Laboratory Studies of the Optical Properties and Condensation Processes of Cosmic Dust Grains

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1. Summary

A laboratory facility for conducting a variety of experiments on single isolated dust particles of astrophysical interest levitated in an electrodynamics balance has been developed at NASA/Marshall Space Flight Center. The objective of the research is to employ this experimental technique for studies of the physical and optical properties of individual cosmic dust grains of 0.1-100 micron size in controlled pressure/temperatures environments simulating astrophysical conditions. The physical and optical properties of the analogs of interstellar and interplanetary dust grains of known composition and size distribution will be investigated by this facility. In particular, we will carry out three classes of experiments to study the microphysics of cosmic dust grains. (1) Charge characteristics of micron size single dust grains to determine the photoelectric efficiencies, yields, and equilibrium potentials when exposed to UV radiation. (2) Infrared optical properties of dust particles (extinction coefficients and scattering phase functions) in the 1-30 micron region using infrared diode lasers and measuring the scattered radiation. (3) Condensation experiments to investigate the condensation of volatile gases on colder nucleated particles in dense interstellar clouds and lower planetary atmospheres. The condensation experiments will involve levitated nucleus dust grains of known composition and initial mass (or m/q ratio), cooled to a temperature and pressure (or scaled pressure) simulating the astrophysical conditions, and injection of a volatile gas at a higher temperature from a controlled port. The increase in the mass due to condensation on the particle will be monitored as a function of the dust particle temperature and the partial pressure of the injected volatile gas. The measured data will permit determination of the sticking coefficients of volatile gases and growth rates of dust particles of astrophysical interest. Some preliminary results based on measurements of photoelectric emission and radiation pressure on single isolated 0.2 to 6.6 micron size silica particles exposed to UV radiation at 120-200 nm and green laser light at 532 nm are presented.

2. Basic Equation of an Electrodynamic Balance

The electrodynamic balance, or a quadrupole trap, consists of a ring electrode kept at an alternating potential and two cap electrodes at opposite DC potentials. A charged particle in the resulting electric field configuration is stably trapped and confined to the null point of the potential if the required stability conditions determined by the applied AC and DC potentials and the AC frequency are satisfied (e.g., Davis, 1985, Spann *et al.*, 2001). For a stably trapped particle, the measurement of the DC potential required to balance the gravitational force, provides a measurement of the charge-to-mass ratio given by:

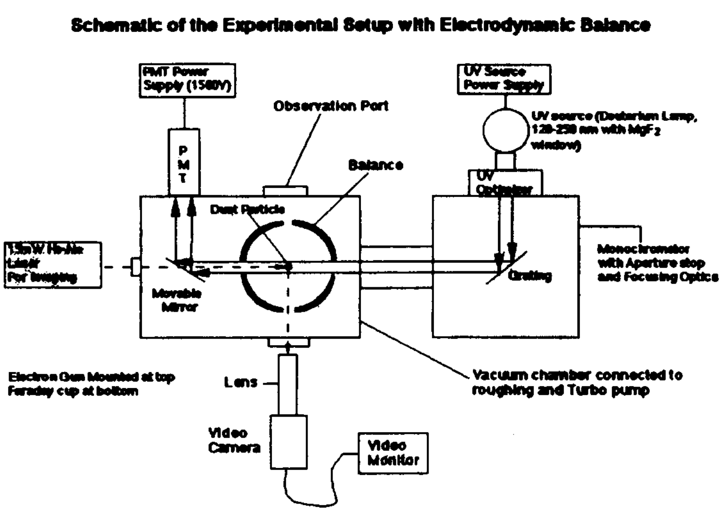
$$\frac{q}{m} = \frac{gz_o}{2C_oV_{dc}}$$

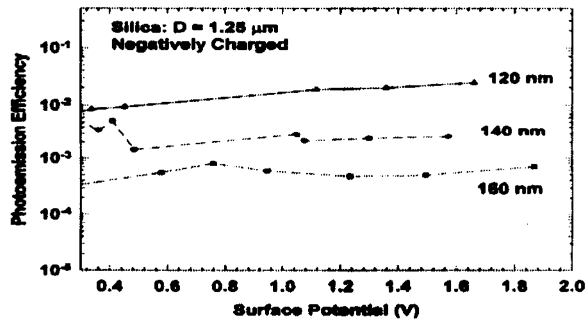
With a single micron size charged particle stably trapped in the balance, evacuated to pressure of 10^{-5} to 10^{-6} torr, and cooled to astrophysical temperature, a variety of experiments may be conducted.

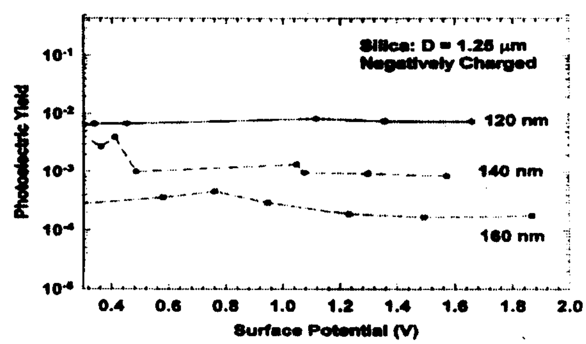
3. Dust Charging by Photoelectric Emissions

The dust grains in astrophysical environments are generally charged by electron/ion collisions or by photoemissions with UV radiation from nearby stars. Photon energies higher than the work function of the material are required for an electron to escape. In a photoemission process from solids, inelastic-scattering processes reduce the electron energy before the electron can escape. The interaction potential for a photoelectron from a grain is different from the corresponding potential of a grounded bulk sample.

Photoelectric efficiencies of particles, defined as the number of photoelectrons emitted/photons absorbed, and corresponding values of photoelectric yields for a neutral particle have been determined for individual negatively charged levitated silica particles of sizes of 0.2 to 6.62 μm size by exposing them to collimated beams of UV radiation of 120 to 160 nm wavelength (Figs. 1 - 2). These results remain to be compared with model calculations and with measurements for bulk materials.







4. Direct Radiation Pressure Measurements on Dust Particles

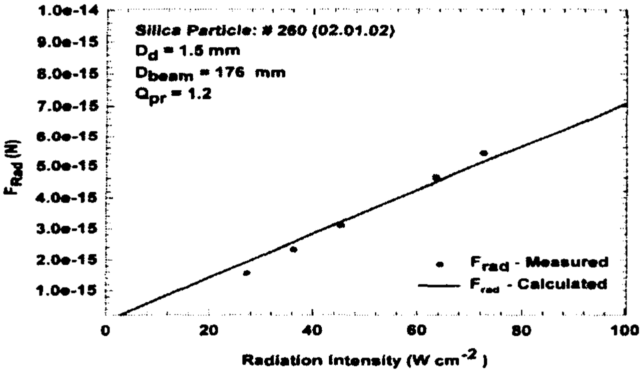
The electrodynamic balance provides a simple and accurate technique of measuring the radiation force F_rad on individual dust particles by balancing it with a change in the DC potential V_dco and calculating it with:

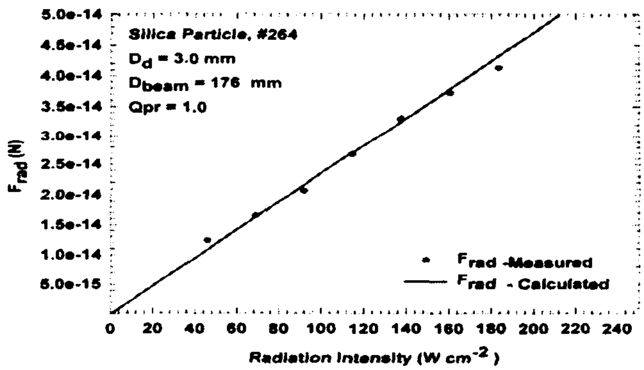
$$F_{rad} = F_g \frac{\Delta V_{dc}}{V_{dco}}, \quad (N)$$

where F_g of diameter D_d with an incident radiation power $P_m w$, and radiation pressure efficiency Q_e is:

$$F_{rad} = 3.33 \times 10^{-12} P_{mw} \frac{D_d^2}{D_B^2} Q_e$$

A comparison of the measured (dots) and calculated (solid line) values of the radiation pressure exerted by green laser light at 532 nm wavelength on silica particles of 1.5 μm and 3.0 μm is shown in Fig. 3).





5. Measurement of Infrared Optical Properties Individual Levitated Dust Grains

The physical nature and chemical composition of unprocessed interstellar dust grains can only be identified through their optical signatures and comparison with laboratory data. Laboratory data relating to the optical characteristics is generally based on measurements on bulk materials with the extinction coefficients obtained from theoretical calculations. The scattering phase function information, however, cannot be obtained from bulk material measurements. The laboratory technique considered here provides information about both the extinction coefficients and the phase function obtained from measurements made directly on individual dust grains and are expected to be a much more accurate description of the astrophysical environments. Specifically we will experimentally determine the complex refractive indices, the extinction coefficients, the scattering phase functions, and the polarization characteristics of isolated individual dust grains of interest in interstellar environments, in the infrared 1-25 μm spectral region (Figs.4- 5). The optical measurements will be made as condensation of ices on the core-mantle particles progresses with time. The spectral range will be extended to both shorter and longer wavelengths with the availability of suitable laser sources. The design and construction of the newly designed cryogenically cooled balance with the capability of making infrared scattering measurements is in progress and is expected to be completed in the near future.

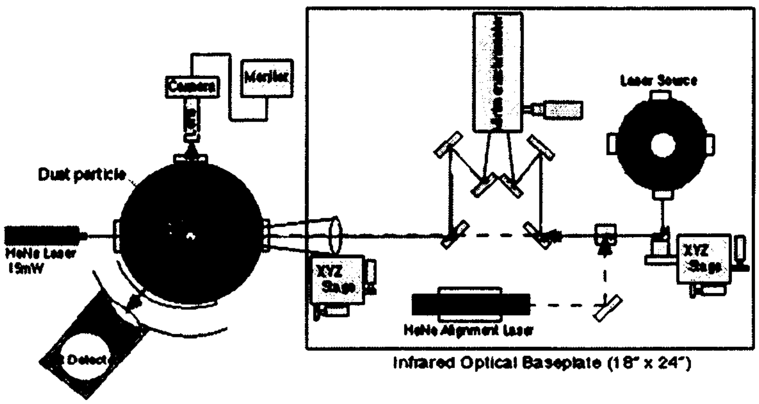
6. Measurement of Condensation of Ices on Individual Dust Grains

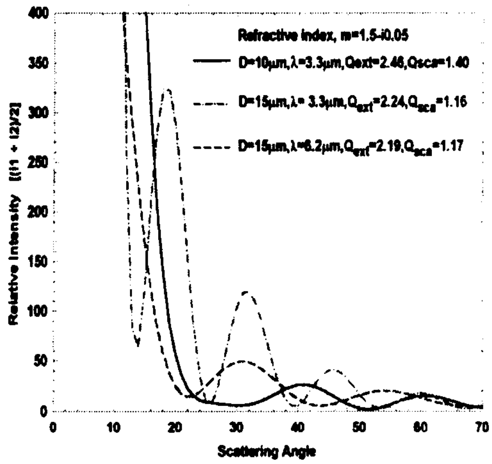
Theoretical and observational arguments indicate the cycling of dust between dense interstellar clouds where star and planet formation takes place, and the diffuse clouds in the interstellar medium. Small silicate particles that are blown out of cool evolved stars are believed to serve as condensate nuclei for volatile gases and organics in dense interstellar clouds leading to the formation of complex organic material. An understanding of the condensation processes is crucial to an increase in our knowledge of the evolution of the solar system bodies. Specifically, we will:

1. Investigate condensation processes in dense interstellar clouds by suspending single nucleus dust grains in the balance in simulated astrophysical environments, injecting volatile gases at a higher temperature, and monitoring the increase in the particle mass and the growth rate. Analogs of dust particles of astrophysical interest produced in the lab at GSFC will be used.

2. Investigate the growth rate of icy mantles on silicate grains of known composition and determine the sticking coefficients.

3. Compare the experimental measurements with calculations based on appropriate theoretical models, leading to a crucial increase in out knowledge of condensation processes in molecular clouds and formation of solar system bodies.





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