

LDEX Sensitivity studies: Material and impact velocity dependence of the total charge yield generated in hypervelocity impacts of micron and sub-micron sized dust particles

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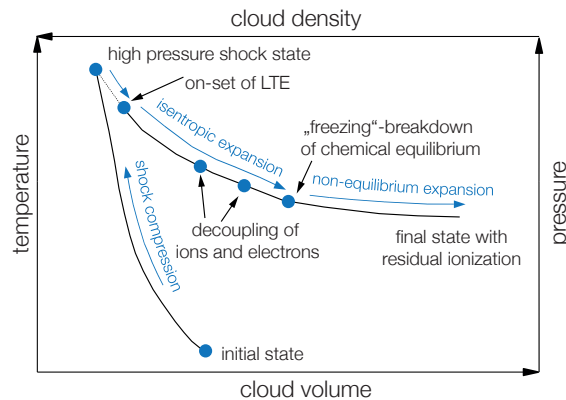


Fig. 1: Principles of shock wave ionization [1].

Introduction: The Lunar Dust Experiment is an impact ionization dust detector scheduled for flight onboard the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission in 2013.

LDEX will map the spatial and size distributions of both the secondary ejecta particles - generated by interplanetary dust impacts, and the putative population of submicron grains - expected to be lofted by plasma effects near the terminators.

The operational principal of LDEX is based on the measurement of impact generated electrons and ions, collected on a hemispherical target and ion sensor, respectively. The geometry of this instrument ensures that the collection efficiency of the ions does not depend on the location of the impact. The characteristics of the emerging plasma, such as the dependence of the generated charge yield on the impact

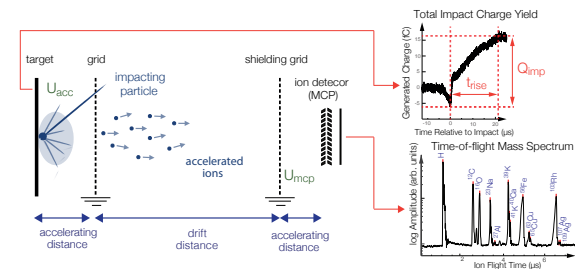


Fig. 2: (left) The schematic drawing of the BERTA time-of-flight mass spectrometer. (right) The resulting signals, the total charge yield generated at the target, and a TOF mass spectrum recorded with a MCP [6].

velocity, the dust and target material as well as the impact angle can be analyzed with a linear TOF mass spectrometer (Fig.2).

Shock Wave Ionization: A successful attempt to describe the impact ionization is the shock wave ionization model [2, 3]. It describes the impact process in subsequent phases (Fig. 1). Depending on the impact velocity and the particle's density, the particle will be partially or even completely evaporated by the following release of the high pressure state, referred as unloading. This expansion is assumed to be isentropic [1]. The hot dense state of the shocked matter can be related to the expanded ideal gas state. Characteristic state variables of the gas, e.g. the degrees of ionization or dissociation, change with expansion and cooling. The ionization degree may be determined from Saha's equation.

Ionization and dissociation will eventually stop,

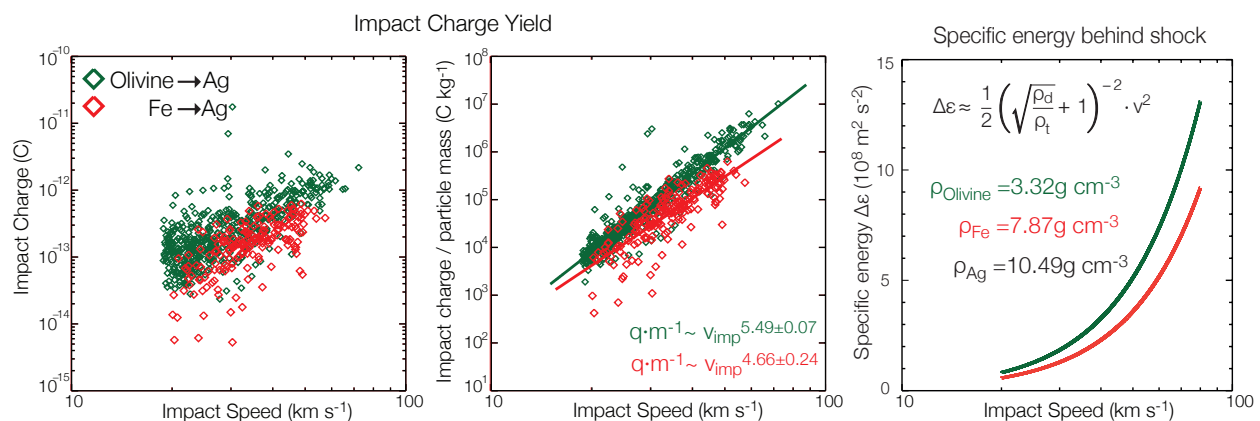


Fig. 3 (left) Total charge yield for impacts of iron and olivine particles hitting a silver target in the limit of a strong shock ($v_{\text{imp}} \geq 20 \text{ km s}^{-1}$) as a function of the impact velocity. (center) Dependence of Q/m on the impact velocity. (right) Dependence of the specific internal energy behind the shock for both investigated material combinations [6].

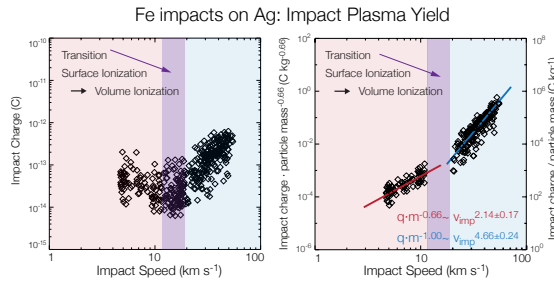


Fig. 4 (left) The total charge generated by iron particles impacting a silver target in dependence on the impact speed. The red area represents impact speed gearing weak shocks and therefore the region of surface ionization. For the blue area, the impact speed is high and subsequently the shock strong enough to cause volume ionization. The purple area represents the transition between the two ionization regimes. (right) Best fits for the exponents in Eq. 2 for low (red) and high (blue) impact speeds. The events with impact speeds in the transition range between surface and volume ionization have been neglected.

after which the degrees of ionization and dissociation will decrease with time following a power law [4]. Recombination shows a similar behavior and will eventually cease entirely. Therefore, the gas expands to infinity in the partially dissociated state with some residual ionization. This phenomenon is called "freezing" of ionization [5].

For extremely high impact velocities, many times exceeding the speed of sound in the particle and the target material, the specific internal energy gained by the particle due to the strong shock depends only on the impact speed v and the ratio of the densities of the particle material ρ_p and the target material ρ_t [2],

$$\Delta \epsilon \approx 1/2 \left(\sqrt{\rho_p / \rho_t} + 1 \right)^{-2} \cdot v^2$$

Experimental setup and results: The residual ions can be recorded with a charge sensitive amplifier (CSA) as shown in Fig. 2. Thus, the shock wave ionization model allows one to relate the initial impact parameters, i.e. impact velocity and material properties, to measurable values such as the impact charge.

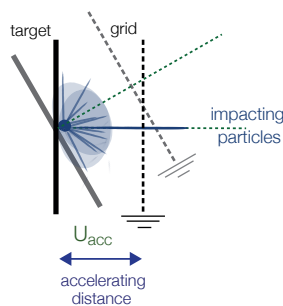


Fig. 5 Sketch of the set up to measure the impact angle dependence of the generated total charge yield

The charge generated during an impact is a function of both particle mass and speed, described by a power law (Fig. 4 and 5):

$$Q = K \cdot m^\alpha \cdot v^\beta \quad (\text{Eq. 2})$$

Depending on the impact velocity and its mass, the particle will be partially or even completely evaporated by the following release from the high pressure state (Fig. 5).

- **Surface ionization** ($v_{imp} \leq 10 \text{ km s}^{-1}$): The ion generation happens predominantly from the surface. The dissipated energy is insufficient to vaporize the particle completely; the particle fragments into small droplets. During the cooling time, mainly impurities with low ionization potentials, i.e. alkali metals, are ionized after their diffusion through the liquid material to the surface from a depletion boundary layer [2].
- **Volume ionization** ($v_{imp} \geq 20 \text{ km s}^{-1}$): For sufficiently large impact velocities, the resulting temperatures are high enough to dissociate the molecules and even ionize the atoms.

Future work: The geometry of the LDEX instrument ensures that the collection efficiency of the ions does not depend on the location of the impact; however, the total charge does remain a function of the impact angle. This dependence was investigated during the calibration campaign at the dust accelerator facility of the Colorado Center for Lunar Dust and Atmospheric Studies (CCLDAS). The resulting data have been compared with similar experiments performed for the calibration of the impact ionization instruments onboard the spacecraft Galileo and the Cosmic Dust Analyzer (CDA) onboard the Cassini spacecraft. In addition, we perform a dedicated measurement with a suitable experimental set up at the dust accelerator facility in Boulder.

The experiments exposes a variety of target materials, to dust particles in the velocity range from 1 to 70 km s⁻¹ and mass range of 10^{-18} to 10^{-12} kg (Fig. 6) and impact angles from 0 to 50°

References: [1] Hornung, K. & Drapatz, S., Residual ionization after impact of large dust particles, ESA (1979). [2] Drapatz, S. & Michel, K.-W., Zeitschrift für Naturforschung 29 a, 870–879 (1974). [3] Gault, D.E. & Heitowitz, E.D., Techreport NASA-TM-X-57428 (1963). [4] Raizer, Y. P., JETP, 37, 580–582 (1959). [5] Zel'dovich, Y. B., & Raizer, Y. P., Physics of Shock Waves and High-Temperature Hydrodynamic Phenomena, Dover (2002). [6] Mocker, A. et al., On the application of a linear time-of-flight mass spectrometer for the investigation of hypervelocity impacts of micron and sub-micron sized dust particles, subm. to Planet. Space Sci. (2012) under review.