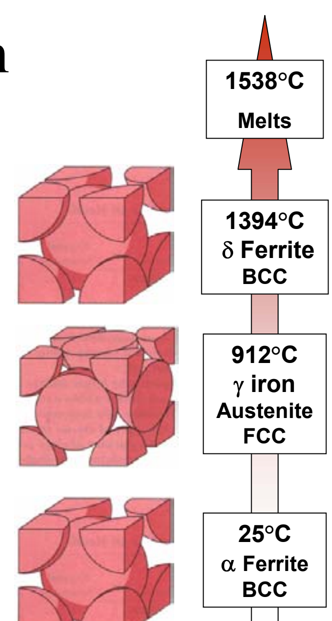
Fe-C Phase Diagram

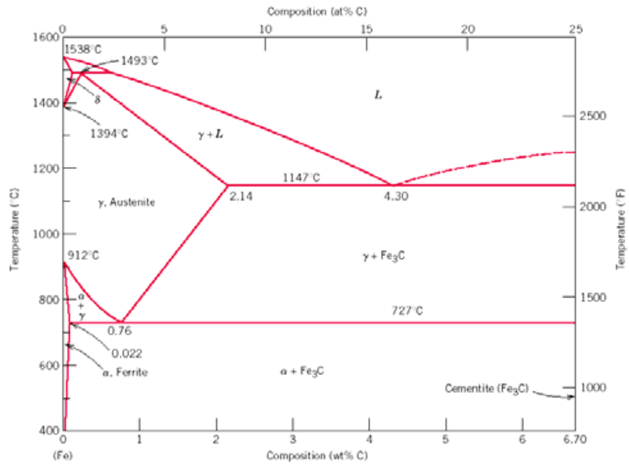
Pure Iron

- Upon heating pure Iron experiences two changes in crystal structure.
- At room temperature it exists as **ferrite**, or α **iron**.
- When we heat it to 912°C it experiences a polymorphic transformation to **austenite**, or γ **iron**
- At 1394°C austenite reverts back to a BCC phase called δ **ferrite.**



Fe-Fe_3C Phase Diagram

- Only part of the phase diagram is shown.
- The left axis is pure iron.
- On the right the phase diagram only extends to 6.70 wt%C
- At this concentration the intermediate compound **iron carbide**, or **cementite** (Fe_3C) is formed

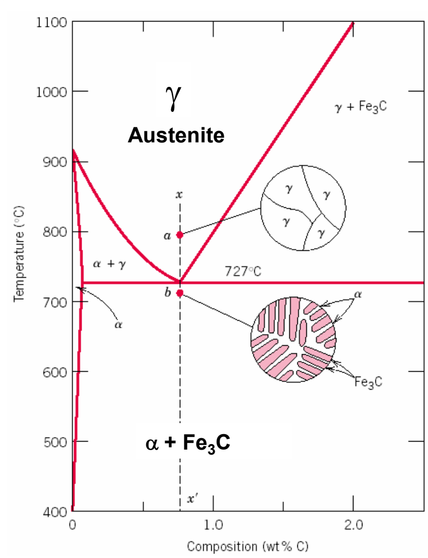


Development of Microstructures in Iron-Carbon Alloys

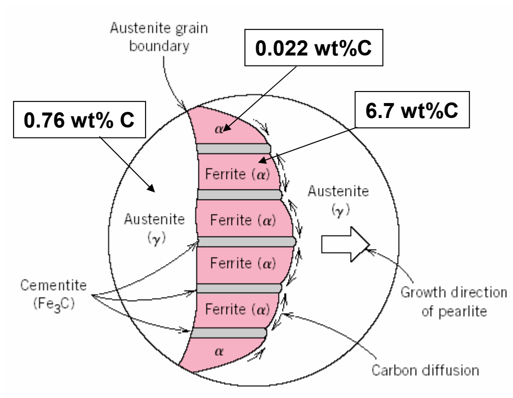
- Various microstructures can be produced in steel alloys depending on
  - carbon content
  - heat treatment
- Equilibrium (slow) cooling from the γ region through the eutectoid composition of 0.76 wt% C

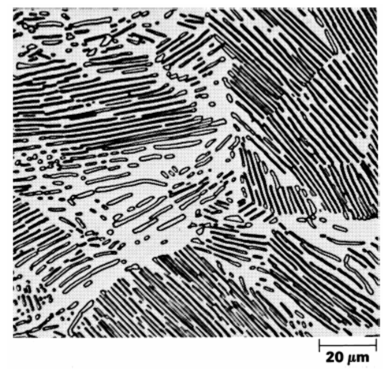
$$\gamma \Rightarrow \alpha + Fe_3C \text{ (Pearlite)}$$

- % α and Fe_3C in eutectoid pearlite



Formation of Pearlite





- Schematic representation of the formation of pearlite from austenite

- Micrograph of eutectoid steel, showing pearlite microstructure.

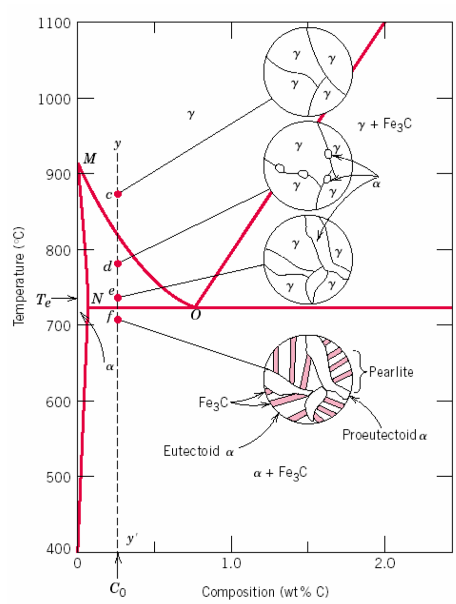
Hypo-eutectoid Composition (wt% C <0.76)

- Composition 0.002 and 0.76 wt% C
- Upon cooling enter a two-phase region

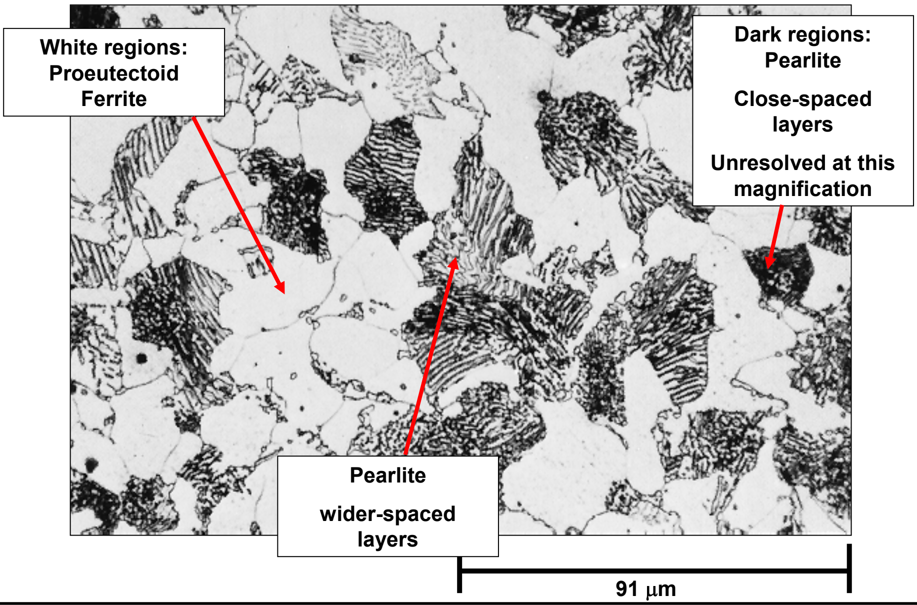
$$\gamma \Rightarrow \alpha + \gamma$$

- Below 727°C the remaining austenite transforms to pearlite

$$\gamma \Rightarrow \alpha + Fe_3C$$

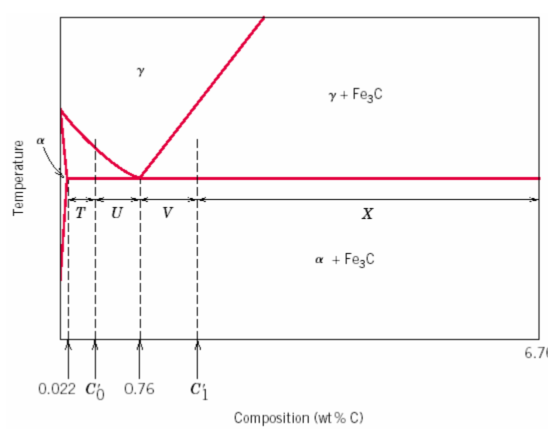


Hypo-eutectoid Composition (0.38 wt% C)



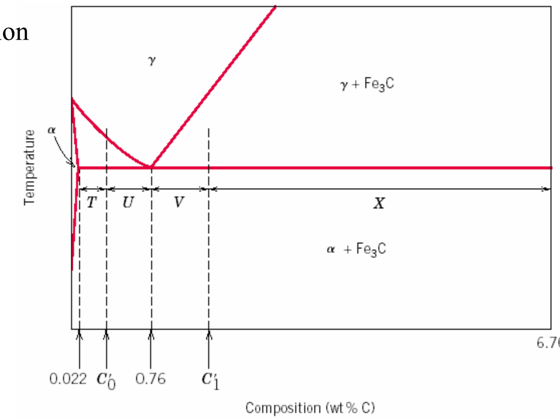
Computing the relative amounts of proeutectoid α and pearlite

- Similar to previous lecture.
- Use the Lever Rule in conjunction with a tie line
- For **hypoeutectic** composition $C'_{0,}$ fractions of pro-eutectic α, and pearlite are:
- α (total) and Fe_3C



Computing the relative amounts of proeutectoid α and pearlite

- For **hypereutectic** composition C'_1



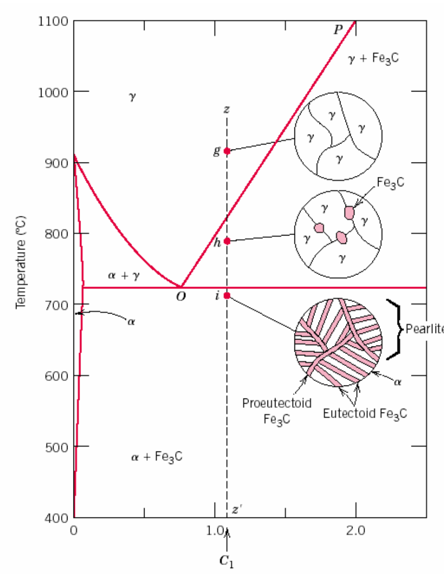
- α (total) and Fe_3C

Hyper-eutectoid Composition (wt% C >0.76)

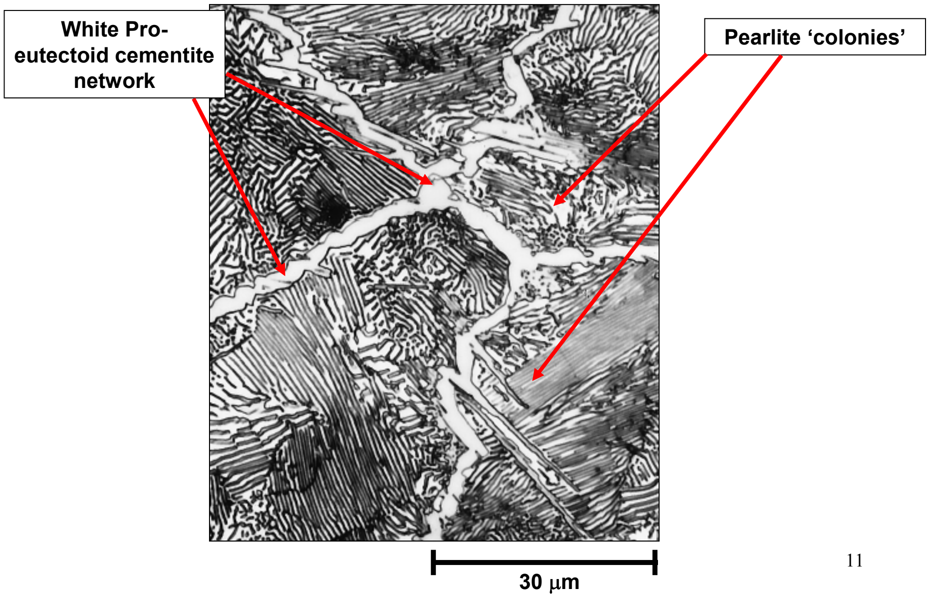
- Composition between 0.76 and 2.14 wt% C
- Upon cooling enter a two-phase region

$$\gamma \Rightarrow \gamma + Fe_3C$$

- The pro-eutectoid cementite phase has begun to form along the γ grain boundaries



Hyper-eutectoid Composition (1.40 wt% C)



Mechanical Properties of Steels

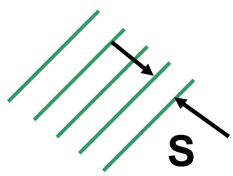
- The mechanical properties of steel are largely dictated by the phase transformations they undergo upon cooling
- If we heat steel to the **single phase austenite region** and vary the cooling rate we can control the microstructure.
- Understanding phase transformations of metallic alloys

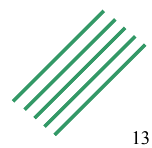
Example: Railway Rails

- Eutectoid composition of 0.76 wt%C
- 100% Pearlite structure
- Pearlite is a natural ‘composite’

- The strength of Pearlite is dictated by its interlaminar spacing, S (μm)

$$\sigma_y = 140 + 46.4S^{-1}$$





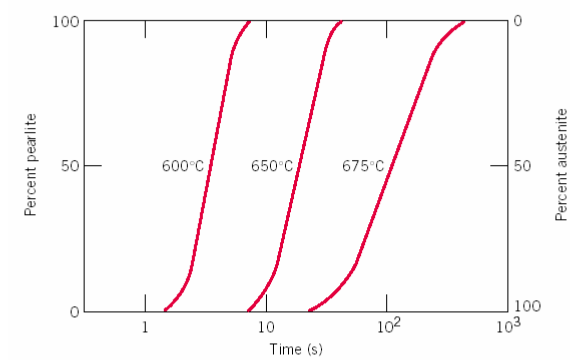
Pearlite

Coarse Pearlite

Fine Pearlite

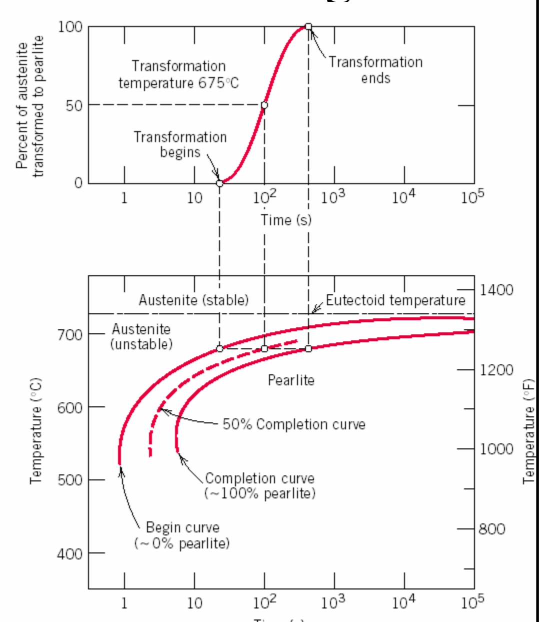
Isothermal Transformation Diagrams

- The rate of transformation of the austenite to pearlite is dependent on temperature
- This temperature dependence can be plotted as % transformation vs. log. time
- Data was collected for each curve, after rapid cooling of 100% austenite to the temperature indicated
  - temperature was then keep constant throughout the course of the reaction

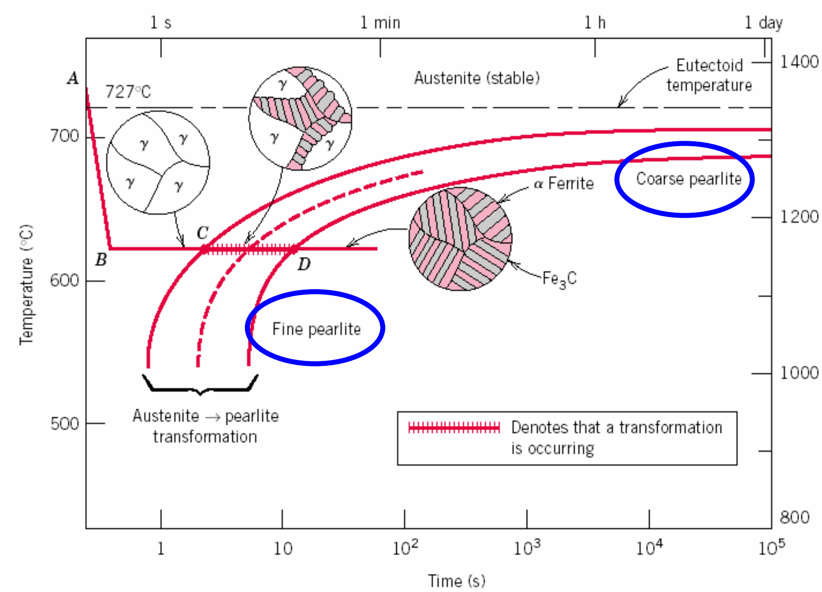


Isothermal Transformation Diagrams

- More convenient to represent time-temperature dependence
  - isothermal transformation diagram
  - generated from the % transformation-versus-log. times measurements
  - Note the eutectoid temperature (727°C)
- Many tests conducted to these construct curves.



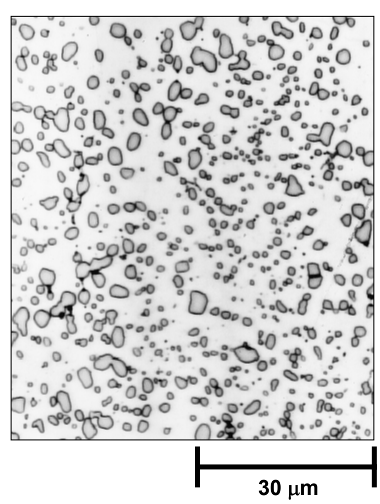
Isothermal Transformation Diagrams



Spheroidite

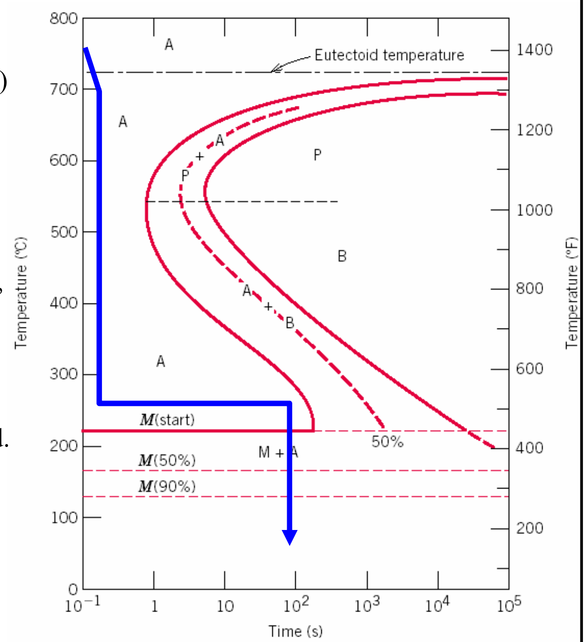
- Hold steel at high temperature

- Large drop in strength occurs
- But ductility is greatly increased



Formation of Martensite

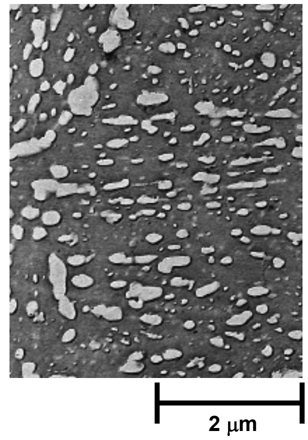
- Non-Equilibrium Cooling
- Carbon must diffuse (move) in order to form pearlite
- Diffusion takes time + temperature
- If the sample is "quenched" (plunged into water)
- A supersaturated and unstable structure is formed.



Characteristics of Martensite Transformation

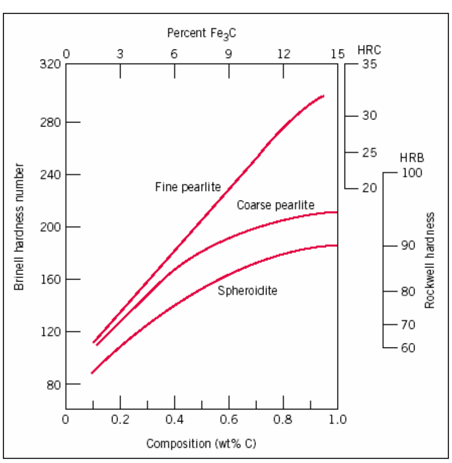
- Occurs by a non-diffusional process
- Transformation occurs extremely fast, i.e. at the speed of sound
- Transformation occurs at temperatures well below eutectoid temperature
- Martensite is very hard (i.e. high σ_y) but is completely brittle
- Not useful as an engineering material
- Must be "tempered"

Martensite

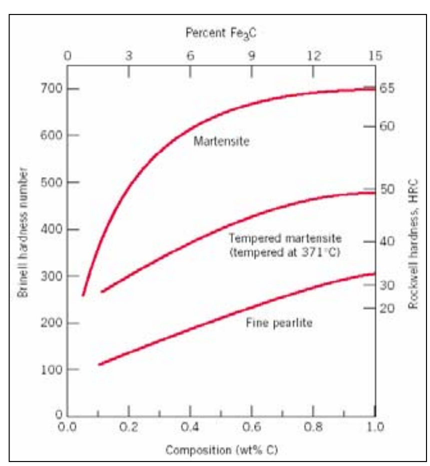


- Quench
  - Needle shaped
  - White areas austenite
    - quenched too fast
- Tempered
  - 564°C
  - small particles cementite
  - matrix is α ferrite

Effect of Carbon Content on Hardness



Brinell Hardness 0 - 320



Brinell Hardness 0 - 750

Effect of Carbon Content on Yield and Tensile Strength