DUST IN COSMIC PLASMA ENVIRONMENTS*

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Abstract. Cosmic dust is invariably immersed in a plasma and a radiative environment. Consequently, it is charged to some electrostatic potential which depends on the properties of the environment as well as the nature of the dust. This charging affects the physical and dynamical properties of the dust. In this paper the basic aspects of this dust–plasma interaction in several cosmic environments – including planetary magnetospheres, the heliosphere and the interstellar medium – are discussed. The physical and dynamical consequences of the interaction, as well as the pertinent observational evidence, are reviewed. Finally, the importance of the surface charge during the condensation process in plasma environments is stressed.

1. Introduction

Cosmic dust, be it interplanetary or interstellar, is invariably immersed in a radiative as well as a plasma environment. Furthermore, the plasma environments that are encountered are generally permeated by magnetic fields. The dust and magnetized plasmas are thermodynamically coupled via exchange of charge, mass, momentum and energy. Such dusty plasmas, which are often referred to as colloidal plasmas, have been studied fairly extensively with reference to flames, solid propellant rocket exhausts, electrostatic precipitation and MHD power generation. For an excellent review of these subjects the reader is referred to the paper by Sodha and Guha (1971).

The interaction of the dust with magnetized cosmic plasmas results in interesting physical and dynamical effects which are apparently observed in planetary and satellite environments (Mendis and Axford, 1974; Mendis, 1978; Hill and Mendis, 1979a; Fechtig et al., 1978) and possibly also in cometary environments (Sekanina, 1976). Other interesting effects of dust–plasma interactions have been suggested with regard to the heliosphere (Parker, 1964; Biermann, 1967; Parthasarathy, 1978) and the interstellar medium (Feuerbacher et al., 1973; see also Spitzer, 1978).

Undoubtedly, this interaction must profoundly influence the nucleation of the grains, as noted recently by De (1979), as well as their subsequent agglomeration. The cosmogonic significance of these processes in planetesimal accretion models, such as that of Alfvén and Arrhenius (1976), is presently under investigation (Hill and Mendis, 1979b).

This paper is an attempt to review, in rather broad outline, the basic aspects of this dust interaction with various cosmic plasmas and to evaluate their significance.


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2. The Charging of Dust Grains

Central to the entire discussion is the electrical charging of dust grains in a given environment. If $Q$ is the electrical charge on a grain at a given time, then

$$\frac{dQ}{dt} = I,$$

where $I$, the total current to the grain surface, depends on the grain charge, the grain surface characteristics (both physical and geometrical) and the environmental conditions (both plasma and radiation). Contributions to (1) may come from (a) thermal and nonthermal electron fluxes, (b) thermal and nonthermal ion fluxes, (c) photoemission, (d) field emission, (e) thermionic emission, (f) secondary emission of electrons due to energetic electron and ion impact, (g) radioactivity and (h) release of electrons during interparticle collisions.

The relative importance of these various currents will, of course, depend on the particular environment in question and the nature of the dust grains.

If we consider the terrestrial environment, it may be shown that (a), (b) and (c) make the only important contributions in the magnetosphere and the upper ionosphere, while (e) may be important for meteoritic dust entering the lower ionosphere (Whipple, 1965). The terrestrial magnetosphere contains both a thermal ($kT \approx 1$ eV) plasma, as well as nonthermal plasmas, with $kT \approx 1$–10 keV for the intermediate energy ‘auroral’ plasma, and $kT \gg 1$–10 keV for the ‘radiation belt’ plasmas. It was shown by Mendis and Axford (1974) that, due to the dominance of the intermediate energy plasma over the thermal plasma, the grains in the night side of the terrestrial magnetosphere could attain equilibrium potentials of 1–10 kV (negative). On the other hand, the grain potential is changed to $\sim +1$ V on the sunlit side due to the effect of the strong photoemission current. More recently, Hill and Mendis (1979a) have considered the charging of interplanetary dust grains entering the Jovian magnetosphere. As a consequence of the decrease of the photoemission flux by a factor $\approx 27$ over the terrestrial case, dielectric grains achieve large negative equilibrium potentials on both the day and the night sides of Jupiter. The calculated values are $-670$ V on the day side and $-830$ V on the night side (Hill and Mendis, 1979a). The time to attain the equilibrium potential varies inversely as the grain radius, and for a 1 $\mu$m grain this time $\approx 10$ h.

The equilibrium potentials attained by grains in interplanetary space have been computed by a number of authors. The most recent estimate gives $\phi = 1.1$ V (Parthasarathy, 1978). Earlier estimates were somewhat larger – e.g., $\phi \approx 6.6$ V (Rhee, 1967) and $\phi \approx 10$ V (Parker, 1964). The discrepancy is largely based on the somewhat excessive values of the quantum yield of photoelectric emission used by the latter authors.

The most detailed treatment of the electrostatic potentials reached by dust grains in circumstellar and interstellar space is due to Feuerbacher et al. (1973). (The reader