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Magnetism and Thermal History of the Terrestrial Planets - Revisited

T. Spohn, D. Breuer
DLR, Institute of Planetary Research, Berlin, Germany (tilman.spohn@dlr.de)

In 1983 Stevenson et al. published a paper explaining the differences in the magnetism of the terrestrial planets from models of the thermal evolution of their cores. From their conclusions, Mercury needed 5 weight-% sulfur in the core (or a similar concentration of another light alloying element) to maintain a liquid core shell. Venus and Mars had completely liquid cores that were stably stratified. Earth's core started to freeze about 2.5 Ga b.p., the dynamo then switched from being driven by thermal convection to driven by chemically convection. The model already allowed for an early thermally driven dynamo on Mars. In the meantime the magnetic properties of the Galilean satellites and Titan have become known and our understanding of mantle convection and the dynamo have improved. In addition, the melting curve of iron, FeS and FeO have become better known. It is thus worthwhile to reconsider the subject which we will do in the present review. Stagnant lid convection has altered our estimate of the cooling rates of the cores and the temperatures in the cores. Thus, Mercury may have a liquid core shell and a dynamo even if the sulfur content were significantly less than 5 weight-%. Moreover, recent dynamo models explain the small amplitude of the field by a screening effect in the stably stratified outermost core. Venus may have had phases of surface recycling and rapid cooling. Even if the planet has an inner core at present, it is possible that the core is warming after the last cooling episode 500 Ma ago in which case a dynamo may still be absent. The data on the melting curves of Fe and FeS together with evidence from the SNC meteorites suggest that the Martian core may be very close to the eutectic composition and the deeper parts of the core may even be on the sulfur rich side. If true, the Martian core would almost certainly be completely liquid and growth of an inner core would not be

available to power a dynamo. Instead, the core would likely remain liquid for a very long time. The Jovian satellites Io is lacking a self sustained magnetic field. This can be explained by the level of tidal heating in the mantle of Io frustrating core cooling. A self-sustained magnetic field has been observed on Ganymede but not for the other major icy satellites of Jupiter and not for Titan. Instead, the icy satellites of Jupiter show induced magnetic fields. The cores of the major satellites are in the pressure range where the FeS melting curve is expected to have a negative slope. In addition, the core compositions of the satellites may be on either side of the eutectic. Depending on core composition, iron snow fall or upward floating of buoyant FeS crystals from the deep core may be important mechanism for driving convective motions and possibly internally generated magnetic fields.