The Effect of Grain Size-Secondary Electron Emission on Grain Growth in Dusty Plasma

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Abstract

The calculation of the charge on an isolated dust grain immersed in plasma with different grain sizes is a challenging one, especially under moderately high plasma temperature when secondary electron emission significant. The discrete charging model is used to calculate the charges of dust grain in dusty plasma. In this model, we included the effect of grain size dependence on secondary electron emission. The results show that the secondary electron emission from the glass dust grains due to energetic electron (40eV) can lead to the small grain to be slightly more positive than the large grain. Under these conditions, the smaller and larger grains would be attracted rather than repelled, which possibly lead to enhanced coagulation rates.

Keywords
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تأثير حجم الحُبَيبَة وانبعاث الالكترونات الثانوية على نمو الحُبيبات في البلازما الغبارية

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الخلاصة

يعد حساب شحنة حُبيبة غبارية معزولة (كثافة الحبيبات قليلة) ومغمورة في البلازما من التحديات المهمة خصوصا في البلازمات الحارة التي يكون فيها الانبعاث الثانوي للالكترونات ذا قيمة معتبرة. لقد تم استخدام نموذج الشحن المنفصل بعد أن ظمنّاهُ تأثير الانبعاث الثانوي لبيان تأثير ذلك الانبعاث على حجم الحُبَيبة.

لقد بينت النتائج إن الانبعاث الثانوي للألكترونات ، الذي تُسبِبَه الألكترونات ذات الطاقات العالية (40eV)، من حبيبات غبارية من الزجاج يزيد موجبية الحبيبات الصغيرة أكثر منه للحبيبات الكبيرة مما يجعلهما اقل تنافراً. تحت هذه الظروف يمكن أن تتعزز إمكانية تشكُل حُبيبات اكبر.

Introduction

There has recently been a renewed interest in the charging of dust grains in plasma and its effect on dust dynamics in astrophysical, solar system environments, laboratory plasma processing and semiconductor manufacturing. Dusty (complex) plasma is normal electron–ion plasma with additional solid or liquid particles (dust grain). The dust grain attains a charge (negative or positive) due to various charging mechanisms, such as, absorption of electrons, ions, secondary electron emission, etc [1, 2].

In laboratory discharges, one can study the growth or coagulation of dust grains (where coagulation is a random growth process whereby particles can stick together via mutual collisions forming large grains) under gas densities and temperatures typical of the nebula from which the solar system was formed. The particulates look like tiny cauliflowers pressed together in irregular strings a growth pattern that offers clues to the rate at which dust particles in interstellar space turned into the clumps of matter, which are large enough to assemble into planets due to gravity [1,3].

The equilibrium charge on a grain is determined by balancing electron, ion, and secondary electron emission fluxes to the grain [3].The secondary electron emission from metal surface is well described by the theory of Sternglass [4]. In this paper, the original Sternglass approach and discrete charging model was used to developed a computer model for the charging process of dust grain. The model provides measurable quantities (the charge accumulated in the grain or the surface potential). We will examine the effect of secondary electron emission on the potential of grain immersed in plasma. We assumed that, The plasma contains, normally, thermal electrons and ions and super thermal electrons (energetic electrons).

Dust Grains Charging Currents

When a small object is immersed in plasma, both electron and positive ion flow to the object and are absorbed on its surface. The electron (or ion) current to the dust particle surface from the surrounding plasma is calculated according to orbit motion limited theory [5]. Generally, the electron current $I_e I_e$ into the dust grain surface is a complicated function of the thermal energy and the kinetic energy of drift electrons. For simplicity , we consider two types of electrons in the anode region of an abnormal dc glow discharge. That was characterized by presence of high energy electrons in addition to the thermal electrons. The thermal electrons with number density $n_e n_e$, was characterized by temperature $T_e T_e$ and high energy electrons with number density of $n_e^h n_e^h$. The kinetic energy, $U_o U_o$, of the energetic electrons is much more than the thermal energy, $KT_e KT_e$, of the thermal electrons .

For Maxwellian electrons, the orbit-limited current to an isolated spherical dust grain of radius a a , and equilibrium surface potential $\varphi_d \varphi_d$ is[6, 7].

$$I_j = 4\pi a^2 n_j q_j \left(\frac{KT_j}{2\pi m_j}\right)^{\frac{1}{2}} \left(1 - \frac{q_j \varphi_d}{KT_j}\right)$$

$$for\ q\varphi_d < 0 \ldots\ldots\ldots\ldots\ldots (1)$$

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$$I_j = 4\pi a^2 n_j q_j \left(\frac{KT_j}{2\pi m_j}\right)^{\frac{1}{2}}$$

$$exp\left(-\frac{q_j \varphi_d}{KT_j}\right) for\ q\varphi_d > 0 \ldots\ldots\ldots (2)$$

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Where K K is Boltzmann constant, q is a charge, m is a mass, and j refers to ion or electron.

In the case of the mono energetic fast electrons, we have:

$$I_h = 4\pi a^2 e n_e^h \left(\frac{2U_o}{m_e}\right)^{\frac{1}{2}}$$

$$\left(1 - \frac{e\varphi_d}{U_o}\right) \ldots\ldots\ldots\ldots (3).$$

Assuming a Maxwellian distribution with temperature $T_s T_s$ for secondary electrons, the emission current $(I_{se})(I_{se})$ from an isolated spherical particle $\varphi_d > 0$ $\varphi_d > 0$ is given by :

$$I_{sc} = \delta I_h \left(1 + \frac{q_j \varphi_d}{KT_s}\right)$$

$$\exp\left(-\frac{q_j \varphi_d}{KT_s}\right) \ldots\ldots (4)$$

$$\exp\left(-\frac{q_j \varphi_d}{KT_s}\right) \ldots\ldots (4)$$,

The secondary electron yield (the number of produced secondary electrons per incident primary particle) is given [8] as:

$$\delta(E) = 7.4\delta_m \left(\frac{E}{E_m}\right)$$

$$\exp\left[-2\sqrt{\frac{E}{E_m}}\right] \ldots\ldots\ldots (5).$$

Where $\delta_m \delta_m$ is the maximum yield for primary electron energy $E_m E_m$. The yield is a function of conductivity, lattice-spacing, and the work function and it depend on atomic radius, number of outer shell electrons, and mean binding energies of the outer shell electrons. $\delta_m \delta_m$ and $E_m E_m$ characteristic parameters of the grain material. Typical magnitudes of these parameters are $\delta_m \delta_m$ ~0.5 to 30 and

E_m E_m ~0.1 to 2 keV. Where, for glass dust grain δ_m δ_m=3, and E_m E_m=400 eV.

Modeling of Charging Process

In dusty plasma charging process, the standard continuous charging model neglects the fact that the currents collected by the dust grain, actually, consists of individual electrons and ions. The discrete charging model converts the OML currents, equations (1-4), into probabilities per unit time of collecting individual charged plasma particles (electron ,or ion). So that, the charge on a grain will fluctuate about the steady-state value (equilibrium charge). Chunshi[9] considers two keys aspects of the collection of discrete plasma particles (electrons or ions) that we should identify and incorporate into the discrete model:

1-The time interval between the falling of two plasmas particles on the dust grain surface varies randomly.

2-The sequence falling of the plasma particle type (electron or ion) on the grain surface is random.

But, neither of the two above is purely random; they obey probabilities that depend on the dust surface potential, φ_d φ_d .

The third key aspect to describe the falling of the energetic electrons on the grain surface; the sequence in which thermal or energetic electrons arrive at the grain surface is random. Also, this is not purely random.

Let us define p_e p_e (φ_d φ_d), p_i p_i (φ_d φ_d), and $p_e^h(\varphi_d)$ $p_e^h(\varphi_d)$ as the probability per unit time for falling a thermal electrons, or ions, and energetic electrons, respectively. One can calculate the probabilities from the OML currents as:

$$p_j = \frac{I_j}{q_j} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$p_j = \frac{I_j}{q_j} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

,

j j refers to plasma particles type . This equation is the key to develop the discrete charging model. It relates the discrete charging model with its probabilities to the continuous charging model with its currents.

Results and Discussions

To show the effect of the grain size on the charging process and for comparison between small (10nm) and large (100nm) grains, we implemented the model as computer experiment. That was done in two cases: first, the case of grain in (normal) plasma containing particles have thermal energies, while the second case the grain immersed in plasma containing energetic electrons in addition to the normal components. Figure (1) shows The charging process for small (10nm) and large (100nm) grain immersed in Hydrogen plasma containing only thermal electrons and ions with energy of a few eV$\mathbf{T_e = T_i = 3\,eV}$ $\mathbf{T_e = T_i = 3\,eV}$, (i.e. no energetic electrons).

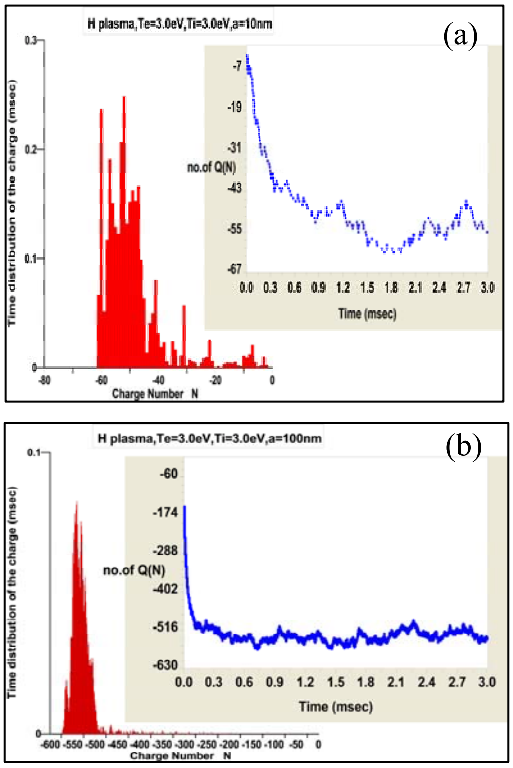
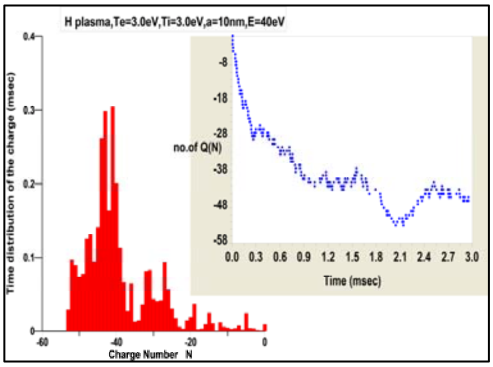


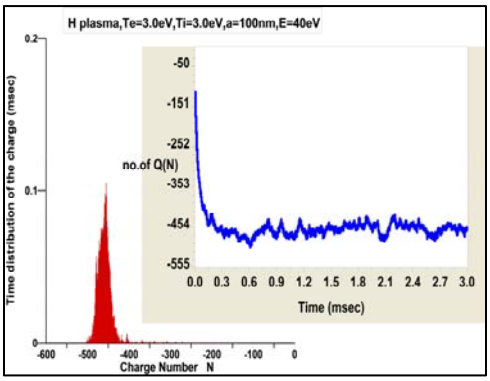
Fig.(1): The time evolution (right) and its histogram (left) of the charge on the grain surface immersed in normal plasma, (a) small grains , (b) large grains.

One can observe from figure (1) that the large grain gains charge value greater than that for the small one. The values of the charge fluctuate with the time of the experiment. That was in agreement with the fact of the individuality of the charges which falls on the grain surface. Also, one can observe that the frequency of the fluctuation on the large grain greater too than that for the small grain. Because of the probability of falling of the charged particles on the grain depends on the area of the surface.

Figure (2) shows the charging process for (10,100nm) dust grains immersed in the Hydrogen plasma. The plasma contains mono energetic super thermal (high energy) electrons with energy (40eV) in addition to the normal components.



(a)



(b)

Fig.(2): The time evolution (right) and its histogram (left) of the charge on the grain surface, (a) small grains , (b) large grains immersed in H plasma containing energetic electrons.

Figure (2) shows the same behavior in figure (1) as comparison between the small and large grains. The other important result is the effect of secondary electron emission on the charging process. The equilibrium charge number $(N)(N)$ and surface potential $(\varphi)(\varphi)$ for dust grain in both figures are summarized in table (1). Where in this table, the symbols are referring to grain radius and without and with refer to the cases without and with energetic electrons.

Table 1: The equilibrium surface potential for (10,100nm) dust grain radius in plasma containing thermal (electrons, ions) and high energy electrons.

a # nm	$N_{without}$	N_{with}	$\varphi_{without}$ V	φ_{with} V
10	-50	-40	-7.5	-5.93
100	-525	-450	-7.8	-6.55

The once result that can observe from table (1), the small grain is slightly more positive than the large grain due to the size effect on the high energy electrons induced secondary electron emission . Because of the primary electron (energetic) penetrates the dust grain a distance comparable to the grain radius, so that secondary electrons could be emitted from all sides of the grain rather than from the front side, as is the case when the penetration depth is much smaller than grain radius. Consequently, small grain (a≈ 10nm) can get positively charged (or less negative), due to their high secondary electron emission [10, 11].
The existence of different –sized grains of opposite polarity (negatively charged large grains and positively charged small grains) is possible, in this condition, the smaller and large grains would be attracted rather

than repelled, which could possibly lead to enhanced coagulation rates. The rapid growth rate is about two orders of magnitude large than that expected from pure thermal coagulation. The high energy electrons lead to this rapid coagulation [1, 11].

Conclusions

In the charging process of a dust grain in a plasma of thermal electrons and ions, the dust grain acquires negatively electric charges while the process in plasma included high energy electrons, the dust grain have less negative charges in range of the energy . Also, the secondary electrons emission from dust grain and the dependence of the secondary emission on the size of dust grain become important to the grain growth (grain size increasing) in processing plasmas because that control the forces between the grains.

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