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Density and viscosity of Fe-Ni-C liquids at high pressures and implications for the liquid cores of Earth and terrestrial bodies

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Liquid cores of Earth and other terrestrial bodies are composed of Fe-Ni metal with certain amounts of light elements (LE). The dynamics of these liquid cores determines the formation and the duration of the planetary dynamo and magnetic field, which are crucial for planetary habitability. Carbon is among the top candidate LE in light of its high cosmic abundance, siderophile nature, and ubiquity in iron meteorites. The physical properties of Fe-Ni-C melts at high-pressure high-temperature (HP-HT) conditions are necessary to understand the composition, structure and dynamics of carbon-rich liquid cores.

Here we report the density and viscosity of $Fe_{90}Ni_{10}$-3 wt.% C and $Fe_{90}Ni_{10}$-5 wt.% C liquids using the synchrotron-based X-ray absorption and radiography experiments combined with Paris-Edinburgh Press, and the first-principles molecular dynamics simulations. The results show that the density of Fe-Ni-C liquids are lower than Fe-Ni liquid, but the bulk moduli of Fe-Ni-C liquids are similar to or slightly higher than Fe-Ni liquid. Thus, the compressional velocity (v_p) of Fe-Ni-C liquids is higher than that of pure Fe-Ni alloy, promoting carbon as a possible candidate to explain the elevated v_p in the Earth's outer core, although the mismatch of both the values and slopes of density and v_p suggests it may not be the sole principal light element. The high v_p of Fe-Ni-C liquids does not match the presumptive v_p from Apollo seismic data, indicating carbon is less likely to be the dominant light element of the lunar outer core. The results of viscosity measurements show a viscosity increase at ~3-5 GPa, coincident with a structural transition in Fe-Ni-C liquids. After the transition, the viscosity becomes 2-4 times higher than those of Fe and Fe-S liquids. The theoretical calculation also indicates a high viscosity of the Fe-Ni-C liquids compared with pure Fe from 5 to 330 GPa. As a result, the level of turbulence in the outer core would be lessened as approaching the inner core boundary for a carbon-rich core in large terrestrial body. It is also anticipated that Fe-Ni-C liquids would percolate in Earth's deep silicate mantle at a much slower speed than Fe and Fe-S liquids.