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Laboratory analogues of Martian electrostatic discharges

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ABSTRACT

Electrical discharges in Martian analogue materials have previously been generated by agitation of the material in a low-pressure carbon dioxide environment. These results have led to the supposition that lightning is likely on Mars, on the basis that the surface material becomes triboelectrically charged, and the charges are then gravitationally separated in dust storms. We have reproduced one of these experiments and find that triboelectric charging of the Martian regolith simulant by the walls of the vessel used can adequately explain all the effects observed. Our results indicate that unless special care is taken to avoid wall effects, the electrostatic properties of a laboratory system cannot be extrapolated to the Martian environment. We also note that charging of the outside of the vessel used can generate transients within the vessel which could be mistaken for electrical discharge signals, unless accompanied by optical emissions.

1. Introduction

Planetary lightning has been observed since the 1970s, and is now thought to be relatively common in solar system atmospheres (Harrison et al., 2008). Lightning is expected to occur on Mars because of triboelectrification within regional-scale dust storms and localised dust devils (e.g. Aplin, 2006). Large electric fields have been measured within terrestrial dust devils (Crozier, 1964), and by analogy, Martian dust devils and storms should also become charged. The Paschen curves for both 10 mbar pure CO_2, and a CO_2–trace gas mixture, more representative of the Martian atmosphere (Buhler and Calle, 2003), imply that discharges should occur at typical electric fields (kV m^{-1}) observed in dust devils. Martian lightning is expected to play a role in the production of trace organic molecules, which may be important for biological processes (Atreya et al., 2006). Despite this clear motivation, there have never been any electrical measurements in the Martian atmosphere, and neither do we know of any forthcoming missions carrying relevant instrumentation. Attempts at remote sensing of radio emissions generated by Martian electrical discharges have also been inconclusive (Ruf et al., 2009; Gurnett et al., 2010; Zarka et al., 2008).

Reports of electrical discharges being readily generated in Martian analogue experiments have supported the suggestion that lightning, generated by triboelectric charging between dust particles, is likely on Mars. Eden and Vonnegut (1973) manually agitated 50 g of dry sand in a 1 l glass flask filled with 10 mbar CO_2. Glow and spark-like discharges could be seen within a darkened room. Mills (1977) mechanically rotated a 5 l glass flask containing washed and dried sand and saw similar discharges at 4–6 mbar. Krauss et al. (2003) describe two experiments using a JSC Mars-1 Martian regolith simulate. (This is weathered ash from the Hawaiian volcano Pu'u Nene, the closest terrestrial spectral analogue to the bright regions of Mars. It comprises crystalline and glassy material, with SiO_2 as the main component (45%), and modal size ~400 μm (Allen et al. (1997)).) The first experiment stirred the analogue material in a polycarbonate vacuum flask filled with 1–11 mbar CO_2, to simulate horizontal mixing from the wind, with a photomultiplier tube to detect any optical emissions and a simple wire probe to detect electric field changes. Numerous optical signals were detected. Repeating the experiment with the Martian simulant sorted by particle size suggested that a mixture of small and large particles produced the most discharges.

In the second experiment, Krauss et al. (2003) set up an apparatus to drop the simulant dust approximately 1 m through a large glass tube. The dust was mixed with glass microballoons and an oscilloscope was connected to the floating bottom plate.

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The signals seen were interpreted as electrical discharges from triboelectric charging in the analogue material, although they were not observed visually.

1.1. Triboelectrification

Triboelectrification is the frictional transfer of charge, explained most simply by the transfer of electrons from one surface to another. The exact mechanism of charge transfer is still poorly understood, but in conductors, the best-understood system, charge transfer is proportional to the difference in the workfunction between the two materials (Lacks and Levandovsky, 2007). Materials with lower workfunctions lose electrons to materials with higher workfunctions, with the charge transfer usually estimated using the the triboelectric series, an empirical list of materials sorted by workfunction (Table 1). In the Martian atmosphere, the charging takes place within one material, and is not described by the triboelectric series.

It is known that agitation of single-material particle systems causes smaller particles to charge negatively and larger ones positively. Lacks and Levandovsky (2007) have explained this phenomenon in terms of transfer of electrons in trapped high-energy states. Smaller particles become depleted of these electrons more quickly than larger particles, which leads to net charge transfer of electrons to the smaller particles from the larger ones. In dust devils, gravitational forces combined with single-material charging cause an electric field to develop between the top and the bottom of the dust cloud, which could lead to electrical breakdown in the low-pressure Martian atmosphere.

The laboratory experiments described above involved agitation of a Martian analogue material to encourage dust–dust charge transfer, which can be explained in terms of the Lacks and Levandovsky (2007) mechanism. However, all these experiments were carried out in relatively small vessels, which could also have transferred charge to the dust by inter-material triboelectrification. The relative magnitudes of charge transferred can be estimated from the triboelectric series (Table 1).

To investigate this, we reproduced an experiment described by Krauss et al. (2003), in which the Martian analogue material (dust) was dropped through a cylindrical tank. Our alternative interpretation of the observations is that the major charging mechanism is between the dust and tank, and that any dust–dust charging signals are dominated by the wall–dust interactions.

2. Experiment

We reproduced the apparatus described by Krauss et al. (2003) as closely as possible with a cylindrical acrylic (poly(methyl methacrylate), or PMMA) tank approximately 1 m long of diameter 0.25 m (Fig. 1). In the top of the tank there is a polythene funnel sealed by a plunger, which is loaded with the JSC Mars-1 simulant. The dust is baked to remove adsorbed water, and the tank is evacuated and filled with 7–9 mbar CO_2. The plunger is then released and the dust falls to the bottom of the tank through another inverted funnel. The metal plate at the top of the tank is electrically grounded, and the voltage on the plate at the bottom of the tank is measured using a high-impedance voltage follower and logged at 5 Hz via an IEEE-488 PC interface.

The voltage on the collector electrode V will be proportional to the charge Q transferred by direct impaction of charged dust

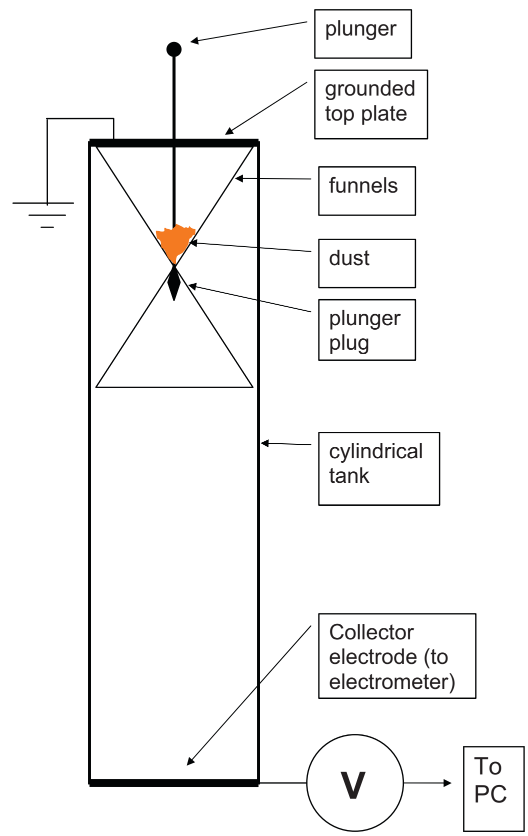

Fig. 1. Apparatus showing the Martian analogue material loaded before a drop (dust drops are activated by pushing down the plunger). The cylindrical tank is mounted on a support frame which permits the tank to be rotated to re-load the Martian analogue material. The carbon dioxide gas supply line and vacuum pump (not shown) are disconnected before each dust drop and rotation, and the tank sealed with a valve.

Table 1
Triboelectric series of materials used in Martian electrostatic experiments. If two materials come into contact, the one with lower workfunction (positioned higher in the table) will charge positively and vice versa. The magnitude of charging increases with separation in the table. Note that there is no significant difference between nylon and glass, and polycarbonate and PMMA.

Material (those at the top charge positively with respect to those below)	Workfunction (reference)	Notes
Sand	3.25 eV (Deng et al., 2010)	Simulant used by Eden and Vonnegut (1973) and Mills (1977).
Nylon	4.08 ± 0.06 eV (Davies, 1969; Kitabayashi et al., 2005)	Plunger material in this experiment.
Glass	~4.16 eV (Bode and Fletcher, 1969)	Tank material used by Eden and Vonnegut (1973), Mills (1977) and Krauss et al. (2003), glass microbeads also mixed with the JSCMars-1 Martian simulant by Krauss et al. (2003) and in this experiment
Poly (methyl methacrylate) (Perspex, acrylic, PMMA)	4.25 eV (Kitabayashi et al., 2005)	Tank material used in this experiment
Polythene	5.25 eV (Kitabayashi et al., 2005)	Funnel material used in this experiment
JSC Mars-1	5.6 eV (Sharma et al., 2008)	Martian analogue material used by Krauss et al. (2003) and in this experiment.