Vertical Interaction Between Dust Particles Confined in a Glass Box in a Complex Plasma

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***Abstract*— In this experiment, falling particle trajectories within and without a glass box placed on the lower electrode in a GEC reference cell were recorded and analyzed and the electrostatic forces exerted on the dust particles measured and compared. Experimental results show that for particles falling in a complex plasma with no glass box, only a single force balance point (i.e., the position where the gravitational force is balanced by the electrostatic force) exists in the vertical direction, while for particles falling inside a glass box, this force balance spans an extended vertical range.**

***Index Terms*— Complex Plasma, Diagnostics, Plasma Sheath, Interaction Force.**

I. Introduction

The study of complex plasmas is important in a variety of research, including both theoretical and applied engineering fields. [1] A complex plasma is defined as a partially ionized gas, consisting of electrons and ions, and containing very small solid particles. [2] This system can be useful in part because it is much easier to observe and model than many atomic systems, but can often behave in similar ways. But in order to for the study of these systems to progress, it's important to first be able to gather information about the charges and forces acting on the particles inside a plasma.

II. Experiment and analysis

Two separate sets of experiments were conducted for this research, one to investigate the forces in the vertical direction, and one to investigate the corresponding forces in the horizontal direction. Both were conducted within one of two modified GEC RF reference cells located in the Center for Astrophysics, Space Physics & Engineering Research (CASPER) lab at Baylor University. This setup is shown in Fig. 1, and consists of two electrodes, the bottom one powered and the top one grounded. A 12.5 mm × 10.5 mm glass box with a glass thickness of 2mm was placed the bottom electrode in order to provide horizontal confinement for the particles. [3] When in use, the cell is filled with Argon gas at [pressure?]. [source] the Melamine formaldehyde dust particles, 8.89 ± 0.09 μm in diameter, are dropped into the cell, [4] and come to rest levitating at some equilibrium point.

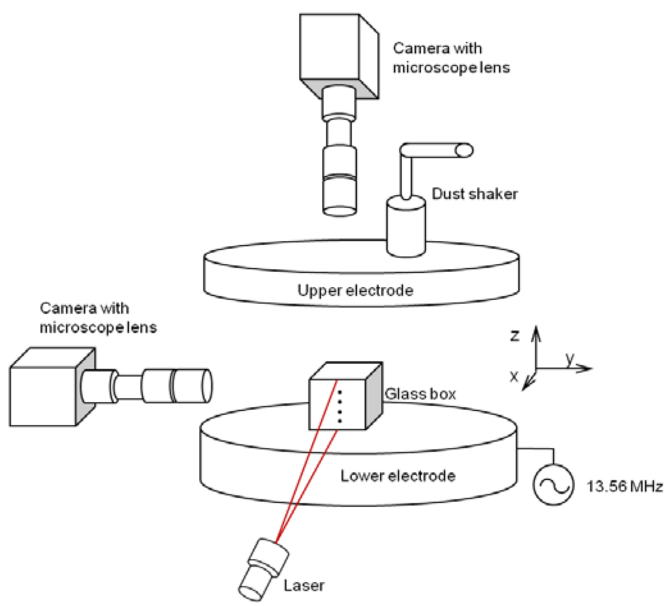

Fig 1. Experimental setup. The Verdi Laser used in the horizontal experiment is not shown. [4]

Both the horizontal and vertical experiments were performed at the DC resonance frequency, which was first determined RF power of 235mV, 252mV, 270mV, 283mV, and 340mV. This was accomplished by applying a DC bias and observing the oscillation for each integer frequency between 1 Hz and 20 Hz. The frequency that appeared to have the largest amplitude was used in future experiments using that RF power.

The first experiment was conducted to collect data in the vertical direction; a DC bias was applied to the system to cause oscillation in the vertical direction, and then shut off. The particle's movement was recorded as it returned to equilibrium. This was done for all five RF powers, and for both a one and two particle chain.

In the second experiment, the particle was pushed horizontally using [technical name for Verdi laser] at [number of watts], not shown in Fig. 1, for a very brief time. Then the laser was shut off the movement was recorded as the particle was allowed to come back to equilibrium.

To understand what happens to the particles dropped into the box, the forces acting on the particle must be understood. The overall force acting on a particle in the plasma comes from a variety of sources. Some are stronger than others, and many are small enough that they may safely be disregarded. For the purposes of this experiment, there are major forces to consider.

There is of course the gravitational force acting in the downward direction. There is also the drag force, caused by the collisions of the particle with the plasma components and acting in the opposite direction of the particle's movement. As the plasma consists of both neutral atoms and ions, there are two different types of drag force. In this case, however, the ion drag force is considerably smaller than it's neutral counterpart, so we will be dealing only with the neutral drag force. This force is described by the equation

(1)

Where [beta] is called the neutral drag coefficient.

The other major force on the particle is the electromagnetic force. Because electrons have a very high speed, they collide with the particles and the walls of the box more often than other types of particles, and cause things in contact with the plasma to accumulate a negative charge. This charge on the walls of the glass box will create a confinement force that acts towards the center of the box on the similarly charged particle. In addition, there will also be an interaction force between a particle and any other particles in the plasma. In this experiment, the total electromagnetic force includes both the confinement force and the interaction force, and will be approximated as

$$F_{ey} = QE_y = Qk\Delta y \qquad (2)$$

or in the horizontal direction as

$$F_{ex} = QEx = Qh\Delta x \qquad (3)$$

These equations are not exact descriptions of the force caused by the electric field; the real description is much more complicated. However, over very small distances, a linear approximation can be used without much loss in accuracy.

This gives an overall force equation of

$$\begin{aligned} F_{xtot} &= m\ddot{x} = qhx - \beta\dot{x} \\ F_{ytot} &= m\ddot{y} = mg + qky - \beta\dot{y} \end{aligned} \qquad (4)$$

in the vertical and horizontal directions, respectively.

Now, in order to relate the force on the particle to this equation, we must first get a trajectory of the particle's motion as it comes to rest. Both the vertical and horizontal data were entered into Matlab to produce trajectories shown in Fig. 2.

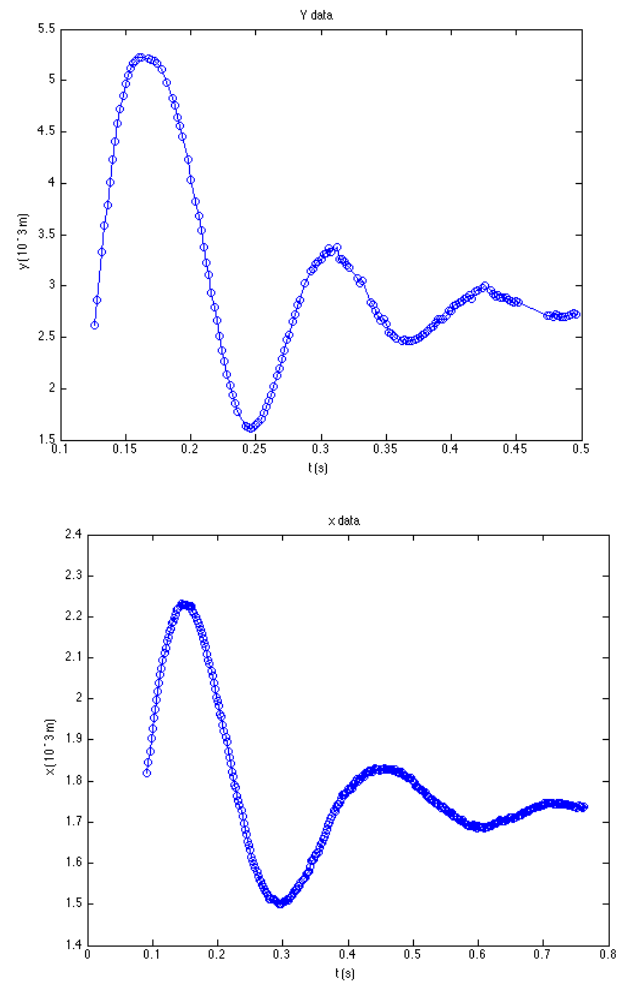

Fig 2. Two example trajectories (position versus time) for the vertical and

horizontal experiments. These trajectories are for one particle with 252 mV RF power.

Once all of these trajectories have been plotted, we can begin gathering information about the forces acting on the particle. The position data was fit to the equation for a damped harmonic oscillator

$$y(t) = ae^{-bt}\cos(ct) + d \qquad (5)$$

This equation contains four constants that are determined when we fit the data. In this case, the ones that are of most importance are *b* and *c*, which are related to variables in our force equation. The constant b is related to neutral drag coefficient by

$$b = \beta/2 \qquad (6)$$

and both constants are related to the electric field strength by

$$c + b^2 = \omega^2$$
$$\omega^2 = Qk/m \qquad (7)$$

This fitting was applied to both the horizontal and vertical data, for both one and two particles, and all five powers. However, the lowest power, 235 mV, did not give sufficiently good data and was not used.

When investigating the values for the neutral drag coefficient, an interesting trend emerged. We had originally assumed that the values for the drag coefficient would be the same in the vertical and horizontal directions when the RF power was the same, but after fitting the data it became apparent this was not the case. The actual values found are shown in Fig. 3.

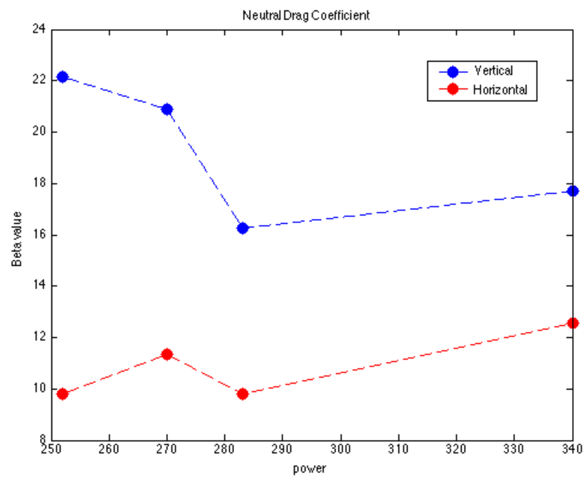

Fig 3. A plot of the neutral drag coefficient values in the horizontal and vertical directions for four different powers. These values are taken from the one particle data.

With the values we found for c, and using data for a particle at rest at equilibrium, we can also find values for the location of the plasma edge for various powers. When the particle is at rest, the downwards force of gravity is balanced only by the electromagnetic force, so for one particle we have

$$mg = Qk\Delta y \qquad (8)$$

And since we know that *Qk* is related to the constants *c* and *b* by eq. 7, we can solve eq. 8 for delta y, giving us

$$\Delta y = g/(c + b^2) \qquad (9)$$

Fig. 4 shows how this value is related to the position of the plasma edge, and Fig. 5 shows the data for this position for various powers.

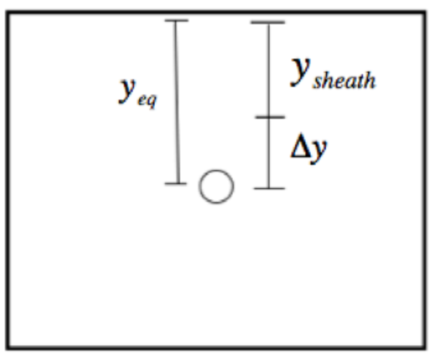

Fig 4. The position of the sheath edge as it relates to the equilibrium position of the particle y1, and the value delta y found from the data. Note that a negative delta y corresponds to positions above the top of the box.

Power (mV)	252	270	283	340
Position (m)	-0.0532	-0.0533	-0.0680	-0.0516

Fig 5. The calculated position of the sheath edge for each of the four powers,

With all of this information, we can move on to finding a value for total force at any given point in our data. Using Matlab, the position data was fit to a polynomial, then the derivative was taken to find velocity. This process was repeated to give acceleration. This gives everything needed to plug into the total force equations, giving us the graphs in Fig 6.

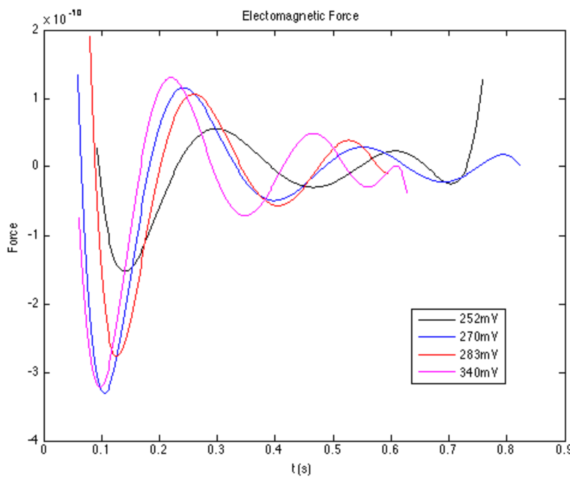

Fig 4. The total horizontal force on one particle for four powers.

Now we have a description of the net force acting on a particle in both the vertical and horizontal directions.

III. Discussion and Conclusions

There are several steps that could be taken to improve the data taken here. First, the limited number of data points makes it difficult to be sure of the trends found, particularly in the case of the apparent discrepancy between the vertical and horizontal drag coefficients. Because this was such an unexpected result, it would be particularly prudent to run many more data points.

Also, the data for total force on one particle could easily be used to isolate the interaction force, if the data for the total force on a two particle chain was also measured. This would give even more information about the system and possibly be a step towards finding the charge accumulated by each of the particles.

References

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