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Electrical conductivity of the magma ocean and silicate dynamos

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Are silicate dynamos possible? So far, planetary dynamos seated in silicate material are unknown. Several lines of evidence motivate the consideration of a silicate dynamo in the early Earth and in super-Earth exo-planets: 1) paleomagnetic evidence of a very early dynamo-generated field 2) models of the early thermal state of Earth in which the mantle is too hot to permit a core-generated field, and 3) the possibility of a deep, thick and long-lived basal magma ocean. The key requirement is that the electrical conductivity of silicate liquids be sufficiently large at the relevant high pressure-temperature conditions (> 10,000 S/m), far exceeding the value measured experimentally up to a few GPa. We have used ab initio molecular dynamics simulations to compute from first principles the value of the electrical conductivity at extreme conditions in systems with compositions that are simple [SiO_2 and (Mg,Fe)O] and rich (MgO-FeO-CaO-Al_2O_3-Na_2O-SiO_2). We find that the primary charge carriers are electrons, i.e. silicate liquids become metallic at extreme conditions. Even iron-free silicate liquids exceed the minimum threshold for dynamo activity, and enrichment in FeO increases the electrical conductivity substantially. We also examine the electronic contribution to the thermal conductivity of silicate liquids, and find that the thermal conductivity is sufficiently small that magma oceans are unstable to convection, further supporting the silicate dynamo hypothesis. We conclude that the Earth's earliest field may have been generated by the magma ocean and that the silicate dynamo may have lasted for a billion years or more.