Ionization Equilibria in Dusty Plasma Environments

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Dust and plasma co-exist in a variety of cosmic and laboratory environments. While dust could act as a sink for the plasma it could also be a primary or additional source of electrons in certain circumstances. These include (a) the presence of a significant UV radiation flux, leading to photoemission, (b) the grains being sufficiently hot, leading to thermoionic emission, (c) the background electrons being sufficiently energetic, leading to secondary electron emission, and (d) the grains being sufficiently small, leading to field emission. Here we will discuss these effects in the context of a few selected environments including photodissociation regions in molecular clouds, hydrocarbon flames, the atmospheres of evolved stars, and laboratory process plasmas.

Evaluation of Grain Charging in a Flowing Plasma

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Using a numerical Particle-In-Cell model of electrons and ions we examine the charging of dielectric dust grains due to particle impacts. As a first step toward a more realistic model we incorporate a bulk neutral flow into the overall plasma velocity distribution. We have discovered that the addition of a bulk flow induces a dipole moment on the dielectric grain charge (Manweiler, et al., 1993; Manweiler, et al., 1996). We provide characterization of the charging moments as a function of flow velocity. In addition, we have examined the effects of charging when two dielectric grains are within several Debye lengths and how this effects the overall-charging scheme. We examine the symmetry between charging of the grains depending upon the orientation of grain separation versus flow direction. We also characterize the overall charging moments on the grains as a function of the intergrain separation and bulk plasma flow speed. Finally, we examine the forces on the grains and how the plasma mediates these forces. We verify Debye shielding effects and also present results indicating that the bulk flow also induces an overall force on the grains. As a summary we present scaling relationship that allow the two-dimensional work to be used in three dimensional models via charging parameterization equations.

REFERENCES

Manweiler, J. W. et al., "The Physics of Dusty Plasmas", P.K. Shukla, et al., Eds., World Scientific, p. 22, 1996.

Manweiler, J. W. et al., 5th Dusty Plasma Workshop, Univ. of Alabama-Huntsville, 1993.

The effect of charge fluctuations on the agglomeration of dust in low pressure plasmas

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We obtain analytical solutions for the agglomeration rate of charged dust grains in ionized gases taking into account the statistical distribution of the dust charge arising from the random nature the charging process. Particles in the plasma are negatively charged and experience overall repulsive interactions. However, in the presence of charge fluctuations the coagulation rate increases (the effective repulsion decreases) when compared to particles of the same mean charge in the absence of fluctuations. The magnitude of this effect is a function of particle size, electron-to-ion temperature and ionic mass. These results are discussed in the context of dust growth in low-pressure plasmas.

New aspects of the Jeans instability in dusty plasmas

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In contrast to a gas, a dusty plasma can support a variety of wave modes each in principle able to impart to the dust grains the randomising energy necessary to avoid Jeans collapse on some length scale. Consequently, the stability to Jeans collapse is more complex in a dusty palsma than it is for a charge-neutral gas. After recalling some of the fundamental ideas related to the ordinary Jeans instability in neutral gases, we will extend the discussion to plasma containing charged dust grains. Besides the usual Jeans criterion based upon thermal agitation, various ways of countering the gravitational collapse can be considered. One is via excitation of electrostatic dust-acoustic modes, the other via novel Alfvén-Jeans instabilities for perpendicularly propagating electromagnetic waves. In particular, waves on the extraordinary mode branch are considered. The wavelengths that are unstable are comparable to the well-known Jeans length for a neutral gas/dust, but there are interesting modifications due to the presence of a magnetic field and charged particles. Furthermore, the effects of the gravitational coupling of a mulitcomponent plasma to a neutral dust are discussed for different frequency regimes. These mechanisms yield different minimum threshold length scales for the onset of instability/condensation.

Lattice Modes in a Dust-Plasma Crystal

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We consider vertical oscillations of dust grains in one and two vertically ordered one dimensional horizontal chains. We show that specific low frequency modes (associated with the vertical vibrations of the dust) can propagate in such a system. We also consider oscillations of N dust grains in a vertically-ordered one-dimensional chain of dust particles immersed in the sheath region. In this case, the number of modes is equal to the number of particles in the chain.

Simulation of Dust Acoustic Waves

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Dust acoustic waves are natural modes of oscillation in a dusty plasma. Growing dust acoustic waves are generated when the plasma flows relative to the dust, via a dust acoustic instability. Such waves are observed in laboratory experiments and are expected to occur in space environments. Low frequency acoustic-like modes are also observed in dusty plasma crystals, where the waves may be modified by lattice effects or strongly coupled plasma effects. To study the generation and properties of dust acoustic waves, we employ several types of numerical methods. We use particle-in-cell (PIC) techniques, which treat the dust grains as individual particles, with the plasma ions either treated as a Bolzmann fluid or as kinetic particles, and the electrons as a Boltzmann fluid. Collisions with background neutrals are also included. We also use molecular dynamics (MD) methods, which treat the interactions between dust grains directly, to investigate strongly coupled plasma effects. We show that the PIC simulations accurately reduce the fluid dispersion relation both in the limit when the dust is modeled as a fluid and when the dust grains are large, discrete particles, as in a lattice. With ion flow, there is considerable change to the wave dispersion, which may be due to the loss of ion shielding. The MD simulations also give the proper fluid dispersion relation at long wavelengths and suggest some strongly coupled behavior at short wavelengths, provided the dust grains are cold enough. Implications of these results for experiments will be discussed.

Status of Collective Processes in Dusty Plasmas

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About seven years ago, the Bochum group predicted for the first time the existence of the dust-acoustic wave (DAW), which is now experimentally verified by several groups around the globe. Since then there has been a great deal of interest in studying various aspects of linear and nonlinear waves in multi-component weakly and strongly coupled dusty plasmas. In strongly coupled systems (such as the dust crystals), there appears a dust-lattice wave (DLW). Our objective here is to discuss the present status of dusty plasma waves and point out the possibility of designing new experiments. Specifically, we shall focus on low-frequency electrostatic and electromagnetic waves, their instabilities, and coherent nonlinear structures (solitary waves and vortices), by including nonideal effects in dusty plasmas. Also discussed is a kinetic theory for dust waves including dust correlations, as well the effects of magnetic fields on waves and instabilities in dusty plasmas when the coupling between the dust grains is either weak or in the intermediate regime. On the other hand, it is found that dust-lattice waves in a strongly coupled dusty crystal can be excited by imposing an oscillating electric field whose frequency is close to the ion plasma frequency in the dusty plasma sheath. Finite amplitude dust-lattice waves, which nonlinearly interact among themselves as well as couple with quasi-stationary disturbances in the background dusty medium, are self-modulated. The nonlinear propagation of modulated DLW is governed by a nonlinear Schröedinger equation, which predicts a stable dust lattice wave packet. The relevance of our investigation to wave activities and their roles in large magnetic facilities (LMF) for dusty plasma crystal studies, as well as to numerous collective processes in low-temperature radio-frequency discharges and space plasmas is discussed.

Hydrodynamic Waves in Dusty Plasmas:
Dispersion and Correlation Properties

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A hydrodynamic description of strongly coupled dusty plasmas is given when physical quantities vary slowly in space and time and the system can be assumed to be in local thermodynamic equilibrium. The linear waves in such a system are analyzed. In particular, a dispersion equation is derived for low-frequency dust acoustic waves, including collisional damping effects. The linear response of the system is calculated from the fluctuation-dissipation theorem and the hydrodynamic equations. The requirement that these two calculations coincide constrains the particle correlation function for slowly varying perturbations. It is shown that in the presence of weakly damped, long-wavelength dust acoustic waves, the dust auto-correlation function is of the Debye-Huckel form and the characteristic shielding distance is the dust Debye length. The results of the theory are compared in detail with experimental results. A curious, and hitherto unexplained, feature of the experimental results on dust acoustic wave dispersion in the low-frequency, long-wavelength limit is shown to be explained by the hydrodynamic dispersion relation when the effect of damping is taken into account.

Dust acoustic waves and instabilities in strongly coupled dusty plasmas

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It has been shown within the context of standard plasma theory that the presence of charged dust in a plasma can lead to very low frequency dust acoustic waves and instabilities. In certain laboratory plasmas, however, the dust is strongly coupled, as characterized by the condition

$$\Gamma_d = Q_d^2 exp(-d/\lambda_D)/dT_d \geq 1,$$

where Q_d is the dust charge, d is the intergrain spacing, T_d is the dust thermal energy, and λ_D is the plasma screening length. When the dust is strongly coupled, the spatial correlation of the dust grains can affect the dispersion relation of dust acoustic waves. We discuss the dispersion properties of these waves in a plasma in which strongly coupled negatively charged dust grains interact with each other via a Yukawa (i.e. screened Coulomb) potential [1]. The strongly coupled gas phase (liquid phase) is considered, using a quasilocalized approximation scheme which had been developed to study waves in strongly coupled plasmas. The effect of dust-neutral collisions are also included. We extend the analysis to investigate the effects of strong dust coupling on an ion-dust two stream instability in a collisional dusty plasma. Applications to laboratory dusty plasmas are discussed.

[1]. M. Rosenberg and G. Kalman,*Phys. Rev. E* **56**, 7166, 1997.

Filamentary and void instabilities in a dusty discharge.

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Ion drag on particles in a gas discharge can excite two kinds of low-frequency instabilities of the dust cloud. Termed the filamentary and great void modes, based on their phenomenological appearance, these instabilities exhibit fluctuations of the dust number density and electron density. The ionization rate and glow are strongly modulated, so the modes are a type of ionization wave. They occur when the particle radius R is sufficiently large that the ion drag force, which scales as the the square of R, exceeds the Coulomb force QE, which scales linearly with R.

The instability develops as follows. A spontaneous rarefaction in the dust number density occurs, and the local electron depletion is suppressed, thereby augmenting the electron density and the rate of neutral gas ionization by electron impact. The dust rarefaction then becomes a region of more intense ionization, which has two effects. First, the region gains a more positive space charge, which tends to attract negatively charged dust particles inward, where they are few in number. This is stabilizing, since it would tend to restore the dust cloud to a uniform equilibrium. Second, ions flow away from the ionization region, applying an outward force on the grains. This force is destabilizing, since it further diminishes the dust number density in the void.

These phenomena are demonstrated in an experiment where carbon grains grow in diameter as a function of time. An rf argon discharge was used to sputter electrodes made of graphite and thereby grow particles. The instabilities are likely to occur in other types of dusty discharges, as well. We characterized the modes by laser light scattering, optical emission imaging, Langmuir probes and electron microscopy. When the particles grow to a critical diameter, the filamentary mode has a sudden and global onset. Later, the larger great void mode appears as a 100% dust-free hole in the dust cloud. Spectrograms reveal that the mode frequency diminishes as the particle diameter grows.

Charging of single micron sized dust grains by secondary electron emission: a laboratory study

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We present the details of a new laboratory study whose objective is to experimentally study the interaction of micron sized particles with plasmas and electromagnetic radiation. Specifically, to investigate under what conditions and to what extent do particles of various compositions and sizes become charged, or discharged, while exposed to an electron beam and ultraviolet radiation environment. The emphasis is the study of the two charging mechanisms, secondary emission of electrons and photoelectric effect.

The experiment uses a technique known as electrodynamic suspension of particles (1). With this technique, a single charged particle is electrodynamically levitated and then exposed to a controlled environment. Its charge to mass ratio is directly measured. Viscous drag measurements and Mie light scattering measurements characterize its size and optical characteristics. The environment to which the particle is expose may consist of room temperature and pressure or a rarefied atmosphere where only one major gaseous constituent is present, or, as in this case, a vacuum environment under electron bombardment or UV radiation (2,3). In addition, the environment can be cycled as part of the experiment. Therefore, using this technique, a single particle can be repeatedly exposed to a controlled environment and its response measured, or a single particle can be exposed to similar environments with minor differences and its response measured as a function of only the changed environmental conditions (4,5).

(1) R. F. Wuerker, H. Shelton, and R. V. Langmuir, J. Applied Phys., 30, 342 (1959).
(2) J. F. Spann, D. J. Maloney, W. F. Lawson, and K. H. Casleton, Appl. Opt., 32, 2152 (1993).
(3) E. J. Davis, and A. K. Ray, J. Colloid Inerface Sci., 75, 566 (1980).
(4) C. A. Kurtz, and C. B. Richardson, Chem. Phys. Lett., 109, 190 (1984).
(5) J. F. Spann, and C. B. Richardson, Atmos. Envirron., 19, 819 (1985).

Inter-Grain Coupling in Dusty Plasma Coulomb Crystals

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We have studied the lattice structure of dusty plasma Coulomb crystals formed in rectangular conductive grooves as a function of plasma temperature and density. The crystal appears to be made of mutually repulsive columns of grains confined by the walls of the groove. The columns are oriented along the direction of the electrode sheath electric field. A simple phenomenological model wherein the inter-grain spacing results from an attractive electric field induced dipole-dipole force balanced by a repulsive monopole Coulomb force is consistent with observed features of the Coulomb crystal.

Pair Correlations in Strongly Coupled Dusty Plasmas

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Correlation functions for dust particles in a strongly coupled plasma are calculated using the Kirkwood approximation. The kinetic integral equation is solved in long as well as short wavelength regimes. In the long wavelength regime, the pair correlation function is of the Debye-Huckel form with a shielding distance of the dust Debye length, and decays exponentially. In the short wavelength regime, when the spatial scale is of the order of the inter-dust-grain distance, the correlation functions exhibits pronounced oscillations and liquid-like behavior, as seen in recent laboratory as well as numerical experiments.

Particle-in-Cell and Molecular Dynamics Simulations of Strongly Coupled Dusty Plasmas: a Comparative Study

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A one-dimensional, strongly coupled plasma is studied by particle-in-cell (PIC) and molecular dynamics (MD) methods. Recent numerical results on particle correlation functions observed by the PIC method [Phys. Rev. Lett. 78, 468 (1997)] are compared with MD simulations and found to be in good agreement. In both simulations, for coupling parameters of order unity, the dust particles exhibit Debye shielding on the spatial scale of the dust Debye length in the presence of low-frequency waves, and the correlation function decays exponentially. Liquid-like or crystal-like correlations among the dust particles when the long-wavelength perturbations are damped by annealing. These features appear to be consistent with recent analytical predictions.

Liquid Plasmas and Plasma Crystals

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Microgravity experiments were performed onboard a rocket, which provided data on strongly coupled colloidal plasmas in the liquid and crystalline states. From these measurements it was possible to determine the properties of this new state of matter, including the solid/liquid interaction. The differences with respect to laboratory measurements operated under full gravity are discussed as well as open theoretical and experimental problems.

Microgravity experiments on strongly coupled dusty plasmas

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Gravity plays an important role for the production and stability of plasma crystals. In laboratory plasmas gravity has to be balanced out by the electrostatic field in the sheath of the electrodes of the experimental apparatus. Thus, in the vertical direction only monolayer crystals or crystals with a few lattice layers can be formed. This restricts the analysis to processes in 2-dimensional or “2 1/2-dimensional” crystals (e.g. the physics of monolayers, nano-crystals or grain boundaries). Under zero gravity larger (volume) systems are possible and the field of plasma crystal research can be extended to include the physics of 3-dimensional systems.

We performed the worldwide first experiments under zero-g conditions on parabolic flights and two sounding rockets. Parabolic flights allow low gravity ($\approx 10^{-2}$g) time periods of between 10 and 15 sec, while we had 6 min of zero-g (10^{-4}g) in the sounding rockets. During these experiments the behaviour of dust particles in a rf-discharge under zero-g conditions is investigated. Very interesting experiments were performed, which are possible only under low gravity conditions. The new phenomena seen on the first sounding rocket experiment launched in Nov. 1996 include a “void” of particles in the center of the experimental apparatus, a poloidal circulation pattern in the perimenter, and the relaxation of the particle cloud after the switch off of the plasma. In the second sounding roket experiment launched in Feb. 1998 we could form a large 3-dimensional plasma crystal while the “void” in the center was stationary. By filling the “void” with dust particles we observed a dust plasma instability which propagates through the dust cloud.

Dusty Plasma Experiments Relating to Noctilucent Clouds

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Noctilucent clouds (NLC), polar mesospheric summer echoes (PMSE) and localized ”bite-outs” in the density of free electrons are caused by small ice particles in the lower ionosphere. Rocket-borne charge collectors have recently found evidence for both positive and negative aerosols near NLC and PMSE layers (Havnes et al., JGR 101, 10838, 1996). The mass distribution of these particles and the reaction rates for electron attachment, photoionization, photodetachment, etc. which are necessary for modeling are not known. Two new experiments are underway to answer these questions. First, a rocket-borne charge-collecting probe with a magnetic field for mass discrimination has been constructed and tested in the laboratory. The magnetic field prevents collection of singly-charged species with mass below a threshold determined by the rocket velocity and the magnetic field strength. Laboratory tests of a prototype probe show that the magnetic field is effective in preventing collection of low energy electrons. Second, a large plasma chamber (0.9 m diameter x 1.2 m) is being fitted with a supersonic nozzle which generates ice clusters. Clusters which become charged will be detected by Faraday cups and their mass distribution will be determined by mass spectrographs. Electron attachment rates willbe inferred from the dependence of the charged fraction on the electron density. An arc lamp source with a cutoff wavelength similar to that of the solar spectrum at 80 km will be used to determine the role of photodetachment and possibly photoionization. Sodium or other impurities may be added to the flow creating the particles to determine whether or not their presence results in a lower work function.

Recent Advances in Meteor Echo Detection and Collection: New Research Capabilities

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Recent upgrades to the Meteor Echo Detection and Collection (MEDAC) systems in the equatorial Pacific have been made. These upgrades include the ability to collect raw data, improved user-friendly diagnostics, and improved post-processing algorithms of the data. The wind-profiler host radars have been modified to 5-antenna beam systems allowing for narrow-beam coplanar studies to be made. In addition, MEDAC has now been deployed in an all-sky meteor radar system located in Greenland.

With the new capabiities in data collection we are able to see a number of different types of echoes that are not the traditional underdense meteor echo. Information extraction about radiants, meteor velocities, Farady rotation, and temperature is now being explored. The narrow–beam coplanar results show interesting new results at Christmas Island where a large diurnal vertical motion has been detected.

This presentation will summarize some of the new advances and opportunities for studies using MEDAC.

Charging of Dust in the Local Interstellar Medium

Hiroshi Kimura and Ingrid Mann

Lorentz forces as well as radiation pressure forces prevent charged dust grains from entering the solar system. On the other hand, dust particles detected with the Ulysses spacecraft have been identified as interstellar from their impact direction as well as their relative velocity to the spacecraft. Also future measurements are planned to study the elemental composition of these particles and also to carry samples back to Earth. We study the electric grain charge of dust particles at the heliospheric boundaries, their resulting motion and selection effects.

Modifications to Collision Cross Sections and Coagulation Rates due to Grain Charging

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Observational evidence of electrical forces acting significantly on small solids is apparently present for both the modern solar system in Saturn's rings (Burns, 1980) and the ancient solar system in chondritic meteorites (Buseck, 1993). It is likely that grain-grain coagulation rates are affected by the distribution of charges on small grains. Plasma particle impacts and photoelectric effects can provide the charges. It appears that some charging is inevitable and that plasma grain interactions need to be evaluated to determine the size of the effect on coagulation rates.

We apply the results of our previous charging work (Manweiler et al., 1996, Manweiler et al., 1993) to models of the early solar nebula. It is expected that the early solar nebula is weakly ionized (Umebayashi, 1988) except in certain instances and locations such as: solar flares in the interior, ultraviolet radiation at the outer boundary, and during enhanced luminosity of the star. Since the grains we study are non-conducting and show strong dipole moments in flowing plasma, we modify the geometric cross sections to include the effects of flowing plasma on non-conducting grains with plasma mediated shielding.

This paper provides results showing how plasma flow affects the processes involved in charging the grains; total charge and charge distribution. We calculate the modifications to the cross sections and subsequent changes in the coagulation rates.

Burns, J. A. et al., Icarus, 44, 339, 1980.
Buseck, P. et al. , Discover, 13, July 1993.
Manweiler, J. W. et al., "The Physics of Dusty Plasmas", P.K. Shukla, et al., Eds., World Scientific, p. 22, 1996.
Manweiler, J. W. et al., 5th Dusty Plasma Workshop, Univ. of Alabama-Huntsville, 1993.
Umebayashi, T. et al., Progress of Theoretical Physics Supplement, 96, 151, 1988.

Dust Streams in the Jovian Magnetosphere

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Impacts of dust stream particles were observed during all passages of the Galileo spacecraft through the jovian system inside 100 jovian radii. Both impact rates, amplitudes and rise-times of impact signals displayed clear correlations with the jovian magnetic field at the position of Galileo. Distinct start and stop times of the dust streams were recognized as well as times in between when the impact direction changed by 180 deg. These three times are compatible with particles entering and exiting the field-of-view of the dust detector and those arriving along the spacecraft spin axis. It is assumed that particles on the same mean trajectory cause this behavior. Model calculation of electromagnetically accelerated dust grains of different sizes, initial speeds, and charge states have been performed for different places of particle release in the jovian system. It is found that only trajectories of particles of high angular momentum can explain the observations. Only trajectories of 5 to 10 nm-sized particles that have been generated outside about 5 Jupiter radii distance from Jupiter match the observed impact directions. It is concluded that the probable source of the dust streams is Io.

Charged Dust Dynamics: Lessons from Jupiter, Expectations for Saturn

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The Jovian magnetosphere shows a number of dusty plasma phenomena. The ring/halo region close to the planet, allows for the remote sensing of the fields and particles environment of the inner most regions of the magnetosphere. The dust streams, seen by Ulysses and Galileo, put constraints on the plasma properties of the Io torus, for example. The magnetosphere sculpts the size and spatial distribution of the small grains often resulting in capture, transport, energization and ejection of the dust particles.

In this talk I will combine Voyager, Ulysses and Galileo observations (imaging, plasma science and dust) to show that small dust grains - acting as active plasma probes - allow for a unique consistency test of our models of Jupiters magnetosphere. I will also make a survey of the past Voyager observations and the expected Cassini measurements at Saturn, where dust plasma effects are important.

Captured Interplanetary and Interstellar Dust at Jupiter

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Interplanetary and interstellar dust particles stream through the Jovian magnetosphere where their orbits are perturbed by the Lorentz force. Energy and angular momentum exchange with the magnetosphere can lead to capture of some sub-micron dust particles into dynamically stable orbits around Jupiter. The captured grains can be on prograde or retrograde orbits, and their final orbits are usually in the semi-major axis range of 2 to 20 Jupiter radii, with eccentricities $\sim 0.1-0.8$ and inclinations $< 20°$ ($i > 160°$ for retrograde orbits). Captured grains have radii between about 0.5 and 1.5 μm. These captured dust particles form a diffuse band of material around Jupiter, outside the main Jovian ring, with a peak normal optical depth of $\tau \sim 10^{-9}$. While this is too low for optical detection, the Galileo dust detector has detected particles on prograde and retrograde orbits around Jupiter whose sizes, orbital properties, and number density are consistent with captured interplanetary and interstellar dust.

Electrostatic charging of Lunar dust

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Perhaps one of the most interesting and controversial science issue from the Apollo era remains the possible electrostatic levitation and transport of lunar dust. This issue is also of great engineering importance in designing and protecting optical devices, for example.

Transient dust clouds suspended above the lunar surface were indicated by the horizon glow observed by the Surveyor spacecrafts and the Lunar Ejecta and Meteorite Experiment (Apollo 17), for example. The theoretical models cannot fully explain these observations, but they all suggest that electrostatic charging of the lunar surface due to exposure to the solar wind plasma and UV radiation could result in levitation, transport and ejection of small grains.

We report on our experimental studies of the electrostatic charging properties of an Apollo-17 soil sample and two lunar simulants MLS-1 and JSC-1. We have measured their charge after exposing individual grains to a beam of fast electron with energies in the range of $20 \leq E \leq 90$ eV. Our measurements indicate that the secondary electron emission yield of the Apollo-17 sample is intermediate between MLS-1 and JSC-1, closer to that of MLS-1.

We will also discuss our plans to develop a laboratory lunar surface model, where time dependent illumination and plasma bombardment will closely emulate the conditions on the surface of the Moon.

Laser-excited Dust Lattice Waves and the Nonequilibrium Phase Transition of the Plasma Crystal

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The knowledge of the interaction of the dust particles is the key for understanding the crystal structure and the phase transition of the plasma crystal. The plasma crystal consists of particles of micrometer size which are trapped in a parallel plate rf discharge. The particles are levitated by a balance of electric field force and gravitation in the sheath above the lower electrode.

The excitation of waves in plasma crystals is a powerful tool to study the interaction forces. We present measurements on the excitation of waves in a single-layer plasma crystal by means of laser radiation [1]. The particles are pushed by the radiation pressure of an argon ion laser. The measured dispersion relation is compared with theories of dust lattice waves (DLW) and dust acoustic waves (DAW). The measured dispaersion is found to be well represented by 2D-DLW. 1D-DLW and DAW are not in agreement with the wave dispersions. From the dispersion relation the screening length of the dust particles in the sheath environment is determined and is found to be of the order of the interparticle distance.

Plasma crystals undergo a phase transition from ordered solid structures to liquid and almost gas-like states when the gas pressure is reduced [2]. The dust particles show an increase in energy from room temperature to about 50 eV. The particles also perform characteristic oscillations about their equilibrium position during the transition. In a linear analysis [3] the transition has been explained by an ion induced instability, where the ion streaming motion results in a formation of regions of enhanced ion density in the wake below the dust particles leading to the oscillatory behavior of the dust particles.

A non-linear model of the phase transition induced by reduction of the gas density will be presented here [4]. Due to the energy transfer from the ion flow to the dust particles the phase transition is a nonequilibrium transition. It is found that the plasma crystal melting comprises a two-step transition. In a first step, the particles are heated due to the instability found in the linear analysis, which does not immediately lead to melting, however. The transition to a liquid state is observed only in a second step. Moreover, the plasma crystal is shown to melt at much higher particle energy than expected from equilibrium melting.

This behavior can be attributed to the fact that high frequency (short wavelength) modes are preferably excited in the crystal, whereas the low frequency modes responsible for equilibrium melting are suppressed. Experimental findings on the melting transition will be compared with the non-linear theory.

[1] A. Homann, A. Melzer, S. Peters, R. Madani, A. Piel, to appear in Phys. Lett. A

[2] A. Melzer, A. Homann, A. Piel, Phys. Rev. E 53 (1996) 2757

[3] A. Melzer, V.A. Schweigert, I.V. Schweigert, A. Homann, A. Piel, Phys. Rev. E 54 (1996) 46

[4] V.A. Schweigert, I.V. Schweigert, A. Melzer, A. Homann, A. Piel, submitted to Phys. Rev. Lett.

Fine-Particle Coulomb Lattice Formed and Controlled in a dc Discharge Plasma

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The Coulomb lattice of strongly-coupled fine particles, which has a two-dimensional hexagonal structure, is formed in a dc discharge plasma. Static and dynamic properties of the fine particles are controlled by changing plasma parameters, particle injection, and electric potentials applied to electrodes for particle levitation and confinement. A double-plasma method is also employed to vary the lattice properties. Vortex flows of the particles are generated by two methods: insertion of a small metal plate biased electrically and application of a magnetic field in the vertical direction.

Experiments on Ion and Dust Acoustic Waves

A. Barkan, N. D'Angelo, R. L. Merlino, and C. Thompson

A review of recent experimental work performed by our group at the University of Iowa on current-driven dust ion acoustic (DIA) and dust acoustic (DA) waves will be presented. A discussion of relevant theoretical work will also be included.

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Fine Particle Plasmas Interacting with Electric and Magnetic Fields

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Fine particle plasmas were produced by irradiation of UV light on aluminum fine particles generated by using boat method. Fine particle plasma densuty was obtained by observing the attenuation and scatter of He-Ne laser light. Fine particle plasma beam has pass through the static electric fields and static magnetic fields. Plasma beam separated into two beams after pass through the fields. We could estimated the charges of particles by using the its separation and trajectory. We are now try making simulations of planetary rings.

Vertical Structures in a Dusty Plasma

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Stable one- and two-dimensional vertical structures are formed from 6-micron diamond particles introduced into a low-density inductively-coupled argon plasma. Vertical ‘strings’ up to seven particles high form readily above a tubular template on the lower electrode, and exhibit remarkable stability. The string remains in tact even in the presence of perturbations sufficient to cause two of the particles to exchange positions. When the template is removed to leave a flat lower electrode, at most two particles remain vertically aligned. Two-dimensional vertical ‘walls’, 4-5 particles high and approx. 200 particles long, exhibit similar stability. Throughout the wall, the particles are arranged with strict vertical alignment, as observed in three-dimensional crystals.

The stability of these structures is discussed in terms of ion flow models.

Dynamics of Particulates in a Dusty Laboratory Plasma

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An understanding of the dynamics of dusty plasmas is necessary for developing means of reducing contamination effects in the microelectronics industry. Experimental evidence suggests that contaminating dust may grow by agglomeration. A thorough understanding of how the charged dust interacts with the plasma and with neighboring dust particulates can help reduce, control, or even prevent particle agglomeration, ultimately resulting in a control of particle size and morphology.

Traditionally, laser light scattering techniques have been employed to experimentally investigate the behavior of dust in the plasma. In this contribution, we revisit the use of laser Doppler techniques to investigate dust behavior, utilized previously by Boufendi and coworkers (J. Appl. Phys 73 (5) p.2160). Laser Doppler Velocimetry in two dimensions allows spatially resolved velocity and concentration to be measured in real time. We will present results of a parametric study which investigated the spatially resolved particle dynamics (2-D velocity and concentration) as a function of chamber pressure, plasma power, reaction time, and particle concentration for monodisperse particles electrostatically trapped in an inert rf plasma.

The dust in this system exhibited energies hundreds of times greater than the surrounding neutral gas, which characteristically decreased with increased pressure, and increased with increased power. The trajectories of the dust appeared to be randomly oriented through the laser probe control volume. Dust energies were highest near the powered electrode and decreased monotonically towards the bulk plasma. Local dust concentrations, however, exhibited a maximum near the center of the particle trap. Experimental evidence suggests that dust concentrations and dust energies are not correlated.

Particle growth in silane plasmas

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Silane plasmas used to produce amorphous hydrogenated silicon films also inadvertently produce silicon particles which become incorporated into the films. While these particles are not large enough to create shorts, they are numerous enough to diminish the film's electrical properties. Our parallel plate rf discharge of pure silane is designed to mimic industrial reactors used to make photovoltaics. We have developed a light-scattering method to measure the size and density of these particles above the substrate. The particle size is determined from the rate of diffusive loss of particles from the gas in the period immediately after the discharge is switched off. The particle density is then found from the intensity of the scattered light using the particle size to calculate the scattering cross section. We have measured the particle size and density as a function of discharge conditions. We observe that the particle growth rate is linear after a brief period of non-linear growth, that the particle density decreases during the discharge, and that both growth rate and density are very sensitive to gas pressure and discharge voltage.

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Production of Waves during Dust Cloud Expansion into a Plasma

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The early time production of waves associated with the expansion of a dust cloud into a background plasma across a magnetic field is studied by using numerical simulations and a theoretical model. Simulation results show that as the dust expands into the background plasma and charges up, a strongly sheared ambipolar electric field develops across the dust cloud boundary. This electric field results in a sheared $E \times B$ electron flow in the boundary. Plasma irregularities are observed to develop in the boundary on a timescale less than the background ion cyclotron period. The irregularities are interpreted to be driven by the strong shear in the electron flow velocity. It is also noted that fluctuations in dust grain charge are associated with the production of the irregularities in ion and electron densities. A model for a velocity shear-driven plasma instability is investigated under these circumstances. The results of the theoretical calculations show good agreement with the numerical simulation results.

Influence of Dust Particles on Non-linear Sheaths

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Non-linear sheaths are existing on all cold walls which the plasma is in a contact. These sheaths determine an interaction of plasmas with wall surfaces including flows of charged particles from plasmas to these walls. In much practical important cases, for example at an interaction of a laser radiation with a pellet, dust particles can be created close to a surface. These particles can strongly influence various plasma properties, including sheaths, due to a selective collection of electrons and ions from plasmas.

The purpose of this work is to study non-linear sheathes in plasmas with dust particles in order to investigate an influence of these particles on sheaths. The PIC method is used for computer modelling of sheaths taking into account the dynamics of dust particle charge in plasmas with self-consistent energy distribution functions of electrons and ions [1-3]. The Coulomb scattering of electrons and ions are taken into account in the framework of the method of stochastic differential equations or the Monte-Carlo method.

Spatial distributions of various sheath parameters were calculated, namely: self-consistent electric potentials and fields, electron and ion densities, their velocity as well as dust particle charges in non-linear stationary sheaths. Obtained results show essential differences of properties of these sheaths from cases of sheaths without dust particles. An influence of dust particles on sheaths depends from a relation of a penetration time of an ion through sheath to an ion collection time or an ion scattering time. An special strong difference is at a condition that these times are about equal. In these cases, an ion flux from a plasma is damping essentially in a sheath but it arrive an electrode so that self-consistent charges of dust particles in sheaths are strongly non-uniform. An electric current in an external circuit is less as in cases without dust particles so that VA characteristics of sheaths with dust particles differ essentially from cases of sheaths without dust particles.

References

1. Chutov Yu.I. et al., J.Plasma Phys. 1996. V.55, part 1. P.87-94.
2. Sytenko O.G.et al., Plasma Phys. and Contr. Fusion. 1996. V.38, No 12a. P.A105-A120

3. Chutov Yu. et al., Physica. 1996. V.B128. P.11-20

MD Simulations of Dipolar Dusty Plasmas

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There has been recent interest in the lattice structure of dusty plasmas produced in plasma reactors. In particular, the origin of planar hexagonal lattices (with dislocations) and simple hexagonal-like configurations normal to the planes have attracted attention. One explanation for the emergence of these configurations is the presence of a competition between spherical Debye-Huckel interactions and dipole interactions induced in the grains by the strong external electric field [H.C.Lee et al., PRE 56,4596(1997)]. We present MD simulations based on such a dust-dust interaction potential,

$$W(R) = \exp^{-k_d R}\left[\frac{(Q^2 - k_d^2 d^2)}{R} - \frac{2d^2}{R^3} - \frac{2d^2 k_d}{R^2}\right]$$

in a non-linear background potential which accounts for the sheath potential and gravity [Hammerberg et al., Strongly Coupled Coulomb Systems 1997, proceeding]. (Here Q is the total charge, d is the dipole moment, and k_d is the Debye wavevector.) Changes in grain geometry due to the presence of the induced dipoles are discussed.

Relaxation of Background Electrons and Ions in Dusty Plasmas

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Plasmas with micrometer or submicrometer size dust particles observed in space plasmas, as well as in many laboratory and technological devices, have been intensively investigated in recent years. These dust particles can strongly influence the plasma properties because of the large charge as well as the dynamics of this charge.

This paper consist of a discussion of numerical investigation results of relaxation phenomena in dusty plasmas with taking into account the charge dynamics of dust particles without the assumption on equilibrium electrons and ions. A collection of background electrons and ions by dust particles have been taking into account in the framework of the modified PIC method, the Coulomb collisions have been simulated in the framework of the method of stochastic differential equations or the Monte-Carlo method.

The obtained results show that the electron and ion energy distribution functions as well as plasma parameters change strongly during the plasma relaxation due to a selective collection of electrons and ions by dust particles with a self-consistent negative charge. The peculiarities of these changes are caused by a dependence of this collection on energy of electrons and ions.

Computer modeling of relaxation phenomena in some dusty crystals shows also an essential influence of a collection of electrons and ions by dust particles on these phenomena. Relaxing background electrons and ions can be non-ideal components of these dusty crystals due to a self-consistent electric potential even in the case if an initial number of electrons and ions in the Debye cube is essentially more one. Besides, electron and ion velocity distribution functions can be strongly non-equilibrium in such plasmas due to a selective collection of electrons and ions by dust particles. Spatial distributions of background electrons and ions around dust particles can be strongly non-uniform so that some sandwich structure of a space electric charge can be realized.

Previous results of these investigations were published in [1-11].

References

1. Chutov Yu.I. at al. Ukrainian Journal of Physics. 1997. V.42, No 8. P. 996-1015.
2. Chutov Yu.I. at al. Contributed papers of 24th European Physical Society Conference on Controlled Fusion and Plasma Physics, 9-13 June 1997, Kongresshaus Bercht-

esgaden, Germany. Abstracts of Invited and Contributed Papers, p.401.

3. Chutov Yu.I. at al. Contributed papers of 24th European Physical Society Conference on Controlled Fusion and Plasma Physics, 9-13 June 1997, Kongresshaus Berchtesgaden, Germany. Abstracts of Invited and Contributed Papers, p.402.

4. Chutov Yu. I. at al. Contributed papers of XXIII ICPIG, 17-22 July 1997, Toulouse, France, V.5, p.V.64-V.65.

5. Chutov Yu.I. et al. J.Plasma Phys. 1996. V.55, part 1. P.87-94.

6. Sytenko O.G.et al. Plasma Phys. and Contr. Fusion. 1996. V.38, No 12a. P.A105-A120

7. Chutov Yu. et al. Physica. 1996. V.B128. P.11-20

8. Chutov Yu.I. at al. In: Double Layers - Potential Formation and Related Nonlinear Phenomena in Plasmas. Edited by SENDAI "Plasma Forum" Tohoku University Sendai 980-77, Japan. Published by World Scientific Publishing Co. Pte. Ltd, Singapure 9128, p.419-428.

9. Chutov Yu.I. et al. Contr. papers of the International Conference on the Physics of Dusty Plasmas, 21 - 25 October 1996, Goa, India. Abstracts of ICPDP'96, p.93

10. Chutov Yu.I. at al. Contributed papers of 1996 International Conference on Plasma Physics, 9-13 September 1996, Nagoya, Japan. V.2, p. 1970–1973.

11. Chutov Yu.I. at al. Contributed papers of 23rd European Physical Society Conference on Controlled Fusion and Plasma Physics, 24-28 June 1996, Kiev, Ukraine. Part III, pp.1183-1186.

Dust Particulate Phonon Interaction

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Interaction of dust particulates and phonons is studied theoretically in the context of plasma crystals. A pair of dust particulates attract each other through the exchange of phonons. A potential produced by the pair of dust particulates is known as a wake potential which was formed behind the dust particulate in the ion flow. We consider stability problem of a gas of dust particulates among which phonons are exchanged, as well as the stability of polygon structures in the plasma crystals.

Surface Electromagnetic Waves in Dusty Plasma

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This report is devoted to the electromagnetic surface waves excited in cylindrical structures consisted with multycomponent magnetized plasma. These dusty charged cylindrical plasmas are present in Space (comet tails,instellar and circumstellar clouds etc). The dispersion relation for the surface electromagnetic waves is analysed for different directions of the magnetic field. It has been shown that the surface electromagnetic waves range of frequencies is defined by the Langmuir and cyclotron frequencies of the charged grains. The frequecies range of waves propagating along the magnetic field and normal to one are different.

In the case of the propogating of the waves along the magnetic field there is a minimum of the wavenumber and surface waves are slow. Their velocity is less than velocity of the volume dusty acoustic wave. If the magnetic field is normal to the plasma boundary , the phase velocity of waves nearby minimum cyclotron frequency may be arbitrary greater of the velocity of the acoustic wave. These waves we used for the explanation some interesting effects in dusty plasma of comets.

Waves in Dusty Plasma Crystals with Dipole Interactions

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Nonsymmetric effective interactions between dust grains in dusty plasmas can arise from a variety of mechanisms such as nonuniform charging, ion focusing and wakes, plasma density gradients, and induced grain polarization. These effects can be included by describing the total effective interaction in terms of its first two multipoles: the monopole term which corresponds to the usual screened Coulomb repulsive interaction, and the dipole term which can be either repulsive or attractive depending on the orientation of the grains. We consider dust waves propagating along the dipole axis in such a system (in its crystalline phase) and dispersion relations are presented.

Low frequency cross-field instabilities in collisional dusty plasmas

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The presence of charged dust in a plasma can lead to the appearance of low frequency dust acoustic waves that can be driven unstable by the drifts of ions and electrons relative to dust. In certain dusty plasma environments with external magnetic and electric fields, the ions and/or electrons can acquire $E \times B$ drifts. We investigate dust acoustic instabilities driven by such cross-field drifts in collisional dusty plasmas. A kinetic analysis is used, and collisions with neutrals are taken into account. Applications to dusty plasmas in the mesopause and in laboratory plasmas such as ECR process plasmas are discussed.

Collisional Electrostatic Dust Cyclotron Instability

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The electrostatic dust cyclotron instability (EDC) in dusty plasmas is analogous to the electrostatic ion cyclotron instability (EIC) in electron-ion plasmas and negative ion plasmas. While the EIC instability is driven by an electron drift along the magnetic field, the EDC instability is driven by an ion drift along B in a plasma with negatively charged dust. The frequency of these EDC waves is of the order of the dust cyclotron frequency, which can be much smaller than the ion cyclotron frequeny due to the dust's small charge-to-mass ratio. Thus, at these lower frequencies, it is necessary to also consider the effect of collisions (ion-neutral, electron-neutral, and dust-neutral).

A kinetic analysis of the electrostatic dust cyclotron instability in a weakly ionized collisional dusty plasma is presented. Three regimes are considered: the collisionless case, in order to compare with the subsequent collisional results, the weakly collisional case, where the wavelength component along B is much smaller than the electron and ion mean free paths, and the strongly collisional case, where the wavelength component along B is much larger than the electron and ion mean free paths. It will be shown that dust-neutral collisions are stabilizing while ion-neutral collisions can slightly increase the growth rate of the instability. Possible applications to space and laboratory environments are also discussed.

Effect of Dust Size Distribution on an Ion Dust Streaming Instability in a Collisional Plasma

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Dust grains have dust size distributions in many space and laboratory dusty plasma environments. This can affect the properties of very low frequency dust waves and instabilities. In this paper we investigate the effect of a dust size distribution on an ion-dust streaming instability in a collisional dusty plasma. A fluid analysis is used, and collisions with neutrals are included. Applications to laboratory dusty plasmas are discussed.

Wave propagation in 2-fluid dusty plasma system

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The propagation of electro-static waves in 2-fluid dusty plasma system is investigated. Earlier discussion on dusty plasma is mainly treated as the 1-fluid dusty plasma system under the condition where only the dynamics of the fluid motion of the dust particles is analized. We investigate the dynamics of the dust particles and ions in this 2-fluid dusty plasma system. The electro-static waves in dusty plasma is developed as the new mode.

Elementary processes: charging and recombination of dusty particles in the ionosphere.

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There are some layers of dust particles 1-5 km in a thickness at heights 80-100 km. The density of these particles changes from 0.5 cm^{-3} to 10 cm^{-3} [1]. Unfortunately, our knowledge regarding dust origination, its composition and particle sizes are far from perfect. However, we can make some evaluations based on experimental data mentioned above. At heights about 80 km, the dust is probably composed of ice, sometimes with metallic impurities. At higher altitudes (90-100 km), the main components of dust are meteor ablation, rocket exhausts products and materials from destroying parts of space vehicles. The average size of such dust particles is a 1 micrometer or less [2]. If the electron temperature increases to 1000-1300K a dust particle may carry about 100 electrons. But the process of electron deposition may have a “fine structure” - it is a complex kinetic phenomenon with own characteristic time, etc.

We assume that the surface states of electrons on a dust particle is analogous to those on the surface of solid hydrogen and liquid helium [3]. Therefore electrons are bound in the normal direction to the surface of a dust particle and remain practically free in the tangential directions. Basing on such assumptions we can obtain that the electron bound energy on the dust surface is near 1eV. Only a few surface states will be realized. When an ion collides with a charged dusty particle the electron-ion heterogeneous recombination with formation of atoms in particular excited states occurs. This is caused by the peculiarity of the decay of a quasimolecule: surface electron - ion with formation of a neutral atom. This process obviously has dominant probability if the surface electron energy is close to the energy of the atom [4]. Therefore, an atom appears in a highly excited state. The intensity of the convention infrared radiation of these highly excited atoms in the vicinity of wavelengths 2-4 micrometer may be evaluated. In conclusions we can assert that this approach may lead to: 1). reasonable estimation of charging and recombination processes with dusty particles as the sources of infrared radiation in the definite part of spectrum; 2). clarification of the possible item of highly excited atoms (atoms in the Rydberg’s states-ARS) in the ionosphere; 3). examination of the charging process of dusty particles in the equilibrium conditions and formulation Sakha - type equation.

REFERENCES

1. O. Havnes et al., “Charged Dust in the Earth’s Mesopause (Effects on Radar Backscatter)”, Physica Scripta, v.45, pp. 535–544 (1992).
2. K. Fricke et al., “Visual and radar observation of rocket induced effects in the upper atmosphere above Andoya Jan. 25, 1995”, 12th EAS Symposium, 29 May–1 June, Norway (1995).
3. E.Kogan, Eu. Martysh, “Optical properties of dielectric surface levels”, Zhur. Tekhnicheskoi Fiziki (USSR),v. 51(7), pp. 1329–1337 (1981) (in Russian).
4. V.Ivchenko, E.Martysh, V.Malnev, “Seismogenic Electromagnetic Emission in Optical and Infrared Range” Inter. Symposium PLASMA-97, Poland, June 10–12, Contrib. Papers,v.1,p.419–422 (1997).

Trapping of dust particles in glow discharge plasmas in the Fisk Plasma Source

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The Fisk Plasma Source (FPS) is a flexible new plasma device that has recently begun operating at Fisk University. Three micron diameter alumina particles are placed on a tray inside the FPS vacuum vessel. Dusty plasmas are produced by suspending the alumina particles in argon DC glow discharge plasmas. A 10 mW HeNe laser is used to illuminate the dust particles in the plasma. Experiments have been performed on the trapping of dust particles in the plasma as a function of the potential on the tray and as a function of the potentials on the anode and cathode. Probes and video images are used to diagnose the behavior of the dust particles in the plasma. Results of experimental and computational studies will be presented.

A Laboratory Study of Secondary Electron Emission of Particles in a Dusty Plasma

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The study of dusty plasmas is filled with numerous observable phenomena in the space environment including interplanetary space, planetary magnetospheres, comets, and planetary rings. Studies have shown that micron size particles or "dust particles" charged and immersed in a plasma can alter a plasma's characteristics while the ions and electrons in a plasma impacting a particle can affect the particles potential. One key to understanding these phenomena is a full understanding of the charging mechanisms of a dust particle in a plasma. In particular, we are interested in studying secondary electron emission.

In this paper, we will discuss present preliminary results from a unique laboratory technique known as electrodynamic suspension of particles. Here, a single charged micron size particle is suspended in a quadrupole trap and then subjected to a controlled environment. Currently, initial measurements and observations have been recorded to calculate the charge to mass ratio. Also steps have been taken to integrate an electron gun into the laboratory set up. Once this is achieved, the particle will be subjected to an electron beam and the particles charge as well as beam current flux will be measured. By using this technique, a better understanding of the microphysics of a single charged particle in relation to secondary electron emission can be achieved.

Very Low Frequency Void Instability in Silane Discharges

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Silane discharges are the workhorses for plasma processing applications as well as for the investigation of particle formation and dynamics. The particles grown in these discharges usually fill almost the entire plasma volume. Under some conditions, however, regions which contain no dust particles, so called voids, are found in these discharges [1].

Here, we present experiments on a void instability, where the dust free regions periodically increase and decrease in size, the ”breathing mode”. This mode has a period of a few minutes. The particle dynamics of this mode is investigated by Mie scattering which allows to determine the size and the density of the involved particles. It is shown that the instability has a slowly and a rapidly evolving phase. The slow phase shows an almost constant (small) size of the void and the fast phase includes the expansion and subsequent collapse of the void. It is found that the growth rate of particle formation and small particles play the main role in this instability.

This behavior can be explained in terms of an analytical model. This model takes into account the growth mechanisms of the dust particles. The “breathing mode” is due to the competition of large and small particles for the silane radicals, which leads to the observed oscillatory behavior of the void region. Also the slow and fast phase are recovered in the model [2].

[1] G. Praburam and J. Goree, Phys. Plasmas 3 (1996) 1212
[2] A. Melzer, A. Homann, A. Piel, V.A. Schweigert, I.V. Schweigert, to be published

Nonlinear Dust-Plasma Interactions of a Cross-Beam System in Interplanetary Space

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Dust plasma interaction is been considered. The present work is an extension of the paper of Mann and Mckenzie [Mann and McKenzie, 1997]. Using the cross-beam configuration we investigate the dust plasma interaction taking into account the inhomogeneity of the solar wind density. The dust interacts in our case with an inhomogeneous collisionless multi-ion plasma. Linear and nonlinear behaviour of the system is been examined and its impact on the dust dynamics will be pointed out.

Subject headings: dust, inhomogeneous multi-ion plasmas, solar wind and interplanetary space

Dynamics of Charged Dust Near the Sun

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We present model calculations of the dynamics of near solar dust. The dynamics of interplanetary dust is expected to change near the sun under the influence of the solar magnetic field. The Lorentz force acting on particles in the solar magnetic field depends on the electric charge and on the velocity of grains. Model calculations of the electric grain charge for particles at different solar distances could not show a significant influence of the grain material on the charge of the grains. However, the dynamics depends on the size as well as the material composition of the dust particles. Calculations have shown that particles of several micrometer in size and beyond are only slightly affected by the solar magnetic field. Their spatial distribution near the Sun still reflects the initial inclination of orbits and hence allows for some clues about the sources of the dust cloud. Strongly absorbing particles are influenced predominantly by radiation pressure forces and are expelled from near solar regions. Small dielectric particles can drift closer to the Sun. They are stronger influenced by the Lorentz force and change their orbital inclinations. Although these effects depend on the solar magnetic field there is no clear indication of a solar cycle variation in the near solar dust dynamics.

Dusty Plasma Effects in the Solar Wind ?

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Although we cannot regard the near solar region as a true dusty plasma, it certainly shows several effects that are interesting from the point of view of dust plasma interactions. Here we describe the interaction of the radially expanding solar wind plasma with charged cosmic dust in Keplerian motion around the Sun within the framework of multi component hydrodynamics. In this cross beam configuration compressive (electrostatic) perturbations can be driven unstable. In particular acoustic like waves propagating against the Keplerian motion coupled to acoustic waves in the solar wind plasma yield instability when their phase speeds are equal. We calculate the growth rates for two sets of particles, one component with size 0.1 micrometer and one component of size 1 micrometer.

Temperature-gradient-driven flows of ions and neutrals in dusty plasmas.

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Dynamics of a low-temperature partially ionized plasma of, e.g., thermal emission converters, plasma diodes, and plasma surface deposition and etching devices, is important for optimization of the operating parameters of the latter. Usually, multi-component plasmas in these facilities are weakly ionized, the sheaths have different temperatures, and the magnetic field is applied externally, or is created by plasma currents [1-3]. As a rule, it is supposed that the plasma dynamics is governed by the Lorentz forces, and the plasma (ion and neutral) viscosities play only the complimentary role in equalizing sheared plasma velocities. We show in this paper, that in a multi-component collisional weakly ionized plasma with temperature gradient, the plasma viscosities do can induce (although in a complicated way) specific plasma flows, which can be realized for some laboratory conditions.

An important feature of the plasma technological devices is the necessary present of natural contamination or dust [4-6]. The dust particles (grains) are normally highly charged by plasma currents, photoemission, secondary emission, etc., and they strongly affect collective properties of a plasma [7]. Here, we demonstrate that the dust contaminants affect plasma transport properties inducing temperature-gradient driven ion flows which can also entrain neutrals in partially ionized laboratory plasmas.

[1]. T. Van Duzer and J.R.Whinnery. in: Crossed-Field Microwave Devices, ed. E.Okress (Academic, New York, 1961).

[2]. C.K. Birdsall and W.B. Bridges. in: Electron Dynamics of Diode Regions (Academic, New York, 1966).

[3]. Yu.P. Raizer. Gas Discharge Physics (Berlin, Springer, 1991).

[4] G.S. Selwyn, J. Singh, and R.S. Bennett, J. Vac. Technol. A **7** (1989) 2758.

[5] M.J. McCaughey and M.J. Kushner, J. Appl. Phys. **69** (1991) 6952.

[6] J.E. Daugherty, R.K. Porteous, M.D. Kilogre, and D.B. Graves, J. Appl. Phys. **72** (1992) 3934.
[7] S.V. Vladimirov, in *Nonlinear Waves and Chaos in Space Plasmas*, ed. by T. Hada and H. Matsumoto (Terra Scientific, Tokyo, 1997), Chapter 7.

Experimental investigation of particle heating in a strongly-coupled dusty plasma

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Recent plasma crystal experiments by various groups have shown particle kinetic energies considerably higher than the room temperature gas that the particles are immersed in. The particle kinetic temperature is determined by a balance between cooling and heating processes. The cooling process is almost certainly neutral gas drag, and the heating mechanism must include electrostatic fluctuations. The exact nature of the heating mechanism, and the origin of the electrostatic fluctuations, remains a topic of research.

We report an experiment to determine whether low-frequency electrostatic fluctuations generated upstream of the particles are carried into the sheath and heat the particles levitated there. A Langmuir probe was used to measure the fluctuation spectrum and electron temperature Te at the sheath edge in a Kr rf plasma. Particle orbits were recorded by using a long-distance microscope and a video camera, yielding particle velocities and the effective particle kinetic temperature, Tp,eff. We found little correlation between the flucutations, which were very low in amplitude, and Tp,eff, suggesting that fluctuations generated upstream of the particles do not account for their heating. Apparently the particles are heated by fluctuations further downstream.

We developed a Langevin model of the particle heating to identify the correct physical paramters to compute from the experimental spectra. This model, which is a generalization of the Langevin model for Brownian motion, should be useful for a wide range of applications, beyond the analysis of the present experiment.

Observations of Dusty Plasma Behavior in Micro-gravity

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An approximately 1 Torr argon plasma containing plastic dust particles of diameters on the order of hundreds of microns was observed in micro-gravity conditions aboard NASA's KC-135 aircraft. The dusty plasma was illuminated by laser light and continuously imaged by a CCD camera. These images and other observations will be presented.

Charge Calculations of Dust Particles in a Plasma
From Their Trajectories During Central Collisions

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Assuming a screened Coulomb potential surrounding each dust particle in a plasma with a constant charge value at fixed plasma conditions, the screening length and also the charge can be calculated from the trajectories of two colliding particles. We present this method and show some results for the determined charge and screening length of identical dust particles in the plasma sheath of an rf discharge as function of the gas pressure.

Dust-acoustic holes and double layers via dust-vortex distributions

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The nonlinear propgation of dust-acoustic waves in dusty plasmas is considered, taking into account nonisothermal ion and dust vortex distributions that arise owing to trapping of dusty plasma particles in the wave potential. It is shown that vortex-like distributions provide the possibility of dust holes (DH) and dust-double layers (DDL), which are nonlinear BGK solutions moving near the dust thermal velocity. The nonlinear dispersion relations for the DH and DDL are obtained and conditions under which they arise are presented. The evolution equations for the DH amd DLL are also discussed. Our results may help to understand the salient features of coherent nonlinear structures in low-temperature laboratory and space plasmas which are far from equilibrium, and which contain a significant fraction of charged dust particulates.

Potential-Driven Vortices of Strongly-Coupled Fine Particles in a Plasma

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Vortex flows of strongly-coupled fine particles are generated in a dc discharge plasma by applying a positive or negative electric potential to a small metal plate situated on an electrode for particle levitation. A sheath structure around the metal plate, which has a big effect on the fine particles, is responsible for the vortex generation. The flow speed decreases with a distance from the plate, providing a velocity shear in the vortex flows. The size, direction, and number of the vortices depend on the plate position and the potential applied to the plate, being consistent with particle simulations.

Measurements of Crystalline Order in Penning Trap Plasmas

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A cloud of Beryllium ions in a Penning trap, which consists of static electric and magnetic fields (B=4.5T), rotates about the magnetic field in order to remain confined. By applying an asymmetric electric field that is rotating in the same sense as the ions, we are able to phase-lock the rotation of these plasmas, therefore enabling precise control of the rotation frequency. Under Doppler laser-cooling, these ions freeze into crystalline structures (Coulomb crystals) which are studied through both Bragg diffraction and direct fluorescent images of the ions. By synchronously strobing the detection camera with the rotating electric field, Laue dot patterns or images of individual ions are obtained. For pancake-shaped clouds (1 to 10 lattice planes), we observe bcc and hcp orderings and multiple (including 5-fold) twinning. In approximately spherical plasmas, single bcc crystals or, in some cases, two or more bcc crystals having fixed orientations with respect to each other are observed. A comparison of the experimental observations with the predictions of analytical theory and simulations will be presented.

Coulomb Crystals of Oil Droplets in a Paul Trap

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Coulomb crystals of up to about 100 charged liquid droplets have been produced in a Paul trap operated with an AC potential of about 5 kV. A steady flow of glycerin droplets is created at the tip of a hypodermic needle at +5 kV potential and is directed into a Paul trap operated in air. The measured standard deviation in the charge is about 6determined by using an added DC potential to offset the particles a known distance from the center of the trap. The spatial configurations of small crystals have been observed and videotaped. The micromotion is not recorded when short video exposures (”sports mode”) are used. The center-of-mass mode of oscillation has been excited by an AC potential applied to the end electrodes. Atmospheric drag causes the modes to be heavily damped and increases the maximum AC trapping voltage for which particles are stable.

Confinement times of dust particles in electrostatic traps

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Electrostatic traps have been used to confine negatively-charged dust particles to orbits about a central electrode in vacuum. The particles are glass microballoons about 50 microns in diameter charged to a potential of about -20 volts. The central electrode, at a potential of about +8 kV, is either a 6-mm diameter rod or a 12-mm diameter sphere. Particle orbits decay gradually until the particles strike the central electrode. Experiments with gas pressures from 10^{-4} to 10^{-7} Torr indicate that the confinement is limited by molecular drag. The longest confinement times are about 6 hours. At lower pressures, there may be dissipation caused by the motion of image charges in the walls of the traps. This is being investigated by varying the placement of the walls and by resistively loading the walls. Resistive dissipation may account for the orbits becoming circular more rapidly than predicted by molecular drag alone. As many as seven particles have been trapped simultaneously and collisions and resonances between particles have been observed.