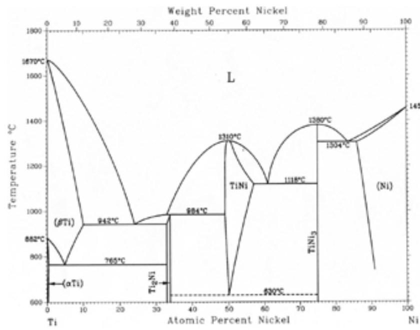
Class 6 & 7: Phase Diagrams



http://met.iisc.ernet.in/~kamanio/subhradeep.htm

PRIME Modules
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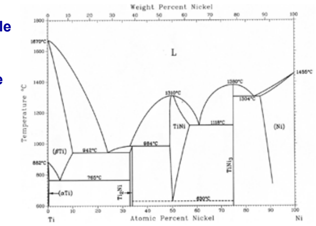
A phase diagram is a plot of the stable phase(s) present as a function of T and composition

Phase diagrams document the stable (predicted phase) as a function of temperature, composition, and/or pressure. The most common phase diagrams are at 1atm pressure and plot T vs composition.



We will talk about 3 types of phase diagrams

- isomorphous
- eutectic
- eutectoid

In designing memory metal applications, phase diagrams are critical in determining the temperature and composition over which one phase NiTi is present.

A phase is a homogeneous portion of a system that has uniform physical and chemical characteristics.

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Examples:

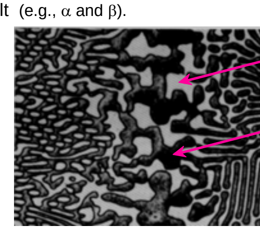
- Pure Iron
- Steel - Solid Solution of Iron and Carbon
- Syrup - Liquid Solution of Sugar and Water
- Ice

Is ice-water a single phase?

What is the difference between component and phase?

- Components:
  The elements or compounds which are mixed initially (e.g., Al and Cu, or Al_2O_3 and Cr_2O_3)
- Phases:
  The physically and chemically distinct material regions that result (e.g., α and β).

Aluminum-Copper Alloy



Adapted from Fig. 9.0, *Callister 3e.*

Adapted from Callister

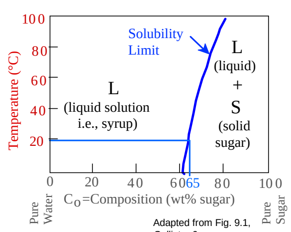
The solubility limit is the maximum concentration for which only 1 phase exists

What is the solubility limit at 20C?

Answer: 65wt% sugar.
If C_o < 65wt% sugar: sugar
If C_o > 65wt% sugar: syrup + sugar.

How does the solubility limit change with temperature?

Solubility limit increases with T:
e.g., if T = 100C,
solubility limit = 80wt% sugar.



Adapted from Fig. 9.1, *Callister 6e.*

Phase Diagram:
Water-Sugar System

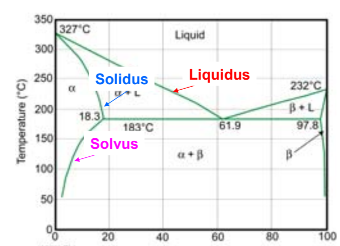
Adapted from Callister

The lines on the phase diagrams mark out solubility limits

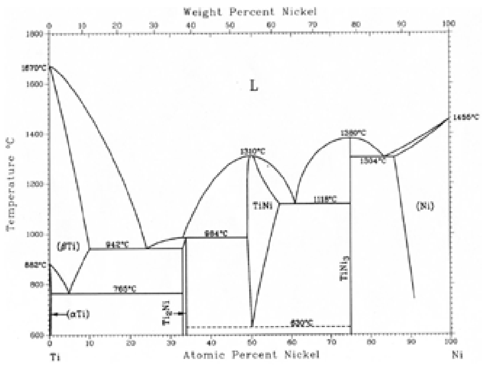
Solidus line marks out the line between a solid and solid + liquid regions

Liquidus line marks out the line between a liquid and solid + liquid regions

Solvus marks out the region where a second phase precipitates out from a solid



Ti Ni Phase Diagram



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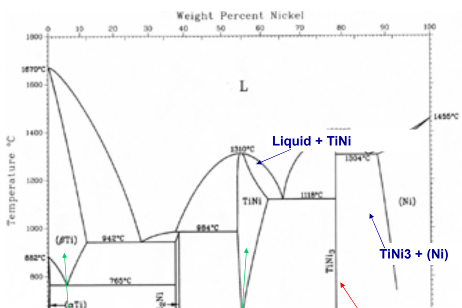
Phases of reach region are determined by the phases of the regions to the left and right

In standard phase diagrams, two phase regions are often not labeled.

The phases present in that region are the single phase regions to the left and right.

In other words, that unlabeled 2 phase region is a transition (contains both) of the 1 phase regions

Ti Ni Example



(βTi) is solid Ti with some Ni dissolved in it as point defects

TiNi is one phase with the Ni and Ti as a basis of two atoms per lattice site on SC lattice

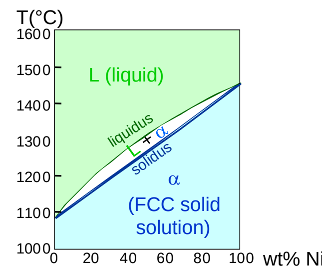
$TiNi_3$: A straight line is an intermetallic compound present only at that exact composition

An isomorphous phase diagram has 1 solid phase

In an **isomorphous phase diagram**, there is complete solid solubility between component A and B.

This means that as you go from pure A to pure B, you have only 1 phase.

In a **congruent transformation**, a solid of one composition transforms directly to a liquid of the same composition.

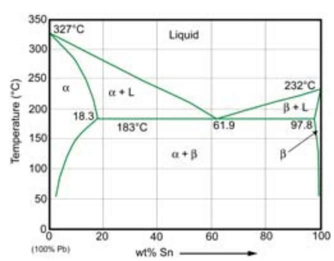


Adapted from Fig. 9.2(a), *Callister 6e.* (Fig. 9.2(a) is adapted from *Phase Diagrams of Binary Nickel Alloys*, P. Nash (Ed.), ASM International, Materials Park, OH (1991).

A eutectic phase diagram contains a point where liquid transforms directly to 2 solids

A **eutectic** phase diagram has an invariant point.

At this point, liquid transforms directly into 2 solids
$L \rightarrow \alpha + \beta$

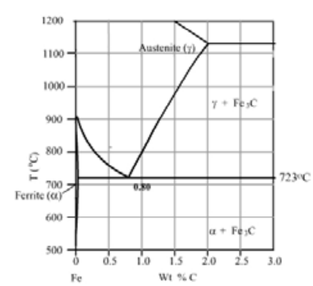


Adapted from Callister
Adapted from Callister

A eutectoid phase diagram contains a point where a solid transforms directly to 2 other solids

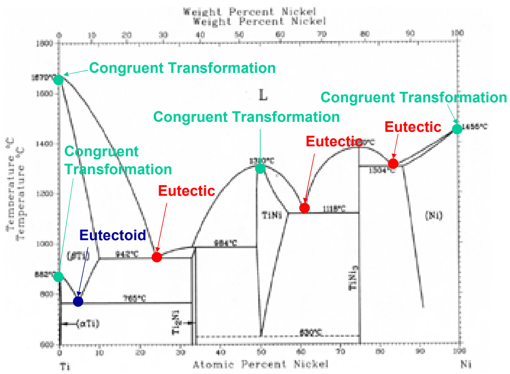
A **eutectoid** phase diagram has an invariant point.

At this point, 1 solid transforms directly into 2 other solids
$\delta \rightarrow \gamma + \varepsilon$



http://www-g.eng.cam.ac.uk/mmg/teaching/typd/addenda/eutectoidreaction1.html

Ti Ni Phase Diagram Example



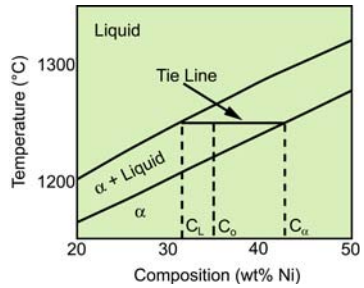
http://met.iisc.ernet.in/~kamanio/subhradeep.htm

A tie line is used to determine the composition of the phases in a 2 phase region

Draw a line horizontal to the x axis at the desired temperature.

This is a tie line.

The intercept of the line with the solidus, liquidus, or soluvs lines gives the composition of the two phases.



Adapted from Callister

In summary, phase diagrams predict the equilibrium phases and compositions

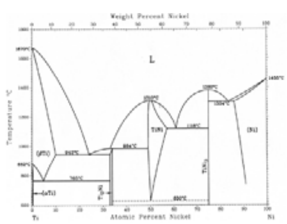
Phase diagrams plot the equilibrium phases as a function of temperature, composition, (and and sometimes pressure).

Three main types of phase diagrams are isomorphous, eutectic, and eutectoid.

The solidus, liquidus, and solvus lines mark out the two phase regions.

Two phase regions can be labeled by the single phase regions to the left and right.

Tie lines are used to determine the composition in 2 phase regions.

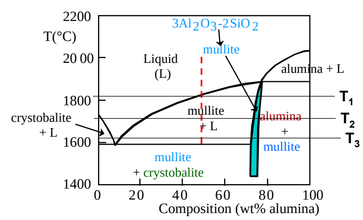


The tie line can be used to determine the relative fraction of each phase

As you cool along the line shown here, you go from mostly liquid to mostly solid. That is, you convert liquid to solid.

As we showed last class, the tie line can be used at any temperature to give you the composition (%A and %B) of the liquid and solid.

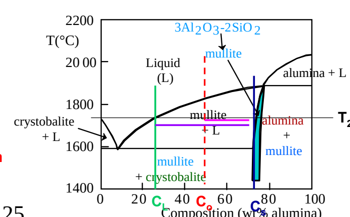
We are also interested in knowing the fraction of liquid and solid you have at any temperature.



Adapted from Fig. 12.27, *Callister 6e.* (Fig. 12.27 is adapted from F.J. Klug and R.H. Doremus, "Alumina Silica Phase Diagram in the Mullite Region", *J. American Ceramic Society* **70**(10), p. 758, 1987.)

The lever rule calculates the fraction of each phase present

The lever rule states that the fraction of the phase is the length of tie line opposite the phase divided by the whole tie line.



Overall composition

$$W_L = \frac{C_s - C_o}{C_S - C_L} = \frac{50-25}{73-25} = 0.52$$

$$W_S = \frac{C_o - C_L}{C_S - C_L} = \frac{73-50}{73-25} = 0.48$$

Adapted from Fig. 12.27, *Callister 6e.* (Fig. 12.27 is adapted from F.J. Klug and R.H. Doremus, "Alumina Silica Phase Diagram in the Mullite Region", *J. American Ceramic Society* **70**(10), p. 758, 1987.)

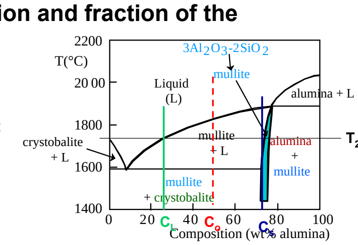
Keep track of the important difference between composition and fraction of the phase

At T_2

The fraction of liquid is 0.52
The fraction of solid is 0.48

The liquid composition is
50 wt% alumina
50 wt% silica

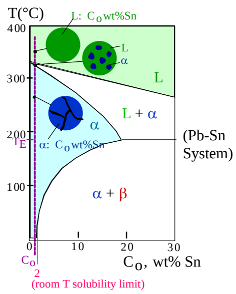
The solid (mullite) composition is
73 wt% alumina
27 wt% silica



Adapted from Fig. 12.27, *Callister 6e.* (Fig. 12.27 is adapted from F.J. Klug and R.H. Doremus, "Alumina Silica Phase Diagram in the Mullite Region", *J. American Ceramic Society* **70**(10), p. 758, 1987.)

The phase diagram tells us about the microstructure based on what forms upon cooling

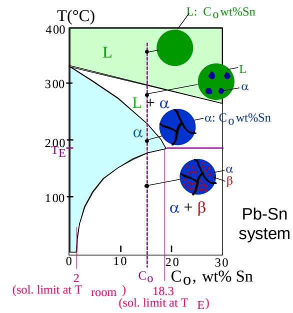
In the simplest case, liquid cools to a polycrystalline solid



Adapted from Fig. 9.9, *Callister 6e.*

The phase diagram tells us about the microstructure based on what forms upon cooling

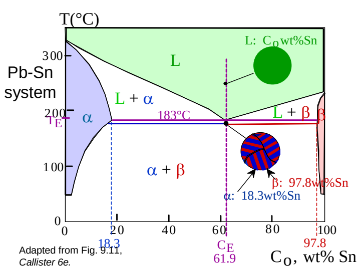
If we move over in composition (more Sn), first the liquid converts to all α and then some β forms



Adapted from Fig. 9.10, *Callister 6e.*

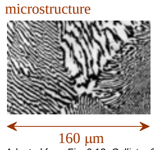
At the eutectic, the liquid all converts directly to α and β

At the eutectic temperature and composition liquid converts directly (completely) to α and β



Adapted from Fig. 9.11, *Callister 6e.*

Micrograph of Pb-Sn eutectic microstructure

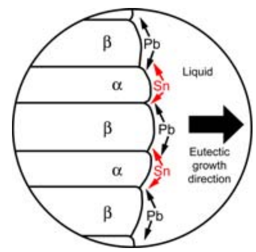


Adapted from Fig. 9.12, *Callister 6e.* (Fig. 9.12 from *Metals Handbook*, Vol. 9, 9th ed., *Metallography and Microstructures*, American Society for Metals, Materials Park, OH, 1985.)

The eutectic lamellar structure forms to minimize diffusion

α is a Pb rich phase. It has to receive Pb, give off Sn, relative to the original C_o.
β is a Sn rich phase. It has to receive Sn, give off Pb, relative to the original Co.

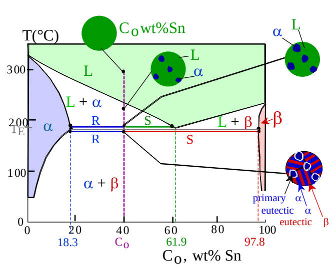
The alternating plates (lamellar structure) forms to minimize the distance Pb and Sn need to diffuse.



W.D. Callister, Materials Science and Engineering An Introduction 5/e, (John Wiley and Sons, New York, 2000).

When you are off the eutectic, solid forms first before the eutectic lamellar

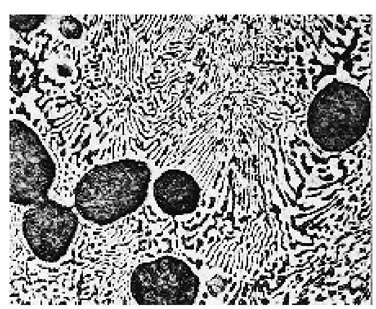
- Just above T_E:
  - C_α = 18.3wt%Sn
  - C_L = 61.9wt%Sn
  - $W_\alpha = \frac{S}{R+S}$ =50wt%
  - $W_L = (1-W_\alpha)$ =50wt%
- Just below T_E:
  - C_α = 18.3wt%Sn
  - C_β = 97.8wt%Sn
  - $W_\alpha = \frac{S}{R+S}$ =73wt%
  - W_β = 27wt%



Pb-Sn system

Adapted from Fig. 9.14, *Callister 6e.*

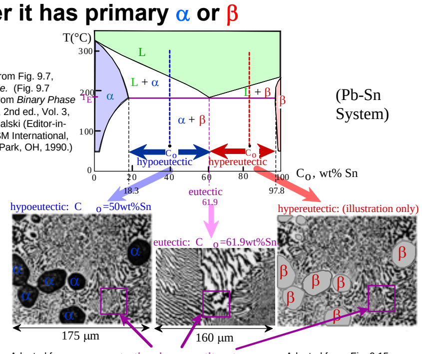
Microstructure of lead-tin alloy of composition
50 wt% Pb - 50 wt% Sn shows primary α and the eutectic structure



W.D. Callister, Materials Science and Engineering An Introduction 5/e, (John Wiley and Sons, New York, 2000).

HYPOEUTECTIC & HYPEREUTECTIC differ in whether it has primary α or β

Adapted from Fig. 9.7, *Callister 6e.* (Fig. 9.7 adapted from *Binary Phase Diagrams*, 2nd ed., Vol. 3, T.B. Massalski (Editor-in-Chief), ASM International, Materials Park, OH, 1990.)



(Figs. 9.12 and 9.15 from *Metals Handbook*, 9th ed., Vol. 9, *Metallography and Microstructures*, American Society for Metals, Materials Park, OH, 1985.)

Adapted from Fig. 9.15, *Callister 6e.*

Adapted from Fig. 9.12, *Callister 6e.*

Adapted from Fig. 9.15, *Callister 6e.* (Illustration only)

In summary, phase diagrams can be used to tell the fraction of each phase and the microstructure

The lever rule is used to tell the fraction of each phase present.

Following each region of phase diagram you go through on cooling can be used to tell the microstructure of a given composition.

If you go outside of the temperature and composition region of TiNi, you will form a second phase. You can determine the microstructure, composition, and fraction of each phase using the phase diagram.