Exercise 3.3 – Phase Diagrams

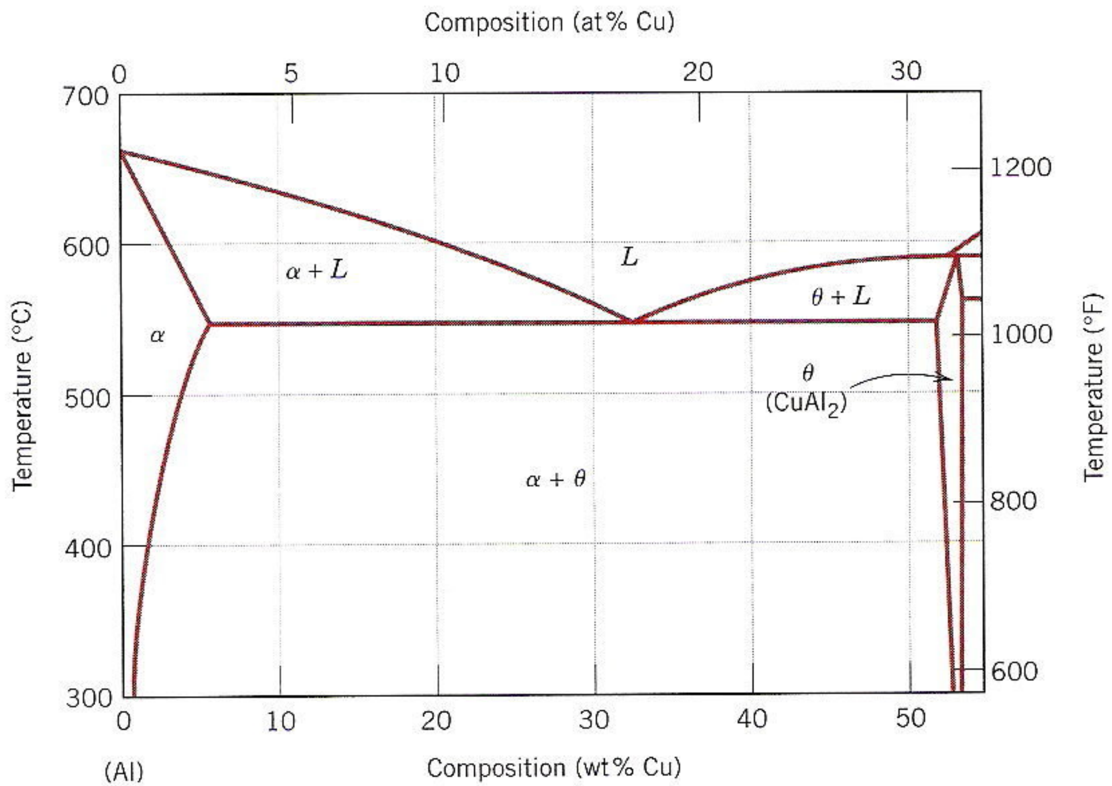
Using the phase diagram for the Al-Cu binary system presented below, determine for an Al-12 wt% Cu alloy:

a) The temperature at which the melt would be expected to begin solidifying

b) The phases present at 600 °C

c) The composition of each of the phases present at 600 °C (expressed in wt%)

d) The fraction of each of the phases present at 600 °C



Exercise 3.3 – Phase Diagrams

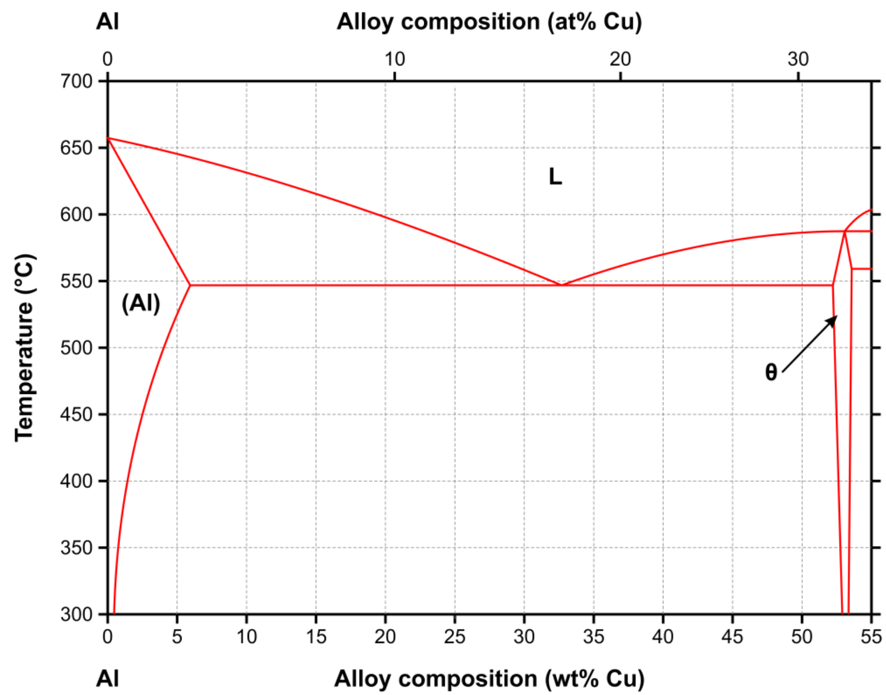
Step 1 – Define

a) Solidification temperature

b) phases present

c) phase compositions

d) phase fractions



Step 2 – Data

Figure provided

Al-12 wt% Cu alloy

Temperature of interest = 600 °C

Step 3 – Theory

Lever rule:

$$X_\alpha = \frac{B-C}{B-A}$$

Where:

X_α=fraction of α phase

A = composition of α phase

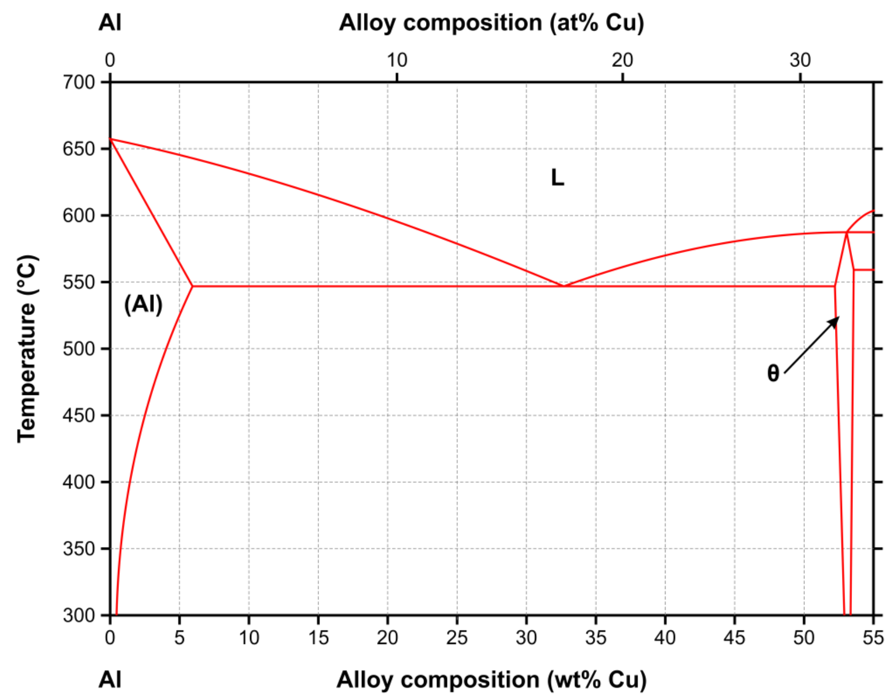
B = composition of β phase

C = bulk composition of alloy

Exercise 3.3 – Phase Diagrams

Step 4 – Estimate

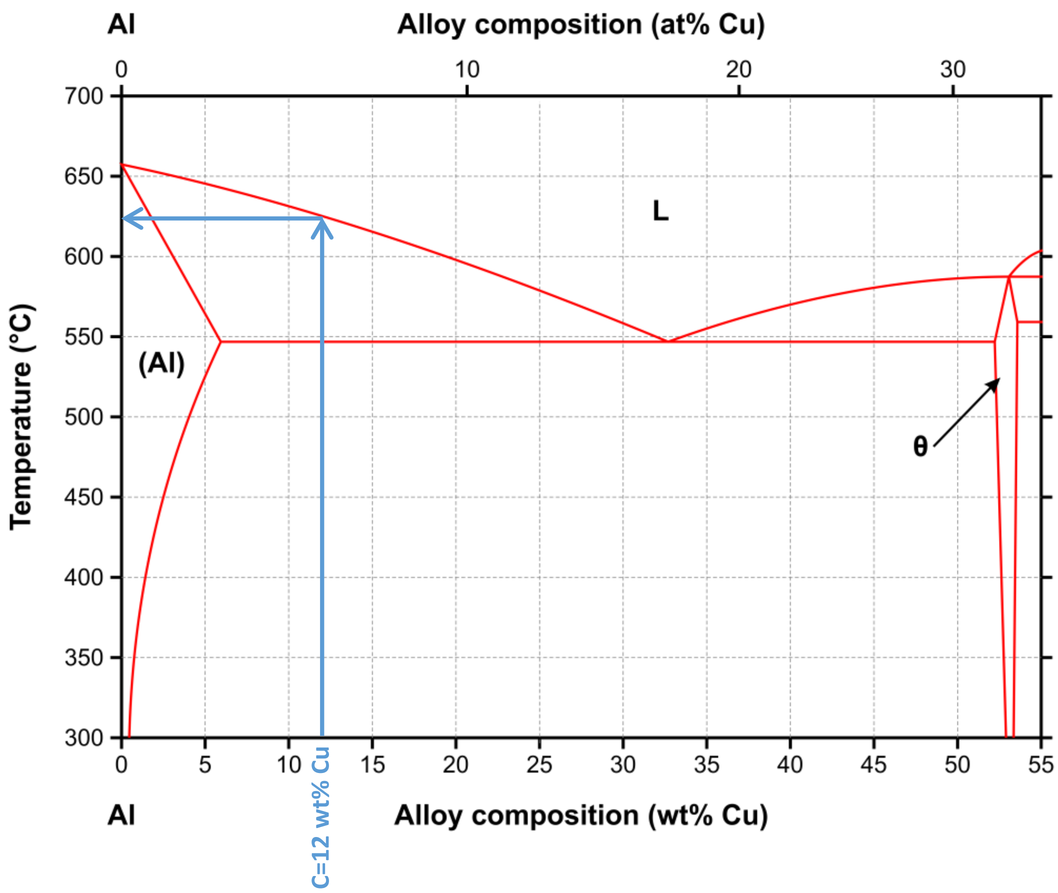
a) *Clearly 550 °C <T<660 °C*
b) *Can't really estimate*
c) *Close to 12 wt% Cu (say ±10 wt%)*
d) *Difficult to estimate but must sum to 1.0*



Exercise 3.3 – Phase Diagrams

Step 5 – Solve

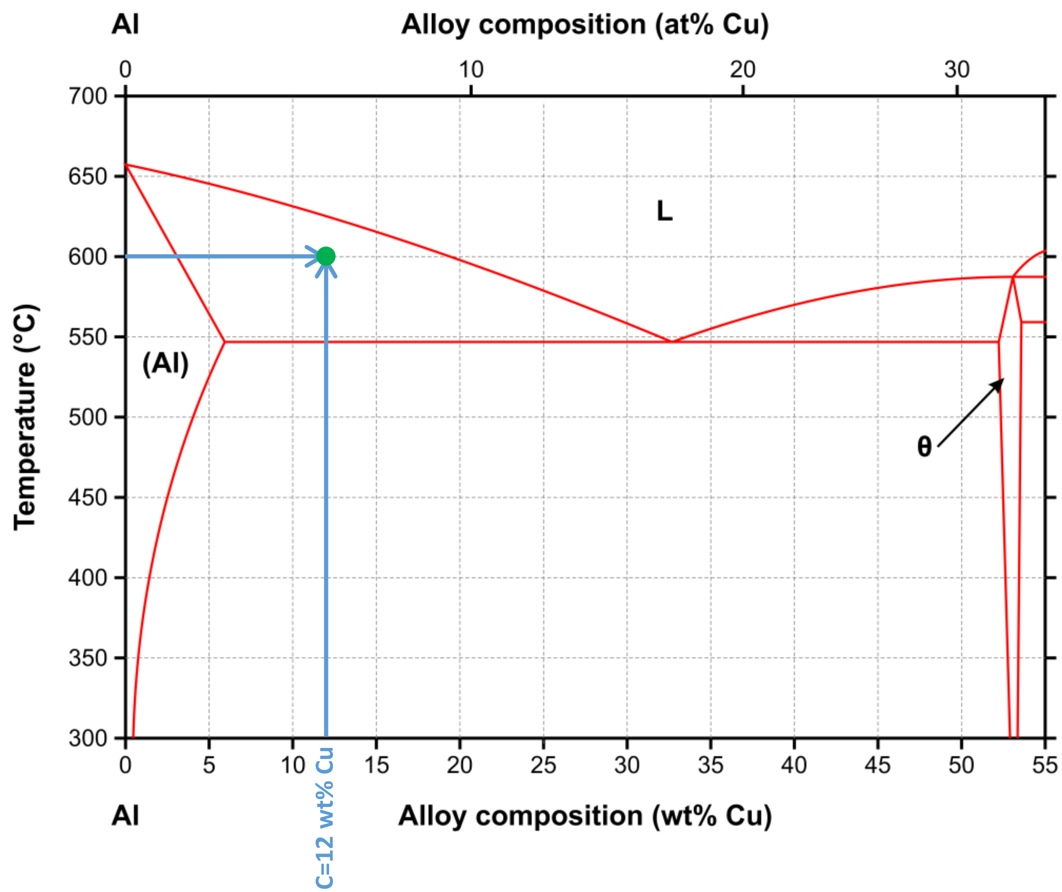
a) Solidification will start at T=623 °C (±10 °C is OK)



Exercise 3.3 – Phase Diagrams

Step 5 – Solve

b) The phases present will be the solid solution of Cu in Al → (Al) and the liquid phase



Exercise 3.3 – Phase Diagrams

Step 5 – Solve

c) Firstly draw the tie line

The composition of the (Al) solid solution will be:

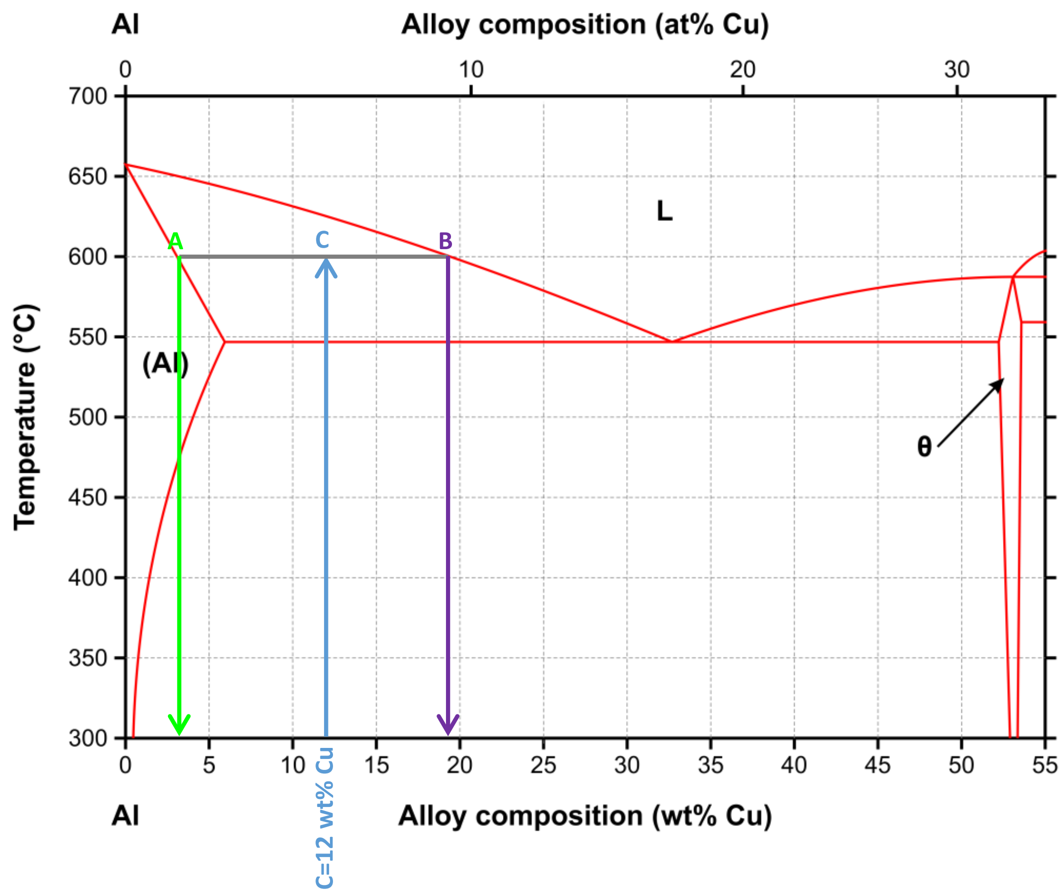
3.2 wt% Cu (= A)

96.8 wt% Al

The composition of the liquid will be:

19.2 wt% Cu (= B)

80.8 wt% Al



Exercise 3.3 – Phase Diagrams

Step 5 – Solve

d) Using the values from part (c)

A = 3.2 wt%

B = 19.2 wt%

C = 12.0 wt%

$$X_{(Al)} = \frac{B-C}{B-A}$$

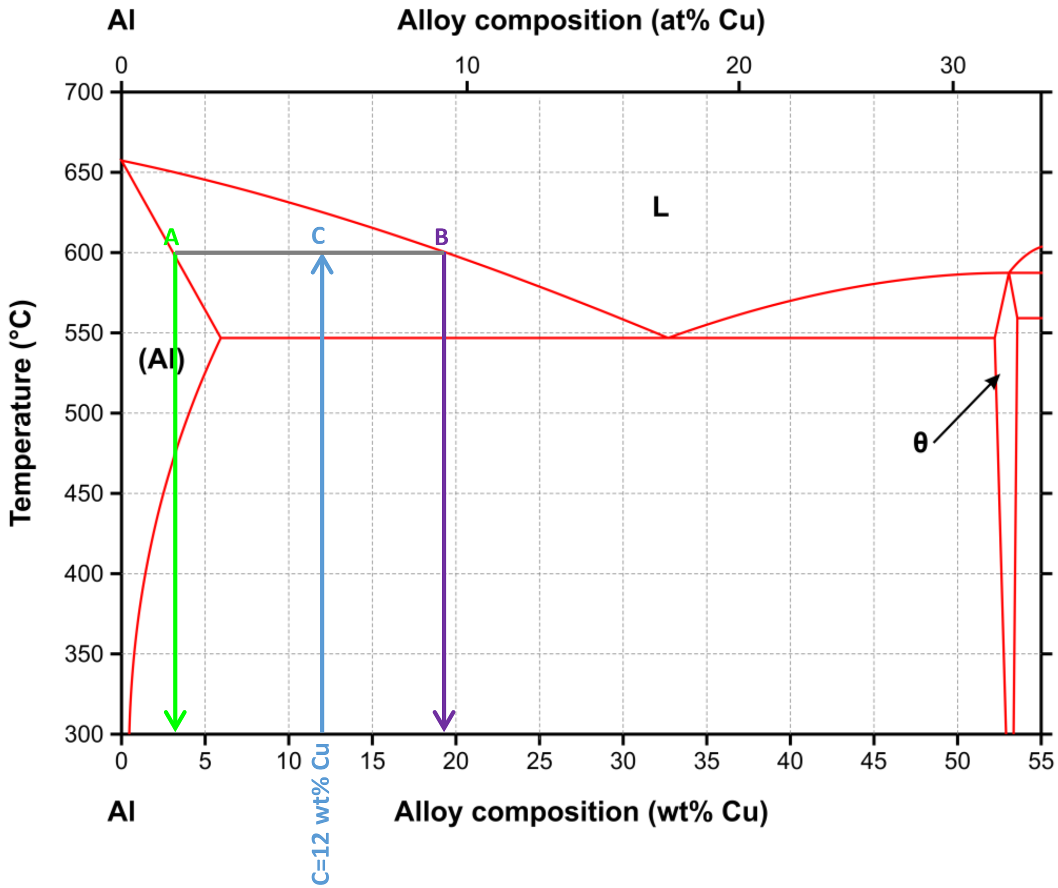
$$X_{(Al)} = \frac{19.2-12.0}{19.2-3.2}$$

$$X_{(Al)} = 0.45$$

$$X_L = \frac{C-A}{B-A}$$

$$X_L = \frac{12.0-3.2}{19.2-3.2}$$

$$X_L = 0.55$$



1. Answer the following questions in respect to the Fe-C equilibrium phase diagram presented below.

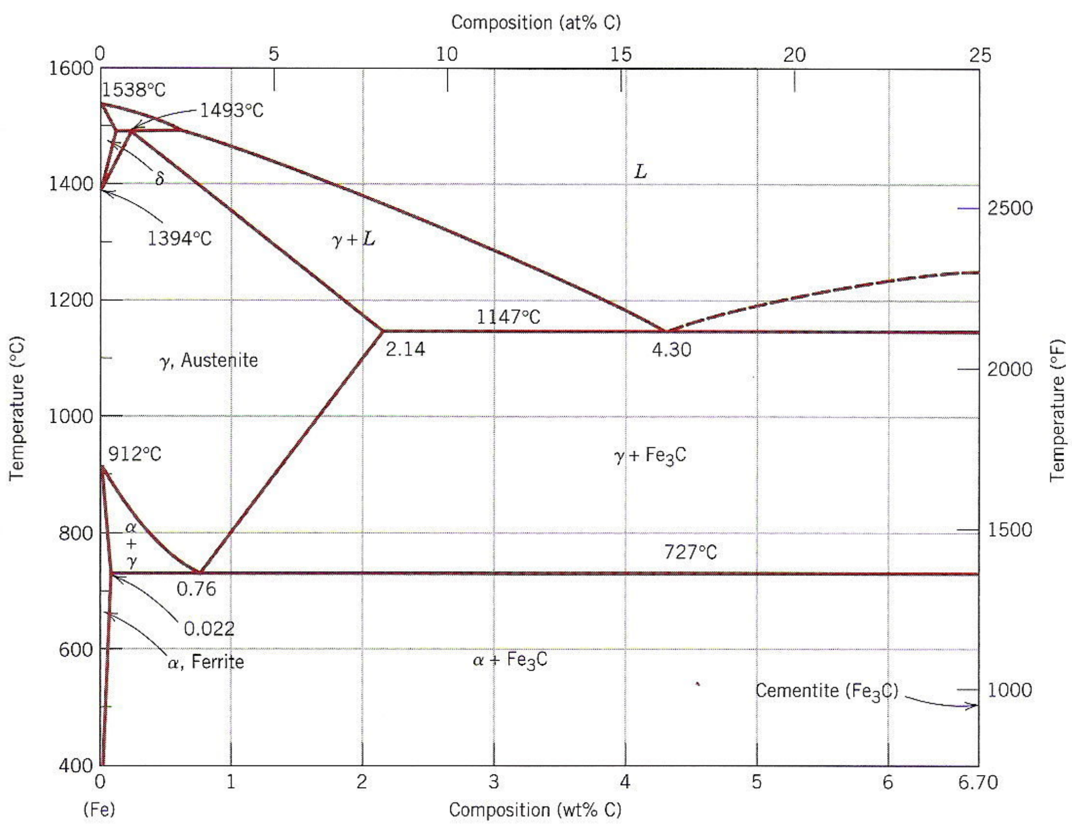
a) What is the eutectic temperature for the Fe-C system?

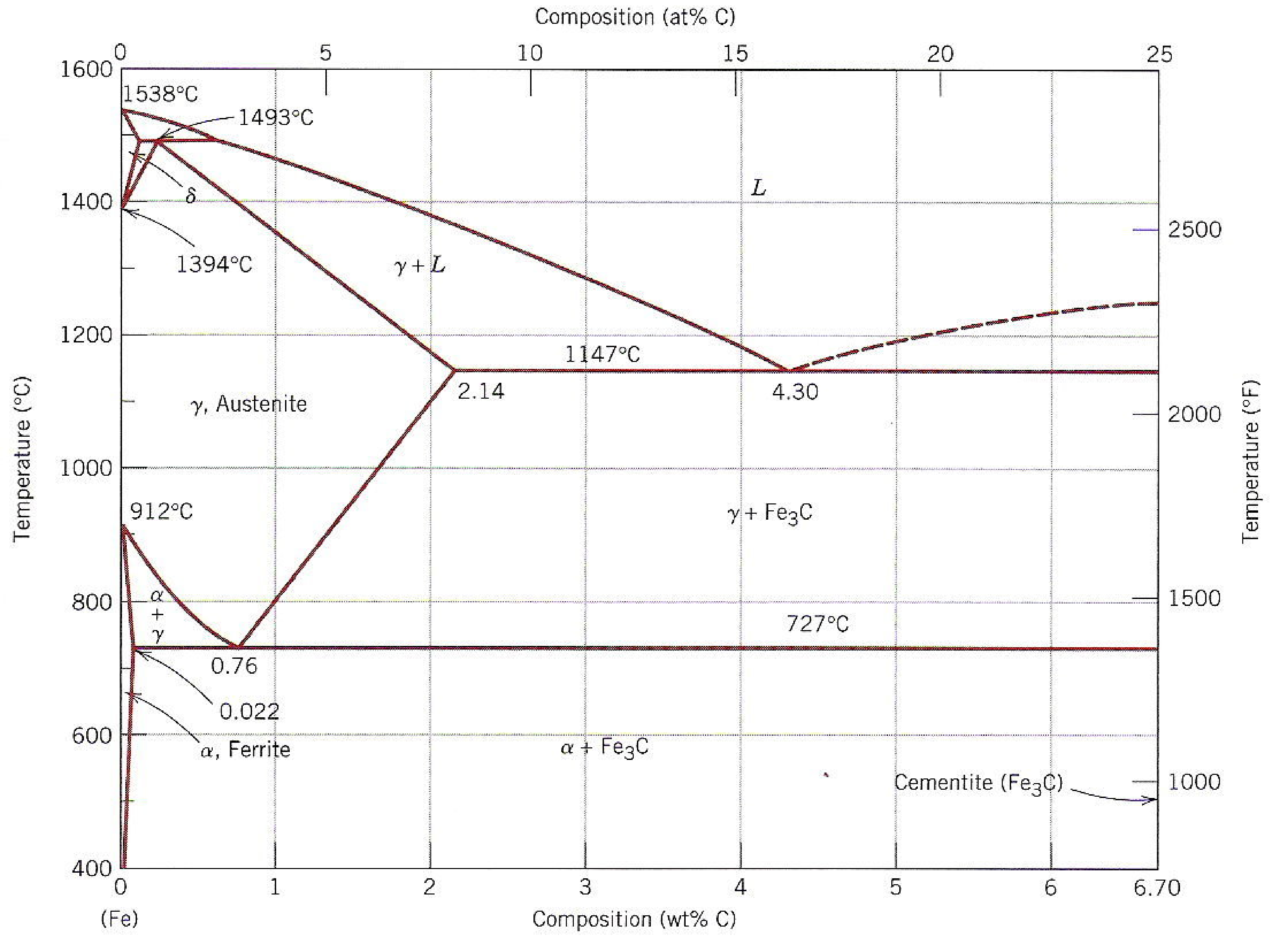
b) What is the eutectoid composition for the Fe-C system?

c) At what temperature would a cast iron containing 1.6 wt% C be expected to start melting?

d) What phases are present in a steel containing 0.35 wt% C held at 750 ºC?

e) What is the maximum solubility of carbon in Austenite at 1000 ºC?





Composition (at% C)
0
5
10
15
20
25
1600
1538°C
1493°C
δ
L
1400
1394°C
γ + L
2500
1200
1147°C
2.14
4.30
γ, Austenite
2000
1000
912°C
γ + Fe_3C
α
+
γ
800
1500
727°C
0.76
0.022
600
α, Ferrite
α + Fe_3C
Cementite (Fe_3C)
1000
400
0
1
2
3
4
5
6
6.70
(Fe)
Composition (wt% C)
Temperature (°C)
Temperature (°F)

In their simplest form, steels are alloys of Iron (Fe) and Carbon (C). The Fe-C phase diagram is a fairly complex one.

Phases in Fe–Fe3C 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

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

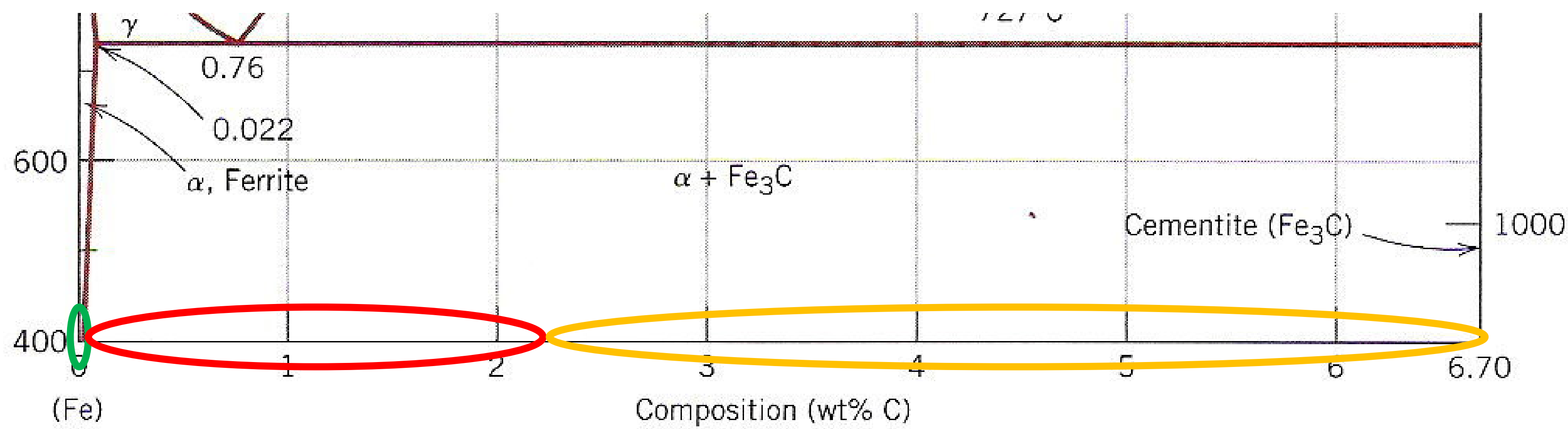
Fe-C liquid solution

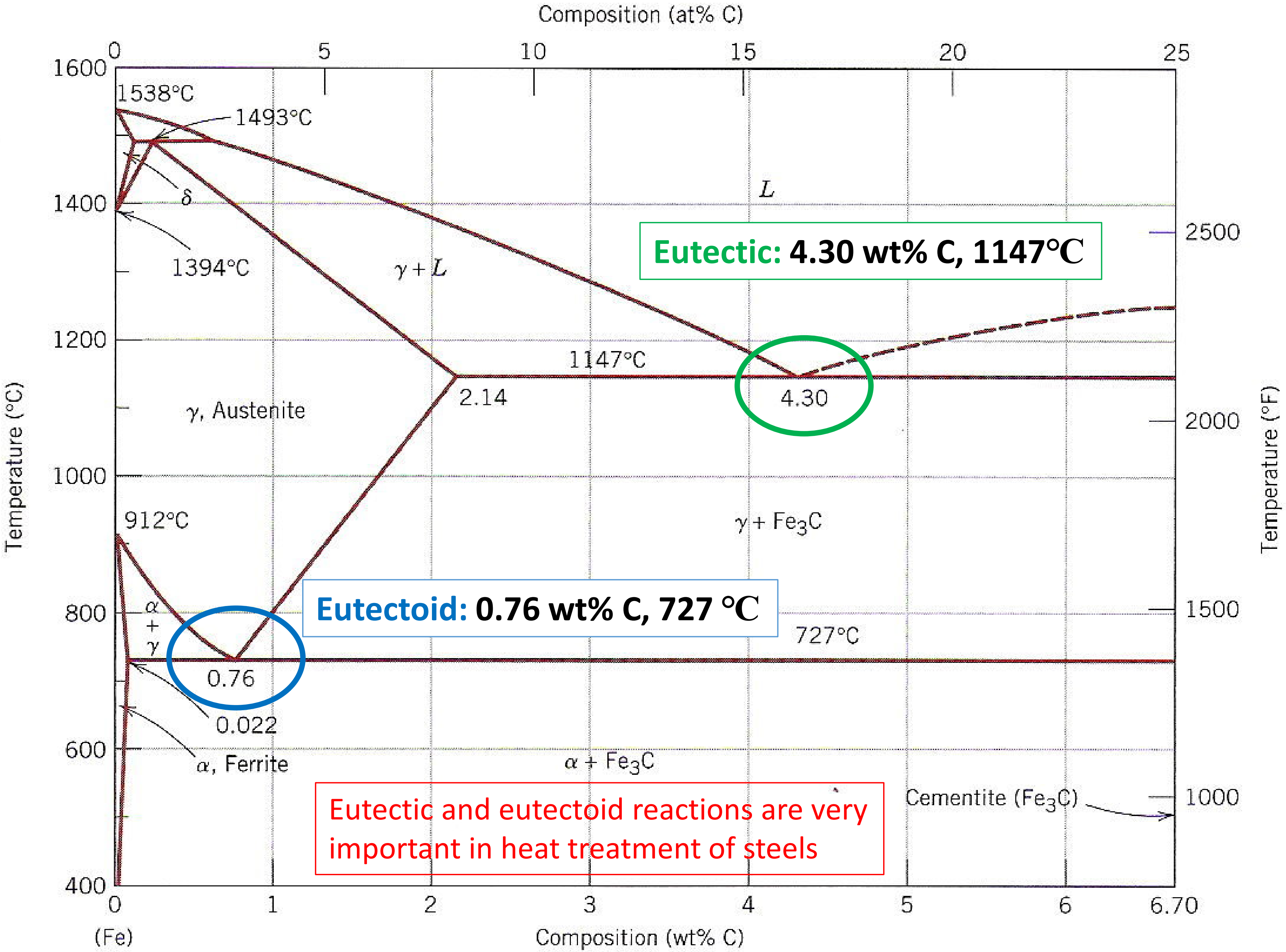
- C is an interstitial impurity in Fe. It forms a solid solution with α, γ, δ phases of iron.
- Maximum solubility in BCC α-ferrite is limited (max. 0.022 wt% at 727 °C) - BCC has relatively small interstitial positions.
- Maximum solubility in FCC austenite is 2.14 wt% at 1147 °C - FCC has larger interstitial 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

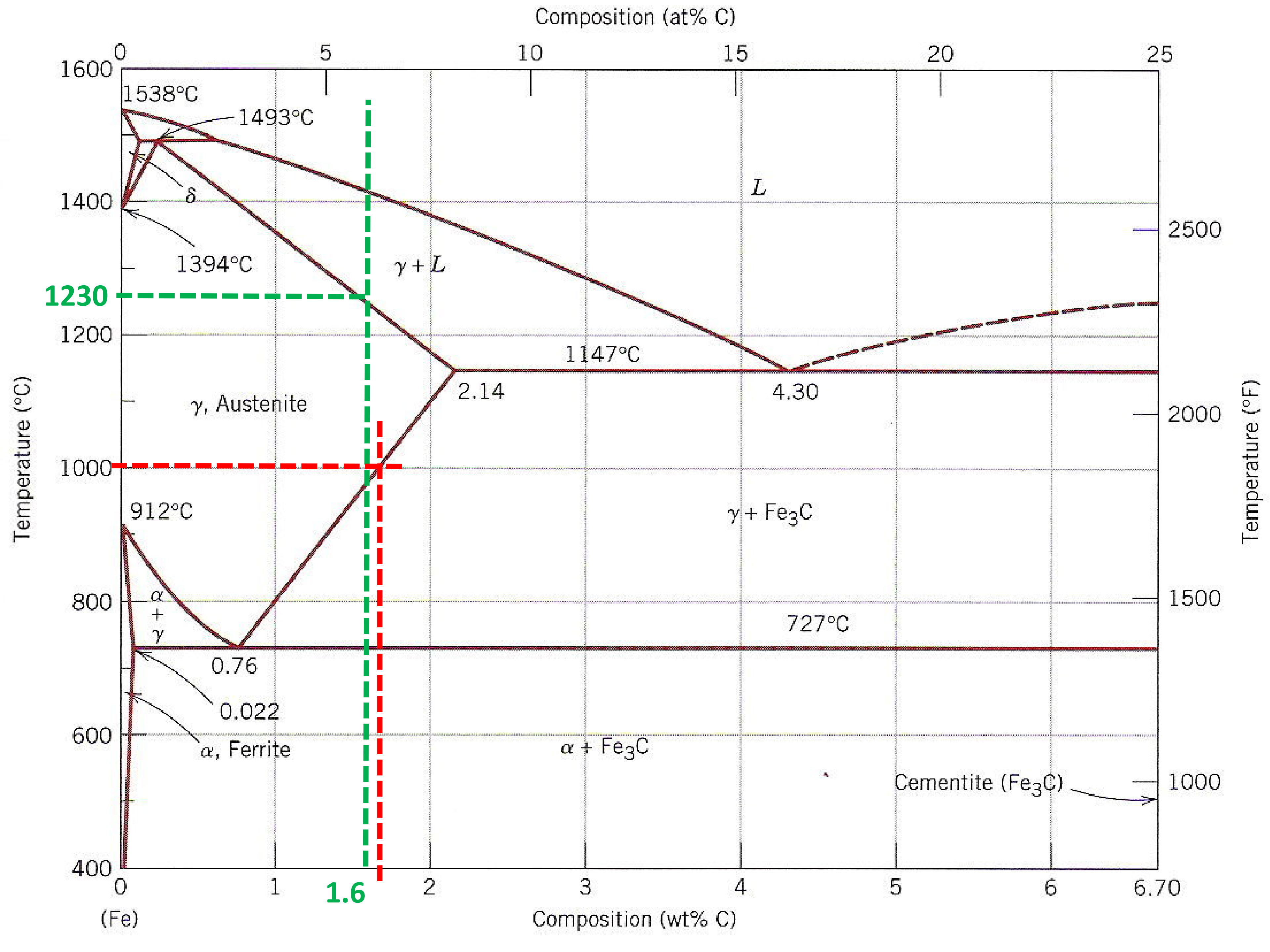
Classification
Three types of ferrous alloys:

- **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 + Fe3C at room T
- **Cast iron**: 2.14 - 6.7 wt % (usually < 4.5 wt %)





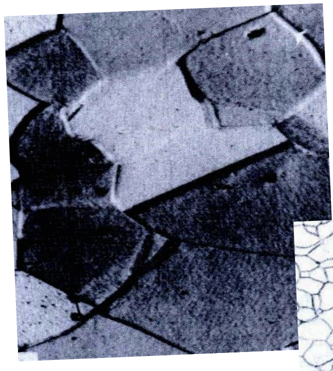
Composition (at% C)
0
5
10
15
20
25
1600
1400
1200
1000
800
600
400
Temperature (°C)
2500
2000
1500
1000
Temperature (°F)
1538°C
1493°C
δ
1394°C
L
γ + L
Eutectic: 4.30 wt% C, 1147°C
1147°C
2.14
4.30
γ, Austenite
912°C
γ + Fe3C
α + γ
Eutectoid: 0.76 wt% C, 727 °C
727°C
0.76
0.022
α, Ferrite
α + Fe3C
Cementite (Fe3C)
Eutectic and eutectoid reactions are very important in heat treatment of steels
0
1
2
3
4
5
6
6.70
(Fe)
Composition (wt% C)



Composition (at% C)
0
5
10
15
20
25
1600
1538°C
1493°C
1400
δ
L
1394°C
2500
γ + L
1230
1200
1147°C
2.14
4.30
γ, Austenite
2000
Temperature (°C)
Temperature (°F)
1000
912°C
γ + Fe3C
800
α
+
γ
1500
727°C
0.76
0.022
600
α, Ferrite
α + Fe3C
Cementite (Fe3C)
1000
400
0
1
1.6
2
3
4
5
6
6.70
(Fe)
Composition (wt% C)

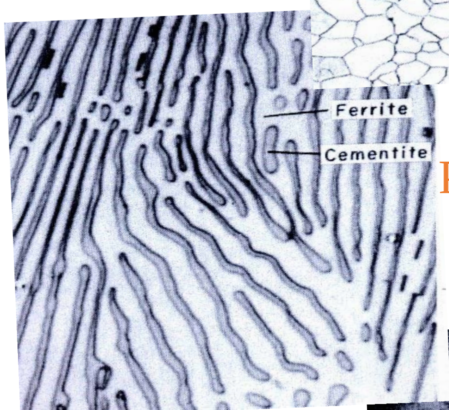
IRON IRON-CARBON DIAGRAM

Microstructure of different phases of steel



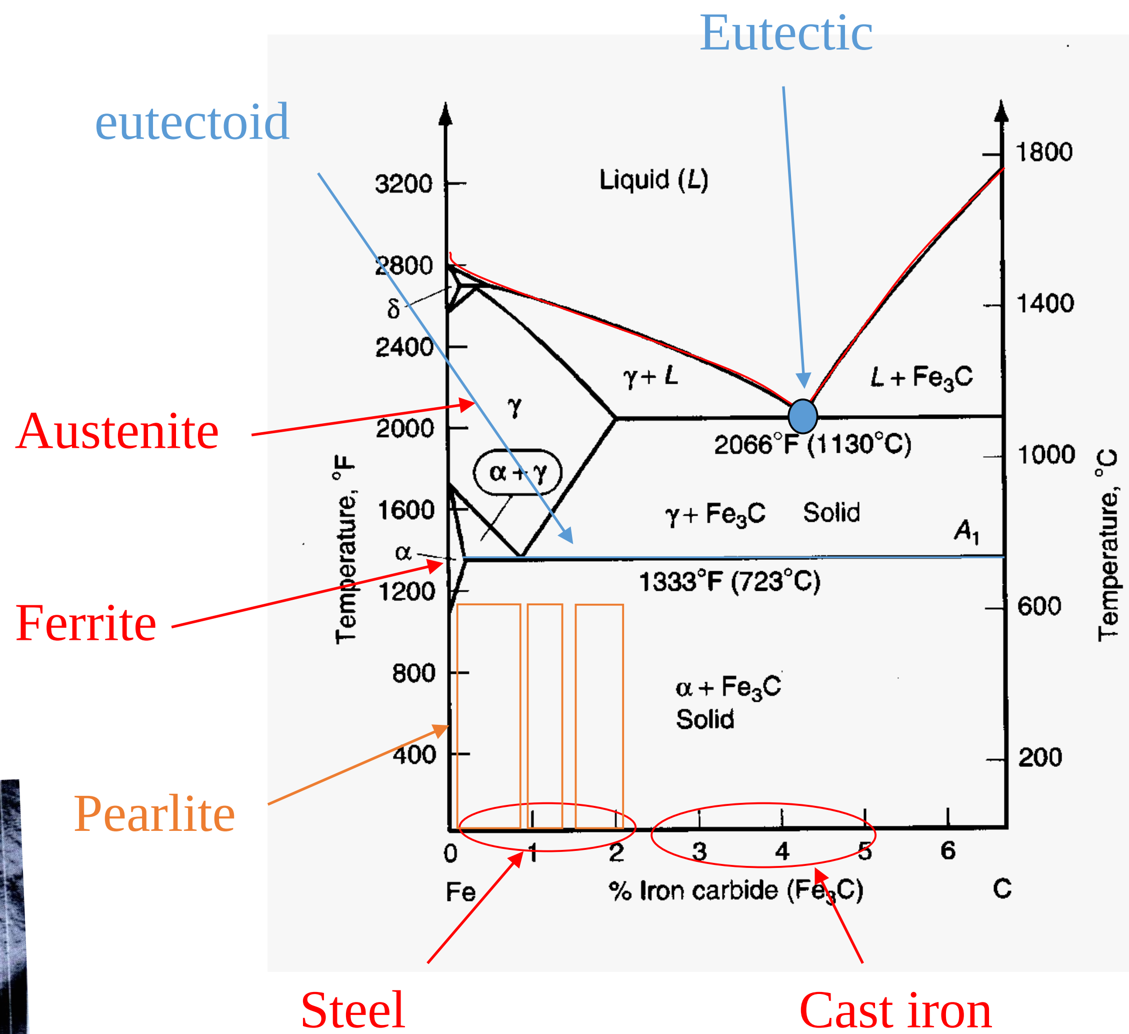
Austenite

Ferrite

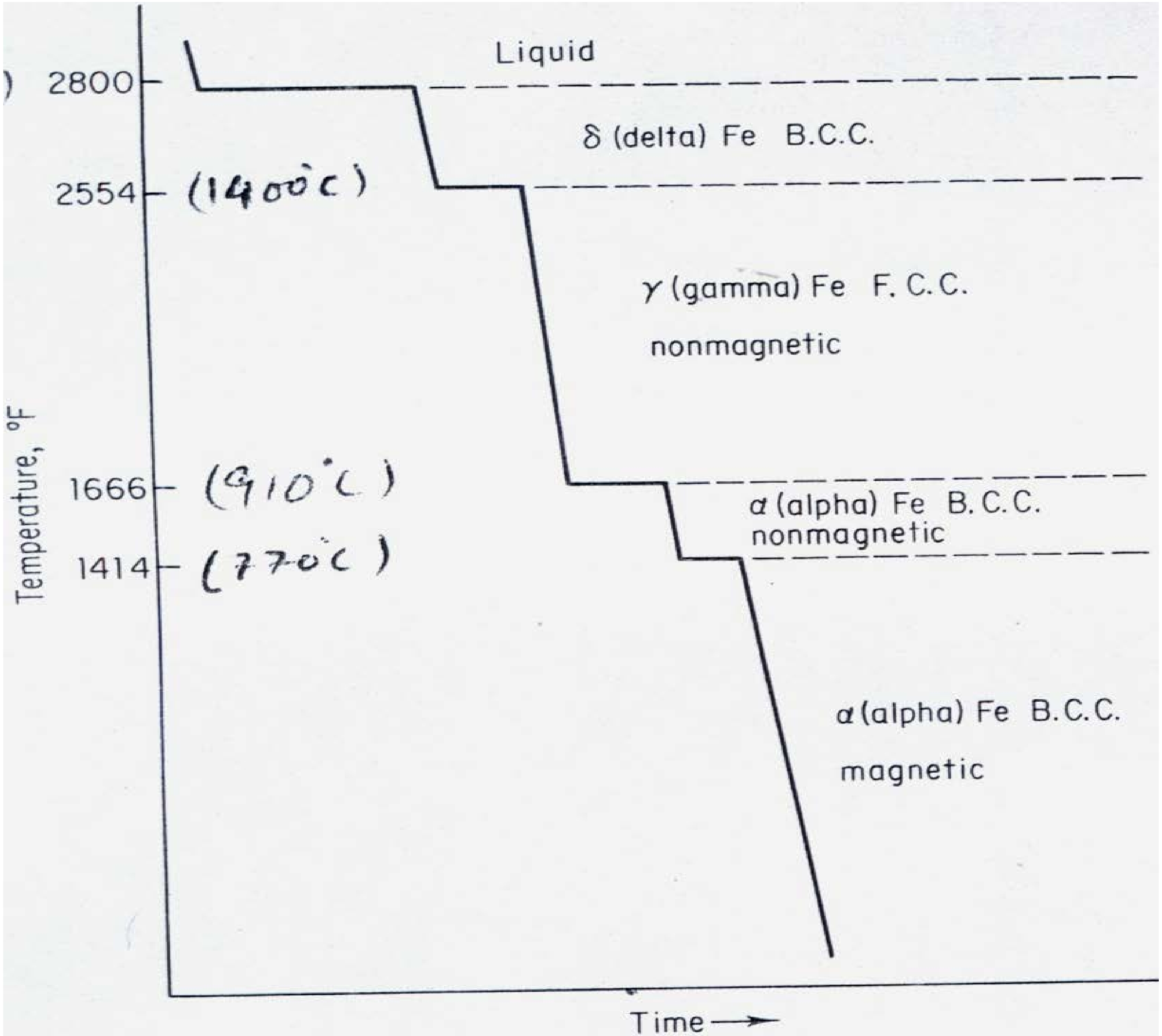


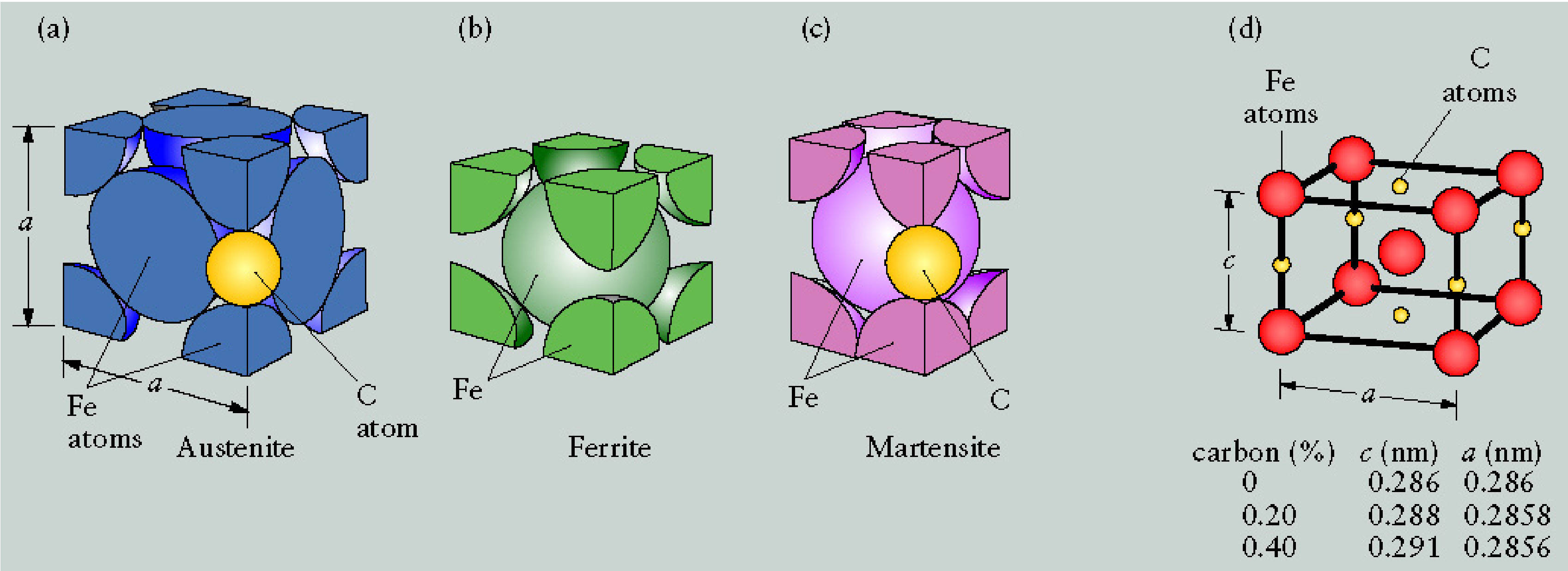
Pearlite

Pearlite



Cooling curve for pure iron





- 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.