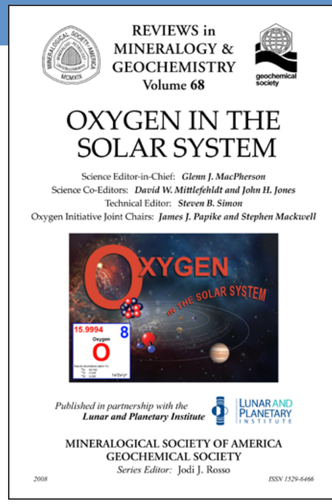
Oxygen in the Solar System[1]

This new volume of Reviews in Mineralogy & Geochemistry provides a comprehensive review of elemental and oxygen isotope components of the solar system at large. Aside from a well-defined unifying theme, what I find unusually useful is the depth of the combined observations, measurements, and theory. This combination makes the text valuable for those wishing to get up to speed in an alien subject area. The book follows oxygen across the solar system in various objects, including planets, asteroids, and the Moon, and from their origins to the present time. In chapter 5, Jensen et al. venture beyond the solar system and review oxygen in the interstellar medium. They include gas- and dust-phase observations and possible reaction scenarios between the two, a subject of relevance to early solar system composition and formational processes.

A subject touched upon in many of the chapters concerns the source of the meteoritic oxygen isotope anomalies. Interest began in 1973 with the observation by Clayton, Grossman, and Mayeda (Science 182: 485–488) of mass-independent oxygen isotope anomalies in the Ca,Al inclusions (CAI) of the Allende meteorite; the work was later extended to reveal that oxygen exists at a bulk-composition level, a feature shared by no other element of the periodic table. This subject has been a paradox for 35 years and, at the conclusion of the book, still is! At the time of the first observations of the oxygen anomaly in CAI, it was believed that this composition must reflect a nuclear process, such as in a supernova, as no chemical process could produce such a composition. It was later demonstrated by Thiemens and Heidenreich (1983, Science 293: 341–345) that this basic assumption was incorrect and new explanations must be sought, a theme of this book. Chapter 4 (Meyer et al.) provides an excellent review of the nucleosynthesis and evolution of oxygen and its isotopes in the galaxy, including the area of isotopic measurements of interstellar grains.

Chapters 8 (Yurimoto et al.) and 9 (Young et al.) provide thorough reviews of the data and recent models associated with meteoritic oxygen isotopes. Chapter 8 is a detailed analysis of the oxygen isotope compositions of chondritic components. An extensive literature exists on this subject, and the authors do a respectable job presenting the data in a tractable and most useful fashion. The possible implications for the astronomical environment for production of the specific meteoritic components are presented, though the discussion largely focuses on the self-shielding model of Yurimoto and the chapter terminates abruptly without any summary. Young et al.



provide an analysis of the chemical models in contention at present: symmetry-dependent chemical reactions and photochemical self-shielding. In 1947, papers by Urey and by Bigeleisen and Mayer utilized statistical thermodynamics and quantum mechanics to provide the theoretical basis for isotope geochemistry and cosmochemistry. As is apparent in this chapter, the isotope effects that likely give rise to meteoritic oxygen isotopes, whether due to photochemical self-shielding, as first suggested by Thiemens and Heidenreich (1983), or to symmetry-dependent chemical reactions that obey non-RRKM theory, are new quantum-level varieties of isotope effects. Such processes are providing the basis for new physical chemical theory as, for example, provided by Marcus (discussed in chapter 9). Potential new experiments are discussed that could yield new insight into the source of the meteoritic oxygen isotope anomalies. Davis et al. (chapter 6) address the issue from the standpoint of the oxygen isotopic composition of the Sun and also deal with issues related to solar system formation. Grossman et al. present a particularly useful comprehensive chapter on the redox conditions in the solar nebula. The experimental and theoretical approaches towards determination of the redox parameters of the solar system as well as the interpretation of the meteoritic mineralogical composition are presented. There is a vast literature of condensation calculations and concomitant chemical-mineralogical interpretation dating back to Grossman's original work in the early 1970s. This comprehensive chapter should be of use to a range of readers, and the discussion of the details of the thermodynamic theory and experimental tests is well presented.

Significant oxygen-bearing reservoirs throughout the solar system are described in chapters on the giant planets and satellites (Wong et al.), comets and interplanetary dust particles (Sandford et al.), and asteroids (Burbine et al. for composition, observations, and structure of asteroidal materials and Franchi for their oxygen isotope composition). Franchi provides a thorough analysis of the oxygen isotopes of bulk meteoritic classes and how their isotopic compositions related to their formation and secondary processes, which include nebular heterogeneity, high-temperature alteration events, parent-body aqueous alteration, and terrestrial weathering. In subsequent chapters by Mittelfehldt et al. and Zolensky et al., the utilization of the oxygen isotope record of meteoritic materials, including chondrules and minerals, is examined to evaluate potential nebular formation processes. A careful analysis of the various correlations of the oxygen isotope composition with meteoritic redox parameters and elemental chemical compositions is presented and discussed, and this analysis reveals that the source of the oxygen isotope composition of meteoritic materials remains enigmatic. This is particularly true now that the first experimental test of the self-shielding model suggests that it may not have been a viable process in the nebula.

Chemically produced, mass-independent isotopic compositions of solar system material have now been employed to study various aspects of chemical cycles on Earth, Mars, and asteroids. Farquhar and Johnston (chapter 16) discuss how this new technique is utilized to study a wide range of oxygen cycles in varying planetary environments. An early chapter by Criss and Farquhar on stable isotope notation and fractionation laws provides an important theoretical construct that is particularly relevant to this chapter and others. The mass-independent isotopic composition of Martian carbonates and sulfates has been used to study atmosphere–regolith chemical interactions on Mars. The observations utilize the anomalous oxygen isotope composition acquired from the atmospheric O_3–CO_2 isotopic exchange currently occurring in the atmospheres of both Earth and Mars. The subsequent chapter by Wadhwha provides further insight into the actual redox conditions and chemical reactions on Mars, as well as on the Moon and asteroids. Farquhar and Johnston also address other large-scale planetary processes involving oxygen that have been investigated recently using mass-independent chemistry. This includes primary productivity in the world's oceans using the mass-independent isotopic composition of molecular oxygen, which is created from the ozone–carbon dioxide isotopic exchange processes. For more than 50 years, numerous attempts to measure the origin and evolution of oxygen in Earth's earliest atmosphere have been made. It is ironic that the best measure to date has been obtained using mass-independent isotope compositions of sulfur, and those observations and theory are presented in the chapter by Farquhar and Johnston.

In sum, this is an excellent book, which I highly recommend to both students and seasoned researchers alike. The use of oxygen as a theme to explore the solar system is well conceived, and this strategy has been successful.

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1 MacPherson GJ et al. (eds) (2008) Oxygen in the Solar System. Reviews in Mineralogy & Geochemistry 68. Mineralogical Society of America, Chantilly, VA, ISBN 978-0-939950-80-5, 618 pp