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Title: Importance of Measurements of Charging Properties of Individual Submicron Size Lunar Dust Grains

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IMPORTANCE OF MEASUREMENTS OF CHARGING PROPERTIES OF INDIVIDUAL SUBMICRON SIZE LUNAR DUST GRAINS

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Summary

This white paper focuses on the important task of acquiring reliable charging properties of submicron/micron individual lunar dust grains in order to understand the physical and dynamical process in the lunar environment.

The lunar surface is mostly covered with a layer of dust grains formed by meteoritic impact over billions of years. Dust grains in the lunar environment are electrostatically charged by solar UV radiation on the lunar dayside, and by interaction with electrons in the solar wind plasma on the night side. In the high vacuum of ~ 10^{-12} torr environment on the lunar surface, the positive and negative charge on the lunar micron/submicron dust grains leads to some unusual physical and dynamical dust phenomena (Criswell, D.R., 1973; Pelizzari et al., 1978; Rennilson, J. J., et al., 1974; Horanyi, M., et al, 1998; O'brien, 2009).

The highly adhesive lunar dust characteristics and the observed lunar dust phenomena of levitation and transportation are attributed to electrostatic charging of the lunar surface and the dust. It is thus of high importance to have a definitive knowledge of the charging properties of lunar dust grains in order to have a clear understanding of the lunar dust environment and to develop mitigating strategies for its effects on human habitats and mechanical equipment.

It is also well recognized that the measurements made on individual submicron/micron size dust grains are expected to be substantially different from the measurements on bulk materials. This has been verified to be the case in the first charging measurements Apollo 11 & 17 individual micron size dust grains by UV photoelectric emissions and by electron impact(e.g., Abbas et al, 2006, 2007; 2008, 2009; *Tankosic and Abbas, 2008*).

In this white paper we bring to attention the importance of carrying out comprehensive measurements of the **charging properties of *individual Apollo 11-17 micron size dust grains by UV photoelectric emissions corresponding to the dominant charging process on the lunar dayside, and by electron impact, corresponding to the charging mechanism on lunar night side at temperatures representing the lunar day-night thermal cycle (~ 80 – 400 K). The acquired experimental data is essential for developing models for lunar dust levitation and transportation, and for development of mitigating strategies for lunar exploration and scientific investigation on and from the Moon.***

1. INTRODUCTION

Dust grains with high adhesive characteristics are believed to be levitated and transported over long distances on the lunar surface. The following observed lunar dust phenomena characterize the complex dust nature of the lunar environment.

1.1 Lunar Dust Phenomena and Dust *Charging Processes*

- The astronauts found the lunar dust to be unexpectedly high in its adhesive characteristics, sticking to the suits, instruments, and the lunar rover.
- A horizon glow over the lunar terminator and high altitude streamers were observed by the astronauts during the Apollo missions.
- Photoelectric emissions with UV radiation at wavelengths less than 200 nm on the day side, leading to positively charged grains.
- Electron/ion collisions on the night side, generally leading to negatively charged grains with low energy electrons.
- Secondary electron emissions by solar wind electrons may produce positively charged grains, and plays a very complex role and needs to be studied.

1.2 Charging Properties of Individual Submicron Size Lunar Dust Grains

- ***Charging properties of individual Apollo 11 and Apollo 17 micron/submicron size dust were predicted and have been unequivocally demonstrated to be substantially different from the available measurements generally made on bulk materials..***
- ***No viable theoretical models for calculation of the properties of individual micron size dust grains are available. The photoelectric yields, and secondary electron emission yields, have to be obtained by experimental methods (e.g., Abbas et al., 2006, 2007, 2009)***

The data essential for a clear understanding of the lunar dust phenomena are currently not available. It is well recognized that the measurements made directly on individual submicron/micron size dust grains are expected to be substantially different from the measurements on bulk materials. This has been verified to be the case in the first charging measurements Apollo 17 individual micron size dust grains by UV photoelectric emissions. The measured photoelectric efficiencies were found to be more than an order of magnitude different from the corresponding bulk measurements reported in the literature. The dust grain size dependence of the charging rates was found to be opposite to what is considered to be the case in the literature. No measurements of charging of Apollo 11 to 17 dust samples by electron impact, other than the limited measurements made by the investigators of this white paper, are currently available.

2. Measurements of Basic Charging Properties of Individual Apollo 11 & 17 Lunar Dust Grains

Preliminary measurements on charging of Apollo 11 & Apollo 17 lunar dust charging by photoelectric emissions simulating dust charging during lunar day, and by low energy electron impact representing the charging process during the lunar nighttime, carried out in the Dusty Plasma Laboratory at MSFC have indicated some surprising results at variance with the currently available experimental data, as well as theoretical models. Examples of some typical experimental results are shown in the following

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2.1 *Charging by Photoelectric Emissions*

The measurement technique employed here is based on an experimental setup employing an electrodynamic balance (EDB) that permits levitation of submicron/micron size individual dust grains in simulated space environments (e.g., Davis, 1985; Spann et al., 2001; Abbas et al., 2002). This technique has been used for measurements of charging of micron size dust grains by photoelectricemissions(Abbas et al., 2006), and by electron beams with energies in the keV range (e.g., Cermak, et al.,1995;Zilavy,et al.,1998). Measurements of photoelectric efficiencies have been carried out on sub- micron/micron dust grains selected from the sample returns of Apollo 17 at room temperature. The particles are exposed to a collimated UV radiation beam of width of ~ 3.5 to 4.5 mm at wavelengths of 120 nm, 140 nm, and 160 nm (photon energies of ~ 10.3 eV, 8.9 eV, and 7.8 eV). Photoelectric efficiency measurements were made on a number of negatively charged dust grains of effective radii in the 0.18 to 11.8 μm range, at UV wavelengths of 120 nm, 140 nm, and 160 nm. A composit plot of the photoelectric yields of all Apollo 17 particles vs. the size parameter $(2\pi a/\lambda)$, is shown in Fig. 1. The only available measurements on bulk lunar fines by Feuerbacher et al., (1972) at the three corresponding wavelengths are also shown for comparison. The measurements made on individual dust grains indicate a strong size dependence of the yields for size parameters less than ~ 100, corresponding to particle radii of ≤ 1 μm at wavelengths of 120-160 nm, decreasing by an order of magnitude for particles of smaller radii. For larger size particles, the yields approach constant asymptotic values, representing values corresponding to bulk materials. The asymptotic values for the three photon energies, however, are larger than the bulk measurements on lunar fines made by Feuerbacher et al. (1972) by factors of ~14 to 38 for the corresponding photon energies.

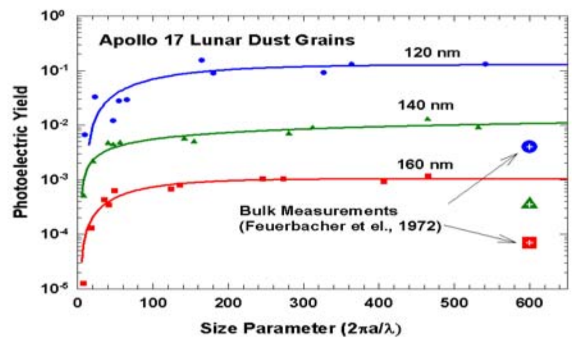
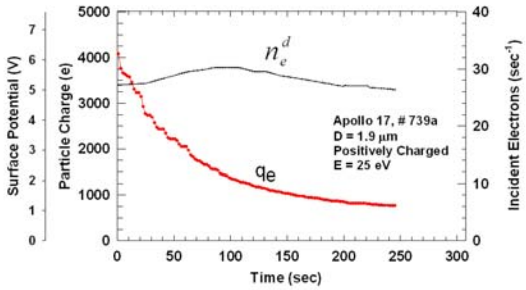


Fig. 1. A composit plot of the photoelectric yields of 10 Apollo 17 dust grains.

2.2 *Measurements of Charging by Electron Impact*

Some typical examples of charging of lunar dust grains by low energy electron impact are shown in Figs.2-3 (a, b). (1).Figure 2a represents the measurements of the charge *q(t)* (in units of elementary electron charge (e) on a positively charged 1.9 μm Apollo 17 dust grain exposed to a 25 eV electron beam discharging from charge of ~ 3800e to an equilibrium charge of ~900e, corresponding to particle surface potentials ϕ_S ~ 5.8 to 1.0 V, attained over a time period of ~ 250 sec with a corresponding number of incident electrons on the particles/sec (n_e^d). The calculated secondary electron emission (SEE) yield for the particle in Fig. 2a increasing from an initial value of zero to a maximum yield of ~ 1 at equilibrium is presented on Fig.2b



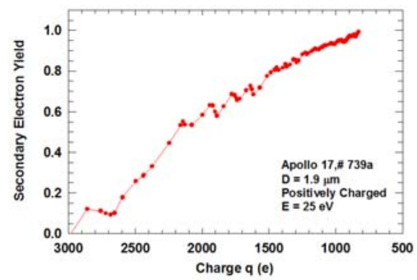
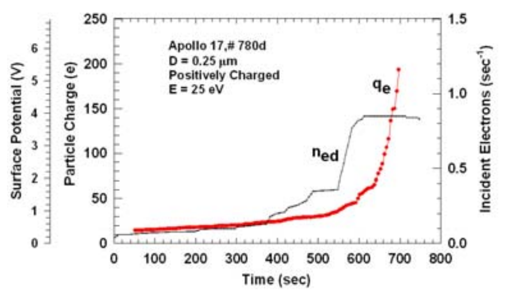


Fig. 2a Discharging of a 1.9μm Apollo 17 positively charged grain by 25eV electron beam.

Fig. 2b Calculated SEE yield for the particle in Fig. 2a



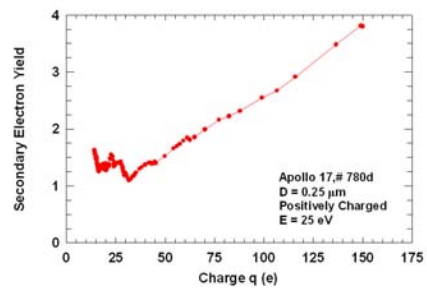


Fig.3a Charging of a 0.25μm Apollo 17 positively charged grain by 25eV electron beam.

Fig.3b Calculated SEE yield for the particle in Fig.3a

Figure 3a represents the charging process of a positively charged 0.25 μm particle to an equilibrium level by secondary electron emission process at the room temperature. In Fig.3b the corresponding SEE yield is given.

Measurements of charging of individual micron size Apollo 17 dust grains levitated in an electrodynamic balance were made by exposing them to electron beams of 25-100 eV. Both positively and negatively charged particles in the 0.3 to 8.8 μm size range were employed for measurements of the charging and discharging processes.

3. Important Conclusions from Laboratory Measurements on Individual Submicron Size Lunar Dust Grains

Following are the most significant conclusions for charging of lunar dust grains by photoelectric emission and by electron impact, that indicate the importance of more comprehensive measurements.

3.1 Charging by photoelectric emissions

(1) Photoelectric emission yields of particles larger than a micron or two in size are more than an order of magnitude higher than for the bulk materials.

(2) The photoelectric yields of submicron size particles are lower than for large size particles. This is in contrast with the existing models indicating higher values for smaller particles.

3.2 Charging by Electron Impact

- Large size positively charged particles discharge to some equilibrium potential when exposed to 25 -100 eV electrons.

- Submicron size positively charged particles at low surface potentials generally charge more positively when exposed to low energy electrons (< 25 eV), and discharge at higher energies (>100eV); the secondary electron emission (SEE) yields are higher for small particles compared with the large.

- Negatively charged particles exposed to 5-100 eV electron beams generally discharge to equilibrium potentials.

- Equilibrium charges of dust grains are a function of the size, electron energy, and density.

- The complex nature of the SEE process implies that both negative and positive dust grains may exist in the same lunar environment.

- The experimental data for charging properties of individual micron size lunar particles is in conflict with the available experimental data for bulk materials as well as with the current semi-empirical theoretical models.
- Comprehensive measurements for charging properties of individual dust grains to address the hazardous issues of dust on lunar robotic and human missions.

4. Recommended High Priority Research Objectives

In view of the conclusions based on preliminary laboratory measurements outlined above, we recommend the following measurements as a very high priority item for lunar exploration

1) Measurements of *photoelectric efficiencies* and yields as a function of grains size of individual dust grains from samples of Apollo 11 to 17 missions obtained under an agreement from NASA- Johnson Space Center, at temperatures representing the lunar day-night thermal cycle (~ 80 – 400 K).

2) Measurements of the charging properties of lunar dust grains charged by electron impact, on individual dust grains selected from sample returns of Apollo 11 to 17 missions *at temperatures representing the lunar thermal cycle (~ 80 – 400 K) during the lunar day and night times*. These measurements need to be carried out at electron energy levels of the solar wind plasma**.**

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