University of Anbar/ Faculty of Engineering

Department of Mechanical Engineering

2nd Semester (2018/2019)

Subject: Engineering of Metallurgy

Course Code: ME2304

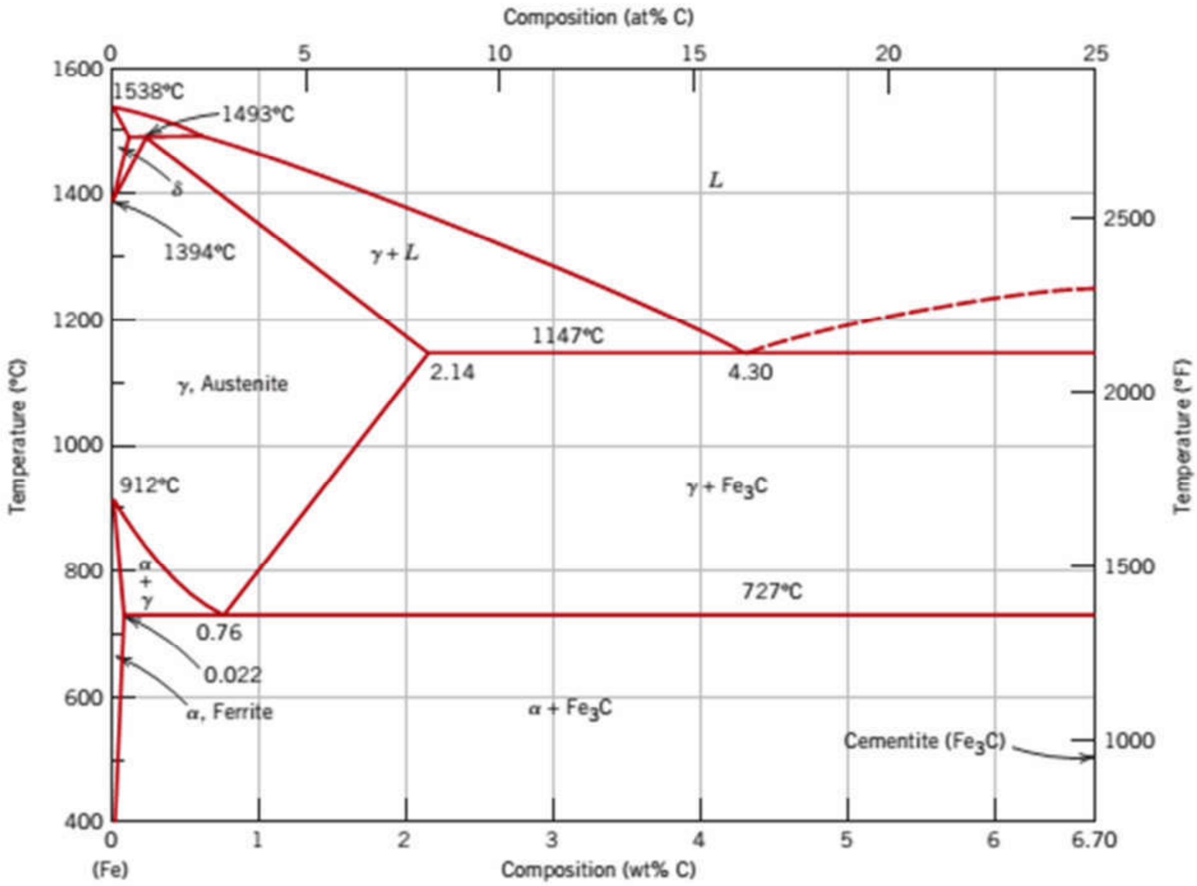
Stage: 2nd Year

Lecturer. Osama Ibrahim

Lecture # 12

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

- Important phases found on the iron–iron carbide phase diagram (Figure Below) are – ferrite (BCC), austenite (FCC), and the intermetallic compound iron carbide or cementite (Fe_3C).
- On the basis of composition, ferrous alloys fall into three classifications:
  1) Iron (< 0.008 wt% C) in α-Ferrite at room temperature
  2) Steel (0.008wt%C to 2.14 wt% C); (α-Ferrite+Fe_3C) at room temperature
  3) Cast iron (2.14 to 6.70 wt% C) (commercial cast irons less than 4.5wt%C).



Iron–iron carbide phase diagram

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 eutectoid temperature (727 ° C).

δ-ferrite solid solution of C in BCC Fe

- The same structure as α-ferrite
- Stable only at high Temperature, 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 Temperature, but decomposes (very slowly, within several years) into α-Fe and C (graphite) at 650 - 700°C.

Fe-C liquid solution: above Liquidus line.

Notes:

- Carbon is an interstitial impurity in Fe. It forms an interstitial 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 γ - 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 nonmagnetic

Eutectic, Eutectoid and Peritectic reactions:

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

- **Eutectic reaction: (at 4.30 wt% C, 1147 °C):** the liquid solidifies to form austenite and cementite phases. Eutectic mixture of (austenite + cementite) called “ledeburite” resulted at eutectic reaction (at 4.30 wt% C, 1147 °C)

$$L \underset{\text{heating}}{\overset{\text{cooling}}{\rightleftharpoons}} \gamma + Fe_3C$$

- **Eutectoid reaction: (at 0.76 wt%C, 727 °C):** upon cooling, the solid phase is transformed into α-iron and cementite.

$$\gamma(0.76 \text{ wt\% C}) \underset{\text{heating}}{\overset{\text{cooling}}{\rightleftharpoons}} \alpha(0.022 \text{ wt\% C}) + Fe_3C(6.7 \text{ wt\% C})$$

- **Peritectic Reaction: (at 0.16% C, 1493°C):** solid phase and liquid phase will together form a second solid phase at a particular temperature and composition upon cooling,

$$\delta(0.11\% \text{ C}) + L(0.51\%\text{C}) \leftrightarrow \gamma\ (0.16\%\text{C})$$

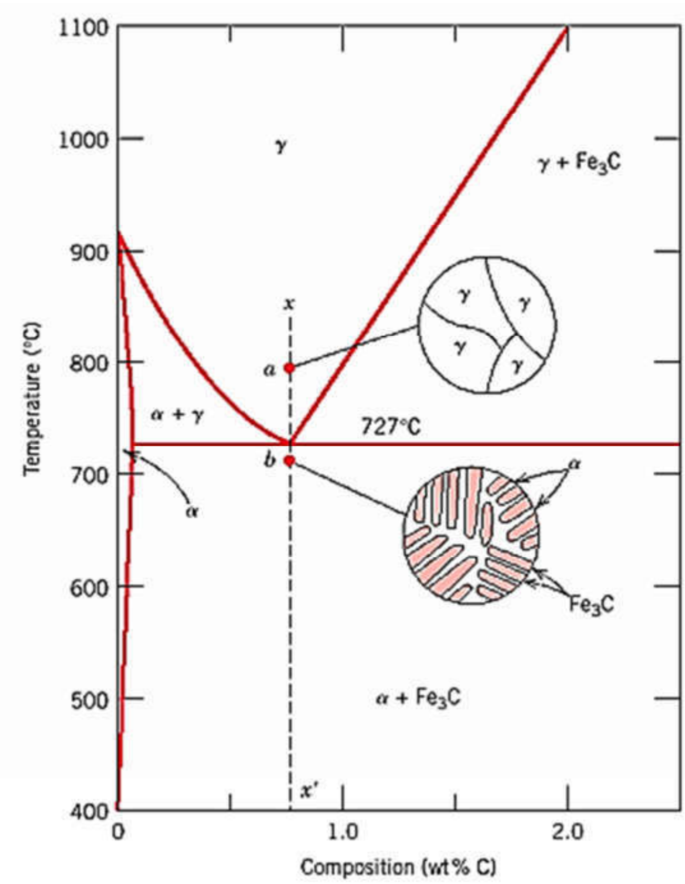
Development of Microstructure in Iron–Carbon Alloys:

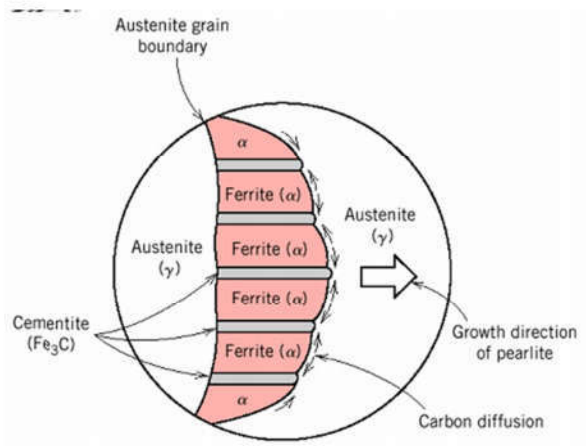
Microstructure depends on composition (carbon content) and heat treatment. In the discussion below we consider slow cooling in which equilibrium is maintained.

Microstructure of eutectoid steel:

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

The reason as layered structure of eutectic structures are formed: 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.





layered structure of eutectic

Figure. Microstructure of eutectoid steel

Microstructure of hypoeutectoid steel:

- **Hypoeutectoid:** steel has a carbon concentration (composition) less than the eutectoid (0.76 wt % C).

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

- Microstructure of hypoeutectoid alloys contain proeutectoid ferrite (formed above the eutectoid temperature) plus the pearlite that contain eutectoid ferrite α and cementite

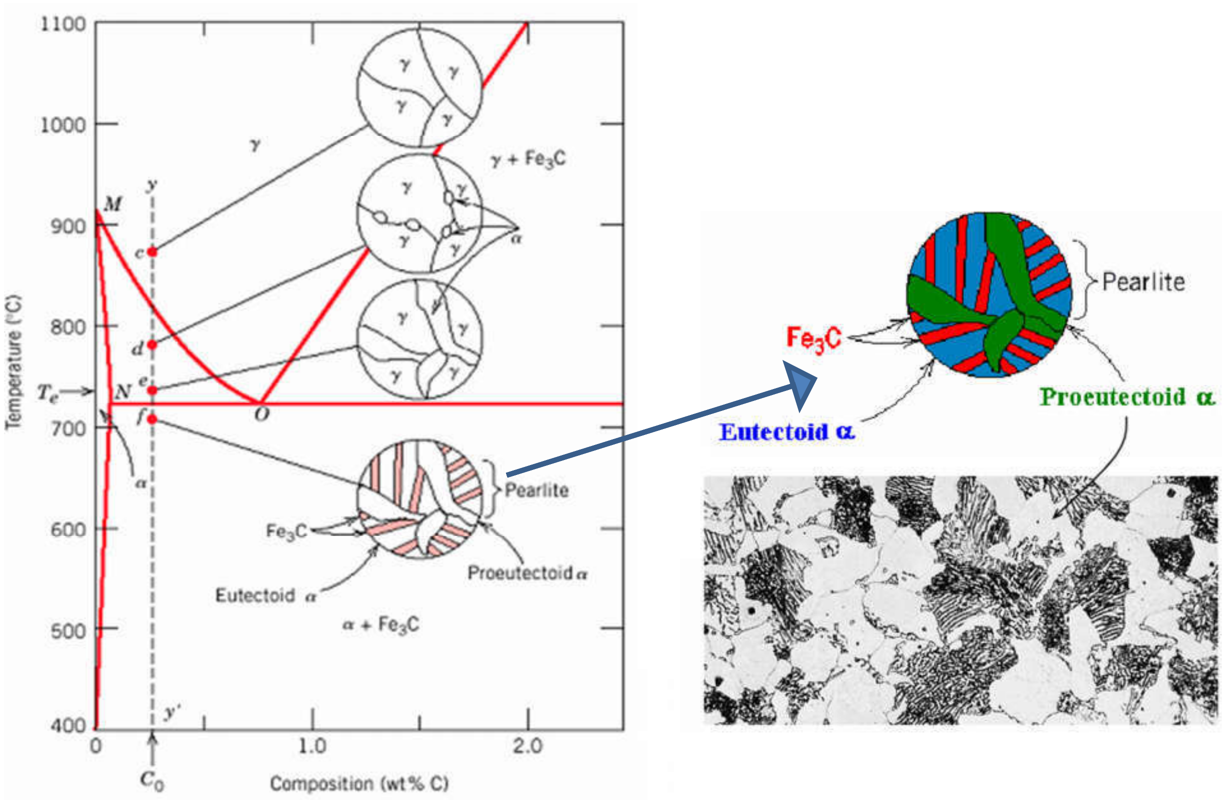


Fig. Microstructure of hypoeutectoid steel

Question: In a hypoeutectoid steel, both eutectoid and proeutectoid ferrite exist. Explain the difference between them. What will be the carbon concentration in each? **Answer**: For a hypoeutectoid steel, the proeutectoid ferrite is a phase that formed above the eutectoid temperature. The eutectoid ferrite is one of the phases of pearlite that formed below the eutectoid temperature. The carbon concentration for both ferrites is 0.022 wt% C.

Microstructure of hypereutectoid steel:

- **Hypereutectoid:** steel has a carbon concentration (composition) more than the eutectoid (0.76 wt % C).

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

- Microstructure of hypereutectoid alloys contain proeutectoid cementite (formed above the eutectoid temperature) plus pearlite that contain eutectoid ferrite α and cementite.

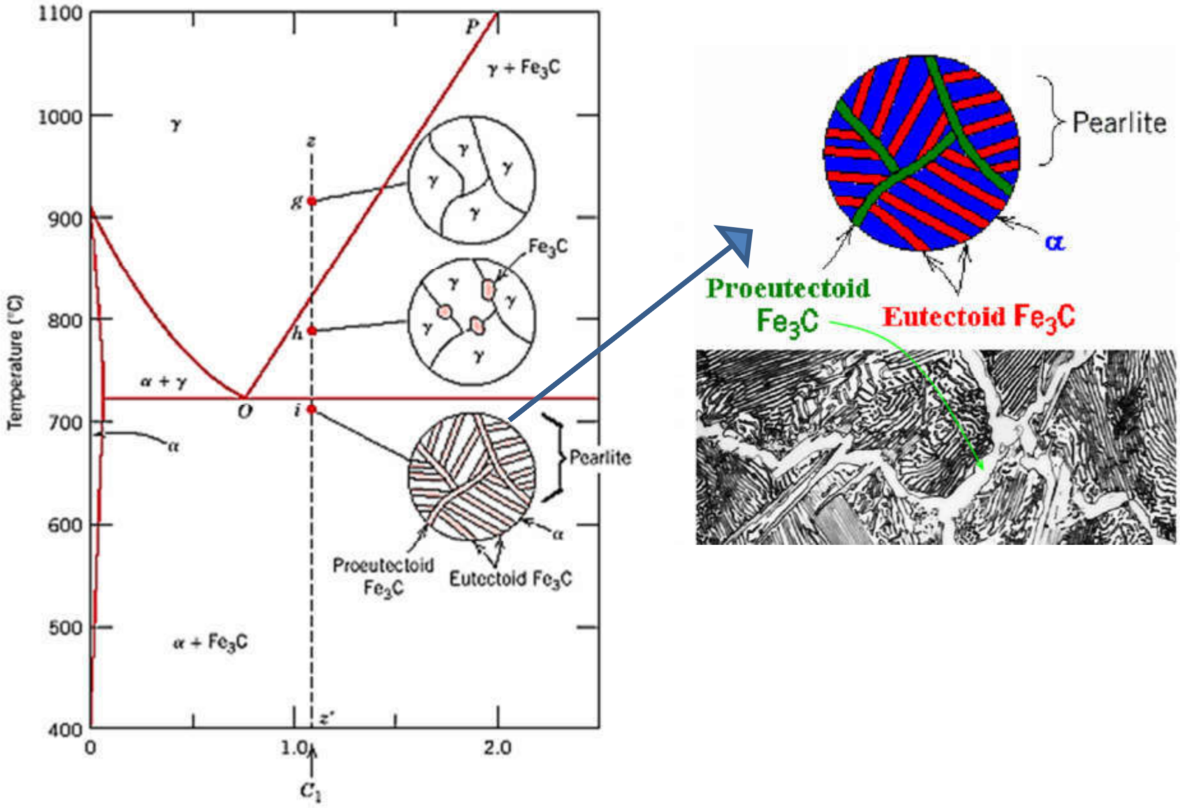


Fig. Microstructure of hypereutectoid steel

Question: What is the distinction between hypoeutectoid and hypereutectoid steels? **Answer**: A "hypoeutectoid" steel has a carbon concentration less than the eutectoid; on the other hand, a "hypereutectoid" steel has a carbon content greater than the eutectoid.

Calculate the amounts of proeutectoid phase (α or Fe_3C) and pearlite?

- Application of the lever rule for hypoeutectoid alloy with composition C_o

The fraction of pearlite, Wp:

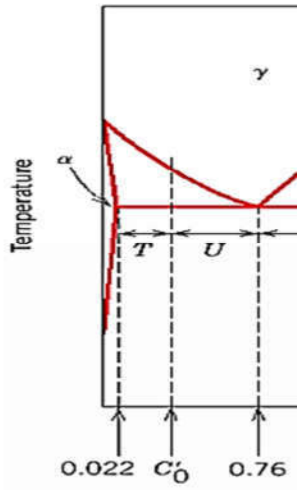
$$W_p = \frac{T}{T + U}$$

$$= \frac{C'_0 - 0.022}{0.76 - 0.022} = \frac{C'_0 - 0.022}{0.74}$$

The fraction of proeutectoid, *Wα*, is computed as follows:

$$W_{\alpha'} = \frac{U}{T + U}$$

$$= \frac{0.76 - C'_0}{0.76 - 0.022} = \frac{0.76 - C'_0}{0.74}$$



➤ Application of the lever rule for hypereutectoid alloy with composition C_1

Fraction of pearlite:

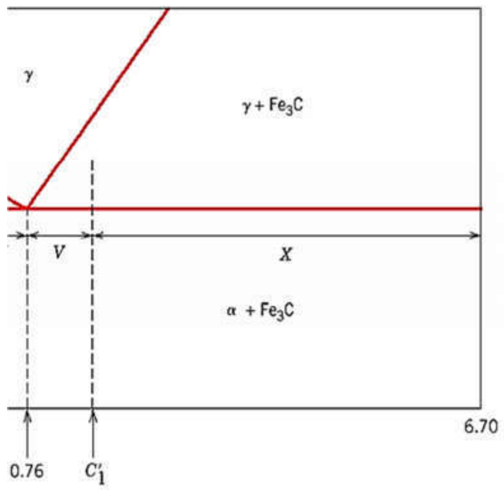
$$W_P = X / (V+X)$$

$$W_P = (6.7 - C_1) / (6.7 - 0.76)$$

Fraction of proeutectoid cementite:

$$W_{Fe3C} = V / (V+X)$$

$$W_{Fe3C} = (C_1 - 0.76) / (6.7 - 0.76)$$



Example: For a 99.65 wt% Fe–0.35 wt% C alloy at a temperature just below the eutectoid, determine the following:

(a) The fractions of total ferrite and cementite phases

(b) The fractions of the proeutectoid ferrite and pearlite

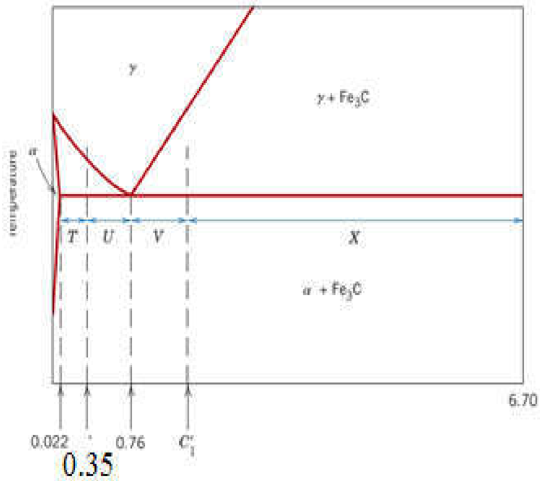
(c) The fraction of eutectoid ferrite

Solution:

a) by application of the lever rule:

The fractions of total ferrite is:

$$W_{\alpha} = (6.7 - Co) / (6.7 - 0.022)$$
$$W_{\alpha} = (6.7 - 0.35) / (6.7 - 0.022)$$
$$W_{\alpha} = 0.95$$



The fractions of total cementite:

$$W_{Fe3C} = (Co - 0.022) / (6.7 - 0.022)$$
$$W_{Fe3C} = (0.35 - 0.022) / (6.7 - 0.022)$$

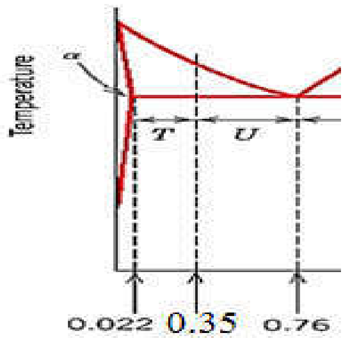
$$W_{Fe3C} = 0.05$$

b) The fraction of the proeutectoid ferrite:

$$W_{\alpha'} = (0.76 - Co) / (0.76 - 0.022)$$
$$W_{\alpha'} = (0.76 - 0.35) / (0.76 - 0.022) = 0.56$$

The fraction of the pearlite:

$$W_P = (Co - 0.022) / (0.76 - 0.022)$$
$$W_P = (0.35 - 0.022) / (0.76 - 0.022) = 0.44$$



c) The fraction of eutectoid ferrite

The fractions of total ferrite: $W_{\alpha} = 0.95$
The fraction of the proeutectoid ferrite: $W_{\alpha'} = 0.56$

Total ferrite = proeutectoid ferrite + eutectoid ferrite
0.95 = 0.56 + eutectoid ferrite
The fraction of eutectoid ferrite = 0.95 - 0.56 = 0.39

H.W. What is the carbon concentration of an iron–carbon alloy for which the fraction of total ferrite is 0.94?

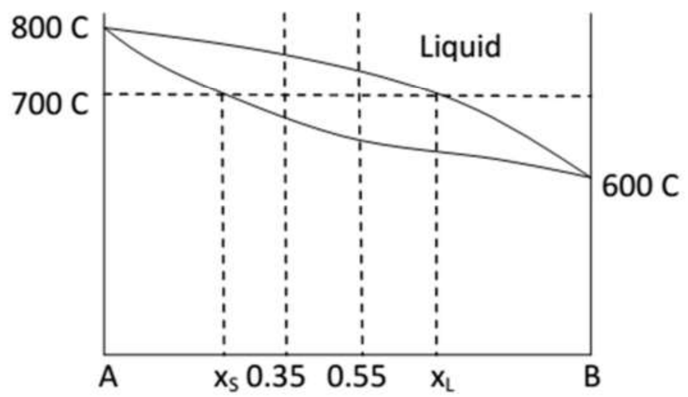
H.W. Compute the mass fractions of α ferrite and cementite in pearlite.

H.W. What is the proeutectoid phase for an iron–carbon alloy in which the mass fractions of total ferrite and total cementite are 0.92 and 0.08, respectively? Why?

H.W. Consider 1.0 kg of austenite containing 1.15 wt% C, cooled to below 727C (1341F).

(a) What is the proeutectoid phase?
(b) How many kilograms each of total ferrite and cementite form?
(c) How many kilograms each of pearlite and the proeutectoid phase form?
(d) Schematically sketch and label the resulting microstructure.

EX: Two metals A (melting point 800°C) and B (melting point 600°C) form a binary isomorphous system. An alloy having 35% B has 75% solid and rest liquid whereas an alloy having 55%B has 25% solid at 700°C. Estimate the composition of solidus and liquidus at the above temperature.
Answer: A schematic binary phase diagram of this system is shown below:



Apply lever rule on alloys with 0.35 B, and 0.55 B

$W_S = (X_L - X_o) / (X_L - X_S)$

$0.75 = (X_L - 0.35) / (X_L - X_S)$

$0.25 = (X_L - 0.55) / (X_L - X_S)$

Solve equations to get:

$X_L = 0.65$

$X_S = 0.25$