Water is Behind the Electrification of Sand

The results of new experiments indicate that surface-adsorbed water molecules are responsible for contact electrification in granular matter, a finding that challenges established models of this phenomenon.

By **Marco G. Mazza**

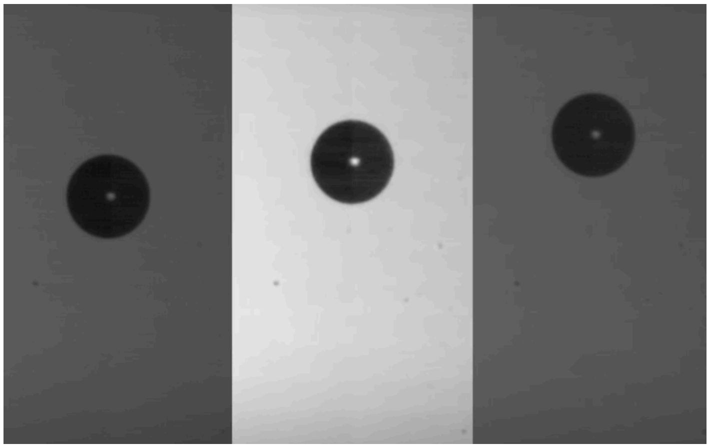
When two surfaces come into contact, they can exchange electrical charge. This fundamental phenomenon is linked to some of humankind's earliest scientific experiments—reports suggest that the ancient Greeks uncovered static electricity after rubbing various materials together. Numerous physical processes are at play when two objects touch. But the mechanism underpinning charge exchange—which is known as contact electrification—has bedeviled scientists for centuries [**1**]. New experiments by Galien Grosjean and Scott Waitukaitis of the Institute of Science and Technology Austria now bring welcome clarity in this field [**2**]. By levitating a single particle and measuring its charge after consecutive collisions with a surface, the researchers were able to uncover a connection between contact electrification and water molecules on the particle and the surface.

Figure 1: Researchers have uncovered a connection between the charge exchange between two granular objects made of the same material and the presence of water molecules on the surface of those objects.
Credit: Calek/stock.adobe.com

When large numbers of insulating particles, such as grains of sand or particles of flour, collide or rub past each other, enormous electric potentials can build up. Such potentials can have dramatic consequences, leading to spectacular discharges, such as the lightning flashes seen during a sandstorm or a volcanic-ash eruption. Closer to home, such discharges can ignite flammable dusts or disrupt powder flows [**3**, **4**]. But a mystery surrounds this contact electrification: How can identical particles exchange charge? In other words, Why does one of the particles become a donor of charge and the other an acceptor?

One factor complicating the understanding of contact electrification is the confusingly large number of material variables involved in charge exchange. These variables include the size and roughness of the particles as well as the temperature and humidity of the environment [**5**]. Despite this complexity, theorists have not been deterred in developing models for contact electrification. Some of these models attribute the charging to quantum-mechanical electron transfer or electrostatic dipolar interactions between particles, while others pin it to the effects of surface chemistry [**6**].

To discriminate between competing models, researchers need experiments that can isolate the mechanisms at work. Faraday



Video 1: This video shows the three steps of Grosjean and Waitukaitis's experiments. (Left) First the silica grain and the silica surface come into contact. (Middle) Then the grain is made to oscillate via a frequency sweep of an externally applied electric field. (Right) Finally any charge on the grain is removed and the system is reset.
Credit: G. Grosjean and S. Waitukaitis [**2**]

cups—hollow metal cylinders—have been the go-to tool for such experiments. The cups are connected to an electrometer, which detects the current created when particles impinging on the cup transfer their charge to the cup. The tool works well when it is used to measure the electrification of a large collection of grains. But it provides too crude a measurement for single-grain experiments, and, importantly, it only provides information on the grain's global charge and not on the charge's spatial distribution. Enter the new study by Grosjean and Waitukaitis.

For their experiments, the researchers turned to acoustic levitation (Video **1**). Their method goes as follows: First they created a standing acoustic wave. Then they used that wave to levitate a single 500-μm-diameter grain of silica so that it hovered above a flat disk, also made of silica. The wave was then briefly turned off, causing the particle to fall and collide with the disk before being captured again.

To measure the buildup of charge on one of the grains during this process, Grosjean and Waitukaitis applied an electric field to the acoustic trap, varying its frequency such that the particle started to oscillate. They tracked this oscillating trajectory using a high-speed camera. Together, these measurements allowed them to extract the grain's electric charge from its acceleration in a manner reminiscent of that used by Millikan to measure the charge of an electron (see **Landmarks—Millikan Measures the Electron's Charge**). Finally, they used a photoionizer—a tool that can be used to remove static charge—to periodically discharge the system, allowing them to reset the system in order to study the statistics of the charging and assess how external factors affected the electrification process. The temperature and relative humidity of the environment were kept constant throughout the experiments.

The results show that the charge on a single grain grows linearly with the number of collisions. This finding excludes "patchy-model" explanations for contact electrification in this system. In such models, patches of charge donors and acceptors are randomly distributed over the surface of a material. If silica has such patches, then some of the grain-surface collisions would have been between donors and acceptors, some between acceptors and donors, and others between like patches. Statistically, over repeated collisions, the net charge would have gone up (more positive), down (more negative), or stayed the same in a random fashion. Instead, the charge always grew in one direction (either more positive or more negative), implying that the mechanism at play comes not from a local phenomenon but rather from a grain-wide property.

Grosjean and Waitukaitis also found that they could reverse the charging potentials of the grain and of the surface by carefully cleaning, baking, and discharging the two objects. For example, in one set of experiments they found that the average charge reversed sign, suggesting that the grain and the surface had switched from being a donor and an acceptor to being an acceptor and a donor. This finding led them to conclude that surface adsorbates—most likely water molecules because of the charge change after cleaning and baking—are behind the electrification process.

The duo is not the first to link adsorbed water with contact electrification (for example, see [**7**]). But by excluding models based on intrinsic properties of the grain, Grosjean and Waitukaitis add to evidence supporting water as the prime candidate. Furthermore, they speculate that adsorption hysteresis of the water may play a key role in the electrification process, as their experiments show that charge exchange depends on how the system is prepared.

These experiments and their interpretation dispel some of the fog around contact electrification. However, several questions remain open. Grosjean and Waitukaitis find no evidence that polarization is involved in contact electrification, in contradiction with earlier experiments [**8**] and theoretical studies [**9**]. Can the new findings be reconciled with these previous ones? Also, the duo study silica, a relatively simple material. Could patchy electrification models be valid for more complex materials [**10**]? Looking at the details of the charging, researchers have previously found that the magnitude of contact electrification scales as a power of the grains' collisional kinetic energy [**5**]. Might Grosjean and Waitukaitis find the same energy dependence using their setup? Finally, if water adsorption is responsible for contact electrification, can a precise relationship be found between the water adsorption level and the magnitude of the charge transfer? Whatever answers researchers find, for now it seems that the secret to making lightning may lie not in a giant, fiery volcano, but in an atomically thin watery coating.

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