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Sub-Neptune Dynamos: Conductivity of Hydrogen-Bearing Silicate Liquids

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Sub-Neptune exoplanets may host long-lived magma oceans beneath hydrogen-rich atmospheres. Recent studies suggest that at the high pressures and temperatures near the atmosphere–magma ocean interface, silicate and hydrogen may become fully miscible, forming a supercritical, chemically mixed fluid rather than a sharply stratified boundary [1,2]. While recent work has begun to constrain the thermodynamic properties and phase stability of such mixtures, their transport properties remain poorly understood. The conductivities of these materials are particularly important because they govern magnetic diffusion, influence thermal evolution, and set a fundamental requirement for dynamo generation.

Here we investigate the electrical conductivity of supercritical $MgSiO_3$–H_2 liquids using first-principles molecular dynamics simulations at 170–245 GPa and 6000–8000 K, spanning 0–4 wt% H_2. Conductivity is computed using the Kubo–Greenwood formalism for electronic transport and velocity autocorrelation methods for ionic contributions. We also report the electronic contribution to the thermal conductivity of the material.

Across all pressure and temperature conditions explored, hydrogen incorporation produces a systematic and substantial increase in electrical conductivity. Pure silicate liquids exhibit semimetallic behavior, while hydrogen-bearing mixtures approach conductivities characteristic of poor metals. Both electronic and ionic contributions increase with hydrogen content and temperature, with pressuring showing a weaker effect, consistent with recent studies [3]. Preliminary iron-bearing cases show further enhancement. These trends indicate that even modest hydrogen enrichment significantly modifies transport in deep magma ocean materials.

To assess dynamo feasibility, we consider the magnetic diffusivity $\eta = 1/(\mu_0\sigma)$ and the magnetic Reynolds number $R_m \sim UL/\eta$. For interior length scales of order 10^3 km and convective velocities on the order of mm/s, our conductivities in the 10^4–10^5 S/m range yield magnetic diffusivities of tens of m^2/s and R_m values on the order of 50–100. These values fall within the regime typically considered sufficient for dynamo action, suggesting that hydrogen-bearing silicate mantles may be able to sustain magnetic fields in sub-Neptunes if vigorous convection is present.

[1] Young, Stixrude, Rogers, Schlichting & Marcum (2024), Planetary Science Journal 5, 268.

[2] Gilmore & Stixrude (2026), Nature 650, 60–64.

[3] Dragulet & Stixrude (2025), Proceedings of the National Academy of Sciences 122, e2509771122.