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 presents.

(2) The compositions of these phases, and

(3) The percentages or fractions of the phases.

The procedures for making these determinations will be demonstrated using the copper–nickel system.

Phases Present

The establishment of what phases are present is relatively simple. One just locates the temperature–composition point on the diagram and notes the phase(s) with which the corresponding phase field is labeled. For example, an alloy of composition 60 wt% Ni–40 wt% Cu at 1100ºC would be located at point *A* in Figure 4*a*; because this is within the α region, only the single α phase will be present. On the other hand, a 35 wt% Ni- 65 wt% Cu alloy at 1250ºC (point *B*) will consist of both α and liquid phases at equilibrium.

Determination of Phase Compositions

The first step in the determination of phase compositions (in terms of the concentrations of the components) is to locate the temperature–composition point on the phase diagram. Different methods are used for single- and two-phase regions. If only one phase is present, the procedure is trivial: the composition of this phase is simply the same as the overall composition of the alloy. For example, consider the 60 wt% Ni-40 wt% Cu alloy at 1100ºC (point *A*, Figure 4*a*). At this composition and temperature, only the α phase is present, having a composition of 60 wt% Ni- 40 wt% Cu. For an alloy having composition and temperature located in a two-phase region, the situation is more complicated. In all two-phase regions (and in two-phase regions only), one may imagine a series of horizontal lines, one at every temperature; each of these is known as a ***tie line,*** or sometimes as an isotherm. These tie lines extend across the two-phase region and terminate at the phase boundary lines on either side. 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. Perpendiculars are dropped from these intersections to the horizontal composition axis, from which the composition of each of the respective phases is read.

For example, consider again the 35 wt% Ni–65 wt% Cu alloy at 1250ºC, located at point *B* in Figure 4*b* and lying within the $\alpha + L$ region. Thus, the problem is to determine the composition (in wt% Ni and Cu) for both the α and liquid phases. The tie line has been constructed across the $\alpha + L$ phase region, as shown in Figure 4*b*. The perpendicular from the intersection of the tie line with the liquidus boundary meets the composition axis at 31.5 wt% Ni- 68.5 wt% Cu, which is the composition of the liquid phase, C_L. Likewise, for the solidus–tie line intersection, we find a composition for the α solid-solution phase, of 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.

Again, the single and two-phase situations must be treated separately. The solution is obvious in the single-phase region: because only one phase is present, the alloy is composed entirely of that phase; that is, the phase fraction is 1.0 or, alternatively, the percentage is 100%. From the previous example for the 60 wt% Ni- 40 wt% Cu alloy at 1100ºC (point *A* in Figure 4*a*), only the α phase is present; hence, the alloy is completely or 100% α.

If the composition and temperature position is located within a two-phase region, things are more complex. The tie line must be utilized in conjunction with a procedure that is often called the ***lever rule*** **(or the *inverse lever rule*)**, which is applied as follows:

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

2. The overall alloy composition is located on the tie line.

3. The fraction of one phase is computed by taking the length of tie line from the overall alloy composition to the phase boundary for the *other* phase, and dividing by the total tie line length.

4. The fraction of the other phase is determined in the same manner.

5. If phase percentages are desired, each phase fraction is multiplied by 100.When the composition axis is scaled in weight percent, the phase fractions computed using the lever rule are mass fractions- the mass (or weight) of a specific phase divided by the total alloy mass (or weight). The mass of each phase is computed from the product of each phase fraction and the total alloy mass.

In the employment of the lever rule, tie line segment lengths may be determined either by direct measurement from the phase diagram using a linear scale, preferably graduated in millimeters, or by subtracting compositions as taken from the composition axis.

Consider again the example shown in Figure 4*b*, in which at 1250ºC both α and liquid phases are present for a 35 wt% Ni–65 wt% Cu alloy. The problem is to compute the fraction of each of the α and liquid phases. The tie line has been constructed that was used for the determination of α and L phase compositions. Let the overall alloy composition be located along the tie line and denoted as C_0, and mass fractions be represented by W_L and W_α for the respective phases. From the lever rule, W_L may be computed according to

$$W_L = \frac{S}{R + S}$$

or, by subtracting compositions

$$W_L = \frac{C_\alpha - C_0}{C_\alpha - C_L}$$

Composition need be specified in terms of only one of the constituents for a binary alloy; for the preceding computation, weight percent nickel will be used (i.e., C_0 = 35 wt% Ni, C_α = 42.5wt% Ni, and C_L = 31.5 wt% Ni), and

$$W_L = \frac{42.5 - 35}{42.5 - 31.5} = 0.68$$

Similarly, for the α phase,

$$W_\alpha = \frac{R}{R + S} \qquad = \frac{C_0 - C_L}{C_\alpha - C_L} \qquad = \frac{35 - 31.5}{42.5 - 31.5} = 0.32$$

Of course, identical answers are obtained if compositions are expressed in weight percent copper instead of nickel.

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. Its derivation is presented as an example problem.

It is easy to confuse the foregoing procedures for the determination of phase compositions and fractional phase amounts; thus, a brief summary is warranted. Compositions of phases are expressed in terms of weight percents of the components (e.g., wt% Cu, wt% Ni). For any alloy consisting of a single phase, the composition of that phase is the same as the total alloy composition. If two phases are present, the tie line must be employed, the extremities of which determine the compositions of the respective phases. With regard to fractional phase amounts (e.g., mass fraction of the α or liquid phase), when a single phase exists, the alloy is completely that phase. For a two-phase alloy, on the other hand, the lever rule is utilized, in which a ratio of tie line segment lengths is taken.