More complex phase diagrams are also observed. In some, the two-phase region touches two axes, in some it touches no axis at all, and some exhibit two or more regions where phase separation occurs.

Because plotting data on equilateral triangles has certain inconveniences, sometimes ternary data are presented on a right triangle, as shown by the smaller inset in Figure 8-13. In this graph, the vertical axis represents one component, the horizontal axis the second component and the third component is obtained by mass balance from the two known fractions.

7.4 kg

Example 8.8: Ternary Systems

Ten kilograms of water are mixed with 10.4 kg acetic acid and 10.87 kg methylisobutyl ketone (MIBK) at 25 °C. Determine the phase of the mixture. If a two-phase system, report the amount and composition of each phase.

Solution The mixture has the overall composition (by weight):

$$z_{\mathrm{w}} = 0.3583, \quad z_{\mathrm{aa}} = 0.2522, \quad z_{\mathrm{mbik}} = 0.3895.$$

This places the state at point E in Figure 8-13, which lies in the two-phase region. We locate the tie line on which this point lies and read the composition of the equilibrium compositions of the two phases:

	Water	Acetic acid	MIBK
Phase 1	0.678	0.262	0.060
Phase 2	0.145	0.246	0.609

By mass balance on component i we have

$$z_i = L_1 x_i^{(1)} + L_2 x_i^{(2)},$$

where L_1, L_2, represent the mass fractions of the two phases and

$$L_1 + L_2 = 1.$$

Substituting into the mass balance equation and solving for L_1 we obtain

$$L_1 = \frac{z_i - x_i^{(2)}}{x_i^{(1)} - x_i^{(2)}}, \quad L_2 = 1 - L_1.$$

This is the familiar lever rule and applies to all three components:

$$\text{water} \qquad L_1 = \frac{0.3583 - 0.145}{0.678 - 0.145} = 0.600,$$

$$\text{acetic acid} \qquad L_1 = \frac{0.2522 - 0.246}{0.262 - 0.246} = 0.610,$$

$$\text{MIBK} \qquad L_1 = \frac{0.3895 - 0.609}{0.060 - 0.609} = 0.600.$$

The system contains 60% (wt) of liquid phase 1 and 40% of liquid phase 2.

Comments The lever rule gives the same answer regardless of which component is used. The small discrepancy between these values arises from inaccuracies in reading the the composition of the equilibrium calculation of the tie line that passes through the given state. Often, ternary graphs will show selected tie lines, but if the desired state does not lie on one of them, we must obtain one through interpolation between the existing tie lines.

8.8 Summary

The most important feature of phase equilibrium in multicomponent systems is that the composition of phases is not the same.[4] If a mixture is brought into the two-phase region, we obtain phases that are preferentially enriched in one or more components. Separations methods such as distillation, absorption, and extraction operate based on this principle.

Separation

The phase diagram is a graphical representation of the phase of the system at a given pressure, temperature, and composition. Phase diagrams of binary systems are presented as Pxy or Txy graphs. A phase diagram consists of areas where a single phase exists, and areas where multiple phases (two or more) exist at equilibrium. The bubble line marks the boundary of the liquid phase and the dew line that of the vapor phase. Between the bubble and dew lines, the system consists of two phases at equilibrium. Tie lines connect the composition of the phases. The lever rule is a simple relationship between the composition of phases at equilibrium, the overall composition, and the relative amounts of each phase. It is nothing but a statement of mass conservation. The phase diagram of ternary systems is usually presented on an equilateral triangle. This graph shows the phase boundaries as a function of composition, at a given temperature and pressure. A series of such graphs is needed to study the phase behavior of a ternary system at various temperatures or pressures.

The solution of problems in phase equilibrium is facilitated enormously if the phase diagram is known. Several systems have been studied experimentally and the results have been collected in extensive databases. However, given the inexhaustible variety of components, compositions, temperatures, and pressures, the chemical engineer will invariably be faced with components, or conditions, for which such data are not available. A main goal in much of the rest of this book is the development of methods to predict phase behavior where data are not available.

4. There are some exceptions, azeotropes, for example, and critical points.