Measurements of Electrical Discharges in Martian Regolith Simulant

A. Fábian, C. Krauss, A. Sickafoose, M. Horányi, and S. Robertson

***Abstract*—Due to the prevalence of Martian dust devils and dust storms, an understanding of the underlying physics of electrical discharges in Martian dust is critical to future Mars exploratory missions. Measurements on the charging of single dust grains show that particles of Martian regolith simulant can have large electric potentials due to triboelectric charging. As a result of this charging, agitated Martian regolith simulant in a low-pressure CO_2 atmosphere produces electrical discharges. Under extremely dark viewing conditions, electrical discharges are visually observed at pressures between 0.1 and 50 torr. Measurements of the frequency and intensity of these discharges as a function of pressure (from 0.1 to 5 torr) and stirring speed (corresponding to wind speeds from 0.1 to 2.6 m/s) show that discharges occur at pressures and wind speeds similar to those expected on the Martian surface.**

***Index Terms*—Electrical discharges, dust devil, dust storm, Mars, triboelectric charging.**

I. INTRODUCTION

WHEN dust particles with different compositions come into contact, a charge can be transferred between the grains. Wind-driven dust studies show that in the case of particles with identical compositions, the particle with a larger radius in a collision preferrentially becomes positively charged. The stratification of particle sizes generated by upwinds within a dust cloud causes an electric dipole to form. When the electric potential within the cloud exceeds the breakdown voltage of the surrounding atmosphere, the potential is released in a discharge.

Triboelectric charging of dust particles and the resultant electrical discharges have been observed in several terrestrial phenomenon, including volcanic plumes [1] and dust devils [2]. Field studies of terrestrial volcanic plumes have observed electric fields of $\approx$5 kV/m [1]. Additional studies show that charge separation in terrestrial dust devils, typically less than 30-m diameter and up to 700-m high [3], can lead to electric fields of $\approx$1.6 kV/m [4].

Due to Mars' low atmospheric presssure, arid climate, and frequently windy environment, it has been suggested that the dust on the surface of Mars should be even more susceptible to triboelectric charging and subsequent electrical discharges than the dust on Earth. The atmospheric breakdown electric field E_b is dependent on the atmospheric pressure and composition. Since the average atmospheric pressure on the surface of Mars is 4.5–6 torr, compared to Earth's 760 torr, E_b on Mars is expected to be $\approx$20 kV/m, while E_b on Earth is $\approx$3000 kV/m. This lower value for E_b implies that any discharges on Mars should occur more frequently but at lower intensities than those seen on Earth. In addition, the dry Martian environment is helpful in maintaining cloud charges since low humidity decreases conductivity. Finally, if dust particles are to charge via contact with one another, sufficiently strong winds must be present to facilitate the dust motion. Based on laboratory experiments and *in situ* measurements, dust particles are expected to move on the surface of Mars with velocities on the order of 1 m/s [5]. Wind speeds greater than this were observed by Mars Pathfinder [6].

The expected susceptibility of Martian dust to triboelectric charging is of particular interest in light of images taken by the Mars Global Surveyor's orbital camera (MGS MOC), which show tracks along the surface of Mars. These tracks are now interpreted as dust devil tracks [7] and seem to indicate that dust devils may occur anywhere on the Martian surface. Martian dust devils can be nearly 6 km in height and tens of kilometers in width [8]. While these features are orders of magnitude larger than their terrestrial counterparts, they are still much smaller than the major dust storms which can cover large portions of the planet and last for several months. The large comparative size of these phenomenon suggests that electrical discharges due to triboelectric dust charging could be numerous and observable. In addition, simulations with particle-in-cell codes have indicated that Martian dust devils may be capable of generating electrical dipole moments comparable to those of terrestrial dust devils [9]. This is supported by theoretical calculations [10], which find that Martian dust devils and storms are likely to have sufficiently large charge separations to produce discharges. To the best of our knowledge, however, no nighttime images have been taken that could reveal discharges occuring in Martian dust storms. Perhaps the studies presented in this paper will help motivate these observations.

It is important that the nature of dust charging on Mars be explored as it directly impacts plans for future Mars exploration. Electrical discharges can affect not only the optical and electrical systems of equipment, but may also affect the safety of future human explorers on the Martian surface.

Previous laboratory work focused primarily on qualitative evidence that charging due to the stirring of fine sand produces visible discharges. When sand was stirred in air, arc and glow discharges were observed between 0.1 and 50 torr [11]. When air was replaced by CO_2, arc and glow discharges were observed at a pressure of 10 torr [12]. While these studies support the idea

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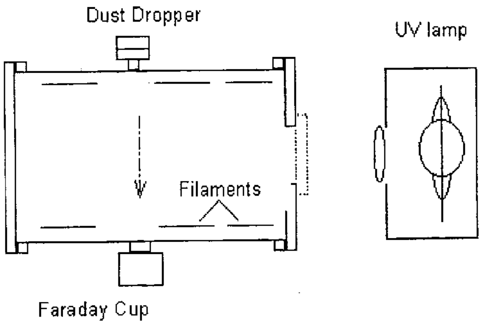

Fig. 1. Schematic diagram of the dust-charging experiment. The filaments are used when doing charging with fast electron beams, and the UV lamp is employed for photoelectric charging experiments.

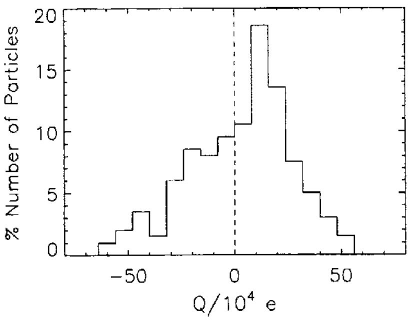

Fig. 2. Triboelectric charge distribution for grains of JSC-Mars-1. The bin size is $8.0 \times 10^4 e$, where e is the elementary charge, which corresponds to a charging potential of 2.6 V. The dashed line is located at zero charge and represents the boundary between gaining and losing electrons.

of electrical discharges occuring due to triboelectrically charged dust particles, no quantitative experiments have been performed which simulate conditions on Mars.

The goal of our experiments is to attain a better understanding of the physics involved in the triboelectric charging of Martian dust and to determine the parameters which favor the occurrence of electrical discharges. We have begun by measuring the triboelectric charging properties of JSC-Mars-1, a Martian regolith simulant. Removed from the southern flank of Mauna Kea, JSC-Mars-1 is composed of volcanic ash particles <1 mm in diameter which contain 43.5% SiO_2. It approximates the grain size, density, porosity, reflectance spectrum, mineralogy, chemical composition, and magnetic properties of the soil of Mars [13]. Based on the large amounts of triboelectric charging observed on individual JSC-Mars-1 particles, discussed in Section II, we have constructed an experiment with which to study electrical discharges in JSC-Mars-1. The frequency and intensity of discharges from agitated Martian regolith simulant in a CO_2 atmosphere as a function of pressure and stirring rate are examined. This experimental setup is described in Section III. Section IV summarizes our initial observations, and Section V focuses on future plans for the experiment.

II. TRIBOELECTRIC CHARGING

Since triboelectric charging of dust particles plays a crucial role in the occurance of electrical discharges, we investigate this process using an experiment which detects the charge on isolated grains. The apparatus (Fig. 1) is the same Double Plasma machine used in previous dust-charging experiments with fast electron beams and UV illumination [14]–[16].

Dust grains are dropped into a vacuum chamber ($\sim 10^{-7}$ torr) at the top and are collected in a Faraday cup mounted below the chamber. The Faraday cup is connected to a sensitive electrometer and measures the charge on the grains. The dropping mechanism, a vibrating plate with a small hole, is adjusted to drop particles infrequently so that the majority of events are due to individual grains. Signals from multiple grains are easily identified by their waveform and are not used. Typical grains in these experiments are 45–53 μm in radius and the smallest charge that can be measured with confidence is $\pm 2 \times 10^4$ electrons.

For particles composed of poorly conducting materials, significant electrostatic charging can be observed without exposing the grains to an electron flux or UV illumination. Due to the experiment's configuration, dust grains are more likely to be in contact with other dust grains than with the vibrating plate. Therefore, the most likely origin of the charge is triboelectricity due to friction between the grains or between the grains and the dropper (made out of zinc). Conducting particles dropped through the chamber do not exhibit this charging, most likely due to the charge being conducted to ground before the grains dropped [16]. A histogram of measured triboelectric charge on JSC-Mars-1 dust particles is shown in Fig. 2. We observe that triboelectric charging leads to a wide charge distribution roughly centered on zero. The capacitance of a spherical grain with a radius of 49 μm is 5.4 fF, so we expect a charge of $\approx 3.4 \times 10^4$ electrons per volt of charging potential. Thus, JSC-Mars-1 particles show extremely large charging potentials, up to ±10 V. While this dust-charging experiment does not attempt to simulate charging processes on Mars, it demonstrates that the Martian regolith analog particles can become highly charged due to triboelectricity.

III. EXPERIMENTAL SETUP

Given the large charging potentials measured on particles of JSC-Mars-1 and knowing that the excitation of CO_2 requires an electron energy of 10.0 eV (with ionization at 14.4 eV) [17], it follows that electrical discharges should occur in JSC-Mars-1 dust. To examine this phonomenon, a 4.7 L polycarbonate vacuum jar with a base radius of 8.5 cm is evacuated to ≈ 0.15 torr, and then CO_2 is added to attain the desired pressure. Approximately 150 mL of JSC-Mars-1 is placed in the bottom of the chamber to form a layer several centimeters in depth.

To simulate the windy conditions inside a dust devil or dust storm, a motor-driven nonconductive stirring rod is used. Both the pressure and the stirring rate can be varied to simulate differing climatic conditions. A tachometer measures the stirring rod's rate of rotation, and the measured revolutions per minute are converted to radians per second Ω. This value is used to calculate a maximum simulated wind speed $V_W = r\,\Omega$, where r is the radius of the stirring rod. Fig. 3 is a schematic diagram of the experimental setup.

When taking data, the entire device is enclosed in a dark container to prevent contamination from outside light. Inside the

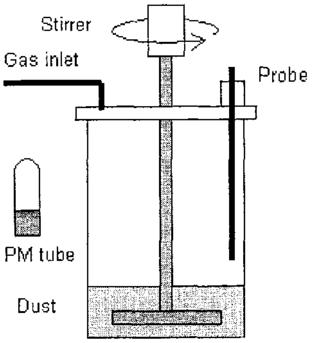

Fig. 3. Schematic diagram of the electrical discharge experiment. Configuration of the experiment allows for the easy alteration of stirring speed and pressure. The dust used in this experiment is JSC-Mars-1. The entire apparatus can be enclosed in a dark chamber while measurements are taken.

container, there is a 1P28A photomultiplier tube which has a maximum response at a wavelength of 3400 (±500) Å. The photomultiplier tube is connected to a counter which determines the number of discharges observed over a given time period. For example, a typical count rate of 3000 discharges is observed over a period of five minutes at a pressure of 1 torr. A wire probe is placed in the chamber and connected directly to the oscilloscope. Signals are seen from the probe coincident with signals from the photomultiplier tube indicating that the discharges are associated with rapidly changing electrical potentials.

IV. OBSERVATIONS OF ELECTRICAL DISCHARGES

Discharges in the chamber are observed visually under extremely dark conditions between pressures of 0.1 and 50 torr. When seen with the naked eye, the color of these discharges is mostly red. Discharges in the chamber are also observed electronically over a range of stirring rates and pressures with the photomultiplier tube and oscilloscope. In addition, discharges are observed when the stirring rod is removed and the regolith simulant is agitated by simply shaking the entire chamber. This indicates that the charging does not require the impact of dust on the stirring rod.

Nine different stirring rates were tested over a range between 21.8 and 48.7 rad/s. These correspond to maximum wind speeds of V_W =1.16 m/s to 2.58 m/s. For each stirring rate, the maximum discharge rate is observed at 1 ± 0.3 torr. Discharge rates decrease rapidly at pressures above and below this value. The results for three different stirring rates are shown in Fig. 4.

Eight different pressures were tested over a range from 0.17 to 5 torr. For most cases, discharges occur most frequently at a stirring rate corresponding to $V_W = 1.38 \pm 0.05$ m/s, while discharges occur least frequently at a stirring rate equating to $V_W = 2.12 \pm 0.05$ m/s (Fig. 5).

Finally, the maximum intensity of the electrical discharges was measured at a constant stirring rate over a range of pressures from 0.26 to 16 torr. Discharges with the largest intensities occur between 1.5 and 6 torr (Fig. 6).

V. DISCUSSION AND FUTURE WORK

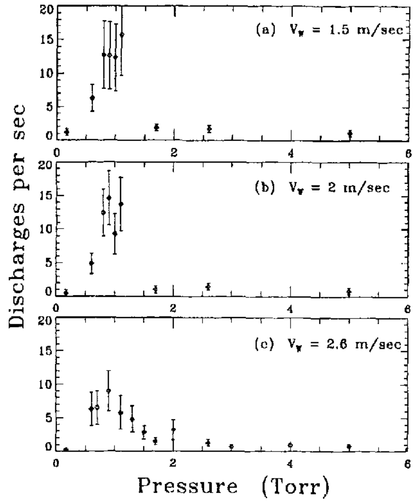

Fig. 4. Number of discharges per second as a function of pressure for three stirring rates which correspond to maximum wind speeds of: (a) V_W =1.5 m/s; (b) V_W =2 m/s; and (c) V_W = 2.6 m/s. In each case, the number of discharges peaks near 1 torr.

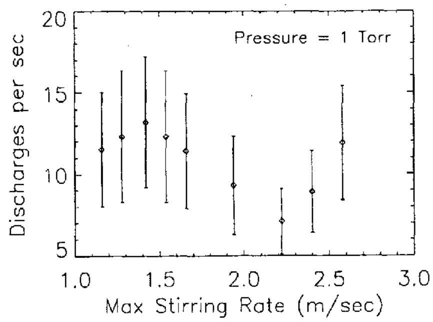

Fig. 5. Number of discharges per second at a pressure of 1 torr as a function of stirring rate. Plots of seven other pressures ranging from 0.17 to 5 torr show similar results.

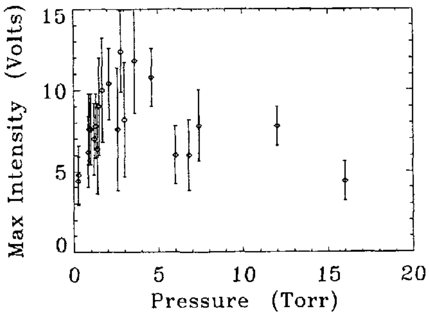

Fig. 6. Maximum measured intensity for discharges as a function of pressure. As seen in this plot, the largest intensities are observed between 1.5 and 6 torr.

The experiments demonstrate that the triboelectric charge on JSC-Mars-1 grains is sufficient to create potentials comparable to the energies needed for excitation and ionization of CO_2, the dominant species in the Martian atmosphere. Electrical discharges are visually observed when the simulant is stirred in low pressure CO_2 at speeds comparable to those expected of Martian winds. This confirms the high possibility of electrical discharges due to dust agitation on Mars.

Continued experiments include sieving the regolith simulant to examine the effects of particle size distribution on triboelectric charging. Additionally, we will use gases with different breakdown characteristics. A spectrometer will be added to determine which energy transitions are most favored in a given environment. We will also be able to determine if these favored transitions are dependent on pressure or stirring speed.

These experiments will help in the development and design of *in situ* experiments that could investigate triboelectric charging and subsequent discharges on the surface of Mars.

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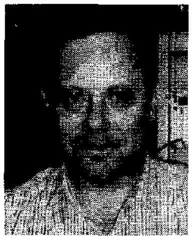

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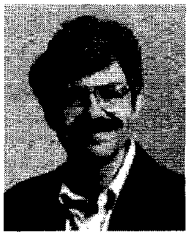

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