THE HARSH ELECTRO-CHEMICAL ENVIRONMENT IN MARTIAN DUST STORMS.
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Introduction: Mars is a planet of many apparent dichotomies in topography, atmospheric evolution, hydrology, and geomagnetism. We describe yet another set of extremes in the area of atmospheric chemistry. While solar photons in fair-weather are a known and well-studied driver of Martian chemistry, there is increasing evidence that electro-chemistry unique to dust storms may be a second new driver of chemical reactions. This new chemical pathway features the formation of harsh, reactive trace species via recombination of products formed following electron dissociation. This new pathway may explain the presence of peroxides in the soil (Viking inferences) and possibly the low levels of atmospheric methane.

The electro-chemistry has its source in the tribo-electric dust grain interactions occurring in dust devils and storms. Large E-fields are suspected to be present in dust storms by the spatial separation of small negative grains (at storm top) and large, positive grains (near surface). These E-fields in the low pressure CO_2 gas would then energize ambient electrons between < 1 eV and 50 eV, which in turn would create new electrons via CO_2 impact ionization (> 14 eV), thereby creating a collisional plasma consisting of CO_2+ ions and electrons. This plasma then drives the new chemistry.

In this presentation, we review the fundamental elements of this new chemical pathway and discuss implications for the Mars environment.

Electrostatic Fields in Dust Storms: Dust storms on Mars are expected to generate and maintain large-scale electric dipole fields, with interior E-field values approaching the atmospheric breakdown levels of ~25 kV/m [1-4]. The E-fields form via grain-grain contact electrification that tends to leave smaller dust particles with a net negative charge and larger sandy grains with a net positive charge [5]. Vertical winds in the storm then mass-stratify (and charge-stratify) the grain distribution as a function of height, creating a downward-directed electric dipole moment and large-scale dipole electric field structure [1,6,7].

Evidence for this charge creation/separation process is in the form of analytical models [1-4] and terrestrial analog studies [6, 8-11]. The former modeling studies all suggest that E-fields at many tens of kV/m can be generated in a convective Martian storm with charging exponential growth time scales on the order of 10's of seconds under ideal conditions. The latter analog studies consistently find relatively large electric fields in small terrestrial dust devils and saltating dust fronts, with dust devil fields > 100 kV/m and dust front fields > 150 kV/m. The E-fields in terrestrial dust devils/fronts are not large enough to create atmospheric breakdown on Earth, but well above the atmospheric breakdown fields of ~ 25 kV/m for the low-pressure Martian atmosphere. Given that very similar analogous aeolian processes occur on Mars, large fields approaching breakdown are anticipated in that planet's dust devils/storms and dust frontal systems.

Associated New Chemistry: A complementary set of papers by Delory et al. [12] and Atreya et al. [13] recently examined the behavior of ambient electrons in the Martian atmosphere under the influence of large E-fields (like that in dust devils/storms/fronts). They found that the electrons evolve in three ways: First, the electron density increases geometrically with increasing E, this due to increasing CO_2 ionizations from energetic E-field driven electrons (see Figure 1a). Second, the electron drift velocity steadily increases with E reaching 5×10^5 m/s near 20 kV/m. Finally, a distinct high energy electron tail develops in the electron distribution, with its power-law rolloff in the 10's of eVs decreasing directly with increasing E [14]. Basically, a collisional plasma develops in a mature dust devil/storm in the low pressure CO_2 atmosphere. This plasma may even glow [15,16]

As described by Delory et al. [12] and Atreya et al. [13], the energetic electrons also affect the ambient molecules in the low pressure gas (see Figure 1 b and c). Specifically, electron dissociation of CO_2 into CO and O^- occurs near 4.4 eV. Without the E-field, the electrons do not possess the intrinsic energy to dissociate the molecule. However, with an electric field, an energetic portion of the electron population now exists (i.e., the tail of the distribution) with the required energy to dissociate the CO_2 and this population (between 4 and 5 eV) is found to increase geometrically with increasing E. Water also undergoes a similar electron dissociation attachment at a number of resonant energies between 6 and 12 eV (the narrow resonance at 6.6 eV is dominant), and Delory et al. [2006] found that the production of dissociated water

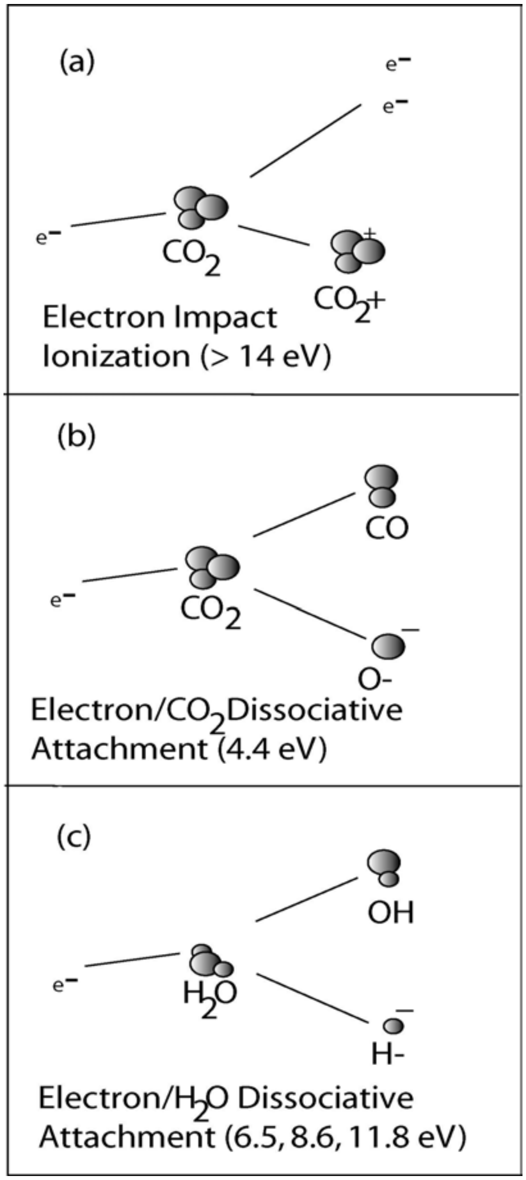

Figure 1 – The interaction of electrons with carbon dioxide and water. (a) Electron impact ionization of CO_2 above 14 eV to create new electrons. (b) Electron dissociation of CO_2 to make CO and O-.(c) The dissociation of H_2O to make OH and H-.

products OH and H^- also geometrically increases with increasing E-field. Atreya et al. [13] examined the subsequent recombination pathways for the dust storm E-field created species CO, O^-, OH, and H^- in the Martian near-surface atmosphere and found that anomalously large amounts of the reactive species H_2O_2 can be created in the atmosphere at concentrations exceeding 200 times that of regular photochemical production. The reactive product H_2O_2 was found to be at condensation levels and hence conclude that the peroxide coats aeolian dust and the surface, and may possibly account for the presumed highly-reactive soil found by the Viking landers [17].

The Loss of Methane in Dust Storms. Farrell et al. [18] recently found that methane can also be dissociated by the same energetic electron processes that are responsible for the dissociation of CO_2. Specifically, methane has an extended dissociation cross section from 10-100 eV, and it is relatively easy to demonstrate that energetic electrons in this range can destroy the molecule. While the lifetime of methane is typically about 300 years in fair-weather regions, in dust storms the destruction time drops to as low as 1000 s due to the presence of the E-field driven energetic electrons.

Implications. These electrochemical models suggest that the atmospheric conditions in Martian dust devils/storms/fronts are relatively harsh, with large E-fields, the creation of a collisional plasma (energetic electrons, CO_2^+, and negative ions), and the formation of reactive species. The dust storms also have the ability to be a strong sink of methane, possibly creating ambiguous measurements for this very important biomarker.

This new meteorology-driven electrochemical environment on Mars is very different from the fair-weather photochemical environment. However, this new environment is not well-studied since most landed systems are specifically designated to be operational in non-dust storm season - a purposeful avoidance of dust storms where this new chemistry exists. MSL will have both the longevity and capability to obtain first-ever measurements in dust features to determine the nature of this new harsh electro-chemical environment. In the meantime, we infer its presence base upon analogy, modeling, and the intriguing Viking lander GEx/LR results.

If this harsh environment exists as modeled, it may yet be one more challenge to the existence of life on the Martian surface, with a seasonal cleansing of the surface of organic material.

References: [1] Melnik, O and M Parrot, (1998). Electrostatic discharge in Martian dust storms, *J. Geophys. Res.,* 103, 29107.[2] Farrell WM et al. (2003). A simple electrodynamic model of a dust devil, *Geophys. Res. Lett.,* 30, 2003GL017606.[3] Farrell WM et al. (2006), The Integration of Electrostatic and Fluid Dynamics within a Dust Devil, J. Geophys. Res., 111, E01006. [4] Zhai, Y., S. A. Cummer, and W. M. Farrell (2006), Quasi-electrostatic field simulations of Martian dust storms, *J. Geophys. Res., 111,* E06016, doi:10.1029/2005JE002618. [5] Ette AII, (1971)., The effect of Hermattian dust on atmospheric electric parameters, *J. Atmo. Terr. Phys.,* 33, 295.[6] Crozier, WD, (1964). The electric field of a New Mexico dust devil, *J. Geophys. Res.,* 69, 5427.[7] Farrell, WM, et al, (2004). Electric and magnetic signatures of dust devils from the 2000-2001 MATADOR desert tests, *J. Geophys. Res.,* 2003JE002088.[8] Freier, GD, (1960). The electric field of a large dust devil, *J. Geophys. Res.,* 65, 3504.[9] Schmidt DA et al, (1998). Electrostatic forces on saltating sand, *J. Geophys. Res.,* 103, 8997.[10] Delory, GT et al., (2002). The electrical satructure of terrestrial dust devils: Implications of multiple vertical measurements of the electric field, *AGU EOS transactions,* Dec AGU.[11] Jackson, T. J., and W. M. Farrell (2006), Electrostatic fields in dust devils: Analog to Mars, *IEEE Trans. Geosci. Remote Sensing*, 44 (10): 2942.[12] Delory, GT et al. (2006), Oxidant Enhancement in Martian Dust Devils and Storms: Storm Electric Fields and Electron Dissociative Attachment, *Astrobiology*, 6, 451.[13] Atreya, S.K., et al. (2006) Oxidant Enhancement in Martian Dust Devils and Storms: Implications for Life and Habitability *Astrobiology*, 6, 439.[14] Nighan, W. L. (1970) Electron energy distributions and collision rates in electrically excited N_2, CO, and CO_2. *Physical Review a (General Physics)* 2, 1989-200.[15] Eden HF and B Vonnegut, (1973). Electrical breakdown cause by dust motion in low pressure atmospheres: Consideration for Mars, *Science,* 180, 962.[16] Farrell, W. M., et al. (2005), Martian dust devil and storm electric fields: The formation of an O- plasma and new local chemistry, *EOS Trans. AGU*, 86 (52), Fall Meeting Suppl., Abstract # P13B-0150.[17] Oyama, V. I. et al. (1977), Preliminary findings of the Viking gas exchange experiment and a model for Martian surface chemistry, Nature, 265, 100. [18] Farrell, W. M. et al. (2006), Martian dust storms as a possible sink of atmospheric methane, *Geophys. Res. Lett., 33,* L21203.