Phase Diagrams in Metallurgy

THEIR DEVELOPMENT AND APPLICATION

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Ao Mestre e amigo, de seu discípulo,

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por abrir-me as portas para um novo mundo do saber.

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PREFACE

Phase diagrams mean more to the metallurgist than mere graphical records of the physical states of matter. They provide a medium of expression and thought that simplifies and makes intelligible the otherwise bewildering pattern of change that takes place as elemental substances are mixed one with another and are heated or cooled, compressed or expanded. They illumine relationships that assist us in our endeavor to exercise control over the behavior of matter. These are no accidental by-products of a system devised primarily for the recording of physical data. They exist because the basic features of construction of all phase diagrams are dictated by a single natural law, the phase rule of J. Willard Gibbs, which relates the physical state of a mixture with the number of substances of which it is composed and with the environmental conditions imposed upon it.

Gibbs first announced the phase rule in 1876, but it was not until the opening of the present century that its significance was appreciated by any substantial fraction of the scientific world. To Bakhuis Roozeboom is due much of the credit for interpreting the phase rule to the scientific public and for demonstrating its usefulness in many of the branches of endeavor in which it is now applied. His celebrated monograph "Die Heterogenen Gleichgewichte vom Standpunkte der Phasenlehre," the first portion of which was published in 1900, is a comprehensive compilation and interpretation of all that was known at the time concerning the constitution of all kinds of chemical systems, metallurgical and otherwise. The completion of this gigantic work, after Roozeboom's death, was due mainly to the efforts of F. A. H. Schreinemakers, E. H. Buchner, and A. H. W. Aten.

Since that time a number of textbooks and monographs on the phase rule have appeared. Three of the most recent of these have been written by metallurgists, for the specific use of metallurgists, namely: G. Masing's "Ternäre Systeme," first published in the German language in 1932 and subsequently (1944) translated into English by B. A. Rogers; J. S. Marsh's "Principles of Phase Diagrams," issued in 1935 as a contribution to the Alloys of Iron Monograph Series; and R. Vogel's "Die Heterogenen Gleichgewichte," a modernized and greatly improved version of Roozeboom's book, published in 1937 as the second volume of the "Handbuch der Metallphysik."

In addition, there have been several comprehensive collections of phase diagrams of the alloy systems. One of the first of these, now obsolete, appeared in the second volume of the "International Critical Tables." In 1936 M. Hansen published the "Aufbau der Zweistofflegierungen," a critical survey of all binary phase diagrams of metal systems that has become the standard reference book on this subject throughout the world. Lesser collections have appeared in several textbooks and handbooks, notably the "Metals Handbook" of the American Society for Metals, the most recent issue of which carries an abridged collection of diagrams that have been revised to conform with the most reliable information available in 1946. The only serious attempt to produce an exhaustive collection of ternary and higher order diagrams is that of E. Janeck, "Handbuch Aller Legierungen," published in 1937. Most of these works include extensive reference to the research literature. A conveniently arranged and nearly exhaustive bibliography on the constitution of alloy systems has been compiled by J. L. Haughton and has been published by The Institute of Metals of Great Britain.

The present book is derived from a series of lectures presented over a period of more than two decades to undergraduate students in the Department of Metallurgical Engineering at the Carnegie Institute of Technology. Some years ago the lecture notes were issued as a mimeographed booklet that has enjoyed modest circulation, having been translated and published in the Portuguese by João Mendes Franca of the Institute of Technologic Research, at São Paulo, Brazil. This reception has encouraged the author to recast the notes in book form.

If this book can be said to have a special mission, a justification for its addition to the literature of phase diagrams, it is to present the subject in a manner that can be grasped by undergraduate engineering students whose primary interest is in the application of phase diagrams to metallurgical problems. To this end, the treatment of thermodynamic principles has been reduced to a minimum and those types of equilibria which are of special importance to chemists but are rarely encountered in metal systems have been deemphasized in favor of those of more immediate interest to metallurgists.

A particular effort has been made to anticipate and to answer those questions which have been observed to arise in the minds of students when first confronted with the various concepts and conventions used in the representation and the interpretation of phase equilibria. This has led to the inclusion of rather frequent excursions into bordering fields of physical metallurgy. Special attention has been devoted also to the pacing of the presentation, which commences at a slow tempo that increases gradually until the later chapters proceed at a rate that presupposes a mastery of the basic principles.

The original lecture notes covered the content of Chaps. 2 to 18, inclusive. An introductory chapter has been inserted for the assistance of those who may have had no previous contact with the subject. Additional chapters on the representation of multicomponent systems and of pressure-temperature diagrams have been included in response to a growing need for means to deal with complex alloy systems and especially those involving gaseous elements. Finally, and as a compromise with the older pedagogy that approached the subject from the viewpoint of the *determination* of phase diagrams rather than their *applications*, a brief chapter on research methods has been included.

Experience indicates that a working knowledge of phase diagrams cannot be imparted by the written or spoken word alone. Just as any mathematical subject must be practiced to be mastered, so the subject of phase diagrams requires practice on the part of the student if he is to obtain anything more than a superficial glimpse into the field. Some problems are given at the ends of several of the chapters; these are intended as suggestions only. The most informative problems are often derived from questions that arise in the mind of the reader. If he will take the time to answer these for himself by applying the principles of phase-diagram construction and interpretation that are presented in the book, he will find himself repaid many times over in progress toward a mastery of the subject.

The manipulation of phase diagrams calls into play some faculties that are rarely employed in other branches of scientific endeavor. Chief among these is space perception, as encountered in three-dimensional diagrams. Those who have had little previous reason to develop this faculty will usually be assisted by mechanical aids to visualization, such as actual three-dimensional models of the diagrams. Some suggestions with regard to ways in which such models may be constructed with a minimum of expense and effort are given in Chap. 18.

In closing, the author wishes to express his gratitude to the people who have assisted with the preparation of illustrations for this book: to Mrs. Wilma Urquhart, Mrs. Miles Price, and Mr. Lloyd Hughes, who prepared most of the photomicrographs; to Dr. Malcolm F. Hawkes, through whose kind permission the photomicrographs of Figs. 5–5, 5–7, 5–8, 5–11, 5–12, 5–13, and 5–15 are reproduced; to Professor C. Muhlenbruch, who supplied the photographs reproduced in Fig. 5–3; to Dr. Chester W. Spencer, who prepared the photomicrographs used in Figs. 9–3, 9–4, and 10–3; and to Felix Cooper for his drawings of three-dimensional subjects.

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