Announcements & Today's Schedule

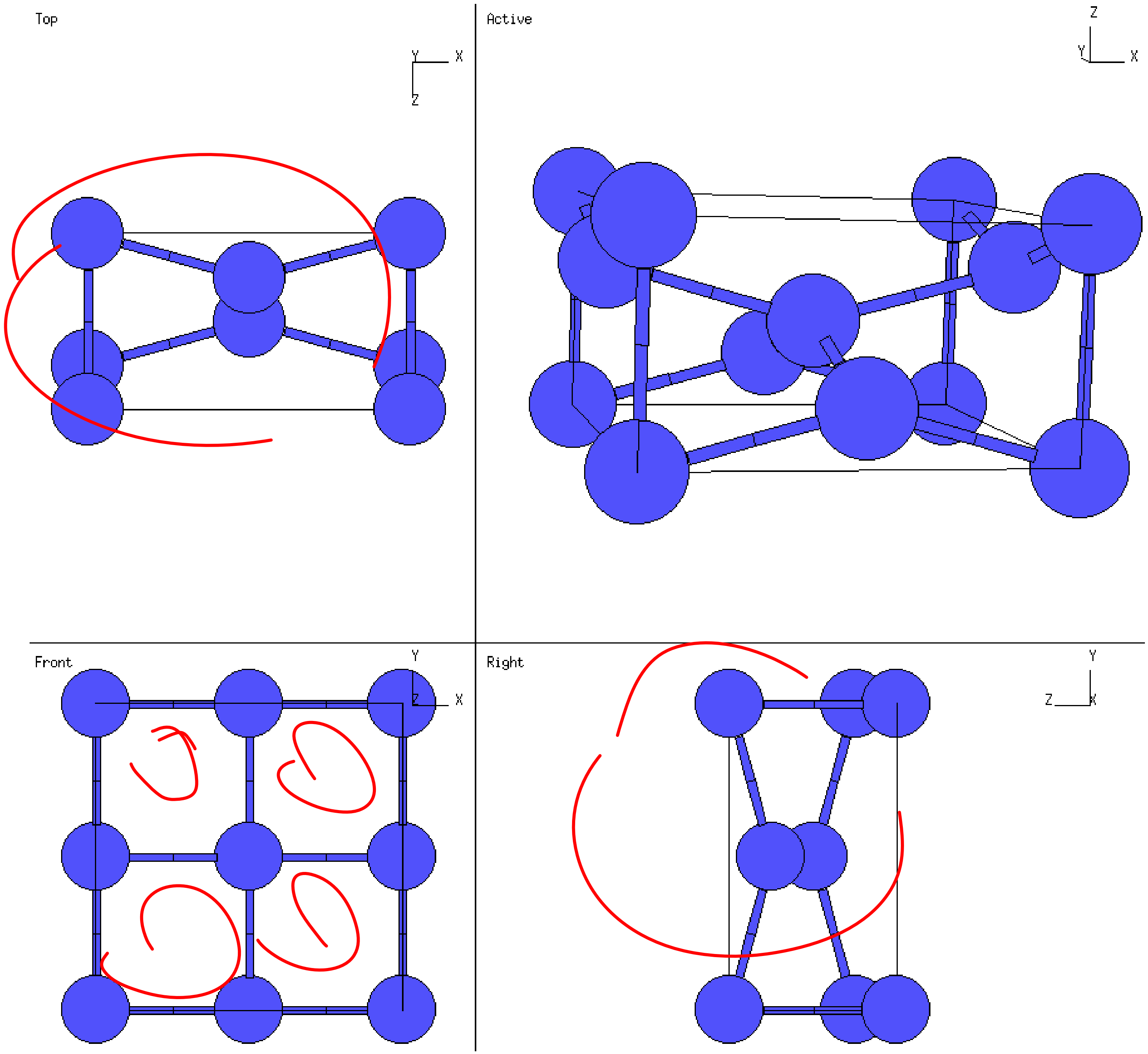
- WebCT#2 graded (*average was 78*), we will discuss it in a moment.
- Lever rule – 'file 'Isoplethal study.pdf' on WebCT
- Starting today, homework solutions will be on WebCT prior to the tutorial quizzes.
- 2nd item on schedule – A bit more on steel and a movie
- 3rd item on schedule – Intermetallic compounds AND more on how to read phase diagrams

Diffusion of Cu in Sn

The diffusion of Cu in Sn is very rapid. It is also anisotropic. At room temperature, the diffusion coefficient in the c-direction (z-axis) is $3x10^{-10}$ m^2/s. The diffusion coefficient in the a-direction (x-axis) is $9x10^{-13}$ m^2/s. The current understanding is that Cu diffuses in Sn by an interstitial mechanism. For this diffusion system, examine the following:

a) The rules for interstitial versus substitutional solid-solutions. Most importantly, think about the atomic radii for Cu and Sn, which are 0.128 nm and 0.106 nm (really 0.151 nm), respectively.

b) The crystal structure of pure Sn (available at http://cst-www.nrl.navy.mil/lattice/struk.picts/a5.s.png)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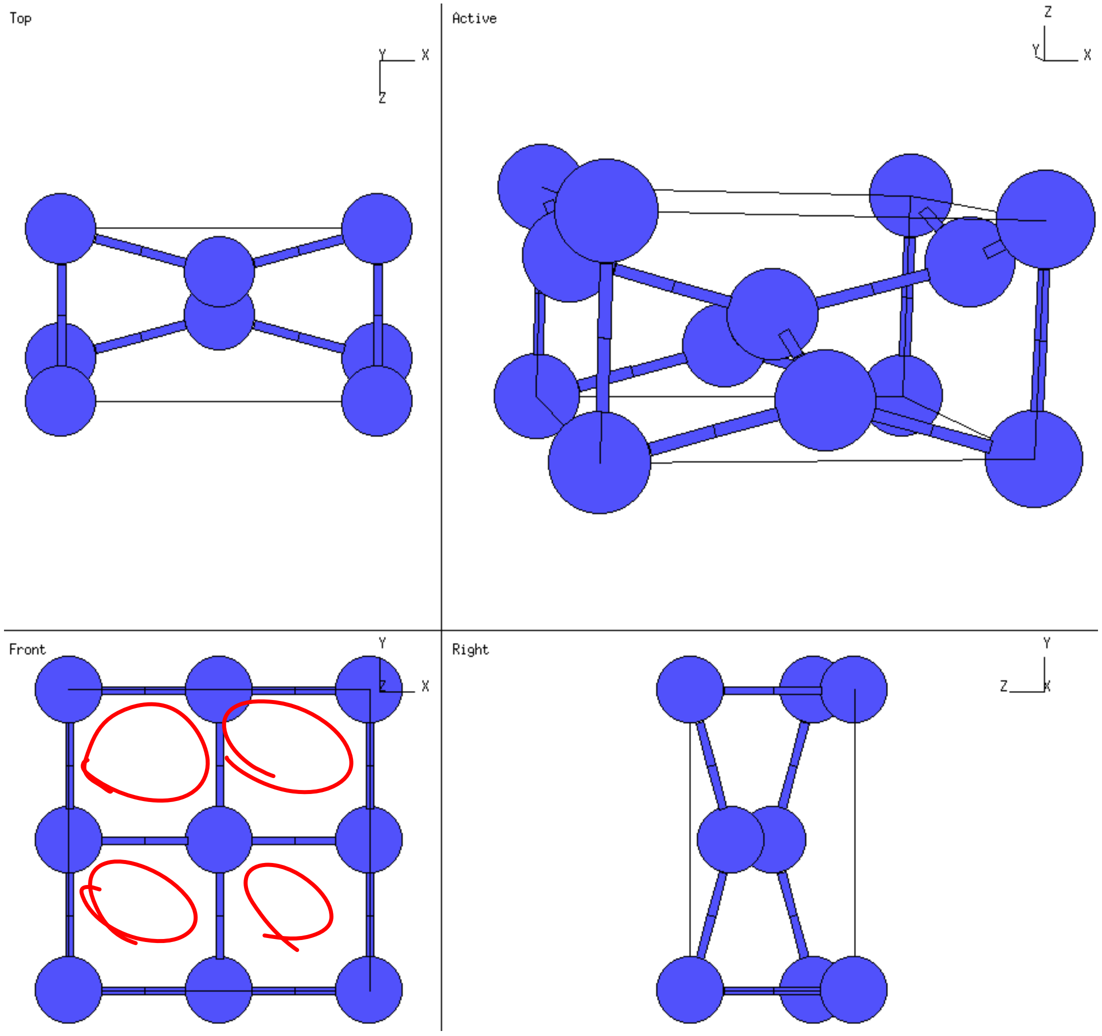
1) Discuss the magnitudes of the diffusion coefficients. Do they make sense, why or why not?

- Most people answered this question in terms of the anisotropy, rather than answering this question.
- At room temperature, we have for Cu in Sn (c-direction: $3x10^{-10}$ m^2/s) and (a-direction x-axis $9x10^{-13}$ m^2/s)
  - From lecture: substitutional diffusion near the melting point for pure metals is 10^{-12} m^2/s
  - From lecture: interstitial diffusion of C in Fe at 1000ºC was $2.5x10^{-11}$ m^2/s
- Answers should have included significant skepticism.
- Answers could have included an eventual yes, due to the crystal structure.

2) Why might the diffusion coefficient be anisotropic?



3) Discuss part (a) from the problem statement. Also, what might be special about this system that allows interstitial diffusion to occur?

- Problem 4.4 from Callister should have helped with this one.
- Only when the atom is very small compared to host, will it readily fit into an interstitial site.
- Hume-Rothery size factor:
  - When less than 15%, substitutional solid solution expected
  - When greater than 15%, *substitutional solubility limited* and possibly
    - Compounds form OR
    - Interstitial solubility (only for small atoms, “B, O, N, C, H”)

Significant skepticism about the Cu atoms fitting was expected!

4) How might the diffusion information presented here be important for Sn-based solders bonded to a Cu pad?

- This problem displayed that we definitely need the lecture scheduled on 12Feb for ‘microelectronic packaging.’
- Some confused this with the Cu-Si example in lecture.
- Some considered the room T diffusion coefficients given as important for the soldering process.

WebCT Quizzes

- **There are two more scheduled later in the term.**
  - **Expect them to be more similar to this one than the first one (i.e. thought-provoking, challenging).**
  - **Read the questions carefully.**
  - **Stick to what you know when doing these. An ‘expert’ answer is not expected. However, a well thought out one is.**

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Iron-Carbon (Fe-C) Phase Diagram

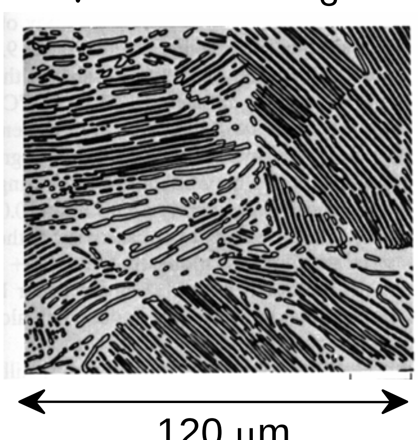
- 2 important points

  -Eutectic (*A*):

  $L \Rightarrow \gamma + Fe_3C$

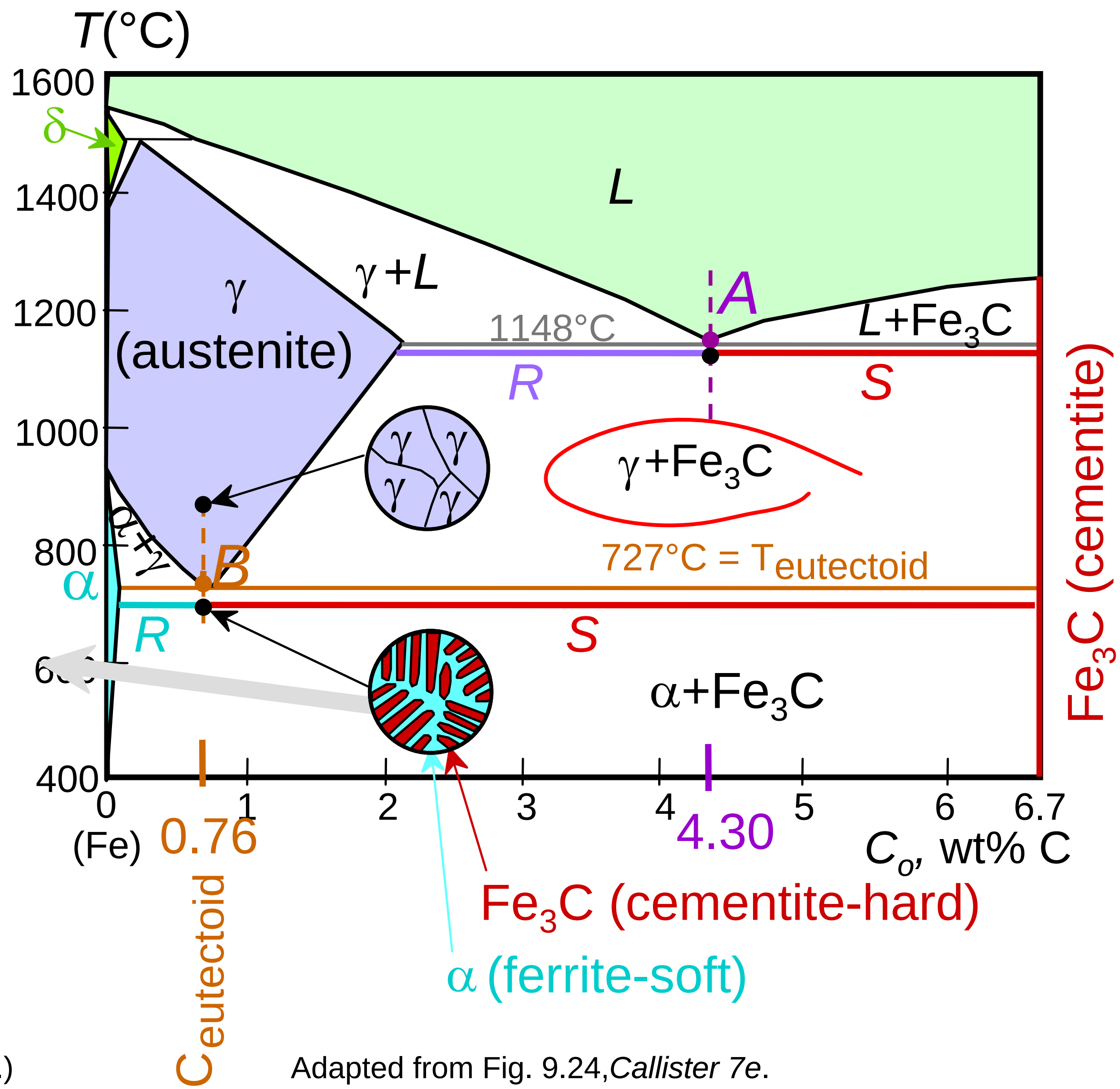
  -Eutectoid (*B*):

  $\gamma \Rightarrow \alpha + Fe_3C$



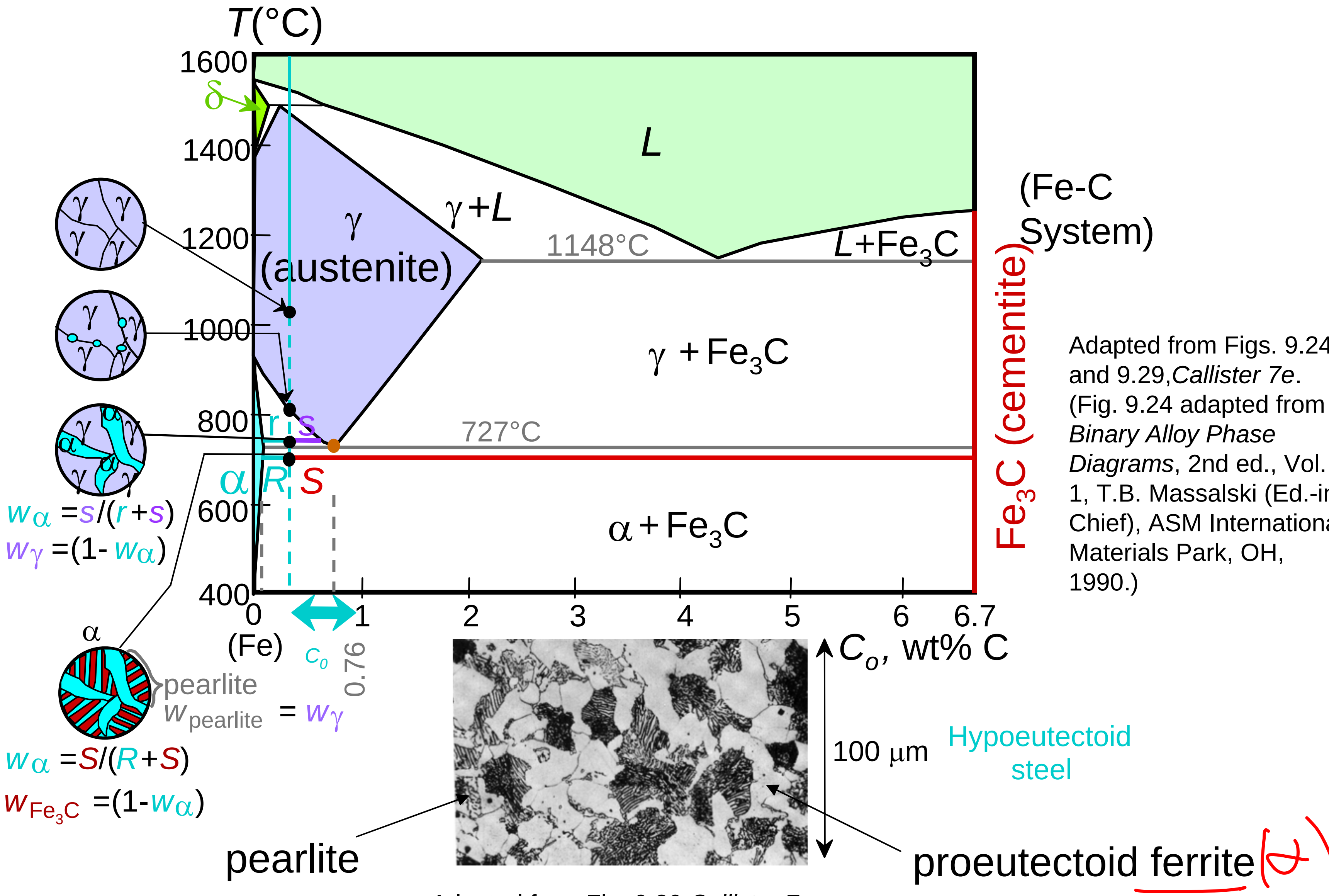
Result: Pearlite = alternating layers of α and Fe_3C phases

(Adapted from Fig. 9.27, *Callister 7e*.)



Adapted from Fig. 9.24, *Callister 7e*.

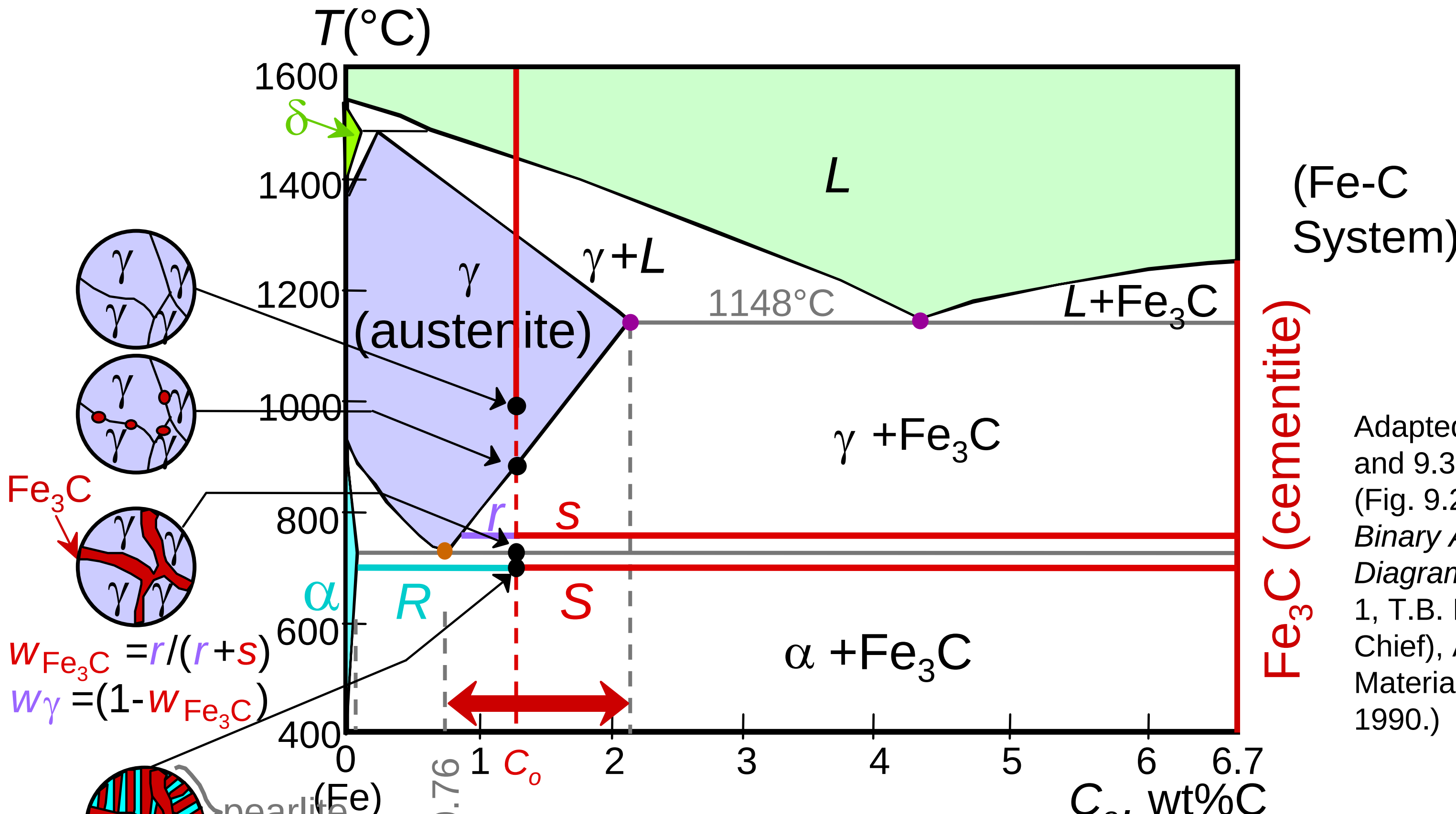
Hypoeutectoid Steel



Adapted from Figs. 9.24 and 9.29, *Callister 7e*. (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 7e*.

Hypereutectoid Steel



Adapted from Figs. 9.24 and 9.32, *Callister 7e*. (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 7e*.

Where might an electrical engineer encounter steel?

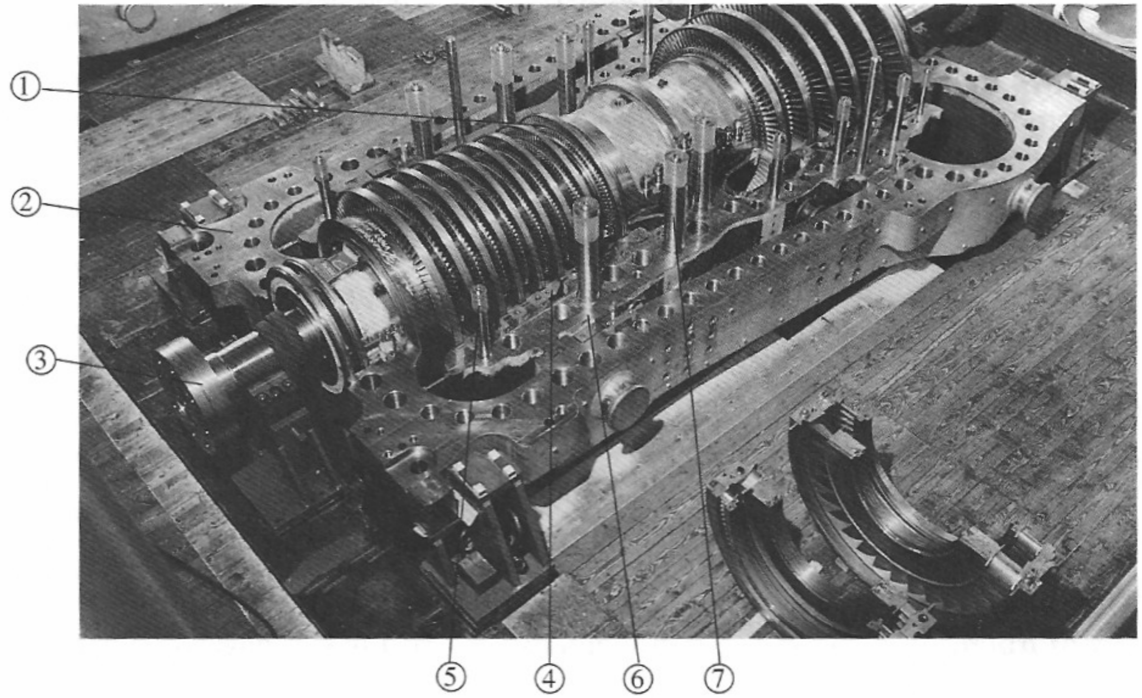


Fig. 5.9 Alloy steels in use: the high pressure section of a power generating steam turbine. The diameter of the turbine is about 1 m. (The low pressure part later on is much bigger.) The various components are identified below. Most of the steels, in fact, qualify as 'stainless' because of their high chromium content, but all the steels, nevertheless, stainless or not, are quenched and tempered (see text). (Courtesy Alstom Power, Mr R.W. Vanstone.) Key to materials indicated on photograph

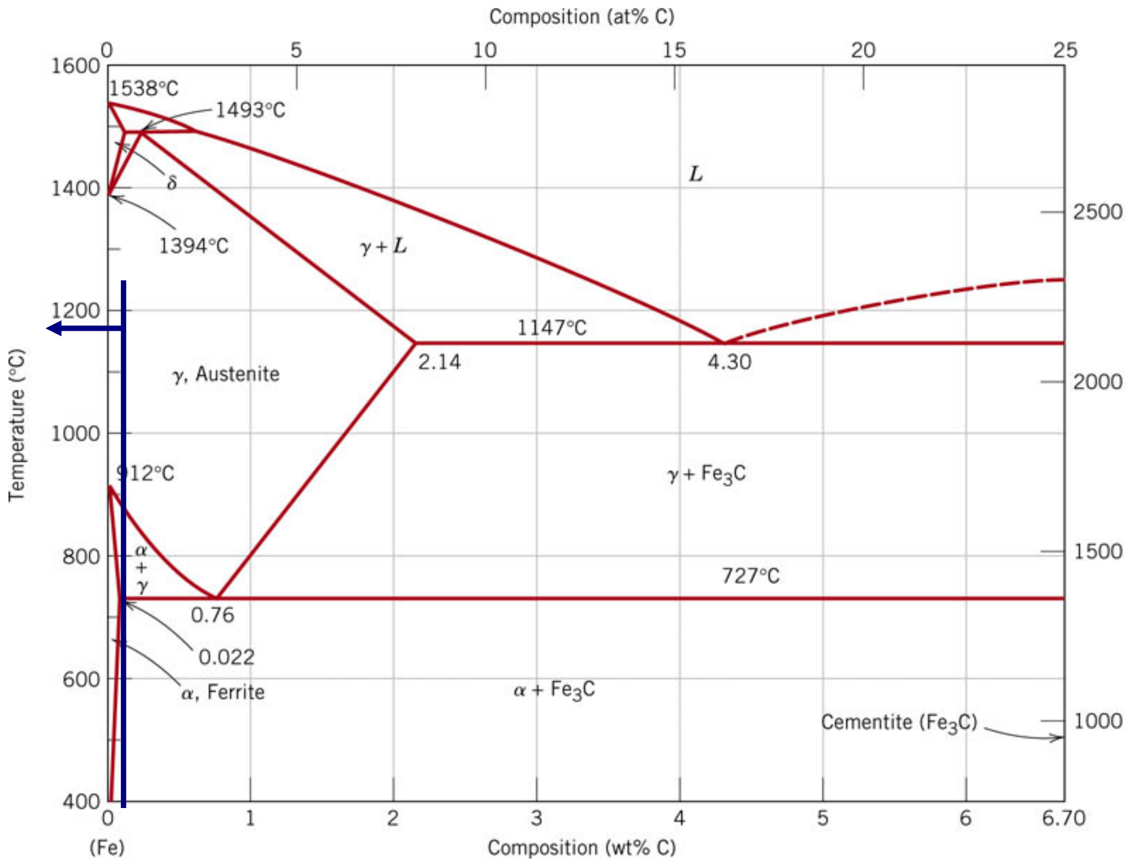
1. Moving blades: 11%CrMoVNbN martensitic stainless steel bar
2. Outer casing: 2.25%CrMo low alloy steel casting
3. HP/IP rotor: 10%CrMoVNbN martensitic steel forging
4. Stationary blading: 9%CrMoVNbN martensitic steel bar and forgings
5. Bolting: 11%CrMoVNbN martensitic stainless steel bar
6. Inner casing: 9%CrMoVNbN martensitic stainless steel casting
7. Bolting: NiCrTiAl (Nimonic 80A) bar (This is not a steel; it is a nickel-based superalloy.)

See I.P. Jones

Three major classes of steels

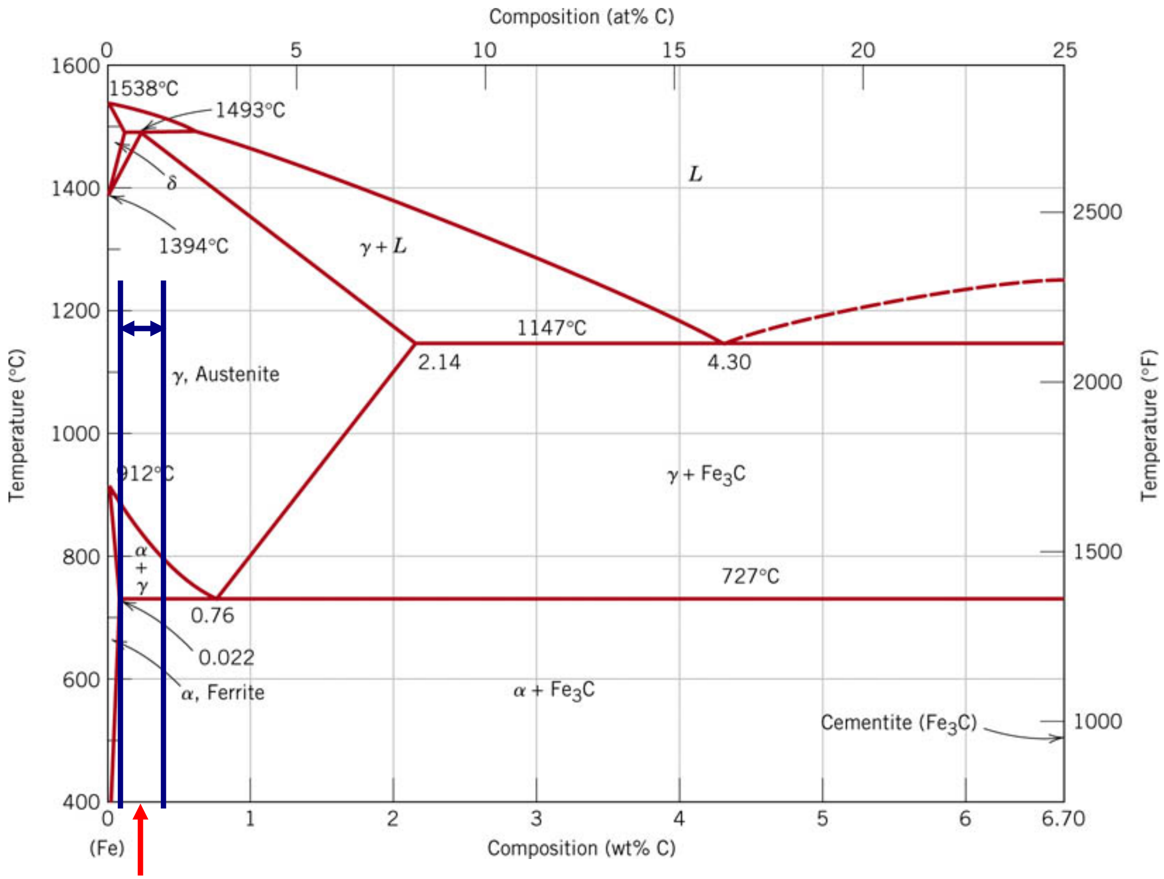
- Plain carbon steel (Fe + C) Mn
  – Slow cooled
  – Fe-C diagram very relevant
- Heat treated steel (Fe + C + alloying elements)
  – Quenched and aged martensite
  – Fe-C diagram relevant
- Stainless steels (Fe + C + a lot of Cr)
  – Processing varies
  – Fe-C diagram not necessarily relevant

Plain carbon steels



- **Low carbon steels**
  - **Less than 0.15 wt% C**
  - **Soft and ductile**
  - **Sheet steel – car bodies**

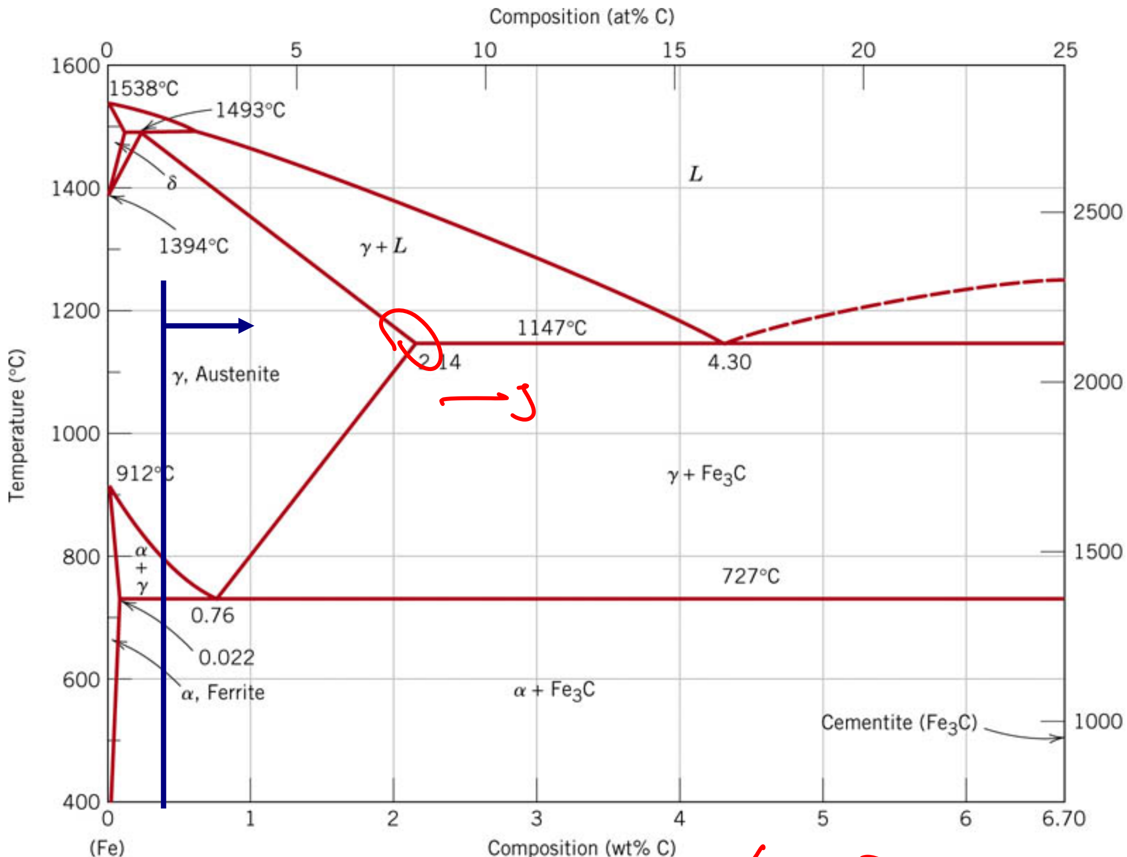
Plain carbon steels



Mild steel (0.25wt% C) – about 90% of all steel is this type

- **Medium carbon steels**
  - **Between 0.15 and 0.4 wt% C**
  - **Stronger, less formable**
  - **Tubes, girders, plates**

Plain carbon steels



- **High carbon steels**
  - **Greater than 0.4 wt% C**
  - **High strength, low ductility**
  - **Ball bearings, chisels, hammers**

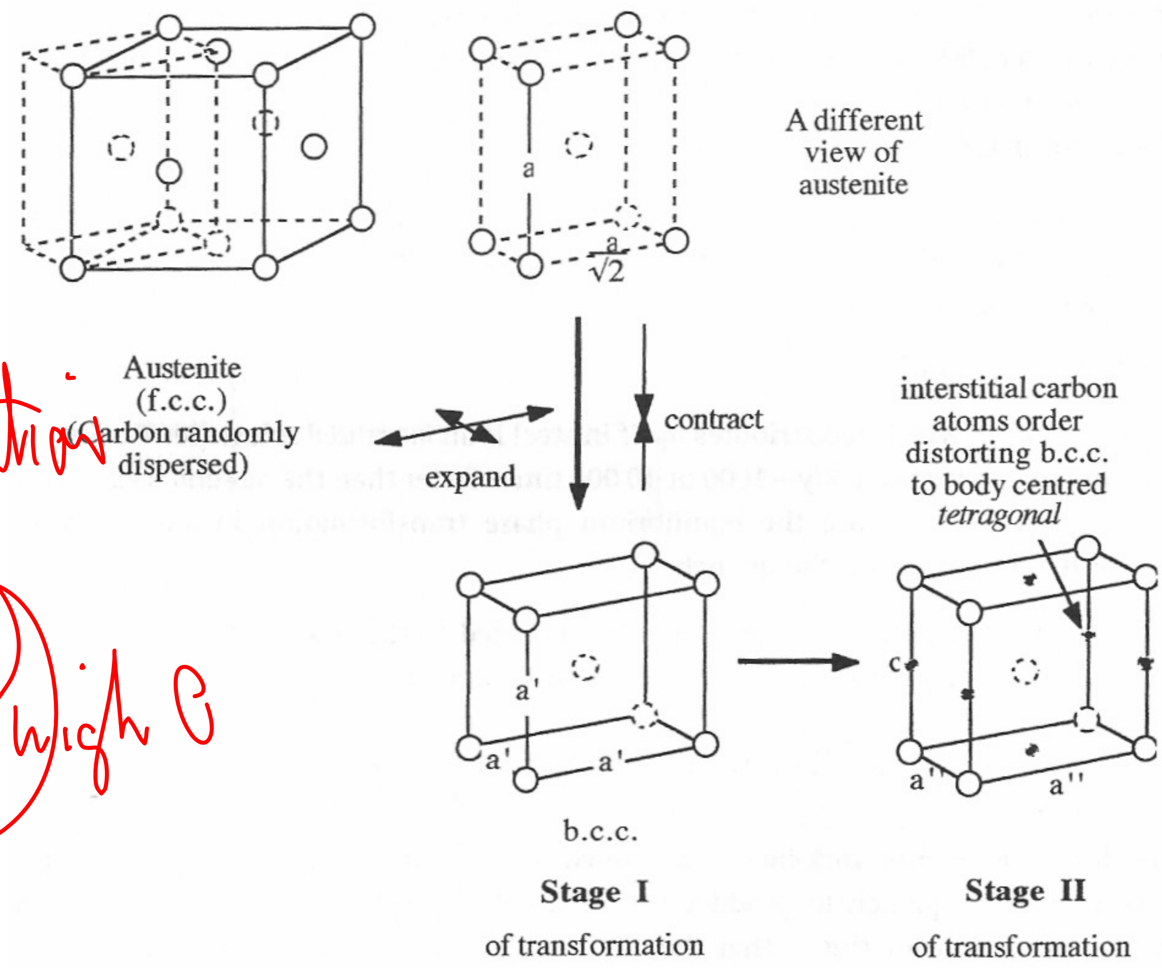
Cast irons

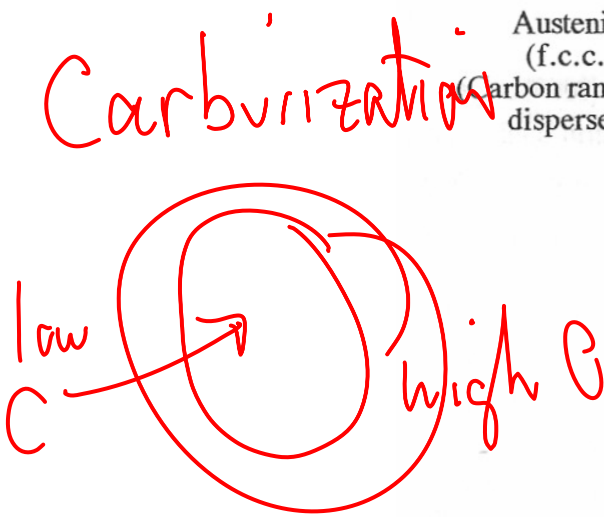
White cast iron (lots of cementite)

Grey cast iron, >2wt% C (graphite)

Heat Treated Steels

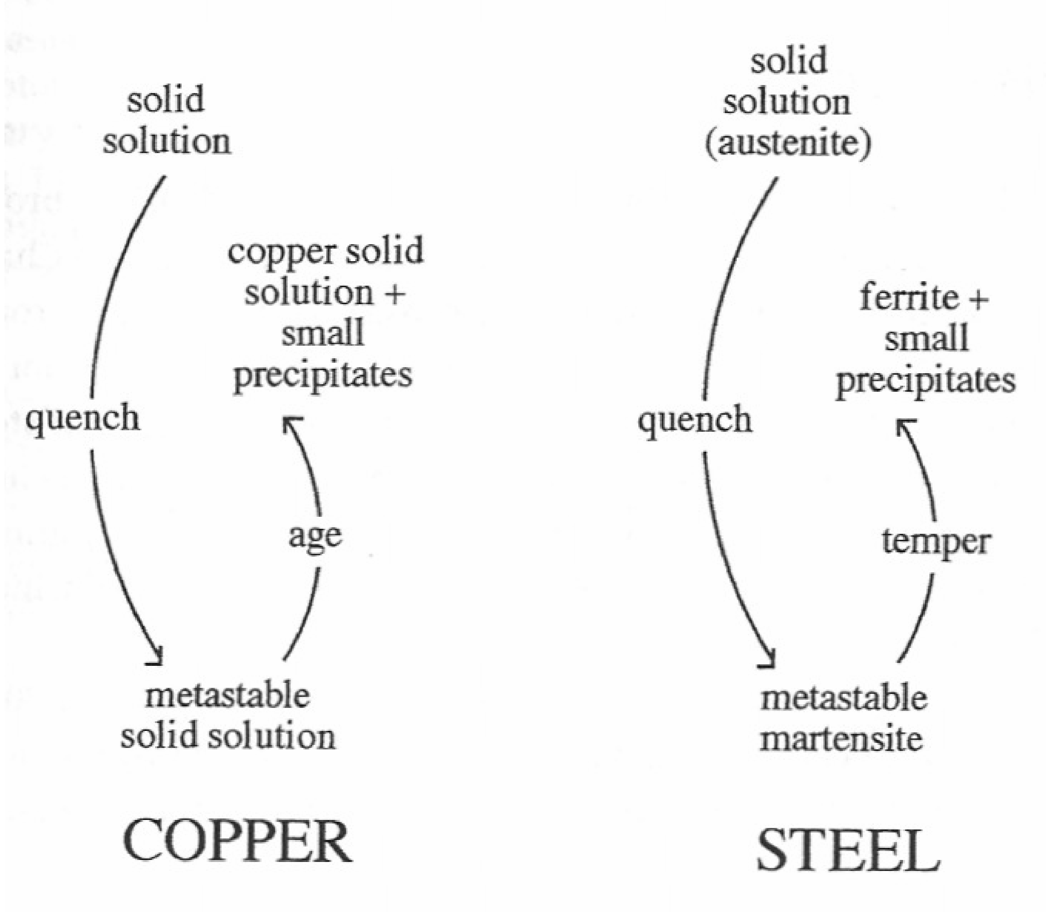
- **Generally an alloyed steel (contains other elements: Mn, Mo, Ni, others)**
- **Quenched and tempered**





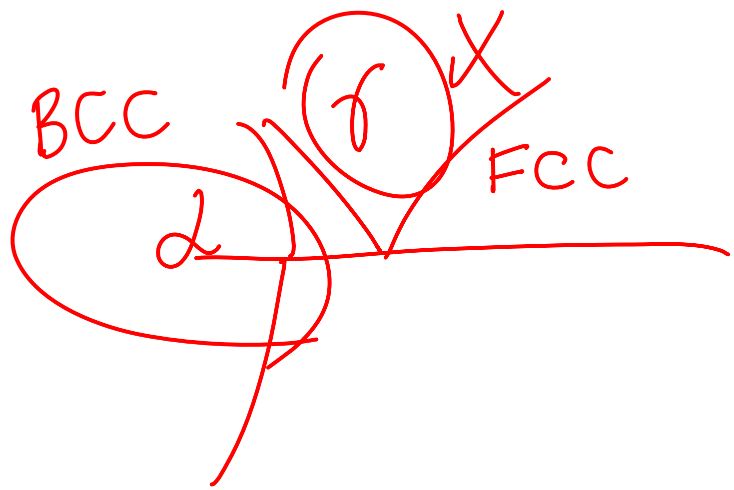
Heat Treated Steels

- Generally an alloyed steel (contains other elements: Mn, Si, others)
- Quenched and tempered



Stainless Steels

- **Add Cr to prevent corrosion**
- **Forms Cr_2O_3 on surface (corrosion barrier)**
- **Very low C content (< 0.08 wt%)**
- **Cr-C compounds eliminate corrosion resistance and make steel brittle**
- **Cr causes the austenite phase to be unstable, so steels with very high Cr content are often called 'ferritic stainless steels'**



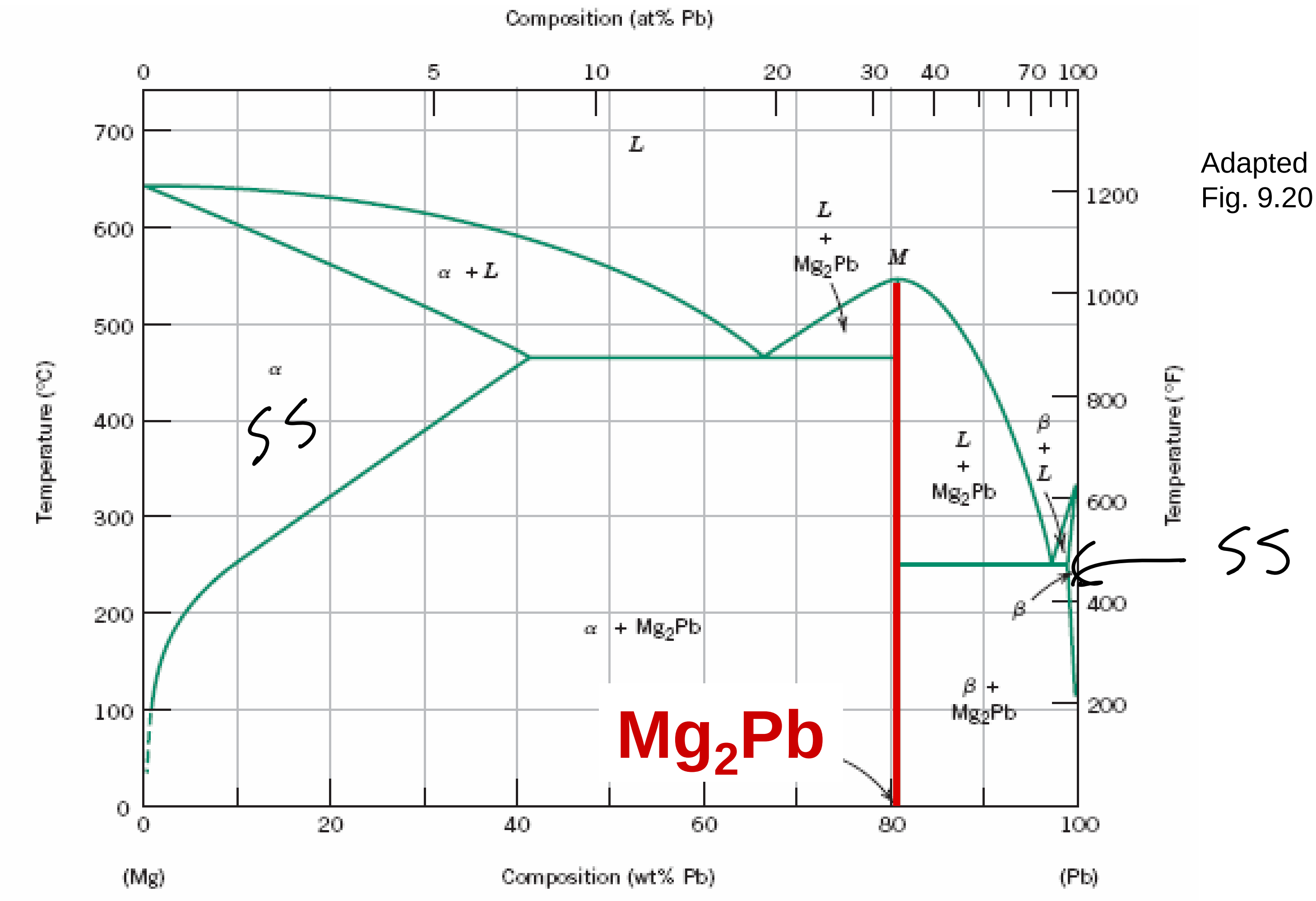
Phase Equilibria

Mg-Pb

	Crystal Structure	electroneg	*r* (nm)
Mg	HCP	1.2	0.160
Pb	FCC	1.8	0.175

- Have different crystal structures, different electronegativities (W. Hume – Rothery rules) suggesting lack of solubility and likely formation of compounds

Intermetallic Compounds



Adapted from Fig. 9.20, *Callister 7e.*

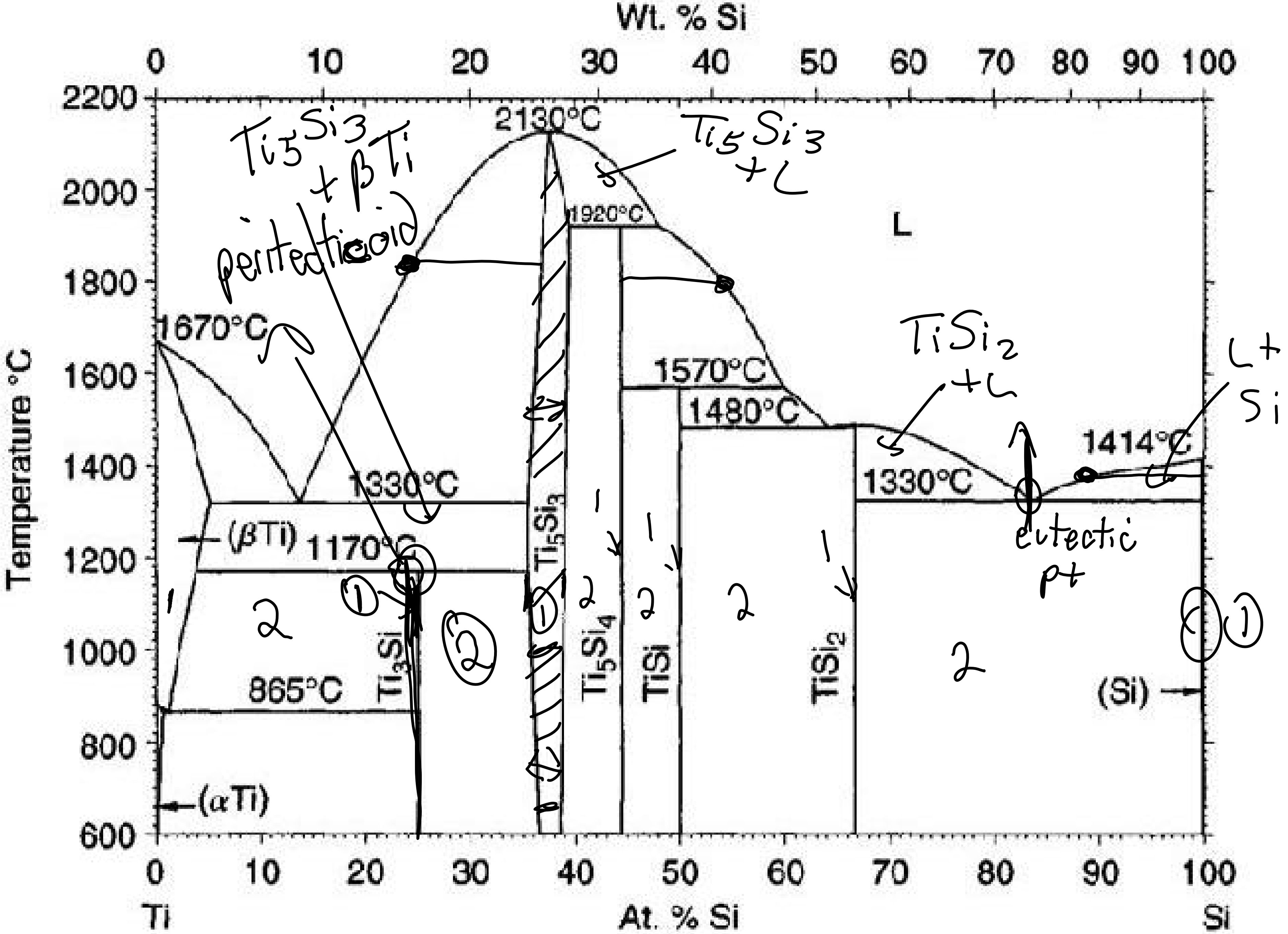
Note: intermetallic compound forms a line - not an area - because stoichiometry (i.e. composition) is exact.

How many phase diagrams are important for electrical engineers?

- To first order –
  - Solder phase diagrams (M-Sn)
  - Silicide phase diagrams (M-Si)
  - Copper phase diagrams (M-Cu)
- Second order
  - Depending on what materials you work with in your job, ANY phase diagram might be important.

Useful e-book from Schulich Library

- http://www.knovel.com/knovel2/Toc.jsp?BookID=717



Wt. % Si
2130°C
1920°C
L
1670°C
1570°C
1480°C
1414°C
1330°C
1330°C
1170°C
865°C
(βTi)
(αTi)
Ti_5Si_3
Ti_3Si
Ti_5Si_4
TiSi
$TiSi_2$
(Si)
Temperature °C
At. % Si
Ti
Si
Ti_5Si_3 + βTi
peritectoid
Ti_5Si_3 + L
$TiSi_2$ + L
L + Si
eutectic pt