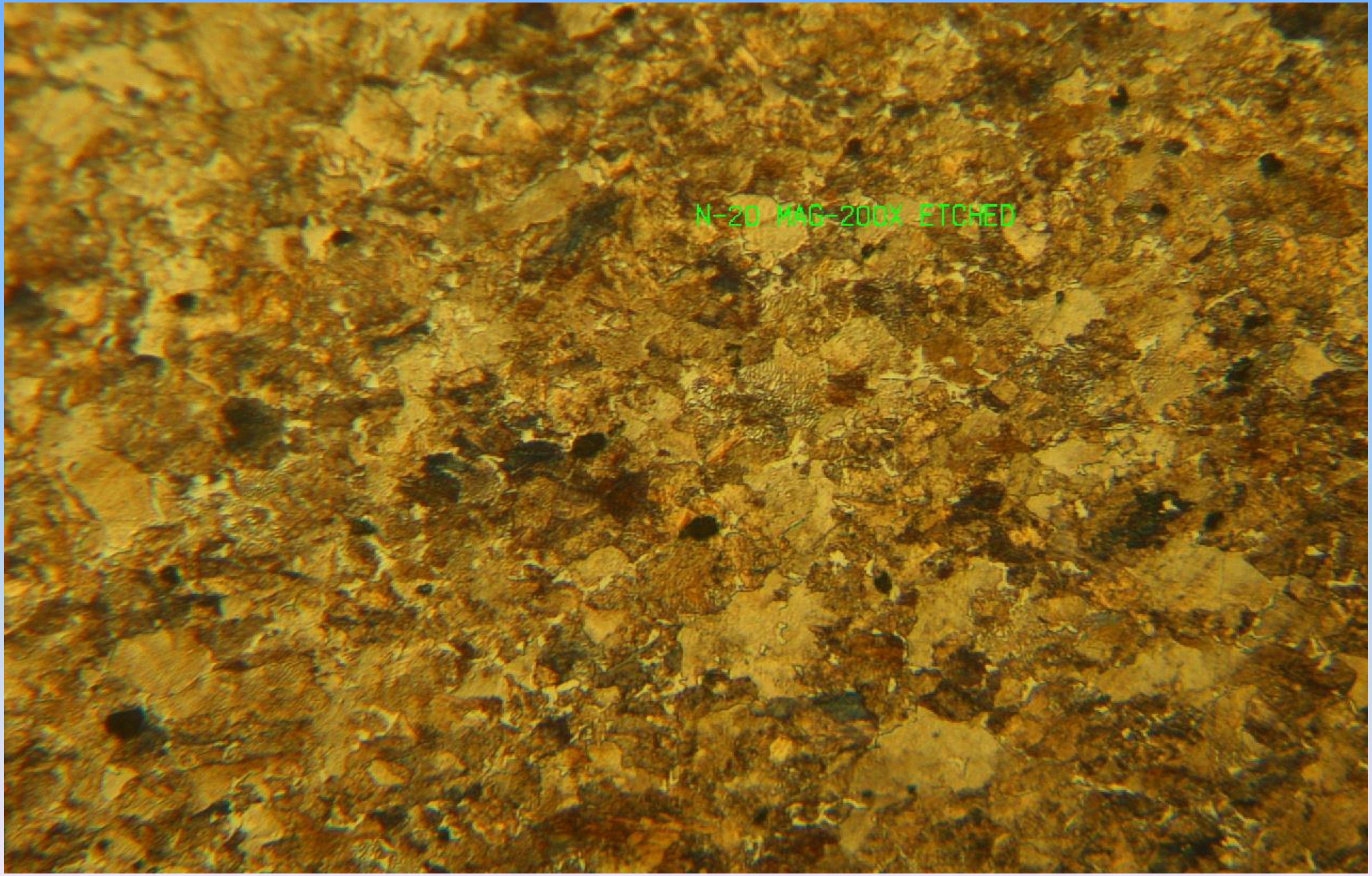
$$Austenite_{0.77\%C;FCC} \rightarrow Ferrite_{0.02\%C;BCC} + Cementite_{6.67\%C}$$

5.5 Eutectoid Steel

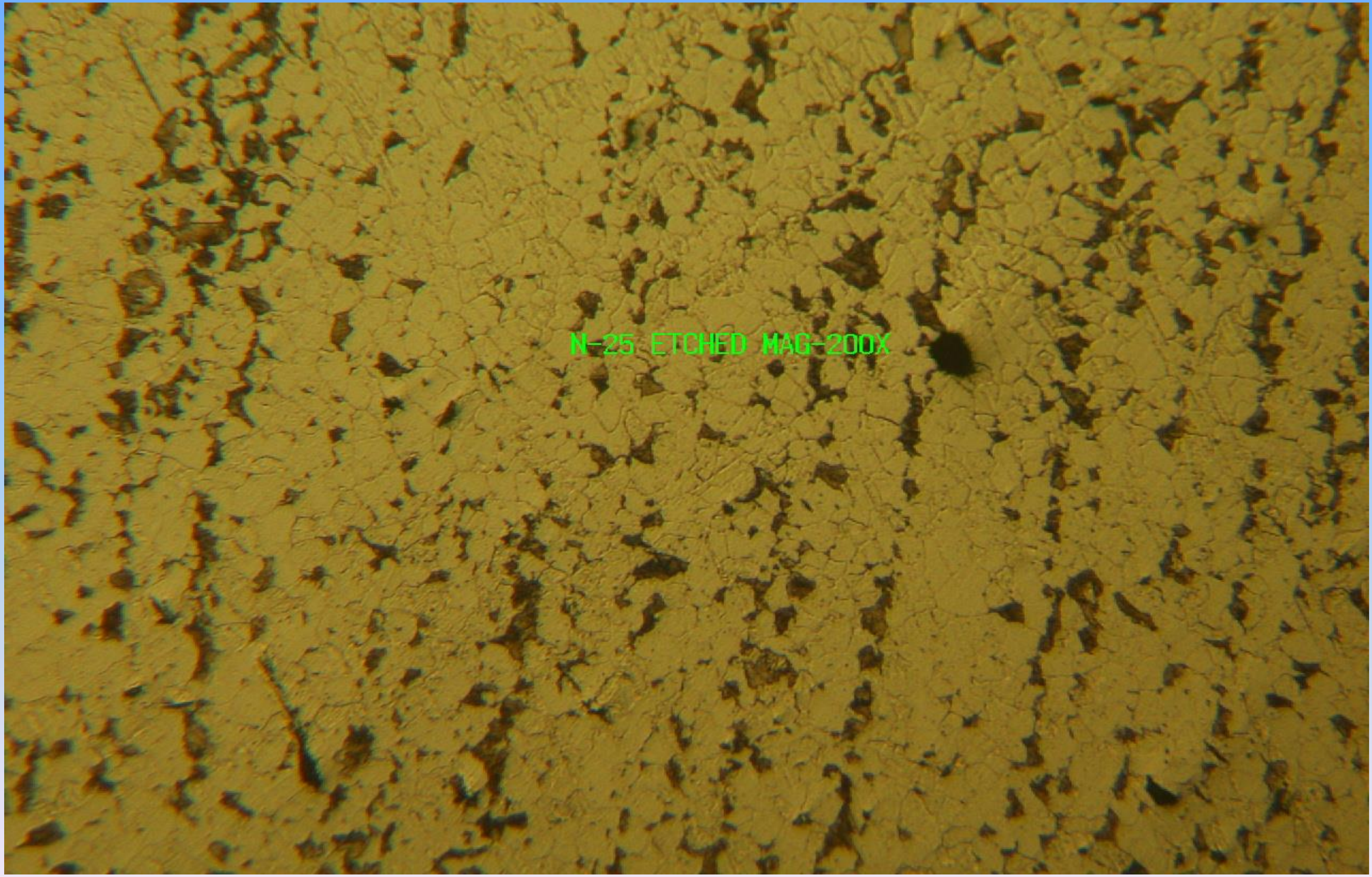
- At 0.77%C by cooling from austenite (FCC) changes to BCC-ferrite (max 0.02%C) and excess C forms intermetalic cementite.
- Chemical crystalline solid separation gives fine mixture of ferrite and cementite. Perlite (right), 1000X.



Medium Carbon Steel



Low Carbon Steel



5.5 Pearlite

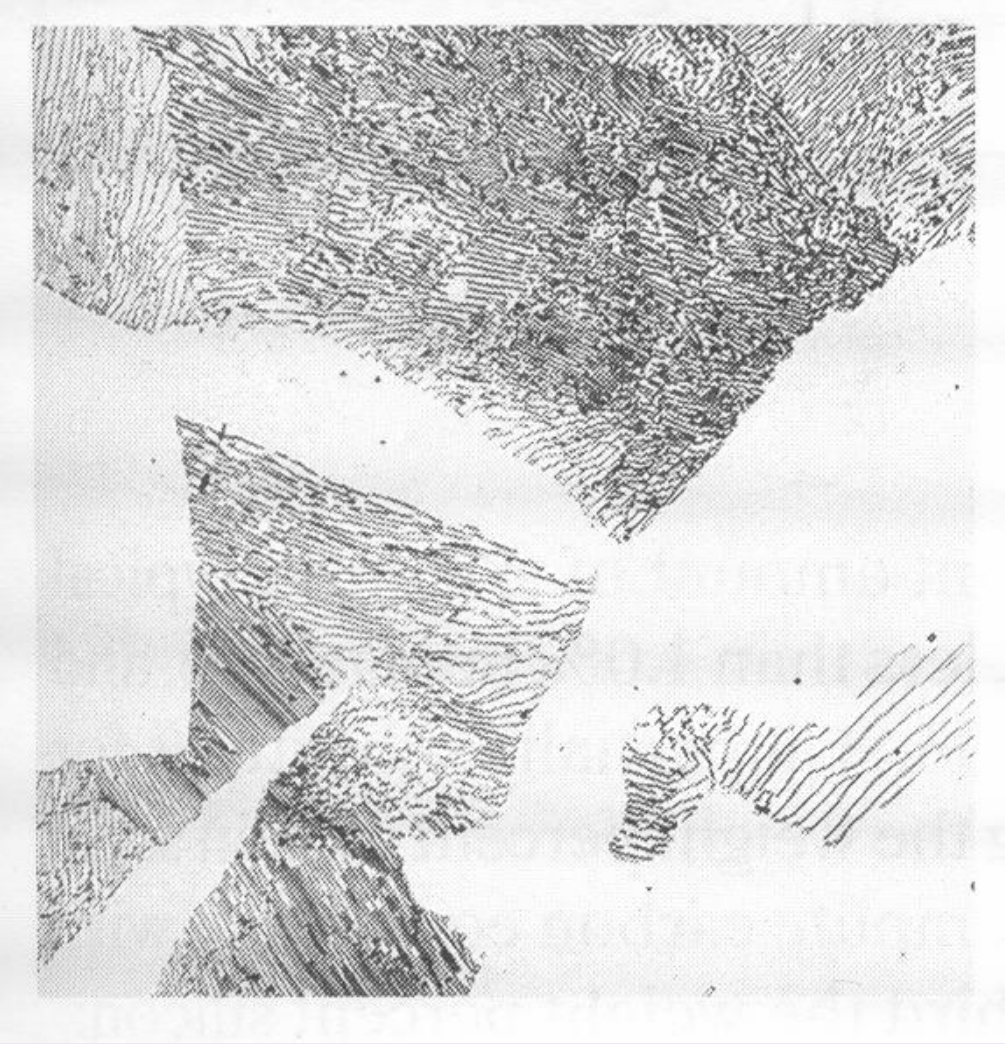
- **Pearlite** is a two-phased, lamellar (or layered) structure composed of alternating layers of alpha-ferrite(88 wt%) and cementite(12%) that occurs in some steels and cast irons.
- It forms by a eutectoid reaction as austenite is slowly cooled below 727C.
- The eutectoid composition of Austenite is approximately 0.8% carbon[1];.

5.5 Pearlite

- Steel with less carbon content will contain a corresponding proportion of relatively pure ferrite crystallites that do not participate in the eutectoid reaction and cannot transform into pearlite.
- Steel with more carbon content will contain a corresponding proportion of relatively pure cementite crystallites that do not participate in the eutectoid reaction and cannot transform into pearlite
- Hypo-vs Hypereutectoid steels

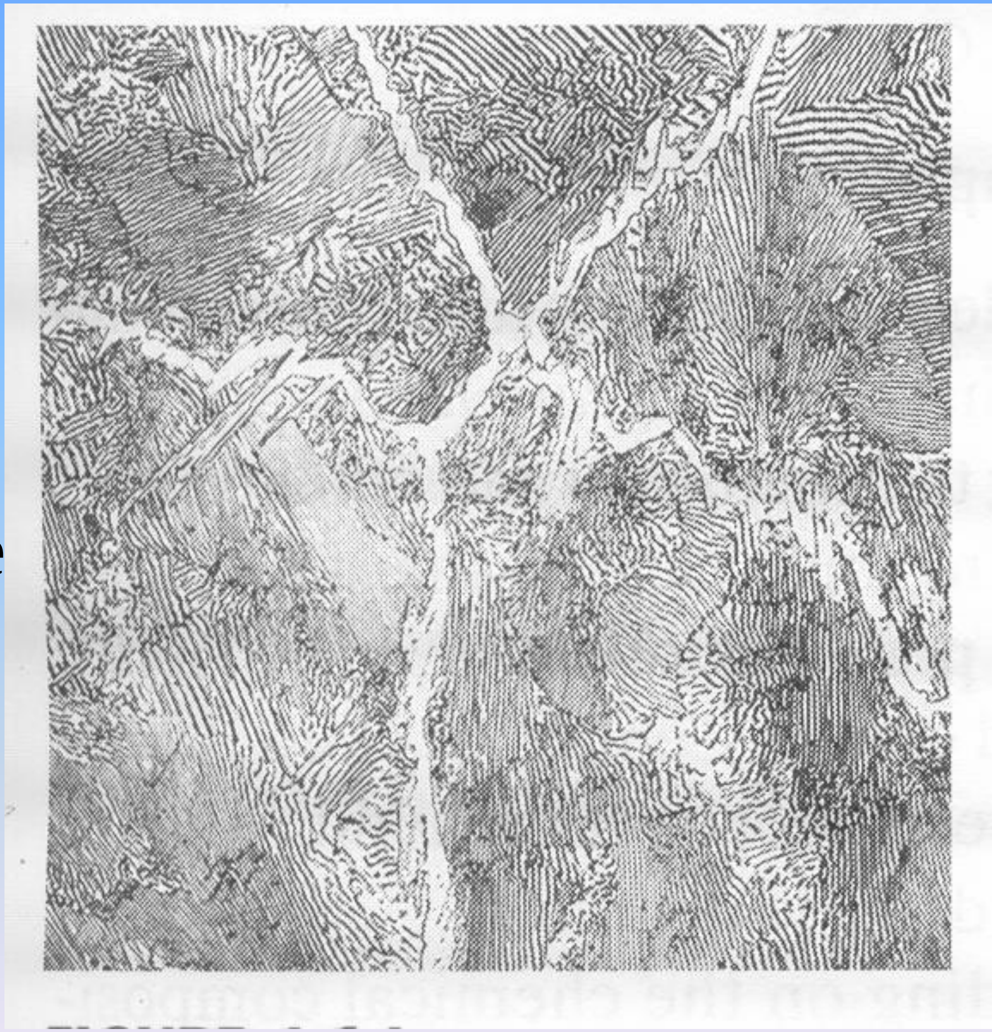
5.5 Hypoeutectoid Steel

- With less than 0.77%C from austenite by cooling transformation leads to growth of low-C ferrite growth. At 727deg.C austenite transforms in to pearlite.
- Mixture of proeutectoid ferrite (white) and regions of pearlite forms.
- Magnification 500X.



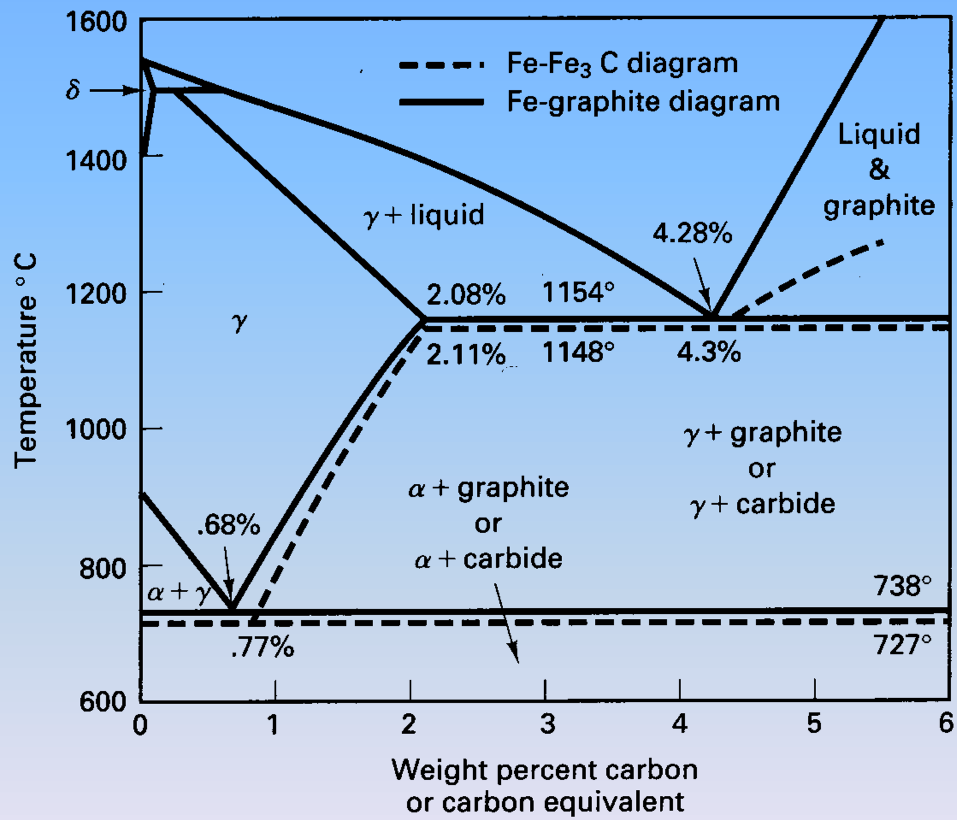
5.5 Hypereutectoid Steel

- With more than 0.77%C, from austenite transformation leads to proeutectoid primary cementite and secondary ferrite. At 727 deg. C austenite changes to pearlite
- Structure of primary cementite and pearlite forms.
- Magnification 500X.



5.6 Cast Irons

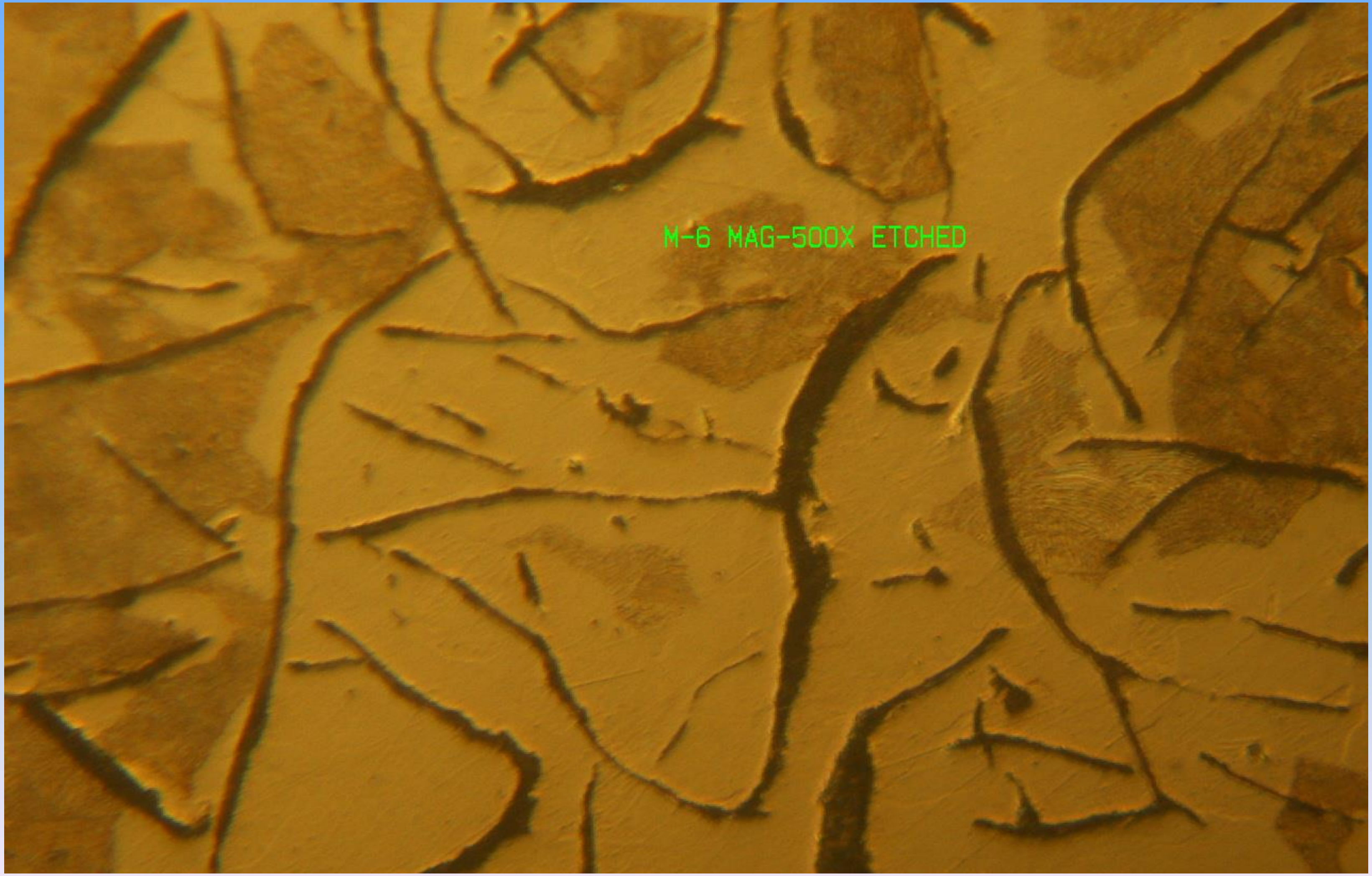
- Iron-Carbon alloys of 2.11%C or more are cast irons.
- Typical composition: 2.0-4.0%C,0.5-3.0% Si, less than 1.0% Mn and less than 0.2% S.
- Si-substitutes partially for C and promotes formation of graphite as the carbon rich component instead Fe3C.



5.6 Gray Cast Iron

- Composes of: 2.5-4.0%C, 1.0-3.0%Si and 0.4-1.0% Mn.
- Microstructure: 3-D graphite flakes formed during eutectic reaction. They have pointed edges to act as voids and crack initiation sites.
- Sold by class (class 20 has min. tensile strength of 20,000 psi is a high C-equivalent metal in ferrite matrix). Class 40 would have pearlite matrix.

5.6 Gray Cast Iron with Lamellar Graphite



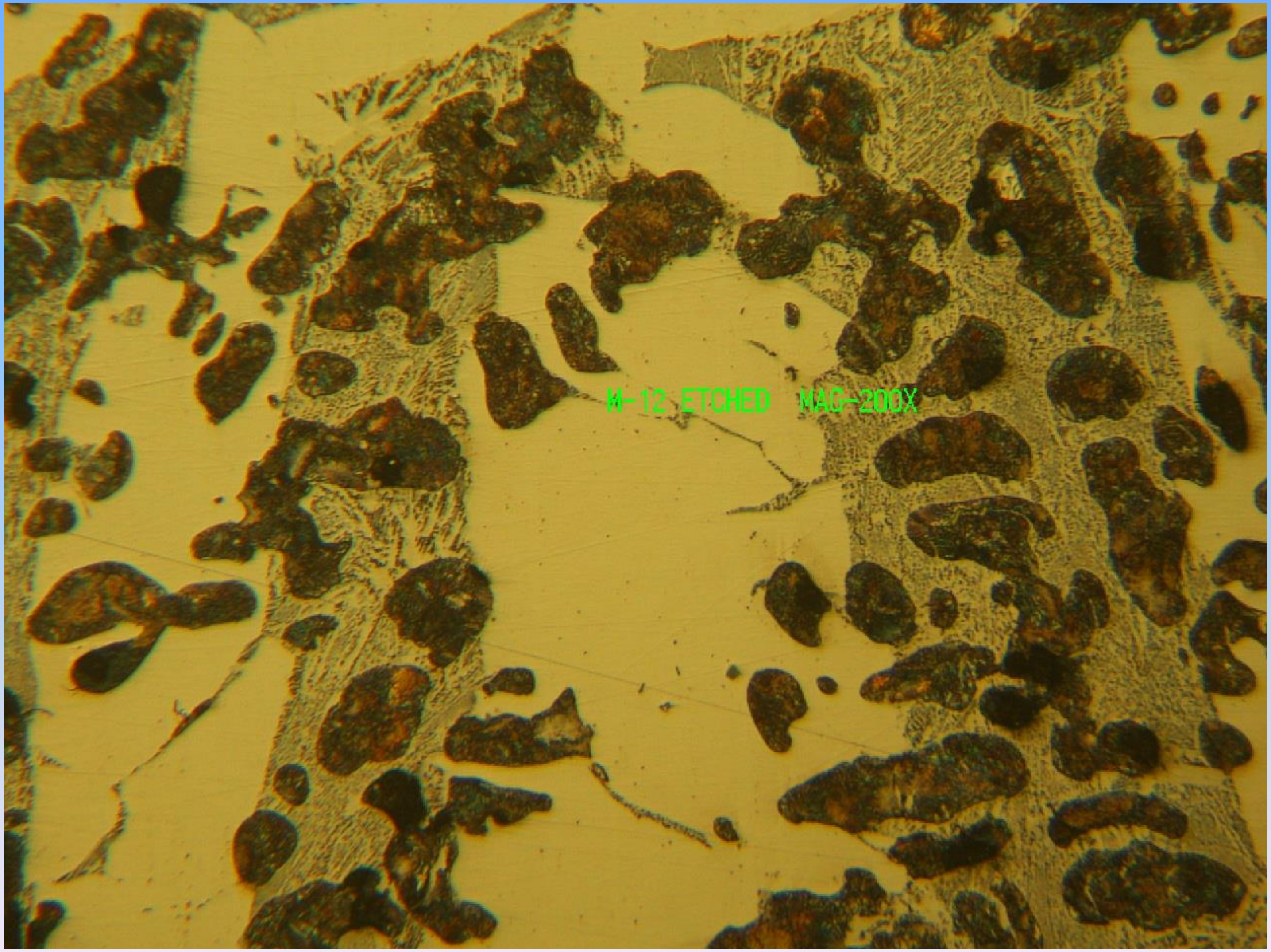
5.6 Gray Cast Iron

- Properties: excellent compressive strength, excellent machinability, good resistance to adhesive wear (self lubrication due to graphite flakes), outstanding damping capacity (graphite flakes absorb transmitted energy), good corrosion resistance and it has good fluidity needed for casting operations.
- It is widely used, especially for large equipment parts subjected to compressive loads and vibrations.

5.6 White Cast Iron

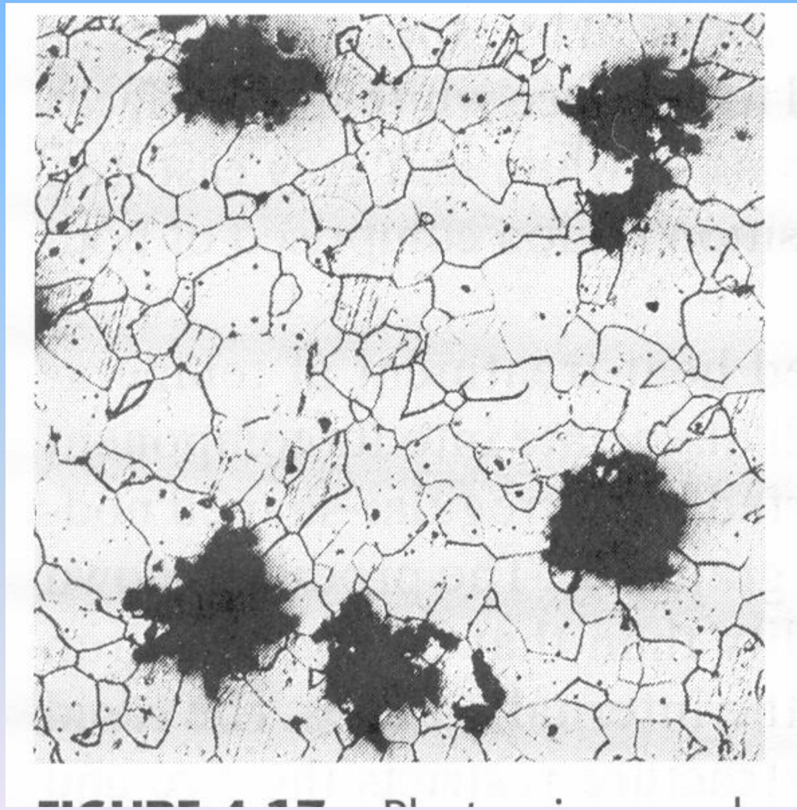
- Composes of: 1.8-3.6%C, 0.5-1.9%Si and 0.25-0.8%Mn.
- All of its carbon is in the form of iron-carbide ($Fe3C$). It is called white because of distinctive white fracture surface.
- It is very hard and brittle (a lot of $Fe3C$).
- It is used where a high wear resistance is dominant requirement (coupled hard martensite matrix and iron-carbide). Thin coatings over steel (mill rolls).

5.6 White Cast Iron



5.6 Malleable Cast Iron

- Formed by extensive heat treatment around 900 deg C, Fe_3C will dissociate and form irregular shaped graphite nodules. Rapid cooling restricts production amount to up to 5 kg. Less voids and notches.
- Ferritic MCI: 10% EL,35 ksi yield strength, 50 ksi tensile strength. Excellent impact strength, good corrosion resistance and good machinability.



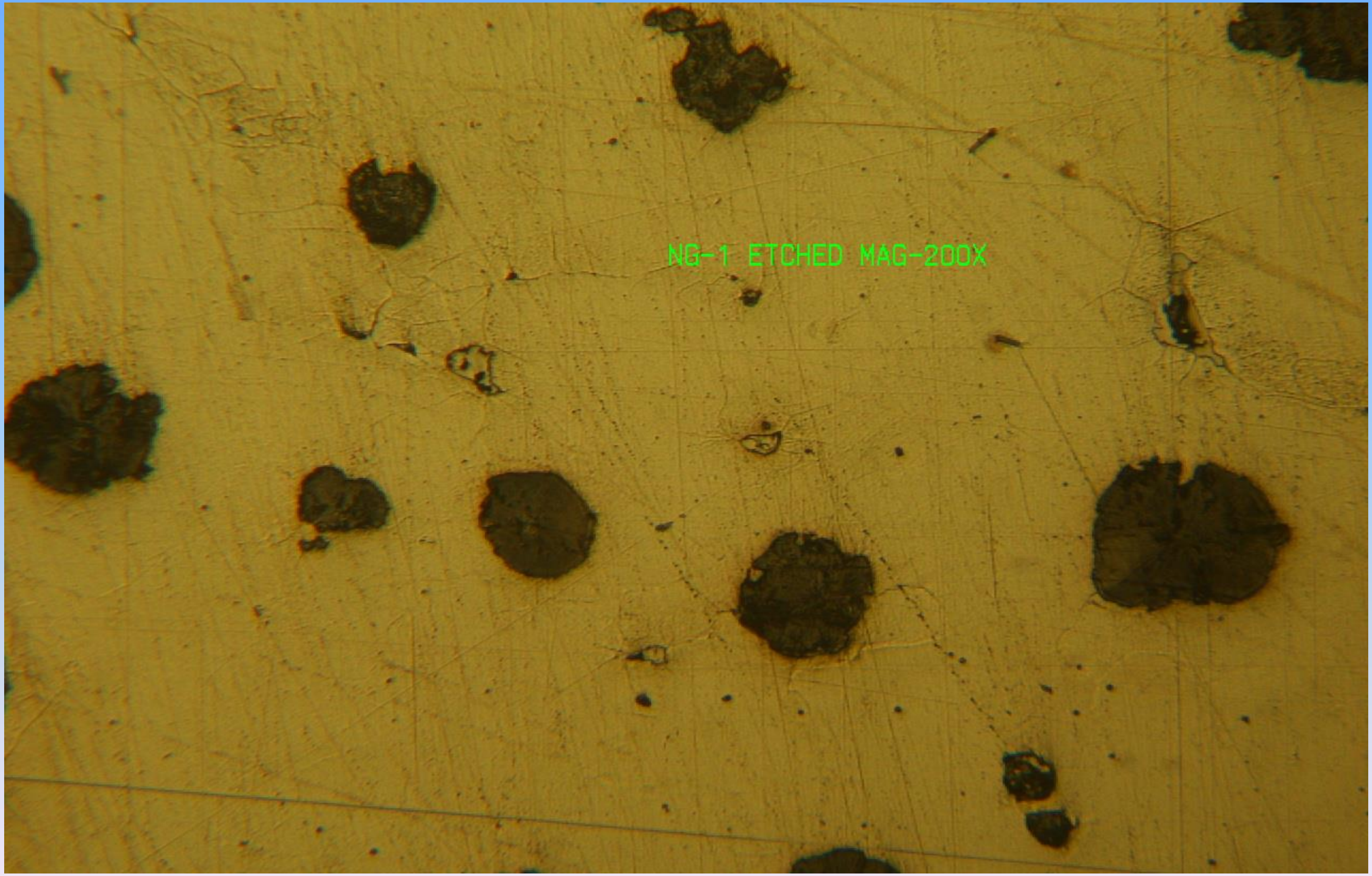
5.6 Pearlitic Malleable Cast Iron

- Pearlitic MCI: by rapid cooling through eutectic transformation of austenite to pearlite or martensite matrix.
- Composition: 1-4% EL, 45-85 ksi yield strength, 65-105 ksi tensile strength. Not as machinable as ferritic malleable cast iron.

Ductile Cast Iron

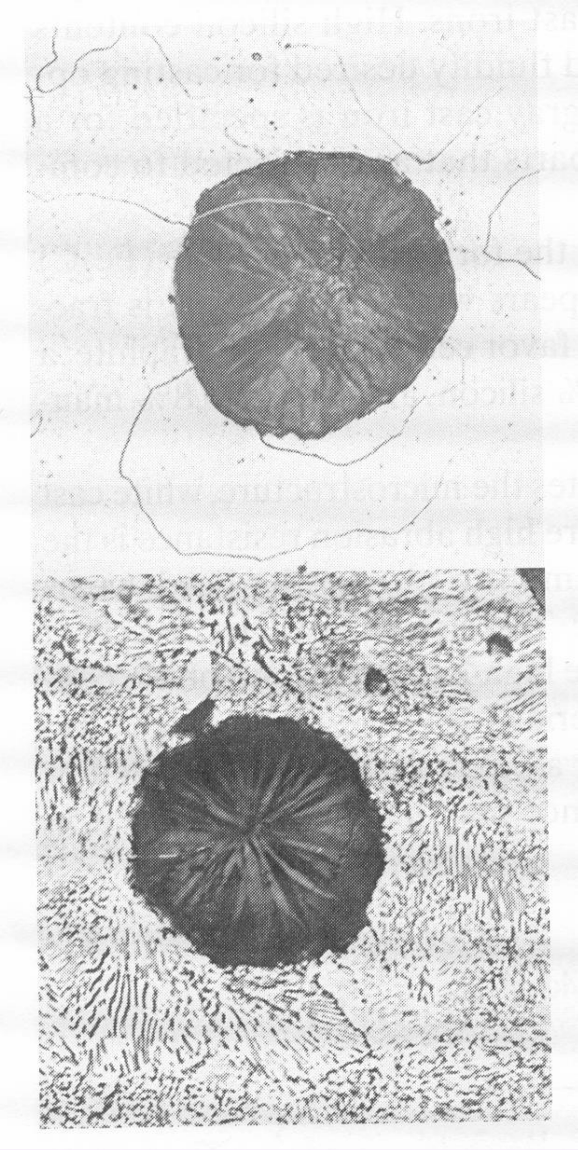
- Without a heat treatment by addition of ferrosilicon (MgFeSi) formation of smooth spheres (nodules) of graphite is promoted.
- Properties: 2-18% EL, 40-90 ksi yield strength, 60-120 ksi tensile strength.
- Attractive engineering material due to: good ductility, high strength, toughness, wear resistance, machinability and low melting point castability.

Nodular Graphite with Ferritic Matrix

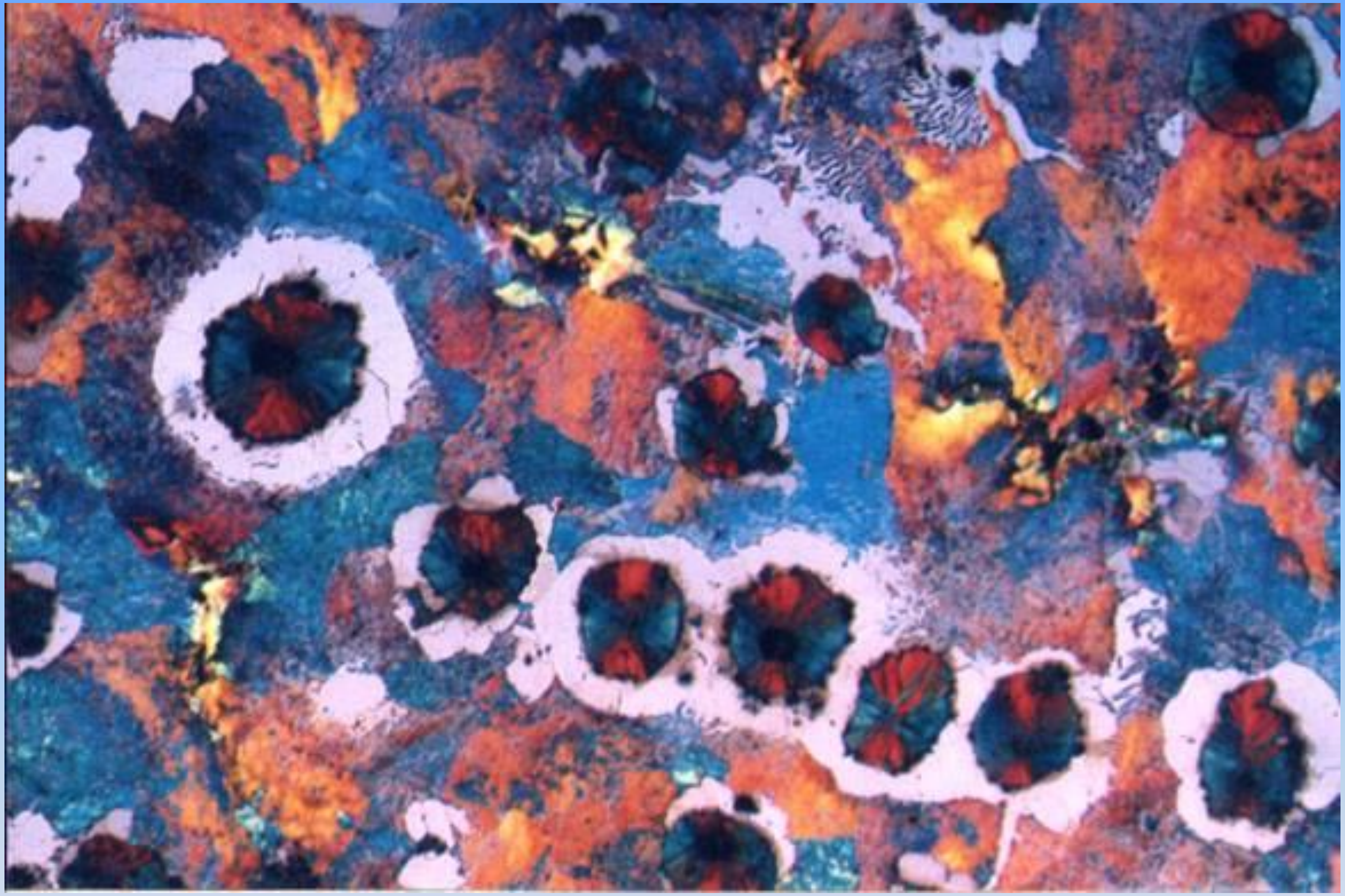


5.6 Malleable Cast Iron

- Ductile iron with ferrite matrix (top) and pearlite matrix (bottom) at 500X.
- Spheroidal shape of the graphite nodule is achieved in each case.



Microstructure

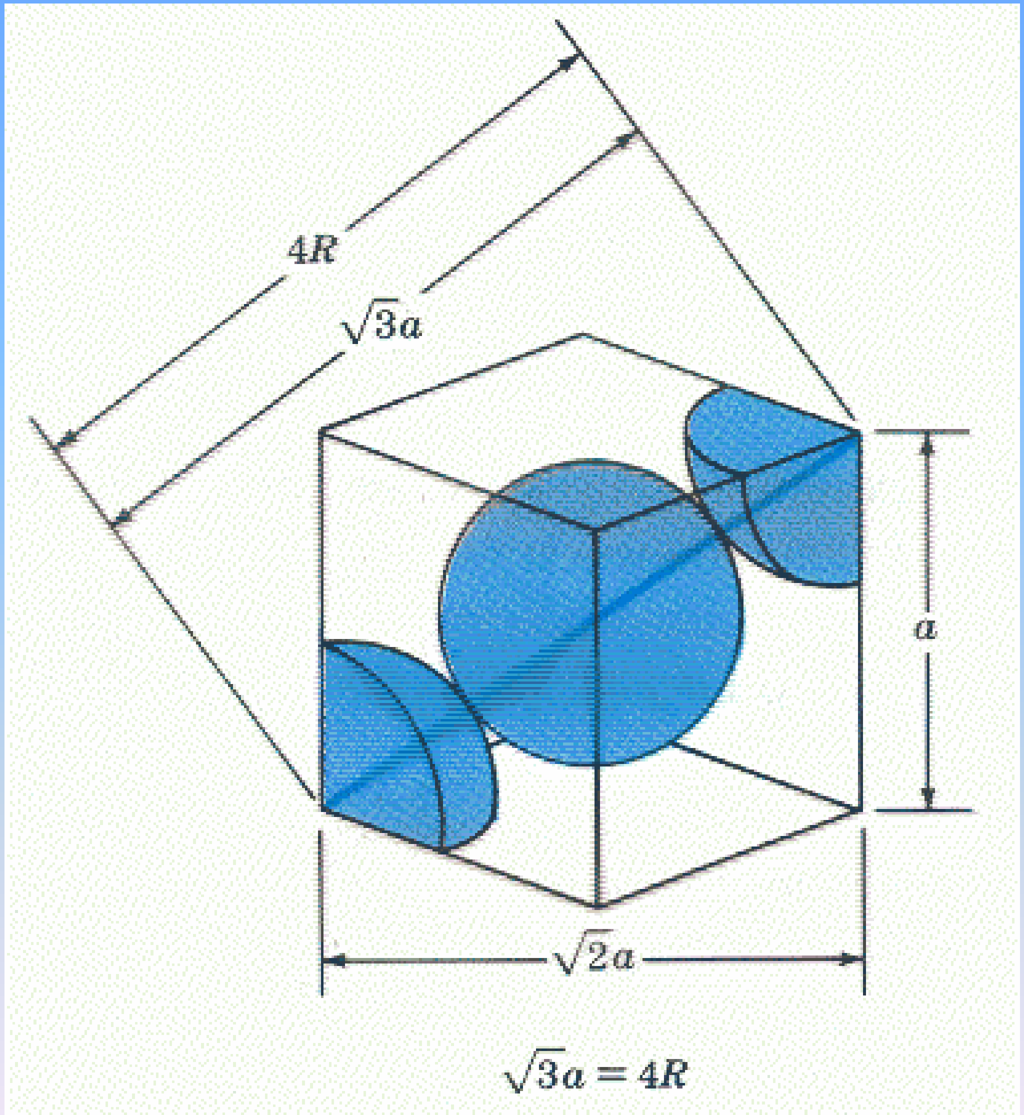


- Globular cast iron

Summary

- Phase diagrams can be used to predict how materials will behave during different heat treating processes
  – Diagrams are used extensively in casting processes to predict needed cooling rates
- Cast irons are specifically used for casting
- Properties of cast irons differ from those of other iron compounds

BCC Unit Cell



FCC Unit Cell