A combined diffusion and fractional condensation model for the chemical and isotopic zoning in FeNi-metal

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Metal-rich CB and CH chondrites are characterized by about 10-20% of chemically and isotopically zoned metal grains [1]. Cores of such zoned metal grains are enriched in Ni and refractory siderophile elements and display very low δ^{56}Fe and δ^{62}Ni (of up to ~ –7 ‰ and ~ –10 ‰, respectively). The observed chemical and isotopic characteristics of these metal grains strongly suggest that they were formed by condensation.

To unravel the formation conditions of these zoned metal grains, we developed a model for fractional condensation of FeNi metal by exponential cooling in a closed system of solar composition. In contrast to a previous model [2] we also consider the condensation and diffusion of individual Fe and Ni isotopes. In addition we use the Hertz-Knudsen equation to calculate the net condensation flux where re-evaporation of isotopes is considered. The latter point is essential to model scenarios for cooling rates where the isotopes partially or completely re-equilibrate with the gas reservoir.

The thermodynamic and kinetic input parameters of this model system are well constrained by experiments (e.g., the Fe-Ni interdiffusion coefficient, the evaporation and condensation coefficient) and therefore the reaction system is controlled by two main input parameters – the initial total gas pressure (which controls the initial partial pressures of Fe and Ni and the condensation temperature of metal) and the average cooling rate. Our model results reveal that for low initial pressure of 10^2 Pa, cooling rates of > 0.3 K/hour are sufficient to result in significant Ni and Fe isotopes fractionation during condensation. To best reproduce the observed chemical and isotopic variations of metal grains in CB/CH chondrites non-canonical pressures for the solar nebula of about 10^5 Pa are required and cooling rates in the range of 10-100 K/hour, where partial re-evaporation of the metal occurs. High initial partial pressures of Fe and Ni, high condensation temperatures and high cooling rates are consistent with an impact-driven formation of CB/CH metal [1].

[1] Weyrauch et al. 2019, Geochim Cosmochim Acta 246: 123–137; [2] Petaev et al. 2003, Geochim Cosmochim Acta 67: 1737–1751.