Mesoscopic Triboelectricity - from Patches to Particles to Planets

759. WE-Heraeus-Seminar

17 Jan – 21 Jan 2022
ONLINE

WILHELM UND ELSE HERAEUS-STIFTUNG

Introduction

The Wilhelm und Else Heraeus-Stiftung is a private foundation that supports research and education in science with an emphasis on physics. It is recognized as Germany's most important private institution funding physics. Some of the activities of the foundation are carried out in close cooperation with the German Physical Society (Deutsche Physikalische Gesellschaft). For detailed information see https://www.we-heraeus-stiftung.de

Aims and scope of the 759. WE-Heraeus-Seminar:

Understanding triboelectricity requires to span scales: On atomic distances the separation of charge carriers happens; surface regions with coherent charging properties form donor or acceptor patches; many of such patches define the charging of a single contact among solid bodies, and a multitude of contacts cumulate for tribocharging of granular particles.

Recently, these scales got expanded to the atmospheric and astrophysical context. Dust mobility on planetary objects, either with atmosphere or air-less bodies such as asteroids or the moon, and the formation of planets itself seem to rely on mechanisms related to triboelectricity.

With refined understanding and new fields of application also new experimental methods have been developed to investigate the effect of triboelectricity in granular matter. This seminar is dedicated to connect the involved research areas, triboelectricity, granular matter research, astrophysics and planetary sciences.

Scientific Organizers:

Dr. Philip Born	DLR Institut für Materialphysik im Weltraum, Köln, Germany E-mail: Philip.born@dlr.de
Dr. Jonathan Kollmer	University of Duisburg-Essen, Duisburg, Germany E-mail: jonathan.kollmer@uni-due.de
Dr. Jens Teiser	University of Duisburg-Essen, Duisburg, Germany E-mail: jens.teiser@uni-due.de

Program

Program

Monday, 17 January 2022

11:00 – 11:15	Scientific organizers	**Kick-off / introduction**
11:15 – 11:30	Stefan Jorda	**About the Wilhelm and Else Heraeus Foundation**
11:30 – 12:30	Scott Waitukaitis	**Making patch models for same-material tribocharging quantitative**
12:30 – 13:30	Nuno Araújo	**Dynamics of charged and polarized grains**
13:30	**Speaker's table**	
	DINNER / BREAKFAST / LUNCH	
14:30 – 15:00	Joshua Méndez Harper	**Contact and frictional electrification on Mars, Titan, super-Earth GJ1214b, and beyond**
15:00 – 15:30	**Mingling Area**	
15:30 – 16:30	Daniel Lacks	**How do charged surfaces lose their charge?**
16:30 – 17:00	**Poster-Flash A**	
17:00 – 18:00	**Poster Session A (MeetAnyway)**	

Program

Tuesday, 18 January 2022

11:00 – 12:00	Shuji Matsusaka	**Characterization and control of particles charged by various methods in electric fields**
12:00 – 12:30	**Poster Flash B**	
12:30 – 13:30	**Poster Session B (MeetAnyway)**	
13:30	**Speaker's table**	
	DINNER / BREAKFAST / LUNCH	
14:30 – 15:30	Corrado Cimarelli	**The bright side of the plume: volcanic lightning and volcanic ash electrification**
15:30 – 16:30	Troy Shinbrot	**Asymmetric triboelectrification: unexpected charging patterns**
16:30 – 17:00	Rolf Möller	**Dynamics of contact eletrification**
17:00	**Speaker's table**	

Program

Wednesday, 19 January 2022

11:30 – 12:30	Tatsushi Matsuyama	**Limitation of Tribocharging due to Gas Discharge**
12:30 – 13:30	Daniel Robert	**Electric ecology and aerial electroreception**

13:30 **Speaker's table**

DINNER / BREAKFAST / LUNCH

14:30 – 15:30	Jonathan Merrison	**Contact electrification in aerosolized dust**
15:30 – 16:30	Christine Hartzell	**Tribocharging of Planetary Dust: An experiment and many follow-up questions**

16:30 – 17:00 **Speaker's table**

Program

Thursday, 20 January 2022

11:30 – 12:30	Marco Mazza	**Hydrodynamic description of granular gases interacting via Coulomb forces**
12:30 – 13:30	Dietrich Wolf	**Collisional cooling, aggregation and cluster stability of charged particles**
13:30	**Speaker's table**	
	DINNER / BREAKFAST / LUNCH	
14:30 – 15:30	Lorin Matthews	**Grain Charging in Astrophysical Environments**
15:30 – 16:30	Jacqueline Krim	**Triboelectricity and the impact of mobile nanoscale species on friction in macroscale contacts**
16:30 – 17:00	**Speaker's table**	

Program

Friday, 21 January 2022

11:30 – 12:30	Gerhard Wurm	**Collisional Charging in Planet Formation**
12:30 – 13:30	Hubertus Thomas	**Charges on particles in complex/dusty plasmas**

13:30 **Speaker's table**

DINNER / BREAKFAST / LUNCH

14:30 – 15:30	Bilge Baytekin	**Static discharging of polymers by light**
15:30 – 16:30	Heinrich Jaeger	**Collisional Contact Charging in Granular Materials**
16:30 – 17:00	Scientific organizers	**Conclusion / Poster prize**

End of seminar

Posters

Posters A

Francesca Orsola Alfano	**DEM analysis of triboelectric charging of carrier particles inside the capsule of a carrier-based Dry Powder Inhaler**
Josh Armitage	**Investigating the Influence of Friction and Material Wear on Triboelectric Charge Transfer in Metal-Polymer Contacts**
Olfa D'Angelo	**Rheology of Lunar regolith on the Moon**
Galien Grosjean	**Using sound to shed light on tribocharging**
Dana Harvey	**Charge Decay on Levitated Particles in Atmospheric Conditions**
Kolja Joeris	**Excessive dipole moment on collisionally charged dimers explained by mesoscopic charge patches**
Felix Jungmann	**Drop Tower experiments reveal charge transfer by ions on dielectric grains**
Isaac Lenton	**Observing elementary charge exchange between an optically trapped micro-particle and air**
Andre Mölleken	**Experimental Setup to Study the Dynamics of Contact Electrification**

Posters A

Cecelia Mweka	**Combining acoustic levitation and capacitive sensing to probe same-material tribocharging**
Erasmo Salvatore Napolitano	**Modelling triboelectric charging in fluidized bed by coarse grained DEM-CFD**

Posters B

Mohammed Istafaul Haque Ansari	**Pattern-transition dynamics, exotic phase-coexistence and controlled convection in vertically vibrated granular matter**
Dongwhi Choi	**Advantageous utilization of triboelectric effect based electric signal generation in engineering**
Florence Chioma Onyeagusi	**Alignment and Aggregation of Sub-mm Particle Clusters through Dipole Moments in Large Electric Fields**
Felix Pertl	**Fantastic surface charges and where to find them**
Nicolas Preud'homme	**Model of cohesion in granular materials using numerical simulations**
Rainer Schraepler	**Preparation of an ISS-Experiment to observe Particle motion and growth to understand early planet formation: The effect of charged and dipole - charged particles**
Ravichandran Sivaramakrishnan	**Numerical simulations of charge transfer between colliding bodies**
Juan Carlos Antonio Sobarzo Ponce	**Investigating the relationship between humidity and surface heterogeneity in same-material tribocharging**
Ya-Chun Wang	**Lunar Regolith Dust Mitigation**

Posters B

Alfred Weber	**Triboelectric charging of nanoparticles and microparticles in particle-wall collisions**
Wenchao Xu Holger Grosshans Gizem Özler	**Explosion hazards during pneumatic powder conveying**

Abstracts of Lectures

(in alphabetical order)

Dynamics of charged and polarized grains

Nuno Araújo[1], **Ryuta Yoshimatsu, André Matias, Gerhard Wurm, Hans Herrmann, Troy Shinbrot**

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Completely identical insulator grains do charge one another upon contact and the charge difference even increases with repeated contact. Several experimental and theoretical works have provided a strong analytic foundation for charging mechanisms due to geometric or material asymmetries, but the mechanism in the case of absolutely identical grains is not at all clear. Here, we investigate the electrostatic charging of an agitated bed of identical grains using particle-based simulations, mathematical modeling, and experiments. We simulate a discrete-element model including electrical multipoles and find that infinitesimally small initial charges can grow exponentially rapidly. We confirm the predicted exponential growth in experiments using vibrated grains under microgravity, and we describe novel predicted spatiotemporal states that merit further study. Finally, we discuss how the charging dynamics emerge from the competition between the polarization and relaxation time scales.

References

[1] R. Yoshimatsu, N. A. M. Araújo, T. Shinbrot, and H. J. Herrmann. *Field driven charging dynamics of a fluidized granular bed.* Soft Matter **12**, 6261 (2016).

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Static discharging of polymers by light

S.D.Cezan[1], H.T. Baytekin[2], B.Baytekin[2]

[1]*Bilkent University Chemistry Department, Ankara, Turkey*

[2] *Middle East Technical University, Ankara, Turkey*

The mechanism of static electricity generation and mitigation on insulator surfaces upon rubbing/contact is one of the few scientific questions that have remained unanswered for millennia. Static charging (tribocharging) of insulators is not just a scientific mystery – it is also a significant problem, especially critical for various industries, e.g., polymer, pharmaceuticals, electronics, and space. Several methods of tribocharge mitigation exist in practice; however, none can reach the practicality of using light in the process. Here I will present light-controlled mitigation of triboelectric charges on common polymers. The tribocharged polymers are discharged upon illumination with appropriate wavelengths of light in the presence of a mediator organic dye. Our method provides spatial and temporal control on mitigation of static charges on common polymer surfaces by a mechanism that involves photoexcitation of organic dyes, allowing an additional 'wavelength control'. This control over charge mitigation also allows manipulating macroscopic objects by tribocharging followed by light-controlled discharging.

References

[1] S. D. Cezan, A. A. Nalbant, M. Buyuktemiz, Y. Dede, H. T. Baytekin, B. Baytekin, Nature Communications **10**, (2019)

The bright side of the plume: volcanic lightning and volcanic ash electrification

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Volcanic plumes, as thunderstorm clouds, generate intense electrical activity and associated lightning discharges, which make them readily detectable at safe distance. While techniques in thunderstorm lightning detection and now-casting have progressed enormously reaching a high level of sophistication, volcanic lightning detection, although being a rapidly evolving field, can still be considered in its infancy. This delay is mainly due to the lack of systematic instrumental observations and the limited number of laboratory experimental investigations, which still hamper a thorough understanding of volcanic lightning and electrification of volcanic plumes in general.

Recent years have seen an increasing amount of report of volcanic lightning at erupting volcanoes (Krakatau 2019, Stromboli 2019, Taal 2020, St. Vincent 2021, La Palma ongoing) to quote some of the most recent), several of which have been detected by worldwide thunderstorm lightning detection networks. However, intrinsic differences make the direct comparison between volcanic plumes and thunderclouds inadequate. In this respect, dedicated methods of investigation of volcanic plume's electrical activity need to be put in place to fully grasp the underlying basic mechanisms.

We are contributing to this effort by pursuing a twofold approach using multi-parametric observation of the electrical activity at target volcanoes and by experimentally reproducing lightning discharges in particle-laden jets in the laboratory. In this presentation, latest advancements in the study of volcanic lightning and plume charging will be discussed in light of observational and experimental results. Particular emphasis will be put on: the discrimination between thunderstorm and volcanic lightning discharges, the competition between "internal" (volcanic) and "external" (atmospheric) factors in plume electrification, the near-vent volcanic jet dynamics and the benefit and limitations of different detection techniques. Finally, the presentation will conclude with a discussion on the future perspectives of volcanic lightning and plume charging as a monitoring tool for active volcanoes.

Tribocharging of Planetary Dust: An experiment and many follow-up questions

C.M. Hartzell[1] and D.P. Carter[1]

[1]*University of Maryland, College Park, MD, USA*

Tribocharging of dielectric materials is poorly understood. Particularly perplexing is the exchange of electrical charge between dielectric grains of the same material, but different sizes. Given the lack of a neutralizing atmosphere on the Moon and other small planetary bodies, it is likely that surface dust grains (called regolith), which are typically dielectric, will become charged during avalanches or during spacecraft exploration activities (e.g., roving, drilling and sampling). Additionally, forces that are typically negligible in the terrestrial environment become significant in the weak gravity environment present on small planetary bodies, like asteroids and comets. Thus, it is important to develop an accurate triboelectric charging model for dielectric grains in order to predict the behavior of regolith. We have expanded a common semianalytical model of dielectric charge exchange by [1] to include a dependence of the quantity of charges exchanged on the relative size of colliding grains. We tested the accuracy of this model using a teststand inspired by the work of [2]. We found that the experimental results do not closely match the model and suggest a positive charge carrier [3]. We are now implementing tribocharging in LIGGGHTS (an open-source discrete element method code) to provide a new tool to test different tribocharging models as well as model tribocharging during spacecraft exploration activities.

References

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Collisional Contact Charging in Granular Materials

Heinrich Jaeger

James Franck Institute and Department of Physics, University of Chicago, USA

Collisional contact charging of sub-millimeter particles and the resulting clustering is important in circumstances ranging from the earliest stages of planet formation to aggregation of airborne pollutants to industrial powder processing. Even in systems comprised of grains of identical dielectric material, contact charging can generate large amounts of net positive or negative charge on individual particles, resulting in long-range electrostatic forces. Remarkably, rather fundamental aspects of contact charging, such as the type of the charge carriers or the nature of the charge transfer mechanism are still under debate [1]. This webinar focuses on recent work where collision events between individual particles are tracked with high-speed video and the charge on single particles can be extracted. In freely falling granular streams we observe collide-and-capture events between charged particles and particle-by-particle aggregation into clusters. Size-dependent contact charging is found to produce a variety of charge-stabilized “granular molecules”, whose configurations can be modeled by taking many-body dielectric polarization effects into account [2,3]. I will also introduce a new approach, based on ultrasonic levitation, for studying contact charging where the very same particles can be forced to undergo multiple head-on collisions. This method allows for measurements under a wide range of environmental conditions as well as applying an electric field, and its exquisite sensitivity makes it possible to determine the net charge transferred in a single contact event [4].

References

[1] S. R. Waitukaitis, V. Lee, J. M. Pierson, S. L. Forman, and H. M. Jaeger, Size-dependent same-material tribocharging in insulating grains, Physical Review Letters 112, 218001 (2014).

[2] V. Lee, S. R. Waitukaitis, M. Z. Miskin, and H. M. Jaeger, Direct Observation of Kepler Orbits and Particle Aggregation in Charged Granular Streams, Nature Physics 11, 733-737 (2015).

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Triboelectricity and the impact of mobile nanoscale species on friction in macroscale contacts.

J. Krim[1]

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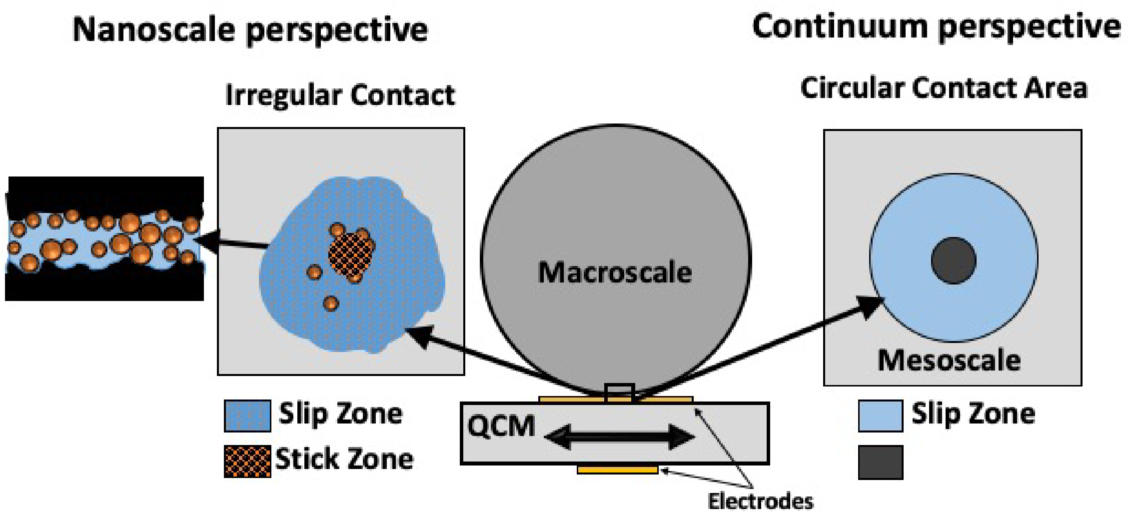
Two experimental studies involving systems with mobile nanoscale consituents will be described. Nanoscale frictional parameters have been successfully linked in each study to macroscopic frictional phenomena. In the first, a MEMS tribometer has been employed to measure friction coefficients in rubbing silica contacts lubricated by trace levels of organic adsorbates with varying degrees of surface mobility. Highly diffusive species, in contrast to immobile adsorbates, are observed to impact frictional energy dissipation mechanisms over the entire regions where the adsorbates migrate, with electrostatic effects being particularly impacted.[1] In the second, the impact of nanoparticles on Mindlin slip phenomena at a solid asperity contact are investigated, and compared to current-day contact mechanics models. The introduction of granular material at the contact reveals the extent to which continuum models break down at nanoscale length scales.[2,3]



References

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How do charged surfaces lose their charge?

C. Heinert,[1] R. M. Sankaran[1] and D. J. Lacks[1]

[1] *Case Western Reserve University, Cleveland, OH, USA*

The electrostatic charge on surfaces can decay over time by bulk or surface conduction to electrical ground, or by charge transfer with ionic species in the surrounding gas phase. In general, these processes occur simultaneously, and it is not possible to disentangle their effects. Here, we study the time dependence of surface charge decay resulting only from interactions with the surrounding gas. Our methodology is based on the magnetic levitation of an electrostatically-charged sample surface to avoid any conductive path to ground. By measuring the surface charge over time, we find that the charge decays more slowly than predicted by previous models based on collisions with gaseous ions, and exhibits a different functional form for the time dependence. The slower decay is attributed to a depletion of ions in the vicinity of the charged surface, and the experimentally-observed charge decay is explained by a new model that considers a spatially-dependent ion velocity.

Characterization and control of particles charged by various methods in electric fields

M. Shoyama and S. Matsusaka

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Particles are charged by contact or friction with different materials. The charge on each particle increases with an increase in the number of contacts and eventually reaches an equilibrium value [1]. The equilibrium charge depends on the contact potential difference related to the work functions of the surfaces. Thus, the polarity and magnitude of the equilibrium charge can be changed by replacing the surface material. However, controlling the charge to an arbitrary value is difficult. As the contact potential difference is affected by electric fields, controlling particle charging using an external electric field is possible [2]. When a strong electric field is applied, instead of contact charging, induction charging occurs [3]. The particles are charged with the same polarity as the electrodes with which the particles are in contact, and the amount of charge can be controlled by the electric field strength. If the surfaces of the insulating particles have slight electrical conductivities, induction charging occur after a small amount of additional time even if the material is not conductive. As the induction charging strongly charges the surfaces of the particles, they are levitated by Coulomb forces along the electric field [4]. Because the charged particles experience electrostatic repulsive forces, induction charging can also be applied to the supply of dispersed particles. In addition, UV irradiation in an electric field increases the positive charge on the particles because of photoemission [5]. In this lecture, various charging methods in the electric fields, electrostatic characterization, and applications to levitation, dispersion, and supply of charged particles are presented.

References

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Limitation of Tribocharging due to Gas Discharge

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The process of contact or tribo-charging consists of two serial sub-processes, i.e., (1) contact and charge transfer and (2) separation and charge fixation. In the separation process, charge back-flow or relaxation may take place with a couple of mechanisms; (a) tunnel current between separated two surfaces in small gap, (b) in partial separation, leakage current from already separated area to the area still in contact. The mechanism (b) may results in small charge generation in case of contacts of conductive materials. Besides, (c) after separation was completed in all the area, potential difference between the two surfaces increases due to the decrease of capacitance as an increase of the gap, with a condition of charge fixation; as far as such contact charging takes place in ambient air, the potential difference may reach to gas breakdown limit. When the gas breakdown took place, the observed charge after the separation process is capped by the relaxation. A quantitative model to determine the maximum charge capped by the relaxation for impact charging of particulate materials was proposed, in which surface potential curve of a particle in separation process is required to stay below Paschen's curve, and the model demonstrated a good agreement with experimental results of single particle impact tests with using 1-3 mm spherical polymer particles [1,2]. An important result here was that the impact charge can be capped by the gas discharge limitation only for a single particle with a single impact event. Then the idea was extended to apply to multiple particle case, where particles were shaken in a metal capsule and the charge generation was measured [3]. As a result, charge per particle was reduced by the number of particles loaded in the shaker because of space charge effect, and it was well explained by a modified model, from another theoretical approach estimating maximum charge of powder in pneumatic conveyer [4]. The model for the conveyer was compared with data in references, and good agreements were shown for relatively coarse particles, and for fines the model gave over estimates. The criterion was around hundreds micro-meter range. To analyze the shaker experiments DEM modeling was tried and it showed a good explanation [5].

References

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Grain Charging in Astrophysical Environments

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Dust is everywhere. 99.99% of the matter in the universe is in the plasma state – it's everywhere, too. What happens when dust and plasma get together? The dust becomes charged – and it can go everywhere. Charged dust is the primary component of many beautiful astrophysical phenomena such as comet tails, planetary rings, protoplanetary disks, and noctilucent clouds. However, it is a problem for missions to airless bodies in our solar system: the Apollo astronauts found that lunar dust can alter the thermal properties of equipment, obscure visors and instrument readouts, degrade seals, and abrade materials. In addition, it poses a health hazard for astronauts if it is inhaled. Understanding the charging and dynamics of dust is vital to understanding our universe as well as exploring our solar system. Numerical modeling of the coupled charging and transport processes allows exploration of environments which can't be easily reached. These models must be validated by comparing with experimental measurements. This talk will provide a brief overview of current capabilities of numerical models and their validation against both ground and space-based experiments.

Hydrodynamic description of granular gases interacting via Coulomb forces

Marco Mazza

Loughborough University, Department of Mathematical Sciences, Loughborough, UK

The empirical observation of aggregation of dielectric particles under the influence of electrostatic forces lies at the origin of the theory of electricity. The growth of clusters formed of small grains underpins a range of phenomena from the early stages of planetesimal formation to aerosols. However, the collective effects of Coulomb forces on the nonequilibrium dynamics and aggregation process in a granular gas – a model representative of the above physical processes – have posed theoretical challenges. We will discuss hydrodynamic equations for aggregating granular gases that exchange charges upon collisions and interact via the long-ranged Coulomb forces. The governing equations describe the evolution of granular temperature, charge variance, and number density for homogeneous and quasi-monodisperse aggregation. We find that, once the aggregates are formed, the granular temperature of the cluster population, the charge variance of the cluster population and the number density of the cluster population evolve in such a way that their non-dimensional combination obeys a physical constraint of nearly constant dimensionless ratio of characteristic electrostatic to kinetic energy. This constraint on the collective evolution of charged clusters is confirmed both by our theory and our detailed molecular dynamics simulations. The inhomogeneous aggregation of monomers and clusters in their mutual electrostatic field proceeds in a fractal manner. Our theoretical framework is extendable to more precise charge exchange mechanisms, a current focus of extensive experimentation.

Contact and frictional electrification on Mars, Titan, GJ1214b, and beyond

Joshua Méndez Harper

University of Oregon, Sensors for Extreme Environments Lab/Department of Earth Sciences, Eugene, Oregon, USA

Contact and frictional electrification, although imperfectly understood, appear to operate ubiquitously in mobilized granular media. Particle charging can lead to dramatic phenomena—the displays of lightning during volcanic eruptions are perhaps the best example in the natural world. Yet, even more subtle electrostatic processes may have profound effects across number of granular systems. For instance, charging of windblown sand may enhance emissions of climate-modulating dust into the atmosphere. Research over the last 50 years has revealed that the manner in which a granular material charges depends on particle size distribution, composition, shape, and dynamics. More recently, fluid phases (gases and liquids) have been recognized as factors that promote or hamper charging in granular media. In Earth's natural systems, contact and frictional electrification typically involves silicate particles agitated in a nitrogen-rich atmosphere with variable amounts of water. However, robotic missions and remote sensing endeavors reveal other worlds with exotic granular materials or atmospheres that differ greatly from our own. Such diversity may lead to electrostatic effects that are not readily intuitive given our experience on Earth. To demonstrate this prospect, we review the evidence for contact and frictional charging in granular systems on three planetary bodies. Firstly, we assess the possibility of electrostatic discharges in a tenuous CO2 Martian atmosphere during dust storms. Further out, we explore how triboelectrification in Titan's hydrocarbon dunes may help sculpt world-wide geomorphic features. Lastly, we discuss a new form of lightning in the salt clouds of super-Earth GJ1214b and whether such exo-lightning could be detectable from Earth.

Contact electrification in aerosolized dust

J. Merrison

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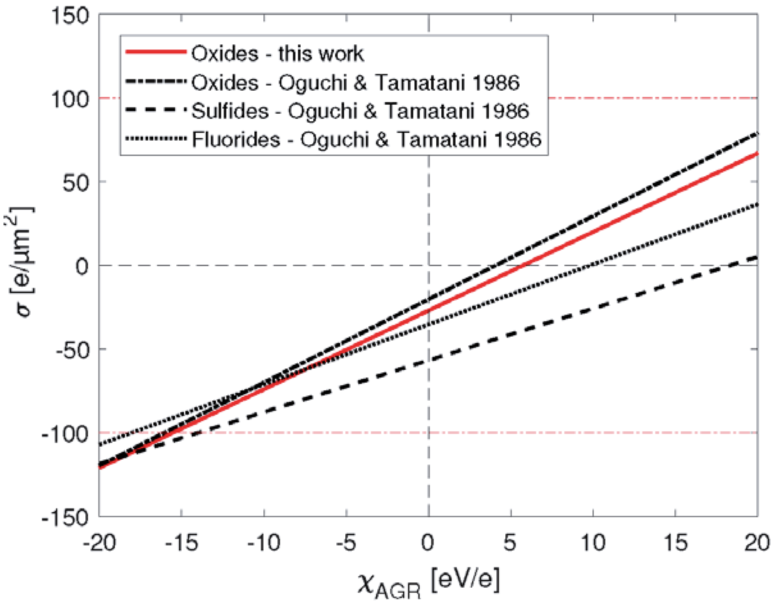
A series of experimental studies have been carried out in which the contact electrification of aerosolized micron-scale particles (1-45µm) has been quantified focusing on the material and size dependence. In one experimental technique laser velocimetry is used to simultaneously determine the size and charge of individual aerosolized grains. The degree of electrification of the dust grains was seen to scale with a certain surface charge concentration. There also seemed to be a maximum surface charge concentration for individual grains of the order of 100 e/µm^2. A predictive model was developed in which the surface charge concentration (σ) correlates linearly with the absolute generalized relative electronegativity (χ_{AGR}): $\sigma = a\chi_{AGR} + b$. The model was successfully applied for both insulators (oxides) and metals and was also in agreement with previous studies of contact electrification using insulators. The χ_{AGR} is material dependent and interpreted as an effective contact potential difference leading to a simple physical predictive model. A challenge for the model is in obtaining reliable and accurate values for electronegativity for all types of material. Additionally there was observed an additional negative surface charge to the contact electrification of the dust compared to the injector (the factor *b*). The origin of this effect is unknown, but might be related to a size dependence.



Figure; Summary of the contact electrification predictive model for insulators including the work of Alois et al. 2017, Alois et al. 2018 (for oxides) and the work of Oguchi and Tamatani 1986 converted into the same units.

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Dynamics of Contact Electrification

R.Möller, A. Mölleken and H. Nienhaus

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Despite the fact that contact electrification is known empirically for centuries, the dynamics of the process have been dealt so far mainly theoretically. We introduce a new experimental method providing a detailed insight in the dynamics of contact electrification. By analyzing the induced electric charges in a parallel plate capacitor, the charge transfer can be measured with unprecedented resolution. In the particular experiment the charge of a small metal sphere bouncing on a grounded planar electrode can be measured with a resolution better than a 1 fC. The temporal resolution <1 µs allows us to verify the prediction of the model for metal-metal contact electrification [1], that during the mechanic contact, which lasts about 6-8 µs, a constant electric potential difference is established. However, in contrast to the generally accepted concept for metal-metal-contacts, we find that the charge remaining after the contact, increases with the impact velocity [2]. In the experiment this can lead to surprisingly high electric potentials for purely metallic contacts, e.g. when a sphere falls from a height of 40mm and bounces on a plate an electric potential of up to 10V is reached.
Moreover, it is revealed that there is no 'memory' of the charge before the contact, because an electric contact is established during the mechanical contact of a few microseconds. Thereby, the potential of the sphere is reduced to the contact potential of a few tenths of a Volt. However, in the very moment when the electric contact breaks, the charge on the sphere establishes a potential of up to 3V within less than 1 µs. On a much slower time scale the potential increases further as the distance between the sphere and the plate grows.
The excess charge rises with increasing contact area or impact velocity. We propose that this is due to a deformation of the contact area which goes along with an increase of the capacity between the sphere and the plate at the moment when the electrical contact is disrupted. This will be important in contact electrification and triboelectricity involving insulators as well, because an enlargement of the contact area by deformation will lead to an enhanced charge transfer in a similar way.

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Electric ecology and aerial electroreception

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Electricity is everywhere and is essential to the functioning of life. Understanding how organisms organise their lives in space and time using natural manifestations of electricity is just as relevant as studying vision or hearing [1, 2]. Whilst the detection of electric currents, electroreception, has been extensively studied in aquatic animals, the capacity of terrestrial animals to detect weak electric fields has received much less attention. We have discovered that bumblebees can detect and learn about the weak electrostatic field that arises as they approach a flower [3] (Fig. 1). This electric field is generated because flying bees are usually positively charged whilst flowers tend to be negatively charged. A third component contributes to this electric interaction; the atmospheric potential gradient (APG) due to atmospheric ionization and the global electric circuit. In view of this Bee-Flower-APG interaction, I will discuss the presence and role of triboelectrification and Coulomb force in the sensory ecology of bees and other terrestrial arthropods and plants. This triboelectric charging may play a pervasive role in the biology of plants and insects. In another example, the capacity of spiders to exploit Coulomb force to generate enough lift to become airborne will be presented [4].

This work opens-up the enticing possibility that many arthropod species, in effect the majority animal species, are capable of aerial electroreception, a sensory modality previously unknown, that humans seem to lack.

Fig. 1. Model visualisation of the electrostatic interaction between a bumblebee and a petunia. Field lines are white, shading shows field strength.

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Asymmetric triboelectrification: unexpected charging patterns

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Contact charging relies on a temporal asymmetry[1]: contact dynamics must differ from separation dynamics, else resulting surfaces would be identical. In this talk, we observe that spatial dynamics are also asymmetric[2]: positively charged surfaces exhibit mesoscopic fractal patterns, while negatively charged surface exhibit spots. This surprising effect is consistent with models indicating that atmospheric ions (e.g. H+ and OH-) may be essential to tribocharging mechanisms.

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Charges on particles in complex/dusty plasmas

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A complex/dusty plasma is an ionized gas containing small solid particles in the range from nanometers to centimeters. Natural dusty plasmas are ubiquitous in space, they can be found in interstellar clouds, Saturn rings, cometary tails, on the Moon and planetary atmospheres. Additionally, dusty plasmas are investigated in the lab where they are called complex plasmas in connection to complex fluids - fluids containing small solid particles.

Charging of solid particles in plasmas is a very important and basic process. The continuous interaction of the dust with electrons and ions from the surrounding plasma as well as with UV radiation lead to its charging. Depending on whether electrons and ions are dominant or the UV flux, the charge can be negative or positive, respectively. Due to the continuous collection/release of charged species from the surface the charge fluctuates.

In this lecture I will discuss the charging and decharging processes of solid particles in plasmas and the interaction of the particles with the surrounding plasma and with themselves.

Making patch models for same-material tribocharging quantitative

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It has been proposed that same-material tribocharging is caused by heterogeneity in material surface properties. If some regions of a material act as charge 'donors' and others as 'acceptors', net charge transfer occurs as a result of statistical fluctuations. This idea is able to account for measurements where the magnitude of same-material charge transfer grows with the square root of the contacting area [1], and is supported by observations of 'charge mosaics' at the nanoscale [2]. Even so, the original formulation the model is essentially a scaling argument, and taken at face value implies that the size of a single donor/acceptor unit is more than 10000 times smaller than the tiniest atom.

In this talk, I will discuss a more rigorous version of the 'patch model' that properly accounts for all relevant length scales [3]. Of particular importance is the size of patches relative to the size of elementary donor/acceptor units, which controls the scale of charge transfer, as well as the scale of fluctuations. Considering this new finding, the prefactor of the $\sqrt{A}$ scaling in [1], and the observed size of mosaics in [2], our model implies the size of elementary donating units to be approximately one atom/molecule. Going further, we speculate on the origin of the patch length scale, and propose that heterogeneous nucleation is a viable candidate. Finally, I will discuss our experimental efforts to test these models, particularly in relation to adsorbed surface water.

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Collisional cooling, aggregation and cluster stability of charged particles

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Collisional cooling and aggregation are well understood, important phenomena in granular gasses – provided the particles either do not carry charges at all or are unipolarly charged. These two cases are very different. Approximate analytical results, confirmed by computer simulations, will be presented that underline the drastic difference, the charges make for the dissipation of kinetic energy [1] and the size distribution of aggregates [2]. In particular it is shown that the relative size distribution narrows down to a universal shape. Much less is known for granular gasses, where charged particles of both polarities are present in equal amounts. Only recently some pertinent results were discovered for this case [3,4], which again are markedly different from the uncharged case.

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Collisional Charging in Planet Formation

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Planet formation begins - as it is widely agreed upon - with collisions of micrometer-sized dust grains sticking together and growing to larger aggregates. However, climbing the size scales, problems are readily encountered. While collisions remain a prevalent process, the outcome of collisions becomes more complex from sticking over bouncing to fragmentation and growth is no longer guaranteed.

In general, charges have always played a part in planet formation but the midplane of protoplanetary disks, where much of the fun takes place, is a rather dark place, i.e. it is optical thick - also for ionizing radiation. Focusing on x-rays and cosmic rays in the past, the midplane has therefore escaped attempts to charge something within for a long time.

In the past, tribocharging was not considered a major actor. There were a few works to exploit tribocharge induced lightning to explain the peculiar class of flash molten grains found in meteorites called chondrules. The role of tribocharging only really changed recently though and after the advent of the bouncing barrier, attributing pebbles a major role in disks and after it became clear that identical grains (same material, same size) can charge as well.

Especially in a bouncing scenario, tribocharging or collisional charging becomes a highly relevant process then. In fact, by now collisional charging has proved to potentially initiate a new intermediate growth phase which might be so efficient that it could smoothly hand over to next evolutionary phases, though this research branch is still in its infancy.

In view of its potential role, a number of experiments have been set up over the last few years to specifically quantify the effects which collisional charging can have on grains in protoplanetary disks. In microgravity experiments the aggregation of charged grains to large clusters has been studied from solid sand sized grains to „real" dust aggregates. Also composition (silicate, water ice) and pressure dependent charging has been studied. More complex surface charge distributions are currently probed by dipole measurements.

Quite recently, it was also shown in addition that tribocharging has a significant share in charging the gas of the disk as well, i.e. charge is not only transferred between solid grains but some of it might leak into the gas phase. This provides a charging source in the midplane of protoplanetary disks which was not considered before and which, in connection with magnetic fields, can turn laminar disks in turbulent ones. This has the potential of opening a new window for triboelectric research.

Abstracts of Posters

(in alphabetical order)

DEM analysis of triboelectric charging of carrier particles inside the capsule of a DPI

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The performance of capsule-based Dry Powder Inhalers (DPI) is highly influenced by the discharge process from the capsule itself. As the capsule rotates and/or vibrates in the inhaler to promote powder discharge and deaggregation, multiple particle-wall collisions occur, possibly inducing triboelectric charging phenomena. In the present contribution, the motion of carrier particles in a hard-shell capsule-based Dry Powder Inhaler (Cyclohaler) has been analyzed through DEM simulations. The accelerated rotational motion of the capsule was simulated considering the point of view of a non-inertial internal observer by rotating the force of gravity and appropriately considering the contributions of fictitious forces. This approach allowed for a punctual mapping of the particle-wall collisions within the capsule from which the calculation of the electrostatic charge accumulation induced by triboelectric charging has been performed. The charge acquired by each particle and the electrostatic forces have been characterized and the extent of triboelectric charging has been compared to other relevant phenomena that occur in the device.

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Rheology of Lunar regolith on the Moon

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The success or failure of exploration missions to sand-covered celestial bodies like the Moon or Mars will depend on humans' ability to understand and overcome the challenges posed by those environments, among which, dealing with the overwhelming presence of regolith on planetary surface [1]. Lunar regolith is constituted of sharp and angular particles, of which roughly 20% are fines (particles smaller than 20 μm) [2]. With high specific surface due to intricate particle shape, the charge-to-mass ratio of this "Lunar dust" is significant, and once electrostatically charged, they can levitate above the Lunar surface [3], and tend to adhere to all surfaces they enter in contact with [4]. Macroscopically, the rheological behavior of regolith on the Moon is sought to be strongly influenced by those particles. Triboelectric charging, as well as photoelectric and plasma charging, are theorized to be the charging mechanisms at play [3]. We propose to reinterpret data collected by the Apollo and Luna missions [2, 4], to provide insight on the rheology of Lunar regolith on the Moon – hence taking into account those electrostatic cohesive interactions, as well as the low gravitational environment. Comparing the rheology we find with that of commonly used "regolith simulants", we conclude that those materials largely fail to reproduce the flow-behavior of Lunar soil. We therefore advocate for a rheological simulant of Lunar regolith, reproducing in particular its mighty combination of adhesive and abrasive properties.

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Pattern-transition dynamics, exotic phase-coexistence, and controlled convection in vertically vibrated granular matter

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Experiments on a two-dimensional monolayer vibro-fluidized granular bed of glass beads revealed various patterned states and the underlying pattern-transition dynamics. At small shaking accelerations ($\Gamma = \mathrm{A}\omega^2/\mathrm{g} < 1$, where A and $\omega = 2\pi\mathrm{f}$ are the amplitude and angular frequency of shaking and g is the gravitational acceleration), the particles remain attached to the base of the vibrating container; this is known as the solid bed (SB). With increasing Γ (at large enough shaking amplitude A/d) and/or with increasingA/d (at large enoughΓ), the sequence of transitions/bifurcations unfolds as follows: SB ("solid bed") to BB ("bouncing bed") to LS ("Leidenfrost state") to "2-roll convection" to "1-roll convection" and finally to a gas-like state [1]. For a given length of the container, the coarsening of multiple convection rolls [2] leading to the genesis of a "single-roll" structure (dubbed the *multiroll transition*) and its subsequent transition to a granular gas are two major findings of these set of experiments [1].

We also report exotic patterns consisting of coexistence of synchronous and asynchronous states [for example, a granular gas co-existing with (i) bouncing bed, (ii) undulatory subharmonic waves, and (iii) Leidenfrost-like states] in experiments on vertically vibrated binary granular mixtures confined in a Hele-Shaw cell [3]. Most experiments have been carried out with equimolar binary mixtures of glass and steel balls of same diameter by varying the total layer height (F) for a range of shaking acceleration (Γ). All patterns as well as the related phase diagram in the (Γ, F) plane have been reproduced via molecular dynamics simulations of the same system. The segregation of heavier and lighter particles along the horizontal direction is shown to be the progenitor of such *phase-coexisting* patterns. At strong shaking we uncover a *partial* convection state in which a pair of convection rolls is found to coexist with a Leidenfrost-like state. The crucial role of the relative number density of two species on controlling the buoyancy-driven granular convection [3] is demonstrated.

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Investigating the Influence of Friction and Material Wear on Triboelectric Charge Transfer in Metal-Polymer Contacts

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A reciprocating tribometer has been modified with a high-impedance electronic measurement circuit for the purpose of addressing how tribology influences triboelectrification. This measurement circuit allows for the accurate measurement of contact potential difference (CPD) and total triboelectric charge generated within the tribometer contact. These electronic properties can now be effectively compared with tribological parameters such as contact force, relative sample velocity, and friction coefficient for varying contacts. In this study we present our apparatus, alongside our findings regarding the influence of material wear mechanisms and friction on the accumulation and dissipation of triboelectric contact charges.

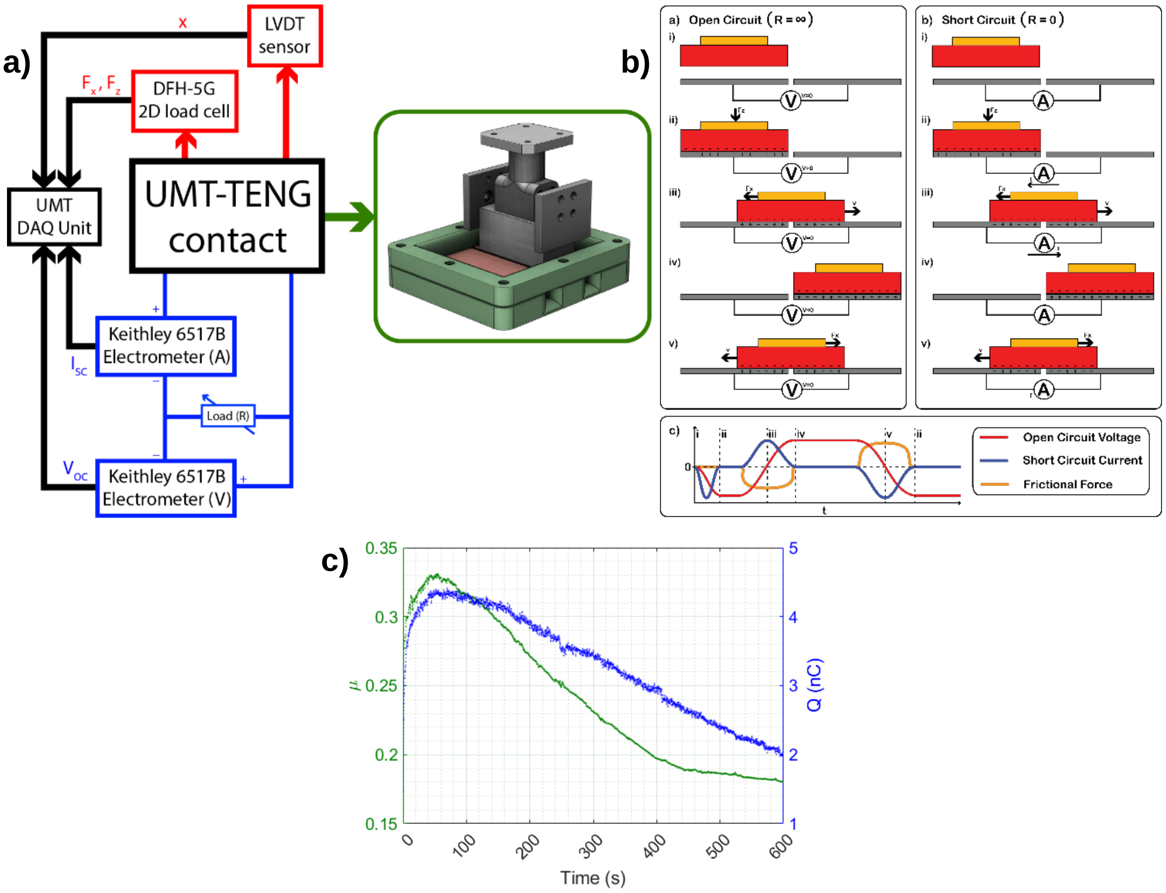

Fig. 1 – **(a)** Schematic of the full testing apparatus (left) accompanied by the assembled contact (right). **(b)** Depicting the operation of a laterally-sliding freestanding-triboelectric-layer triboelectric-nanogenerator (SF-TENG). **(c)** Friction coefficient (left) and triboelectric charge (right) over time for an example PTFE-on-Aluminium SF-TENG contact within the testing apparatus.

Advantageous utilization of triboelectric effect based electric signal generation in engineering

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Triboelectric signal generation, which is originated from sequential contact and separation of two different materials including liquid, is highlighted as a novel mechanism for development of various types of energy harvesters as well as self-powered sensors. Unlike most of the regarding research as materials and chemistry oriented approaches, the role of the classical mechanics in aforementioned triboelectric signal generation is introduced. By adopting the ordinary power transmission unit into the triboelectricity based energy harvester, called triboelectric nanogenerator (TENG), the output performance can be significantly increased and such remarkable increase allows us to use the triboelectric signal generation mechanism more practically. As one of the representative examples, the effective biomechanical energy harvesting via triboelectric signal generation is introduced. Along with it, the advantageous effect of the triboelectric signal generation on the operation of the classical mechanical elements, which are frequently employed for direct power transmission, is proposed. In this regard, the self-triggered mechanical sensors, which enable us to inform various characteristics of the machine components, are proposed. Since the electric signal can be generated without any other external power sources, the present sensor can be considered as self-triggered. Gear and brake are one of the most ordinary and effective components for transmitting mechanical power as a core component of machines. Given that the operation of the gear and brake in power transmission is based on sequential contact and separation between two separated components, the simple modification of the outermost surface of the conventional machine components enables us to spontaneously generate triboelectric signal during ordinary power transmission. The present approach to utilize state-of-the-art triboelectric signal generating mechanism could open new application fields by converging it with the classical mechanics.

Using sound to shed light on tribocharging

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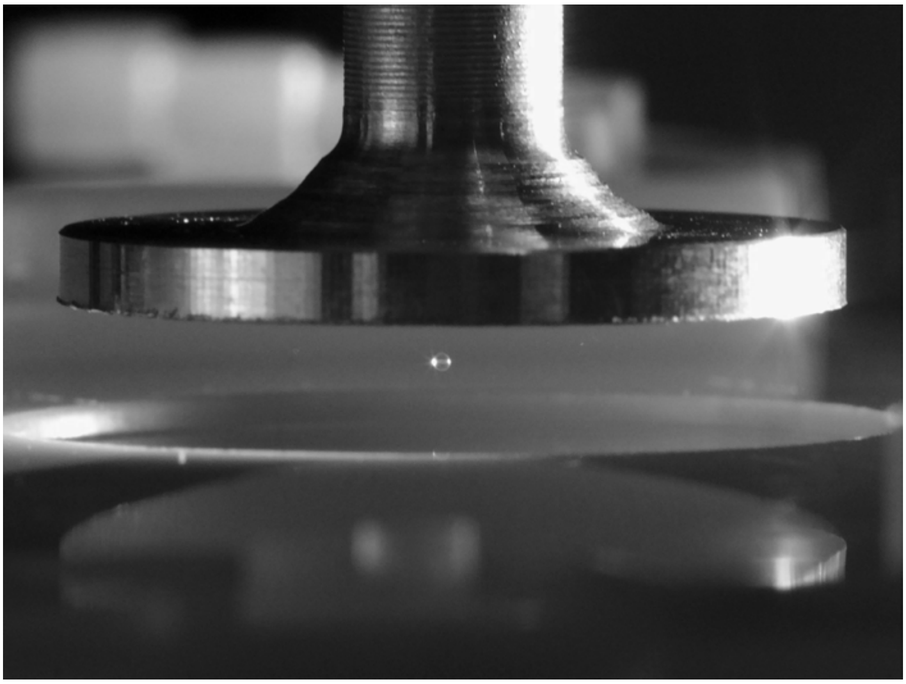
The fundamental workings of contact electrification are still widely debated. Among the many hurdles to overcome, producing clean data and isolating the parameters that drive charging certainly rank high. Here, we use a technique inspired by [1] and [2] where contactless charge measurements are performed by applying electric fields on acoustically-levitated particles. Collisions with a substrate are initiated by timed interruptions of the acoustic trap. Levitation eliminates any unwanted contact with the samples that can influence the measurements. We isolate individual properties by working with identical materials prepared under slightly different conditions. Using this method, we can precisely measure charging rates in a wide variety of situations, allowing us to address fundamental questions such as the role water plays in contact electrification.



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Charge Decay on Levitated Particles in Atmospheric Conditions

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The transport of small atmospheric particles across the world's oceans is crucial for the global biome, for example, dust from the Sahara feeds the Amazon rain forest. This transport can be enhanced by electrostatic forces when individual particles are charged. Yet little is known about the lifetime of charge on such lofted particles. Laboratory measurements are challenging since particles must be levitated and manipulated without contact. Here we use an acoustic radiation trap to levitate and measure the net charge on isolated, millimetric particles for days. Particles are charged with an ionizer, and we adjust the phase of the acoustic field to move the particle through a Faraday cup. Increasing the humidity causes a transition in charge decay behavior from linear, to logarithmic, to exponential while decreasing the half-life from 5 days to 0.1 days. This behavior is observed in negatively charged polystyrene, amaranth, pumice, and aerogel particles. Humidity introduces water mobility on the surface, which may explain the faster charge decay with increased humidity. Half-life in dry environments was also strongly dependent on the polarity of the charged particle and UV wavelength, indicating various charge carriers and bound states on the particle surface. Discharge mechanisms such as ion recruitment by diffusion to the particle surface and the photoelectric effect can explain the range of half-lives from minutes to days.

Excessive dipole moment on collisionally charged dimers explained by mesoscopic charge patches

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The experimentally observed oscillation of dimers of collisionally charged glass spheres (434 micrometers) in an electric field can not explained by their individual net charges or the induced dipoles alone. Static dipoles are a possible explanation. [1]

In our model those static dipoles are introduced via patches of charges on the particles surface. The particel is discretized by arranging 100000 point charges on its surface. Collisional charging is modelled by adding charge to patches of these point charges. Patch size and charge magnitude for each collision is variable. The charge magnitude is drawn from a double exponential distrubtion at for each patch. Each modelled particle undegoes 150000 collisions and the charge configuration is saved every 10000 steps beginning at step number 30000. From this data set 1500 spheres are drawn randomly to build a dimer. For this configuration of two particles the maximum possible dipole moment is assumed. While we don't know the typical charge transferred in one collision, this uncertainty gives us freedom to scale the resulting charge magnitudes but not the geometrical aspects of the simulated charge distribution.

To conclude, the simulated combinations of single particle dipoles and absolute charge differences agree well with our experimental observation and reach a parameter region not accessible otherwise.

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Drop Tower experiments reveal charge transfer by ions on dielectric grains

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In research of collisional charging, it is an unsolved question which kind of charge carriers are responsible for the charge separation. Discussions are reaching from electrons over ions to material transport. As many parameters have an influence on the charging process it is challenging pin down the kind of charges that are transported. [1]

We performed drop tower experiments in which insulating glass spheres of half-mm diameter were shaken in a granular bed and released into a capacitor under microgravity. Thus, we can measure net charges and calculate the charge transfer in particle-particle collisions and in particle-electrode collisions.

In particle-particle collisions, one would expect the sum of the charges of both particles to be conserved. Comparing the charges before and after the collision, this is not the case. 20% of the absolute net charge can be lost and obviously emitted into the gas phase. Since the absolute charge is always reduced in these cases, positive and negative charges are transferred on short timescales [2]. Thus, electrons cannot be the only carriers.

When particles collide with the electrodes they sometimes stick and discharge on time scales of seconds. The field polarity is the driving parameter here, transferring charge always in one direction. In rebound collisions there is no dependency on the field, but the same number of charges is transferred. This can be explained best by a deposition of ions on the particle's surface. [3] Most likely ions are provided by water patches. [4]

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Observing elementary charge exchange between an optically trapped micro-particle and air

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We are surrounded by microscopic particles, from pollen and dust through to dead bacteria and volcanic ash. Typically, these particles are electrostatically charged. Charge can accumulate due to different mechanisms including interactions with other particles, interactions with ions, or the presence of large electromagnetic fields. Recent results have suggested particles can spontaneously exchange with the surrounding air.

Using optical tweezers, we are exploring the mechanisms for charge exchange between isolated micro-particles and the surrounding air. Optical tweezers use light to apply piconewton scale forces, enabling us to levitate and manipulate individual microspheres without mechanical contact. By applying an alternating electric field to the trapped particle, we are able to continuously monitor the particle charge with sub-electron resolution. Preliminary results suggest that the rate at which charges are exchanged depends on particle material, surface area, and most importantly, the humidity of the surrounding air. Our hypothesis is that this occurs due to preferential adsorption of OT- and H+ ions. By using our data to estimate the binding energies of these charges, we aim to test this hypothesis. Our results could shed light on situations ranging from cloud formation and dust storm electrification, through to pollination; anywhere micro-particle charging plays a crucial role.

Experimental Setup to Study the Dynamics of Contact Electrification

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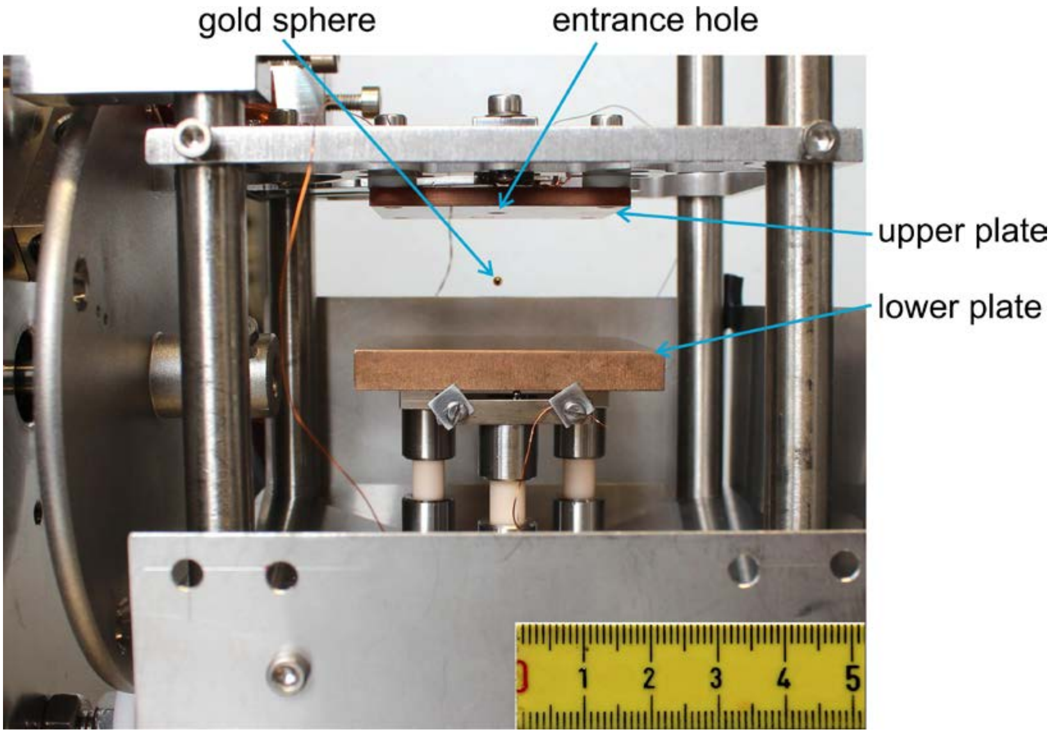
We have developed an experimental method to follow the charge of a small sphere bouncing on a grounded planar electrode [1]. The experiments are carried out under vacuum of 10^{-7} mbar. A daisy chain mechanism allows to study repeatedly the charge transfer for a set of a few small spheres. The latter bounce within a parallel plate capacitor. The charge on both plates is measured by very sensitive charge amplifier on a time scale down to 1 µs with a charge resolution of about 1 fC.



Picture of the experimental Setup

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Combining acoustic levitation and capacitive sensing to probe same-material tribocharging

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The mechanism behind contact electrification, particularly for identical materials, remains largely unresolved. In our group, we use acoustic levitation to measure charge exchange between a small glass sphere and a glass plate. In this particular setup, we improve upon this method by incorporating a capacitive technique to measure charge. One advantage of this is a higher temporal resolution, which will allow us to observe charge exchange events in real-time. A second advantage is the ability to acquire a large amount of statistics in a short period of time. Ultimately we will use this setup to explore the role of humidity on the statistics of charge transfer between identical materials

Coarse grained DEM-CFD modelling of triboelectric charging in fluidized bed

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In fluidized beds used as polymerization reactors, triboelectric charging of particles may cause severe issues that lead to costly plant shutdowns. The main problems are of two types: agglomeration of particles within the reactor body and wall "sheeting", that leads to the formation of hard and consistent polymer lumps that get very difficult to eliminate.

This phenomenon, although well known, is still not fully understood, as it results from the complex interplay between the hydrodynamics and the charged particle interactions. Simulations based on the DEM-CFD approach can help understand the origin and characteristics of the issues affecting fluidized bed operation. However, they typically suffer from severe limitations on the feasible size of the systems, particularly in relation to the number and size of the considered particles. To overcome them, coarse graining methods have been proposed for contact and drag forces acting on the particles.

In this contribution, coarse-grained DEM-CFD simulations are proposed in which particle-particle and particle-wall triboelectric interactions are considered. A condenser model for charge transfer is implemented in the DEM part of the code. Scaling relations for the coarse graining method, i.e. to relate representative grain (*parcel*) properties with those of the original particles, are investigated both analytically and in simulation applications. To this purpose, pure DEM simulations are compared with coarse-grained results in shaken system and in fluidized beds. The former case is used as validation, for the availability of experimental measurements, while the second one is used as test of the interaction of particle tribocharging and the two-phase hydrodynamics in fluidized bed applications.

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Alignment and Aggregation of Sub-mm Particle Clusters through Dipole Moments in Large Electric Fields

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Particle collisions in dust clouds can generate large electric fields due to tribocharging. Each contact between grains leads to charge transfer depending on grain size, material and ambient atmosphere, which results in complex charge patterns on the individual particles [1]. Investigating the nature of tribocharging and its impact on small grains is crucial to understanding agglomeration processes and transportation behavior in the sub-mm range. However, electric charging via collision does not only cause net charges, it also generates dipoles or higher-order moments. To analyze the influence of dipole moments on particle motion in an electric field, we conduct experiments with the help of acoustic trapping [2]. As the correlation between an external electric field and electric dipoles induces a torque, the rotational motion of a freely levitating particle cluster allows us to calculate a permanent dipole moment located on the observed grains. We identify dipole moments in the order of 10^{-15} to 10^{-14} Cm for various agglomerate configurations. First results suggest that dipole moments on clusters, that previously have been agitated by shaking, are significantly higher than those of samples that have not been shaken beforehand. Additionally, clusters align along an equilibrium angle depending on the external electric field. In an aeolian cloud, this will change the cross-section of an agglomerate with respect to the gas drag, which, in turn, has a significant impact on particle transportation and sedimentation. Future experiments with acoustic levitation will shed light on the timescales of charge transfer and charge redistribution among grains and particle clusters.

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Fantastic surface charges and where to find them

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Kelvin Probe Force Microscopy (KPFM) provides nanoscale information about charge exchange during contact electrification. However, the precise signal KPFM measures is not charge, but rather the potential difference between the tip and ground that minimizes the force on the tip. For insulators, this voltage arises due to the presence of surface charges. While the problem of predicting a KPFM voltage from an arrangement of surface charges is straightforward, the inverse problem is complex. Without a method to convert voltage to surface charge density, the signal from KPFM remains qualitative.

We develop a method to convert KPFM voltage maps to surface charge density maps. Due to superposition, the measured KPFM voltage at any location is the summed contribution from the 'point-charge' KPFM voltage of each carrier on the surface. We take advantage of this and do FEM simulations to determine the Green's function for the tip-sample-ground system, and then use this as a kernel with which we deconvolve the KPFM map and recover the charge distribution. We test our approach by creating artificial charge maps, generating KPFM data from these, and then recovering high-fidelity copies of the original input. Moving forward, we will use this approach to precisely extract surface charge densities from experimental data, thus bringing KPFM from qualitative to quantitative.

Model of cohesion in granular materials using numerical simulations

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When comparing the flow of cohesive and non-cohesive powders, one clearly sees differences in the dynamics of both powders. The interpretation of the interaction between particles called cohesion has progressively been attributed to the apparition of electrostatic charges on the surface of particles when they collide. We investigated the effect of cohesion on the flow of cohesive powders in a 2D rotating drum using DEM simulations. To bypass the puzzling complexity of contact charging, a simplified model of intermediate range attraction between grains has been used to reproduce the flow of electrostatic granular materials (see Figure 1). We show that a simple model of cohesion correctly reproduces the dynamics of cohesive granular materials as we observe significantly different flow behaviors when cohesion is added. Plug flow appears in the rotating drum for a wide range of rotation speeds when cohesion becomes sufficiently strong. We propose a measurement of surface flow fluctuations to quantify the strength of cohesion, inspired by the previous observation of plug flow. Then, we make use of the results to include the effect of cohesion into a theoretical granular materials flow model (Dury *et al.* [1]). A good agreement is obtained between theory and numerical measurements of the granular bed's dynamic angle of repose which allows us to propose a method for estimating the microscopic cohesion between grains based on the measurement of surface fluctuations.

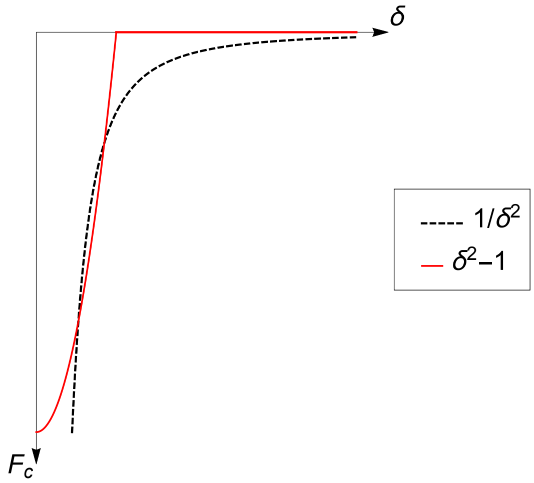

Figure 1: Cohesion model used for numerical simulations (in red) compared to the theoretical interaction potential between particles due to electrostatic charges (dashed, in black). F_c corresponds to the attractive force applied on particles as a function of the surface-to-surface distance between particles δ.

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Preparation of an ISS-Experiment to observe Particle motion and growth to understand early planet formation: The effect of charged and dipole - charged particles.

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Our group is in the preparative phase of an ISS-experiment concerning coagulation and motion of µm sized particles in the context of planet formation. In this poster we show pre-experiments on a suborbital flight that revealed, that our particles are charged and dipole-charged (caused by the coagulation of particles with opposite charge), which e.g. strongly enhances Brownian coagulation.
In the second part we propose how we plan to manage these challenge in our forthcoming ISS-experiment: (1) An application of electrical fields (AC and DC) -- while the particles were observed with a long distance microscope -- to quantify the charges and dipoles. (2) Utilizing of hydrophobic particles to reduce charging and to compare with experiments with hydrophilic and strongly charged particles. (3) Particle injections with different (and also very low) velocities to vary - and reduce the amount of charges on the particles.

Numerical simulations of charge transfer between colliding bodies

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Charge-separation in cirrus clouds, a precursor for lightning in the atmosphere, occurs through the inelastic collisions and consequent transfer of mass between ice particles of different sizes. The amount of mass, and thus charge, transferred directly depends on the kinetic energy lost during the collision. We study, using particle-resolving direct numerical simulation (DNS) in two dimensions, the collisions of circular bodies of different sizes settling under gravity in externally imposed flows. We vary the nondimensional Reynolds number Re = U a_1 / v, where U is the settling velocity scale, a_1 is the radius of the larger particle and v is the fluid viscosity; the ratio of particle sizes a_2 / a_1 ; and the scale of the background shear velocity U_f . In the absence of externally imposed shear, we find that wake capture is effective for small Re and leads to collision, but that the relative velocities at collision are small, while larger Re leads to glancing approach between particles of different sizes. Externally imposed shear enables particle collisions at significantly higher relative velocities, and thus to larger mass and charge transfer. We will quantify the dependence of the magnitude of charge transfer on the strength of externally imposed flow.

Investigating the relationship between humidity and surface heterogeneity in same-material tribocharging

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Same-material insulator tribocharging represents a mystery within a mystery in the field. Apodaca et al. [1] suggested that same-material tribocharging might be caused by statistical variations in surface properties. This was supported by the observation that charge exchange scales with the square root of the contact area. However, the specific properties involved remain unclear. We are testing the hypothesis that the surface heterogeneity is caused by patches of adsorbed water. In our experiments, we bring two pieces of ultra-smooth, soft materials into conformal contact and measure the charge exchange with a Faraday cup. We are varying the humidity to verify if and how it influences the square root scaling. Moving forward, we will use AFM-techniques to map charge and look for correlations with water surface coverage.

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Lunar Regolith Dust Mitigation

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Since the Apollo missions, it has been a common complaint in both manned and unmanned space missions that dust is an eminent issue to which a straightforward solution does not exist. On certain regions of the lunar surface, dust particles are under constant bombardment of solar wind plasma and UV radiation, which have been suggested to cause the so-called "lunar horizon glow", where a continuous mobilisation of dust is observed. The interaction between particles are largely assisted by electrostatic forces induced by the photoelectric phenomenon. Once the particles are in motion, the cycle is kept incessant by tribocharging as well.

Theoretical models have been developed to understand the charging of dust particles at rest and immersed in a plasma; however, experimental work in these areas remain substantially behind. The dust mitigation experiment aims to investigate the effect of vacuum and UV on the efficacy of electrostatic dust removal. As already demonstrated by NASA and other institutions, EDS (electrodynamic dust shield) is an effective method to remove charged particles of a certain size range. This however, has not been thoroughly explored with the combined condition of vacuum and UV radiation. Previous experiments done by researchers have shown that allowing the dust particles to reach vacuum with the chamber also removes their surface charges, rendering them insusceptible to the dielectrophoretic forces generated by the EDS. In order to introduce a charge onto the particle surface, one method would be to irradiate UV onto the particles, creating a charge imbalance by photoelectric effect.

Preliminary tests show that the EDS system is indeed very effective and efficient when there is charge on the dust particles. More measurements are required with different parameters, such as electrode configuration, voltage, frequency etc., to determine the optimal system, and an implementation of a UV lamp in the near future will also reveal if the theoretical models are accurately predicting the dust dynamics.

Triboelectric charging of nanoparticles and microparticles in particle-wall collisions

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Abstract

Particle-wall collisions may lead to significant particle charging. This phenomenon has been investigated for nanoparticles in a low pressure impactor and for micrometer particles in helical tube.
On the one hand, silver nanoparticles, produced by spark discharge, were impacted onto platinum sputtered targets, as well as SiO_2 nanoparticles produced by spray drying. The influence of the impaction angle and the particle size on the triboelectric charging was investigated. While for perpendicular impaction the charge transfer behavior of previous work was confirmed, the oblique impaction revealed new phenomena. Additional charge transfer was observable, which increases with obliqueness. Increased contact area, friction forces and rolling of the particles were identified as likely reasons for higher charge transfer at oblique impaction. The possibility of mass transfer between particle and target due to the high-energy collisions was also investigated by SEM and Auger electron spectroscopy.
On the other hand, particle-wall collisions were realized in a turbulent helical pipe flow. In this case, the triboelectric particle charging was controlled by applying a high voltage on the helix. In fact, the particle charge was shifted from negative to positive when increasing the applied voltage passing across the common triboelectric series. The acquired particle charge was related to particle size and material combination of particle and wall.

Keywords: low pressure impactor, triboelectric charging, nanoparticles, oblique impaction, charge transfer, mass transfer

Explosion hazards during pneumatic powder conveying

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Ignitions and explosions in the chemical and process industry can occur during the handling of combustible powders. Especially dust deposits and triboelectric charging, which cause smoldering fires and spark discharges, are a prime danger to operational safety. Up to today, the discharges of the accumulating electrostatic energy caused numerous catastrophic dust explosions, tremendous economic losses, and the loss of lives of workers and residents. Out of all industrial powder operations, pneumatic conveying leads by far to the highest charge levels due to the high flow velocities. However, the simulation of powder charging during conveying is of greatest challenge. It requires modeling of fluid mechanics (turbulent conveying airflow), surface science (triboelectric charge exchange, adhesion), and electrostatics (forces between charged particles). Also, only limited in-situ measurement technologies exist. Therefore, powder charging still relies on purely empirical control. We will present our advances in recent years in developing simulation tools and measurement technology. In particular, we created the open-source simulation tool pafiX. The tool contains a new particle charging model based on single-particle experiments. Our simulations predict bipolar charge distributions and their dependence on the particle mass flow rate. Further, we model the interaction of charged particles and the formation of deposits. We also studied the formation of deposits experimentally using our pneumatic conveying system. The appearing deposit pattern depends on the particles' size and the flow Reynolds number. Moreover, we investigated the influence of temperature and humidity on powder charging.