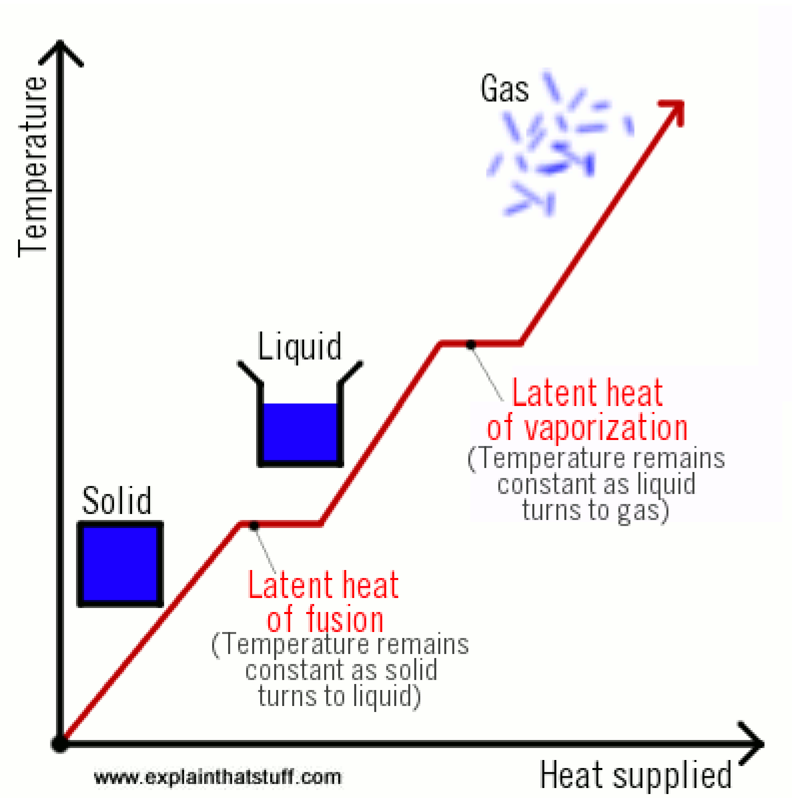
- **ENTHALPY OF FUSION:** the amount of energy that must be supplied to a **solid** substance (typically in the form of heat) in order to trigger a change in its physical state and convert it **into** a **liquid** (when the pressure of the environment is kept constant).
- **ENTHALPY OF VAPORIZATION:** the amount of energy (enthalpy) that must be added to a **liquid** substance, to transform a quantity of that substance into a **gas**.

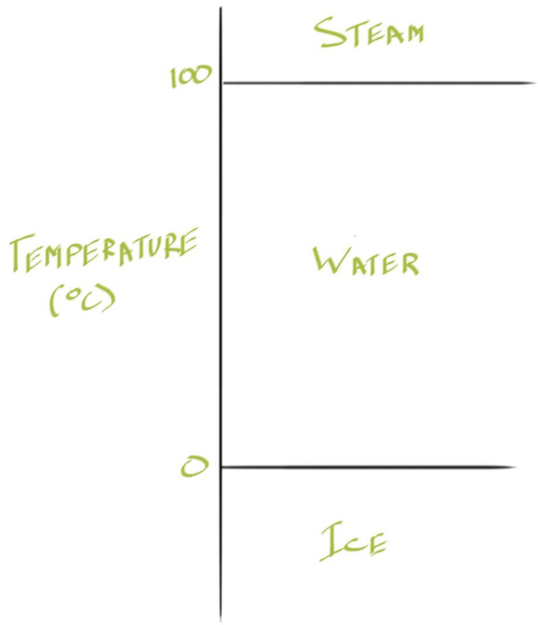


$$q = mc\Delta T$$

- **<u>Chapter 11: Phase Diagrams</u>**

A phase diagram is nothing more than a graphical depiction of the equilibrium phases for all the possible combinations of temperature and composition.

1. THE TEMPERATURE AXIS:
    - y-axis
    - One dimensional phase diagram for pure water:



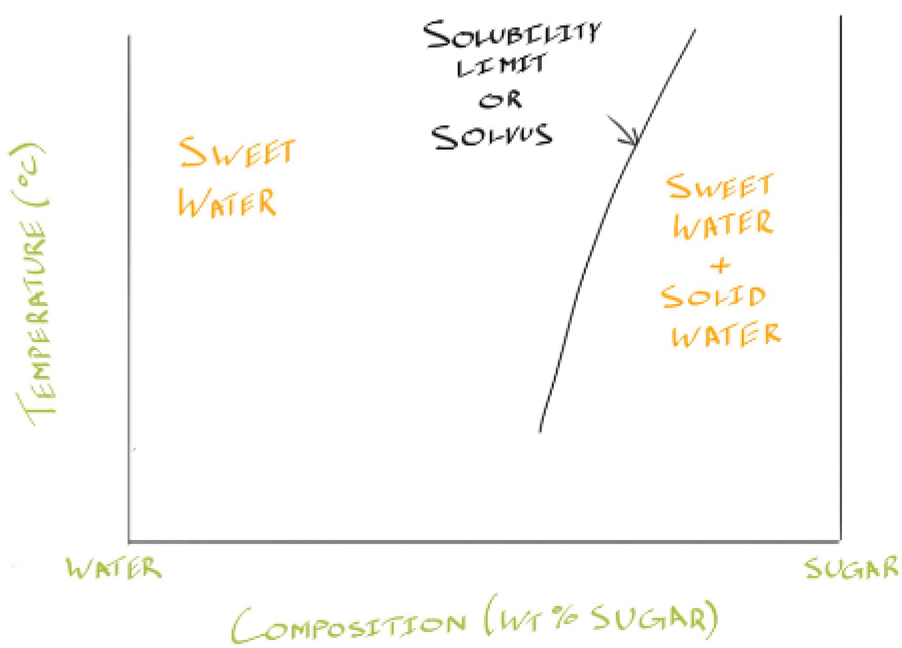
- As you can see, this simple phase diagram tells us that water below 0 C will exist as ice, between 0 C and 100 C it will form liquid water, and above 100 C it will exist as water vapor.
- These phases at these specific temperature ranges are the phases that result in the system being at the lowest energy level (the most thermodynamically stable).

2. THE COMPOSITION AXIS:
   - We could add an "x-axis" hat would represent the amount of sugar that we are adding to water

Figure 2: A schematic two-component (binary) water-sugar phase diagram. At sufficiently high sugar concentrations (compositions) we know from experience that solid sugar will persist, in equilibrium with the sweet water.

- Binary phase diagram
- This axis would be called the composition axis since it would indicate the amount of the second component, sugar, that we are adding to our first component, water.

3. SATURATION: THE SOLUBILITY LIMIT
   - The maximum amount (limit) of solute that can be dissolved in a solvent is known as the solubility limit, or the solvus.
   - add this line to our phase diagram, remembering that we know it must increase (towards higher compositions) as the temperature is raised.



★ TERMINOLOGY:
   - PHASE: part of the system we are looking at that looks and behaves the same way. There are no separate parts in a single phase region. It all looks and behaves the same.
     - For example, if you add sugar to your coffee and stir it it forms a single phase, namely sweet water. All of the sweet water looks and behaves the same as any other bit of the sweetwater, because it is all the same phase. On the other hand, if we added sand to our coffee we would find that there were two phases, namely water and solid sand. The water looks and behaves differently from the sand.
   - COORDINATES: The possible combinations of temperature and composition on a phase diagram

❖ BINARY PHASE DIAGRAM:

➢ binary phase diagram is one that has two components

➢ unary system would have only one component

➢ ternary system would have three components

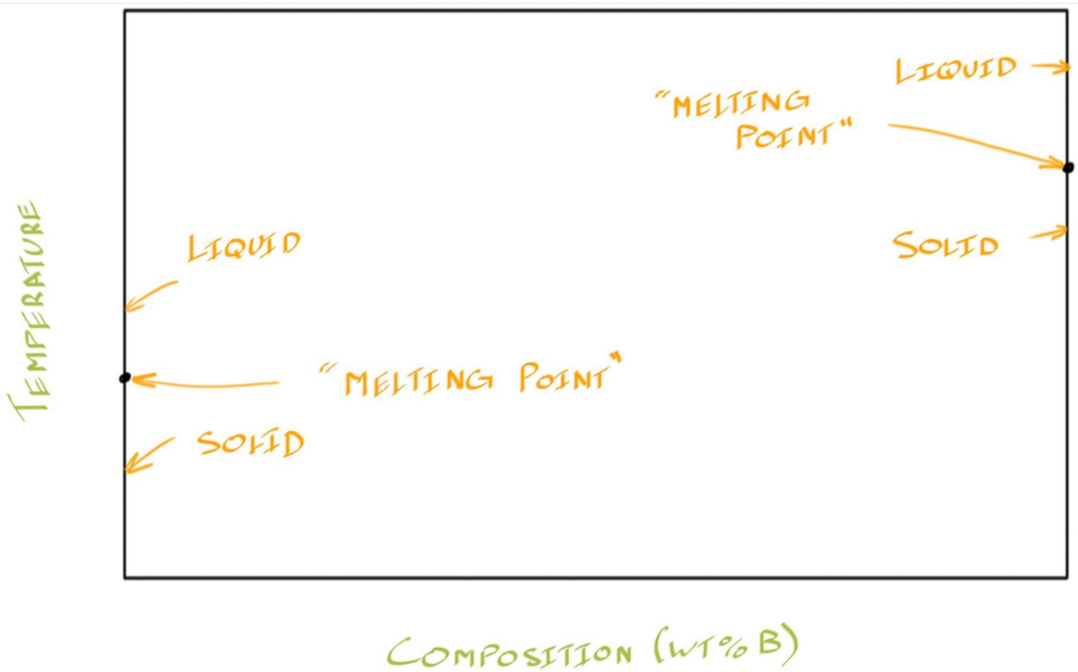


Figure 4: A schematic binary isomorphous phase diagram for the hypothetical two-component A-B system, showing only the melting points of the pure components.

- ISOMORPHOUS PHASE DIAGRAM:
    - ISOMORPHOUS SYSTEM: is one where both components are completely soluble in each other

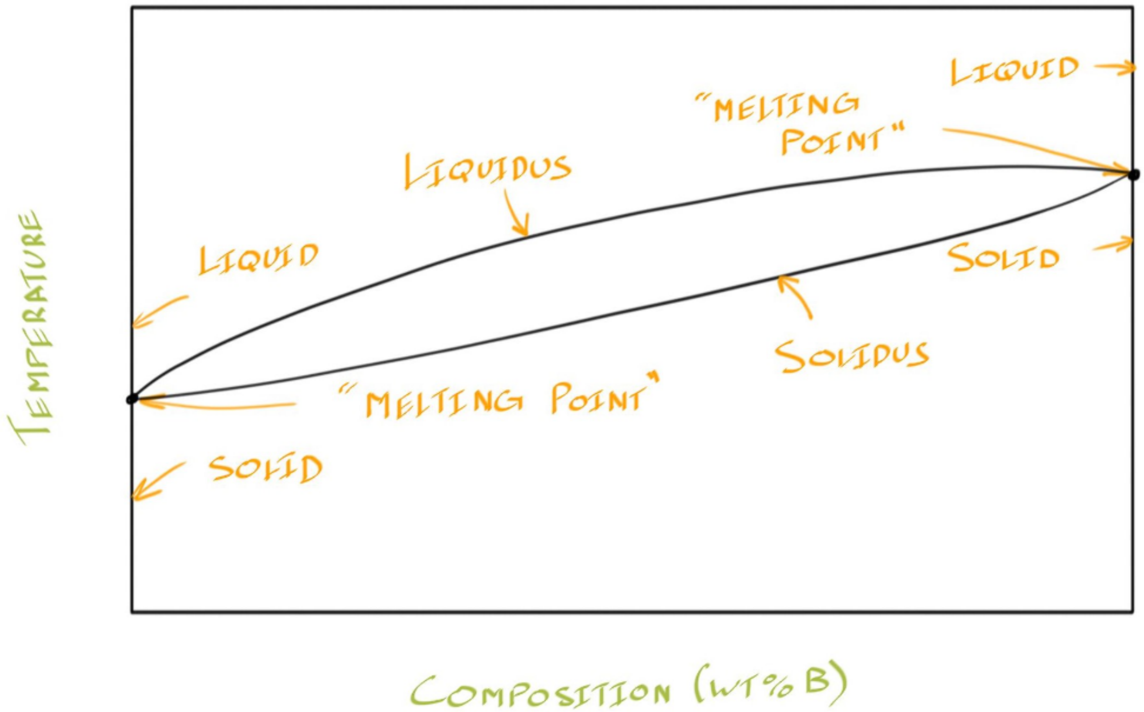
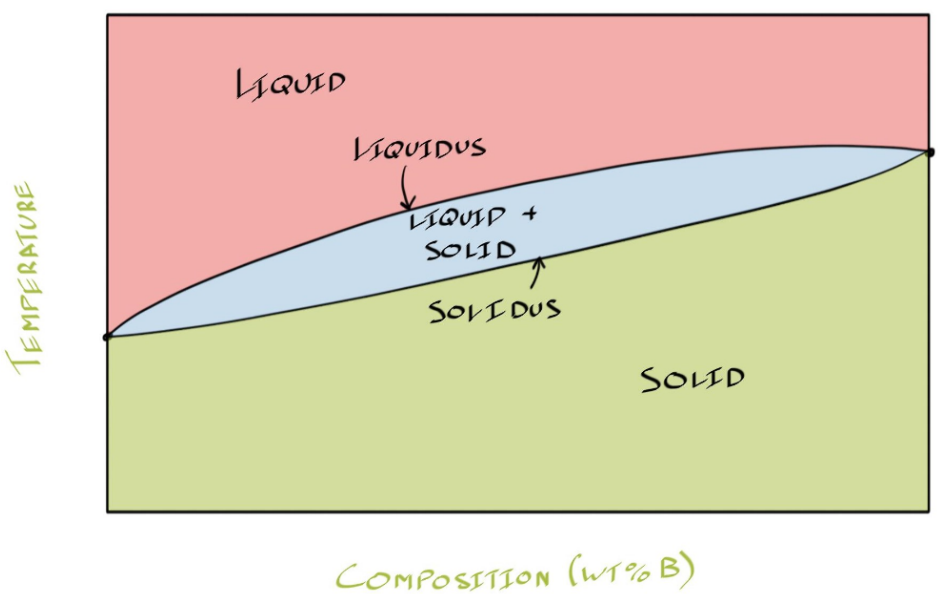


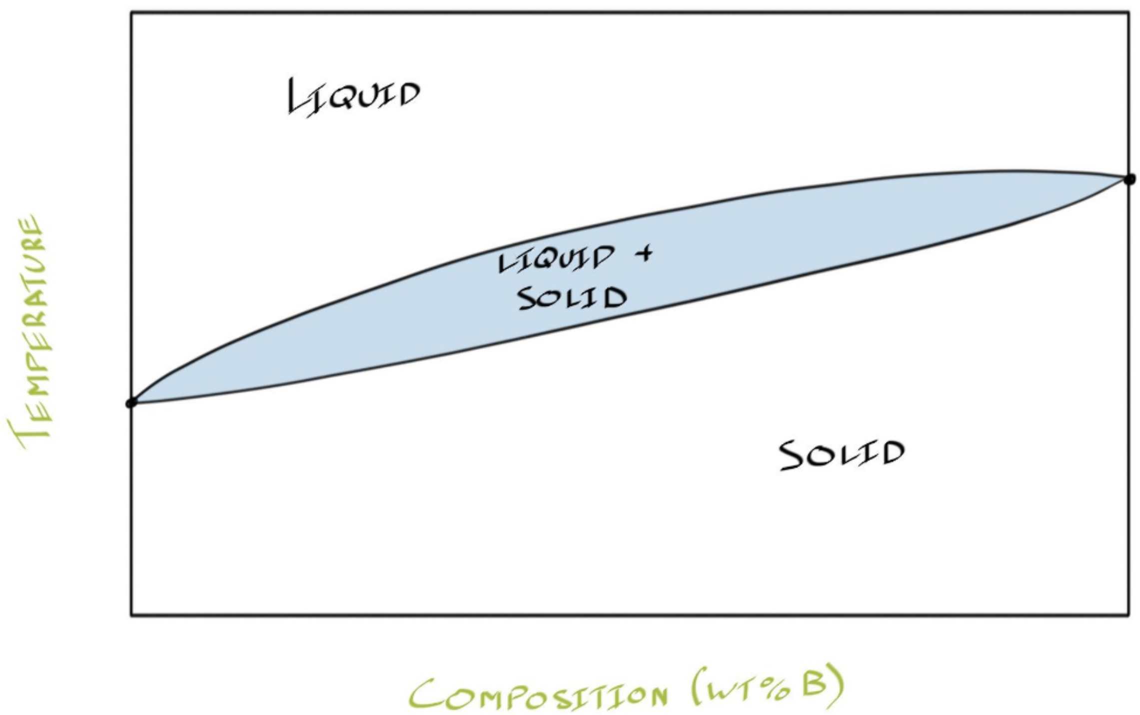
Figure 5: A schematic binary isomorphous phase diagram for the hypothetical two-component A-B system, showing the liquidus and solidus.

- The term isomorphous roughly means that there is only one structure in the solid phase.



- There is one area for the solid phase, with no phase boundaries breaking it up.
- we can dissolve as much component B in component A as we want without forming a second phase.
- Note that this is different from what we saw with water and sugar. Remember in the sugar-water system that when we added enough sugar to water we reached a solubility limit and the excess sugar formed a second phase.
- If you took a close look (with a microscope, for example) at the solid phase at a number of different compositions you would find that it looked generally the same in terms of its structure.

➔ TWO PHASE REGION:



- For any combination of temperature and composition points that reside inside the little blue area our system will contain two phases in equilibrium, namely the liquid and the solid.
- You could say that the system was partly melted, or partly solidified in that region. And it would stay that way forever if you didn't change the temperature or composition.

➔ COMPOSITION OF EACH PHASE:

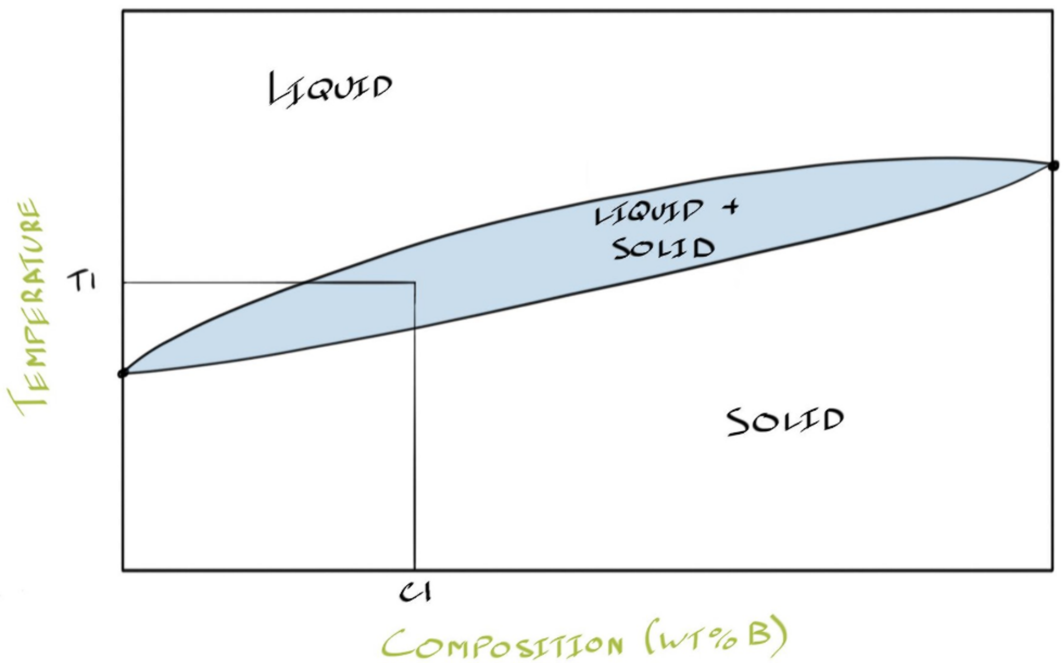


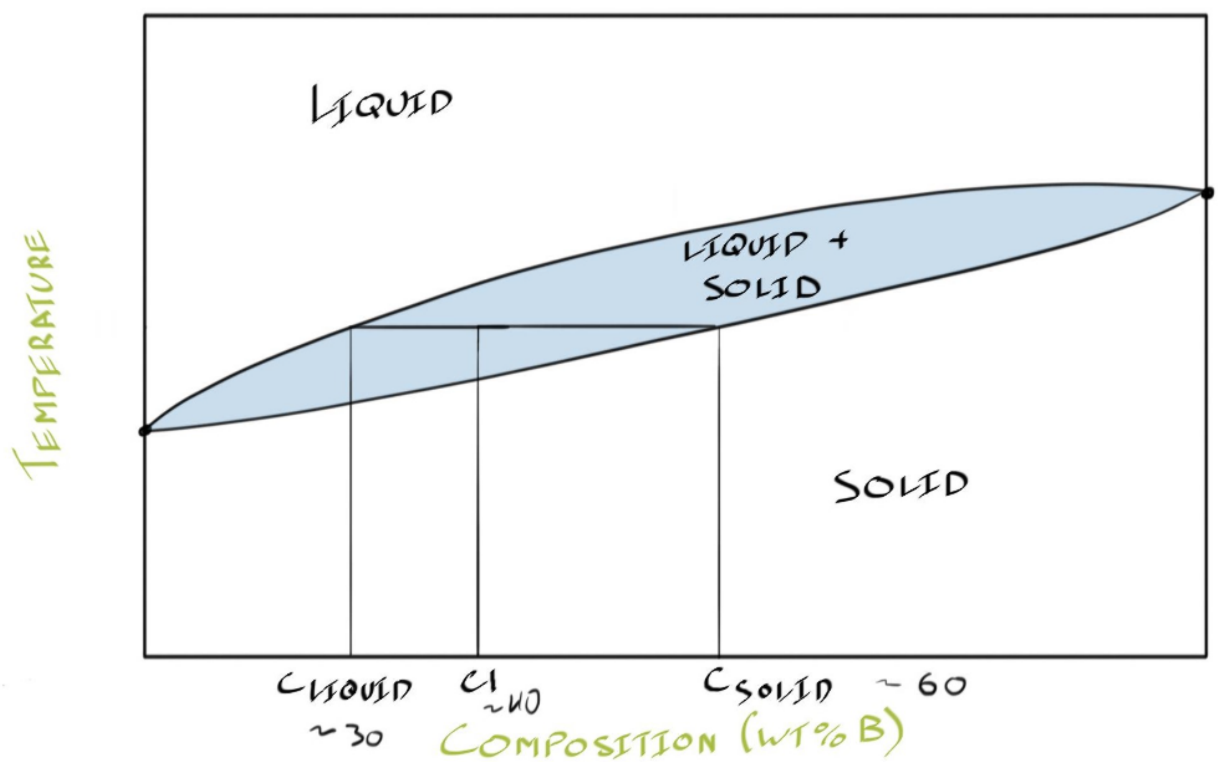
Figure 8: A hypothetical alloy of composition C1, heated to a temperature T1 is shown to exist as two-phases on this schematic binary isomorphous phase diagram for the two-component A-B system.

- That is, how much compo-nent A and compo-nent B are in each of the liquid and the solid.
- First, we would need to identify the temperature and composition on the phase diagram to confirm we were in the two phase region, as shown by the point at composition C1 and temperature T1

➔ THE TIE LINE:

On a binary phase diagram, a tie line is simply a fancy term for a horizontal line spanning a two-phase region from a phase boundary (line) on one side to the phase boundary on the other side. Drawing a tie line from a given temperature and composition point does several things:

1. Tells us what phases are in the two-phase region
2. Tells us how much of each component is in each of the two phases (that is, the composition)
3. Forms the basis for our lever rule calculation, derived and explained in the next section.



- ★ THE LEVER RULE:
  - To find out the concentration of different phases present

$$M_{B,Total} = M_{B,in\ Liquid} + M_{B,\ in\ Solid}$$

$$M_{B,\ Total} = M_L C_L + M_S C_S$$

$$\frac{M_{B,\ Total}}{M_{Total}} = \frac{M_L}{M_{Total}} C_L + \frac{M_S}{M_{Total}} C_S$$

$$C_0 = \frac{M_L}{M_{Total}} C_L + \frac{M_S}{M_{Total}} C_S$$

$$\frac{M_L}{M_{Total}} = W_L$$

$$\frac{M_S}{M_{Total}} = W_S$$

$$C_0 = W_L C_L + W_S C_S$$

$$W_L + W_S = 1$$

$$W_S = 1 - W_L$$

$$C_0 = W_L C_L + (1 - W_L) C_S$$

$$C_0 = W_L C_L + C_S - W_L C_S$$

$$C_0 = W_L (C_L - C_S) + C_S$$

$$W_L = \frac{C_0 - C_S}{C_L - C_S}$$

So the Lever rule is,

$$Weight\ fraction\ of\ a\ phase = \frac{Opposite\ side\ of\ lever}{Total\ length\ of\ lever}$$

- ★ EUTECTIC:
  - ○ A binary eutectic phase diagram is a phase diagram for a system that has one specific melting point that is below the melting point for each of the components.

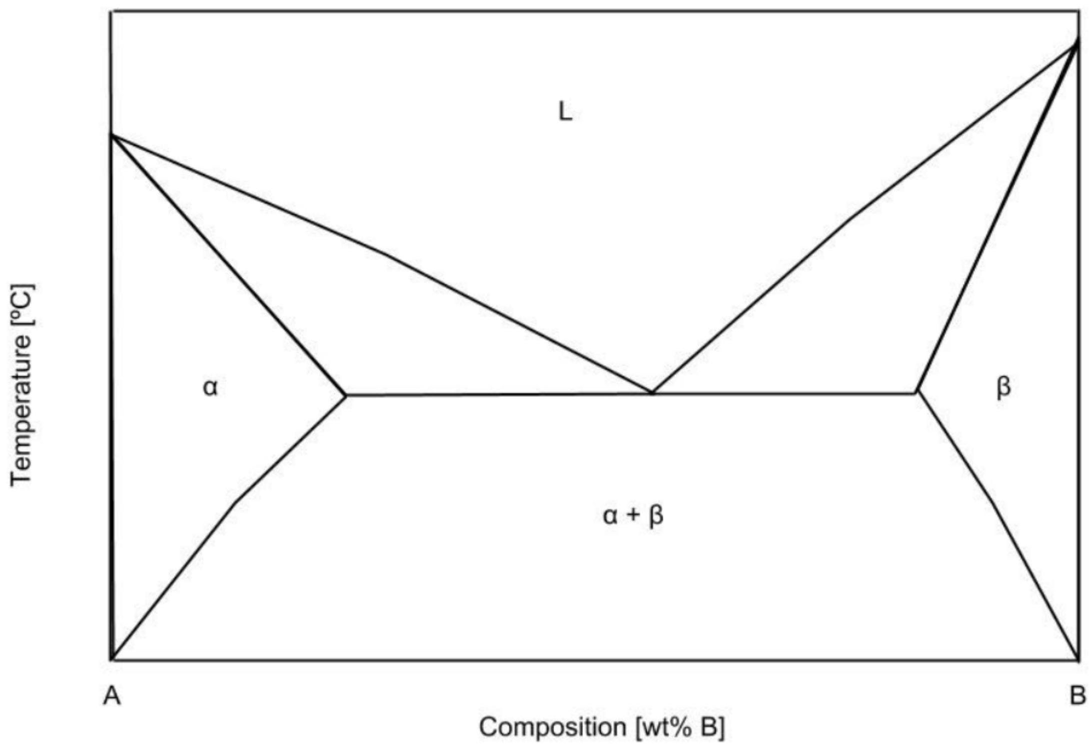


Figure 22: A schematic diagram of a generalized binary eutectic phase diagram. Note that the solid phases are named using lower case Greek letters and the liquid is just indicated with a capital L

★ IRON-CARBON SYSTEM

- Eutectic Point

Eutectic point is a point where multiple phases meet. For the iron-carbon alloy diagram, the eutectic point is where the lines A1, A3 and ACM meet. The formation of these points is coincidental.

At these points, eutectic reactions take place where a liquid phase freezes into a mixture of two solid phases. This happens when cooling a liquid alloy of eutectic composition all the way to its eutectic temperature.

The alloys formed at this point are known as eutectic alloys. On the left and right side of this point, alloys are known as hypoeutectic and hypereutectic alloys respectively (‘hypo’ in Greek means less than, ‘hyper’ means greater than).

- Phase Fields

The boundaries, intersecting each other, mark certain regions on the Fe3C diagram.

Within each region, a different phase or two phases may exist together. At the boundary, the phase change occurs. These regions are the phase fields.

They indicate the phases present for a certain composition and temperature of the alloy. Let’s learn a little about the different phases of the iron-carbon alloy.

- Different Phases
    - α-ferrite

Existing at low temperatures and low carbon content, α-ferrite is a solid solution of carbon in BCC Fe. This phase is stable at room temperature. In the graph, it can be seen as a sliver on the left edge with Y-axis on the left side and A2 on the right. This phase is magnetic below 768°C.

It has a maximum carbon content of 0.022 % and it will transform to γ-austenite at 912°C as shown in the graph.

    - γ-austenite

This phase is a solid solution of carbon in FCC Fe with a maximum solubility of 2.14% C. On further heating, it converts into BCC δ-ferrite at 1395°C. γ-austenite is unstable at temperatures below eutectic temperature (727°C) unless cooled rapidly. This phase is non-magnetic.

    - δ-ferrite

This phase has a similar structure as that of α-ferrite but exists only at high temperatures. The phase can be spotted at the top left corner in the graph. It has a melting point of 1538°C.

- Fe3C or cementite

Cementite is a metastable phase of this alloy with a fixed composition of Fe3C. It decomposes extremely slowly at room temperature into iron and carbon (graphite).

This decomposition time is long and it will take much longer than the service life of the application at room temperature. Some other factors (high temperatures and the addition of certain alloying elements for instance) can affect this decomposition as they promote graphite formation.

Cementite is hard and brittle which makes it suitable for strengthening steels. Its mechanical properties are a function of its microstructure, which depends upon how it is mixed with ferrite.

- Fe-C liquid solution

Marked on the diagram as 'L', it can be seen in the upper region in the diagram. As the name suggests, it is a liquid solution of carbon in iron. As we know that δ-ferrite melts at 1538°C, it is evident that the melting temperature of iron decreases with increasing carbon content.