Chapter 10

Phase Diagrams

Concept Check 10.1

Question: *What is the difference between the states of phase equilibrium and metastability?*

Answer: For the condition of phase equilibrium the free energy is a minimum, the system is completely stable meaning that over time the phase characteristics are constant. For metastability, the system is not at equilibrium, and there are very slight (and often imperceptible) changes of the phase characteristics with time.

Concept Check 10.2

Question: *A copper-nickel alloy of composition 70 wt% Ni-30 wt% Cu is slowly heated from a temperature of 1300°C.*

(a) At what temperature does the first liquid phase form?

(b) What is the composition of this liquid phase?

(c) At what temperature does complete melting of the alloy occur?

(d) What is the composition of the last solid remaining prior to complete melting?

Solution: Upon heating a copper-nickel alloy of composition 70 wt% Ni-30 wt% Cu from 1300°C and utilizing Figure 10.3a:

(a) The first liquid forms at the temperature at which a vertical line at this composition intersects the α-($\alpha + L$) phase boundary—i.e., about 1350°C;

(b) The composition of this liquid phase corresponds to the intersection with the ($\alpha + L$)-L phase boundary, of a tie line constructed across the $\alpha + L$ phase region at 1350°C—i.e., 59 wt% Ni;

(c) Complete melting of the alloy occurs at the intersection of this same vertical line at 70 wt% Ni with the ($\alpha + L$)-L phase boundary—i.e., about 1380°C;

(d) The composition of the last solid remaining prior to complete melting corresponds to the intersection with α-($\alpha + L$) phase boundary, of the tie line constructed across the $\alpha + L$ phase region at 1380°C—i.e., about 78 wt% Ni.

Concept Check 10.3

Question: *Is it possible to have a copper-nickel alloy that, at equilibrium, consists of an α phase of composition 37 wt% Ni-63 wt% Cu, and also a liquid phase of composition 20 wt% Ag-80 wt% Cu? If so, what will be the approximate temperature of the alloy? If this is not possible, explain why.*

Answer: It is *not possible* to have a Cu-Ni alloy, which at equilibrium, consists of a liquid phase of composition 20 wt% Ni-80 wt% Cu and an α phase of composition 37 wt% Ni-63 wt% Cu. From Figure 10.3a, a single tie line does not exist within the $\alpha + L$ region that intersects the phase boundaries at the given compositions. At 20 wt% Ni, the L-($\alpha + L$) phase boundary is at about 1200°C, whereas at 37 wt% Ni the ($L + \alpha$)-α phase boundary is at about 1225°C.

Concept Check 10.4

Question: *At 700 °C (1290 °F), what is the maximum solubility (a) of Cu in Ag? (b) Of Ag in Cu?*

Answer: (a) From the copper-silver phase diagram, Figure 10.7, the maximum solubility of Cu in Ag at 700°C corresponds to the position of the β-(α + β) phase boundary at this temperature, or to about 6 wt% Cu.

(b) From this same figure, the maximum solubility of Ag in Cu corresponds to the position of the α-(α + β) phase boundary at this temperature, or about 5 wt% Ag.

Concept Check 10.5

Question: *Below is a portion of the H_2O-NaCl phase diagram:*
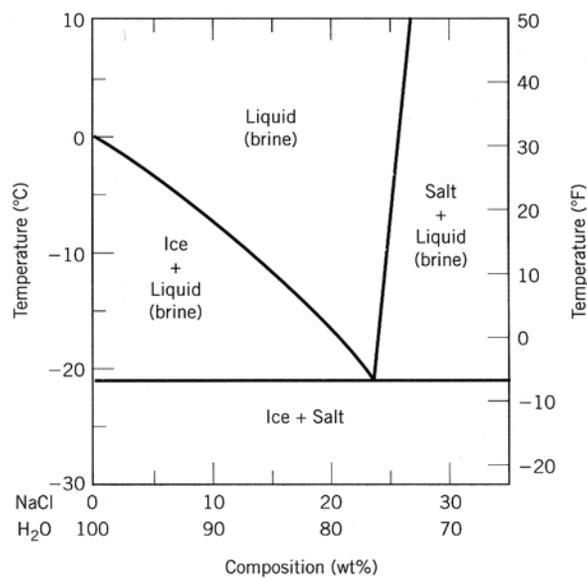
(a) *Using this diagram, briefly explain how spreading salt on ice that is at a temperature below 0 °C (32 °F) can cause the ice to melt.*

(b) *At what temperature is salt no longer useful in causing ice to melt?*

Solution: (a) Spreading salt on ice will lower the melting temperature, since the liquidus line decreases from 0°C (at 100% H_2O) to the eutectic temperature at about -21°C (23 wt%

NaCl). Thus, ice at a temperature below 0°C (and above -21°C) can be made to form a liquid phase by the addition of salt.

(b) At -21°C and below ice is no longer useful in causing ice to melt because this is the lowest temperature at which a liquid phase forms (i.e., it is the eutectic temperature for this system).

Concept Check 10.6

Question: *The figure below is the hafnium-vanadium phase diagram, for which only single-phase regions are labeled. Specify temperature-composition points at which all eutectics, eutectoids, peritectics, and congruent phase transformations occur. Also, for each, write the reaction upon cooling.*
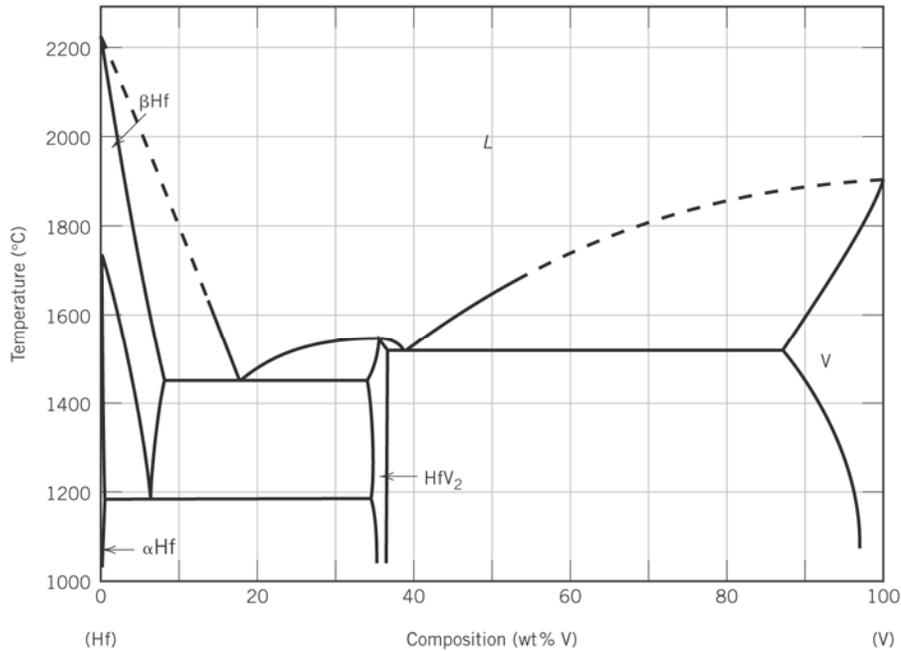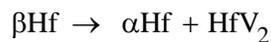

Answer: There are two eutectics on this phase diagram. One exists at 18 wt% V-82 wt% Hf and 1455°C. The reaction upon cooling is
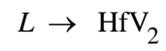
$$L \rightarrow \beta Hf + HfV_2$$

The other eutectic exists at 39 wt% V-61 wt% Hf and 1520°C. This reaction upon cooling is

$$L \rightarrow HfV_2 + V(\text{solid solution})$$

There is one eutectoid at 6 wt% V-94 wt% Hf and 1190°C. Its reaction upon cooling is

$$\beta Hf \rightarrow \alpha Hf + HfV_2$$

There is one congruent melting point at 36 wt% V-64 wt% Hf and 1550°C. The reaction upon cooling is

$$L \rightarrow HfV_2$$

No peritectics are present.

Concept Check 10.7

Question: *(a) For the SiO_2-Al_2O_3 system, what is the maximum temperature that is possible without the formation of a liquid phase?*

(b) At what composition or over what range of compositions will this maximum temperature be achieved?

Answer: (a) According to Figure 10.26 this maximum temperature is $1890 \pm 10°C$, (b) which is possible for compositions between about 77 wt% Al_2O_3 and virtually 100 wt% Al_2O_3.

Concept Check 10.8

Question: *For a ternary system, three components are present; temperature is also a variable. What is the maximum number of phases that may be present for a ternary system, assuming that pressure is held constant?*

Answer: For a ternary system ($C = 3$) at constant pressure ($N = 1$), Gibbs phase rule, Equation 10.16, becomes

$$P + F = C + N = 3 + 1 = 4$$

Or,

$$P = 4 - F$$

Thus, when $F = 0$, P will have its maximum value of 4, which means that the maximum number of phases present for this situation is 4.

Concept Check 10.9

Question: *Briefly explain why a proeutectoid phase (ferrite or cementite) forms along austenite grain boundaries.* Hint: *Consult Section 5.8.*

Answer: Associated with grain boundaries is an interfacial energy (i.e., grain boundary energy—Section 5.8). A lower net interfacial energy increase results when a proeutectoid phase forms along existing austenite grain boundaries than when the proeutectoid phase forms within the interior of the grains.