# FUNDAMENTALS OF METAL ALLOYS, EQUILIBRIUM DIAGRAMS

Chapter 5-Part 1



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# 5.1 Introduction
# 5.2 What is a Phase?

- Phase is a form of material having characteristic structure and properties.
- More precisely: form of material with identifiable composition (chemistry), definable structure, and distinctive boundaries (interfaces) which separate it from other phases.
- Phases can be continuous or discontinuous

# 4.2 Phases

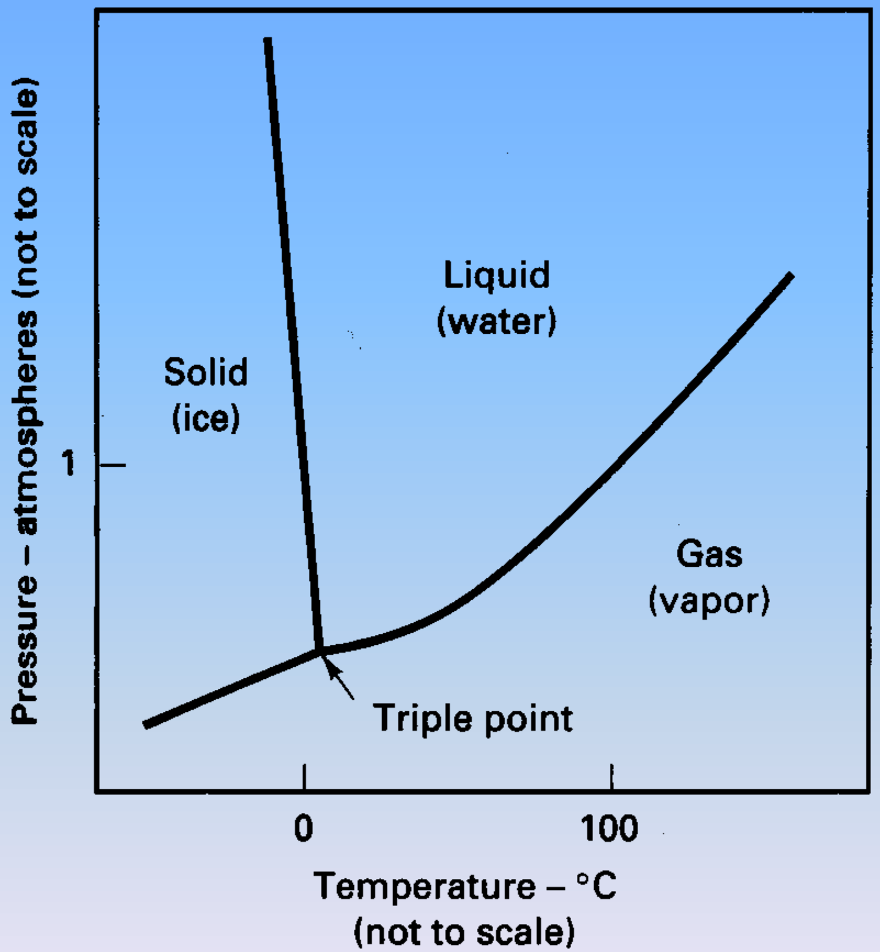
- Phase can be continuous (air in the room) or discontinuous (salt grains in the shaker).
- Gas, liquid or solid.
- Pure substance or solution ( uniform structure throughout).

# 5.3 Phase Equilibrium Phase Diagrams

- An equilibrium phase diagram is a diagram that shows the natural tendencies of a material or material system
  - Pressure, temperature, and composition are important
- Transitions are encountered when a material changes phase
- Sublimation occurs when a material goes from a solid to a gas
  - Freeze drying operates on this principle

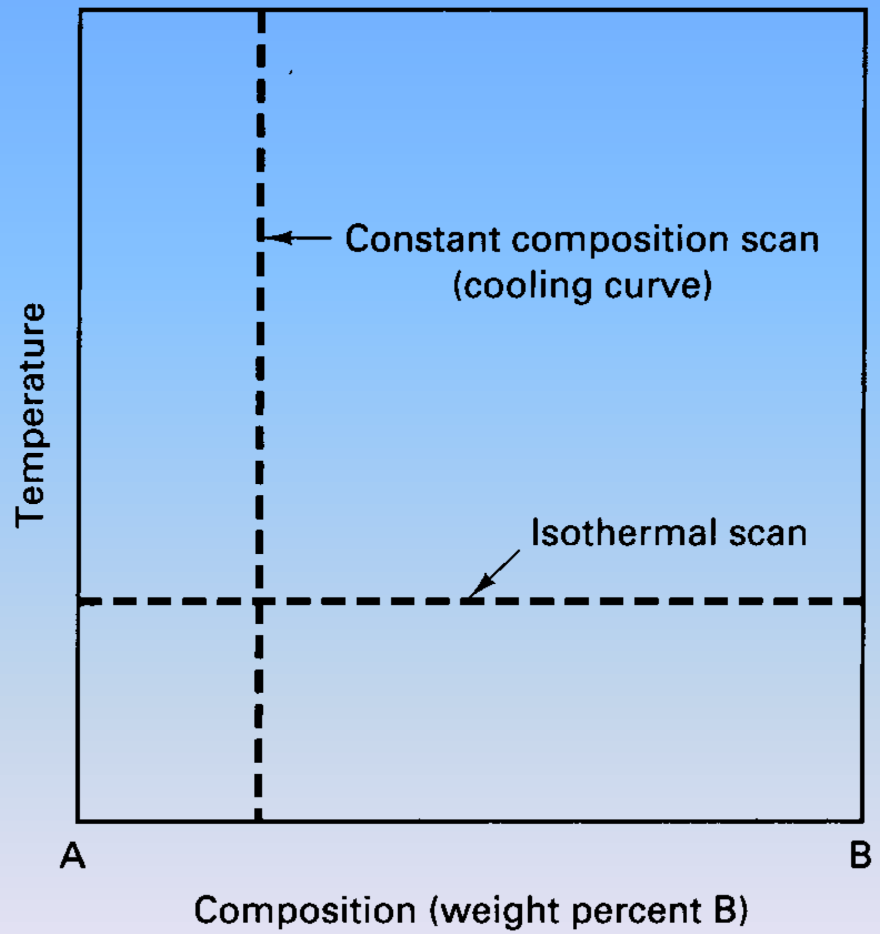
# 5.3 Equilibrium Phase Diagrams

- Graphic mapping of the natural tendencies of a material or a material system (equilibrium for all possible conditions).
- Primary variables: temperature, pressure and composition.
- P-T diagram (the simplest).



# 5.3 Temperature-Composition Diagrams

- Engineering processes conducted at atmospheric pressure (P/T variations).
- The most common: temperature-composition phase diagrams.

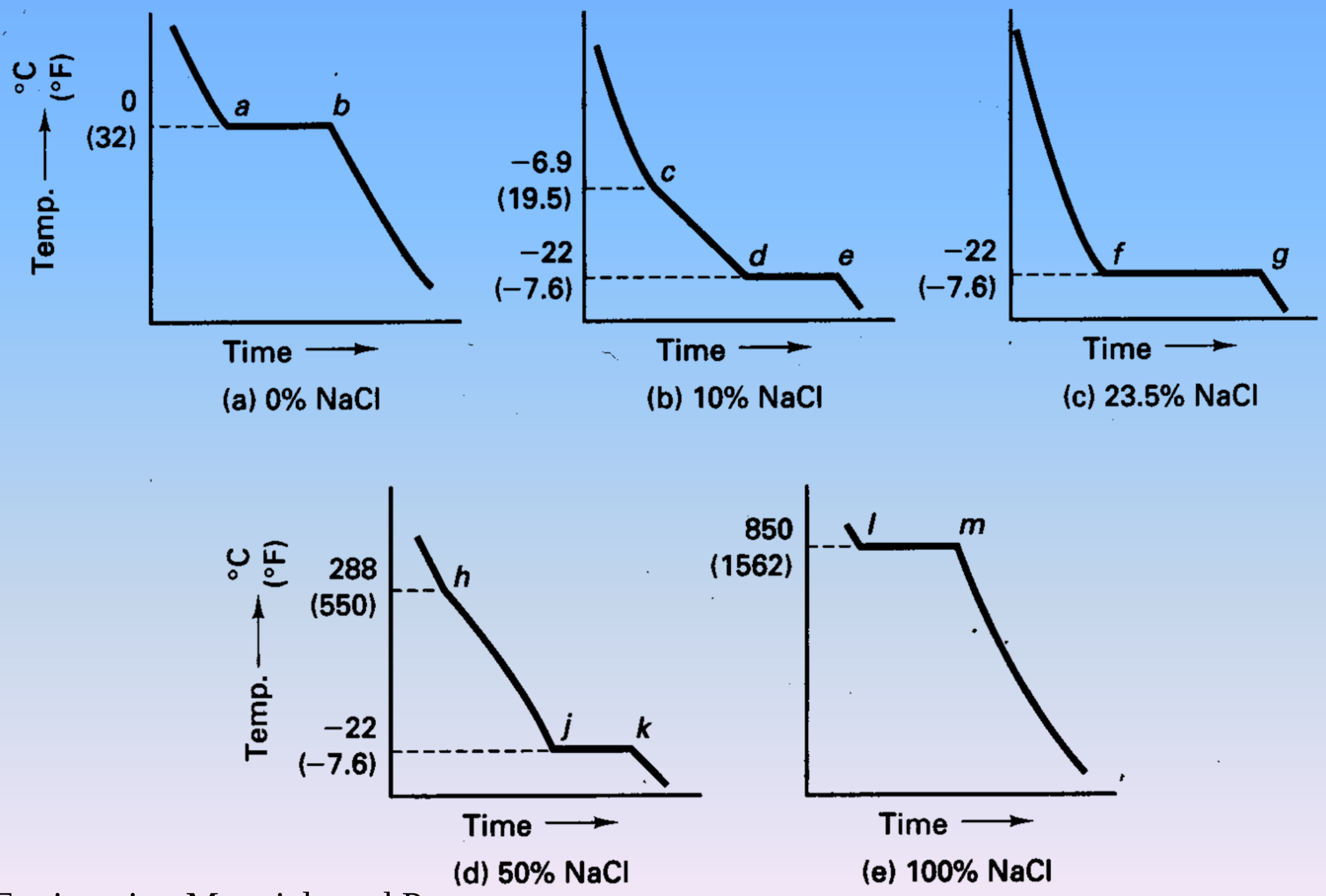


# Cooling Curves

- Figure 5-4 shows  the transition points of a temperature time curve for a solution of NaCl in water
- Line a-c-f-h-l shows the lowest temperature at which the solution is totally liquid, known as a liquidis line

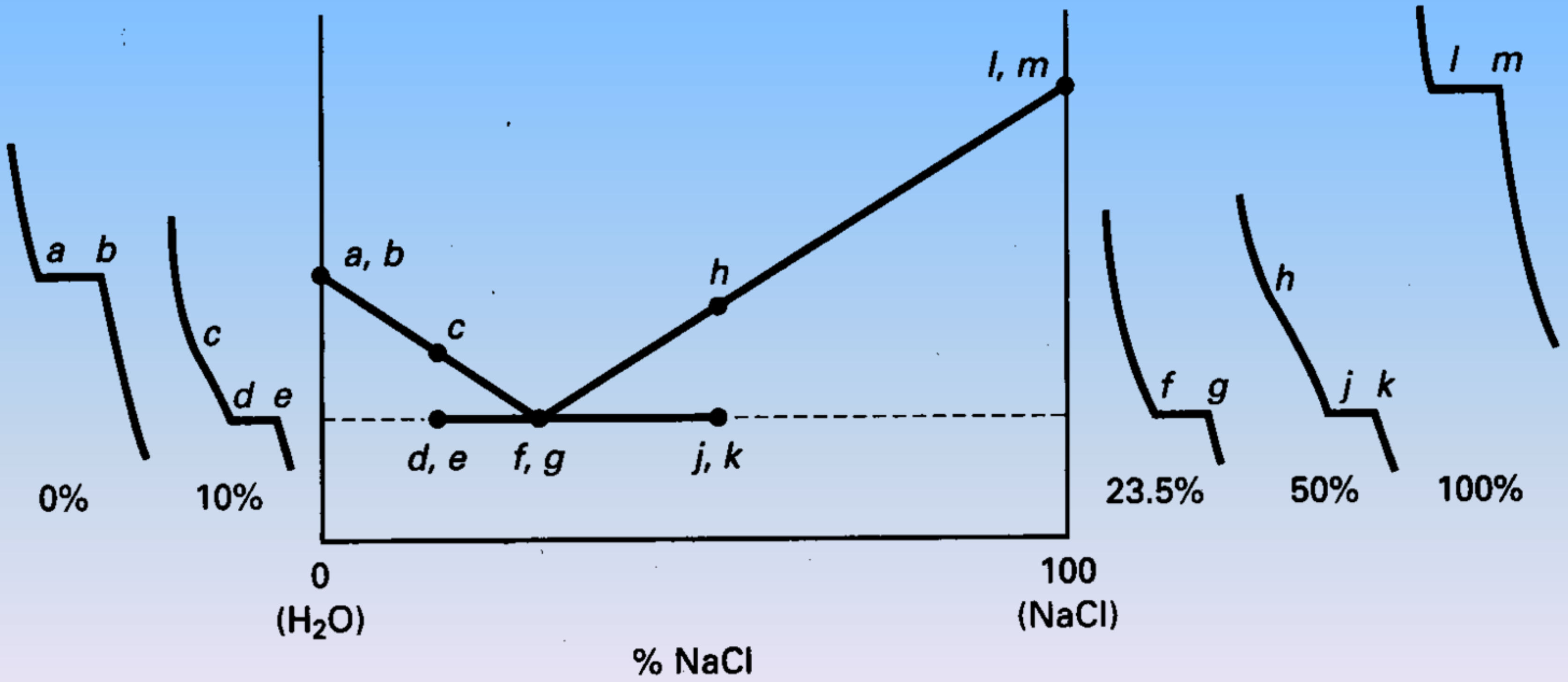
# 5.3 Cooling Curves

- Cooling curves for NaCl-H20 combinations:



# 5.3 Cooling Curves

- Partial equilibrium diagram of NaCl-H20 system



# 5.3 Solubility

- Solubility limits.
- Degree of solubility determines properties.
- I-Two metals completely soluble in each other.
- II- Two metals soluble in liquid state and insoluble in solid state.
- III-Two metals soluble in liquid state and partially soluble in solid state.

# Solubility

- A solvus line on an equilibrium phase diagram shows a limit to the materials solubility
- If the two materials are completely soluble in one another, then the diagram is simple
- The lowest temperature at which the material is 100% liquid is the liquidis line
- The highest temperature at which the material is 100% solid is the solidus line
- Between the two lines is a region where the liquid and solid solutions both exist

# Partial Solid Solubility and Insolubility

- The saturation point is the solubility limit of the two materials at a given temperature
- If the temperature is decreased, the amount of solute that can be held in solution decreases
- Two materials are insoluble if they can not be held in solution



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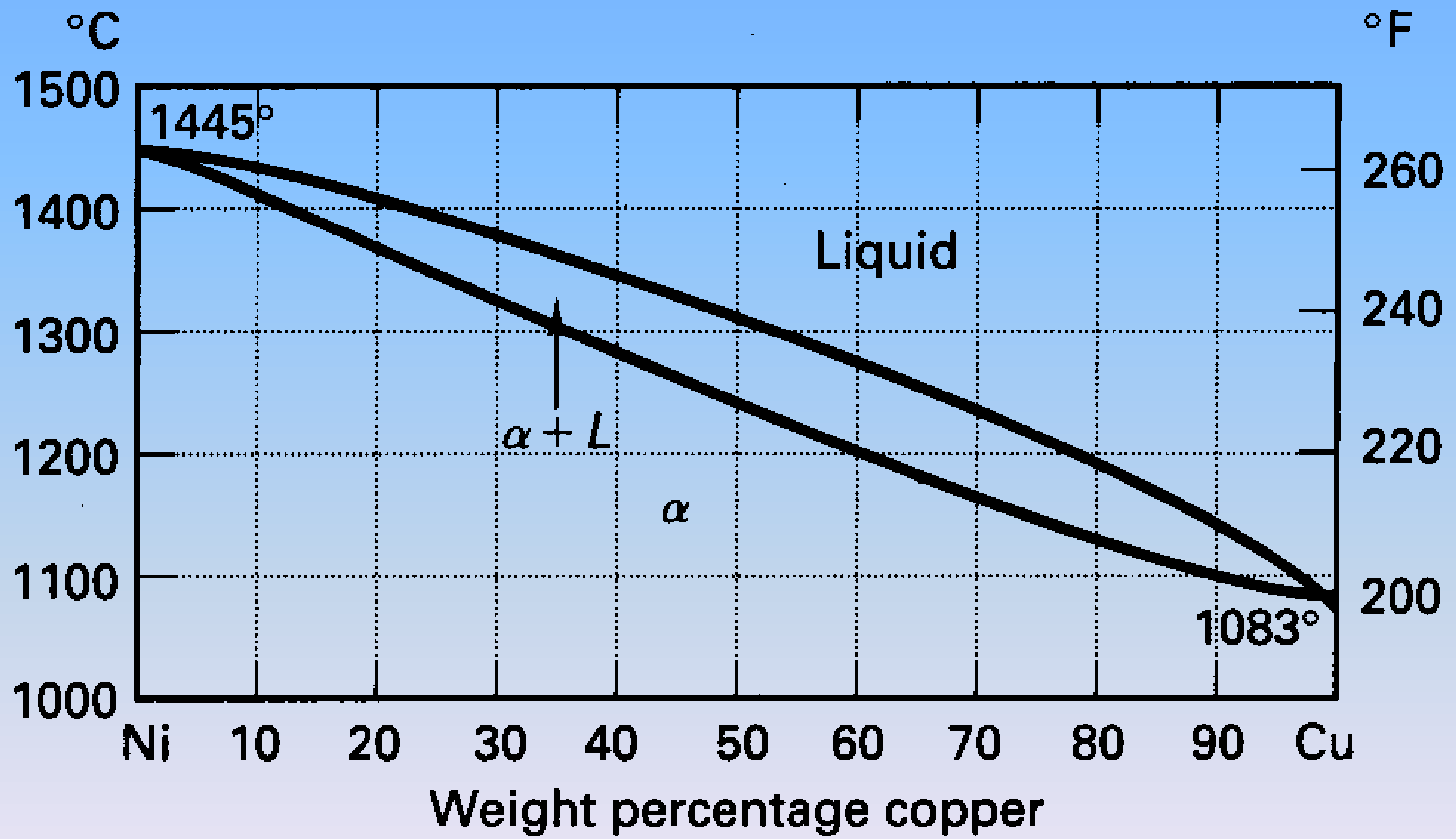
# 5.3 Complete Solubility

- Copper-Nickel equilibrium diagram



# Solubility Diagrams

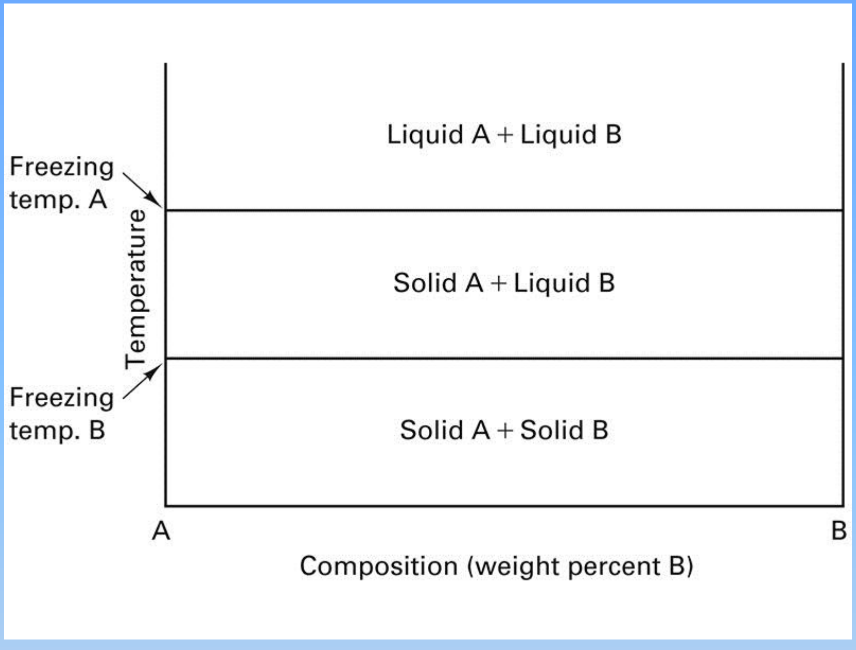
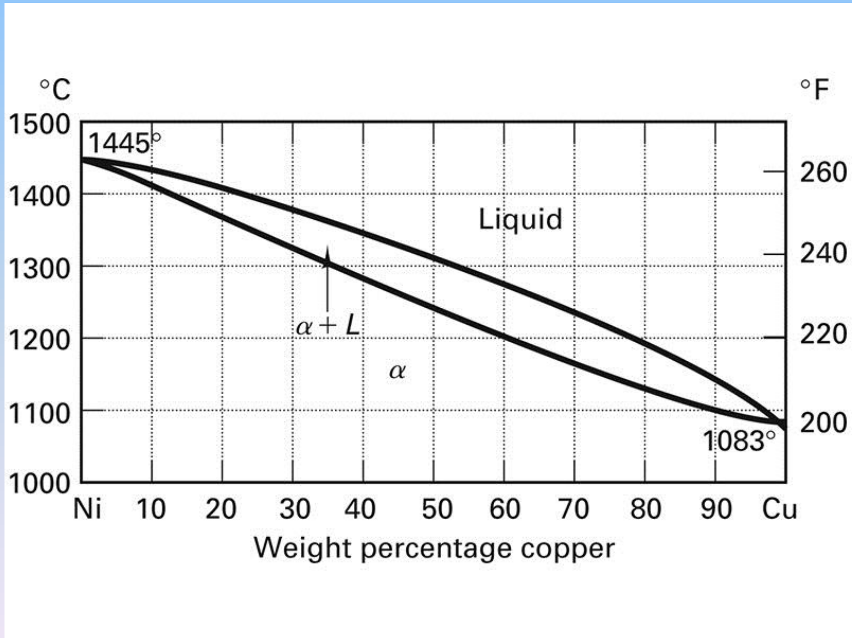
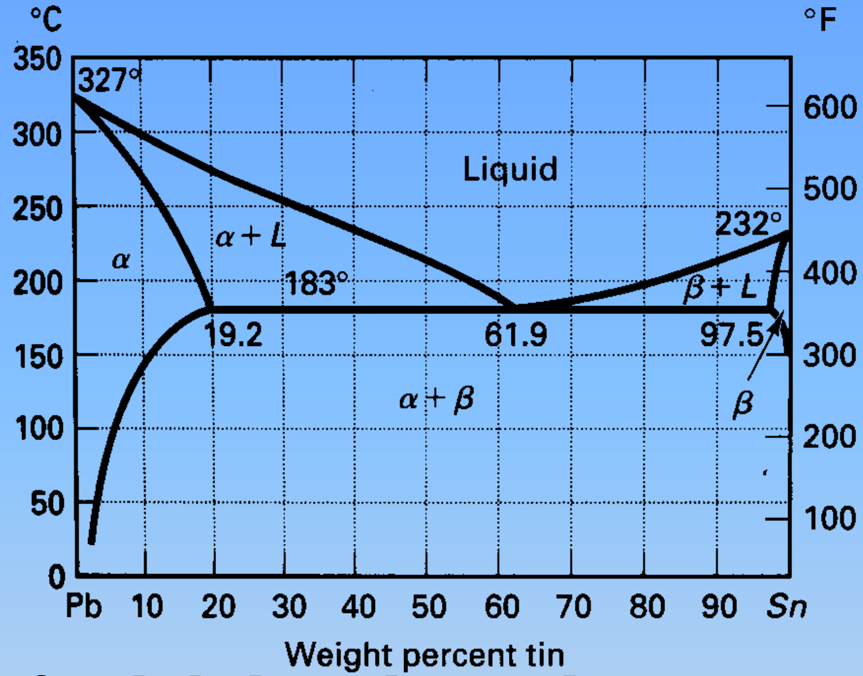



**Figure 5-7** (Above) Equilibrium diagram of two materials that are completely insoluble in each other in both the liquid and solid states.

**Figure 5-6** (Below) Copper-nickel equilibrium phase diagram, showing complete solubility in both liquid and solid states.



# 4.3 Partial Solid Solubility




- Degree of solubility depends on temperature
- At max. solubility, 183°C: lead holds up to 19.2 wt% tin in a single phase solution, and tin holds up to 2.5wt% lead and still be a single phase.

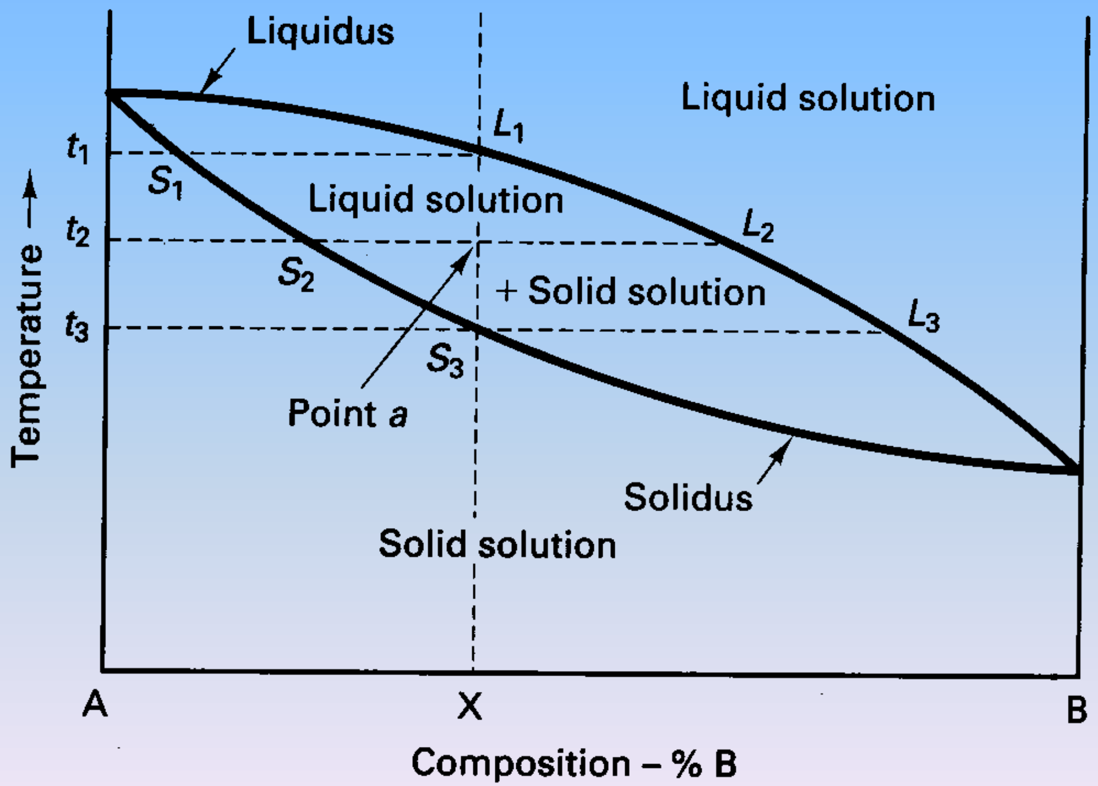
# 5.3 Utilization of Diagrams

- The phases present.
- Composition of each phase ( single phase region or two phase region).
- In two phase region a tie-line should be constructed.
- The amount of each phase present: lever-law calculation using a tie-line.

# 5.3 Utilization of Diagrams

$$Liquid\ phase\ amount = \frac{a - S_2}{L_2 - S_2} \times 100\% = \%\ by\ mas$$

$$Solid\ phase\ amount = \frac{L_2 - a}{L_2 - S_2} \times 100\% = \%\ by\ mass$$



# Solidification of Alloy X

- As temperature drops, more solid forms
- The chemistries of both the liquid and the solid phases follow the tie line endpoints
- The chemistry of the liquid follows the liquidis line and the solid follows the solidus line
- When the temperature is decreased at constant composition the material becomes solid phase when it crosses the solidus line

# Intermetallic Compounds

- If two components in a compound can only exist at one atomic ratio, the compound is known as a stoichiometric intermetallic compound
- Appears as a single vertical line in the equilibrium phase diagram
- If some degree of variability is tolerable, then the vertical line will extend into a single phase region

# 5.3 Example Problem

*Given data :*

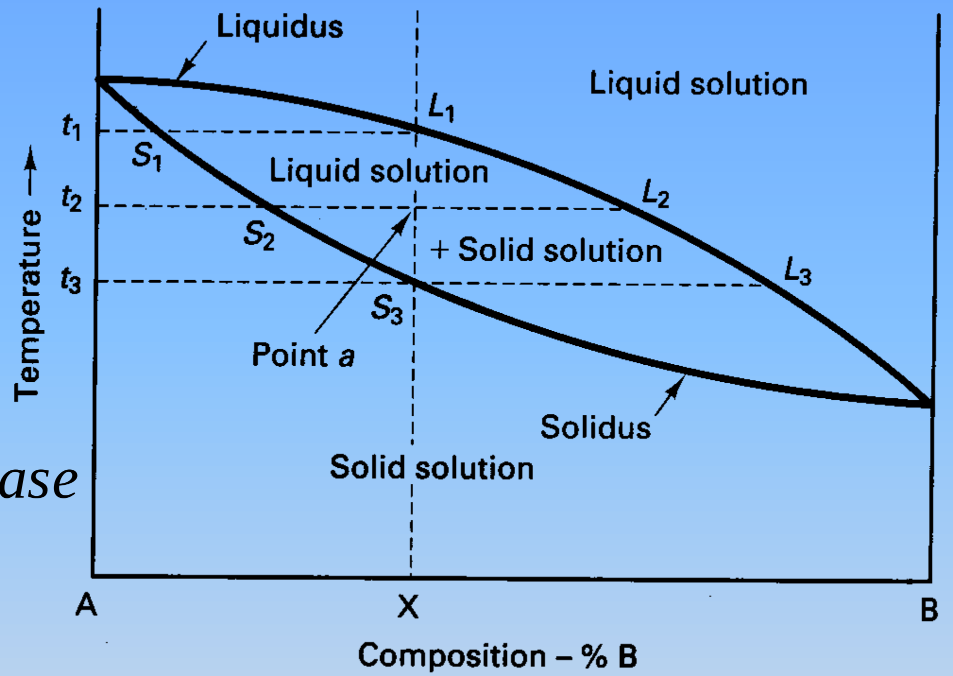
$X = 36\% \text{ of } B$

$a = 36\% \text{ of } B$

$L_2 = 72\% \text{ of } B$

$S_2 = 18\% \text{ of } B$

*Compute liquid phase and solid phase % amounts by mass.*




$$\text{Liquid phase amount} = \frac{36-18}{72-18} \times 100\% = 33.33\ \%\ \text{by mass}$$

$$\text{Solid phase amount} = \frac{72-36}{72-18} \times 100\% = 66.67\ \%\ \text{by mass}$$

# 5.3 Three Phase Reactions

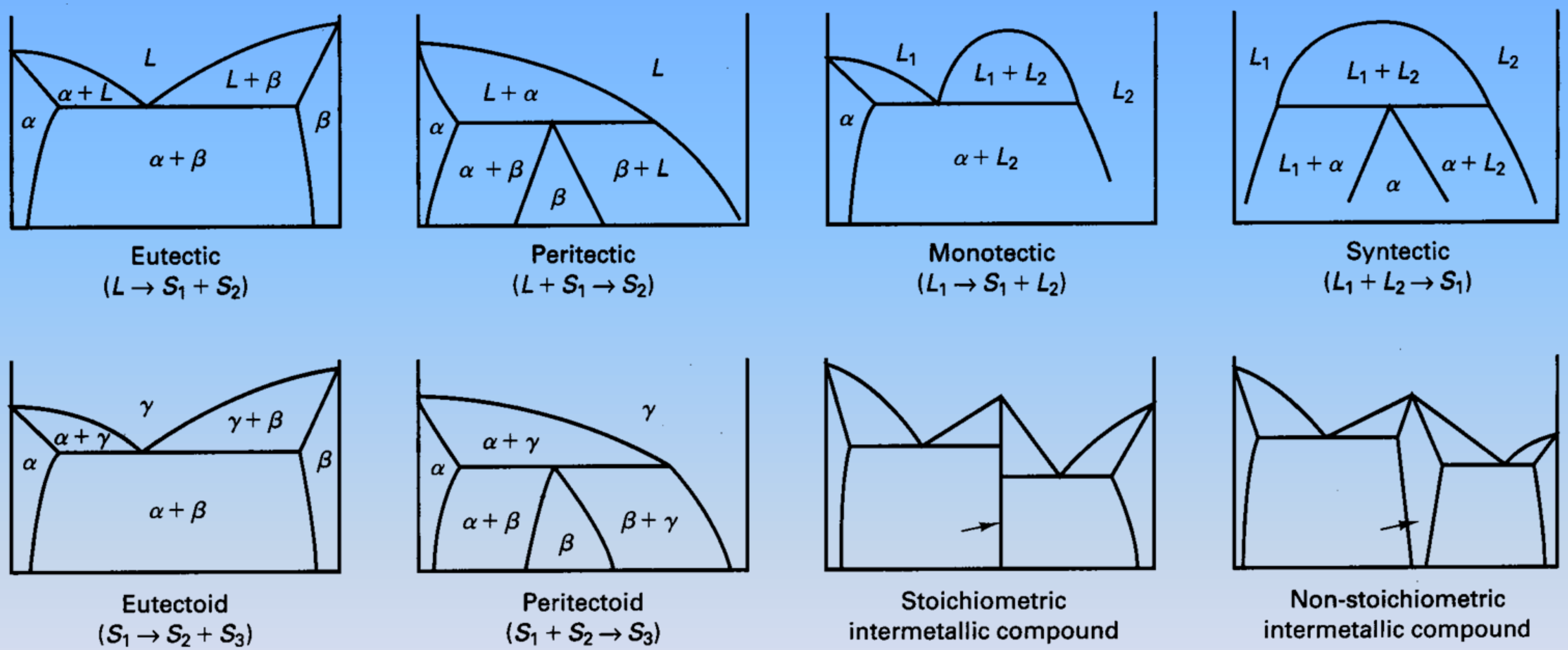



**Figure 5-9** Schematic summary of three-phase reactions and intermetallic compounds.

# Summary

- Phase diagrams can be used to predict how materials will behave during different heat treating processes
  - Diagrams are used extensively in casting processes to predict needed cooling rates