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SHORT COMMUNICATION

Static Electrification of Dust Particles in a Hot Tenuous Plasma

K. TENNAKONE
Department of Physics, University of Sri Lanka, Vidyodaya Campus, Nugegoda, Sri Lanka.

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In this paper we show that dust particles in a hot tenuous plasma of electrons and positive ions can acquire positive or negative static charges. Experimental evidence to support the theory is given. Possible astrophysical implications of the process are discussed.

We assume that dust particles (by dust particles we mean fine grains of solid matter having dimensions much greater than that of an atom or a molecule) are in thermal equilibrium with a tenuous nonrelativistic plasma at temperature T. Heated solid dust particles in the plasma will emit thermionic electrons. The number of thermionic electrons N_1 emitted per sec per unit area is given by Richardson's equation[3]

$$N_1 = Ae^{-\varphi e/kT}. \qquad (1)$$

where k = Boltzmann constant and e = electronic charge. When quantum mechanical tunneling from the surface is neglected, the constant A in the equation (1) takes the value,[3]

$$A = 4\pi mk^2T^2/h^3. \qquad (2)$$

where m is the mass of the electron and h is Planck's constant. The work function φ is few electron volts for most solid materials.[3] As positive charge accumulates on the surface of the grain, (due to electron loss) N_1 diminishes, because electrons will have to do more work to overcome the attraction due to positive charge on the particle. We assume that a dust particle is a sphere of radius r. Then the additional energy needed to remove an electron from its surface when the particle is charged is 4π sre, where s is the surface charge density measured in electronic charges on the particle. Thus the effective work function is changed to ($\varphi + 4\pi$ rse) and the equation (1) becomes,

$$N_1 = As^{1\,-(\varphi e\,+\,4\pi rse)/kT}. \qquad (3)$$

At equilibrium, the rate at which the charge is lost from the dust grains due to thermionic emission must be equal to the rate at which the negative charge is deposited on the grain as a result of impact of electrons and ions in the plasma. If n = number density of electrons in the plasma = number density of positive ions, U_- = velocity of the electrons and U_+ = velocity of positive ions. The negative charge incident on the surface of the grain per sec per unit area is

$$N_2 = n/^3 (U_- - U_+) \tag{4}$$

At equilibrium $N^1 = N_2$. Thus equating expressions (3) and (4) we get

$$s = (v - \varphi)/4\pi r, \tag{5}$$

where

$$v = (kT/e) \text{ in } 3A/n (U_- - U_+). \tag{6}$$

From (5) and (6) it is seen that s is positive or negative according to as $\varphi < v$ or $\varphi > v$. However, for negative s equation (3) correctly describe electron emission only if

$$\varphi > 4\pi r/s. \tag{7}$$

When the condition (7) is not satisfied, the electron emission from a surface is not thermionic emission, but field ion emission,[1] which is governed by an expression different from (3). It follows equation (5) that for $s < O$, s satisfies the condition (7) provided $3A > n (U_- - U_+)$. Therefore the dust grains in the plasma can acquire either positive or negative charges depending on whether $(\varphi - v\nu)$ is positive or negative. But if $3A < n (U_- - U_+)$ the condition (7) cannot be satisfied and (5) does not give the surface charge correctly.

To make numerical estimates we consider a plasma of slightly ionized hydrogen. From the Saha ionization equation, the number of electrons per unit volume in the plasma is given by

$$n = (2\pi mkT)^{3/4} (2n_o) 1/2_h - 3/2_e - I/kT, \tag{8}$$

where n = number of unionized atoms per unit volume. The velocity of electrons in the plasma is,

$$U_- = (kT/m)^{1/2}, \tag{9}$$

and that of positive ions given by a similar expression is negligible. Hence from equations (2), (8) and (9) we obtain

$$v = (kT/e) \text{ in } [1.42 (mkT/h^2)^{3/4} n_o{}^{-1/2}] + 1/2e. \tag{10}$$

Unless the plasma is extremely dense the quantity inside the square bracket is positive and the condition $3A > n(U_- - U_+)$ holds. The Table 1 gives the values of v (volts) computed from the equation (10) for various temperatures and densities. Since the work function for most common solid materials is approximately 2 — 10 eV, it follows from the Table 1 and Equation (5), that at low temperatures and high densities dust grains in a plasma could have negative static charges. At high temperatures and low plasma densities the surface charge becomes strongly positive. At a temperature of 10^4, K the total charge on a dust grain of radius 10^{-6}cm in ionized hydrogen (ionization energy I=13.6eV) containg 10^8 atoms per cm^3 is approximately 10^{-6} e.s.u. (a positive charge approximately 10^4 times the electronic charge).

TABLE 1. Values of v computed from equation (10) for various temperatures and plasma densities.

T K	10^3			10^4			10^5		
$n_0 cm^{-3}$	1	10^8	10^{18}	1	10^8	10^{18}	1	10^8	10^{18}
v (V)	8.6	8.1	7.2	26.9	20.9	12.2	222.2	162.8	76.5

As the dust particles are very massive compared to the ions in the plasma, presence of charged dust grains in a plasma cannot be demonstrated by conductivity measurements of the plasma. However, it is possible to give one simple experimental fact as evidence for the effect we have predicted. It is well known that flames have the power to neutralize charges on surfaces. A charged glass rod passed over a flame gets discharged. This may be due to the presence of ions in the flame. But the interesting thing to note is that even if the rod is held at a distance more than one foot from a Bunsen flame the rod gets discharged. The mean free path of electrons and positive ions in air is very small.[4] It is not possible for the ions in the flame to travel a distance one foot from the flame. Nevertheless, charged dust grains from the flame can travel long distances and neutralization of the charged rod is due to these particles ejected from the flame.

The effect we have described should have important astrophysical implications. The central region of the galaxy is known to contain a tenuous plasma of hydrogen and helium heavily loaded with dust.[5] Static charges on such dust grains could assist condensation in presence of electric fields. The same process might enhance condensation of matter to form protostars and planets.

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