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Implications of the Fe-snow regime on inner core growth and thermal buoyancy in Ganymede's core

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The detection of a magnetic field at the Galilean moon Ganymede was one of the most surprising discoveries of the Galileo mission. Ganymede's magnetic field is believed to be caused by an active dynamo in the core (1). A purely thermally driven dynamo is assumed to be active only during the first few hundred million years after accretion and core formation. Consequently, a compositionally driven dynamo was suggested for Ganymede's core by (2,3,4). Such a dynamo is caused by freezing of an iron-rich core and the flow due to the associated density variations. The most recent experimental studies for eutectic Fe-FeS-alloys show a decrease of the eutectic temperature with increasing pressure for pressures less than 14 GPa (5,6). The negative slope of the eutectic melting temperature can lead to crystallization regimes in cores of small planetary bodies, which are very different from the one known from Earth's core. Assuming core compositions on the Fe-rich side of the eutectic, Fe precipitates at the core-mantle boundary rather than at the core center. Due to gravity these solid Fe particles sink towards the core center and eventually remelt–as a consequence a chemical gradient develops in the fluid core before an inner core can form.

In this study, we develop a detailed thermodynamic model for Ganymede's core and investigate the chemical gradient forming in the core. We concentrate on the questions whether the chemical gradient can stabilize the core flow against thermal buoyancy and how long it takes for an inner core to form. The reference model of 10 wt.% initial sulfur concentration and a thermal expansion of α=9.2·10^{-5} K^{-1} requires a reduction of core temperature by ΔT=50 K to form a chemical gradient across the entire core region. Thermal evolution models of Ganymede (3) then suggest a timescale of 1 billion years for the Fe-snow regime until an inner core grows. The average sulfur gradient for the reference model is $\Delta x_s/\Delta r$=0.0047 wt.%/km. That implies a density difference of $\Delta\rho$=266 kg/m^3, which in turn results in a required temperature difference between the core center and the core-mantle boundary of ΔT=493 K necessary for thermal motions to overcome the compositional density difference. The actual adiabatic temperature difference between the core-mantle boundary and the core center is only about 95 K. Accordingly, a superadiabatic temperature gradient is required to overcome the stable chemical one. Thus, for a core composition on the Fe-rich side of the eutectic, thermal bouyancy most likely does not contribute to the dynamo generation in Ganymede's core. Whether the described sedimentation process of Fe-snow is sufficient for driving a dynamo and, if so, for reproducing a magnetic field of the required strength, is not known and needs to be studied.

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