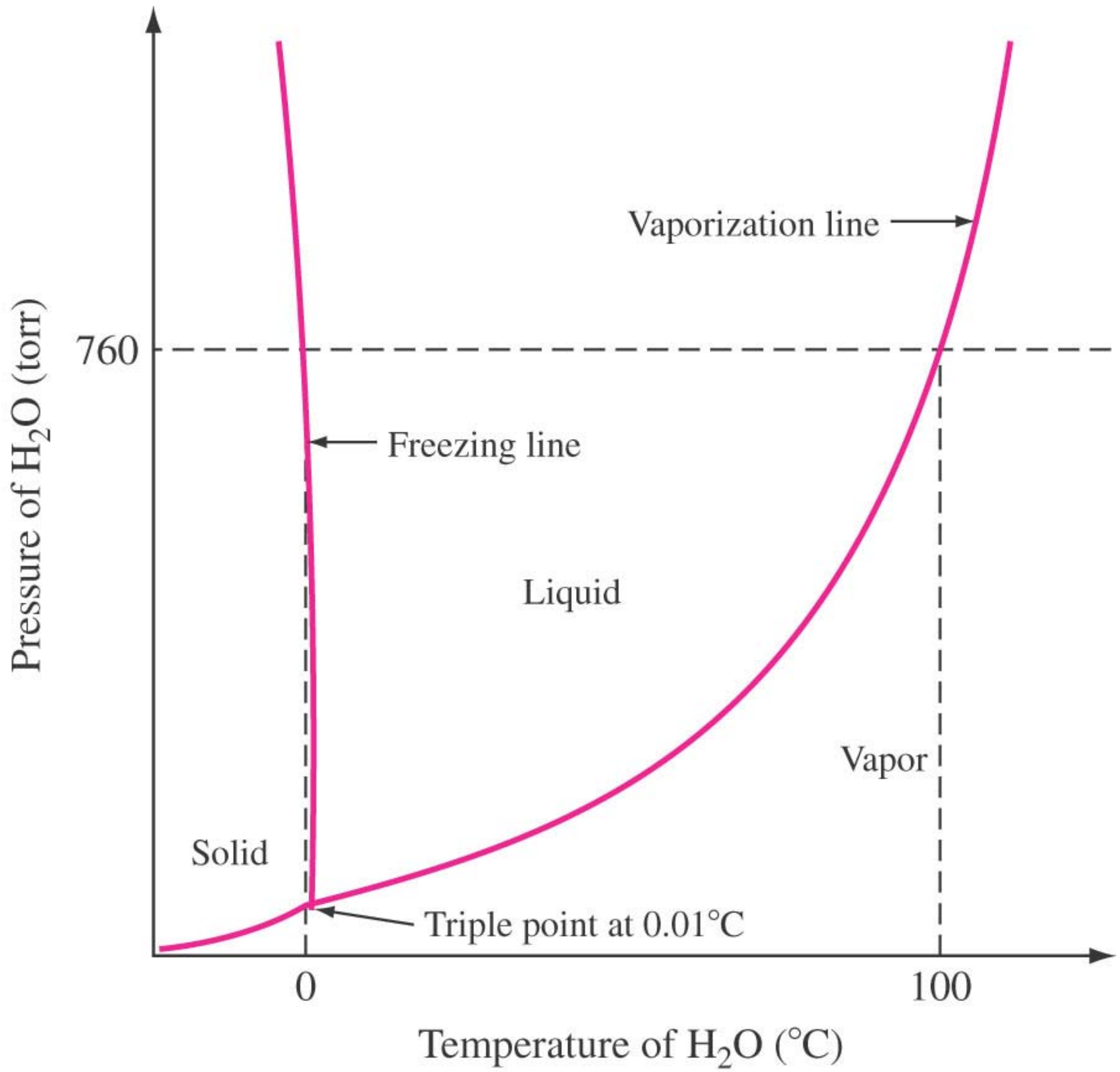
Alloys & Their Phase Diagrams

Objectives of the class

Gibbs phase rule
Introduction to phase diagram
Practice phase diagram
Lever rule
Important Observation: One question in the midterm



Pressure of H2O (torr)
760
Vaporization line
Freezing line
Liquid
Vapor
Solid
Triple point at 0.01°C
0
100
Temperature of H2O (°C)

Gibbs phase rule

$$P + F = C + 2$$

P: number of phases (ie, solid, liquid, or gas)
C: number of components
F: Degree of freedom

Simple Example

Water:

a) At the triple point:

$P = 3$ (solid, liquid, and gas)

$C = 1$ (water)

$P + F = C + 2$

$F = 0$ (no degree of freedom)

b) liquid-solid curve

$P = 2$

$2+F = 1 + 2$

$F = 1$

One variable (T or P) can be changed

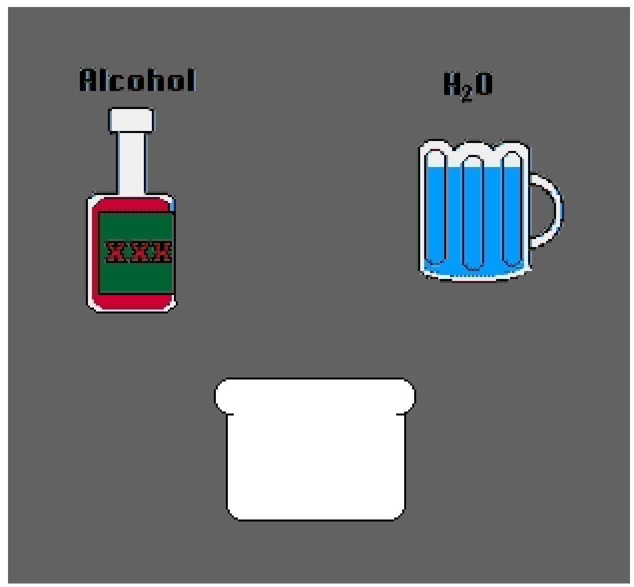
c) Liquid

$P = 1$

So $F = 2$

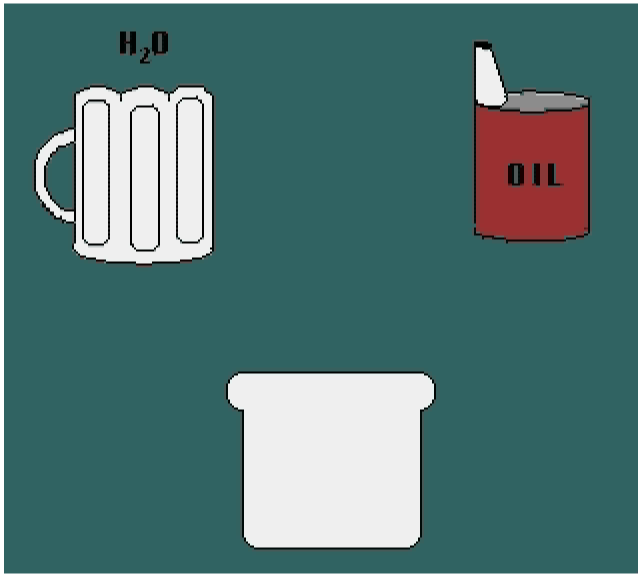
Two variables (T and P) can be varied independently and the system will remains a single phase

Unlimited Solutibity



Limited solubility

No Solubility



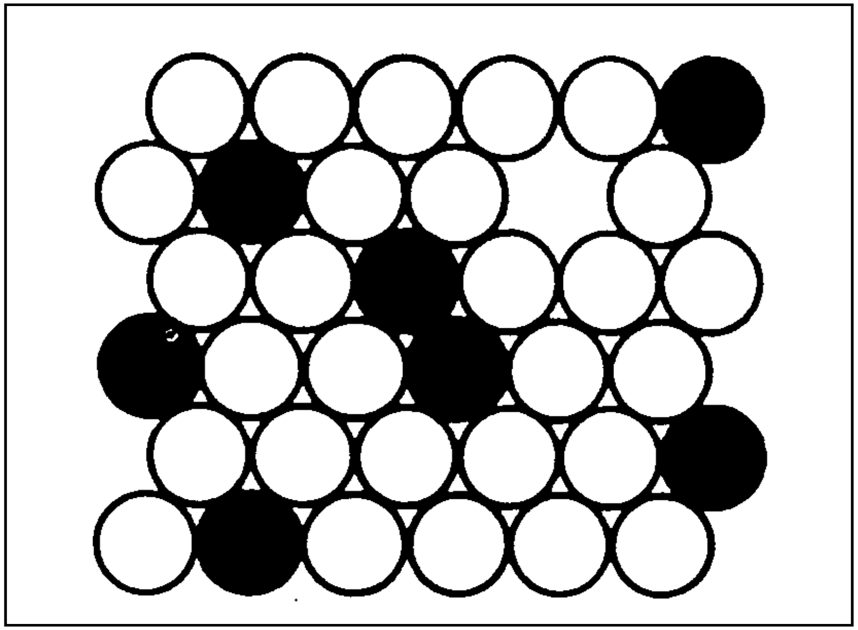
Binary Isomorphous Alloy Systems

A mixture of two metals is called a ***binary alloy*** and constitutes a ***two-component*** system.

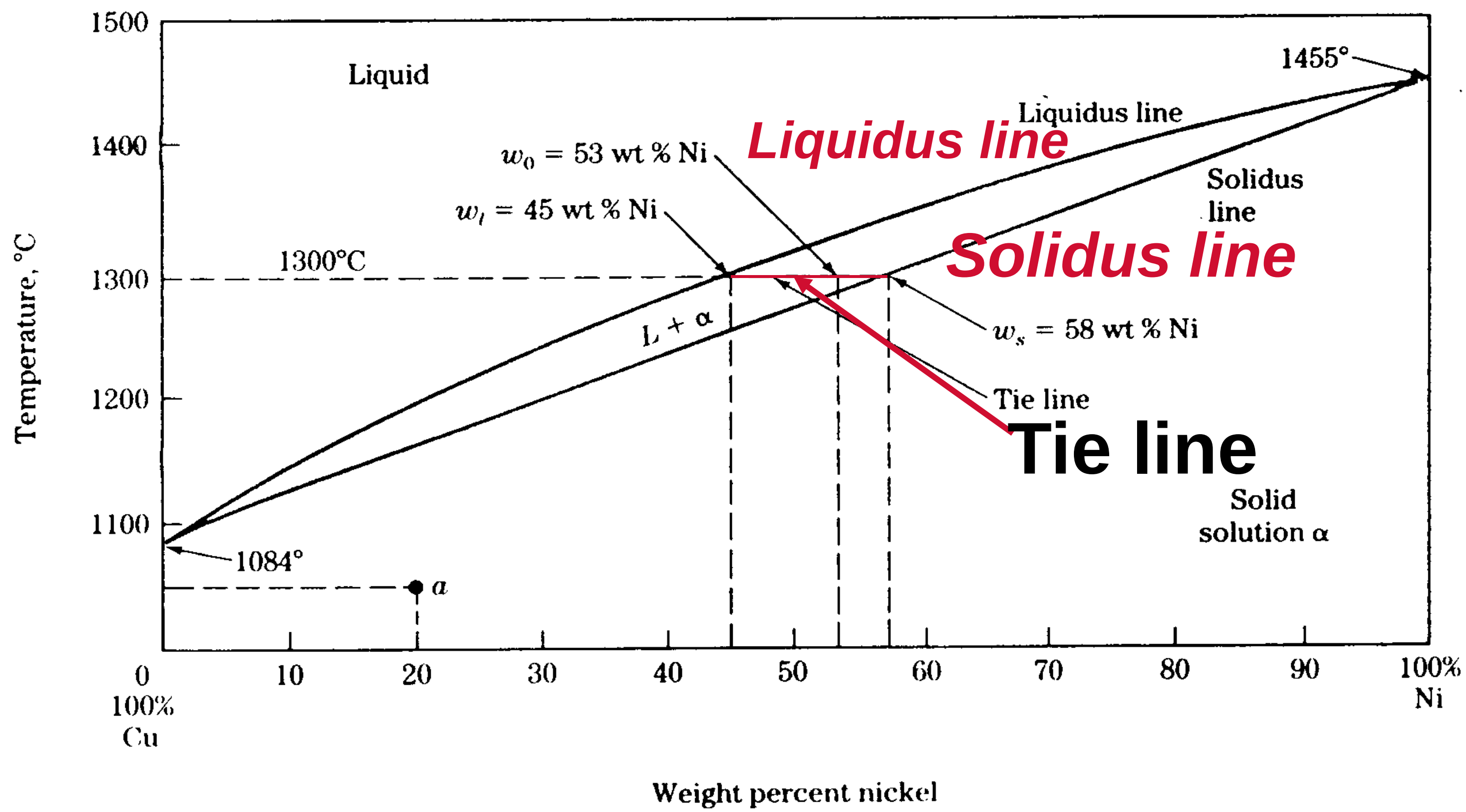
Each metallic element in an alloy is called a separate ***component.***

Isomorphous systems contain metals which are completely soluble in each other and have a single type of crystal structure.

Cu-Ni: A Substitutional Solid Solution

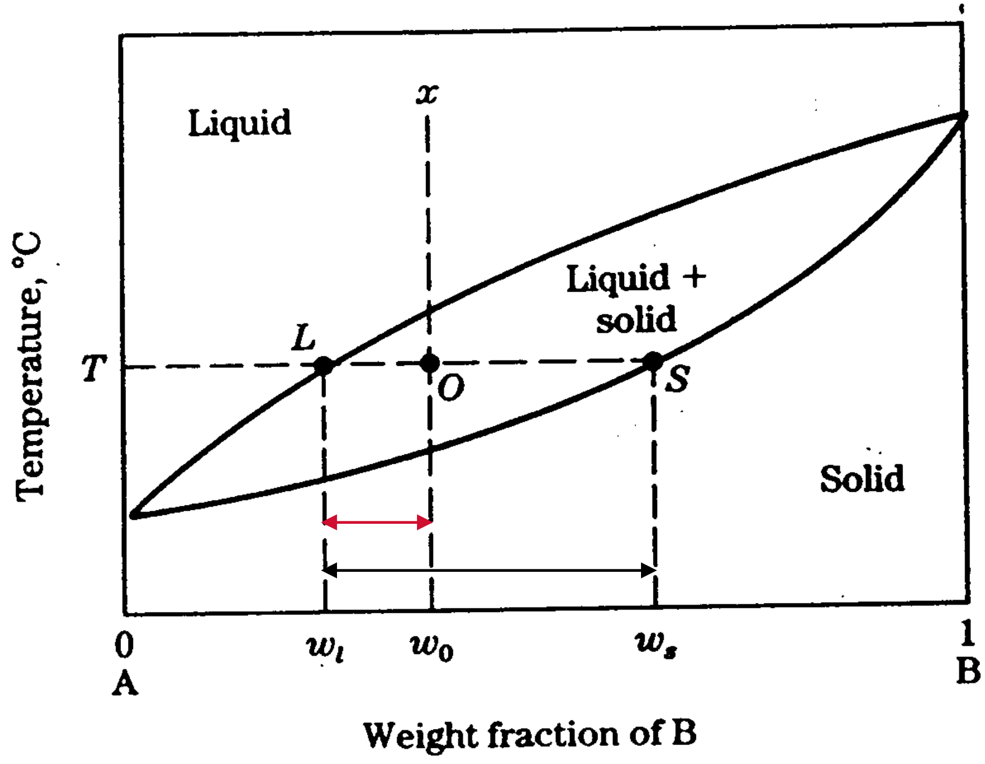


Cu-Ni: Binary Isomorphous Alloy Example



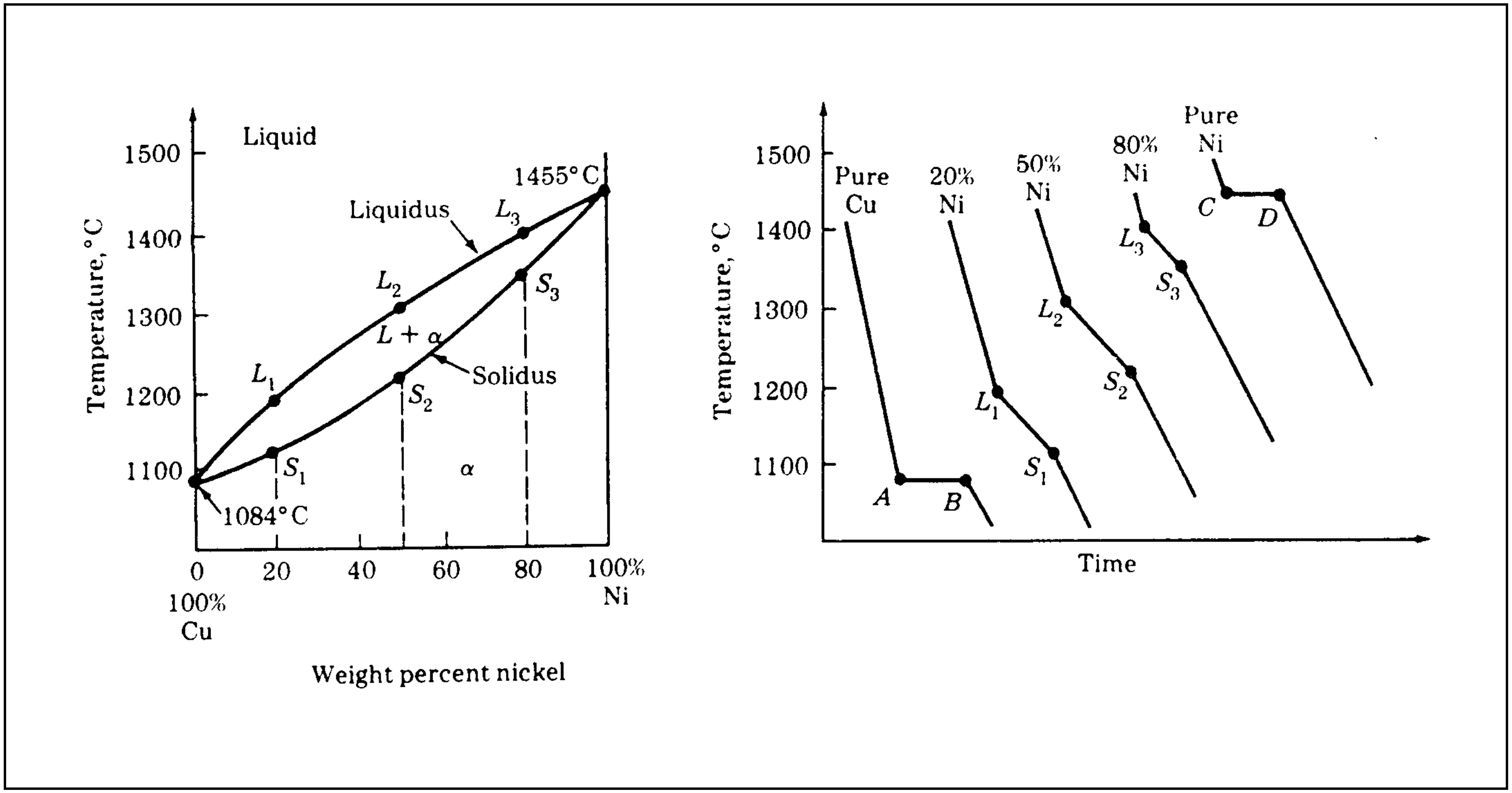
The Lever Rule

To compute the amount of solid phase:

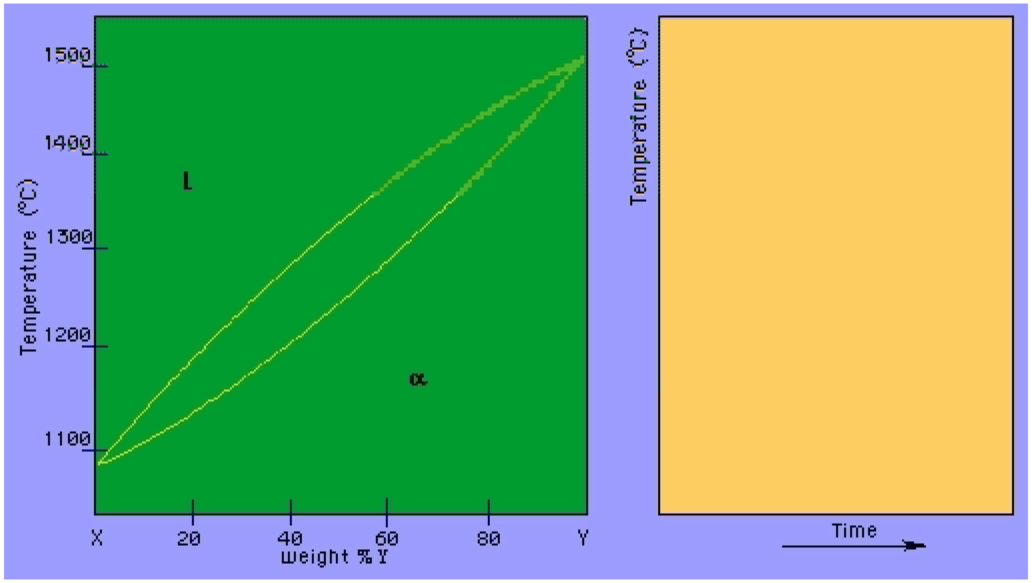


Fraction of the solid phase = (Wo – Wl)/(Ws-Wl)

Cu-Ni: Cooling Curves

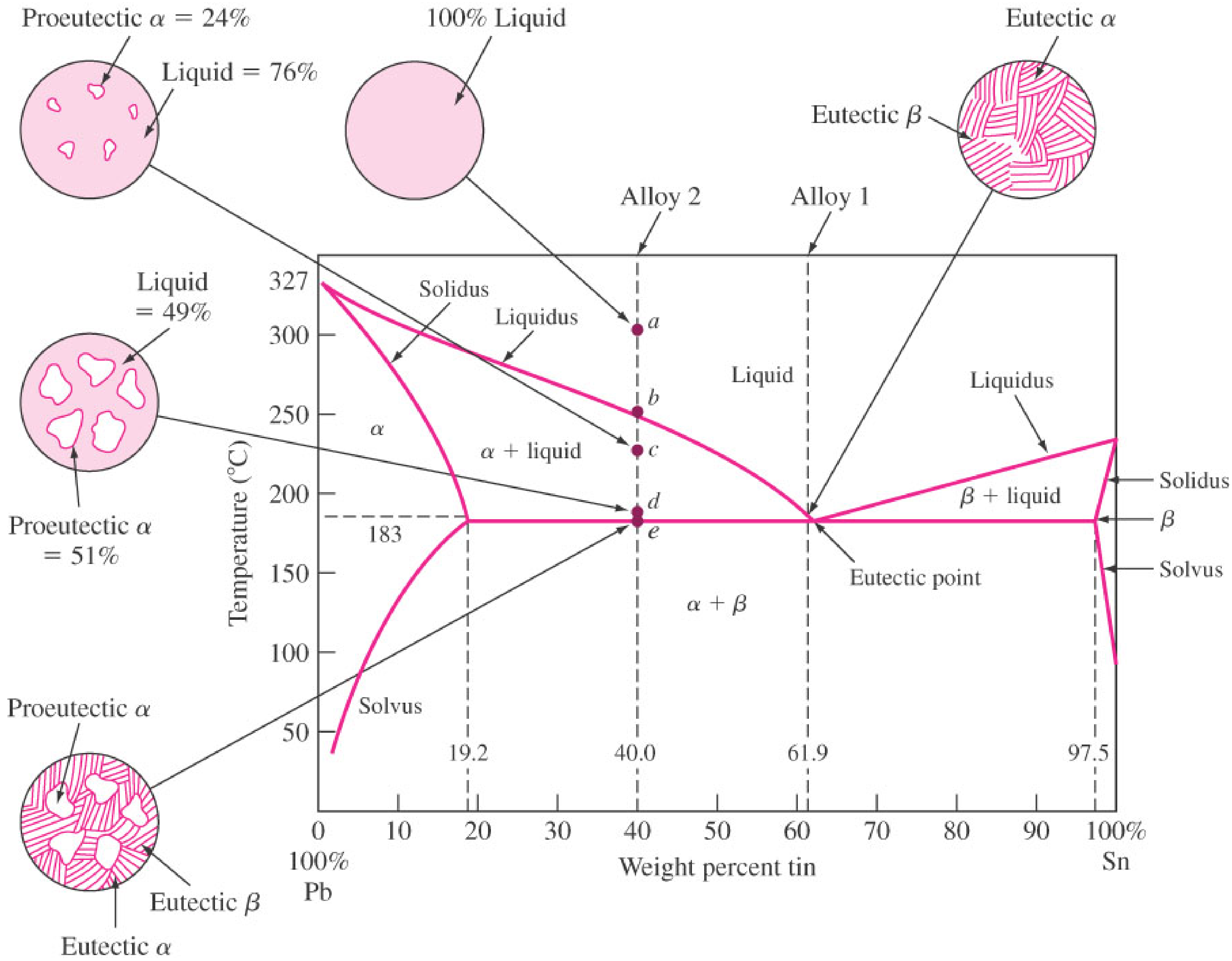


Cooling curve

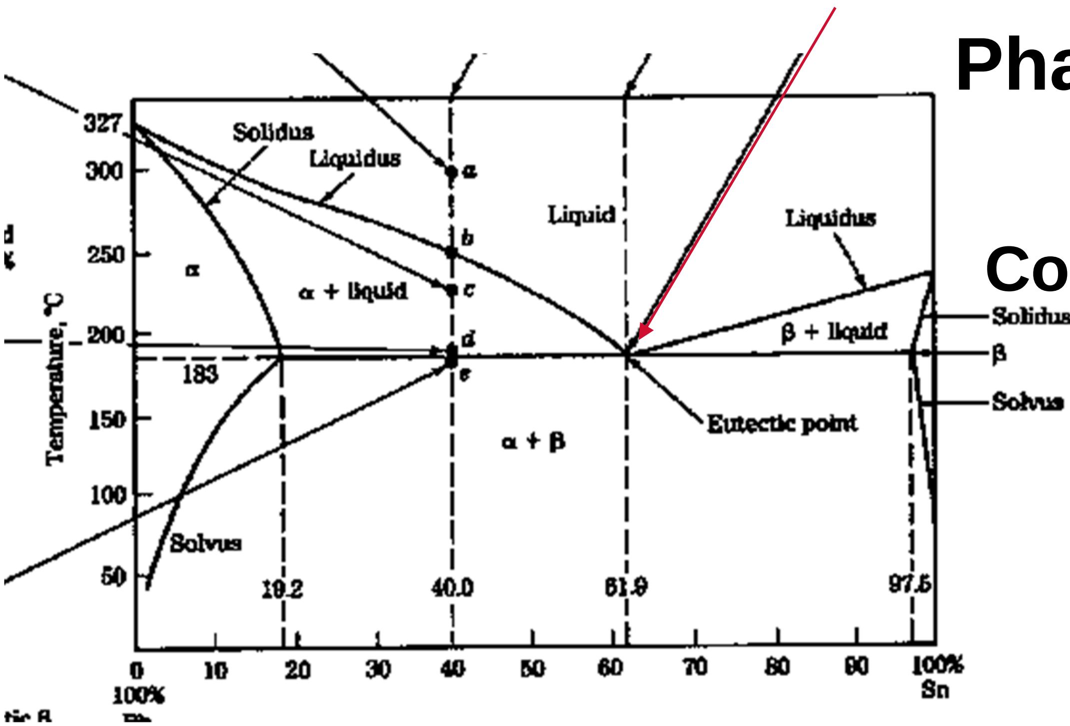


Some examples

Binary Eutectic Alloy Systems



Eutectic composition:

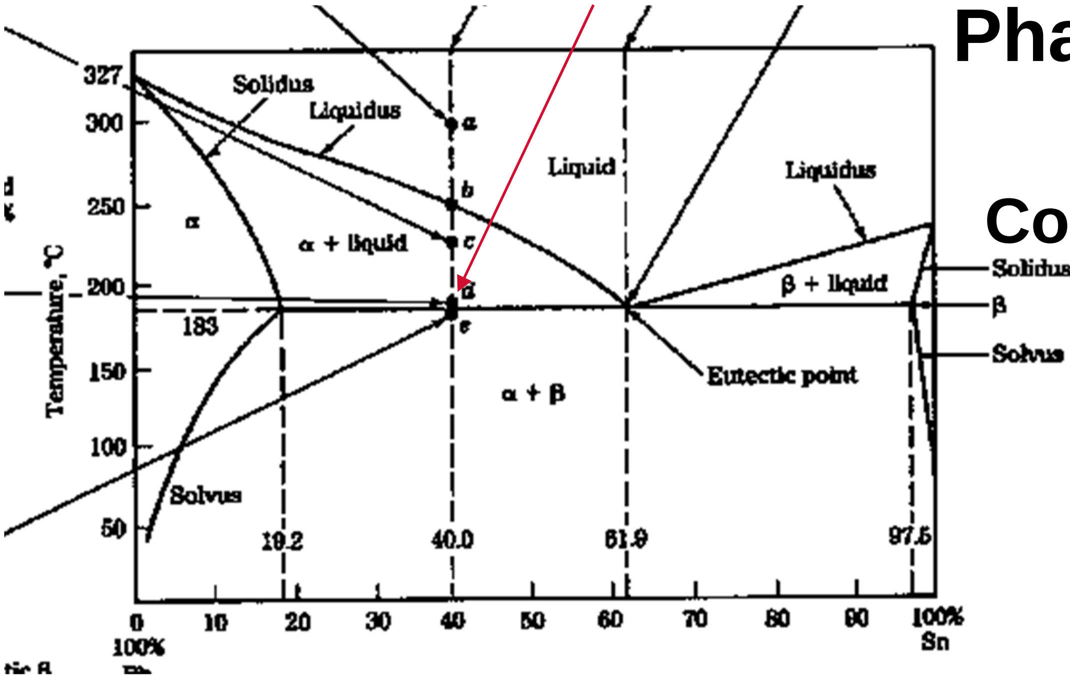


Phases: alpha and beta

Composition of the phases:
Alpha: 19.2% Sn
Beta: 97.5% Sn

Amount of phases:
45.5% of alpha: (97.5-61.9)/(97.5-19.2)
54.5% of beta phase

Example: Point D

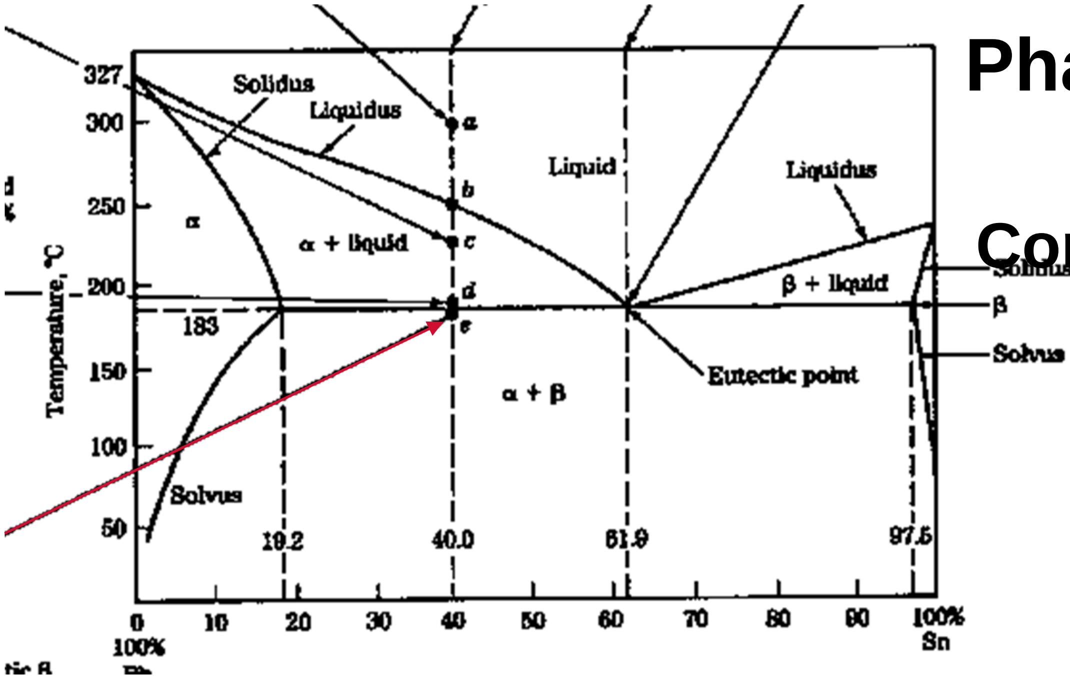


Phases: liquid and alpha

Composition of the phases:
Alpha: 19.2% Sn
Liquid: 61.9% Sn

Amount of phases:
51% of alpha phase: (61.9-40)/(61.9-19.2)
49% of liquid phase

Example: Point E



Phases: alpha and beta

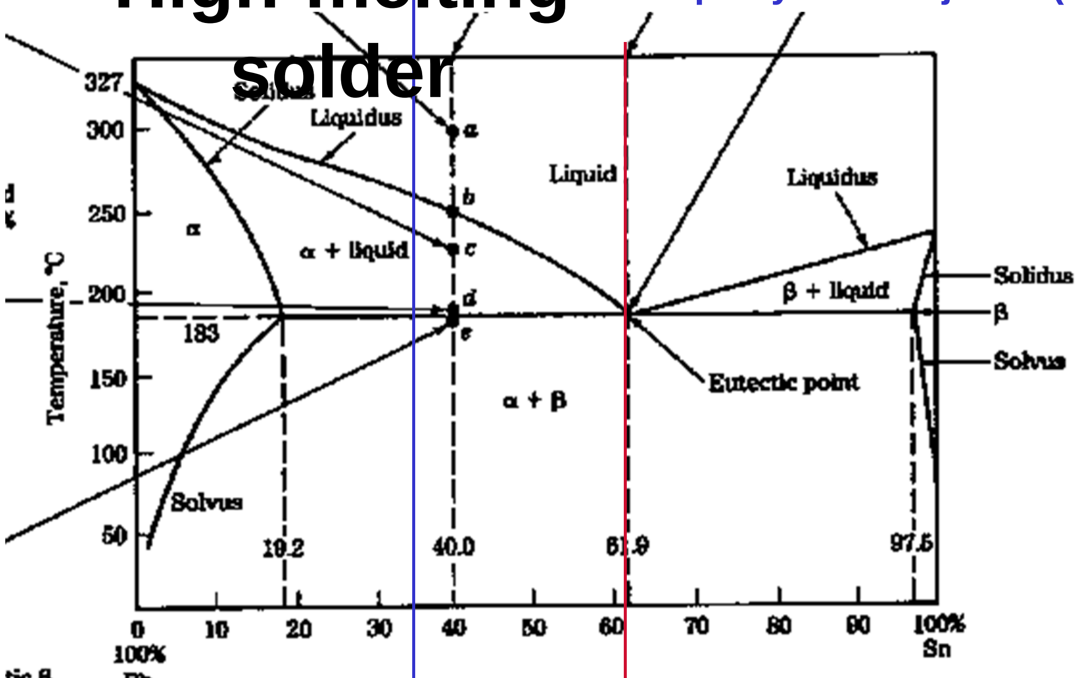
Composition of the phases:
Alpha: 19.2% Sn
beta: 97.5% Sn

Amount of phases:
73% of alpha phase: (97.5-40)/(97.5-19.2)
27% of beta phase

So what?

High-melting solder

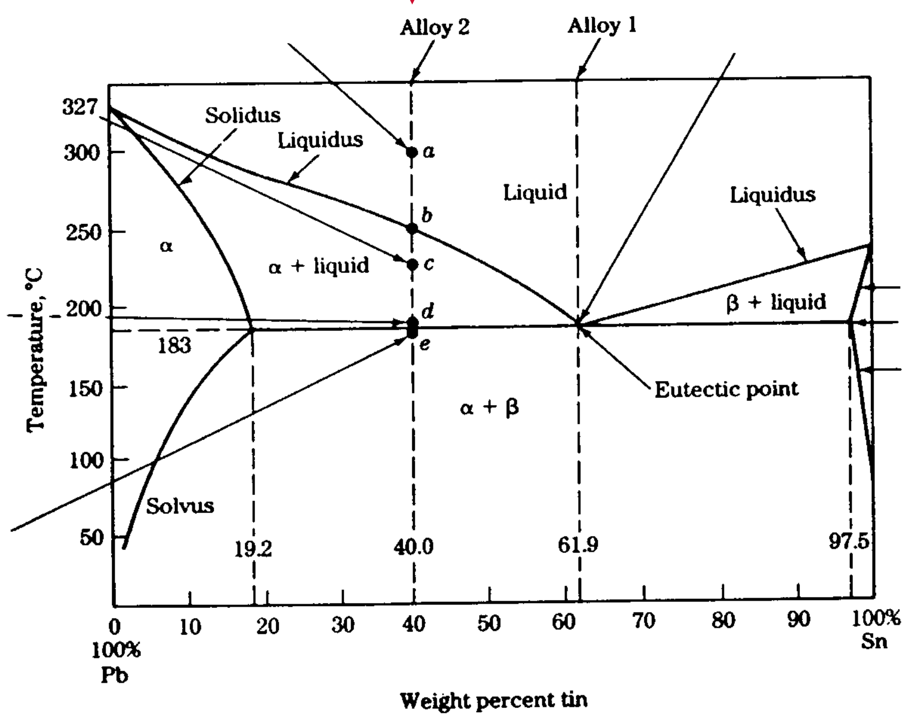
Plumbers' solder: pasty used in joints (Romans) and car body filling

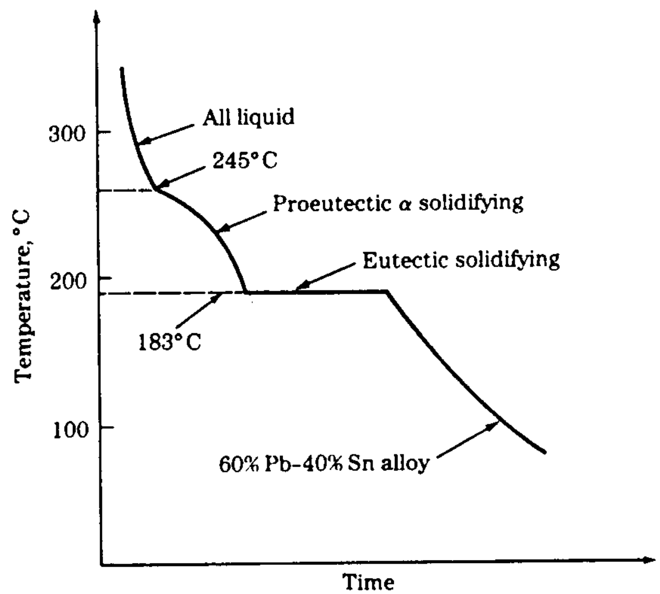


Soft: eutectic (free flowing): electronic assemby

Eutetic: from the Greek easy melting

A Eutectic Cooling Curve





Temperature-time cooling curve
for 60% Pb – 40% Sn alloy

Eutectic Microstructures

There are a number of different "morphologies#" for the two phases in a binary eutectic alloy.

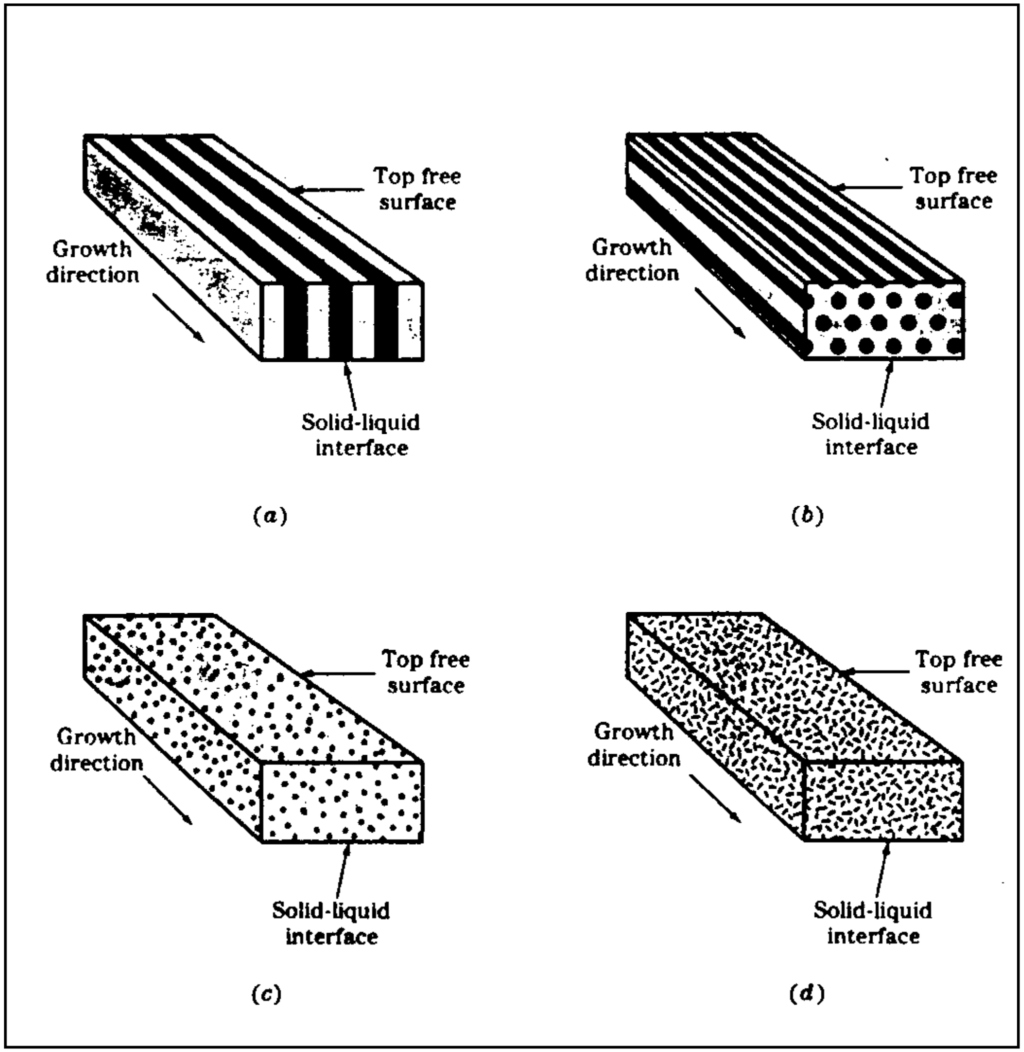
Of prime importance is the minimization of the *interfacial area* between the phases.

The rate of cooling can also have an important effect.

Eutectic Microstructures

Schematic illustration of the various eutectic microstructures: (a) lamellar, (b) rodlike, (c) globular, and (d) acicular (or needlelike).

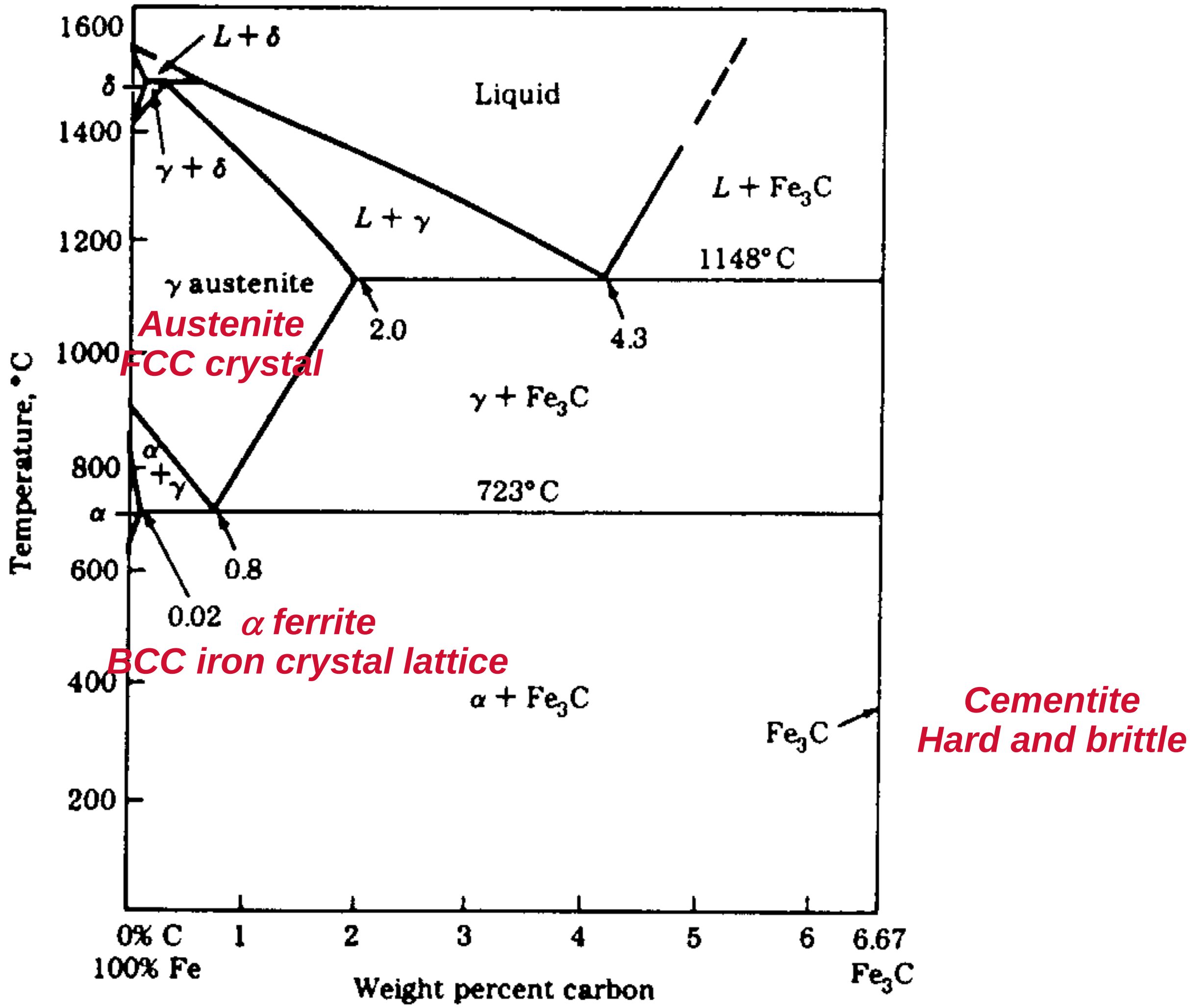
Morphology means the "form", "shape" or "outward microstructure" of a phase.



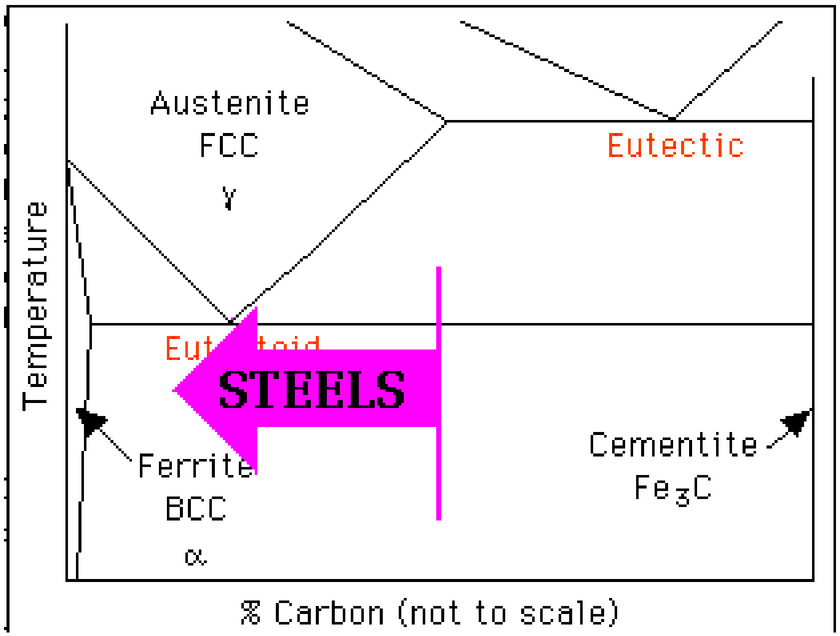
Microstructure evolution

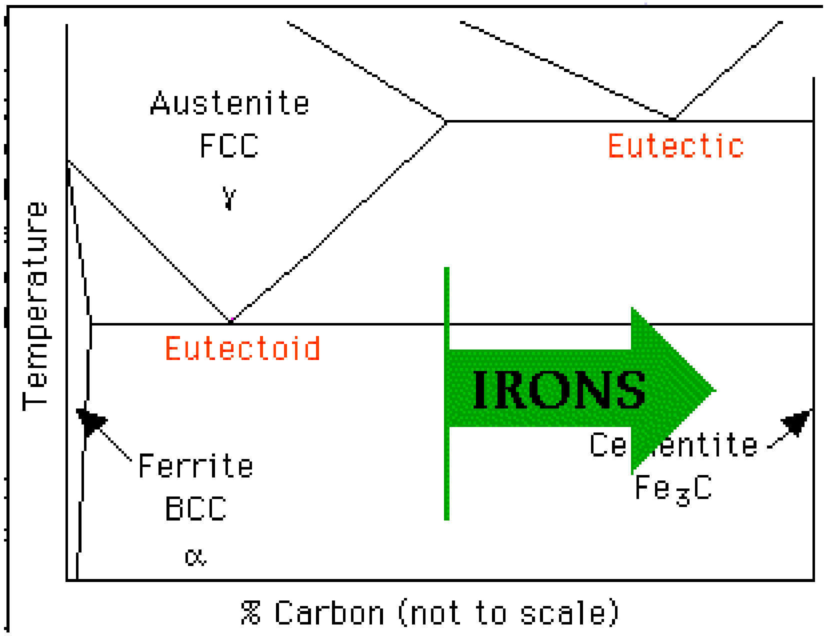
Equilibrium Microstructure of Steel Alloys

The Iron-Iron Carbide Phase Diagram

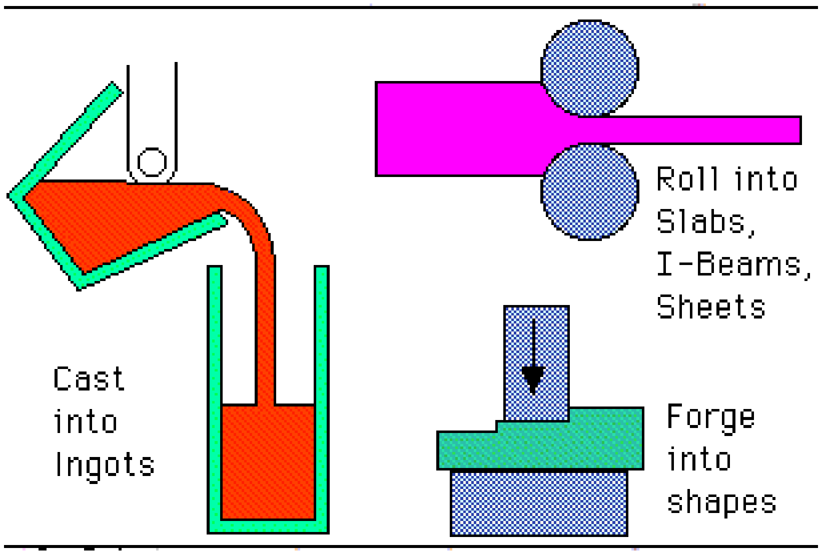


Steels and Irons





Forging



Roll into
Slabs,
I-Beams,
Sheets
Cast
into
Ingots
Forge
into
shapes

Forging

Plain-Carbon Steel

Steel can be defined as an Iron alloy which transforms to *Austenite* on heating.

A plain-carbon steels has no other major alloying element beside carbon.

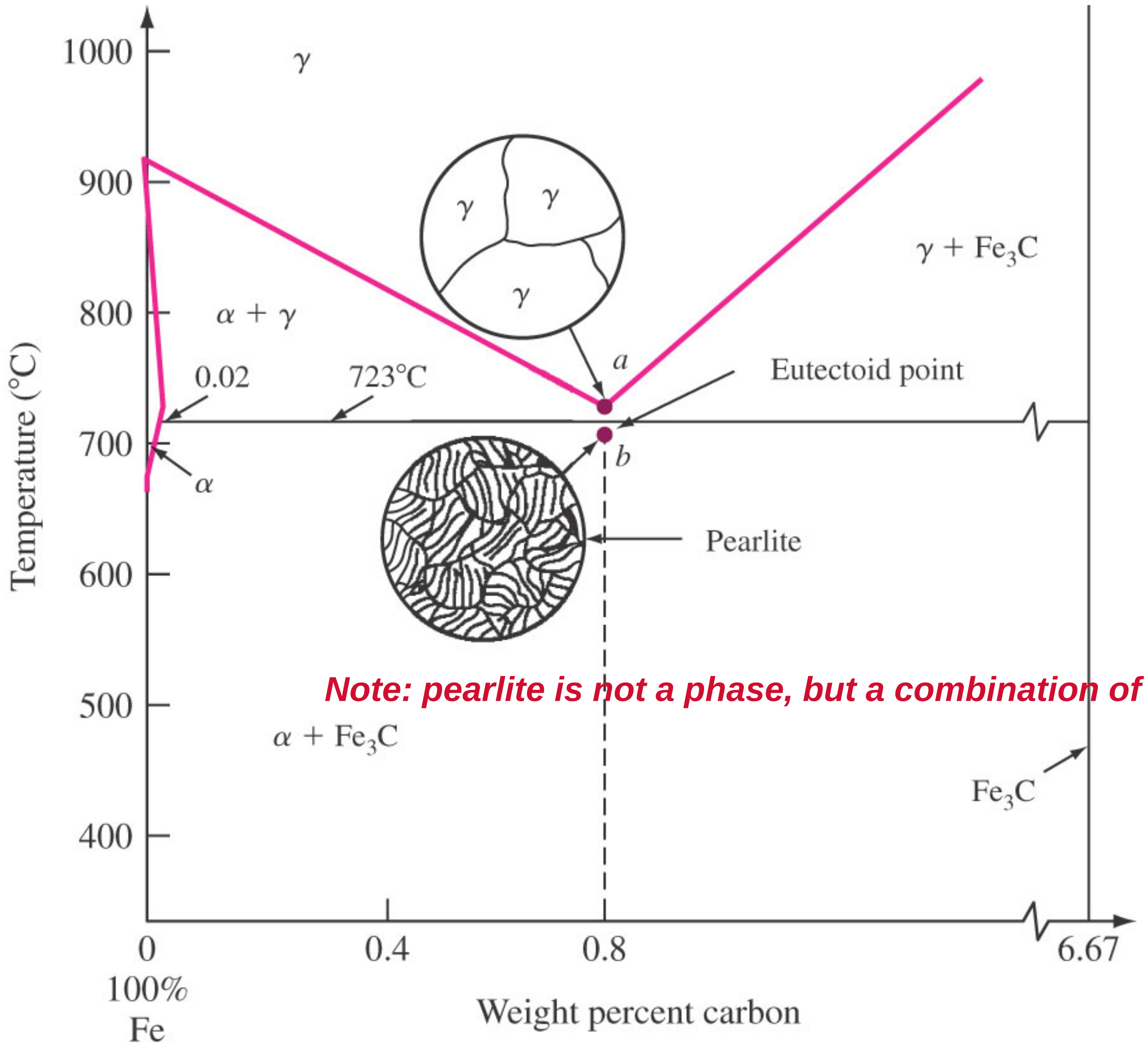
When a plain-carbon steel is slowly cooled from the Austenitic range it undergoes the eutectoid transformation.

Construction steel

Construction steel alloys used for concrete reinforcing bars and structural shapes have been traditionally been 0.1-0.2% C plain-carbon steels with only minor additional elements.

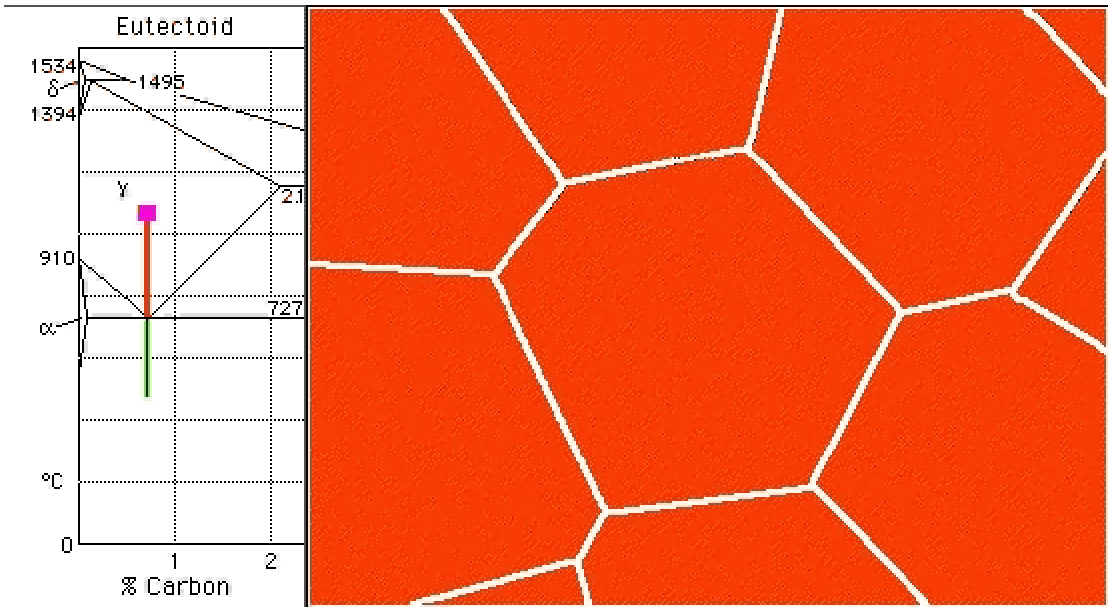
In general these alloys are called *Low-alloy Steel* and for most purposes they can be considered plain-carbon steel.

The Iron-Iron Carbide Eutectoid System



Note: pearlite is not a phase, but a combination of ferrite and cementite

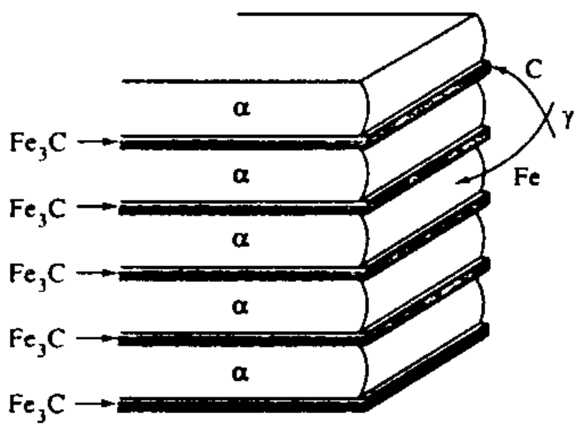
Eutectoid



Eutectoid Microstructures

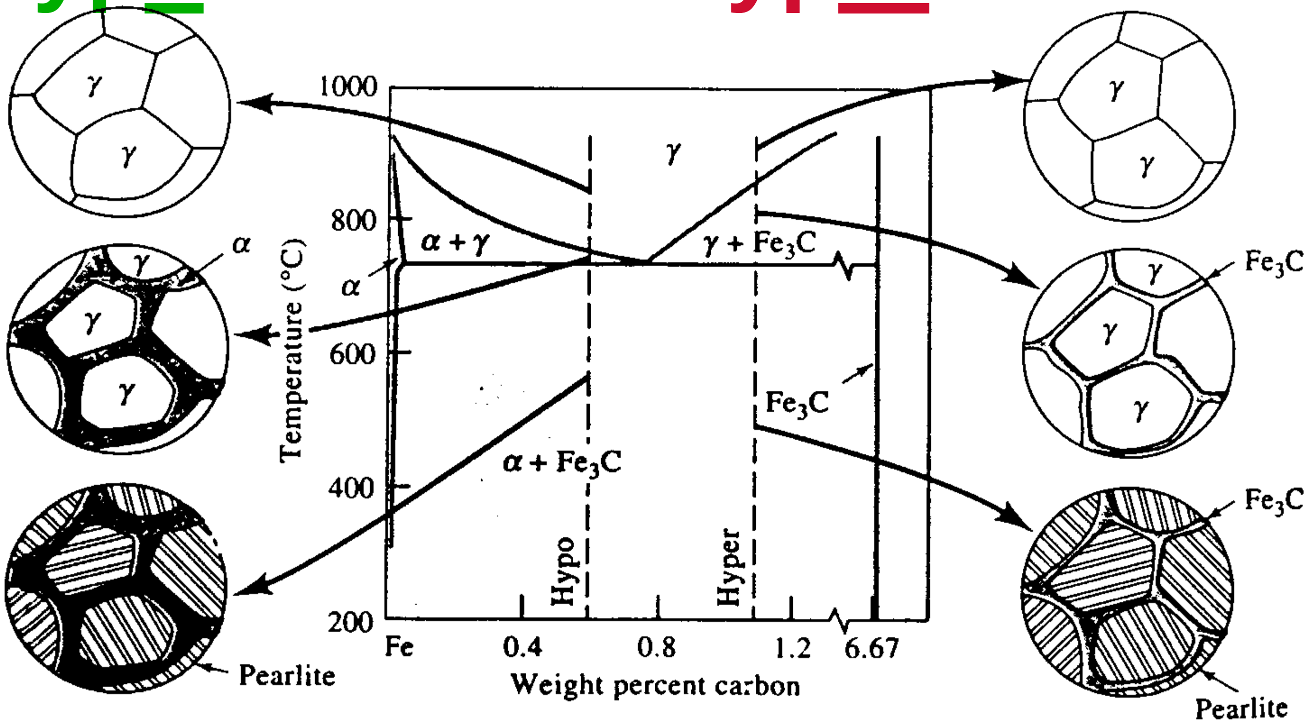
Just like the eutectic systems there are a number of different "morphologies#" for the two phases in a binary eutectic alloy.

The most common morphology for eutectoid areas in the Fe-Fe_3C system is lamellar. (This is because most steel is relatively slowly cooled through the eutectoid phase transformation.)



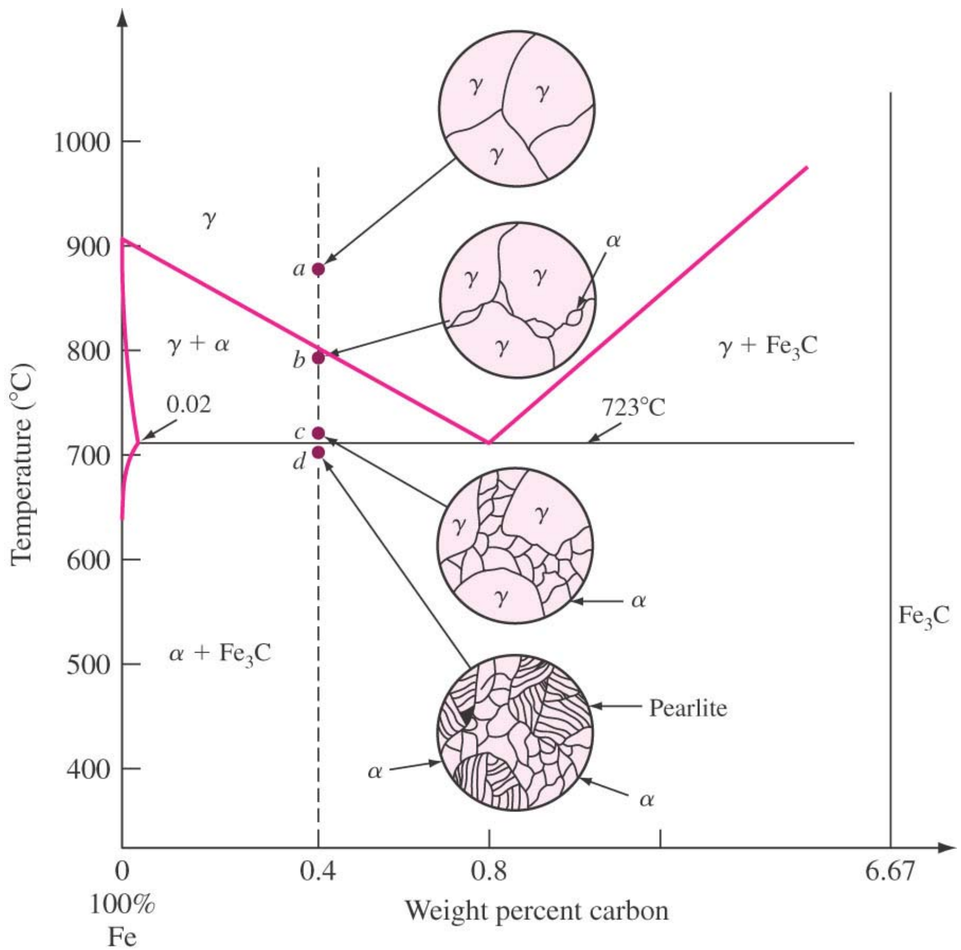
Evolution of Eutectoid Steel Microstructure

Hypoeutectoid Hypereutectoid

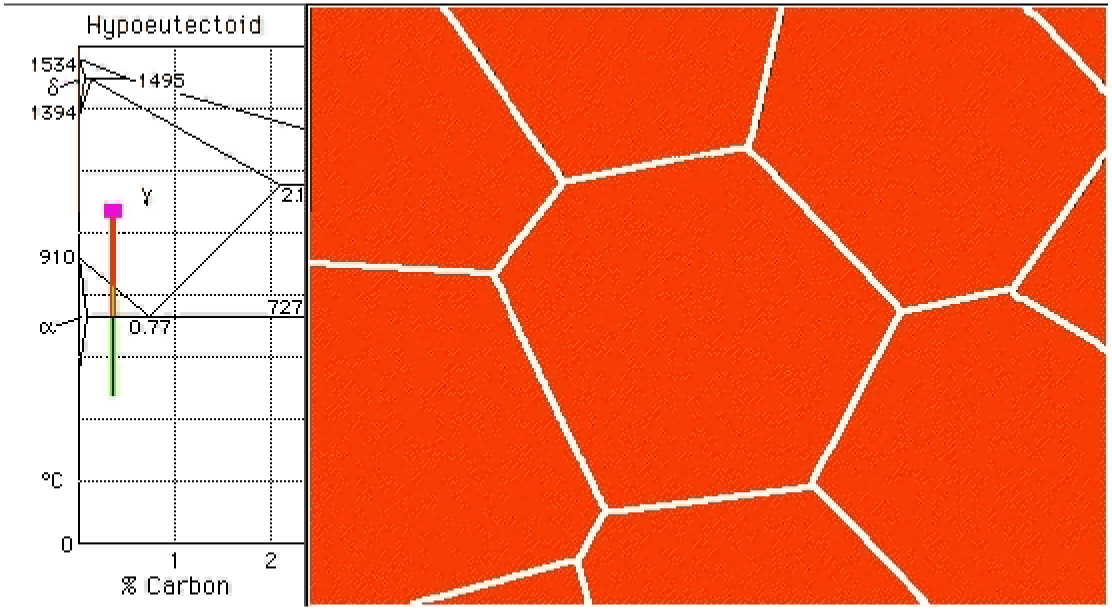


Slow Cooling of Plain-Carbon Steels

Transformation of a 0.4% C hyp<u>o</u>eutectoid plain-carbon steel with slow cooling.

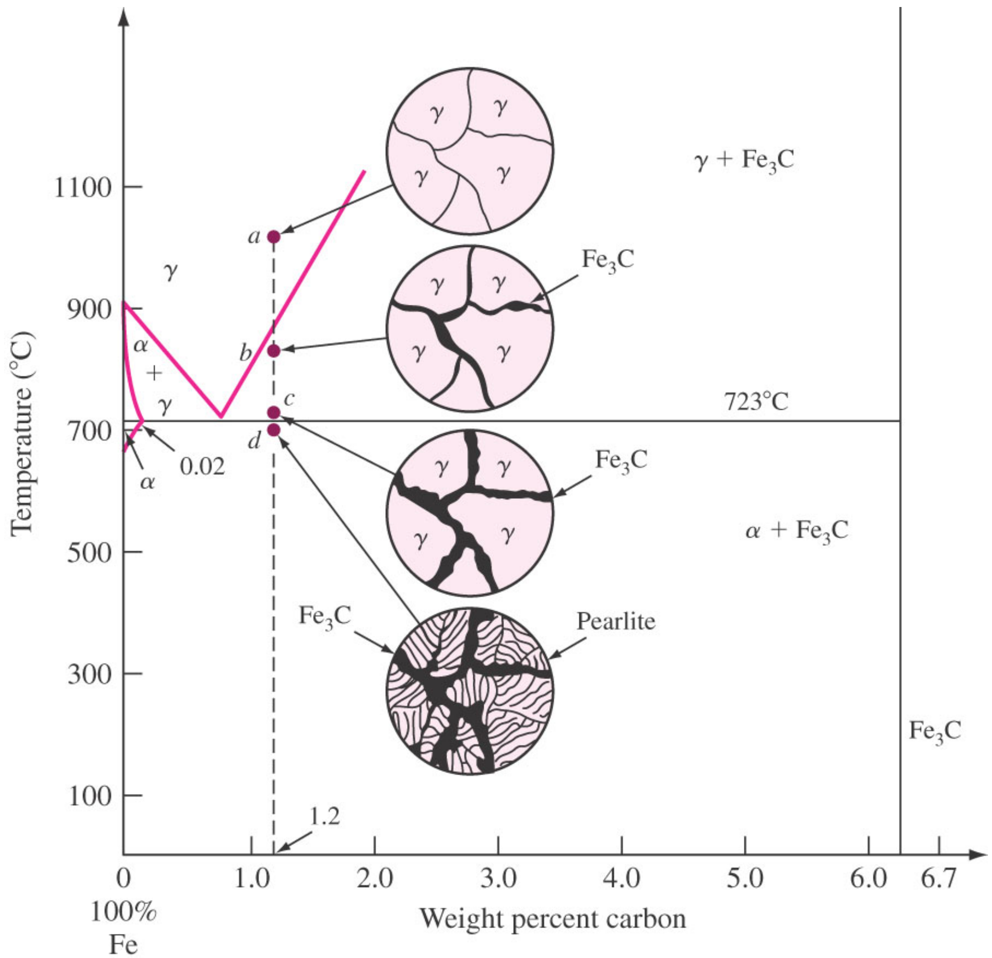


Hypoeutectoid

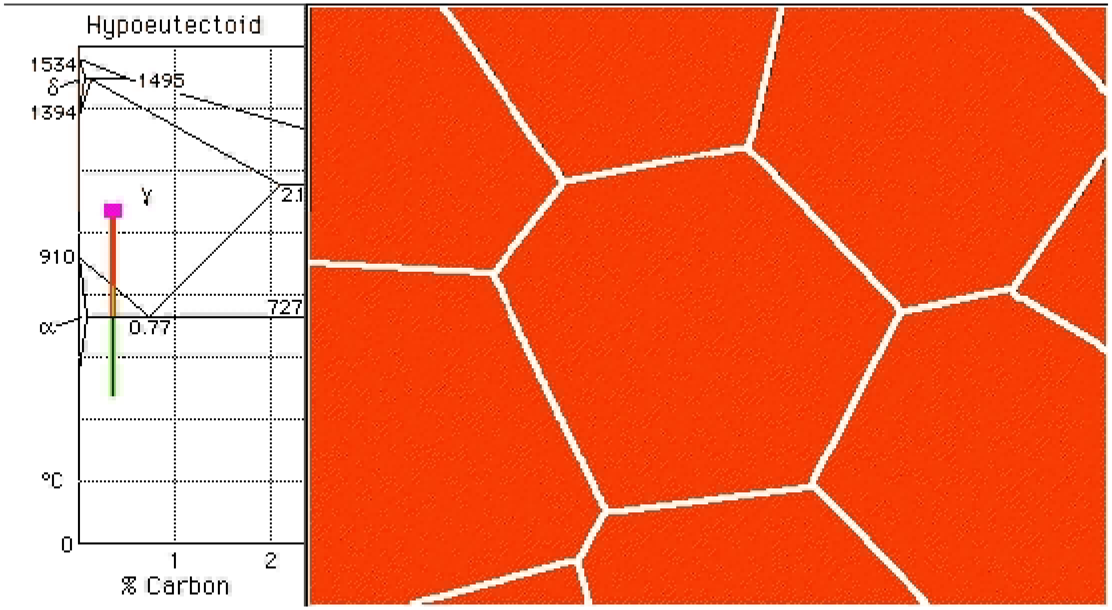


Slow Cooling of Plain-Carbon Steels

Transformation of a 1.2% C hyp*er*eutectoid plain-carbon steel with slow cooling.



Hypereutectoid

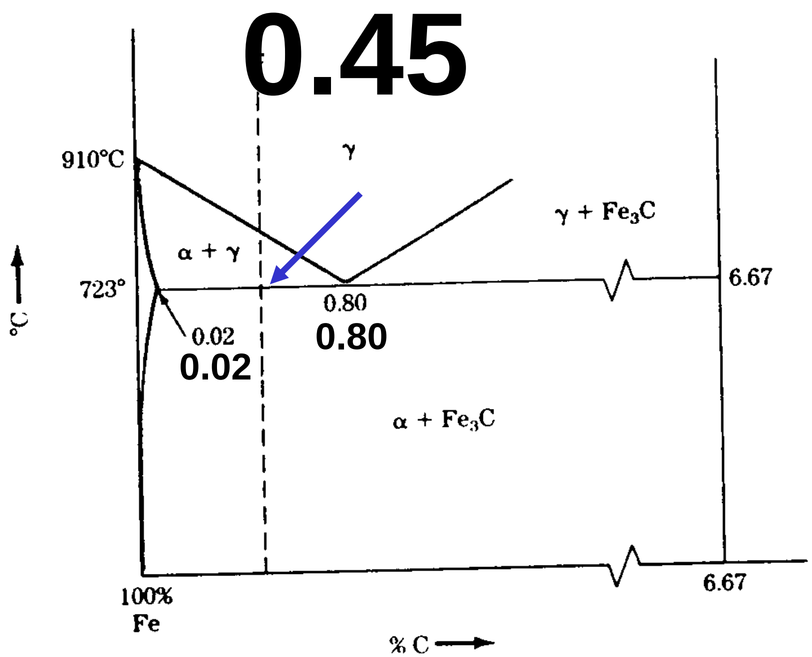


Carbon Steel (90% of the steel production)

- Low alloy steel (up to 6% of chromium, nickel, etc)
- Stainless steel (18% chromium and 8% nickel)
- Tool steels (heavy alloyed with chromium, molybdenum, tungsten, vanadium, and cobalt).

Problem

A 0.45%C hypoeutectoid plain-carbon steel is slowly cooled from 950 C to a temperature just slightly above 723 C. Calculate the weight percent austenite and weight percent proeutectoid ferrite in this steel.



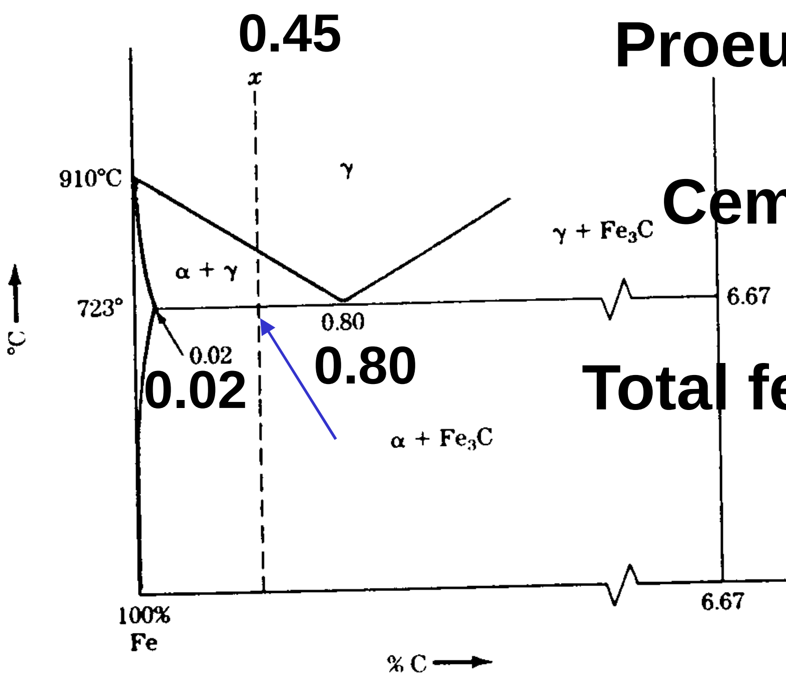
Austenite = (0.45-0.02)/(0.80-0.02) = 55.1%

Proeutectoid Ferrite =(0.80-0.45)/(0.8-0.02)
= 44.9

A 0.45%C hypoeutectoid plain-carbon steel is slowly cooled from 950 C to a temperature just slightly below 723 C.

(a)Calculate the weight percent proeutectoid ferrite in this steel.

(b) Calculate the weight percent eutectoid ferrite and the weight percent eutectoid cementite in this steel.



Proeutectoid Ferrite =(0.80-0.45)/(0.8-0.02)

=44.9%

Cementite = (0.45-0.02)/(6.67-0.02) = 6.5%

Total ferrite = (6.67-0.45)/(6.67-0.02) = 93.5%

Eutectoid ferrite =

total ferrite – proeutectoid ferrite

= 93.5 – 44.9 = 48.6%

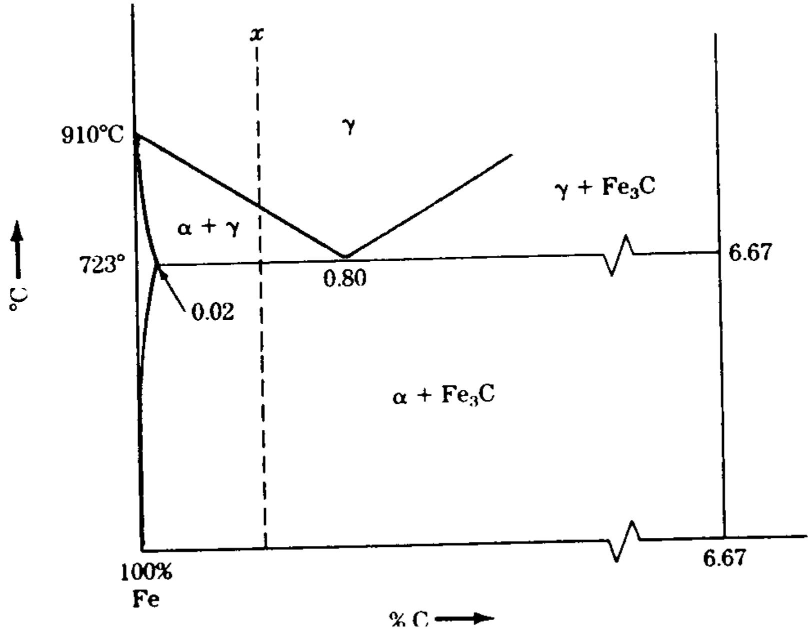
Problem

A hypoeutectoid steel contains 22.5% eutectoid ferrite. What is the average carbon content?

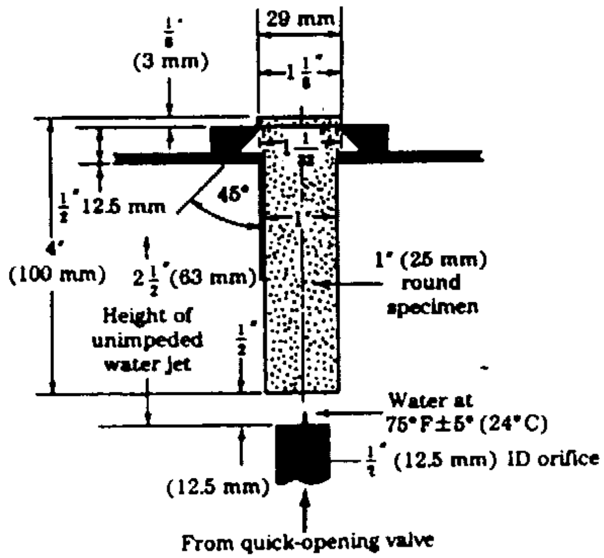
Total ferrite= proeutectoid ferrite + eutectoid ferrite

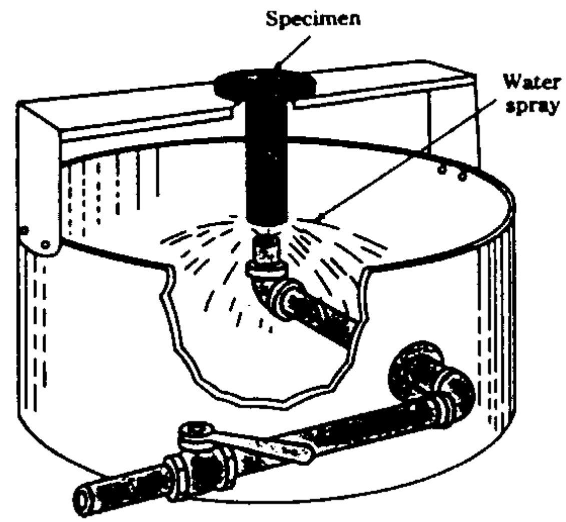
$$(6.67-x)/(6.67-0.02) = (0.80 - x)/(0.8-0.02) + 0.225$$

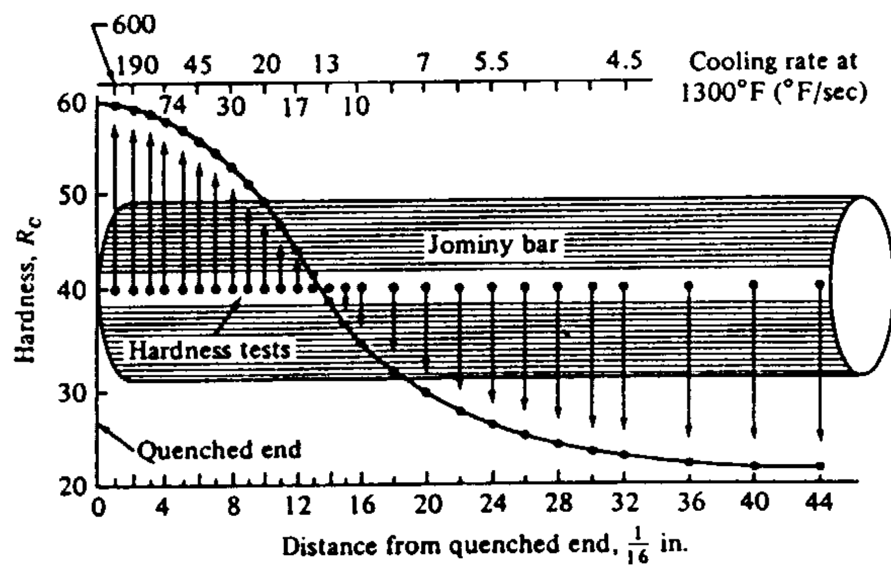
X =0.2



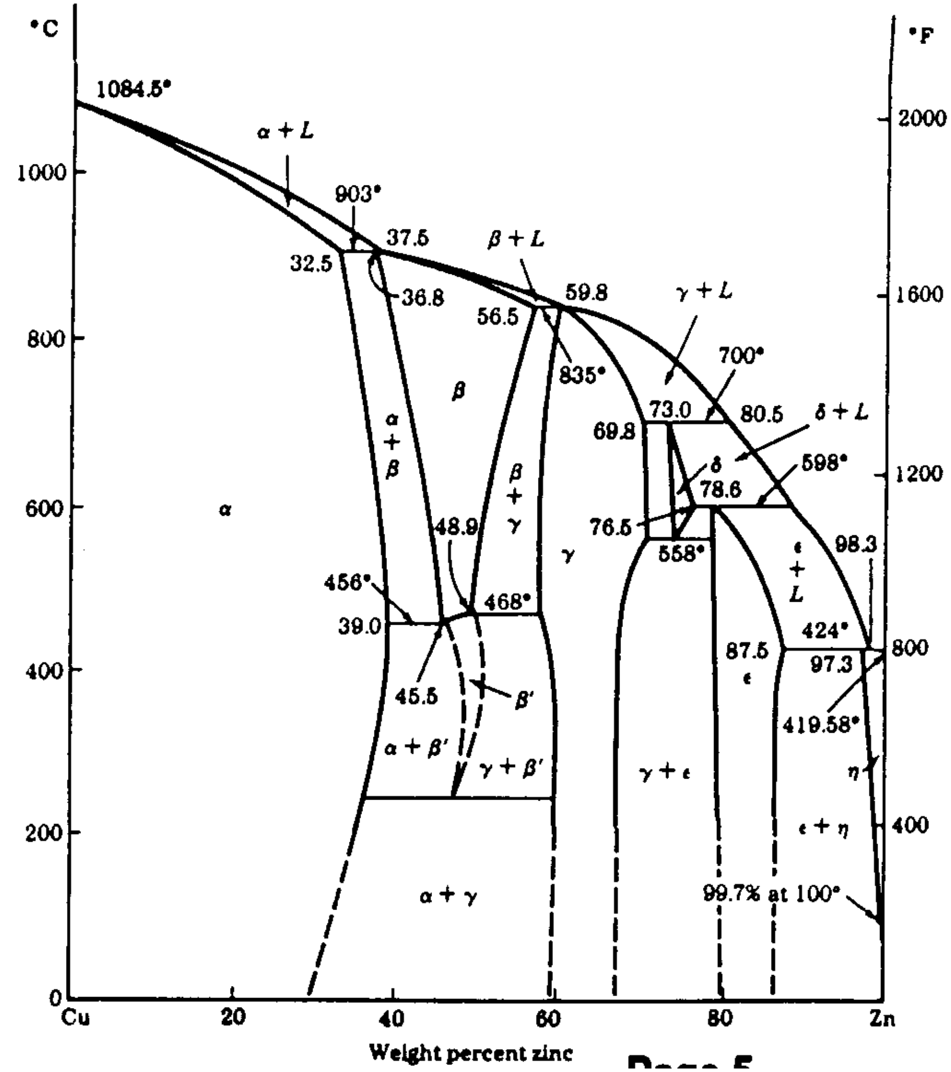
Jominy Hardenability Test







Intermediate Phases - Cu-Zn Example



Hypoeutectoid Phase Diagram

If a steel with a composition *x*% carbon is cooled from the Austenite region at about 770 °C ferrite begins to form. This is called *pro*eutectoid (or *pre-*eutectoid) ferrite since it forms before the eutectoid temperature.