BOSTON UNIVERSITY

COLLEGE OF ENGINEERING

MATERIALS SCIENCE LABORATORY

ME306

LAB #4

Phase Diagrams & Solid Solutions

Introduction

The purpose of this lab is to introduce you to phase diagrams, solid solutions and solid solution strengthening.

Theory

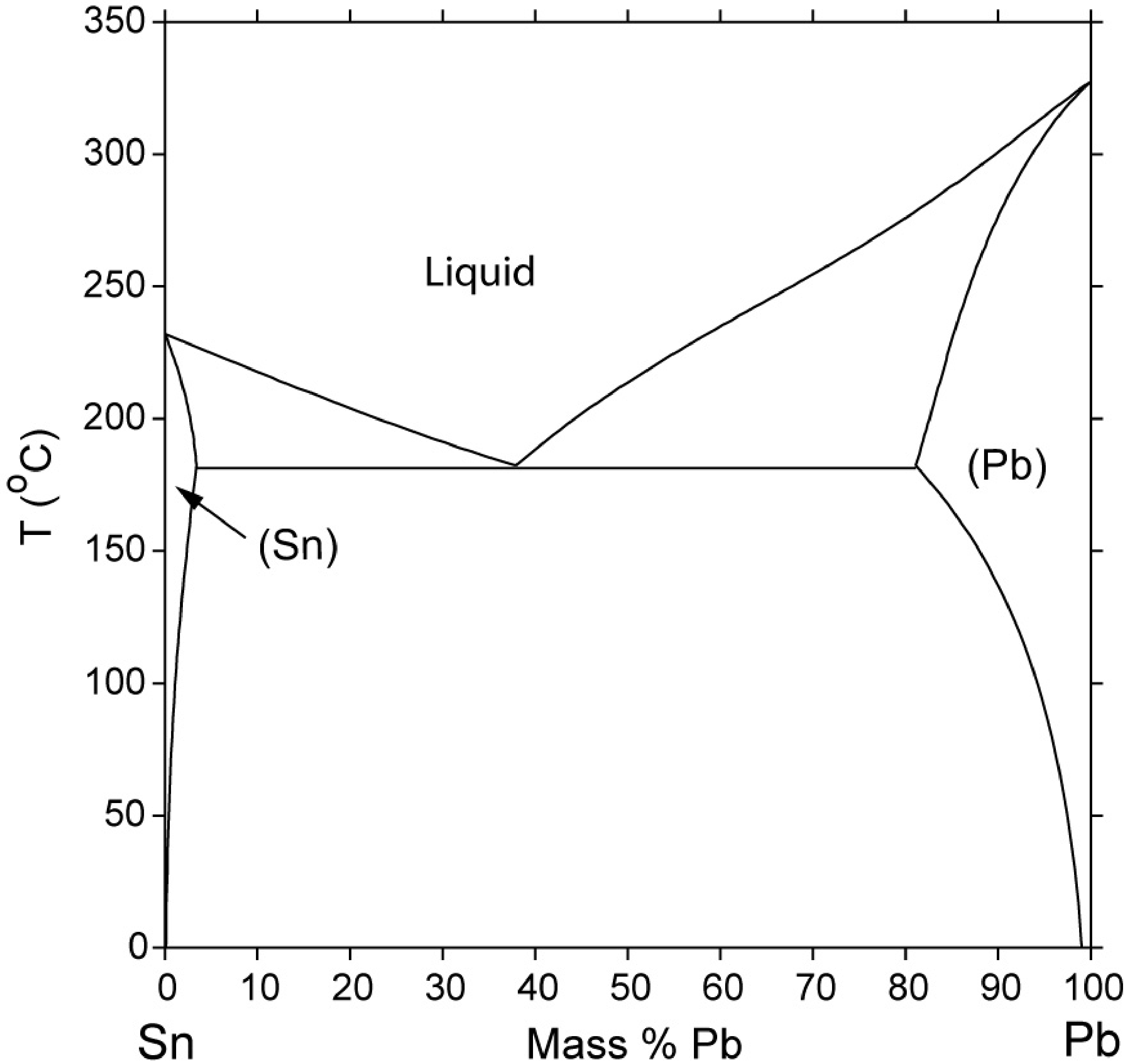
A phase is a homogeneous part of a system. The phases present in a metal system and the way in which they are distributed (size, shape and number of precipitate particles) critically affect the properties of metals. Therefore knowledge of phases and phase diagrams is a prerequisite for understanding most metal systems and their properties. Phases also exist in polymers. However, the dominant characteristic of polymer structures, often even in molten state, is the absence of thermodynamic equilibrium. For this reason, phase diagrams for polymers are seldom useful.

A component is a pure metal or a compound. A single element, such as mercury, is a single component whether it is present as a solid, liquid, gas or some combination of these phases. Binary alloys are defined as two-component systems. It is important to be able to determine the number of phases and the number of components in a given system. The number of phases present can be illustrated in a phase diagram. Phase diagrams plot stable phases (under equilibrium conditions versus composition). Phase diagrams can be experimentally obtained for binary allows by plotting cooling curves, or analytically by evaluating the thermodynamic basis of phase diagrams.

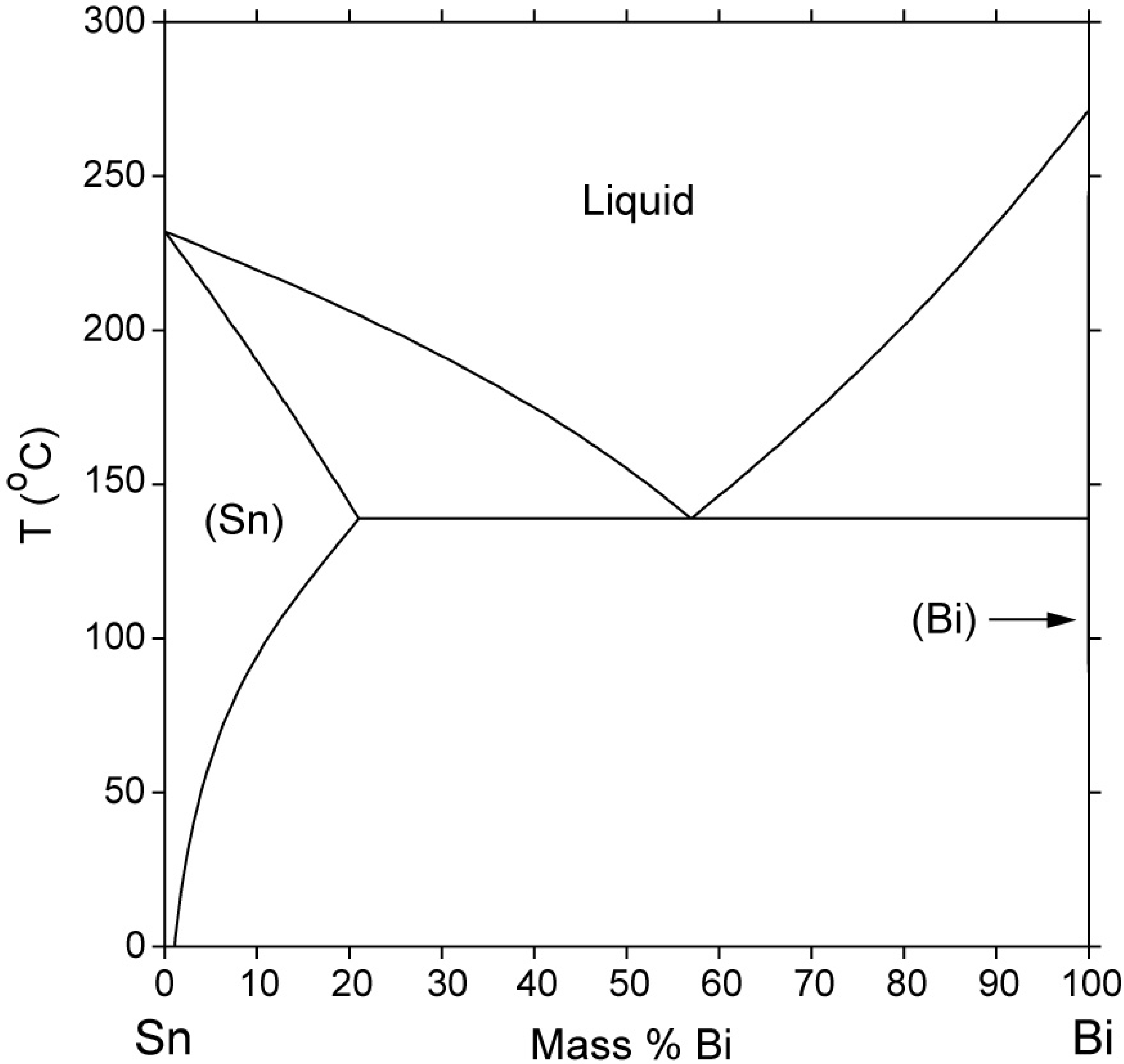
Phase diagrams can provide a wealth of information: melting points, phases present, compositions of phases present, relative amounts of phases present at a given set of conditions and solubilities. One of their most useful applications is the interpretation of microstructures. For example, if there is a question in identifying a constituent in a microstructure, a knowledge of the approximate overall composition of the alloy in combination with the phase diagrams enables the question to be resolved. Very simply, if one knows whether, say, a Ag-Cu alloy, is hypoeutectic or hypereutectic, then immediate identification of the proeutectic constituent is possible. For example, a 40% Ag - 60% Cu is hypoeutectic, therefore the dendritic proeutectic must be the copper-rich β phase.

Many combinations of 2 elements produce reactions that involve 3 separate phases. These are called invariant reactions such as eutectic and peritectic. The simple phase diagrams of Lead – Tin (Pb – Sn) and Bismuth – Tin (Bi – Sn) are shown below.

Phase Diagram for Lead-Tin



Phase Diagram for Bismuth-Tin



Solid Solutions

When different materials are combined, as when alloying elements are added to metals, a solid solution is produced. The solid solution can be understood as a “mixture” (at a microscopic level) of two elements, generally of metals in alloys. A solid solution is homogenous and has uniform properties and structure as opposed to a mixture which has “chunks” of different materials each with its own set of properties.

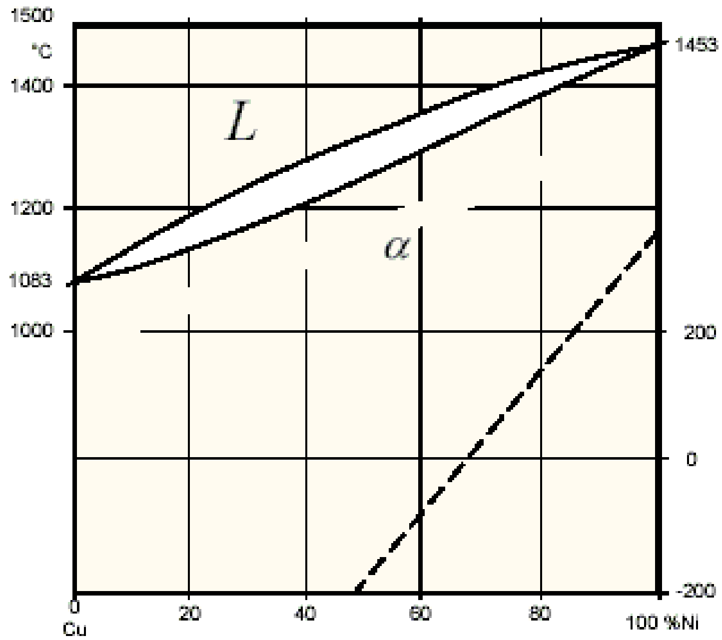
If two molten metals were mixed, the resultant liquid would be homogenous. The liquid alloy has the same composition, properties and structure everywhere because the two metals have unlimited liquid solubility. When the metals are in the molten state, the atoms are far apart and so there is no restriction for the size and compatibility of the atoms. However, when the molten metals solidify, the atoms are ordered and the atomic spacing becomes smaller. Under these circumstances, there is a possibility that a single homogenous solid phase is not produced.

Consider two metals A and B, if we try to dissolve B in A, and if atom B is larger than atom A, there will be compressive stresses near the B atoms. On the other hand, if atom B is smaller than atom A, there will be tensile stresses near the B atoms. Since the lattice tries to minimize the stresses, there will be a limit on the number of B atoms that can dissolve in the A lattice. We call this limited solid solubility. For example, in a Cu-Zn system, maximum solid solubility of Zinc in Copper is 30% at room temperature. Since solubility depends on the atomic spacing, it is reasonable to expect greater solubility at higher temperatures.

If the atom B is about the size of A, then the stresses developed by the substitution of A by B atoms are minimal. In this case, there is unlimited solid solubility. Another case where there is unlimited solid solubility is when atoms B are small enough to fill in the voids of the A lattice. Conditions for unlimited solid solubility are given by Hume Rothery Rules. For example in the Cu-Ni system, copper completely dissolves in nickel for any proportions of nickel and copper.

By producing solid solution alloys, we cause solid solution strengthening. In the copper nickel system, solid substitutional atoms (say nickel) are intentionally introduced into the copper lattice. The addition of nickel in the copper lattice produces a strengthening effect.

In this lab, we will study six samples of the Cu-Ni system. The samples are of various compositions of Copper and Nickel. The hardness will be measured on each of these samples.



Instructions:

1. Record the cooling curves for the 4 Bi-Sn and 4 Pb-Sn alloys

2. Take Rockwell hardness measurements for Cu-Ni alloys.

Questions:

1. Plot the cooling curves for the Bi-Sn system on one graph and the Pb-Sn system on another graph, labeling phase transition points.

2. From the Bi-Sn and Pb-Sn phase diagrams, determine which unknown alloy corresponds to the following compositions:

   Bi-Sn alloys (A, B, C, D)
   - 70 Bi 30 Sn
   - 56 Bi 42 Sn (eutectic)
   - 40 Bi 60 Sn
   - 21 Bi 79 Sn

   Pb-Sn alloys (I, II, III, IV)
   - 81.5 Pb 18.5 Sn
   - 70 Pb 30 Sn
   - 38.1 Pb 61.9 Sn (eutectic)
   - 30 Pb 70 Sn

3. Plot hardness as a function of the percentage of Cu and in the same graph.

4. Explain your results and relate to solid solution strengthening and microstructure.

5. How many grams of nickel must be added to 500 grams of copper to produce an alloy that has a liquidus temperature of 1350°C. What is the ratio of the number of nickel atoms to copper atoms in this alloy?

   NOTE: Pay attention to the standard x-axis units of a phase diagram