Experimentation to understand planet and proto-planet formation.

K. Righter[1] , [1]NASA Johnson Space Center, Mailcode XI2, 2101 NASA Parkway, Houston, TX 77058;
kevin.righter-1@nasa.gov

Introduction: Experimental petrology has placed constraints on a wide variety of nebular and planet formation processes such as chondrule formation, CAI crystallization, asteroid magmatism, mantle melting, core formation, element partitioning related to radiogenic isotopes and heat production. Although great progress has been made, there remain several key problems where more data are required to constrain modelling, both empirical and thermodynamics-based. Here I will focus on several areas with implications for meteoritics and planetary science, including systems of low fO_2, constructing models that include both metal and silicate for mantle melting and differentiation, high pressure phase equilibria relevant to full range of silicate mantles, and core-mantle equilibria where H and O are specified, and their effects are measured.

Solar nebular oxygen fugacity is very low compared to Earth and Mars. Portions of the nebula, represented by aubrites and enstatite chondrites, for example, equilibrated at fO_2 as much as 6 to 8 log fO_2 units below the IW buffer [1]. At such low fO_2 conditions, Fe is almost entirely reduced to metal, S will partition strongly into silicate melts, and some multi-valent elements such as Cr, V, Ti, Mo, W, will be stable in their lowest valence form. All these factors will substantially affect phase equilibria and element partitioning at the low fO_2. Very little experimental work has been completed at such conditions, and is needed to make modelling robust, and to calibrate predictive expressions.

Differentiation of small bodies such as Vesta involves stabilization of metallic iron from molten chondritic pre-cursor material, and segregation of the metal to the core where it equilibrates with the molten silicate mantle. This process includes equilibration of metallic liquid with silicate liquid, followed by solidification of the metal and silicate in the core and mantle, respectively [2]. Models exist for the metallic systems and the silicate systems, but there is still not a model that includes metal and silicate together, thus allowing an integrated treatment of differentiation that includes metal and silicate both. Efforts should be made to join these two systems, so the differentiation process can be modeled end to end with a single modelling approach. Such a model would, of course, also be applicable to aubrites, angrites, and other such small differentiated bodies.

Modelling of phase equilibria in planetary mantles has made substantial progress in the last few decades. Predicting mantle mineralogy and mantle phases crystallizing from early partially or fully molten mantles, however, requires additional experimental data to constrain the phase equilibria of certain compositions, and the volumetric properties of melts at high pressures. For example, the compressibility of peridotitic liquids at high pressures is based on limited data on komatiitic liquids and is not of sufficient resolution to allow confident prediction of behavior of FeO [3]. Thus, our understanding of FeO and Fe_2O_3 in deep planetary mantle – which potentially help to control the fO_2 of planetary interiors and their interaction with the atmosphere – is currently limited [4]. Effort should be focused on determining volumetric properties of FeO- and Fe_2O_3-bearing silicate melts at high pressures to allow more robust modelling.

Planetary cores. The last several decades have seen advances in knowledge of phase equilibria in planetary metallic liquids in the Fe-S-C-Si systems, with a solid understanding of this 4-component system across a wide PT range [5]. Two additional elements – H and O - are stable in metallic cores, yet very little work has been completed with these elements included. Hydrogen may be moderately siderophile at high pressures, and even a small amount dissolved in the core would have significant implications for the phase equilibria and for H budget of a given planet [6]. While not siderophile, oxygen could nonetheless be soluble in Fe metal in several wt.% , thus having potential to influence phase equilibria and element partitioning [7]. Even though H and O pose experimental difficulties, efforts should be made to study them in more detail at conditions relevant to the terrestrial planet interiors; this would allow mor realistic modelling of planetary cores.

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