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AN IRON-RAIN MODEL FOR CORE FORMATION ON ASTEROID 4 VESTA

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Asteroid 4 Vesta is differentiated into a crust, mantle, and core, as demonstrated by studies of the eucrite and diogenite meteorites and by data from NASA's Dawn spacecraft. Most models for the differentiation and thermal evolution of Vesta assume that the metal phase completely melts within 20 degrees of the eutectic temperature, well before the onset of silicate melting. In such a model, core formation initially happens by Darcy flow, but this is an inefficient process for liquid metal and solid silicate. However, the likely chemical composition of Vesta, similar to H chondrites with perhaps some CM or CV chondrite, has 13-16 weight % S. For such compositions, metal-sulfide melting will not be complete until a temperature of at least 1350 °C. The silicate solidus for Vesta's composition is between 1100 and 1150 °C, and thus metal and silicate melting must have substantially overlapped in time on Vesta. In this chemically and physically more likely view of Vesta's evolution, metal-sulfide drops will sink by Stokes flow through the partially molten silicate magma ocean in a process that can be envisioned as "iron rain". Measurements of eucrites show that moderately siderophile elements such as Ni, Mo, and W reached chemical equilibrium between the metal and silicate phases, which is an important test for any Vesta differentiation model. The equilibration time is a function of the initial metal grain size, which we take to be 25-45 microns based on recent measurements of H6 chondrites. For these sizes and reasonable silicate magma viscosities, equilibration occurs after a fall distance of just a few meters through the magma ocean. Although metal drops may grow in size by merger with other drops, which increases their settling velocities and decreases the total core formation time, the short equilibration distance ensures that the moderately siderophile elements will reach chemical equilibrium between metal and silicate before metal drop merger becomes important. In this model, there must be at least 30% melting of the silicate phase when metal melting is complete, corresponding to a crust thickness of at least 30 km on Vesta, consistent with Dawn gravity observations. Greater degrees of silicate melting and a correspondingly thicker crust are possible if Vesta accreted sufficiently rapidly.