PRE-CONTACT MICRODISCHARGE FROM CHARGED PARTICULATES

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ABSTRACT/RESUME.

The effect of the potential and charge on particles approaching a conducting surface in space is examined for close proximity immediately prior to contact. Induced fields, which may lead to currents prior to contact, have been calculated and shown to exceed electrical stress limits of common materials. Relationships for the capacitance and field in this region have been established and simulated in Simion software for a smooth and a roughened surface. In the laboratory, electrostatically charged spheres have also been dropped on to a detector surface in vacuo to quantify the induced charge on approach to a space-borne dust detector of the Ulysses class and to investigate pre-contact discharge. This has been demonstrated and the effect measured; both ions and electrons from the pre-contact discharge have been measured at velocities lower than thresholds for ion liberation by shock desorbtion or cratering. For satellite approach, and contact, the mechanism could lead to frequent micro-discharge initiation from ambient space debris associated with the same satellite or e.g. in the Space Station environment. Locally generated debris such as paint flakes [1] would be encountered at well below the threshold velocity of impact damage from the general space debris population or from meteoroids. Relationships for the field and capacitance for approaching particles are presented.

1. INTRODUCTION.

The charging of micro-particulates and of satellites in space is a universal phenomenon; sharing a common environment, the two classes of “particle” differ only by scale – microns or metres typically. Even in the same environment, differing electrical behaviour may result from the nature of the differing surfaces and hence the approach and contact of microparticles will, in general lead to a charge exchange. Indeed, even if the potentials are the same at large separation distances, their approach will lead to unequal potentials by virtue of the surrounding space charge distributions (Debye shielding [2]) and the change in capacitance of and between the two bodies. In general a charge exchange will be inevitable and we therefore examine some consequences of this. This charge exchange may lead to a discharge in the near vacuum of space, by electron or field emission; in a conductor, this will be preceded by the formation of induced charges which redistribute themselves as the approach distance decreases; if the field strength is exceeded, particulate or satellite target material can be vaporised or ionised (the auto emission effect proposed by Sysoev et al. [3]. This leads to opportunity for detection, by analysis of the ions, but at higher velocities this is followed closely by the liberation of matter in various states by the cratering process [4]. Relationships between the different mechanisms of charge liberation at differing velocities, which is of interest to detectors in space [4], are examined in the simulations. Autoemission may especially affect the calibration of these detectors where the microparticles are highly charged by the acceleration process. Results of low velocity tests are applicable to satellite impacts where such discharges and impact plasma generation may trigger the discharge of pre-existing charge distributions or high current sources on power buses.

2. PARTICULATE POTENTIALS IN SPACE.

The existence of a potential on a body in a radiation environment and one of active charge distributions is inevitable. For satellites, the potential is usually not of high consequence and, indeed, takes care to be measured. Because of the isolation, discharge of the overall charge cannot take place and surface field effects are small even for the high potentials found in Geostationary space. These may reach some minus 20 kV in the plasma sheet for microparticles, as in studies recently reported by Graps [5]; in more diffuse interplanetary space this relaxes to some few volts positive in sunlight. The high potentials in the Geo-environment, however, can lead to forces sufficient to disaggregate and fragment typical meteoroids. This was proposed following earlier detection of swarms of meteoroids in near-Earth space [6] on the HEOS II micrometeoroid detector in a high eccentricity Earth orbit; if the disaggregated particles are recharged to the same potential this will lead to a cascade down to very small sizes until a higher binding strength for the sub-units is reached [7].

Although, for satellites, the net charge does not affect the orbital motion we find for small particles that the interaction with the geomagnetic field competes with gravity and other forces. The time constant associated with establishing equilibrium potential is inversely proportional the particle diameter and hence whereas a satellite stabilises in a matter of seconds, for a micron particle this may typically approach an entire orbit in GEO space. Orbital studies are reported for space debris particulates in this environment [7] and in same contract the effect of internal charging and bootstrap charging is examined. Here, we restrict ourselves to take a first look at the likely consequences of the induced charge and current for a particle approaching a conducting satellite surface. The charge on the particle remains constant during approach, but is accompanied by a change of capacitance of the particle varying from the free space self capacitance ($4\pi\varepsilon_0$ times the particle radius $r(m)$) to that of a mutual capacitance between the particle and its induced image charge.

3. PRE-CONTACT CHARGE RELATIONSHIPS.

In the schematic of Fig. 1, the situation for a charged particle approaching a conducting surface, because the original charge on the particle is retained as the distance decreases the surface potential falls below the free space value due to the increasing capacitance between the particle and its image but the field between the particle and plate increases to high values. The potential therefore can be found, and the maximum field at close distances if we know this capacitance relationship. Although unable to find a ready relationship for all distances one of the authors [8] used the method of images to solve the potential at arbitrary distances and calculate the capacitance. The result, shown in Fig. 2, shows this value which varies from the self-capacitance at large separations ($4\pi\varepsilon_0 r$) to an increasing value at close separations. But the form of the increase at close distances increases only logarithmically with s and, because of this slow increase, the field between the particle and plate will always increase to a high value prior to contact. The maximum field at close distances is calculated as the sphere surface potential divided by the separation distance. At close distances a fit through the capacitance-separation distance yielded an equation which fitted (to within 1 percent error) a relationship as shown in Eq. 1.

$$\frac{C}{C_0} = \ln\left(\frac{r}{s}\right)^{1/2} + 1 \tag{1}$$

The surface potential V, compared to the free space potential V_0 is similarly given by Eq. 2.

$$V = \frac{V_0}{\left(\ln\left(\frac{r}{s}\right)^{1/2} + 1\right)} \tag{2}$$

$$\text{where } V = \frac{V_0}{r} \text{ at } s \to \infty$$

The approximate relationship in Eq. 2, which we hope to extend to a full functional relationship, permits an equation for the maximum field to be found, namely Eq. 3.

$$E = \frac{V_0}{s\left(\ln\left(\frac{r}{s}\right)^{1/2} + 1\right)} = \frac{V_0}{r}\cdot\frac{r}{s}\frac{1}{\left(\ln\left(\frac{r}{s}\right)^{1/2} + 1\right)} \tag{3}$$

At arbitrary distances (as shown in Fig. 2) we have calculated, by the method of images the capacitance for a 100 micron sphere as a function of its separation s from a plate; results are tabulated in Table 1 and reinforce the weak dependence on separation distance from the plate at close distances. Even at separation 10^{-5} of the 100 micron radius particle, namely 10^{-9} m, the capacitance has increased to only 6.6 times the free space value. Clearly we are talking here of separations approaching atomic scale, and real factors such as surface roughness enter to modulate the ideal results calculated. The field will nevertheless reach very high values and immediately prior to contact would be 10^9 V m^{-1} even for a particle charged initially to only 5 V. The opportunity – or perhaps the inevitability – of pre-contact discharge by autoemission is clearly illustrated by this example.

Table 1. Capacitances between a sphere and plate for separation *s* relative to sphere radius *r*. A maximum of some 7 times the free space value is reached even for separations as close as atomic dimensions. Surface roughness will affect these results and has been studied in simulations.

***s* (m)**	***s/r***	***C/C*$_0$**	**E_{max} V m^{-1} (V_0=5 V)**	**E_{max} V m^{-1} (V_0=1000 V)**
10^{-9}	1×10^{-5}	6.658	3.00×10^{9}	6.01×10^{11}
10^{-8}	1×10^{-4}	5.292	3.78×10^{8}	7.56×10^{10}
10^{-7}	1×10^{-3}	4.379	4.57×10^{7}	9.13×10^{9}
10^{-6}	1×10^{-2}	3.238	6.18×10^{6}	1.24×10^{9}
10^{-5}	1×10^{-1}	2.156	9.28×10^{5}	1.86×10^{8}
10^{-4}	1	1.341	1.49×10^{5}	2.98×10^{7}
10^{-3}	10	1.048	1.91×10^{4}	3.82×10^{6}
10^{-2}	100	11.555	1.99×10^{3}	3.98×10^{5}
10^{-1}	1000	1.000	2.00×10^{2}	4.00×10^{4}

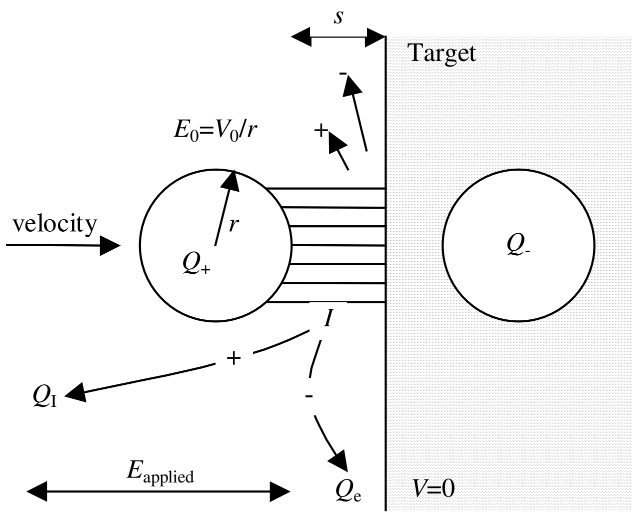

Fig. 1. Schematic of a charged particle approaching a conducting surface. The original charge on the particle is retained as the distance decreases but the charge redistributes itself, together with image charge redistribution on the target surface. The potential falls below the free space value due to the increasing capacitance between the particle and its image but the field between the particle and plate increases to high values. The autoemission curent is illustrated as *I*; the maximum field is $E_{max}=V/s$. A pre-contact discharge may be initiated by electron emission leading to local heating and vaporisation of the target or particle. The relationship for capacitance at close distances is charted in Fig. 2.

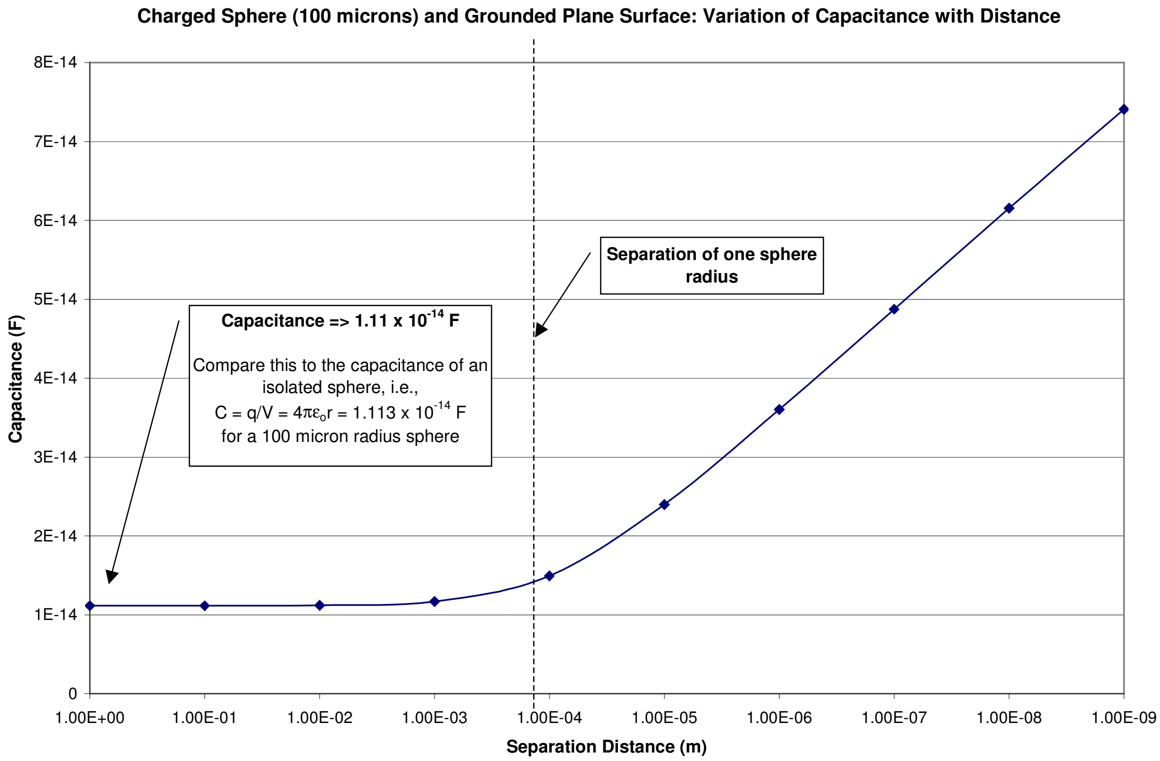

Fig. 2. Capacitance between a spherical particle of radius r and smooth plate, shown as a function of the logarithmic separation distance, *s*. This varies from the self-capacitance at large separations ($4\pi\varepsilon_0 r$) to an increasing value at close separations. The form of the increase at close distances is logarithmic with s and because of this slow increase the field between the particle and plate will always increase to a high value prior to contact. Values are shown in Table 1.

4. LABORATORY MEASUREMENTS WITH CHARGED MICROSPHERES.

Spheres of 1 mm were dropped in gravity from a height of some 0.5 m, first in air and then in vacuum. The spheres brushed against a small needle held at potentials up to 5 kV at release. The charge on the particles was measured by allowing them to pass through a Faraday cylinder; from the pulse, the velocity and the arrival time on the target was computed to associate induced effects with the position of the particles. Various potentials were used but the results here refer to 5 kV charging potential. A matrix of varying conditions was explored to examine the cause and effect of the signals measured on the target and the ion collector of the Ulysses type dust detector. The target comprised a hemispheroid of diameter 0.5 m at ground potential and was biased with minus 350 V on a charge collector near the radius of curvature. Collection of most of the ions liberated at the target is achieved and electrons (of approximately the same value because of overall charge neutrality) are detected at the target before the ion signal. Measurements are achieved using a high impedance charge amplifiers. Results, shown in Tables 2 and 3 demonstrate the autoemission effect at low velocities.

Table 2. Charge values measured during the drop of 1 mm radius spheres, electrostatically charged by a 5 kV contact, on to a Ulysses type detector at a velocity of approximately 2 m s^{-1}

Signal	**Average charge (Coulombs)**
Particle electrostatic charge (from 5 kV)	3.58×10^{-10}
Impact detector	3.51×10^{-10}
Charges measured on Ion collector:	
Ion collector plasma	1.27×10^{-13}
Ion collector induced charge	1.10×10^{-14}

5. SIMULATION.

Using SIMION simulations were made to map fields and potentials for the situation of charged spheres at varying distances from a conducting plate. The surface charge corresponding to the induced image was mapped and integrated to check overall charge conservation. The geometrical configuration of the Ulysses detector was also entered into a suite and the induced charge on the target established at differing distances form the target and for differing distances from the central axis of the detector. Results showed, with due consideration of the amplifier characteristics of the flight detector, that pre-induction could trigger the charge measurement and also influence the velocity measurements made in Geostationary space aboard the Express II satellite with the Ulysses type GORID detector [9]. Full results of the simulations are reported [7, 8] and also the effect of internal charging and bootstrap charging.

Table 3. Parameters tested for autoemission in charged particle drops; induced signals are caused only by particle charges and ionisation signals only if the particles are charges and an applied field extracts the charge by separation of the ions and electrons.

Condition	**Pre-sensing charge sensor**	**Ulysses impact detector target**	**Ulysses Ion collector**
Needle voltage 0 kV ..	No	No	No
.. Ion voltage 0 kV	No	No	No
Needle voltage 5 kV ..	Yes	Yes	Induced Signal
.. Ion voltage 0 kV	Yes	Yes	No ionisation signal
Needle voltage 5 kV ..	Yes	Yes	Induced signal
.. Ion voltage 350 V	Yes	Yes	Intermittent (small) ionisation signal

6. CONCLUSIONS

By analysis, by simulation and by laboratory measurements we have quantified the effect of induced charge for charged spherical microparticles approaching a conducting surface. We find electrostatic pre-induction can influence detection in space borne detectors; this is unlikely to be of significance in interplanetary space but could be important in near Earth and Geosationary space and, particularly, in the locally generated space debris environment associated with every satellite.

Bootstrap charging has been found to be insignificant because it is readily discharged by particle rotation. Internal charging has been characterised but, in terms of the net behaviour of particulates and impact processes, it has no significant consequences because it readily attracts surface charge to negate its effect.

Because of the slowly increasing capacitance between the particle and the approaching surface, the electric field in the gap increases to very high values even for low potentials on the particles.

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7. REFERENCES

1. Mandeville J.C. and Rival M., Enhanced Debris/Micrometeoroid Environment Models and 3-D Tools - Technical Note TN2 : Review and Selection of a Model for Ejecta Characterization, Partial Report 452200/01, ONERA-CERT Toulouse, 1996

2. Krall, N. A. and Trivelpiece, A. W., *Principles of Plasma Physics*. Tokyo: McGraw-Hill Kogausha, Ltd. ISBN 0 07 035346 8. pp. 3-4, 1973

3. Sysoev, A. A., Ivanov, V. P., Barinova (Komova), T. V., Surkov, Yu. A. and Vysochkin, V. V., 'Mass Spectra Formation from Charged Microparticles'. *Nucl. Instr. and Meth. in Phys. Res. B.,* **122**, 79–83, 1997

4. J A M McDonnell, Cosmic Dust, Chapter 6. J Wiley and Sons, 1978

5. Graps, A., Technical Note 2 – Evaluation of GORID data, *Update of Statistical Meteoroid / Debris Models for GEO*, ESA Contract 13145/98/NL/WK, 2000

6. Hoffman, H. –J, Fechtig, H., Grün, E. and Kissel, J.,. 'First Results of the Micrometeoroid Experiment S215 on the HEOS 2 Satellite'. *Planet. Space. Sci.,* **23**, 215-224, 1975

7. UniSpace Kent, Meteoroid and Debris Flux and Ejecta Models, Final Report, ESA Contract No.11887/96/NL/JG, 1999

8. Agutti, E.D., Charged Particulates in GEO: The Role of Electrostatic Charge in Particulate Impacts on the GORID Dust Detector, Master's Dissertation, University of Kent at Canterbury, 1999

9. Drolshagen, G., Svedhem, H., Grün, E., Grafodatsky, O., Prokopiev, U., Microparticles in the Geostationary Orbit (Gorid experiment), Adv. Space Res., Vol. 23, No. 1, pp. 123-133, 1999.