# THE ELECTROSTATIC POTENTIAL OF INTERPLANETARY GRAINS

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Abstract. A new method is presented for calculating the electrostatic potential of cosmic grains taking into account the plasma sheath and its bulk velocity. Results for various solar wind situations are given.

## I. INTRODUCTION

The electrostatic potential of interplanetary grains is an important parameter since it determines the magnitudes of corpuscular drag exerted by the solar wind and of the Laplace force exerted by the interplanetary magnetic field. These forces dominate the effects associated with gravitational attraction and solar radiation pressure (e.g. Poynting-Robertson effect) for the very small grains ($\lesssim 0.1$ micron). The lifetime as determined by the sputtering by solar wind ions will also depend upon the grain's potential.

## II. PREVIOUS METHODS

The problem of the floating potential of a body immersed in a plasma is a classical one which has been mainly addressed in two fields separately:

1. Cosmic grains: Spitzer (1941) considered the interaction between a spherical grain and a plasma as a simple problem of particle collection in a Coulomb potential; he neglected all surface effects. Other authors improved Spitzer's model according to their particular assumptions. For instance Feuerbacher et al. (1973) introduced a model of symmetric photoelectric emission and de Bibhas (1974) developed an approximate theory similar to those of Mott-Smith and Langmuir (1926) and Medicus (1962) for spherical probe theory. All these theories rest on the assumption that the grain is at rest in the surrounding plasma. A drift velocity has also been introduced as a perturbation of the above mentioned models by some authors.



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2. Plasma probe and spacecraft charging theory: there are many papers concerned with the behaviour of bodies in collisionless plasmas with no reference to grain problems. The first partial theory of particle collection by probes was given by Mott-Smith and Langmuir (1926) for spherical and cylindrical bodies absorbing (or neutralizing) the charged particles which strike them (no other surface effect was taken into account).

Recently the development of spacecraft technology required the investigation of the value of the floating potential of bodies in space plasmas.

The main difficulty introduced by surface effects is that the distribution function of the emitted (or reflected) particles depends upon the sheath structure and the potential of the body which depend upon the particles: this increases the circularity and the non-linearity of the equations describing the system. Some possible effects are mentioned in Fig. 1.

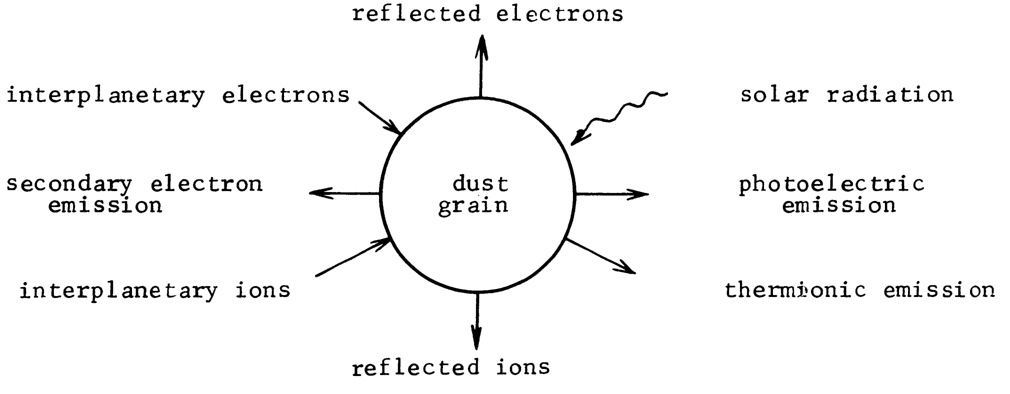


Fig. 1: Processes which may be important in determining the electrostatic potential of an interplanetary grain.

Mott-Smith's and Langmuir's theory was progressively improved for plasmas at rest by many authors as reviewed in Lafon's (1976) thesis, among them Bernstein and Rabinowitz (1959) and Laframboise (1966). Finally, the problem was completely solved by Lafon (1975,1977), who gave an unified theory based on a systematic method of classification of orbits, taking any surface effect (emission or reflection of particles at the surface of the body) into account and reducing numerical computations to the minimum.

## III. NEW METHOD

The problem of building a completely self-consistent model for a spherical body, for any surface effects and plasma compositions, with

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no approximation concerning the sheath was solved by Lafon, Lamy and Millet (1979). The effects due to the finite distance of the body from radiating stars are included. It is shown that the determination of the collected currents in the "Orbital Motion Limited" regime (Lafon 1975) is exact for a grain at rest in the surrounding plasma and quite accurate in the presence of drift velocities or of a disymmetry in the emission (or reemission) of particles by the body. The floating potential is shown to be unique in any case and its value is found whatever the preferential directions which can be different for particles of various species. Finally, the limits of validity of the model are discussed.

Now, introducing a bulk velocity of the plasma as a whole with respect to the body leads to the loss of spherical (or cylindrical) symmetry. This completely changes the nature of the problem and, strictly speaking, none of the above mentioned theories holds. The strongly inhomogeneous zone (sheath) surrounding the body and governing the particle collection has a very complicated structure and an exact theory would require too many (and too expensive) numerical computations. More or less crude approximations are now necessary. Of course a similar perturbation occurs when the body emits photoelectrons as a result of asymmetric radiation.

We can, however, get rid of this drawback in the case of dust grains because the size of the collecting body is always much smaller than the Debye length of the main components of the ambient plasma: this enlarges the range of potential for which "Orbital Motion Limited" (Lafon 1975) calculations can be performed.

## IV. RESULTS FOR INTERPLANETARY GRAINS

In the solar system, the multiple effects determining the charge of the grain are summarized in Figure 1. However, the most important ones - and ones which were considered in this study - are photoelectric emission and sticking of solar wind electrons and ions (except at small heliocentric distances where thermionic emission should play an important role). Under similar assumptions, Belton (1966), Wyatt (1969) and Rhee (1967) arrived at values between 5 and 10 volts at 1 AU.

The main problem, as already pointed out by Belton (1966), is the lack of pertinent experimental data for the processes mentioned above. In this study, we benefited from the works of Feuerbacher et al. (1972, 1973) and Grard (1973) for the distribution functions of the photoelectrons emitted by various materials. Accordingly, we retained two of them representative of low (graphite) and high ($Al_2O_3$) photoelectric yields as typical examples (Table 1). We do not imply at all that these materials are present in the solar system, but we simply wish to obtain results in two extreme cases. Experimental data on more realistic materials (iron, olivine) will be obtained soon by a group at Rennes University (Robin and collaborators).

Table 1: Photoelectric temperatures and densities at 1 AU. from the Sun

| | density | temperature | | density | temperature |
|---|---|---|---|---|---|
| $Al_2O$ : | $1670\times10^6$ $m^{-3}$ | $1.03\times10^4$ °K | C: | $150\times10^6$ $m^{-3}$ | $1.14\times10^4$ °K |

We considered spherical grains and took into account their non-homogeneous illumination by the Sun. The possible effect of grain size upon the photoelectric yield (Watson, 1972,1973) was left out and all sticking probabilities are assumed equal to 1. All distribution functions have been adjusted to mixtures of Maxwellian functions, with drift velocity of the grain with respect to the ambient plasma. Our results are given in terms of the electrostatic potential of the grain which has the advantage of being independent of its radius and physically more meaningful.

It is now well established that the solar wind has distinct components, a quiet solar wind component (QSW), high speed streams (HSS), interfaces and non compressive density enhancements (NCDE) whose relative importance depends upon the solar wind activity. As representative examples, we have retained both QSW and HSS in the present study. Details of their characteristics may be found in Lafon et al. (1979) and are summarized in Table 2.

Table 2: Parameters for two representative components of the solar wind: quiet solar wind (QSW) and high speed streams (HSS)

| | | $H^+$ | $He^{++}$ | $\bar{e}$ core | $\bar{e}$ halo |
|---|---|---|---|---|---|
| QSW | T(K) | $9.3\times10^4$ | $3.7\times10^5$ | $1.25\times10^5$ | $7\times10^5$ |
| V=410 km $sec^{-1}$ | $n(cm^{-3})$ | 8.5 | 0.425 | 8.74 | 0.61 |
| HSS | T(K) | $2.3\times10^5$ | $1.3\times10^6$ | $8.5\times10^4$ | $7\times10^5$ |
| V=740 km $sec^{-1}$ | $n(cm^{-3})$ | 4.5 | 0.2 | 4.78 | 0.125 |

Our results are presented in Table 3; they include the cases of zero bulk velocity to show the influence of this parameter. The influence of the bulk velocity is mainly important through the positive ions. Consequently it is rather limited in case of high photoelectric yield when the (positive) potential of interplanetary grains is essentially controlled by the photoelectrons and the plasma electrons which have a thermal energy greater than their bulk kinetic energy. On the contrary for carbon (low yield), the role of the solar wind does appear clearly as both the nature of the solar wind and its bulk velocity noticeably affect the potential.

Table 3: The electrostatic potential of interplanetary grains at 1 AU. from the Sun. Normal velocity is equal to 410 km $sec^{-1}$ for QSW and 740 km $sec^{-1}$ for HSS.

| material | $Al_2O_3$ | | C | |
|---|---|---|---|---|
| bulk velocity | 0 | normal | 0 | normal |
| QSW | 3.36 | 3.48 | 0.63 | 0.90 |
| HSS | 4.12 | 4.36 | 1.92 | 2.27 |

We started to investigate the variation of the electrostatic potential with heliocentric distance. We chose an "average" model for the photoelectric effect (corresponding to an average photoelectric yield) which is characterized by

$$n_{eg} = 8.3\times10^{8}\ m^{-3}\ , \quad T_{eg} = 1.14\times10^{4}\ °K \quad \text{at} \quad 1\ AU.$$

We further supposed that $T_{eg}$ depends only upon the solar spectrum (and not upon the distance) while the electronic photoelectric density $n_{eg}$ varies with the solar intensity, i.e., as $R^{-2}$. The results are presented in Table 4 using an average quiet solar wind whose characteristics were

Table 4: Electrostatic potential V (Volts) as function of heliocentric distance.

| R (R ⊙) | $N_{pp}=N_{ep}$ ($m^{-3}$) | $T_{ep}$ (°K) | $T_{pp}$ (°K) | V (Volts) |
|---|---|---|---|---|
| 5 | $1.5\times10^{10}$ | $1.0\times10^{6}$ | $7.6\times10^{5}$ | 2.016 |
| 10 | $3.7\times10^{9}$ | $8.5\times10^{5}$ | $5.0\times10^{5}$ | 2.326 |
| 20 | $9.2\times10^{8}$ | $6.9\times10^{5}$ | $3.3\times10^{5}$ | 2.326 |
| 50 | $1.4\times10^{8}$ | $5.4\times10^{5}$ | $1.6\times10^{5}$ | 2.636 |
| 100 | $3.0\times10^{7}$ | $4.4\times10^{5}$ | $7.9\times10^{4}$ | 2.946 |
| 215(=1 AU.) | $5.2\times10^{6}$ | $3.6\times10^{5}$ | $3.6\times10^{4}$ | 3.256 |
| 430(=2 AU.) | $1.3\times10^{6}$ | $2.9\times10^{5}$ | $1.7\times10^{4}$ | 3.256 |

compiled by Lamy (1975). The electrostatic potential increases slightly with increasing heliocentric distance and levels off at 1 AU. However, the values for $R \lesssim 20\ R⊙$ are of academic interest since thermionic emission will come into play and increase the potential.

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