GRAIN CHARGING IN A DUSTY PLASMA

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Dusty plasmas are found in planetary rings, cometary tails and the protoplanetary nebula. Dust grains immersed in a plasma become charged. This charge affects the motion of the grain in the electromagnetic field of a planetary magnetosphere and is involved in both the formation of the spokes in Saturn's rings and the erosion of those rings by micrometeorites. Additionally, the charge on the grain affects the coagulation rate of the dust into planetesimals in the protoplanetary nebula.

To find the equilibrium charge on a dust cloud immersed in a plasma, one must solve the charge and current conservation equations simultaneously for the dust cloud potential. The dusty plasma remains overall charge neutral with the requirement that the cloud length scale is much larger than λ_D, the plasma Debye length. The Debye length is the radius of a sphere outside which the electrons shield the potential of the ion they surround.

$$\lambda_D^{-2} = \frac{4\pi e^2}{kT_e}(n_e + Z_i^2 n_i)$$

The restriction given to the scale length of the cloud is $L > \lambda_D$. This scale length is related to the number density of the dust by $L = N_d^{-1/3}$; therefore the above requirement for a hydrogen plasma (Z_i=1), becomes

$$N_d < (\frac{8\pi e^2 n_o}{kT_e})^{\frac{3}{2}}.$$

As long as this inequality is true, charge conservation holds within the dusty plasma.

The above restriction that charge must be conserved can be expressed (1) in the form

$$Q_i + Q_e + Q_{dc} = Z_i e n_i - e n_e + U\int_{r_{min}}^{r_{max}} r \cdot dn(r_d) = 0$$

where the charges on a dust cloud with a size distribution have been included. The variable U represents the surface potential on the dust grains (cloud potential minus plasma potential) which should be constant for various size grains in a tenuous plasma.

The dust density distribution function is widely accepted to be a power law (1) and is given as

$$dn(r) = Cr^{-s}dr$$

where s is generally between 0.9 and 4.5 for planetary systems and approximately 3.5 for interstellar space. The constant C is defined by

$$N_d = C\int_{r_{min}}^{r_{max}} dn(r),$$

with N_d being the total dust density.

Defining the parameter P as in earlier papers (1)

$$P = 6.95\text{x}10^6 \; n_{eo}^{-1} T_{eV} C\int_{r_{min}}^{r_{max}} r^{1-s}dr,$$

allows the above equations to be recast into the form,

$$\exp(\frac{eV}{kT_e}) - Z_i \exp(-\frac{Z_i eV}{kT_i}) - P(\frac{eU}{kT_e}) = 0$$

The total current to the grain must also be zero for equilibrium, so we have the additional constraint

$$J_{tot} = J_i + J_e + J_{se} + J_t + J_{ph} = 0$$

where the sources are due to ion, electron, secondary electron emission, tunneling electron and photoelectric currents, respectively. In the present paper, only clouds well-shielded from photoelectric currents are considered, so J_{ph}=0.

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For a given temperature regime, the appropriate currents can be substituted into the equation above. The resulting system of nonlinear equations generated may then be solved using a modified Powell hybrid algorithm and a finite-difference approximation to the Jacobian for U and V and for a range of P and R values.

As a test of the method, we assume a 1 eV hydrogen plasma. The results for grain potential vs. P (with R values ranging from 0 to 0.9) are shown in Fig. 1 and agree well with an earlier paper (1). Figure 2 shows the equilibrium potentials of the plasma and dust cloud as a function of P for a 1 eV Maxwellian plasma, allowing N_d to vary from 10^{-3} to 10^3. The plasma density n_{eo} is 10^3, and the distribution of sizes remains constant at r_{min}=0.01 micron and r_{max}=1.00 micron. Again, this result agrees with previously published results (1). Since at low temperatures, the secondary electron and tunneling currents are negligible, the -2.5 eV grain potential is also compatible with results published by Goertz and Ip (2). Any deviation from Havnes' results can be attributed to the secondary electron current which, albeit small, is present.

References: (1) Havnes, O. T.K. Aanesen and F. Melandso, *JGR Vol. 95, No. A5*, pp. 6581-6585, 1990.
(2) Goertz, C.K. and W-H Ip, *Geophys. Res. Lett. 11*, pp. 349, 1984.

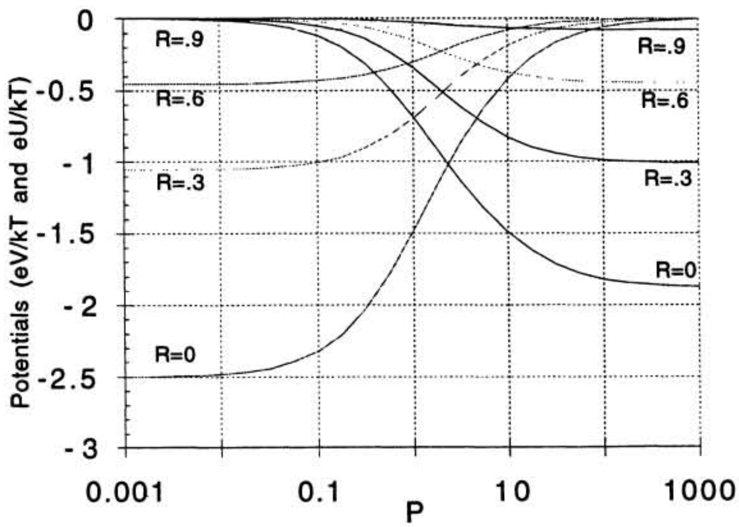

Figure 1

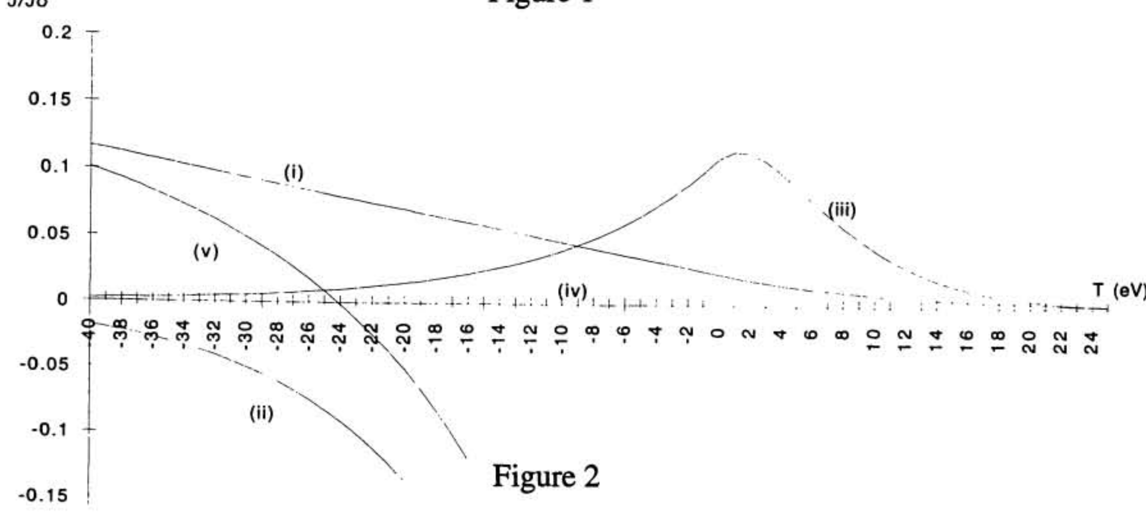

Figure 2

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