

Chapter 2

Basic dusty plasma principles

2.1 Deby shielding

A fundamental characteristic of the behavior of the plasma is its ability to shield out electric potentials that are applied to it. Suppose an electric field is applied into a plasma by putting two charged metal surfaces connected to a battery. The charged surfaces would attract potentials of opposite charges and almost immediately a cloud of ions will surround the negatively charged surfaces and a cloud of electrons will surround the positively charged surface. If the plasma were cold and there were no thermal motions, there would be just as many charges in the cloud as on the surfaces, and the shielding would be perfect. On the other hand, if the temperature is finite, the particles that are at the edge of the cloud, where weak electric field is present, would have enough thermal energy to escape from the electrostatic potential well. The edge of the cloud occurs at the radius where the potential energy is approximately equal to the thermal energy KT , where K is Boltzman's constant and T is the temperature of the species, of the particles, and the shielding is not complete. Potentials of the order KT/q can leak into the plasma and cause a finite electric field to exit [Chen, 1984]. This plasma shielding effect is a unique consequence of the fact that the dust grain is immersed in a plasma. Fundamental differences exist between dusty plasmas and electron-ion plasmas because of dust charging processes. A measure of the plasma shielding is called

the Debye length λ_D which is given by

$$\lambda_D = \sqrt{\frac{\epsilon_0 K T_e}{n e^2}} \quad (2.1)$$

where e is the electron charge and n is the plasma density. Note that describing the plasma as a quasineutral gas means that its neutral enough to assume $n_i = n_e = n$. In this study, we consider a dusty plasma composed of electrons, ions, and dust grains. The grain radius a is usually much smaller than the Debye length λ_D .

2.2 Intergrain spacing

We consider a multi-component dusty plasma composed of electrons, singly charged positive ions, and extremely massively charged dust grains, in a neutral background. The dust grain radius R is usually much smaller than the dusty plasma Debye length λ_D . When the intergrain spacing d is much smaller than λ_D , the charged dust particulates can be treated as massive point particles similar to multiply charged negative (or positive) ions in a multi-species plasma. Note that for dusty plasmas $d \leq \lambda_D$ and the dust particles can be considered as massive point particles where the effect of neighboring particles can be significant. For dust-in-plasma $d > \lambda_D$ and the dust particles are completely isolated from their neighbors.

2.3 Coulomb coupling parameter

Charged dust grains can be either weakly or strong correlated depending on the strength of the Coulomb coupling parameter

$$\Gamma_d = \frac{Q_d^2}{dT_d} \exp(-d/\lambda_D) \quad (2.2)$$

where $d = (3/4\pi n_{d0})^{1/3}$ is the intergrain spacing, n_{d0} is the initial dust density, Q_d is the dust charge, T_d is the dust thermal energy. When $\Gamma_d \gg 1$, the dust is strongly coupled and this condition is met in several laboratory dusty plasmas, such as dust “plasma crystals” [Mendis, 1996; Morfill *et al.*, 1996]. When the dust is weakly coupled, the dispersion relation of waves is not affected by the spacial correlation of the dust grains. A dusty plasma is considered as a weakly coupled as long as $\Gamma_d \ll 1$. Previous works [Winske *et al.*, 1998; Winske and Rosenberg, 1998] investigated the dust-acoustic instability produced in this regime using a one-dimensional simulation model assuming constant dust charge.

2.4 Dust charging

There are several processes which cause the charge on a grain, calculation of the equilibrium charge on a grain can become quite complex if all processed are included. For grains in a plasma with a temperature T_e for electrons (mass m_e) and T_i for ions (mass m_i) the fact that the flux of electrons have a thermal velocity v_{te} which is larger than that of the heavier ions which have a smaller thermal velocity v_{ti} will make the grain charge Q and its surface potential ϕ_s negative. In general, the charge Q on a grain changes because of the electron and ion currents according to the relation $\frac{dQ}{dt} = I_e + I_i$ and charge equilibrium occurs when $I_e + I_i = 0$ or $\phi_s = -2.51kT/e$ for an electron-ion plasma. Figure 2.1 shows a simple charging process on a dust particle. The charge itself is related to the surface potential by $Q = C\phi_s$, where C is the capacitance of a grain in a plasma [Goertz, 1989]. The density of electrons and ions far away from the dusty plasma where the plasma is charge neutral is n_0 . On the other hand, the primary

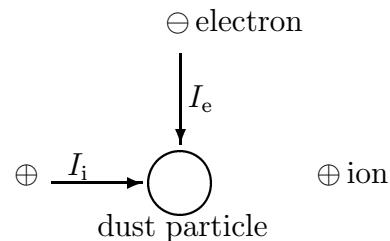


Figure 2.1: Charging on a dust particle

electrons can, if they are energetic enough, release secondary electrons, which causes the surface potential to become positive. The absorption of plasma ions also tends to make the surface potential positive. The currents of primary electrons and ions are, of course, affected by the surface potential of the grain (of radius a) itself and depend on the relative velocity between the plasma and the grain. If the surface potential is negative, electrons are repelled, and current to the grains carried by them is reduced. On the other hand, ions are attracted, and their current is increased.