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Coulomb Clusters in Dusty Plasmas: Dynamics and Stability.

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Coulomb cluster is a phenomenon in classical physics which is still under substantial amount of attention. These clusters are characterized by the strong electrostatic interaction of highly charged particle trapped within an external confining potential. Examples of such systems include ion traps [1] and quantum dots [2]. Investigation in this area had been further encouraged in the past few decades with the discovery of complex (dusty) plasmas and the increase in the computer simulation of complex plasma experiments. In discharge complex plasma system, micron-sized dust particles which are highly negatively charged ($\sim 10^4 e$) repel each other under strong coulomb forces to arrange themselves into well ordered structures. Such structures with limited number of particles are referred as Coulomb clusters in dusty plasma.

Here we report the results obtained from analysis of our experimental data in single plane dust clusters made from dust particles of two different diameters (2.71μm and 6.21μm) along with the numerical simulation of the allowed states of such system. In experiment, metastable states have been observed for clusters formed from smaller dusts. The stability of the configuration obtained was investigated and planar-7 was found to be the most stable (see Fig.1). It was found that the stability of clusters consisted from large and small particles are different. The magnetic field has no influence on the cluster stability.

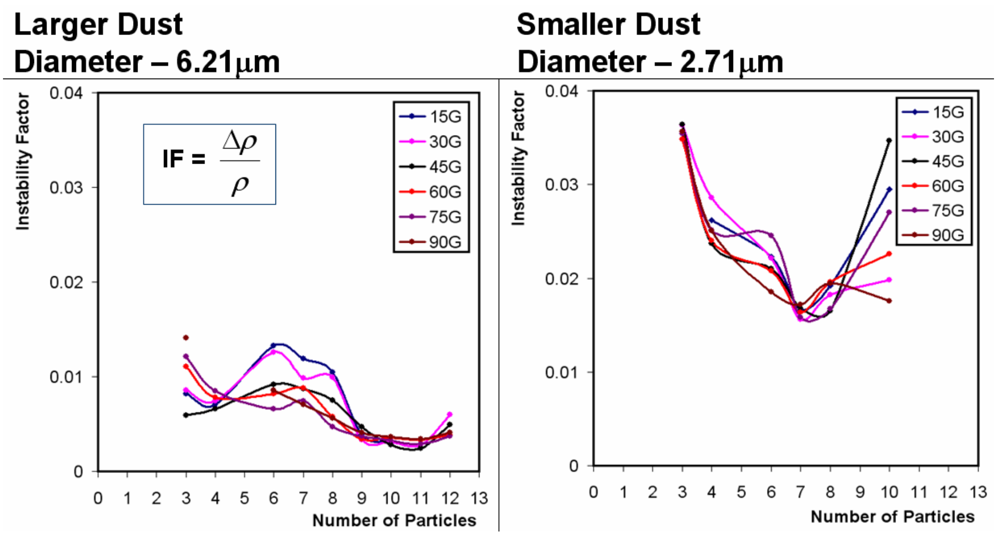
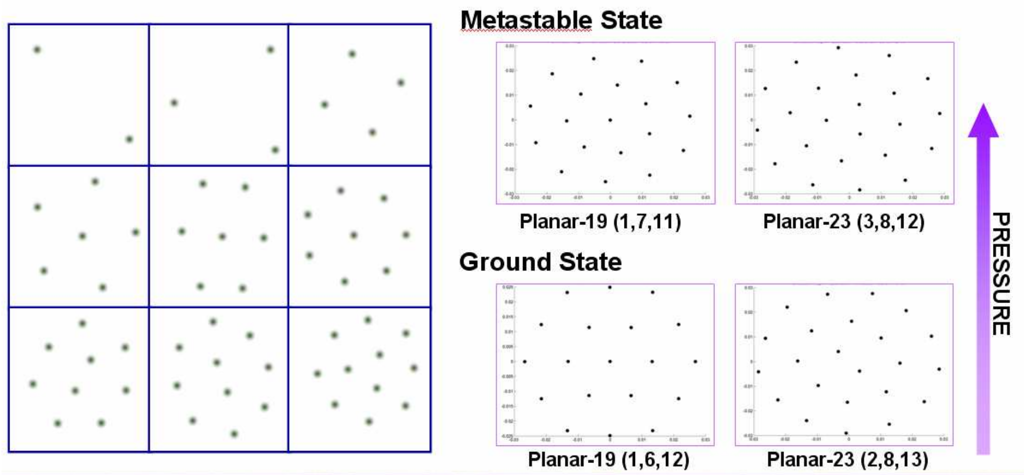


Figure 1. Instability factor for different clusters at different magnetic field strength.

For different number of particles in a cluster, there is a unique structure which corresponds to its ground state in that particular experimental condition see Fig.2 (a). A simple simulation model is provided for single plane clusters. The model is based solely upon inter-particle coulomb interaction in a confining potential. The model allowed us to predict the structural configuration of the dust clusters under particular experimental conditions. It was shown that the configuration of Coulomb clusters depends on friction force (pressure). Consequently, particle systems can be stabilized into both ground and metastable states (see Fig.2) Ground states are found to occur for all cluster sizes, whereas metastable states may occur for only particular sizes.



a) b)

Figure.2. Experimental and simulated cluster configurations.

Stable Coulomb clusters are well known to establish themselves into concentric shells given a sufficient number of particles (see Fig.2). Such phenomenon is an understandable attempt to reduce the energy in the system by maximizing the total interparticle distance whilst not encouraging large radial distances from the centre of the well (this is a compromise between Coulomb energy and well energy). These concentric shells only occur in system of 6 particles or more with typically 1-5 particles in inner-most shell. Associated with each configuration is a potential energy which is the consequence of the cluster's potential energy in the well and particle-particle interaction potential energy. Within any stable configuration this energy is fixed and so particles maintain the same radius from the centre of the well (otherwise the well energy of the system is compromised). The case is not so simple however, when considering a particle's motion along the axis of the stable shell. Clearly the radial distances of the particles do not change in this situation and so the well contributes nothing to the change in energy of the system, though it is not obvious whether the inter-particle distance is increasing or decreasing. Indeed this will depend on the number of particles in each shell involved in the rotation.

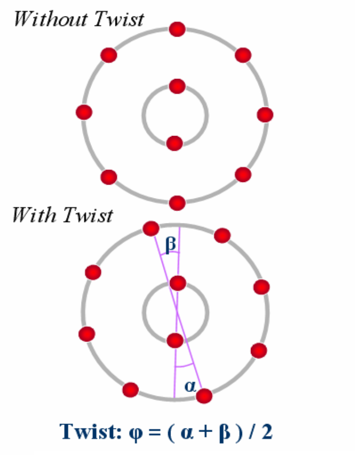


Figure 3. Twist definition.

We have chosen to consider the inter-shell rotation of a planar-10 system with a packing sequence of either (2,8) or (3,7). The twist angle (or twist) describes the magnitude of the inter-shell rotation of a cluster, which can be determined as shown on Figure 3. To establish the relationship between the change in Coulomb energy (as a result of changing inter-particle distances) and inter-shell rotation we model the system with particles distributed evenly on two circles. Particles on the outside then move along their shell with potential energy measured at all stages. Our results showed that in both cases [(2,8) and (3,7), movement along the outer-shell has a definite effect on energy. *0* rad and ~*0.40* rad twist for (2,8) and ~*0.2* rad and ~*0.25* rad for (3, 7).correspond to the higher and lower energetic states for both clusters. Thus we can expect fewer occurrences of these systems with higher energies, as any deviation from the exact positions will see this excess energy continue to dissipate until a more stable equilibrium is reached.

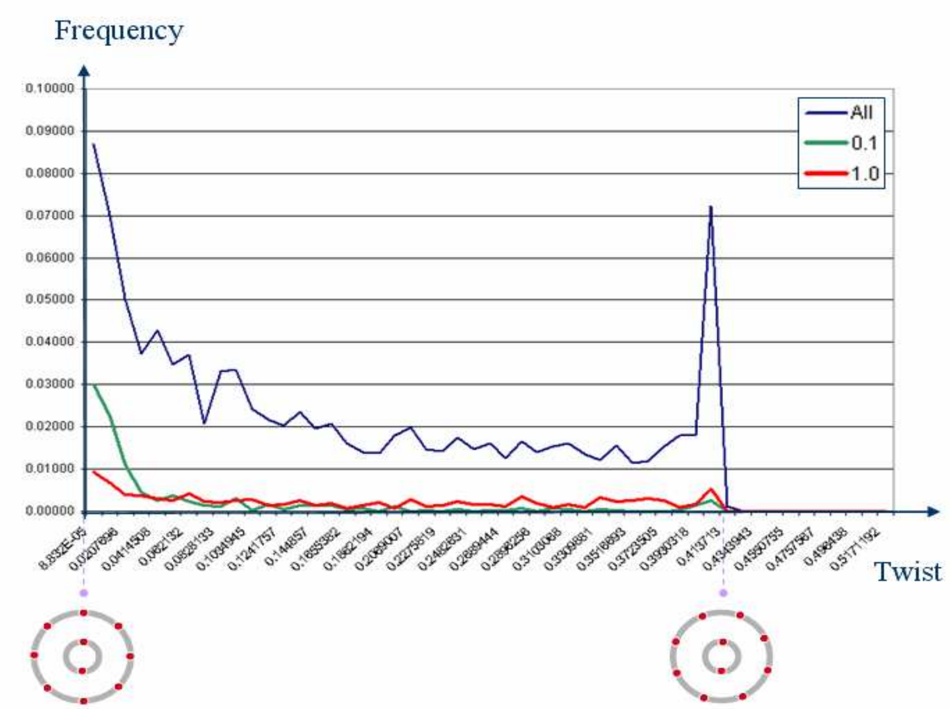


Figure 4. The twist frequencies of (2,8) system.

Our investigation in planar-10 cluster began with the discovery of stable structures with common twist sizes. Our initial aim was to determine the preferable inter-shell rotation favored by the system and if these correspond to those indicated previously. Our results (Fig.4) clearly showed that preferred states of inter-shell rotation do exist as expected from our discussion on inter-shell rotation. Whilst we might expect a twist of *0* rad to be the least common configuration for the planar-10 (2, 8) system, our results showed that it is the most common. For planar-10 (3, 7) system, the results are again far from that anticipated with a very distinct peak occurring in the middle of the twist spectrum at *~0.32* radians, and a minor peak later at *~0.48* rad, although this still differs from the prediction of 3 favorable twist sizes. An immediate conclusion of the observed twist frequencies found in the above results is that clusters in fact do not obey the energy-twist relationship that was derived from the model described above. In this model system energy should decrease sinusoidally as the twist of the system increases. This would imply that structures with a larger twist, corresponding to a lower energy would be more common, having reached a more stable equilibrium. As we observe however, this is not strictly the case.

We will explain these results by reconsidering the inter-shell rotation in a (2, 8) packing sequence as in fact being part of a greater inter-shell interaction, which changes the shape of the outer shell. We justified already that since the system is dynamic, it will seek the minimum energy which it can achieve. As such, we derived probabilities of twists based on the twist energy. This idea remains correct, as the nature of the problem is still dynamical. It is indisputable that inter-shell rotation does occur, however the obtained results suggest there is an additional aspect to the intershell interaction. The only way to minimize energy for a given configuration without compromising the inter-shell rotation is to distort the stable shells (that is, we refute the previous assumption that these shells are rigid curves). Although in such case, the particles are able to compensate for any additional Coulomb energy (owing to the inter-shell rotation) by further reducing their radial distance as much as possible. The overall effect is the change of the outer-shell from circular (when the twist *~0.4*rad) to elliptical (when the twist *~0* rad).

Reference

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