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Shape and Charge: Faraday's Ice Pail Experiment Revisited

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Faraday pail measurements of charged dielectrics are not as straightforward as previously thought.

Electrically insulating objects gain a net electrical charge when brought in and out of contact. This phenomenon, known as triboelectrification, is very common and familiar to many of us from a car static zap, to the danger of ignition for hydrocarbons flowing through poorly grounded pipes, to the transfer of inks in a xerographic device. Despite our familiarity with triboelectrification, we still do not have a complete chemical picture of its origin,[1−4] and the exact mechanism by which objects that do not conduct electricity gain an electric charge remains a long-standing scientific puzzle.[4−6] In this issue of *ACS Central Science*, Soh and co-workers explore another aspect of this phenomenon: the relationship between static charge and the shape of the objects.[7]

The first written account on the static charging of insulators is attributed to Thales of Miletus (ca. 600 B.C.). The topic became popular after Benjamin Franklin's iconic "Philadelphia kite" experiment in the 18th century. The systematic study of this phenomenon began with the famous 1844 ice pail experiment by another scientific icon, Michael Faraday. Various versions of this experiment demonstrate the effects of electrostatic induction are still performed today and not only for demonstration purposes. With virtually no exception, engineers, physicists, and chemists attracted by the centuries-old scientific puzzle of triboelectricity turn at first toward Faraday's device (with the only difference of a modern electrometer replacing an electroscope). The precision of the commercial Faraday pail unit is often as good as 0.001 nC, the equivalent of only 6 million elementary charges. A Faraday pail connected to a high-precision electrometer enables simple and reliable measurements of the net electrostatic charge of powders, liquids, and solid samples.

The Faraday pail is a straightforward voltage measurement, or at least so we thought. Now a team led by Siowling Soh alerts us of a trap in the reproducibility of this measurement.[7] In their work, Soh and co-workers showed that changing the shape of a statically charged object changes the coulombs reading by the pail/electrometer setup. Bending a charged plastic sample while holding them inside the pail results in drops of about 0.05−0.2 nC. This change is reversible: charge magnitude picks up again when the plastic sheet is returned to its extended state (Figure 1). The authors propose a mechanism involving migration of ionized air molecules, which immediately calls for more strict environmental control when aiming at measuring such small charge levels. In most laboratories, there is normally a shield placed over the pail to ensure that measurements are not affected by nearby static charges, but air is seldom excluded from the pail.[8]

This new research carries a cautionary message on what to consider when preparing a sample for Faraday pail measurements.

This phenomenon (i.e., the relationship between the charge and the three-dimensional shape) seems to be general: it is independent of the type of atmosphere and materials used in experiments, as well as the sample's net charge sign

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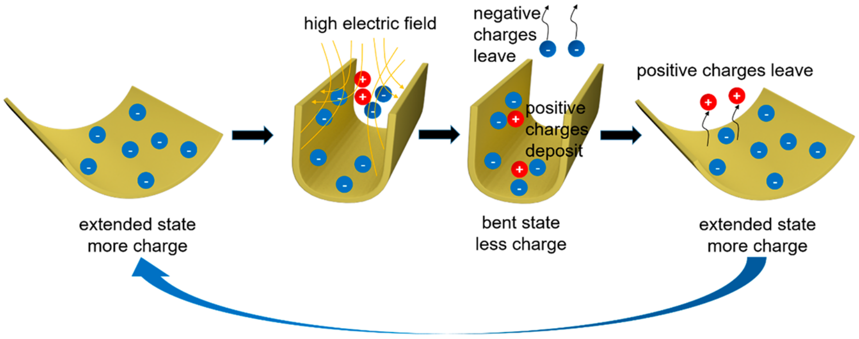

Figure 1. Schematics of the mechanism of the variable and reversible charge change when its shape is changed from an extended state to a bent state repeatedly.

(net positive or net negative). The lack of a relationship with the gas that is in contact with the sample possibly points to water-related effects, which could be addressed in the future by exploring the magnitude of these reversible changes in materials with different macroscopic wetting.

Numerical calculations performed by Soh and co-workers showed an increase in the electric field outside the bent samples, which in turn drives the ionization of the surrounding air molecules, thus generating positive and negative ions inside the pail. The positive ions are attracted to and deposited on the negatively charged surface. It is unclear why adsorbed cations would be rapidly desorbed from a solid surface bearing a net negative charge when the material is relaxed to its equilibrium shape. Although the authors do not discuss the possibility of an exoelectron emission when the sample is folded on itself, this factor could account for at least a fraction of the drop in charge. Electrons are known to emit from insulators upon friction, fracture, and plastic mechanical deformation.[9]

This new research carries a cautionary message on what to consider when preparing a sample for Faraday pail measurements. While triboelectricity remains a largely engineering- and energy-dominated field, chemical aspects of static electricity are now emerging.[10] The findings by Soh and co-workers will guide the design of new triboelectric generators, as well as inspire chemists to discover the nature of the adsorbed ions contributing to the charge drop. Recent work on the electrostatic effects of adsorbed bicarbonate anions (from atmospheric CO_2 dissolved in water) points toward a sensible starting point for future work on the subject.[11]

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