Determination of the Confining Potential in Dusty Plasma Experiments

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Abstract— **In dusty plasma experiments, the confining potential of the GEC rf Reference Cell is commonly assumed to be parabolic. There are various ways to test this assumption, many of which interfere with the plasma. We use the noninvasive method of perturbing a single particle suspended in the plasma with laser pulses. In this experiment a cw laser (532nm, 0.01-.05W) supplied the radiation pressure force on a single MF microsphere. The trajectory of the particle is then analyzed to determine the confining potential. We varied the size of the confining cutout, pressure, system power, and DC bias to better understand their effects on the shape of the confining potential. The experiments showed that the potential did have a parabolic shape and that increasing the cutout size, gas pressure, and DC bias all decreased the curvature of the parabola.**

Index Terms—**Complex Plasma, Dusty Plasma, Condensed Matter Physics.**

I. INTRODUCTION

DUSTY plasmas are very common in space and in processing environments utilizing plasmas. They occur in the interstellar medium, proto-stellar and -planetary clouds, and planetary rings. Starting with the desire of semiconductor manufacturing companies to eliminate dust from their processes, dusty plasmas have become a common area of study in the last 15 years. Scientists have discovered the formation of crystal structures under certain conditions [1]. There are similar structures that occur naturally in space.

The Gaseous Electronics Conference (GEC) radio frequency (rf) Reference Cell [2] was devised to create a reference for studying plasmas systems. To contain the particles above the electrode during experiments, some use a cutout [3] or raised ring [4] to create a confining potential for the particles above the lower electrode. Other methods of perturbing the particle have been tried, such as hitting the particle with a laser from above [5], hitting a dust cloud with a counterpropagating laser beam [6], using a wire in the system to deliver an electric pulse [7], or adding a low frequency component to the driving frequency to the lower electrode [5]. We used a 1 in. diameter, 1 mm deep cutout, and perturb the particle with a focused laser beam, incident on the particle parallel with the plane of the lower electrode.

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II. THEORY

There are many forces at work in a dusty plasma. However, depending on the experimental conditions, some of these forces can be ignored. The thermophoretic force effects mixtures of particles via a temperature gradient, which we can ignore both because our system is very large compared to the volume of ionized gas, and the large diameter of the lower electrode. The ion drag force is the interaction of the ionized gas particles, in this case argon, and the charged dust within the plasma. The positively charged ions move vertically from the upper to lower electrode, and primarily interact with vertical stacks of particles. We do not consider the ion drag force because we only have a single particle. The radiation pressure force, supplied by the Nd:YVO_4 laser, which we are using to push the particle, does not apply because we are looking at the return path of the particle, after the laser pulse. Vertically, the equal but opposite forces of gravity and the vertical component of the electrostatic force cause the particle to levitate. As we are only looking at the return path of the particle, we only need consider the horizontal forces.

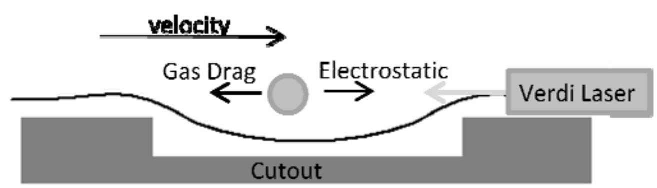

Figure 1: The laser pushes the particle to the edge of the confining potential (black line) and the gas drag force slows its return to the center.

During this portion of the particle trajectory there are only 2 significant horizontal forces acting on the particle: gas drag and the horizontal component of the electrostatic force (Fig 1). A finite difference method is used to determine the velocity of the particle at each position, where j refers to frame number:

(1) $\dot{x}_j = \frac{x_{j+1} - x_{j-1}}{2t}$

The net force on the system can be described by:

(2) $F = -R\dot{x} + \frac{dU}{dx}$

Under similar conditions, the value R was determined using the equation and coefficient from [4]. By integrating this equation you obtain an equation for the potential energy as a function of position:

(3) $U(x(t)) = U_0 - \frac{M\dot{x}^2}{2} - R\int_{t_1}^{t_2} \dot{x}(\tau)^2 d\tau$

Once velocity is known, the potential energy can be obtained by equation 3.

Many researchers have assumed the potential to be of the form $U=bx^2$ [8]. In this experiment we seek to verify that the potential does have a parabolic shape, and how its shape varies under different pressures, cutout diameters, and external DC biases.

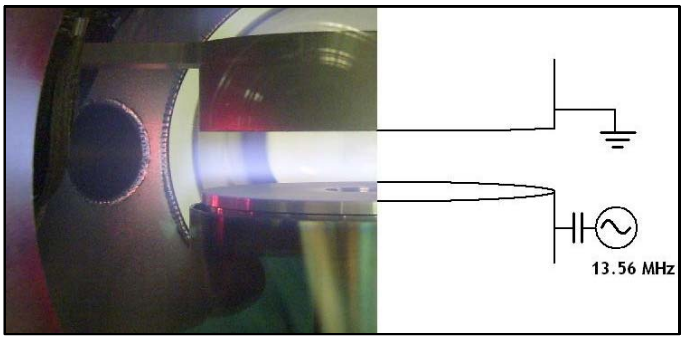

Figure 2: CASPER's GEC rf Reference Cell.

III. Process

A. Experimental Setup

A modified GEC rf Reference Cell was used for these experiments (Fig. 2). The upper electrode is a grounded ring with the walls of the chamber serving as ground. The upper electrode port is an optical window allowing imaging of the particles from above and incorporating feedthroughs for particles into the system. Powering the system, the lower electrode is capacitively coupled to an rf signal generator and amplifier through a T-type matching network. The lower electrode has a stainless steel sheath ground shield and a Teflon insulator. To confine the particles above the lower electrode, an aluminum plate is placed on the lower electrode with a circular cutout. Illuminating the particle is a 50 mW LASARIS™ diode laser at 685 nm, with a 5º fan angle line generating lens. Images were captured with a CCD camera (Sony HR50) through a zoom lens (Edmund Industrial Optics™ #52-274 Close Focus Zoom Lens) mounted above the cell. To perturb the particle we use a Verdi™ G-Series Optically Pumped Semiconductor Laser operating at 532nm ±2nm and between .01 and .05W [9].

A single 8.82µm ±0.13µm Nile Blue Melamine Formaldehyde particle was dropped into the plasma where the Coulomb force balances against gravity, holding the particle above the lower electrode. This was done with the plasma generated at pressures from 75 to 175 mTorr, 1 to 5 Watts, an external DC bias from -7 to -52 Volts, and cutouts from .25 to 1 inch in diameter.

B. Procedure

At all conditions the laser was aligned for maximum displacement and pulses were manually-triggered. Care was taken to ensure images used for the return path of the particle did not include any frames where the laser was still interacting with the particle. For each run images were taken at 60 fps for 10 second bursts. The images were then run through a MATLAB program to track the particle's position in each frame (Fig. 3). Using the method outlined in Section II, a potential vs. position graph was obtained for each return path. As seen in Fig. 4, a parabolic fit most accurately represents the shape of the potential. This was observed under all parameters.

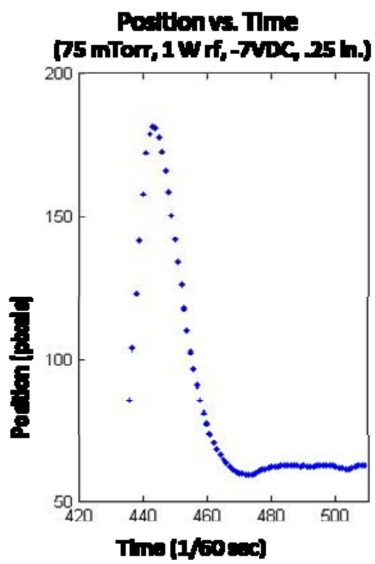

Figure 3: Position versus Time

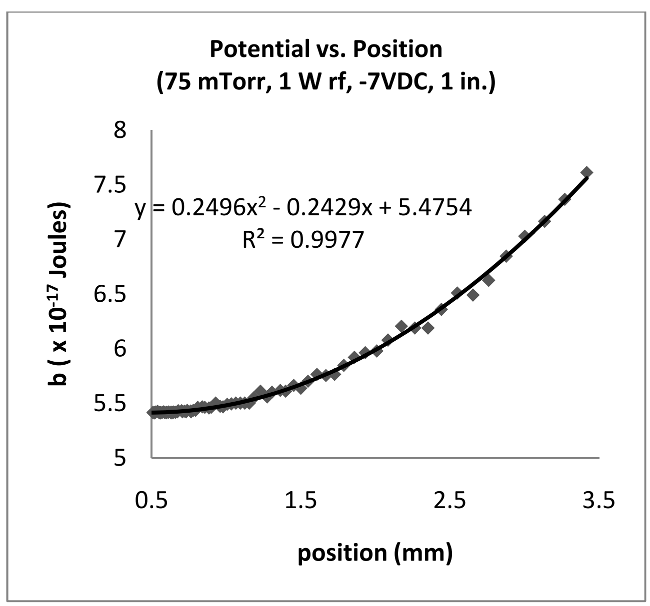

Figure 4: Potential versus Position

IV. Results and Discussion

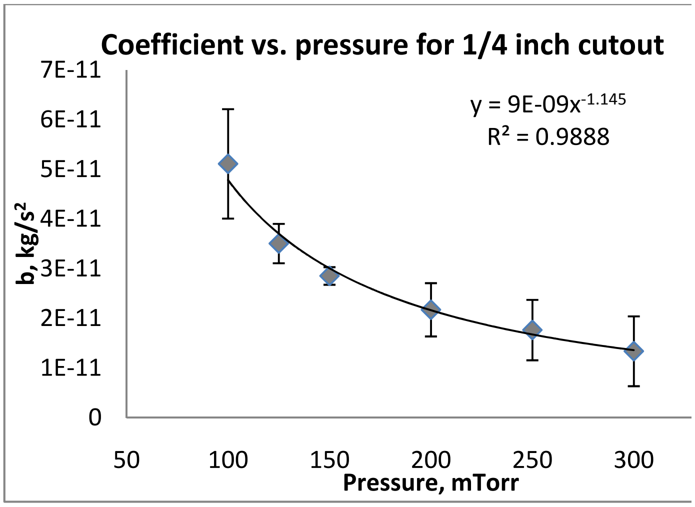

Figure 5: Coefficient of curvature under varying pressure.

Thus far only a small portion of the data has been analyzed. However, some trends have emerged. The coefficient of the potential is graphed for varying pressures in Fig. 5. As the pressure is increased the coefficient of the potential decreases nonlinearly. Similarly, for an external DC bias, increasing in magnitude, the curvature of the potential well decreased (Fig. 6).However, from the graphs of the energy of the potential versus particle position, we can state that the potential well has a parabolic shape.

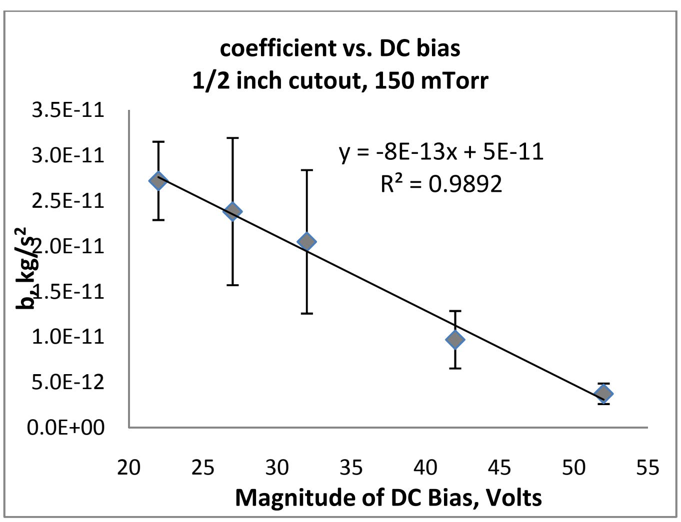

Figure 6: Coefficient of curvature under varying DC bias.

In the future the researchers would like to look at the effect of thermophoresis on the shape of the potential well, and the forces acting on the particle when it is stationary while being pushed against the edge of the potential well.

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