This textbook provides an intuitive, mathematically rigorous introduction to the thermodynamics of the rich variety of planetary processes. It first builds a solid understanding of the foundations of thermodynamics, and then it explains everything else in terms of this understanding. Besides, it provides many examples of analytical and numerical calculations. Open Maple procedures (downloadable from the book’s website) are included, which the reader may use and expand as favored.

The book is organized in 14 chapters. After a general introduction to conservation laws, Chapter 1 introduces the first law of thermodynamics. At the end of the chapter, there is a discussion of the nature of planetary materials, that seems to be found nowhere else. Chapter 2 focuses on the energy conservation. It gives a thorough quantitative presentation of all sources of planetary internal energy. The discussion of energy dissipation and thermodynamic cycles in Chapter 3 leads to the second law of thermodynamics. Chapter 3 covers heat diffusion and advection in planetary bodies. Thermodynamic potentials, including Gibbs free energy, are introduced in Chapter 4 in a mathematically formal way. In Chapter 5 the foundations for the study of chemical equilibrium are laid, including a comprehensive discussion of the use of composition as a thermodynamic variable. Activity is defined in an unusual way — but in view of the author, in the mathematically most appealing way. The discussion of non-ideal activity is focused chiefly on the concept itself, and on the computational difficulties associated with its mathematical representation. There is no space to delve in detail into the huge field of solution theory in crystals (Chapter 5), fluids (Chapter 9), melts (Chapter 10), and electrolyte solutions (Chapter 11). The equations needed to calculate phase boundaries are developed in full and implemented in a series of progressively more complete Maple procedures (Chapters 1, 5–9). The rules that phase diagrams must abide by in order to be thermodynamically valid are explained in Chapter 6. The author emphasizes the concept of universality of critical thermodynamic behavior by highlighting the similarities among critical phenomena (Chapter 7), lambda phase transitions (Chapter 7), and the critical point of fluids (Chapter 9). He underlines the use of non-dimensional variables as much as possible, including in usual contexts such as the discussion of critical mixing and solvi (Chapter 7), high pressure and temperature behavior of solids (Chapter 8), critical phenomena in fluids (Chapter 9), concentration of non-equilibrium atmospheric species (Chapter 12), and energy dissipation by planetary differentiation (Chapter 2). Chapter 8 contains a simple yet mathematically rigorous presentation of the equations of state for solids and thermal pressure. Chapter 9 deals with the discussion of fluids that can be described as volatiles. These can be gases, liquids, and strongly incompressible fluids, or supercritical fluids whose physical properties vary continuously between those of gases and liquids. The calculations are performed considering chemical equilibrium and the Gibbs free energy minimization. All necessary equations are derived, and the accompanying implementation in Maple is presented. Chapter 10 focuses on the ways in which melts form in planetary interiors. There are explained some new insights, especially related to volatile-fluxed melting. Chapter 11 starts with the discussion of dilute solutions in general, and then it shifts the focus to electrolyte solutions. “Toy models” of ozone depletion (Chapter 12) and greenhouse warming (Chapter 13) are presented as applications for chemical kinetics and radiative heat transfer, respectively. Chapter 12 also contains an introduction to non-equilibrium thermodynamics. Finally, Chapter 14 examines life, and in particular how life may have originated, from a strictly thermodynamic point of view.

The book includes a large number of well chosen references and suggestions for further reading. In all chapters Worked Examples are enclosed, which contain explanations and discussions which are not repeated elsewhere. The work is an ideal textbook on planetary thermodynamics for advanced students in the Earth and planetary sciences.

Reviewer: Claudia-Veronika Meister (Darmstadt)
MSC:
85-01 Introductory exposition (textbooks, tutorial papers, etc.) pertaining to astronomy and astrophysics
85A20 Planetary atmospheres
86A10 Meteorology and atmospheric physics
83C40 Gravitational energy and conservation laws; groups of motions
85A15 Galactic and stellar structure
80A10 Classical and relativistic thermodynamics
94A17 Measures of information, entropy

Keywords:
Maple; thermodynamics; planetary physics; equations of state; elastic energy; heat capacity; laws of thermodynamics; enthalpy; chemical reactions; planetary heat flows; gravitational binding energy; accretion; contraction; tidal heating; radioactive heating; transport processes; heat diffusion; cooling of planetary bodies; heat advection; entropy; Carnot cycle; Gibbs free energy; chemical equilibrium; partial molar properties; non-ideal solutions; phase equilibrium; phase diagram; critical phase transition; critical mixing point; crystalline solids; Landau theory of phase transition; Born-Mie equation of state; fugacity; standard state fugacity; planetary volatiles; fluid phases; giant planet interiors; melting; dilute solutions; electrolytes; non-equilibrium thermodynamics; chemical diffusion; kinetics of heterogeneous processes; radiative energy transfer; post-nebular atmospheres; extraterrestrial life; entropy and life

Software:
Maple

Full Text: DOI