Binary Phase Diagrams

- A binary phase is a two component system. Temperature & Composition are the usual variables in binary phase diagrams.
- Pressure changes often have little effect on the equilibrium of solid phases. Hence, binary phase diagrams are usually drawn at 1 atmosphere pressure.
- Binary phase diagrams are most commonly used in alloy designing.
- The Gibbs phase rule is reduced to F = C – P + 1. (1 is for T).
- Fe-Ni, Cu-Ni, Ag-Au, Al_2O_3-Cr_2O_3, Pb-Sn and Fe-Fe_3C are the examples for a two-component system.

Classification of binary phase diagrams

- These have been classified based on:

1. Two metals Complete Solubility in both liquid & solid states- Isomorphous binary alloy system.
2. Partial Solubility in solid state-Eutectic system
3. Phase diagram containing three phase reactions

The tie-line rule -The Lever Rule

A tie-line is a horizontal line drawn in a two-phase region of a binary phase diagram, to determine the composition of two phases.

- Consider the phase diagram of metal A (Cu) and metal B (Ni). The composition is plotted on X-axis and temperature on Y-axis. Let x be the alloy composition of interest and T be the temperature of interest.

Simple procedure to find the equilibrium compositions of the two phases

1. A tie line is constructed across the two-phase region at the temperature of the alloy.

2. The intersections of the tie line and the phase boundaries on either side are noted.

3. Vertical lines are dropped from these intersections to the horizontal composition axis,

from which the composition of each of the respective phases is determined.

4. The opposite arms of the lever are proportional to the fraction of the solid and liquid

phases present (this is the lever rule).

$$W_L = \frac{LO}{LS} \quad and \quad W_S = \frac{OS}{LS}$$

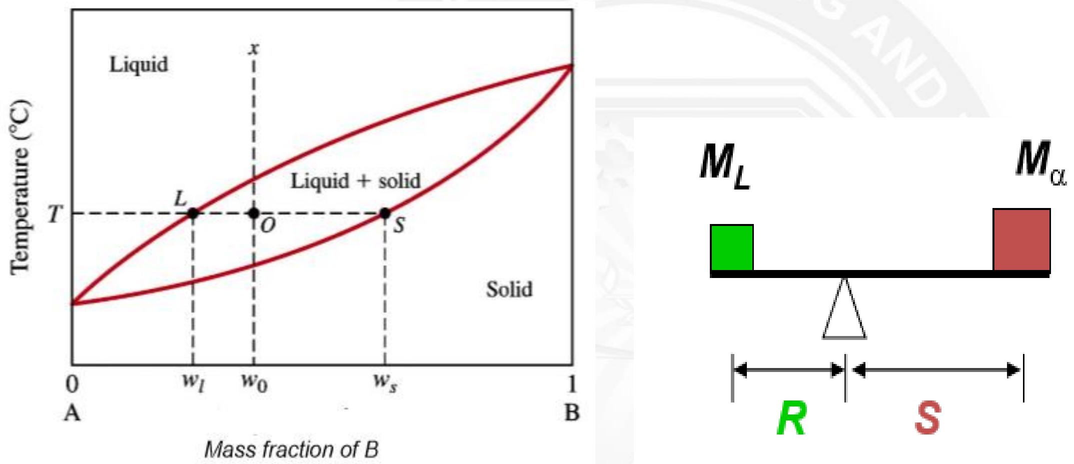


Figure.1.9 Tie line and lever rule

Lever Rule

The lever rule is used to find the fractions of liquid phase and solid phase in the binary alloy in the two-phase state at equilibrium.

The rule can be obtained by using the law conservation of mass.

Let W_L be the weight fraction of liquid phase and W_S be the weight fraction of solid phase in the binary alloy in the state B.

Then $W_L + W_S = 1$ ………… (1)

The mass fraction of Ni in the liquid phase + the mass fraction of Ni in the solid phase must be equal to the mass fraction of Ni in the $S + L$ phase.

The mass fraction of Ni in the liquid phase of mass fraction $W_L = C_L W_L$

The mass fraction of Ni in the solid phase of mass fraction $W_S = C_S W_S$

The mass fraction of Ni in the $(S+L)$ phase = C_o

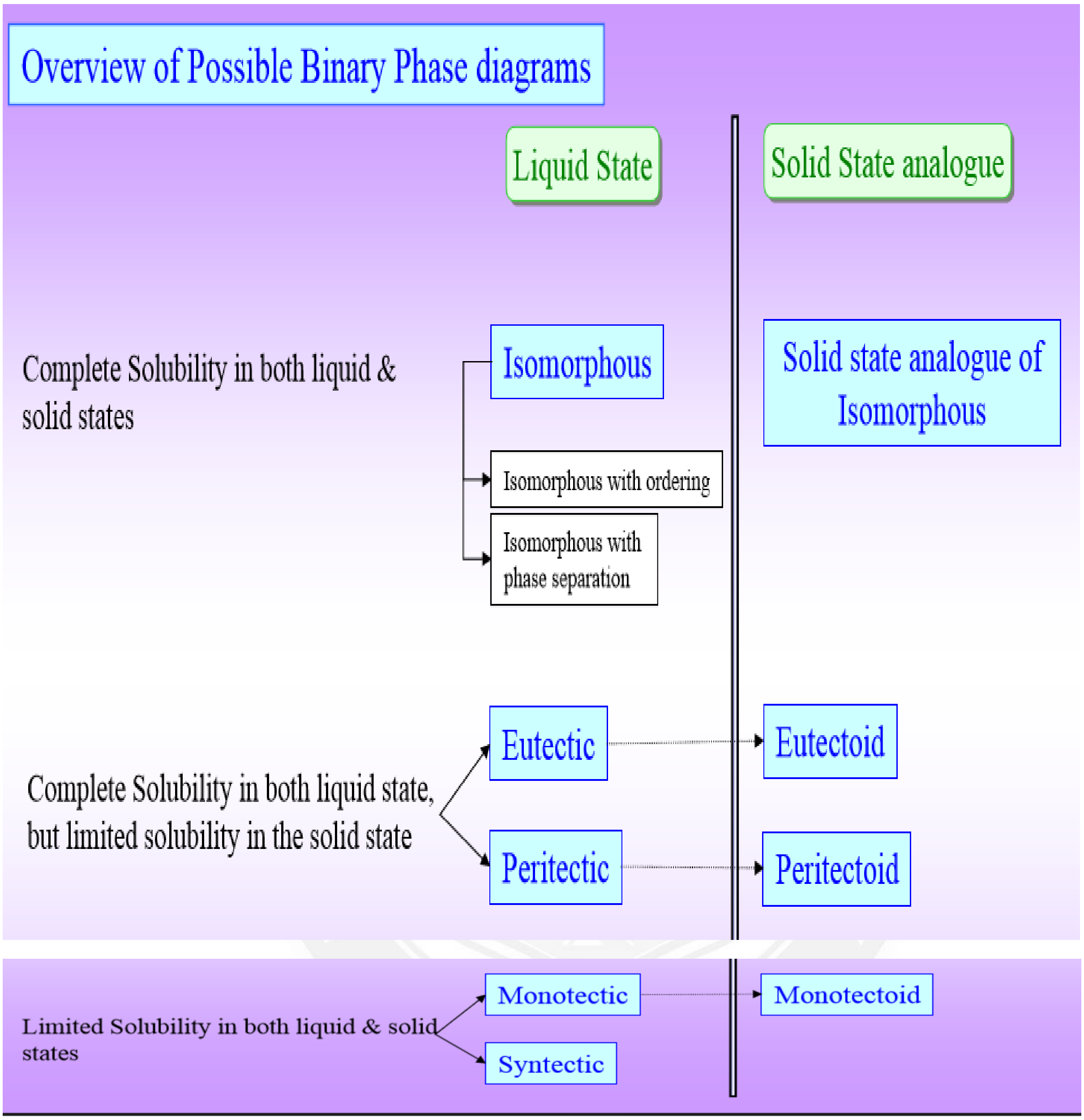
So $C_L W_L + C_S W_S = C_o$ ……………… (2)

From equations (1) and (2)

$$W_L = \frac{C_S - C_o}{C_S - C_L} \quad \text{and} \quad W_S = \frac{C_o - C_L}{C_S - C_L}$$

Thus one can find the composition of liquid phase and solid phase in the two-phase system and also the composition of the constituents in the liquid phase and the solid phase, using the phase diagram.

Overview of Possible Binary Phase diagrams



Isomorphous binary alloy system

In some binary metallic systems, the two elements completely soluble in each other in both the liquid and solid state. In these systems, only a single type of crystal structure exists for all compositions of the components, and therefore they are called isomorphous systems.

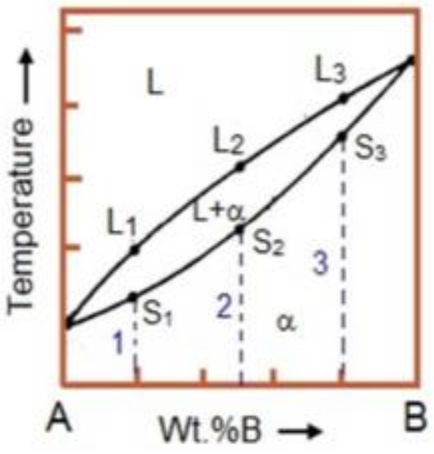
- An important example of an isomorphous binary alloy system is the copper–nickel system.
- Temperature is plotted along the ordinate, and the abscissa represents the composition of the alloy.
- The composition ranges from 0 wt% Ni (100 wt% Cu) on the left horizontal extremity to 100 wt%Ni (0 wt% Cu) on the right.
- Three different phase regions appear on the diagram, a solid (α) field, a liquid (*L*) field, and a two-phase (α+ *L)* field.
- The solid (α) phase is a substitutional solid solution consisting of both Cu and Ni atoms, and having an FCC crystal structure.
- The liquid *L* is a homogeneous liquid solution composed of both copper and nickel.
- This complete solubility is explained by the fact that both Cu and Ni have the same crystal structure (FCC), nearly identical atomic radii and electronegativities, and similar valences.
- **Liquidus** line is the line or boundary that separates liquid and liquid + solid phase regions. The liquid phase is present at all temperatures and compositions above this line. **Solidus line** is the line or boundary that separates solid and solid + liquid phase regions. The line below which solidification completes is called solidus line.
- The intermediate region between liquidus and solidus lines is the two-phase region where liquid and solid coexists. It can be noted that the two metals are soluble in each other in the entire range of compositions in both liquid and solid state. This kind of system is known as 'Isomorphous'system.

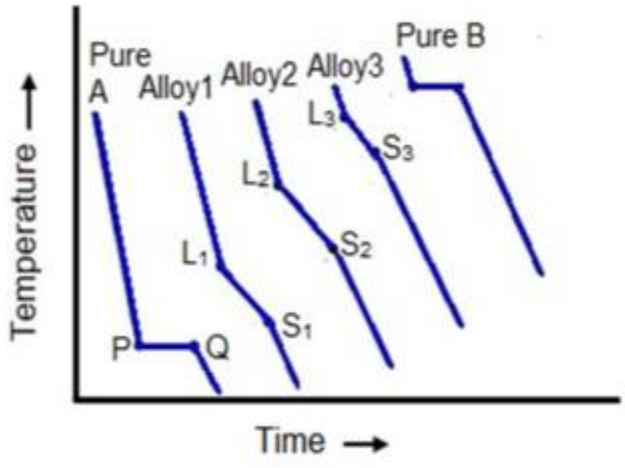
- The copper–nickel system is termed **isomorphous** because of this complete liquid and solid solubility of the two components.
- The melting temperatures of pure copper and nickel are 1085ºC and 1453ºC, respectively. At temperatures below about 1085ºC, copper and nickel are mutually soluble in each other in the solid state for all compositions.

For example, upon heating an alloy of composition 50 wt% Ni–50 wt% Cu (Figure 9.3*a*), melting begins at approximately 1280ºC (2340ºF); the amount of liquid phase continuously increases with temperature until about 1320ºC (2410ºF), at which the alloy is completely liquid.

Cooling curves

- Upon cooling from liquid state, the temperature of the pure metal (A or B) drops continuously till melting point at which solidification starts.
- Solidification happens at a constant temperature (line PQ) as F =0 (F = 1 –2 +1 = 0). The temperature drops again on completion of solidification.
- For any alloy (1, 2, 3 etc.) temperature drops till the liquidus (L_1, L_2, L_3). However, in this case, solidification proceeds over a range of temperature as F = 1 (2 –2 + 1 = 1).
- Once solidification completes at the solidus (S_1, S_2, S_3) the temperature drops again.





INTERPRETATION OF PHASE DIAGRAMS

For a binary system of known composition and temperature that is at equilibrium, at least three kinds of information are available:

(1) the phases that are present,

(2) the compositions of these phases, and

(3) the percentages or fractions of the phases.

Phases Present

- An alloy of composition 60 wt% Ni–40 wt% Cu at 1100ºC would be located at point *A* in Figure 9.3*a*; because this is within the solid (α) region, only the single α phase will be present. The Gibbs phase rule is reduced to F = C – P + 1. Here C=2 and P=1 $\therefore F = 2-1+1=2$
- On the other hand, a 35 wt% Ni–65 wt% Cu alloy at 1250 ºC (point *B*) will consist of both solid and liquid phases at equilibrium. Here C=2 and P=2 $\therefore F = 2-2+1=1$

Determination of Phase Compositions

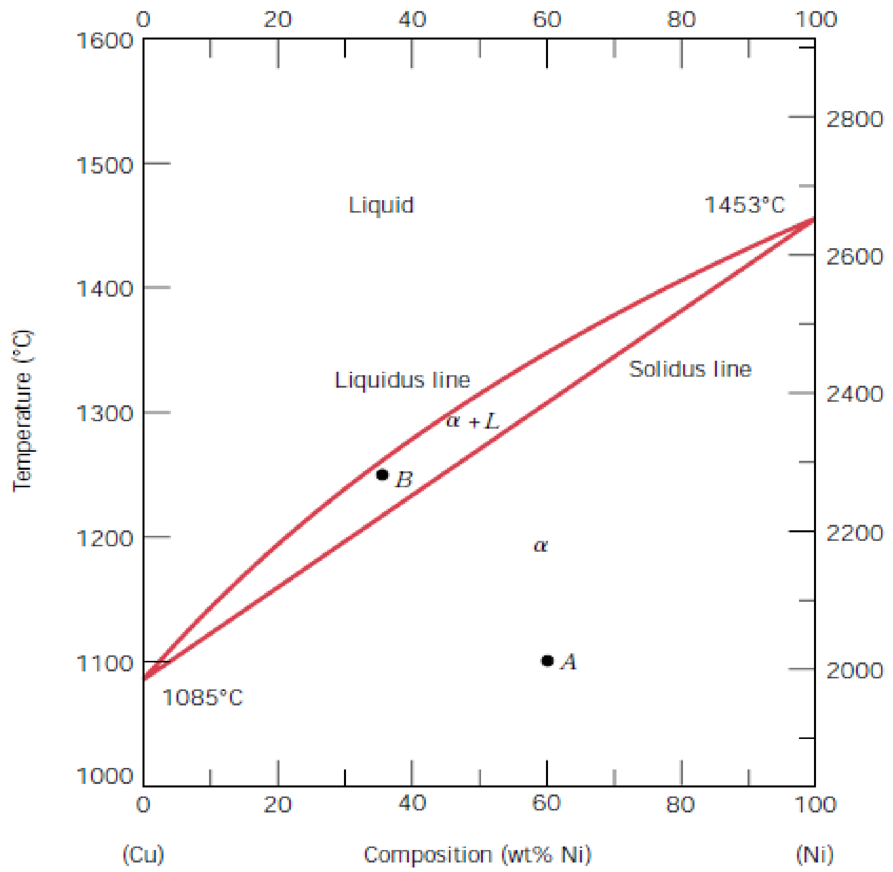
- For an alloy having composition and temperature located in a two-phase region, the situation is more complicated. To compute the equilibrium concentrations of the two phases, the following procedure is used.

1. A tie line is constructed across the two-phase region at the temperature of the alloy.

2. The intersections of the tie line and the phase boundaries on either side are noted.

3. Vertical lines are dropped from these intersections to the horizontal composition axis,

from which the composition of each of the respective phases is determined.



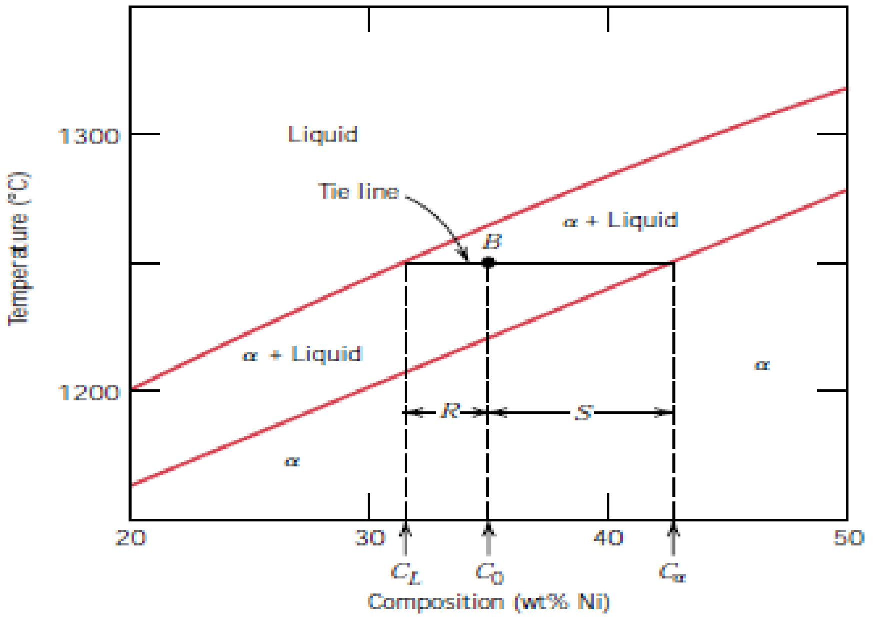


Figure1.10 Isomorphous binary alloy system and its phase composition

Overall composition C_o = 35 wt% Ni–65 wt% Cu alloy at 1250 ºC, located at point *B*

Liquid composition C_L = 31.5 wt% Ni–68.5 wt% Cu

Solid composition C_α =42.5 wt% Ni–57.5 wt% Cu.

Determination of Phase Amounts

- The relative amounts (as fraction or as percentage) of the phases present at equilibrium may also be computed with the aid of phase diagrams. Then we have to apply the **lever rule.**

From figure,

C_o = 35 wt% Ni C_L = 31.5 wt% Ni C_α =42.5 wt% Ni

$$W_L = \frac{C_\alpha - C_o}{C_\alpha - C_L} = \frac{42.5 - 35}{42.5 - 31.5} = 0.68 = 68\%$$ and

$$W_\alpha = \frac{C_o - C_L}{C_\alpha - C_L} = \frac{35 - 31.5}{42.5 - 31.5} = 0.32 = 32\%$$

- Thus, the lever rule may be employed to determine the relative amounts or fractions of phases in any two-phase region for a binary alloy if the temperature and composition are known and if equilibrium has been established

Al_2O_3 –Cr_2O_3 binary alloy system

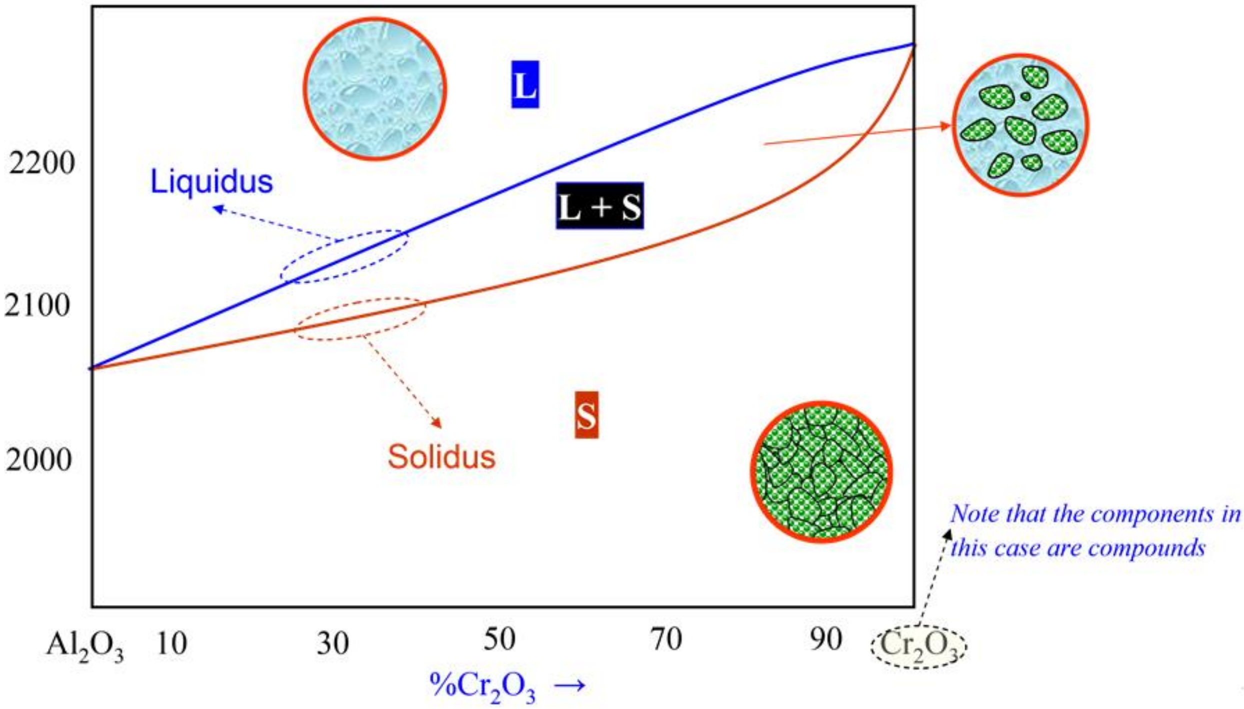


Figure.1.11 Al_2O_3 –Cr_2O_3 binary alloy system

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