STUDY OF THE EFFECTS OF THE ELECTRIC FIELD ON CHARGING MEASUREMENTS ON INDIVIDUAL MICRON-SIZE DUST GRAINS BY SECONDARY ELECTRON EMISSIONS.

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Introduction: The dust charging by electron impact is an important dust charging process in Astrophysical, Planetary, and the Lunar environments. Low energy electrons are reflected or stick to the grains charging the dust grains negatively. At sufficiently high energies electrons penetrate the grain leading to excitation and emission of electrons referred to as secondary electron emission (SEE). Available theoretical models for the calculation of SEE yield applicable for neutral, planar or bulk surfaces are generally based on Sternglass Equation (1954) [1]. However, viable models for charging of individual dust grains do not exist at the present time. Therefore, the SEE yields have to be obtained by some experimental methods at the present time.

We have conducted experimental studies on charging of individual micron size dust grains in simulated space environments using an electrodynamic balance (EDB) facility at NASA-MSFC [e.g. 2-5]. The results of our extensive laboratory study of charging of individual micron-size dust grains by low energy electron impact indicate that the SEE by electron impact is a very complex process expected to be substantially different from the bulk materials [2]. It was found that the incident electrons may lead to positive or negative charging of dust grains depending upon the grain size, surface potential, electron energy, electron flux, grain composition, and configuration.

Considering the complex unexpected nature of the final results, a detailed study of the possible sources experimental errors and uncertainties was carried out and discussed in previous publications [e.g. 2]. However, despite the satisfactory explanations, some critical comments have been made in the literature [6] about some experimental sources of uncertainties in our measurements and the final results.

In this paper we give a more elaborate discussion about the possible effects of the AC field in the EDB on dust charging measurements by comparing the secondary electron emission time-period (τ_{em} (s/e)) with the time-period (τ_{ac} (ms)) of the AC field cycle in the EDB that we have briefly addressed in our previous publication [3]. The results and discussion presented here, along with discussion presented in Abbas et al [3], clearly indicate that our measurements on charging of individual submicron/micron size dust grains remain unaffected by the AC field applied to ring electrode of the EDB in the wide range of the V_{ac} amplitude and frequency employed in the measurements.

Experimental Setup: The measurements were conducted using an experimental facility based on the EDB. The experimental set-up consists of: particle injector, EDB (with the top and bottom DC electrode and the AC ring electrode), DC and AC power supplies, vacuum system, electron gun, and the monitoring equipment. The experimental setup is shown in Fig. 1.
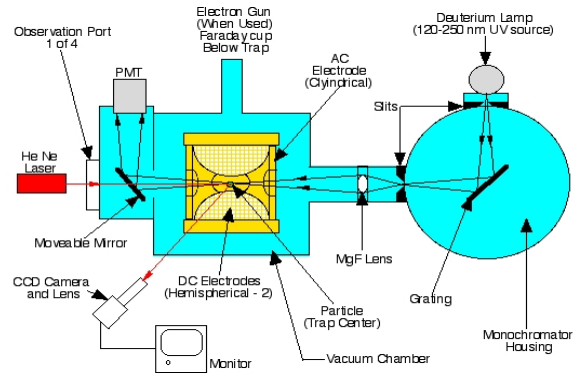

Fig.1. Experimental Setup

The particle generator employing a pressure impulse technique is used for charging the particles [e.g. 7]. The balance itself consists of spherically shaped DC top and bottom electrode and a ring AC electrode with apertures made to allow optical access to the trapped particle. The trap is placed in a vacuum chamber. A 5 mW-HeNe laser and a CCTV camera with a zoom microscope lens is used to observe the particle by projecting the scattered light onto a TV monitor.

Experimental technique for measurements on charging by the electron impact: The particles are injected into the balance at atmospheric pressure. Once the particle is stably trapped and the particle injector is removed, the electron gun (Kimball Physics ELG-5/EGPS-5A) is placed on the top of the chamber. The system is then evacuated to pressures of ~ 1-5 torr at which the effective diameter is determined by measurements based on marginal stability conditions ("spring point" measurements) [e.g. 8]. The particle diameter has to be determined separately because the direct measurements on the EDB provide the charge to mass ratio only. This technique is based on slowly varying the electrical parameters of the EDB to a point near an unstable regime when the particle begins to oscillate. The system is then evacuated to pressures of ~ 10^{-5} torr, and the suspended lunar dust grain is exposed to 25 eV electron beam. A Faraday cup located

below the bottom electrode of the trap is used to measure the incident electron current. As the particle charge changes, the particle is manually balanced against gravity by adjusting V_{DC}. The change in particle charge is then determined as a function of time in accordance with equation:

$$q(t) = \frac{g z_o m}{C_o} \frac{1}{V_{DC}(t)} \qquad (1).$$

With the value of V_{DC} needed to balance the gravity, the mass m that is calculated using the effective particle diameter determined by the "spring point" technique, and ρ particle mass density, the particle charge $q(t)$ is calculated from equation (1) as a function of time. With this measurement technique one electron change in particle charge can be detected in certain regimes.

Results and Discussion: In this paper we have reviewed the secondary electron emission time from the above described measurements that have been conducted on a number lunar 0.2-0.3 μm size Apollo 11 & 17 dust grains and 0.2 μm SiO₂ spherical particles with the amplitude of the V_{ac} voltage applied to the ring electrode of the EDB varying V_{ac} from ~ 260 V to 780 V and the corresponding frequency f_{ac} from 300 Hz to 1200 Hz.

Fig.2 shows charging of a positively charged (a) 0.29um size Apollo 11 dust grain and (b) 0.2um SiO2 particle when exposed to a 25 eV electron beam.
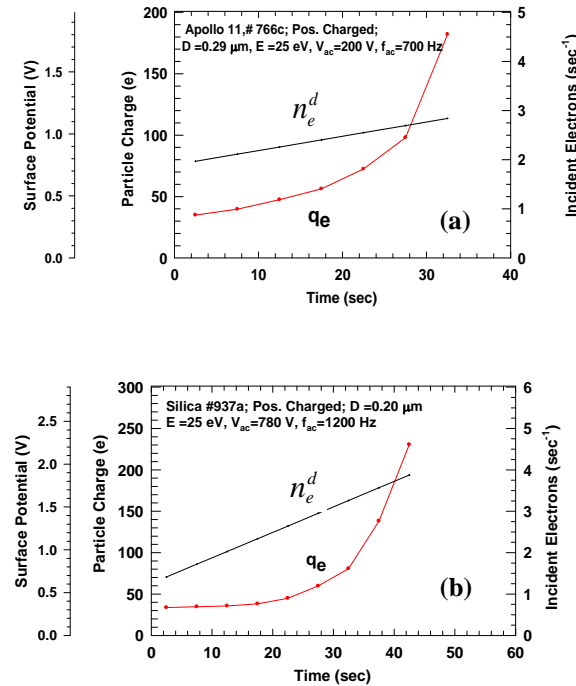

Fig.2 Charging of a positively charged (a) 0.29μm size Apollo 11 dust grain with V_{ac}=200 V and f_{ac}=700 Hz and (b) 0.2μm SiO₂ particle when exposed to a 25 eV electron beam with V_{ac}=780 V and f_{ac}=1200 Hz

Particle	D(μm)	f [Hz]	δ_{em} (e/s)	τ_{em} (s/e)	τ_{ac} (ms)	N_{cyc}/e
AP11	0.29	700	2.6	0.38	1.43	266
AP11	0.30	750	4.0	0.25	1.33	188
AP17	0.26	300	2.6	0.39	3.33	117
SiO₂	0.20	650	5.0	0.20	1.50	133
SiO₂	0.20	1050	2.9	0.35	0.95	368
SiO₂	0.20	1200	3.4	0.30	0.83	361

Table.1 The table shows charging rates (δ_{em}), SEE times (τ_{em}), time period of the cycle of the AC field in the EDB (τ_{ac}) and the number ac-cylces required for one electron emission (N_{cyc}) for 0.2-0.3 Apollo 11 dust grains and three 0.2 um size SiO₂ spherical particles.

From the plots presented in Fig.2 for 0.29μm size Apollo 11 dust grain and 0.2μm SiO₂ particle as well as the similar plots for the other particles considered here, we determine the time interval for charging of the particles to estimate the average charging rates (δ_{em}). The experimentally obtained secondary electron emission times (τ_{em}) are compared with time period of the cycle of the AC field in the EDB (τ_{ac}) and the results have been presented in Table 1.

For the typical cases of particles presented here, the rates of charging by SEE are estimated to be ~ 2.6 to 5.0 electrons/s with the corresponding electron emission times ~200 to 380 ms and the number of AC-cycles (V_{ac} = 260-780 V, f_{ac} = 300-1200 Hz) required for one electron emission to be as large as 117 to 368 cycles.

Conclusions: The experimental data considered here indicate that the SEE process from dust grains, requires relatively long electron emission time, and for measurements in the EDB that requires a large number of AC cycles even for one electron emission. Calculations based on the charging rates obtained from our experiments clearly show that the charging process by SEE in the EDB, with the amplitudes and at the frequencies of the AC field employed in the measurements, requires an averaging process over many time-periods of the AC cycle. Therefore, the measurements of the charging properties represent the average values corresponding to the beam energy, unaffected by the AC field.

References: [1] Sternglass, E. J. (1954) *Sci/Pap* 1772, Westinghouse Lab., Pittsburgh, PA. [2] Abbas, M. M. et al (2010) *ApJ 718*, 795–809. [3] Abbas, M. M. et al (2012) *ApJ,* 756,14pp. [4] Abbas, M. M. et al. (2006) *ApJ 645* 324-336. [5] Abbas, M. M. et al. (2007) *Planet. Space Sci.*, 55, 953. [6] Nemecek, Z. et al (2011) *ApJ* 738, 14. [7] Spann J. F. et al. (2001) *Phys. Scr*. T89, 147. [8] Davis, E.J. (1985) *Langmuir, 1*, 379-387.