MME 208 PHASE DIAGRAMS

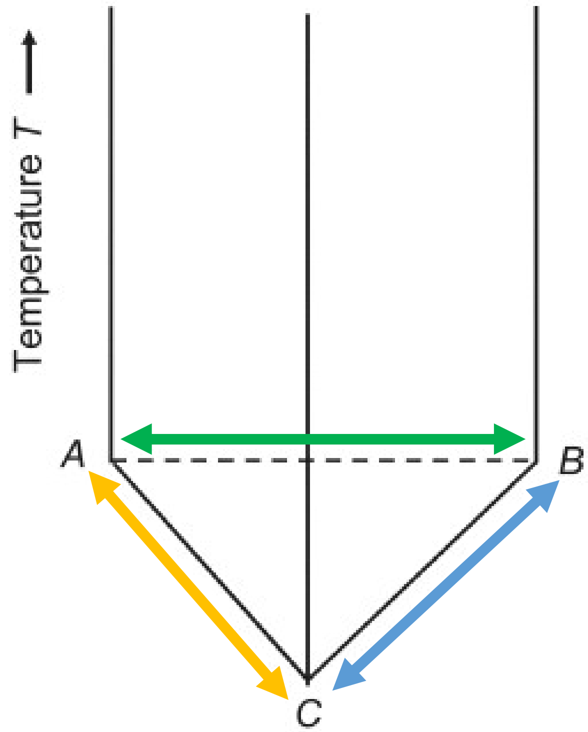
Ternary Phase Diagrams

TERNARY PHASE DIAGRAMS

Ternary systems are those having three components. It is not possible to describe the composition of a ternary alloy with a single number or fraction, as was done with binary alloys, but the statement of two independent values is sufficient. For example, the composition of an Fe-Cr-Ni alloy.

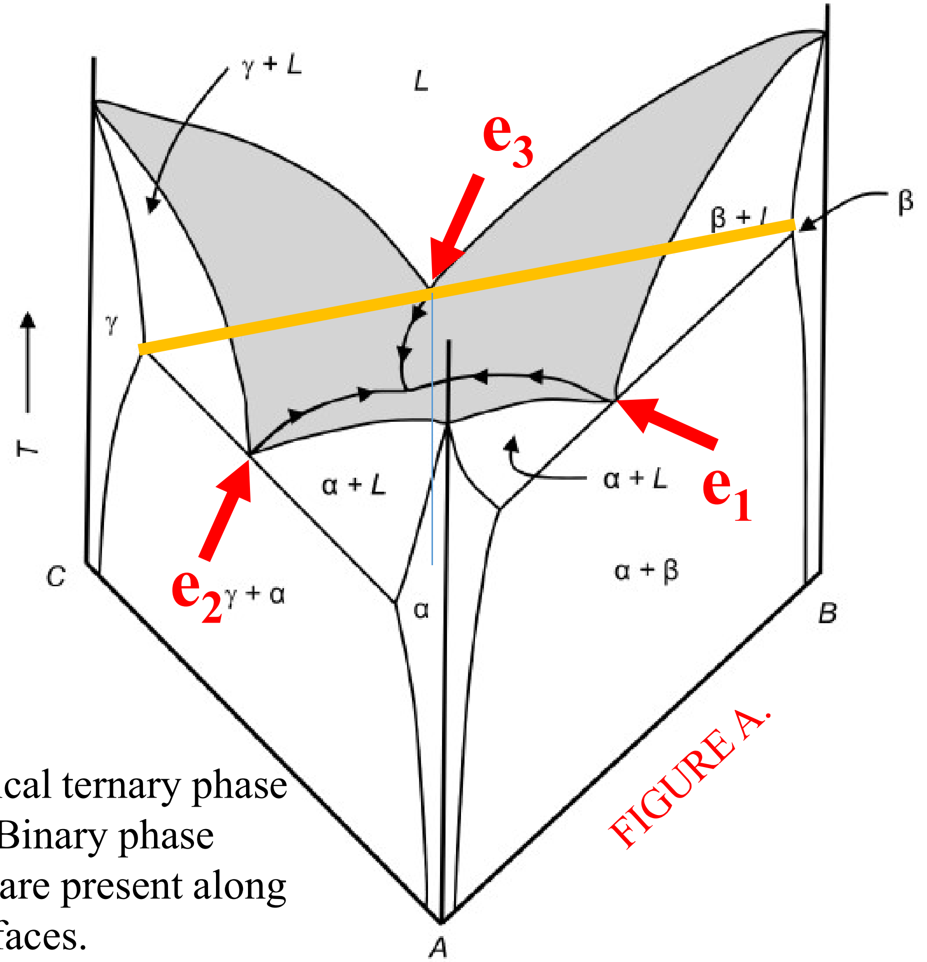
SPACE MODEL OF TERNARY SYSTEMS

The model used is a triangular prism, in which the temperature is plotted on the vertical axis, and the composition is represented on the base of the prism, which may be conveniently taken as an equilateral triangle. Thus, in Figure, **the vertical sides of the prism represent the three binary systems, *AB*, *BC*, and *AC*, that make up the ternary system, *ABC*.**



SPACE MODEL OF TERNARY SYSTEMS

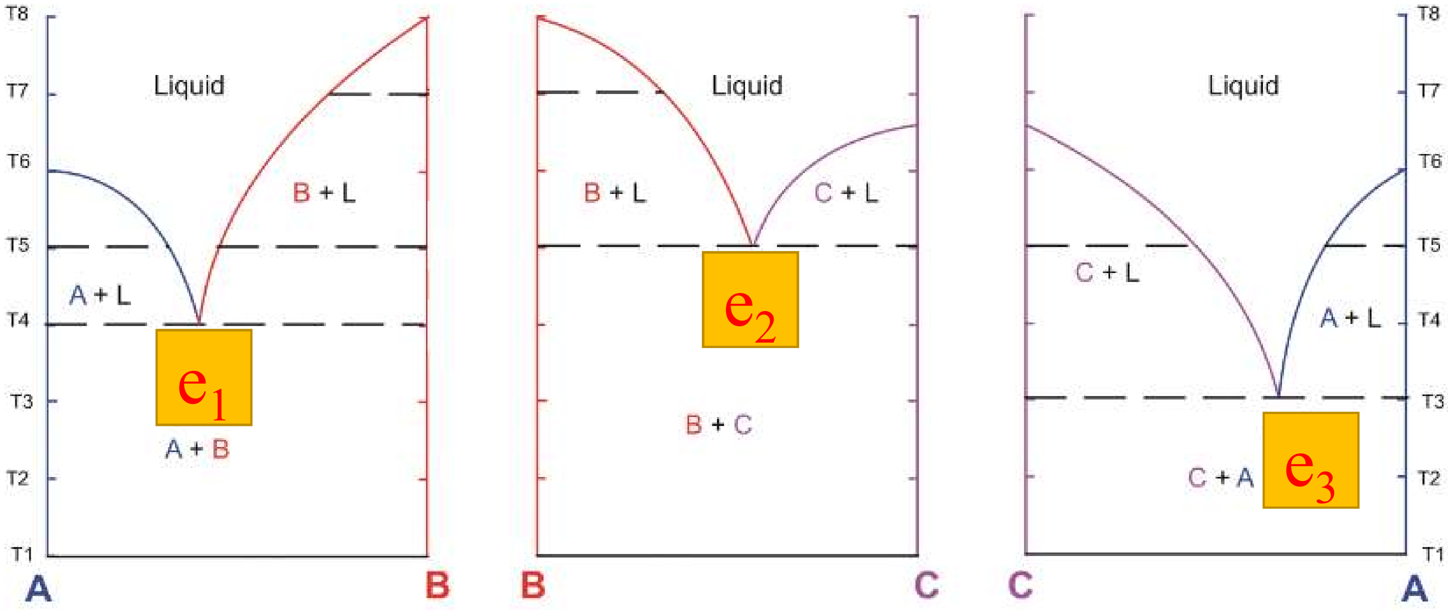
A hypothetical ternary phase space diagram made up of metals *A*, *B*, and *C* is shown in Figure. This diagram **<u>contains two binary eutectics on the two visible faces of the diagram, and a third binary eutectic between elements *B* and *C* hidden on the back of the plot.</u>**



Hypothetical ternary phase diagram. Binary phase diagrams are present along the three faces.

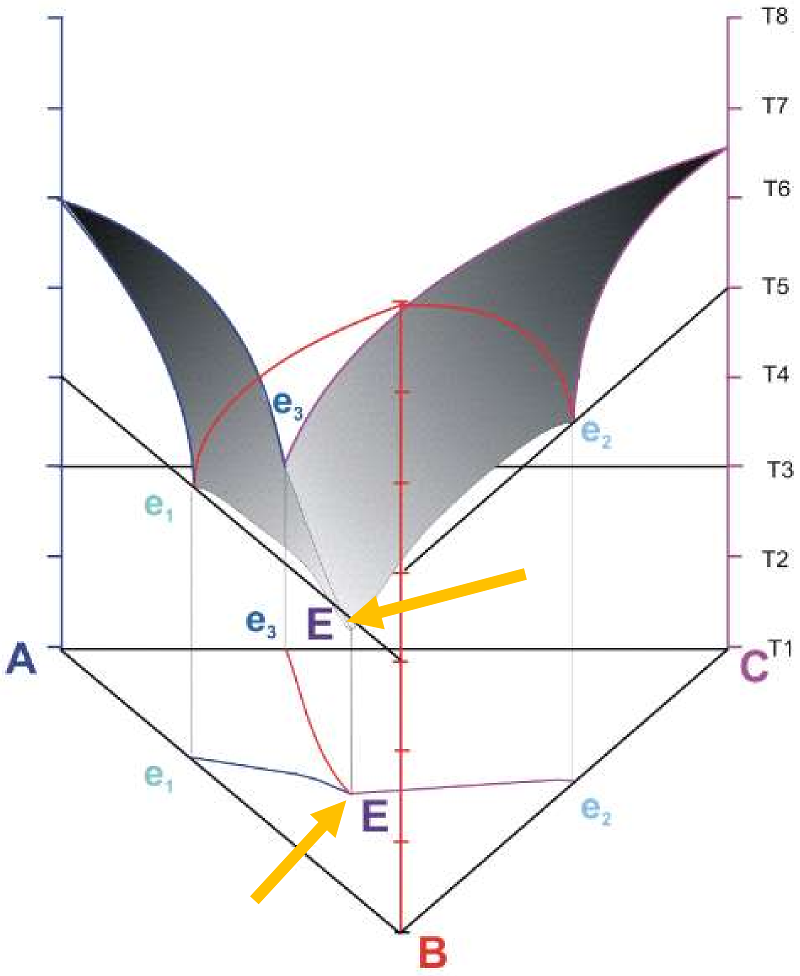
FIGURE A.

SPACE MODEL OF TERNARY SYSTEMS



e_1, e_2 and e_3; Represent the three **binary eutectics points** in the binary diagrams

SPACE MODEL OF TERNARY SYSTEMS



E; Represent the **ternary eutectic point.**

SPACE MODEL OF TERNARY SYSTEMS

It is difficult to use the 3-D ternary plot, the information from the diagrams can be plotted in two dimensions by any of several methods, including the liquidus plot, the isothermal plot, and a vertical section called an isopleth.

LIQUIDUS PLOT

The temperature at which freezing begins is shaded in previous Figure A. In Figure 10.3, **these temperatures for each composition are transferred onto a triangular diagram; the liquidus temperatures are plotted as isothermal contours. This presentation is helpful in predicting the freezing temperature of an alloy. The liquidus plot also gives the identity of the primary phase that will form during solidification for any given alloy composition.** Similar plots, known as solidus plots, showing solidus freezing are sometime presented.

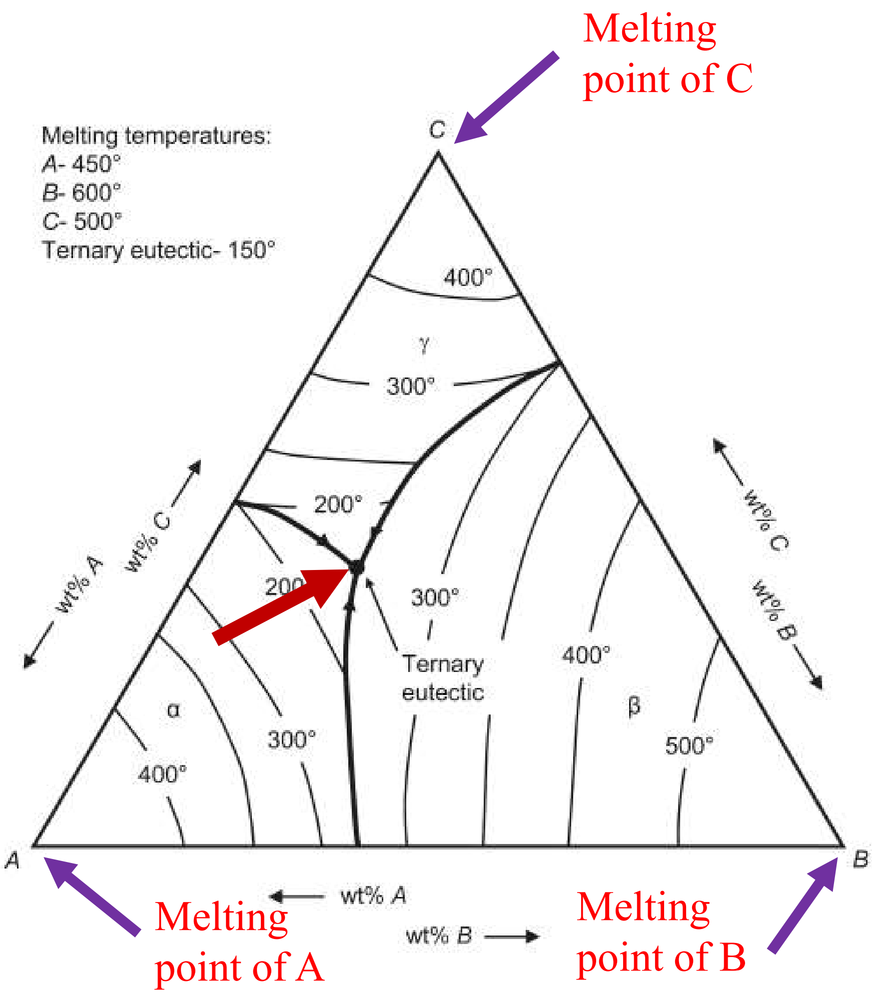


Fig. 10.3 Liquidus plot for hypothetical ternary phase diagram. Adapted from Ref 10.1

ISOTHERMAL PLOT

An isothermal plot shows the phases present in any alloy at a particular temperature and is useful in predicting the phases and their amounts and compositions at that temperature. An isothermal section from Fig. A at room temperature is shown in Figure 10.4. Isothermal plots are by far the most useful because they allow compositional analysis

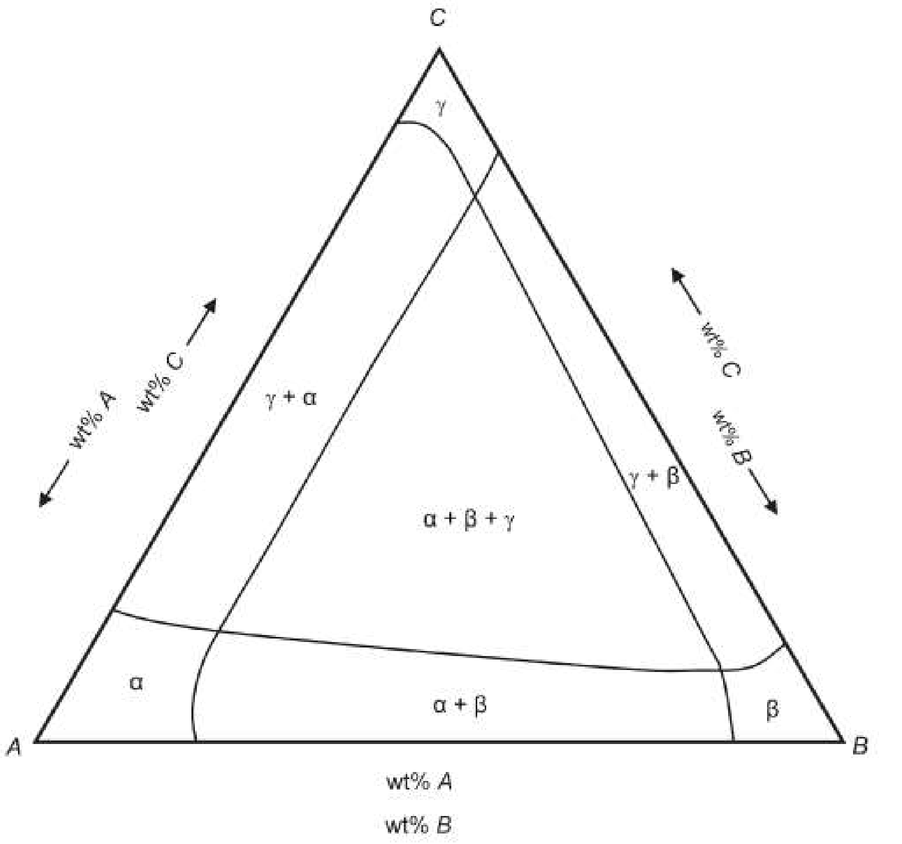


Fig. 10.4 Isothermal plot at room temperature for hypothetical ternary phase diagram. Adapted from Ref 10.1

ISOPLETH

Certain groups of alloys can be plotted as vertical sections, also called isopleths. These sections often represent a fixed composition of one of the elements, while the amounts of the other two elements are allowed to vary. These plots show how the phases and structures change when the temperature varies and when two of the elements present change their respective amounts. An isopleth through the hypothetical diagram (Fig. A) at a constant 40% *C* is shown in Fig. 10.5.

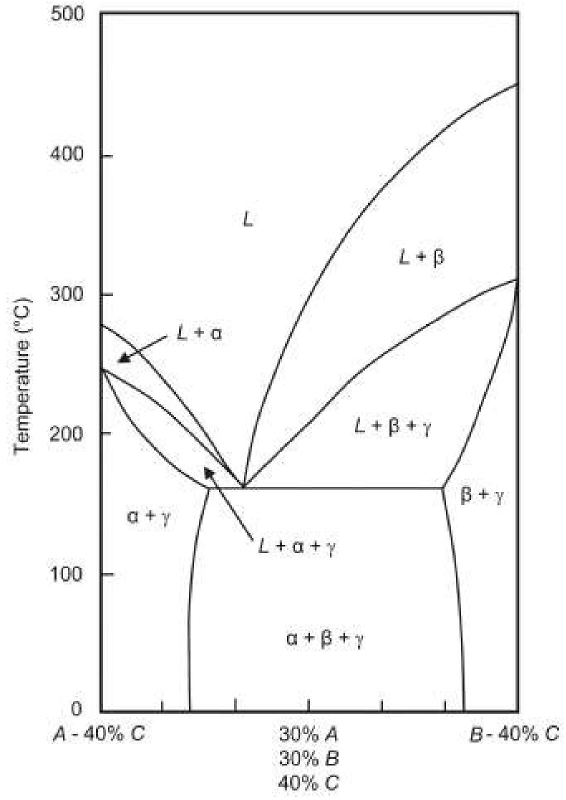


Fig. 10.5 Isopleth through hypothetical ternary phase diagram at a constant 40% C. Adapted from Ref 10.1

SINGLE-PHASE BOUNDARY AND ZERO PHASE FRACTION LINES

Two-dimensional (2-D) sections of any multicomponent phase diagram, whether it is an isotherm or an isopleth, can be read by focusing on two lines that refer to one particular phase.

1. Single Phase Boundary Lines (SPB)
2. Zero Phase Fraction Lines (ZPF)

SINGLE PHASE BOUNDARY LINES (SPB)

The single-phase boundary line is found on any section that contains a single-phase region. The line is what its name implies. It is the boundary line around that single-phase region. **It can be used, for example, to determine compositions and temperatures where an alloy can be thoroughly solutionized.**

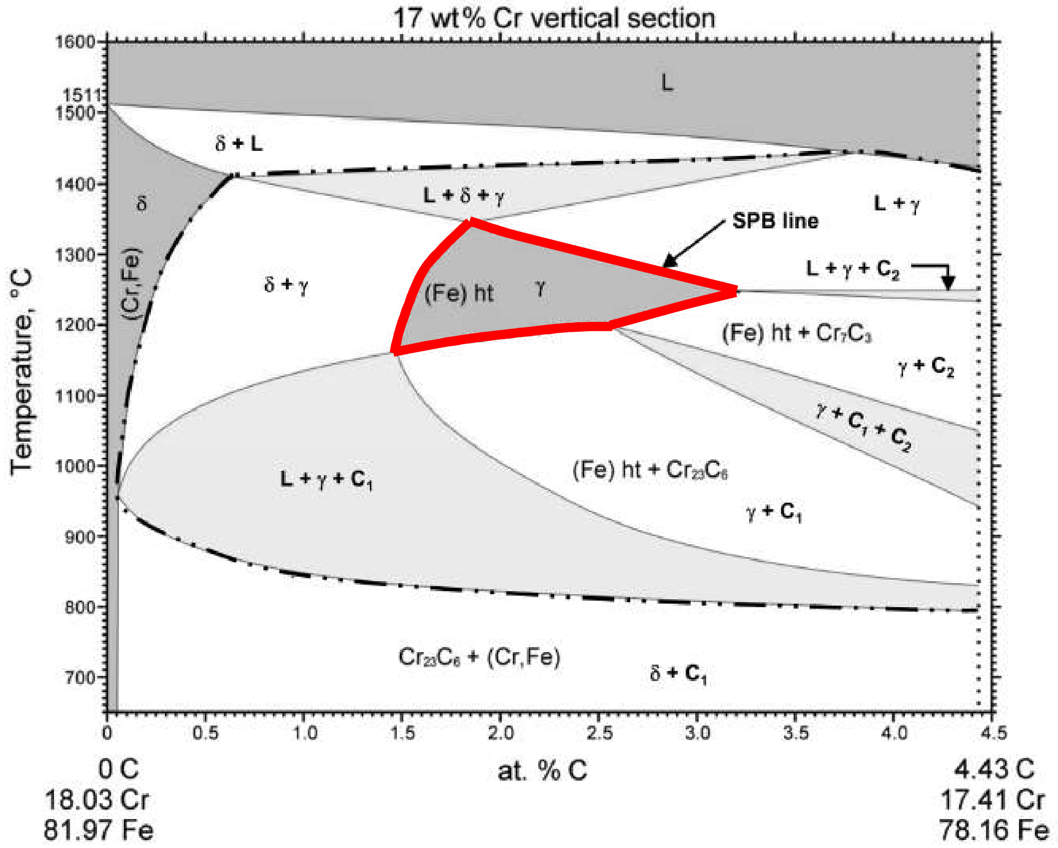


Fig. 10.6 C-Cr-Fe isopleth showing single-phase boundary (SPB) lines and zero-phase boundary (ZPB) lines. Source: Ref 10.2

ZERO PHASE FRACTION LINES

The zero phase fraction line is a line that surrounds all regions on the diagram where the phase occurs. It can be used to avoid a phase, for example an embrittling phase, or promote a phase, for example a precipitation-hardening phase.

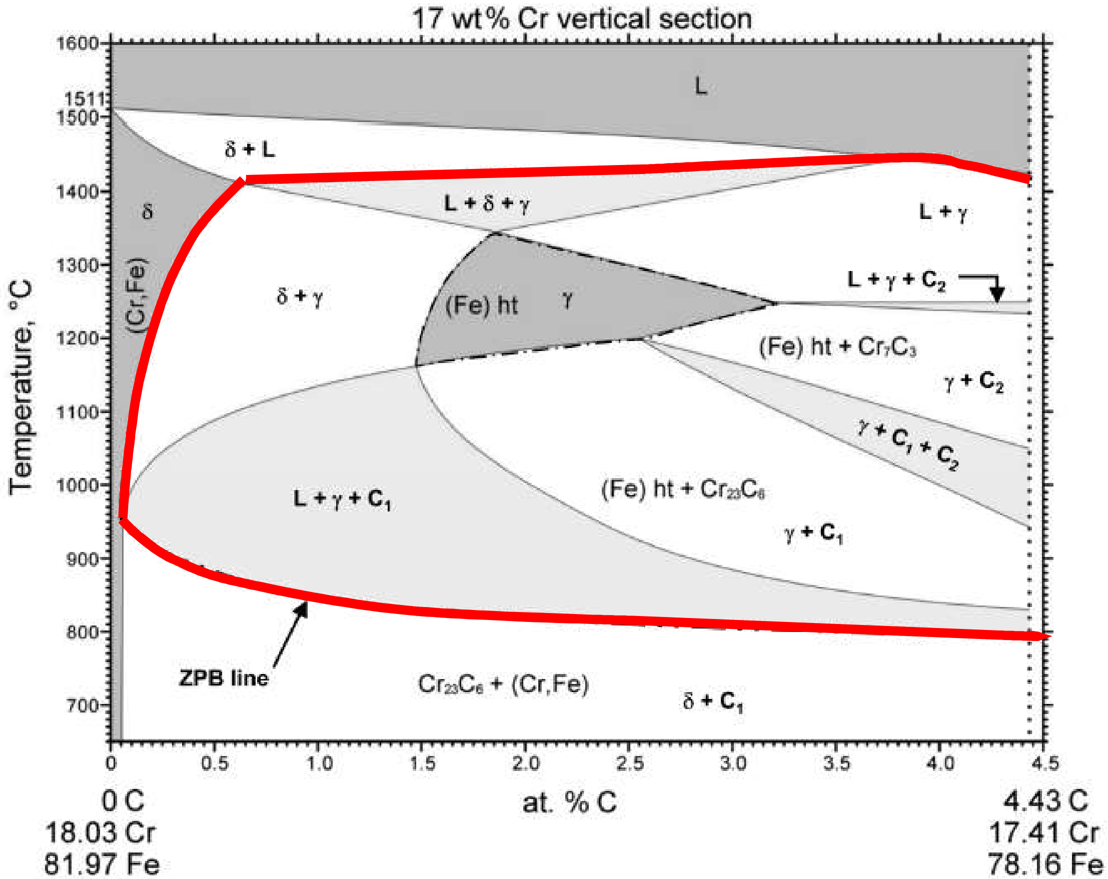


Fig. 10.6 C-Cr-Fe isopleth showing single-phase boundary (SPB) lines and zero-phase boundary (ZPB) lines. Source: Ref 10.2

THE GIBBS TRIANGLE

For convenience in reading composition, an equilateral triangle may be ruled **with lines parallel to the sides** (Fig.). Composition may then be read directly

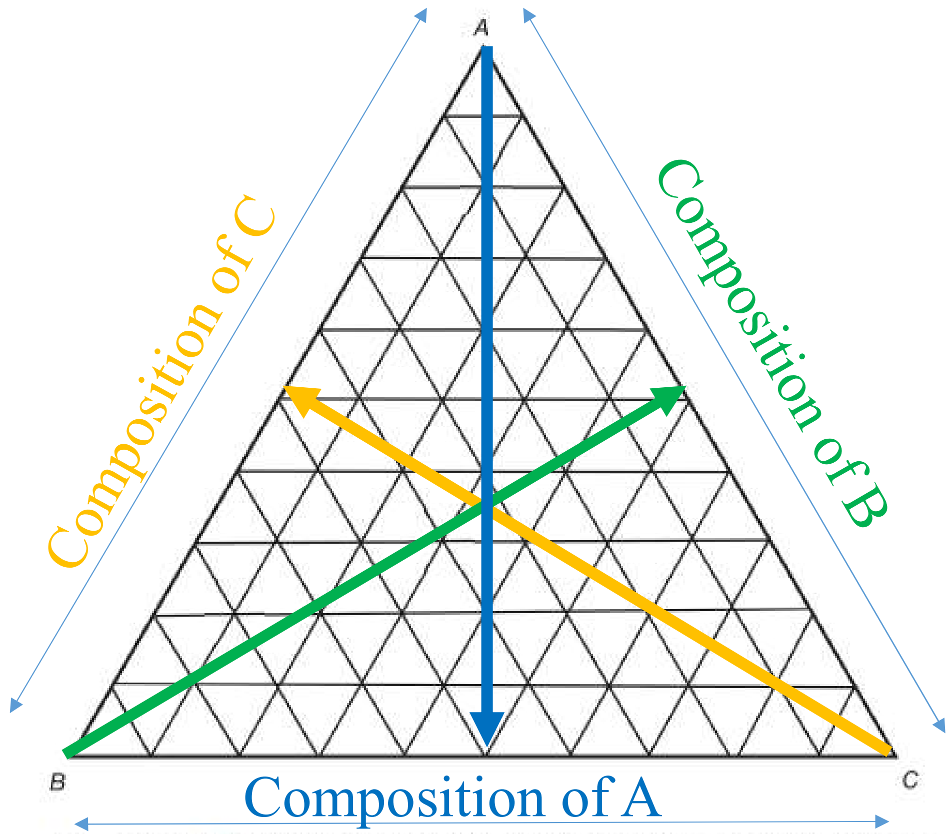
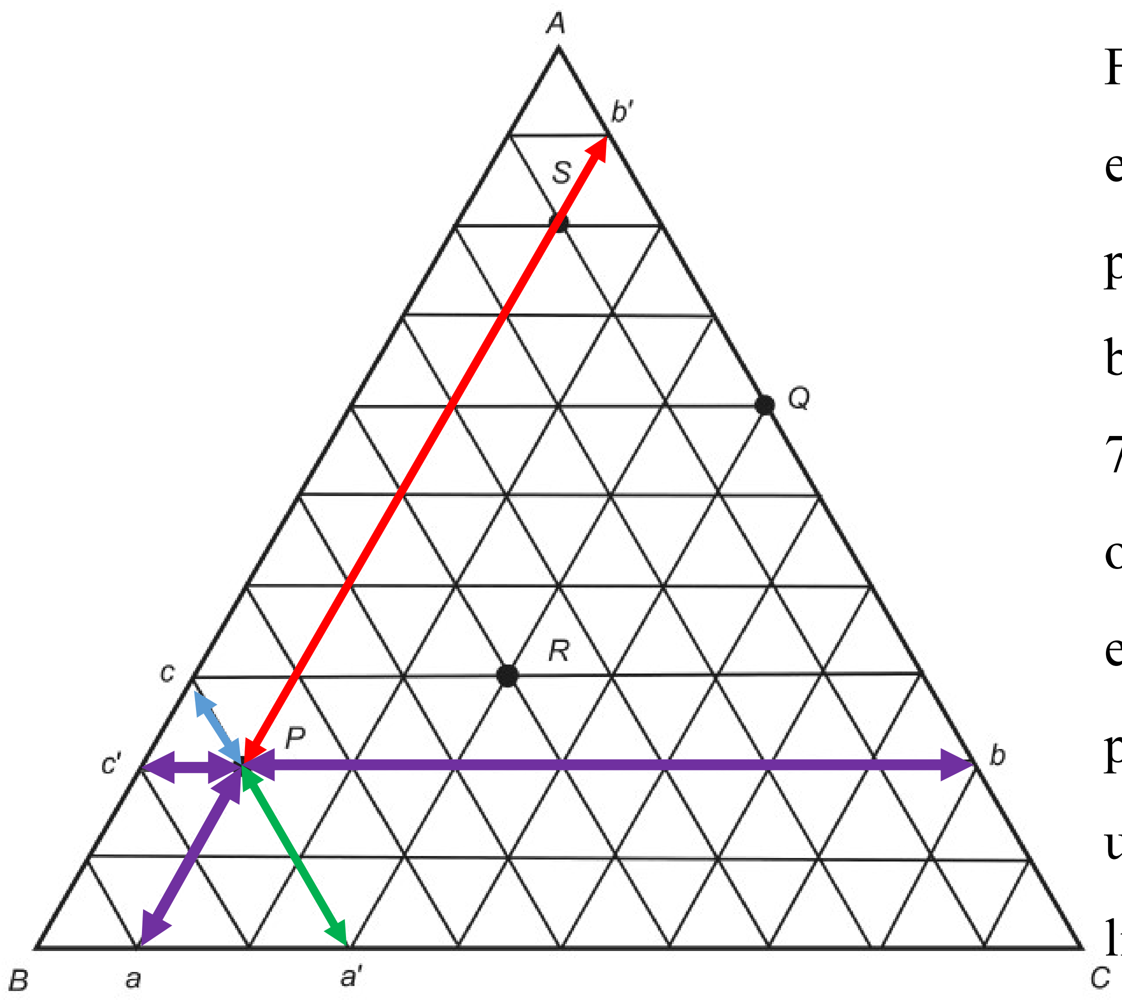


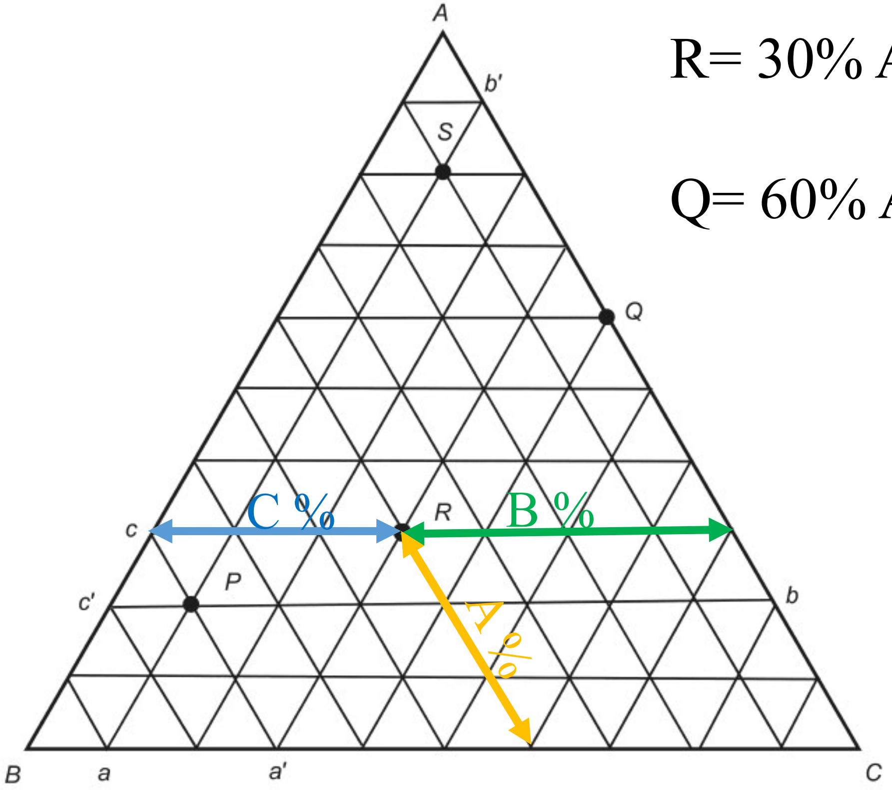
Fig. 10.8 The Gibbs triangle with composition lines. Adapted from Ref 10.3

THE GIBBS TRIANGLE



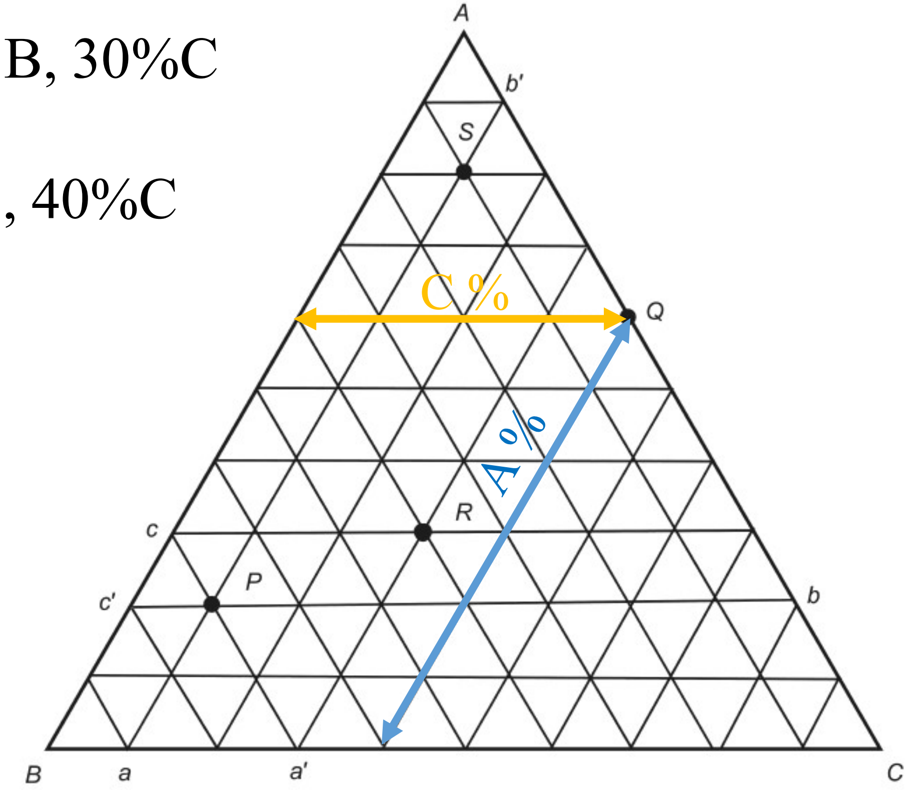
For convenience in reading composition, an equilateral triangle may be ruled with lines parallel to the sides. Composition may then be read directly, for example, P = 20% A + 70% B + 10% C. At point P, the percentage of A is represented by the line Pa (or equivalently Pa'), which is 20 units long; the percentage of B by the line Pb (or Pb'), 70 units long; and the percentage of C by the line Pc (or Pc'), 10 units long.

THE GIBBS TRIANGLE



R= 30% A, 40% B, 30%C

Q= 60% A, 0%B, 40%C



TIE LINES

If any two ternary alloys are mixed together, tie lines can be shown. The composition of the mixture will lie on a straight line joining the original two compositions. This is true regardless of the proportions of the two alloys in the mixture. Conversely, if an alloy decomposes into two fractions of differing composition, the compositions of the two portions will lie on opposite ends of a straight line passing through the original composition point.

TIE LINES

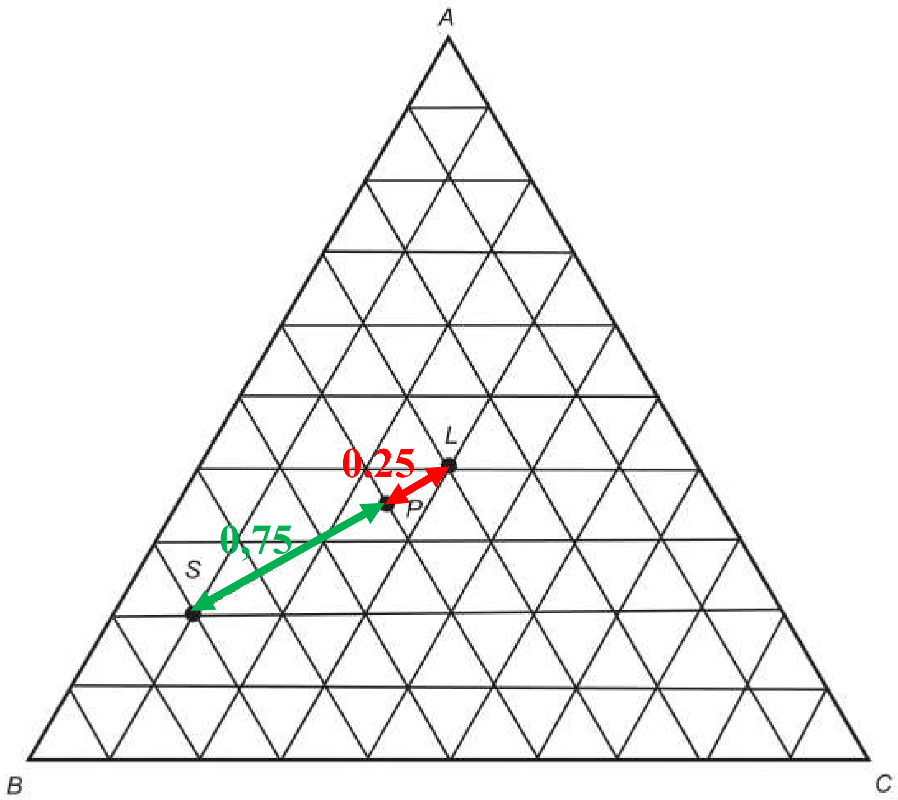


Fig. 10.9 The Gibbs triangle with tie line. Adapted from Ref 10.3

Points *S* and *L* represent two ternary alloys of respective composition: 20% *A* + 70% *B* + 10% *C* and 40% *A* + 30% *B* + 30 % *C*. Suppose that one part of *S* is mixed with three parts of *L* and the mixture is analyzed. The analytical result will be:

$$0.25 \text{ x } 20\% \, A + 0.75 \text{ x } 40\% \, A = 35\% \, A$$

$$0.25 \text{ x } 70\% \, B + 0.75 \text{ x } 30\% \, B = 40\% \, B$$

$$0.25 \text{ x } 10\% \, C + 0.75 \text{ x } 30\% \, C = 25\% \, C$$

TIE LINES

It is both isobaric and isothermal, because it lies in the composition plane, which is drawn perpendicular to the temperature axis and corresponds to the case of constant atmospheric pressure (i.e., it would be drawn perpendicular to the pressure axis if a fourth dimension were available). The lever principle is applicable to SL line. Therefore, the line *SL* might represent the condition of an alloy of composition *P* that is partially frozen, at the temperature under consideration, and consists of 25% solid of composition *S* and 75% liquid of composition *L*:

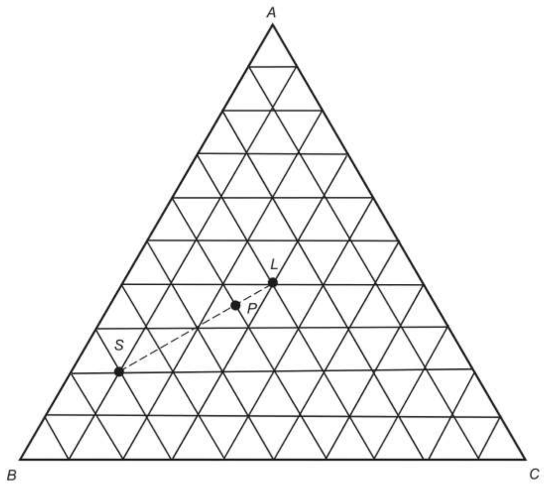


Fig. 10.9 The Gibbs triangle with tie line. Adapted from Ref 10.3

$$\% \, S = \frac{PL}{SL} \times 100$$

$$\% \, L = \frac{SP}{SL} \times 100$$

TERNARY ISOMORPHOUS SYSTEMS

A Temperature - composition (*T*-*X*-*Y*) diagram of an isomorphous system is shown in Fig. 10.10. Here, the liquidus and solidus become surfaces bounding the *L* + α space. Above the liquidus, all alloys are fully molten; below the solidus, all are completely solid. As in binary systems, the two-phase region, *L* + α, is composed of tie lines joining conjugate liquid and solid phases. In the ternary system, however, the tie lines are not confined to a 2-D area but occur as a bundle of lines of varying direction, but all horizontal (isothermal), filling the 3-D two-phase space.

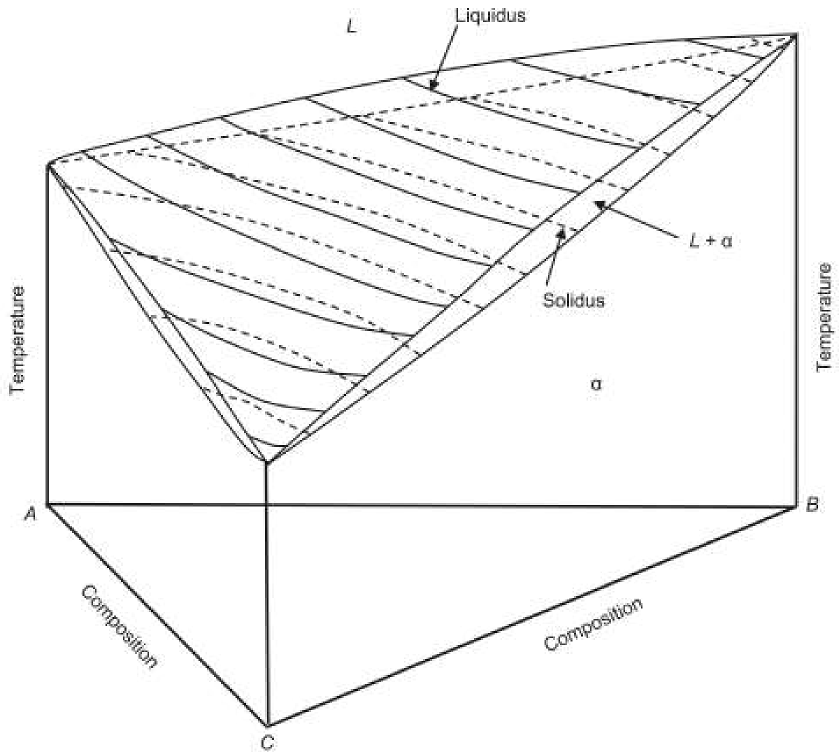


Fig. 10.10 Temperature-composition space diagram of a ternary isomorphous system. Adapted from Ref 10.3

ISOTHERMAL SECTIONS.

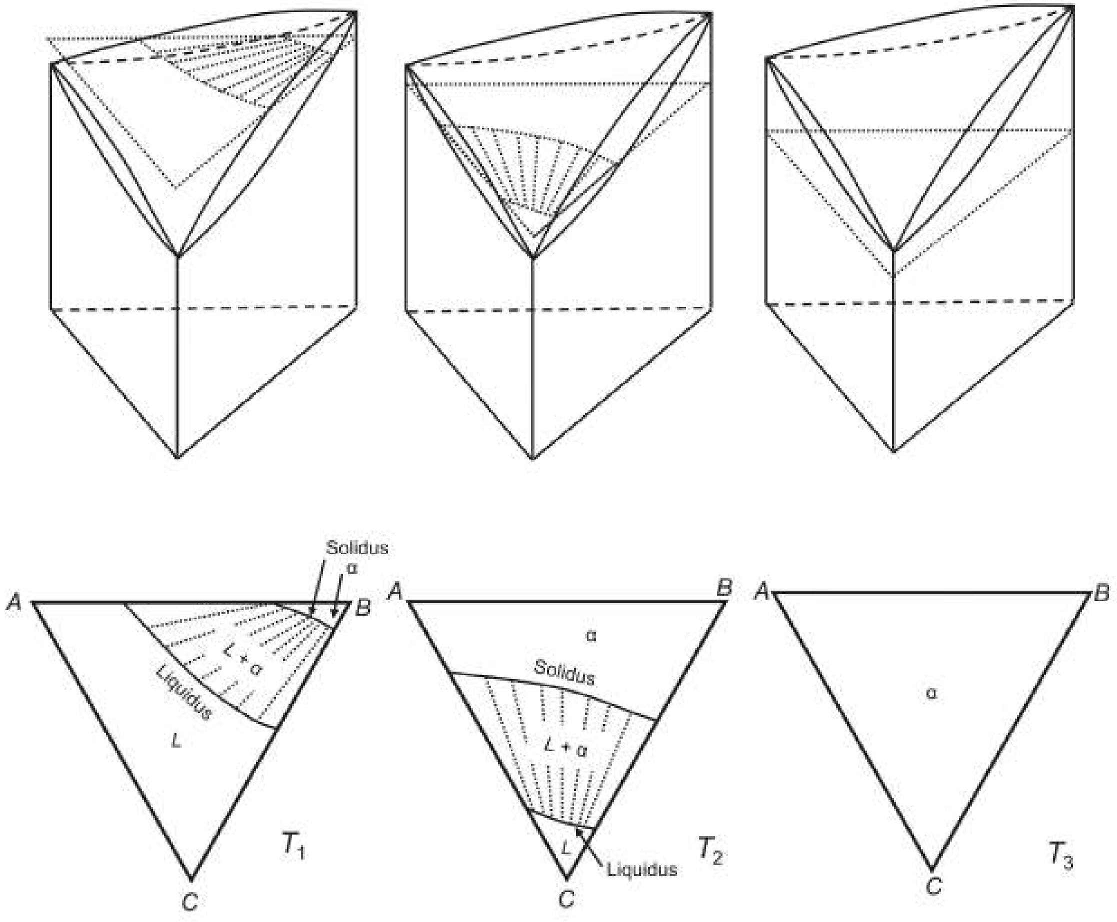


Fig. 10.11 Isotherms through a ternary isomorphous phase diagram. Adapted from Ref 10.3

LIQUIDUS AND SOLIDUS PLOTS

It is possible in certain cases to telescope a group of isotherms into a single diagram. For example, the isothermal lines that were used to delineate the liquidus surface in Fig. 10.10 may be projected onto a plane, such as the base of the diagram, giving the liquidus projection presented in Fig. 10.12. Each line is derived from a separate isotherm and its temperature should therefore be indicated on the line.

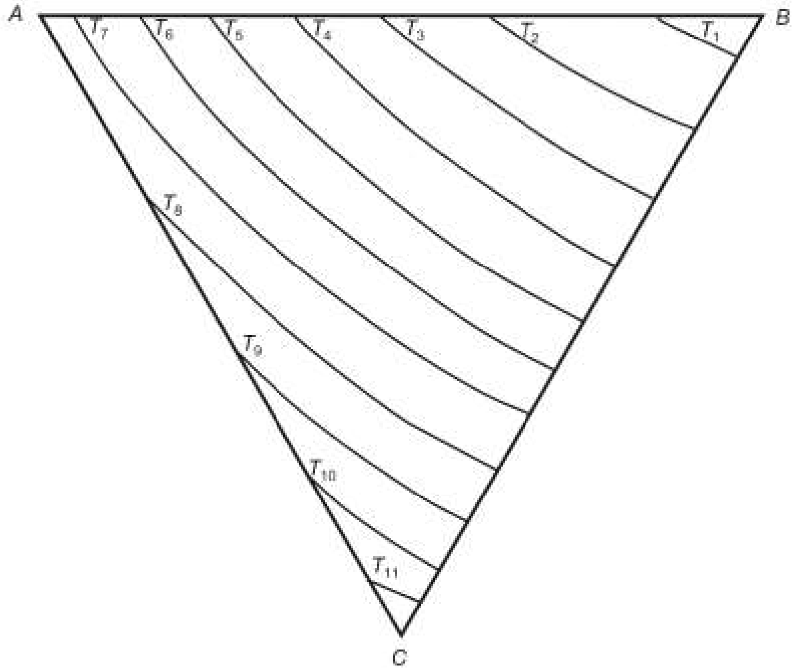


Fig. 10.12 Liquidus projection of the diagram shown in Fig. 10.10. Adapted from Ref 10.3

VERTICAL SECTIONS (ISOPLETHS)

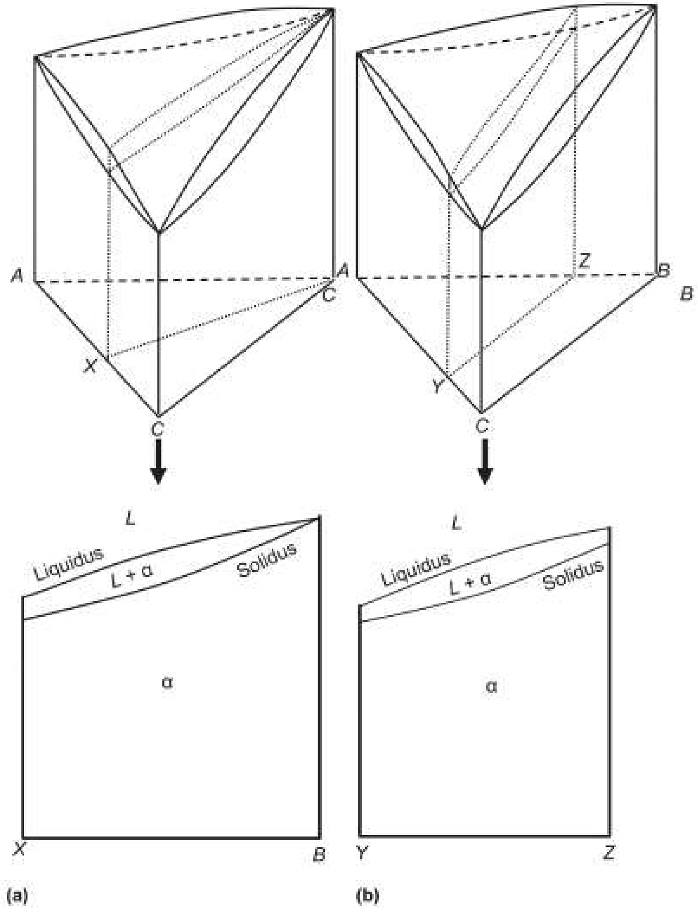


Fig. 10.13 Isopleths through an isomorphous system. Adapted from Ref 10.3

FREEZING OF A TERNARY İSOMORPHOUS ALLOY

- The course of equilibrium freezing of a typical alloy of a ternary **isomorphous system** may be followed by reference to Fig. 10.17. Inscribed on the base of the diagram of Fig. 10.17 is a projection of the tie lines and the paths of composition variation of the liquid and solid phases. **The liquidus path starts at the *X* composition and ends at L_4, while the solidus path starts at α_1 and ends at *X*.** All tie lines, $\alpha_1 L_1$, $\alpha_2 L_2$, $\alpha_3 L_3$, and $\alpha_4 L_4$ pass through *X*. The same information is presented in somewhat more realistic fashion in Fig. 10.18, where the complete isotherm for each of the temperatures from T_1 to T_4 is given.

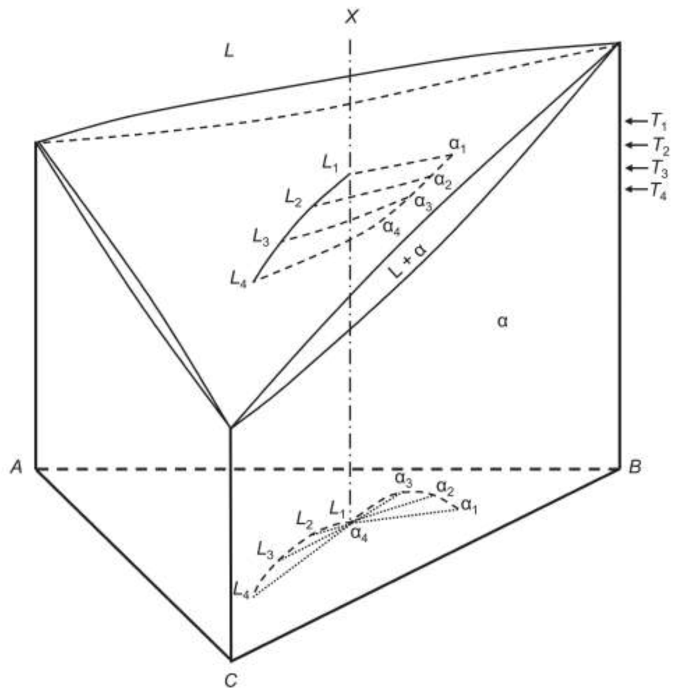


Fig. 10.17 Path of composition change of the liquid *L* and solid α phase during the freezing of a solid-solution alloy. Adapted from Ref 10.3

FREEZING OF A TERNARY İSOMORPHOUS ALLOY

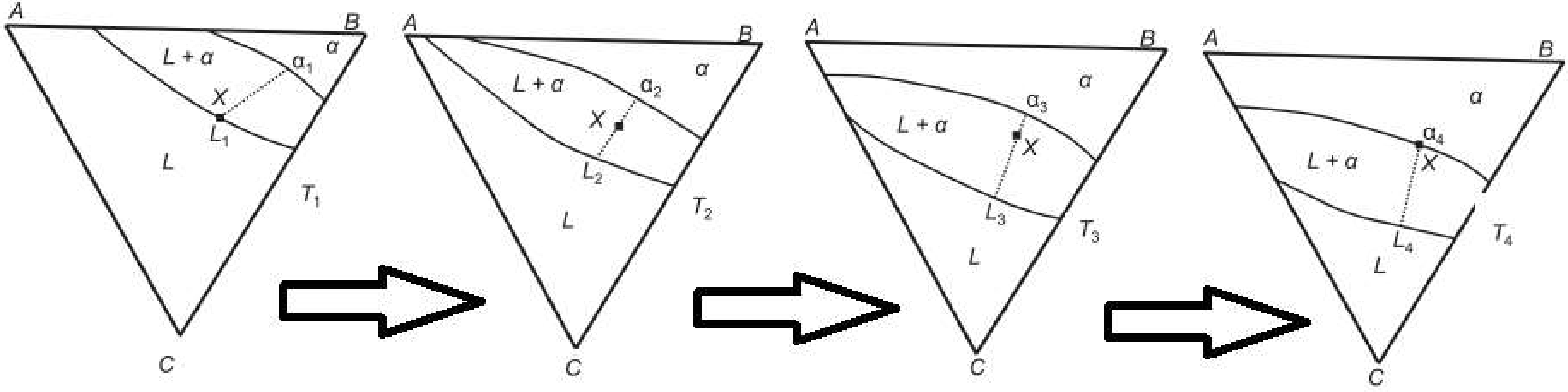
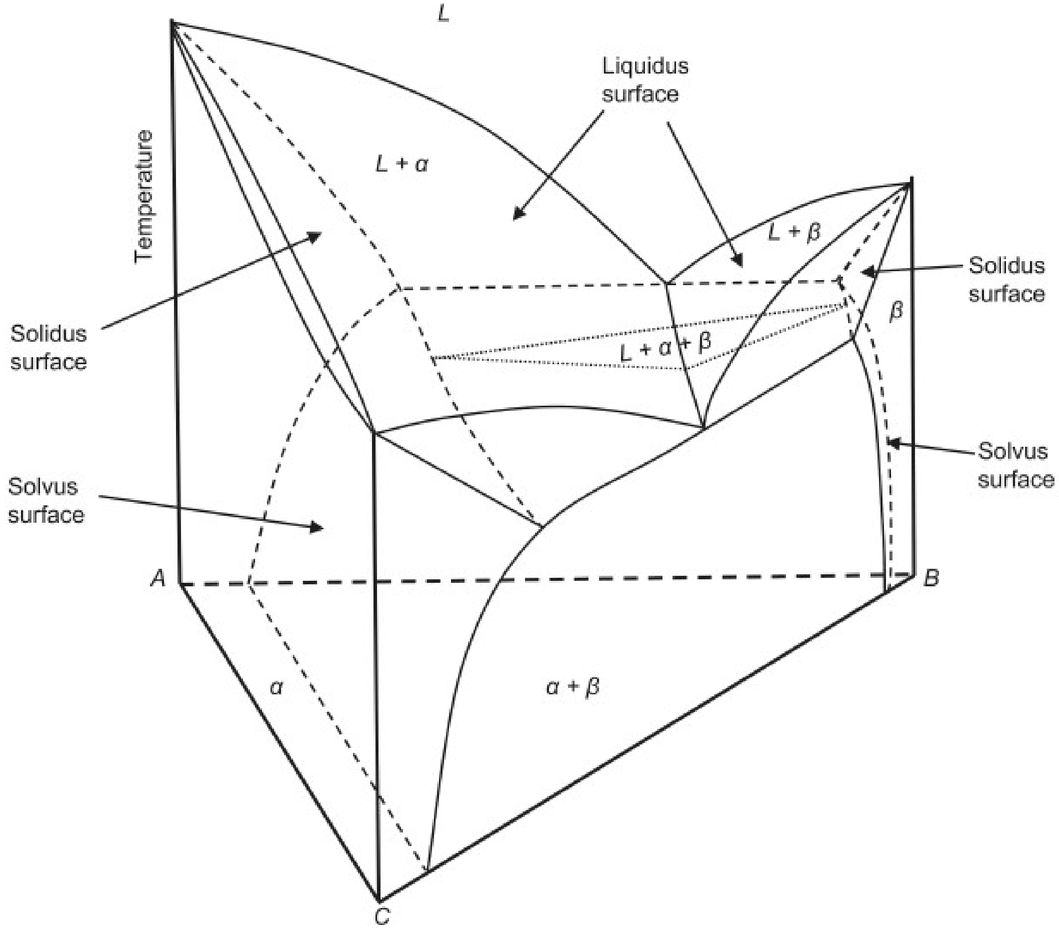


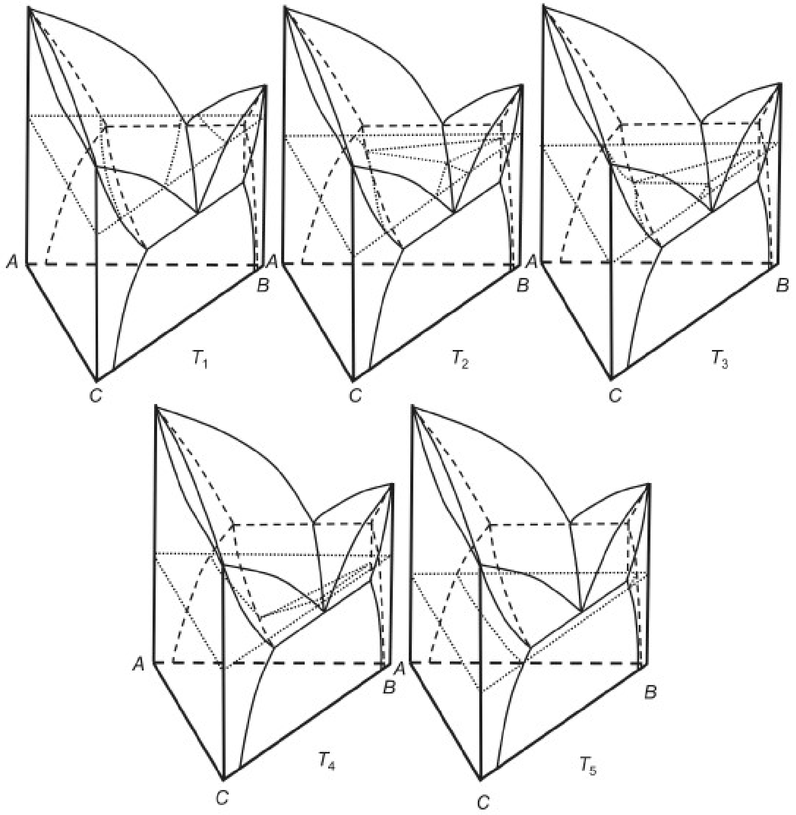
Fig. 10.18 Progress of equilibrium freezing of a ternary isomorphous alloy. Adapted from Ref 10.3

EUTECTIC SYSTEM WITH THREE-PHASE EQUILIBRIUM

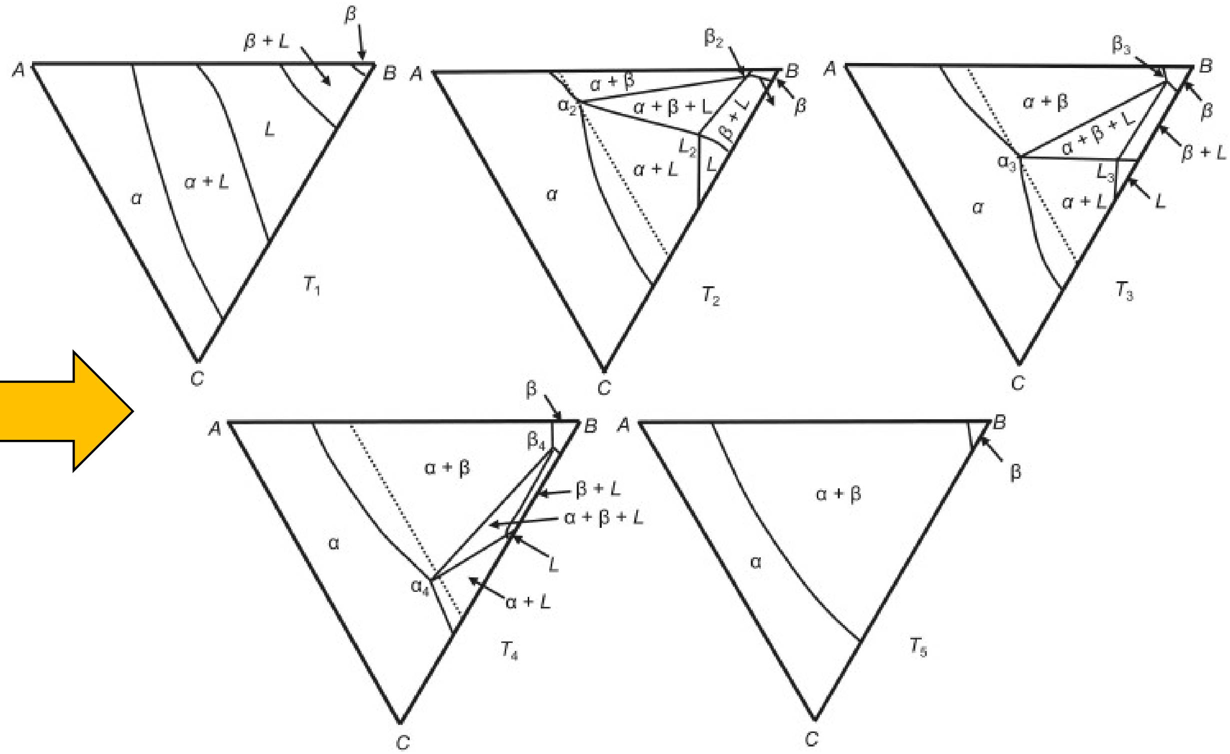
One of the binary systems involved in this ternary system is isomorphous; the other two are of the eutectic type. There are three one-phase regions: *L*, α, and β; three two-phase regions: ***L* + α**, ***L* + β**, and **α + β**; and one three-phase region: ***L* + α + β.**



EUTECTIC SYSTEM WITH THREE-PHASE EQUILIBRIUM

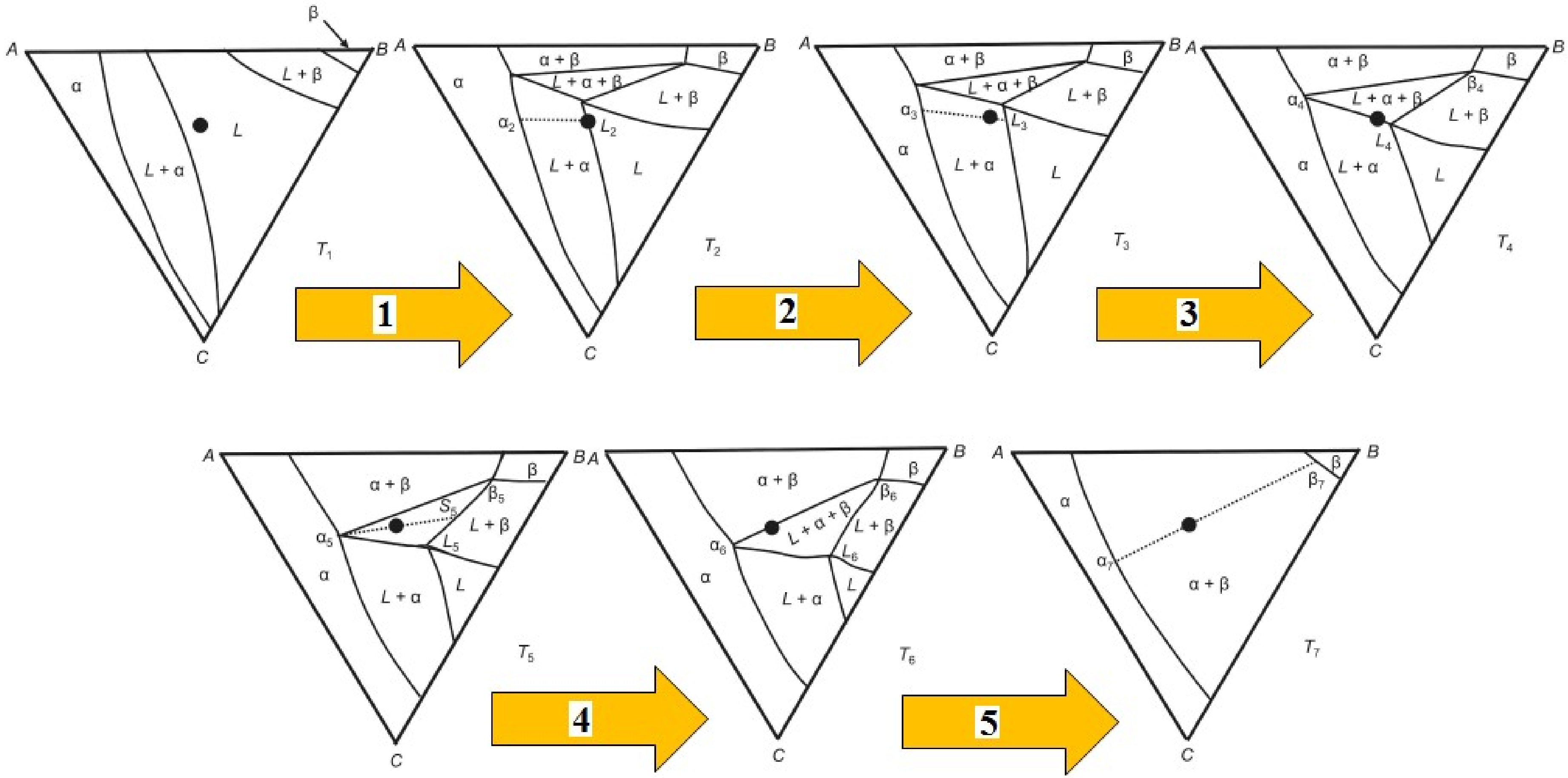


isotherm



Isotherms through the space diagrams

FREEZING OF A TERNARY EUTECTIC ALLOY



PERITECTIC SYSTEM WITH THREE-PHASE EQUILIBRIUM

This diagram has the same number of fields as in the previous example, and they are similarly designated. The most evident difference is in the *L* + α + β field, which has been inverted to produce the peritectic reaction.

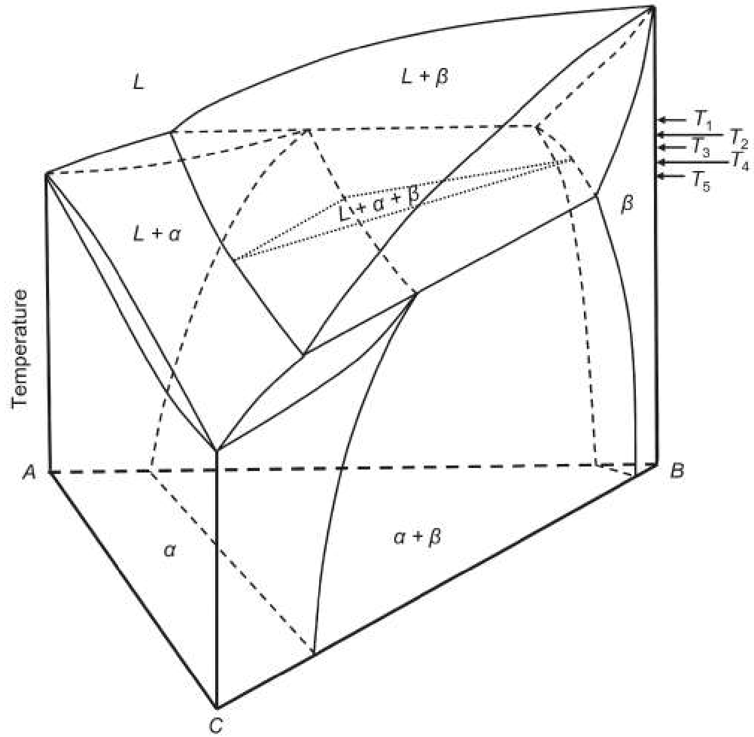


Fig. 10.24 Three-phase equilibria in a ternary system with a peritectic reaction. Adapted from Ref 10.3

PERITECTIC SYSTEM WITH THREE-PHASE EQUILIBRIUM

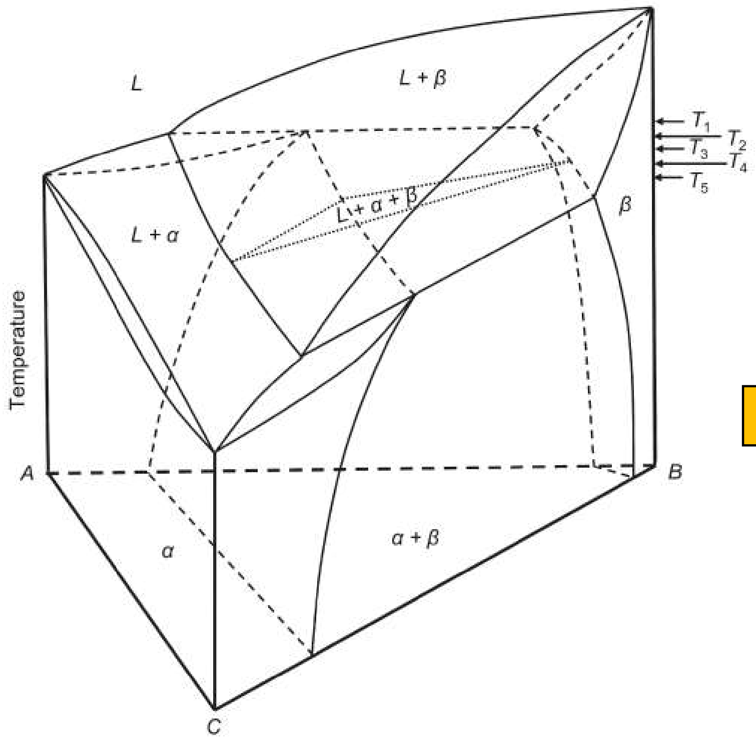


Fig. 10.24 Three-phase equilibria in a ternary system with a peritectic reaction. Adapted from Ref 10.3

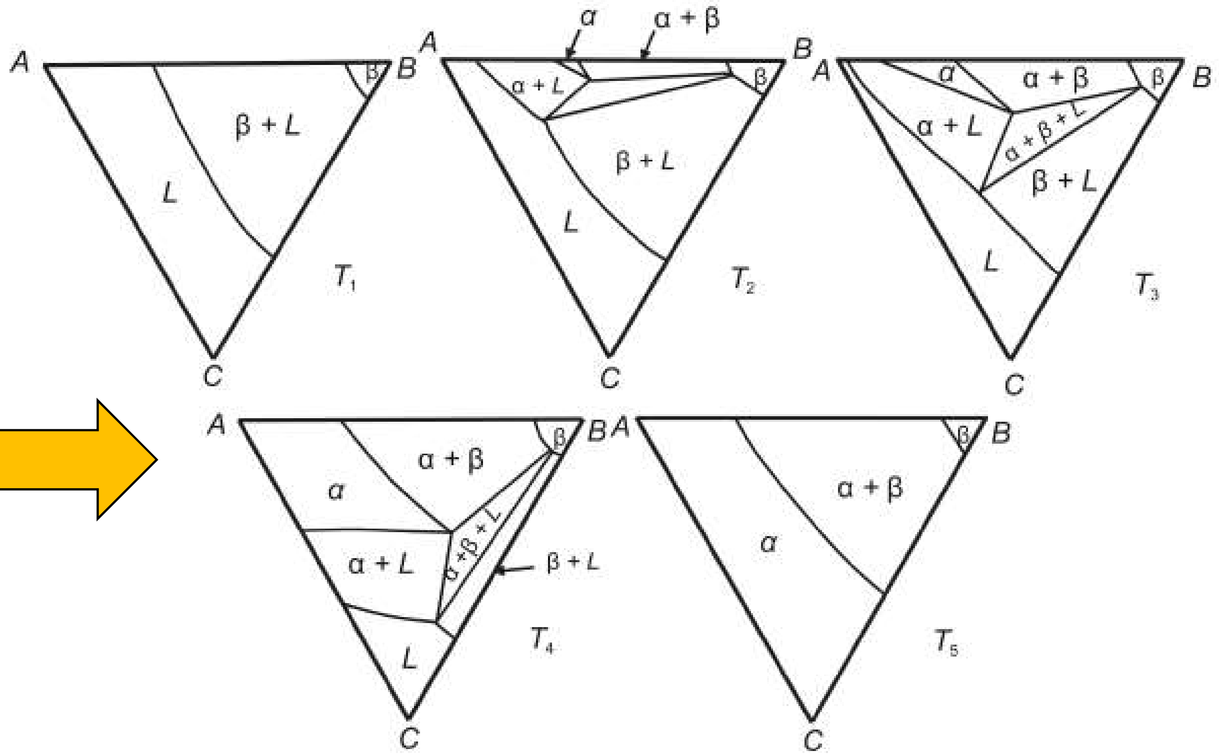


Fig. 10.25 Isotherms through the space diagram of Fig. 10.24. Adapted from Ref 10.3

TERNARY FOUR-PHASE EQUILIBRIUM
$(L \longrightarrow \alpha + \beta + \gamma)$

The ternary eutectic plane has been shaded to make its location more apparent. The three corners of the triangle touch the three one-phase regions α, β, and γ and are so labeled. The liquid composition occurs at point *L* within the triangle, where the liquidus surfaces from the three corners of the space diagram meet at the lowest melting point of the ternary system.

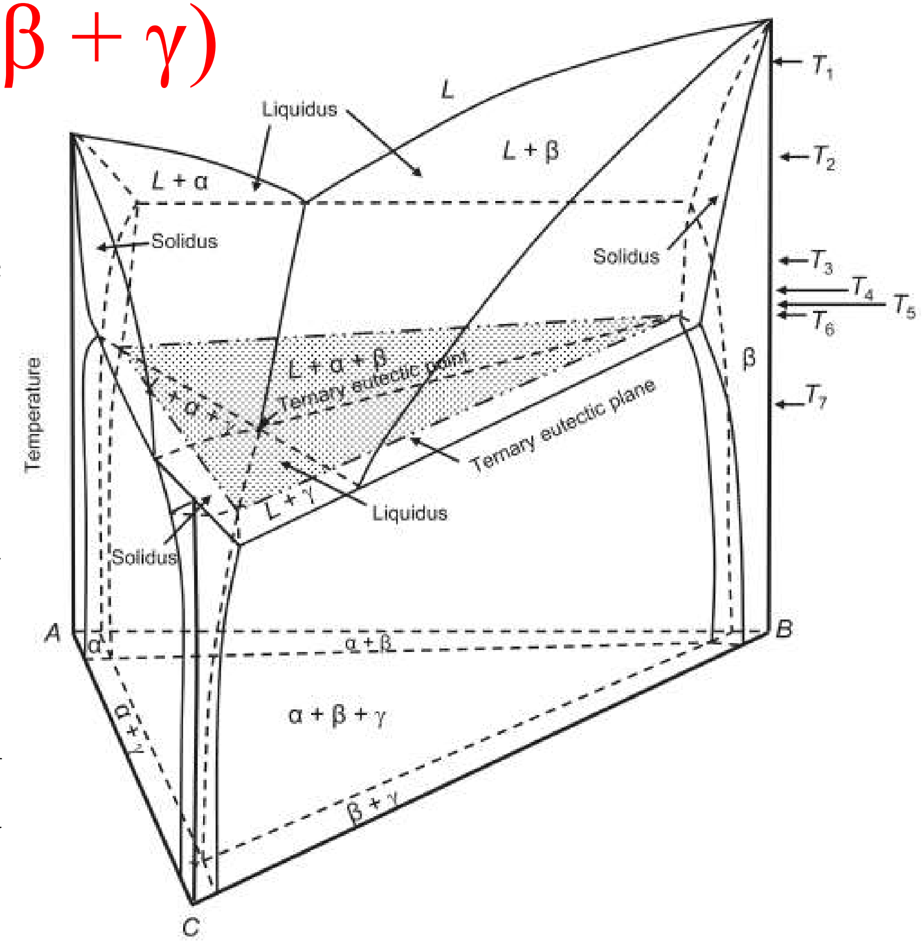
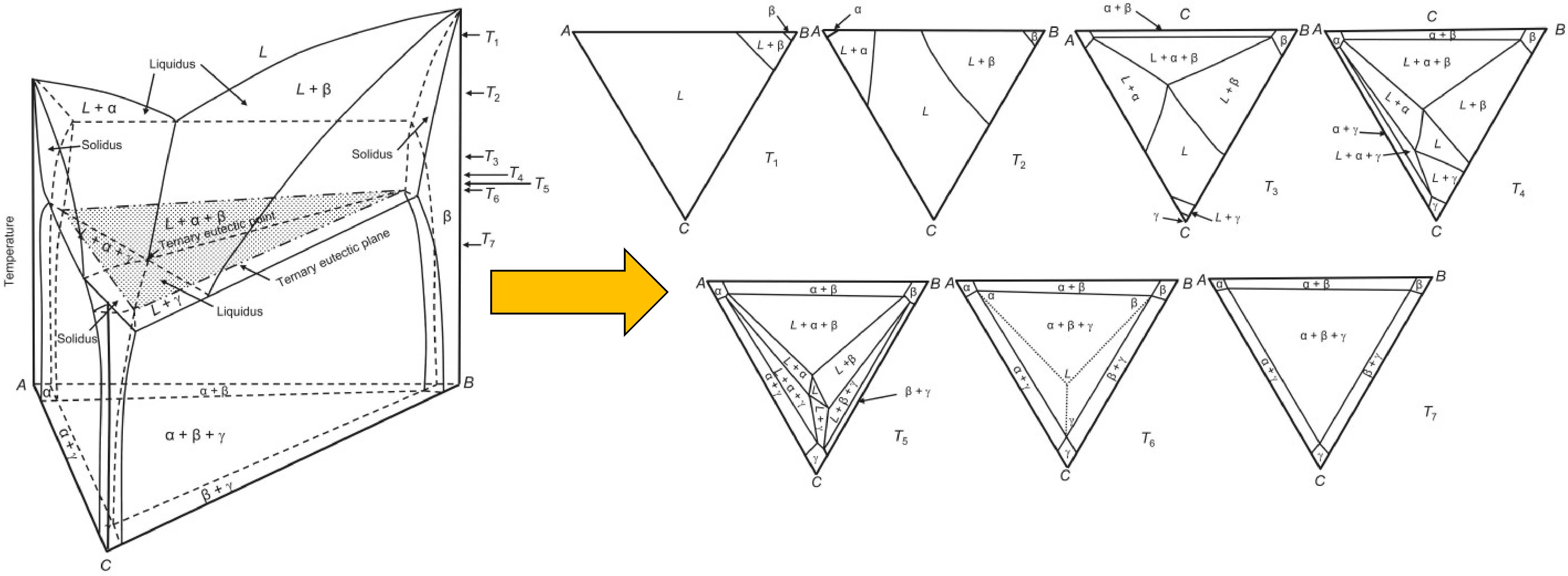
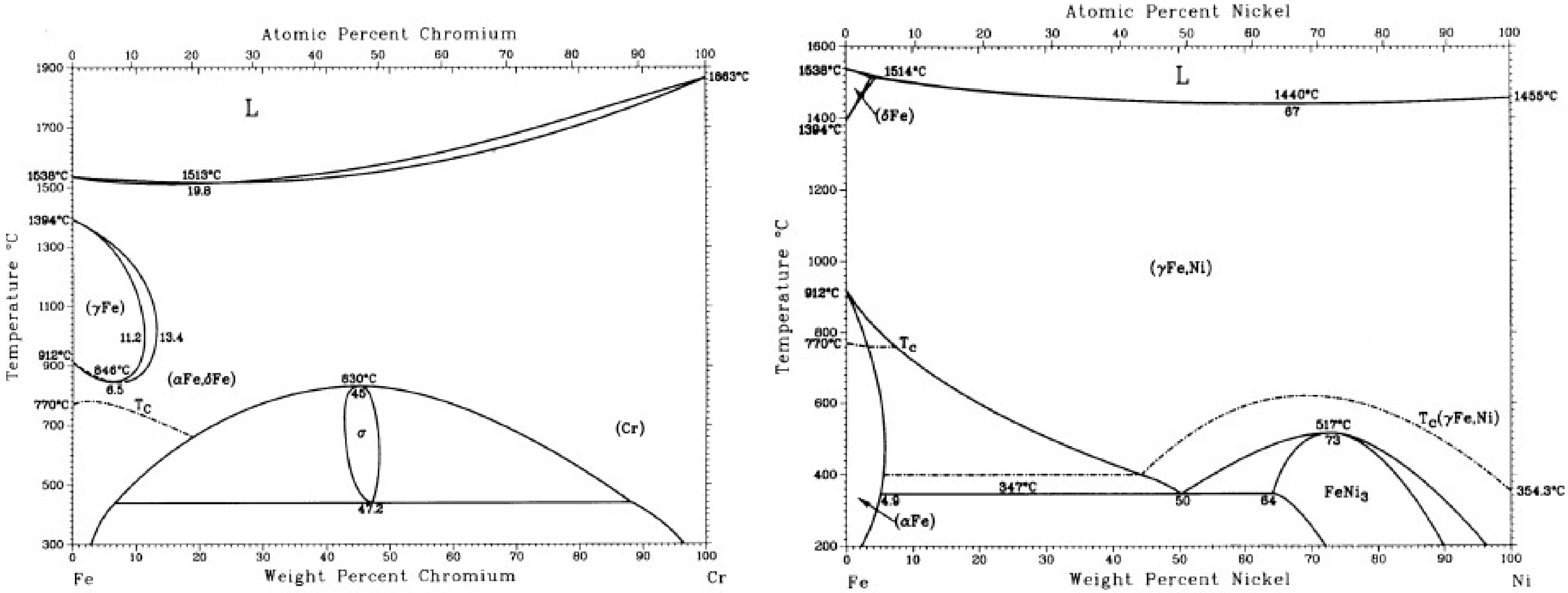


Fig. 10.27 Temperature-composition space model of a ternary eutectic system with the reaction $L \rightarrow \alpha + \beta + \gamma$. Adapted from Ref 10.3

TERNARY FOUR-PHASE EQUILIBRIUM

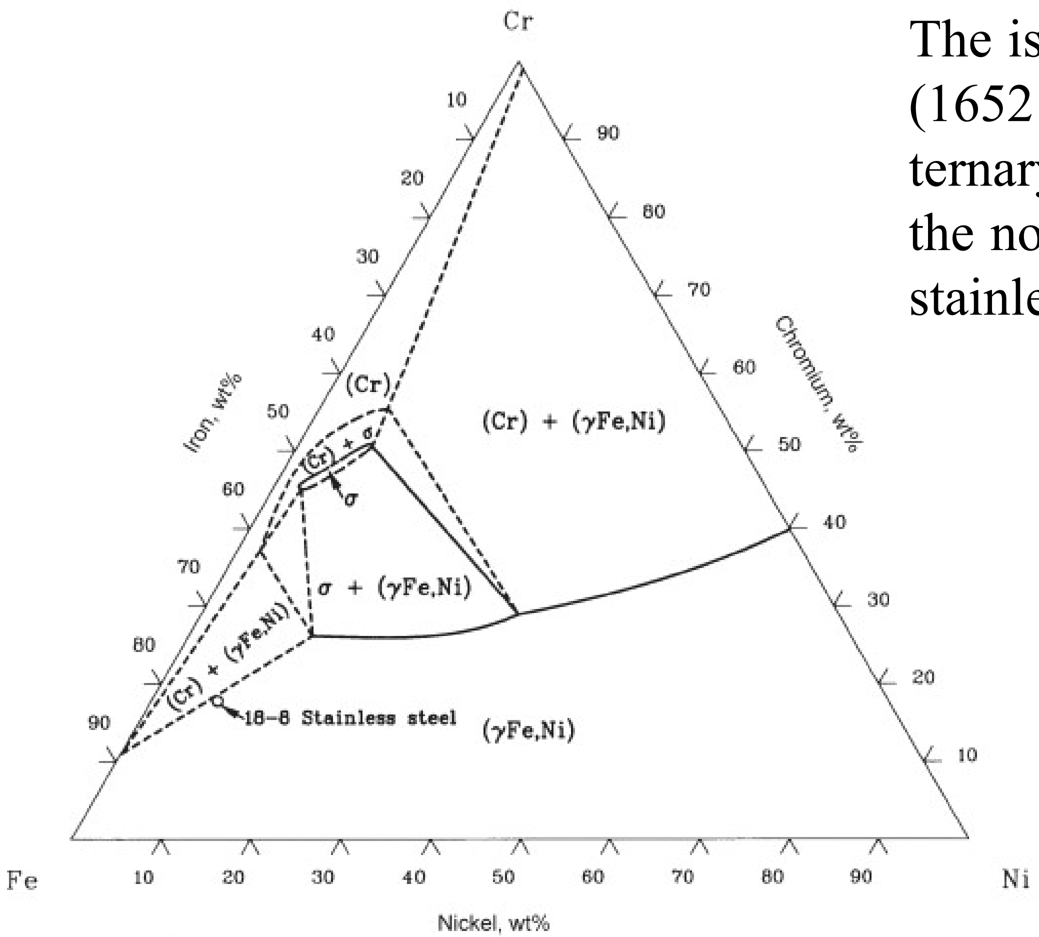


EXAMPLE: THE FE-CR-NI SYSTEM



Two representative binary iron phase diagrams, showing ferrite stabilization (iron-chromium) and austenite stabilization (iron-nickel).

EXAMPLE: THE FE-CR-NI SYSTEM



The isothermal section at 900 °C (1652 °F) of the Fe-Cr-Ni ternary phase diagram, showing the nominal composition of 18-8 stainless steel.