HIGH-TEMPERATURE IONIZATION OF DUSTY GASES AND IMPLICATIONS FOR CHONDRULE FORMATION IN CURRENT SHEETS.

Steven J. Desch[1] and Neal J. Turner[2]. [1]School of Earth and Space Exploration, Arizona State Univ. E-mail: steve.desch@asu.edu. [2]Jet Propulsion Laboratory, California Institute of Technology.

Introduction: The coupling of gas to magnetic fields is determined by its degree of ionization. Gas in the inner solar nebula was dusty and potentially also hot (~ 10^3 K). All previous studies of hot, dusty gases have assumed that alkalis in the gas, especially potassium, thermally ionize in the gas phase ($K^0 + H_2 \rightarrow K^+ + e^- + H_2$) and recombine in the gas phase ($K^+ + e^- \rightarrow K0 + \gamma$), and use the Saha equation to predict the ionization. This is incorrect in dusty plasmas, as recombination overwhelmingly occurs on grain surfaces. Dust grains also overwhelmingly affect the ionization of the gas as well, through thermionic and ion emission. These effects have never been considered before; we include them for the first time in a calculation of the ionization state of hot, dusty plasmas [1].

Thermionic Ionization: Thermionic and ion emission refer to the ejection of electrons and ions from hot solids, at rates given by Richardson's Law and the Saha-Langmuir equation. We find that typically these processes dominate over all other ionization sources at temperatures T > 800 K. A new ionization equilibrium equation applies, one involving the work function of the solids rather than the first ionization potential of potassium. For T < 800 K, ionization is constant with temperature, but for T > 800 K, the degree of ionization increases with T and exceeds that predicted using the Saha equation. The timescales to achieve ionization equilibrium are hours to days in the solar nebula.

Short-Circuit Instability: Our calculations are relevant to the nebular environment in which the "short-circuit instability" has been predicted to occur and to lead to chondrule formation [2,3]. This instability, which can act in current sheets (regions of oppositely oriented magnetic field), relies on higher temperatures to rapidly lead to higher ionizations, dissipating magnetic energy in flare-like events. We find this is impossible unless T > 800 K in the ambient gas, or else the ionization does not increase with rising temperatures. This is inconsistent with retention of primary sulfur in chondrule precursors, which requires T < 650 K [4]. The timescale on which the ionization grows, hours to days, also is often longer than the timescale on which the system cools by radiation, hours, hindering an increase in ionization due to heating.

The short-circuit instability requires that magnetic fields diffuse rapidly into the current sheet, faster than the system can radiatively cool (in hours); this sets a *lower* limit on the magnetic diffusivity. But the existence of current sheets requires a magnetic instability like the magnetorotational instability; this sets an *upper* limit on the magnetic diffusivity. Depending on the opacity of the region, we find little or no overlap in these constraints, making it unlikely the short-circuit instability can occur.

Conclusions: Our work on ionization of hot, dusty gases considers thermionic emission for the first time. Applied to the short-circuit instability, our calculations show it is unlikely to occur and appears inconsistent with chondrule formation.

References:

[1] S. J. Desch and N. J. Turner, *The Astrophysical Journal,* in revision. [2] Hubbard, A. et al. 2012, *The Astrophysical Journal* 761: 58-67. [3] McNally, C. et al. 2013, *The Astrophysical Journal Letters*, 767:2-7. [4] Rubin, A et al. 1999, *Geochimica Cosmochimica Acta* 63: 2281-2298.