the full symmetry of the system, there are symmetric images of the attractor elsewhere in the phase space. For example, in a reflection-symmetric system, if an attractor is not invariant under reflection, there must exist a second attractor that is the reflected image of the first. In a symmetry-increasing bifurcation, two or more such symmetry-related attractors collide, resulting in a new attracting set having greater symmetry than before. Such a bifurcation produces a transition to time-averaged states of greater symmetry.

The potential scientific importance of symmetric attractors and symmetry-increasing bifurcations motivates the research described by Field and Golubitsky. However, they have not written a research monograph, and applications to physically interesting systems are not considered in any detail. Rather, the authors provide an elementary and reasonably accessible introduction to the theoretical constructs by examining the behavior of various symmetric mappings in one and two dimensions. These dynamical systems offer the simplest setting in which symmetric attractors and symmetry-increasing bifurcations arise and the results are easily visualized; indeed, the attractors found here define stunning patterns, which have been beautifully rendered by color-coding the trajectories that cover the attractor. In more precise terms, the colors are assigned to reflect the local concentration of the trajectory on the attractor. The resulting catalogue of brilliant geometric patterns can be enjoyed even if no deeper understanding of the underlying mechanism is attempted.

That would be unfortunate, though, since Field and Golubitsky explain in detail how the illustrations were produced, starting with the equations needed to define the various maps and ending with a listing of the computer programs used to calculate the images of the attractors. In the process the reader is offered a brisk introduction to complex numbers and complex arithmetic, the precise definition of symmetry through the concept of a group of transformations, discrete dynamical systems including the logistic map and period-doubling cascades, and chaotic attractors. A final chapter explores the extension of these ideas to nondeterministic "iterated function systems." Here one considers a set of symmetric mappings (two or more) and constructs trajectories by iterating a randomly chosen map at each point of the trajectory. Basic theorems due to Barnsley regarding the existence of unique attractors for these stochastic systems are explained.

This book nicely complements two other popularly written books, *Does God Play Dice?* by Ian Stewart (Blackwell, 1990) and *Fearful Symmetry: Is God a Geometer?* by Golubitsky and Stewart (Blackwell, 1992), which focus on dynamical chaos and symmetry breaking, respectively. Whereas the popular scientific literature on these topics is fairly extensive, *Symmetry and Chaos* is the only presentation of symmetric chaos and symmetry-increasing bifurcations outside the technical literature. Although these ideas may not have the same impact on the physical sciences as chaos and symmetry breaking, there is growing interest in the symmetry of a time-averaged chaotic state as one tool for analyzing states of so-called spatiotemporal chaos. Field and Golubitsky have written a unique book that will appeal both to casual readers intrigued by the patterns of symmetric chaos and to scientists interested in testing the relevance of the underlying mathematics.

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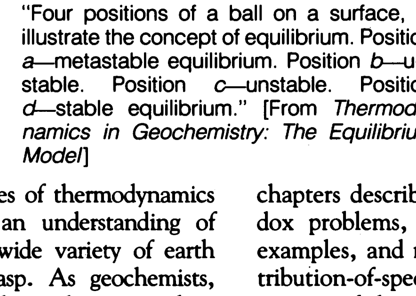
Phase Equilibria

Thermodynamics in Geochemistry. The Equilibrium Model. GREG M. ANDERSON and DAVID A. CRERAR. Oxford University Press, New York, 1993. xx, 588 pp., illus. $75 or £65.

Thermodynamics, the science that relates chemical and physical changes of matter to heat flow and work, is useful in a large variety of practical problems and can help us understand some of the most fundamental questions in science. Indeed, because its laws governing the flow of energy apply to all physical systems, thermodynamics can be considered the grammar for the language of science. There are numerous good books introducing the laws of thermodynamics and developing their consequences. Thus, as Anderson and Crerar acknowledge in their preface, one may wonder, "why another book on thermodynamics?" The answer will become clear to the reader of this book, which provides an innovative, careful, and complete development of the subtleties of thermodynamics that anyone seeking an understanding of phase equilibria in a wide variety of earth processes needs to grasp. As geochemists, Anderson and Crerar have drawn on their extensive experience in both research on and teaching of the problems of phase equilibria to develop a cohesive treatise with well-explained examples. I imagine it will become the standard text for teaching the basics of thermodynamics as well as introducing more advanced models of solution theory, not only in the earth sciences but also in many branches of engineering. It will also likely become a classic reference for working scientists.



"Four positions of a ball on a surface, to illustrate the concept of equilibrium. Position *a*—metastable equilibrium. Position *b*—unstable. Position *c*—unstable. Position *d*—stable equilibrium." [From *Thermodynamics in Geochemistry: The Equilibrium Model*]

The book begins by drawing a clear distinction between reality and the thermodynamic model. Like any model, thermodynamics is governed by simple mathematical relations. The authors review this mathematics, showing the relationship between variables, functions, differentials, and a number of transforms. Energy minimization and metastable equilibrium constraints are then elucidated in the context of this mathematical framework. A separate chapter is devoted to thermodynamic terms and concepts, including metastability, degrees of freedom, stable and metastable equilibrium, partial and local equilibrium, reversible and irreversible processes, and single-valued and continuous properties. The zeroth, first, and second laws of thermodynamics are then introduced, with the second law developed through a discussion of the thermodynamic temperature scale and the equality of temperature ratios to the negative of heat ratios between states rather than the typical discussion of Carnot cycles. This approach seems to be more intuitive to students and therefore more effective in conveying the fundamentals of entropy. The subsequent discussion of the statistical interpretation of entropy using configurational probability theory and the partition function avoids the appearance of being grafted onto a classical approach, as is the case in many textbooks.

Having developed all the useful functions of state, the authors go on to consider simple mineral systems. The constructs of activity, ideal and dilute solution, standard states, and the equilibrium constant are evolved. An up-to-date explanation of the thermodynamics of solutions includes discussions of the models of Margules for solids, Redlich and Kwong for gases, and Pitzer as well as Helgeson, Kirkham, and Flowers for aqueous electrolytes. Separate chapters describe approaches to solving redox problems, with a variety of real-life examples, and methods of undertaking distribution-of-species calculations, with discussion of the theory behind reaction path modeling.

This book strikes a good balance between developing the fundamental concepts and presenting techniques to solve practical problems. The illustrations are simple but effective, and problems are given at the ends of the chapters. One of the book's greatest strengths is its consideration of the interrelationships in thermodynamics as a mathematical model and its development of the concept of metastability in a thermodynamic context. Previously, I used a combination of three textbooks to teach thermodynamics: Garrels and Christ's *Minerals, Solutions and Equilibria*; Lewis and Randall's *Thermodynamics*, as revised by Pitzer and Brewer; and Klotz and Rosenberg's *Chemical Thermodynamics*. I now use *Thermodynamics in Geochemistry: The Equilibrium Model* because of the clarity of its explanations and its effectiveness in conveying the nature of the grammar of science.

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