New Journal of Physics
The open access journal at the forefront of physics
Deutsche Physikalische Gesellschaft DPG IOP Institute of Physics

Experimental evidence for electrostatic discharging of dust near the surface of Mars

To cite this article: C E Krauss *et al* 2003 *New J. Phys.* **5** 70

New Journal of Physics
An Institute of Physics and Deutsche Physikalische Gesellschaft Journal

Experimental evidence for electrostatic discharging of dust near the surface of Mars

C E Krauss[1], M Horányi[1,2] and S Robertson[2]
[1] Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80309, USA
[2] Department of Physics, University of Colorado, Boulder, CO 80309, USA
E-mail: corinne.krauss@colorado.edu

New Journal of Physics **5** (2003) 70.1–70.9 (http://www.njp.org/)
Received 7 January 2003, in final form 7 May 2003
Published 13 June 2003

Abstract. Laboratory experiments have shown that single non-conductive dust grains can attain large electric potentials due to triboelectric charging. When grains within a dust cloud interact, they become charged. An electric field forms when upwinds within the cloud cause a separation of large and small particles. We have performed laboratory experiments to determine the necessary conditions for triboelectric charging in a cloud of Martian regolith simulant to break down a low-pressure CO_2 atmosphere and create electrical discharges. The range of pressures and the simulated wind speeds over which discharges are observed have been determined. The effects of particle-size distribution on the observed discharge rates are also discussed.

Contents

1367-2630/03/000070+9$30.00

1. Introduction

When dust particles come into contact with one another, charge can be transferred between the grains. Laboratory experiments have demonstrated that this effect, referred to as triboelectric charging, can lead to extremely large charging potentials for individual non-conductive grains [1]. Wind-driven dust studies show that when the colliding particles have identical compositions, the particle with the larger radius in a collision preferentially becomes positively charged [2].

In dust storms, upwinds within a dust cloud can cause the smaller, negatively charged particles to be lifted higher in the cloud while the larger, positively charged particles remain near the surface. This charge separation causes the formation of an electric field. The strength of the electric field depends on the dust density and the amount of charge generated on each grain. When the electric potential within the cloud exceeds the breakdown voltage of the surrounding atmosphere, the charge is released in a discharge similar to lightning.

Triboelectric charging of dust particles and the resultant electrical discharges have been observed in several terrestrial phenomena, including volcanic plumes [3] and dust devils [4]. Field studies of terrestrial volcanic plumes have observed electric fields of ≈ 5 kV m^{-1} [3]. Additional studies show that charge separation in terrestrial dust devils, typically less than 30 m in diameter and up to 700 m in height [5], can lead to electric fields of ≈ 1.6 kV m^{-1} [6]. At 760 Torr, the average atmospheric pressure on Earth, the terrestrial breakdown electric field is ≈ 3000 kV m^{-1}.

For comparison, dust devils on Mars can measure 6 km in height and hundreds of metres in diameter [7]. At Martian atmospheric pressures, 4.5–6 Torr, the breakdown electric field is expected to be ≈ 20 kV m^{-1}, two orders of magnitude lower than the terrestrial breakdown value.

In the 1970s, it was qualitatively shown that stirring sand in air produced arc and glow discharges at pressures between 0.1 and 50 Torr [8]. When air was replaced by CO_2, arc and glow discharges were observed at a pressure of 10 Torr [9]. While these studies support the idea of electrical discharges occurring due to triboelectrically charged dust particles, they were extremely qualitative.

The two experiments described in section 2 are designed to study quantitatively the factors which enhance or inhibit the creation of electrical discharges due to triboelectric charging in a simulated low-pressure Martian environment. The independent effects of horizontal mixing and vertical charge separation are explored. The results of the experiments are presented in section 3. Section 4 summarizes our work to date and discusses some practical applications.

2. Experimental setups

2.1. Horizontal mixing apparatus

To examine the creation of electrical discharges due to horizontal mixing, a 4.7 litre polycarbonate vacuum jar with a radius of 8.5 cm is evacuated to ≈ 0.2 Torr and then filled with CO_2 to attain the desired pressure, 1–8 Torr. Approximately 700 ml of a regolith simulant is placed in the bottom of the chamber to form a layer several centimetres in depth. Figure 1 shows a schematic diagram of the experimental setup.

Both the pressure and the stirring rate of the apparatus can be varied to study differing atmospheric conditions. To simulate the windy conditions inside a dust storm, a motor-driven non-conductive stirring rod is used. A tachometer measures the stirring rod's rate of rotation.

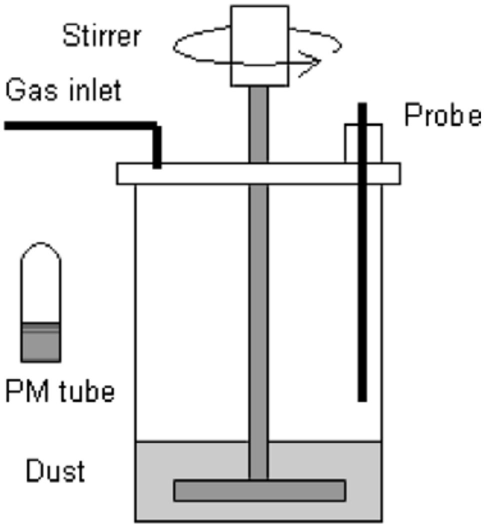

Figure 1. Schematic diagram of the horizontal mixing apparatus. The entire apparatus is enclosed in a dark chamber when data are taken.

The number of rotations per minute are converted to radians per second, Ω, and this value is used to calculate a maximum simulated wind speed, $V_W = r\Omega$, where r is the radius of the stirring rod.

Discharges are detected by a 1P28A photomultiplier tube which has a maximum response at a wavelength of 3400 ($\pm$500) Å. The photomultiplier tube is connected to a computer which determines the number of discharges observed over a given time period. For example, a typical count rate of 3300 discharges is observed over a period of 5 min at a pressure of 1 Torr and a simulated wind speed of 3.5 m s^{-1}. Additionally, changes in the electric field are detected by a wire probe that is placed in the vacuum chamber and connected directly to an oscilloscope. When taking data, the entire device is enclosed in a dark chamber to prevent the photomultiplier from detecting outside light sources.

This experiment uses JSC-Mars-1, a regolith simulant which reproduces most of the known properties of the dust on Mars [10]. Removed from the southern flank of Mauna Kea, JSC-Mars-1 is composed of weathered volcanic ash particles <1 mm in diameter which contain 43.5% SiO_2. Previous work done in our lab has shown that JSC-Mars-1 particles can have extremely large charging potentials, up to $\pm$15 V [1]. These particles are used to create electrical discharges in a CO_2 environment since CO_2 has an excitation energy of only 10.0 eV and an ionization energy of 14.4 eV [11].

2.2. Vertical drop apparatus

The second apparatus demonstrates that electrical discharges are created due to vertical charge separation in a low-pressure atmosphere. A 1.2 m glass tube with a radius of 17 cm is evacuated to $\approx$20 mTorr and then filled with CO_2 to attain the desired pressure, 1–8 Torr. Two funnels are arranged in the tube in an hourglass shape, separated by a 3.8 cm movable plug. A magnet at the top of the experiment operates the plug, controlling the dust flow. Figure 2 is a schematic diagram of the experimental setup.

A dust mixture of 100 μm JSC-Mars-1 particles and 53 μm glass microballoons is placed in the upper funnel with the plug closed. Because the dust particles have different compositions, the

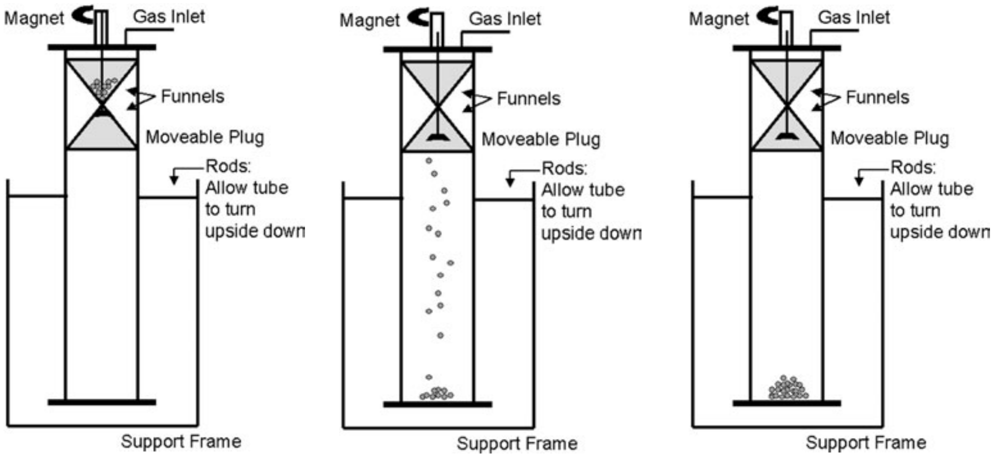

Figure 2. Schematic diagram of the vertical drop apparatus. Three time steps are shown to demonstrate the vertical fall of the dust. The glass tube flips upside down to reset the experiment.

particle charging is not governed by which particle has a larger diameter but by which material ranks higher on the triboelectric series. Materials which appear higher on this empirically determined list will gain a positive charge compared to materials which appear lower on the list. In this case, the JSC-Mars-1 charges negatively compared to the glass microballoons.

When the plug is moved, the dust drops down the tube. Because the glass microballoons have a smaller ratio of mass to surface area, they are able to stay aloft a short while longer than the JSC-Mars-1. This charge separation creates an electric potential which can break down the local atmosphere.

Data are taken in this experiment over a range of pressures and over a large number of drops. The upper plate of the experiment is electrically grounded while a voltage probe is attached to the bottom, floating plate. The signals from the probe are read by an oscilloscope which records the voltages observed during each dust drop.

The entire device is suspended vertically on a frame which allows it to be turned upside down. This recharges the experiment by moving the dust back into the upper funnel.

It is important to note that the hole in the funnels through which the dust falls is 2.5 cm in diameter. This passage is large enough to prevent most of the falling dust from rubbing against the hole through which it falls, thus a negligible amount of charging occurs due to the passage of the dust from the upper funnel to the main chamber. The vast majority of the charging is therefore due to the dust-on-dust contact.

3. Results

3.1. Horizontal mixing observations

The frequency and intensity of discharges have been examined over a range of pressures from 1 to 8 Torr and a range of simulated wind speeds between 1.5 and 5.2 m s^{-1}. Under extremely dark viewing conditions, discharges are visible to an observer with dark-adapted eyes. When observed electronically with an oscilloscope, the discharges coincide with signals from the probe, indicating that the discharges are associated with rapidly changing electric fields.

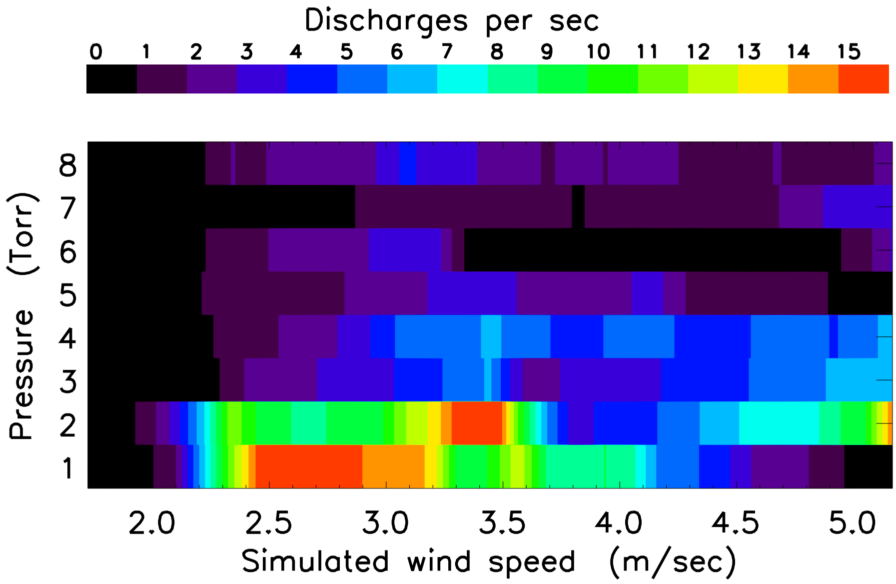

Figure 3. Discharge rates from the horizontal mixing apparatus as a function of pressure and simulated wind speed. The key above the plot denotes the colours representing different discharge rates.

The observed discharge rates are a function of the pressure and the simulated wind speed. The effects of these two parameters are shown in figure 3. The discharge rates are also dependent on the amount of regolith stirred. However, the observed trends of local maxima and minima within the discharge rates are independent of the dust loading.

For all pressures, a clear discharge rate threshold occurs between simulated wind speeds of approximately 2.0–2.2 m s^{-1}. The discharge rate is negligible below this threshold but increases rapidly once the threshold is crossed. (This threshold is not apparent in figure 3 for a pressure of 7 Torr due to the low resolution of the plot.) Above 2.5 m s^{-1}, no clear trend in discharge rate compared to the simulated wind speed has been observed for all pressures. A more detailed analysis shows that, while trends may be observed for several pressures, they do not hold throughout the entire data set.

The atmospheric pressure has a strong effect on the overall number of discharges observed. Maximum discharge rates occur near 1 Torr. This means that discharges are more likely to occur on Mars at locations of slightly lower than average pressure. Additionally, minimum discharge rates occur between 6 and 7 Torr. Yet, even at these pressures, discharges are not completely suppressed, they are simply observed at a much slower rate. This confirms that discharges should occur near the Martian surface.

The effect of particle size on electrical discharges was examined by determining the discharge rates for three particle-size distributions. Distribution 1 is that which occurs naturally in JSC-Mars-1: 51% 250–1000 μm, 24% 150–249 μm and 25% $<$150 μm. Distribution 2 consists of particles $>$355 μm, and distibution 3 consists of particles $<$120 μm. Figure 4 shows that a mixture of small and large particles is required in order to produce a significant number of discharges. When only large or only small particles are used, the discharge rates are suppressed by a factor of 5 or more, depending on pressure.

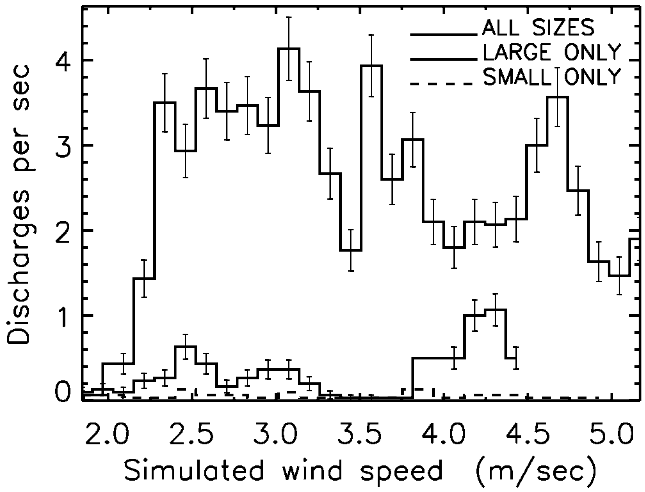

Figure 4. Discharge rate from the horizontal mixing apparatus as a function of wind speed for three particle-size distributions. A significant number of discharges occur only when there is a mixture of particle sizes. While the discharge rates presented here are for a pressure of 8 Torr, similar results are obtained at other pressures.

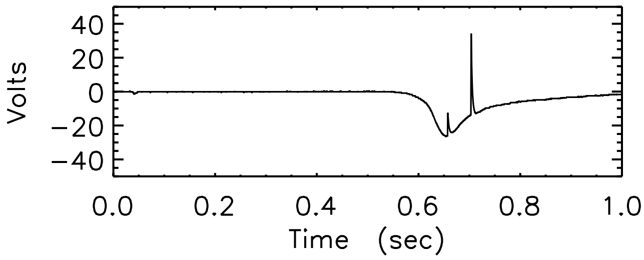

Figure 5. A typical voltage reading for a single dust drop in the vertical drop apparatus for a pressure of 4 Torr. The broad negative dip is a signature of the charged dust hitting the bottom of the experiment. The larger, negatively charged JSC-Mars-1 particles begin arriving at the bottom of the chamber after ≈0.55 s, and the lighter, positively charged glass microballoons approach the bottom of the chamber ≈0.1 s later. The narrow spikes represent electrical discharges.

3.2. Vertical drop observations

Discharges are observed both visually and electronically when dust is dropped through a vertical distance with no charging mechanism other than dust-to-dust contact. A sample waveform for a single dust drop is shown in figure 5.

As the dust falls down the chamber, the larger, negatively charged JSC-Mars-1 particles separate from the positively charged glass microballoons. After a freefall time of ≈0.55 s, the JSC-Mars-1 particles approach the bottom of the chamber, causing the electric potential within the chamber to become negative. When the glass microballoons approach the bottom of the chamber ≈0.1 s later, the two charge clouds are recombined and the potential within the chamber returns to zero. This separation and recombination of charge can be observed in the

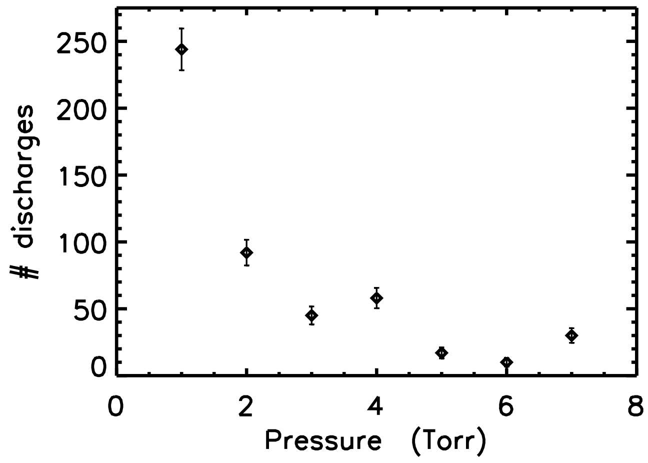

Figure 6. Number of discharges observed as a function of pressure for the vertical drop apparatus; 200 individual dust drops were made for each of the pressures shown. As with the horizontal mixing apparatus, the number of discharges decreases with increasing pressure.

wide depression in the voltage reading. Any discharges occurring during the dust drop cause a rapid fluctuation in the electric potential which is represented by a sudden spike in the voltage reading (figure 5).

The broad drip which represents the change in the electric potential, and thus the amount of charge the dust particles are gaining, remains consistent between drops. However, the occurrence of actual discharges is not consistent because it depends on the specific motions of the falling particles. The number of observed discharges per drop usually varies from 0 to 4, with extreme cases containing as many as seven discharges. The height of the narrow spikes, measured by the voltage probe, determines the intensity of the discharges. Discharge intensities range between 0.1 and 50.0 V.

The frequency of discharges has been examined over a range of pressures from 1 to 8 Torr. In all, 200 dust drops were made at each pressure, and the resulting voltage traces were analysed by an automated computer program. The program determined the number of observed discharges by searching for narrow spikes, signified by rapid fluctuations in the first and second derivatives, in the voltage signal. The results are shown in figure 6. As with the horizontal mixing apparatus, there is a trend in the number of discharges observed as a function of pressure. The number of discharges decreases as the pressure increases until a minimum is observed at 6 Torr. Although not shown in figure 6, additional data show that the number of discharges also decreases for pressures below 1 Torr.

4. Discussion

Our experiments show that triboelectric charging is a sufficient mechanism to create electrical discharges in a low-pressure CO_2 atmosphere. In order for a significant amount of discharges to occur, a range of particle sizes is necessary.

Besides particle-size distribution, two additional parameters have been determined to have strong effects on the discharge rate: atmospheric pressure and mixing rate. Dust vertically dropped or horizontally mixed demonstrates that low atmospheric pressures favour electrical discharges. Dust horizontally mixed also shows that if the simulated wind speeds are below a threshold value, no discharging occurs.

This work is of particular interest to the study of the electrical activity within large dust storms and dust devils on Mars and other dusty planetary surfaces. An understanding of the conditions which favour electrical discharges is crucial since these discharges may affect optical and electrical systems of equipment, interfere with radio communications, and affect the safety of future human explorers on the Martian surface.

Numerous environmental factors have led to the conclusion that dust near the surface of Mars is even more susceptible to triboelectric charging and subsequent electrical discharges than dust on Earth. Mars has a low atmospheric pressure, 4.5–6 Torr, and thus a low breakdown electric field value. This means that lightning 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 charge separation since low humidity decreases conductivity. Finally, Mars can have winds which are sufficiently strong to facilitate dust motion and thus allow charging via dust-to-dust contact to occur.

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 numerous dust devils on the Martian surface. 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 phenomena suggests that electrical discharges due to triboelectric dust charging on Mars could be numerous and observable.

The work presented here is just the first step in understanding the creation of electrical discharges due to triboelectric charging in low-pressure atmospheres. Future laboratory work must be done to determine whether other factors may have an affect on the discharge capabilities of dust grains. Factors such as mass loading, temperature, humidity and atmospheric composition must be analysed to provide a complete picture. Additionally, a simple theoretical model addressing the fundamental aspects of the triboelectric charging and subsequent discharges is still required to explain many of the smaller trends observed in the above data.

Acknowledgments

The authors acknowledge support from the NASA Space Science Graduate Student Research Programme (NGT5-50345) and thank Matt Triplett and Zoltan Sternovsky for their assistance in building the apparatus.

References

[1] Sickafoose A A, Colwell J E, Horányi M and Robertson S 2001 Experimental investigations on photoelectric and triboelectric charging of dust *J. Geophys. Res.* **106** 8343–56

[2] Stow C D 1969 Dust and sand storm electrification *Weather* **24** 134–40

[3] Anderson R 1965 Electricity in volcanic clouds *J. Geophys. Res.* **148** 1179–89

[4] Karma A K 1972 Measurements of the electrical properties of dust storms *J. Geophys. Res.* **77** 5856–69

[5] Kieffer H H, Jakosky B M, Snyder C W and Matthews M S (ed) 1992 *Mars* (Tucson, AZ: University of Arizona Press)

[6] Crozier W D 1970 Dust devil properties *J. Geophys. Res.* **75** 4583–5

[7] Thomas P and Gierasch P J 1985 Dust devils on Mars *Science* **230** 175–7

[8] Mills A A 1977 Dust clouds and frictional generation of glow discharges on Mars *Nature* **268** 614

[9] Eden H F and Vonnegut B 1973 Electrical breakdown caused by dust motion in low-pressure atmospheres: considerations for Mars *Science* **180** 962–3

[10] Allen C C, Jager K M, Morris R V, Lindstrom D J, Lindstrom M M and Lockwood J P 1998 Martian soil simulant available for scientific, educational study *EOS Trans. Am. Geophys. Union* **79** 405

[11] McDaniel E W 1964 *Collision Phenomena in Ionized Gases* (New York: Wiley)