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Account

Electrified Water: Liquid, Vapor and Aerosol

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Many reports associate electrostatic charge in dielectrics with water, either bulk, finely dispersed in aerosol or as atmospheric vapor. Two widespread but currently controversial assumptions relevant to this topic are the prevalence of electroneutrality and the passive role of water in electrical phenomena, dissipating charge due to its significant electrical conductivity. Early reports from Faraday, Kelvin and their contemporaries also point towards an active role of water as an electrifying agent. Unfortunately, these have been largely ignored or treated as scattered pieces of scientific curiosity, for over a century. New trends in this area have been developing since the late 1990s, due to a number of findings leading to radically new ideas. These derive from the experimental demonstration of widespread occurrence of non-electroneutral water and from charge partition associated with a number of interfacial phenomena, even in electrically shielded environments within grounded enclosures. This is an account on the formation and persistence of electrified water in various natural or anthropic environments, followed by experimental results obtained under well-defined conditions that are revealing different mechanisms for the role of water in charge acquisition and dissipation in dielectrics.

Keywords: vapor electricity, electrified interfaces, electric double layer, charge carriers

1. Introduction

Electrostatics is an old area of scientific research that lagged behind most other areas of natural sciences and especially chemistry and physics, during the 20th century.[1,2] This odd situation is largely due to persistent oversimplification of complex phenomena and to widespread but unproven ideas on the nature of excess charge in dielectrics, as well as on its formation and stability.[3]

The role of interfaces as important sites for electric charge accumulation or exchange is well established in solid-solid, liquid-liquid and liquid-solid systems.[4] However, this is not the case for gas-liquid or gas-solid interfaces. Indeed, the effects of excess charge on the surface tension of water including electrocapillary phenomena for pure water under air were recently published, for the first time.[5] Many scientific disciplines study water, ice and other liquids in the atmosphere paying greater or lesser attention to their electrification but this is done while fundamental understanding of droplet charging is still being built up. A short account on the current situation is in the following paragraphs.

1.1. Liquid-air interface: aerosols

The importance of aerosols in atmospheric phenomena is paramount,[6] including a large number of chemicals discharged in the atmosphere by natural and anthropic phenomena. Aqueous aerosols are particularly relevant for cloud formation, stability and rain or snow precipitation, while clouds are also important as precursors of atmospheric aerosols formed by other chemical substances.[7] Aqueous aerosol nucleation has received considerable attention and the reported concentration of nanometer-sized atmospheric ions is in the 200-2500 cm^{-3} range. Charge imparted by ions contributes to aerosol particle formation,[8] but the ion-mediated particle fraction is small compared to the neutral pathways.[9]

Many authors in this area relate atmospheric electricity to liquid water or ice particles and they assign the origins of atmospheric electricity to diverse events, like atmospheric gas ionization due to high-energy particles reaching Earth atmosphere from space, and to ice particle breakdown. The effects of ionizing radiation are relatively well-understood but charge generation associated with the fracture of solids is not,[3,10] even though it is observed frequently.

Recent literature in this area also considers water splashing as a source of charged aerosol particles.[11,12]

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Lenard[13] investigated natural waterfalls and observed that negative charges are found away from a waterfall while detecting positive ones nearby the splash. The author explained his results based on the double layer of charges at the liquid-gas interface: oriented dipoles at the surface of bubbles attract positive or negative charges from the bulk, depending on the nature of the liquid. Either Plateau-Rayleigh instability or mechanical shattering break water jets or bubbles into a spray with a droplet size distribution. In the case of pure water in contact with air, the surface layer carries excess negative charge while the balance accumulates in the bulk. For this reason, the smaller droplets with a larger surface area/volume ratio carry net negative charge while the larger particles carry excess positive charge. Other mechanisms will be examined in section 1.5 of this article. One topical work verifies that splashing water is a source of nano-sized, singly charged aqueous atmospheric ions[14] identified as water-based species and makes interesting proposals for charge separation mechanisms. Another report focusing on the cluster and intermediate ions near a waterfall showed 100-fold higher concentration of negative 1.5-10 nm ions near a waterfall as compared to 100 m away from it,[15] while the difference was not significant for larger ions. Thus, even though experiments on charge production by splashing were reported long ago, they are still a great challenge to experimenters. Current situation is not very different from the following report by Gill and Alfrey[16] in 1952: "…experiments were made…to see if charges were produced when water drops splashed…Charges were certainly produced of a considerable magnitude but, as seems the fate of many meteorological experiments, the results were most inconsistent. Not only did the magnitudes vary but also even the polarity. The only reproducible fact was that distilled water was always much more effective than ordinary water."

The formation of electrified drops by mechanical disruption of liquids is also known as the "balloelectric effect". Following Natanson,[17] it may be expected as a consequence of statistical fluctuations of ion density in the liquid,[18] and it may also have a role in cloud electrification.[19,20]

Many researchers are devoted to laboratory study of aerosol formation, properties and stability, often related to important practical problems in industrial, energy, safety and health contexts. However, aerosol charge is not yet a major concern in this context and many publications on aerosols do not even refer to charge. This situation is quite different from the literature on liquid sols, where zeta potentials or particle charge data are given in nearly every paper. As an example of the scarcity of data on aerosols, the very first report on the electric charge of particles generated during cooking activities appeared in 2014.[21] However, instruments for the determination of atmospheric ion concentration,[22] charge,[23-26] size and velocity are increasingly available.[27] Notwithstanding, a US patent was granted for "an electrothermodynamic generator for the substantially isothermal conversion of the internal heat power of a flowing charged aerosol gas to electric power".[28,29]

1.2. Vapor electricity and electrification during phase change

In 1840, an unusual electrical shock incident a few miles from Newcastle, UK, led Lord Armstrong to send Faraday a description of this unprecedented electrical phenomenon. When an engine-man, working on a faulty boiler, placed his hand in a leaking steam while his other hand was on a metal valve, a violent electrical discharge took place.[30] Using an electrometer, Faraday found the engine steam to be positively charged and later he speculated that friction of steam against other materials was responsible for charge partition between vapor and the contacting materials.[31] This experiment is more often mentioned than reproduced and it has no satisfactory explanation, yet. Later in that century, Lord Kelvin created the well-known "Kelvin's thunderstorm".[32] So far, there is not a quantitative description of these often-mentioned experiments, testifying to current poor understanding of both. The situation is probably related to serious problems observed while handling liquid fuels:[33] large crude carriers sank or suffered severe damage following explosions caused by sparks produced during tank washing with steam.[34] A different case of electrification during phase transition is the appearance of a potential difference across the solid-liquid interface during melting and crystallization,[35,36] especially in the important case of dendrite formation from supercooled water.[37]

1.3. Biological and health effects

Aqueous aerosols participate in most anthropic environments, from the sprays used in agriculture to the plume leaving power plants, inhalers used for medical purpose, Flügge drops[38] emitted by humans that may remain in the atmosphere for long periods and a host of other systems. On the other hand, there is much but often-disputable[39] information showing that small electrified particles or ions in the air affect the human organism.[40] "Ionizer" commercial units claim beneficial effects through the generation of negative ions, while an excess of positive ions may cause headaches and nausea. Following

Kreuger and Reed,[41] serotonin (5-hydroxytryptamine) levels depend on the polarity and concentration of air ions breathed and negative air ions reduce levels of this powerful neurotransmitter. Serotonin, which is synthesized in serotonergic neurons of the central nervous system, elicits both synaptic inhibition and excitation, playing a key role in behavioral systems like regulation of mood, depression and sleep, where increased concentrations of this neurotransmitter result in a behavioral hyperactivity syndrome with head twitching, resting tremor, and hypertonicity.[42] For this reason, the modulation of serotonin at synapses is a major action of several classes of pharmacological antidepressant drugs that selectively block serotonin M-receptors on peripheral neurons.[43] Given the importance of stress in human life, it is not surprising to find commercial equipment being sold based on the beneficial effects of negative ions in the environment that are supposed to prevent symptoms such as headaches and nausea.

Much more recently and using a modified electrospray setup, Demokritou and co-workers[44] from the Harvard School of Public Health transformed atmospheric water vapor into "engineered water nano-structures (EWNS)". These are charged nano-doplets of water, typically 25 nm diameter, believed to be reactive oxygen species encapsulated by an electron-rich water shell that can inactivate bacteria via cell membrane oxidation. Because it is simple and environmentally friendly, this method received great attention from the non-specialized media and has the potential to become an important tool for disinfection technology. However, the structural features of EWNS and its mode of action still deserve much additional scrutiny.

1.4. Mechanisms for charge formation in dielectrics

Electrets and tribocharged insulators are the most important scientific and technological cases for charge formation in dielectrics. Although some electrets have their mechanisms well recognized since the description of the Costa Ribeiro effect[35] (also known as thermo-dielectric effect), the fundamental basis for insulator charging is constantly revisited.[45] In fact, triboelectrification is the oldest known manifestation of the electrical sciences and can be traced back to the ancient Greeks but important new evidence for charge carrier speciation in insulators appeared in the past decade. Since then, different groups presented evidence in favor of electrons[46,47] or ions[48-51] as charge carriers.

Kelvin force microscopy has been used to investigate contact electrification. Recent experiments[52] showed that by contacting two surfaces of identical chemical composition, a mosaic of charges appear on both surfaces, contradicting the implicit widespread concept of the triboelectric series. Terris *et al.*[53] and Knorr[54] also described charge patterns obtained by scratching an atomic force microscopy (AFM) tip on dielectric surfaces and observing a bipolar potential distribution at the microscopic scale. The authors' group showed that multipolar potential patterns are also formed at the macroscopic level, as well.[55] Polytetrafluoroethylene (PTFE) rubbed with polyethylene (PE) displays macroscopic charge mosaics presenting large islands carrying either positive or negative net charge, including macroscopic electric dipoles. Species responsible for tribocharged patterns were identified as polymer ions formed by polymer chain scission followed by electron transfer according to the polymer chain electronegativity, e.g., perfluorinated alkyl residues acquire predominantly negative charge while alkyl residues are predominantly positive. Since polymers are in general immiscible, cation and anion chain fragments segregate forming positive and negative charged islands, following Flory-Huggins theory. A schematic view of the mechanism described is shown in Figure 1.

1.5. Mechanisms for charge formation in aerosols

There is consensus neither on the species responsible for charge transfer and storage in dielectrics nor on the mechanisms for their formation, although this is well-known in metals and semiconductors.[2,56] The same applies to charge appearance in droplets and aerosols,[37] where a detailed laboratory investigation by Takahashi[57] allowed the author to put forward a mechanism for charge generation on thunderstorms based on riming electrification. His laboratory results are consistent with the pattern of charge separation taking place within water-freezing regions of thunderstorm clouds. Besides, according to Iedema *et al.*,[58] at temperatures below 150 K the slight ferroelectricity shown by natural vapor-grown ice allows it to develop large electric fields, but this is not relevant on Earth's atmosphere.

1.6. Excess charge in bulk water and in adsorbed water

The ability of water to store electric charge was recently debated[59,60] and it is now clear that water with excess charge is easily obtained in the laboratory. There is also evidence showing that excess charge in water is a usual feature of water from different places,[61] in common containers. Different authors showed that water-gas interfaces build up negative charge.[62,63]

Water dropping from an electrically biased needle acquires excess charge that can be stored in a Faraday

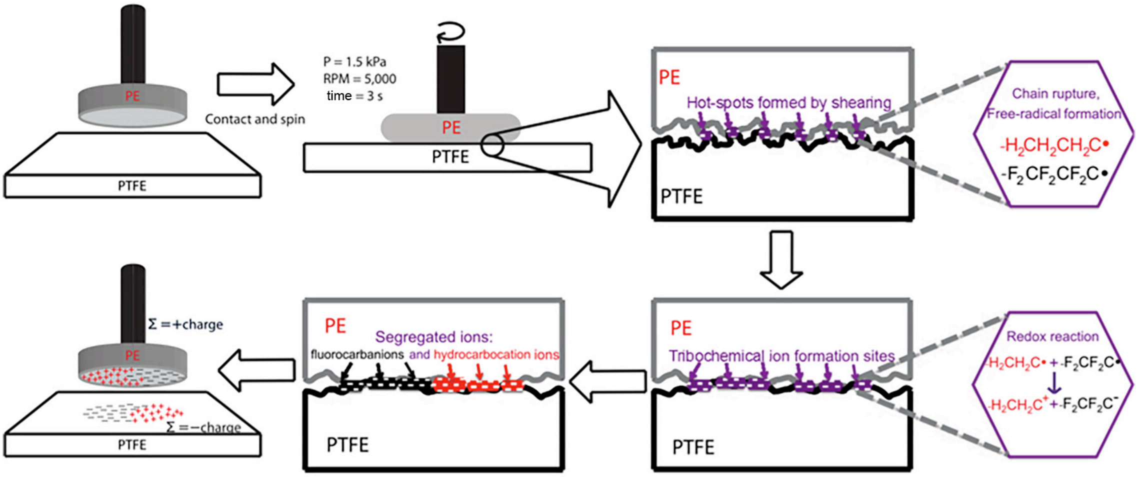

Figure 1. Schematic description of the mechanism for tribocharging dielectric polymers [reprinted with permission from reference 55].

cup, as shown in Figure 2a. Measurements of the surface tension of charged water as a function of needle voltage were made using two different methods: drop shape and drop volume/weight.[55] The results are shown in Figure 2b, showing a marked decrease in the surface tension. The drops are distorted into streaks of electrified liquid, at V > 9 kV, showing that electrostatic repulsion overcomes surface tension.

In these experiments, it is possible to measure charge, potential and surface tension of the electrified liquid, obtaining all the information provided by electrocapillarity experiments. This has been a limited topic of study due to the scarcity of conducting non-reactive liquids, like mercury. However, the experimental protocols used by Santos *et al.*[5] are adaptable to most common liquids at room temperature and this can largely broaden the scope of electrocapillarity. One important outcome of these experiments is the demonstration that potential drop at the water-air interface is a few tens of volts only, when the water drop is biased in the kV region. On the other hand, water density and viscosity are unaltered, showing that charges are accumulated at interfaces only.

Many related findings derived from the availability of practical and reliable means to measure electrostatic potential, based on the Kelvin method. Measurements with high spatial resolution are now used in Kelvin force microscopy and these are highly sensitive to air humidity, as shown in Figure 3. In Figure 3, positive electrodes appear as bright stripes while the negative (grounded) electrodes appear dark. At low humidity, silica does not change its electrostatic potential but under high relative humidity (RH) the dark areas spread out from the negative electrodes to the silica domain.

During this work, many evidences suggested that exposure to water can impart charge to solid surfaces, even on isolated samples under electric shielding and within grounded enclosures. Further experiments were then performed using hydrophobic[65] and hydrophilic[66] solids, using both macroscopic and nano-sized Kelvin electrodes.

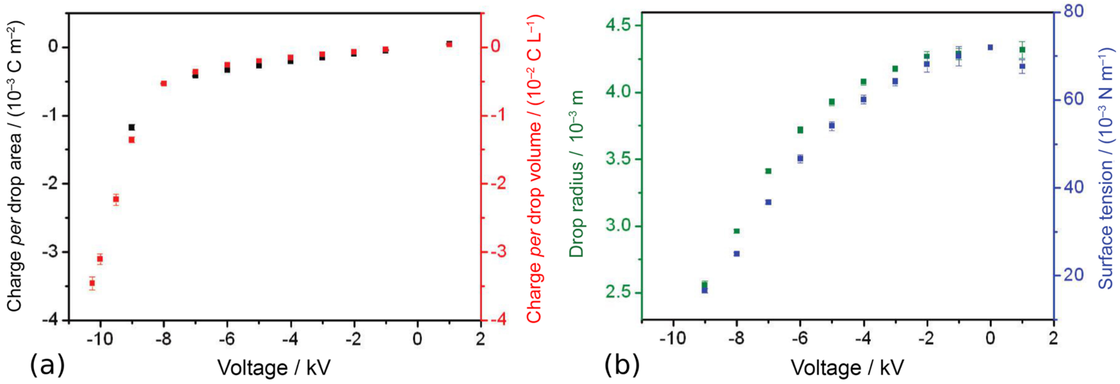

Figure 2. (a) Excess charge on water dropping from a biased needle, as a function of the needle voltage relative to ground. These measurements were made within a 3 × 3 × 4 m³ Faraday cage to avoid drop distortion by large electric fields; (b) drop radius and surface tension of water dropping from a metallic needle, as a function of needle voltage [reprinted with permission from reference 5].

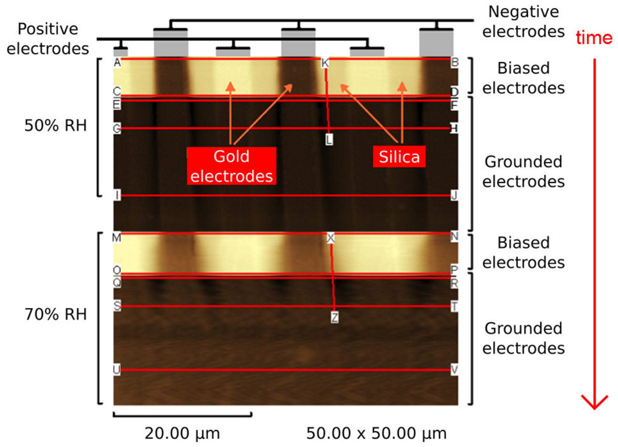

Figure 3. An experiment showing the effect of air humidity on the state of surface charging. The sample is silica on a Si wafer, partly covered with interdigitated gold electrodes and the image is an electric potential map obtained by Kelvin force microscopy. The sample is scanned from top to bottom. Under 50% RH, electric potential on silica is steady and uniform but it changes gradually at 70% RH, showing that silica gradually acquires negative charge.[64]

Table 1. Average electric potential change measured by Kelvin force microscopy on various solids

Substance	ΔV_m / V	
Iron oxide	–0.464 ± 0.004	acid
$MgSO_4$	–0.229 ± 0.008	acid
Silica	–0.172 ± 0.015	acid
Cellulose	–0.104 ± 0.007	acid
Aluminum oxide	–0.055 ± 0.016	acid
Calcium oxide	+1.657 ± 0.115	base
MgO (30-50% RH)	+0.195 ± 0.062	base
Nickel oxide	+0.060 ± 0.017	base
Aluminum phosphate	+0.039 ± 0.007	base

ΔV_m: average electric potential change; RH: relative humidity.

The conclusion is that water vapor adsorption-desorption changes the electric state of solids, this means, the moist atmosphere as well as pure water itself are the sources of charge. A typical experimental result is in Figure 4 and results for many known acid and base solids are in Table 1.

Acidic solids acquire negative charge from water vapor, while basic solids become more positive. This is assigned to selective adsorption of OH^- or H^+ ions, respectively. Figure 5 is a schematic description of ion partition at solid surfaces.[67]

Ion partition during water vapor adsorption is the basis of the recently discovered metal electrification by adsorption of water vapor, also known as hygroelectricity.[67] This is demonstrated building an asymmetric capacitor, this means, a capacitor with electrodes made using different metals. When this is within moist air or even immersed within pure water, a potential difference builds up spontaneously, as shown in Figure 6. The capacitor may be cyclically short-circuited and reopened for many cycles and it is thus a potential source of electrical energy.

Charge partition and transfer during water vapor adsorption led to the recognition of the atmosphere as a source and sink of electric charge.[68,69] An additional factor for water ion partition is the electrochemical potential[4] of hydronium or hydroxide ions under a non-zero electrostatic potential situation.[70] Following equation 1, water is rigorously electroneutral only when it is under zero potential, a rare situation on Earth's surface, that is part of the Earth capacitor[71] where large potential gradients prevail:

$$\mu_i^0 = \mu_i + RT \ln a_i + z_i FV \qquad (1)$$

where μ_i^0 is the standard chemical potential for ionic species i, R is the gas constant, T is the temperature, a_i is the activity of the ion, z_i is the valency of the ion, F is the Faraday constant and V the electric potential.

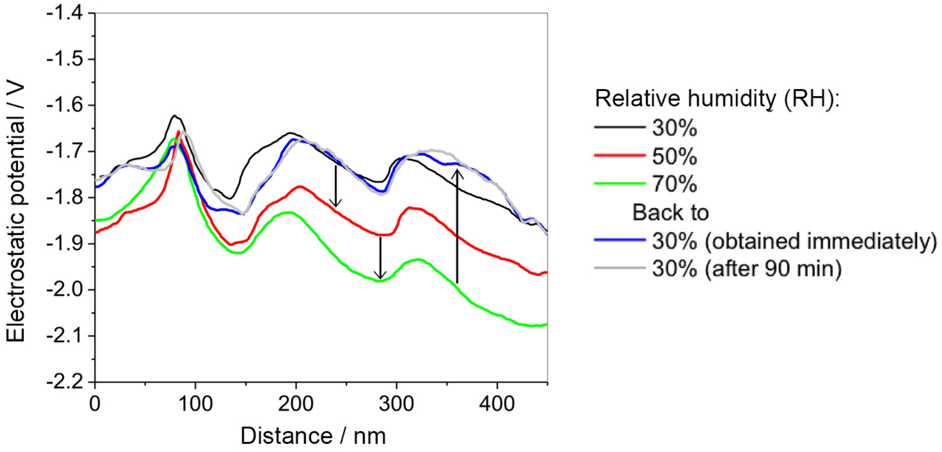

Figure 4. Electric potential variation on Stöber silica surface as a function of the relative air humidity. Increasing humidity makes silica surface more negative, reversibly. The plots are linescans measured in a Kelvin microscope [reprinted with permission from reference 66].

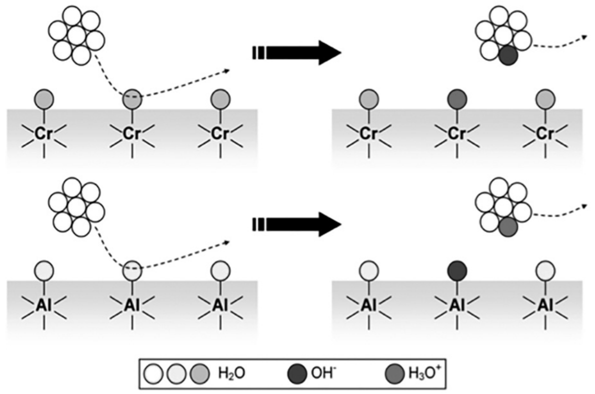

Figure 5. Ion partition during water vapor adsorption and desorption events. A cluster of water approaches a basic (acid) surface and departs leaving (picking up) an H$^+$ ion [reprinted with permission from reference 67].

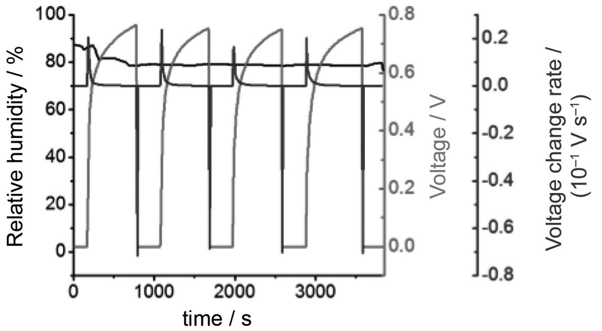

Figure 6. Spontaneous charging of an asymmetric capacitor formed by two metal sheets (Al and stainless steel) separated by a sheet of filter paper in the presence of moist air.[67]

Whenever water is at equilibrium under positive potential, it contains excess OH$^-$ ions, while negative potential leads to excess H$^+$ concentration. This was verified under laboratory conditions, by exposing filter paper sheets to tribocharged insulators, when the paper acquires charge opposite to that of the neighboring charged materials, as seen in Figure 7. When the electrified insulator is withdrawn, charge in the paper falls back to zero.[72] These results are interpreted considering equation 1 and they show that paper shields electrostatic charge effectively, but only at high humidity.

However, this does not mean that positive water is significantly acidic, because significant charge variations require minute excess concentrations, as expressed in the electrochemical equivalent, 96454 C *per* mol. We recall that a few nanocoulombs are easily detected in the laboratory but the detection of nanomols of H$^+$ or OH$^-$ ions requires sophisticated tools.

2. Charged Aerosols

Preliminary experiments made in this laboratory to detect excess electric charge in aerosols or vapor from different liquids revealed an intrinsic electrostatic charging behavior. A robust and reproducible method to generate a current of aerosol is a nebulizer used for inhalation. Charge separation during the formation of aerosol is detected by targeting the flowing aerosol into the interior of a Faraday cup and simultaneously measuring the electrostatic

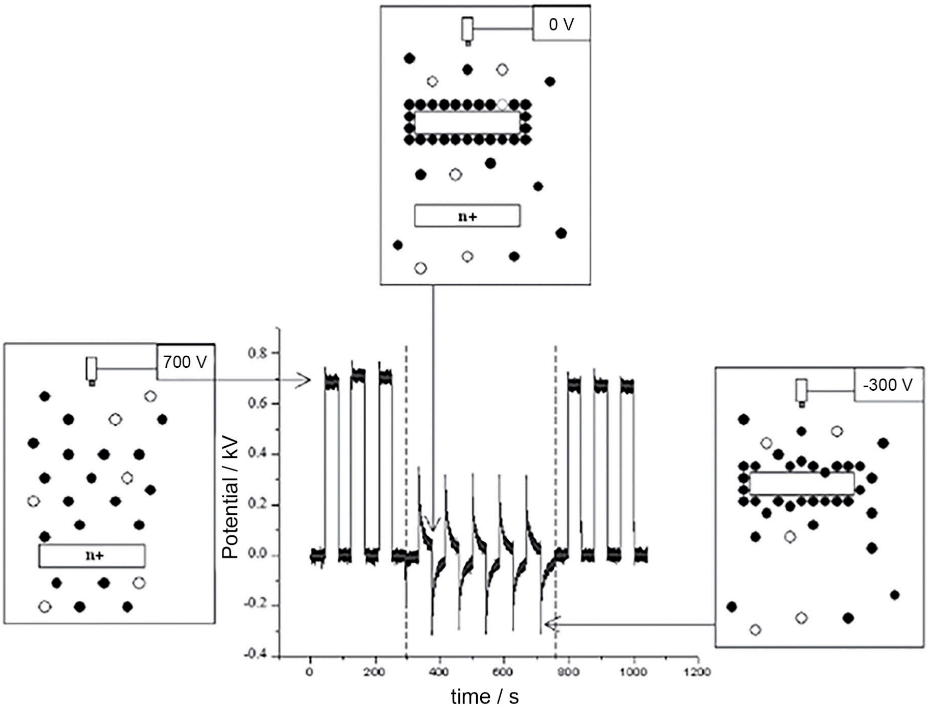

Figure 7. Schematic representation of the mechanism proposed for the observed potential changes.[72]

potential of the nebulizer, using a macroscopic Kelvin electrode. A commercial compressed-air nebulizer was used to produce a fine mist of deionized water or NaCl aqueous solutions. Aerosol is formed by pumping air at high velocity through the fine holes immersed in the liquid close to its surface, dragging the liquid and transforming part of it in an aerosol. Prior to use, nebulizers made of polypropylene (PP) were gently cleaned with neutral detergent, rinsed thoroughly with deionized water, immersed in ethanol for 20 min and finally dried at room temperature while laying on an insulator mat. The final rinse is based on the effect of ethanol to suppress residual electrostatic charges on insulators.[73] The nebulizer was carefully filled using a syringe pump ending in a grounded metallic needle.

The experimental setup is schematically shown in Figure 8. Experiments were conducted by recording both electrostatic potential of the nebulizer and the aerosol charge, simultaneously.

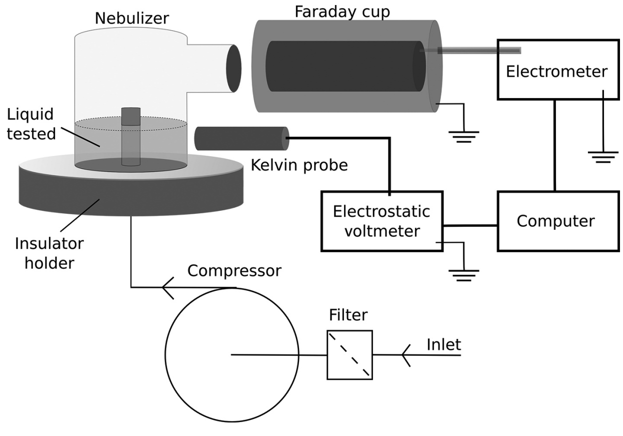

Figure 8. Setup to measure charge on aerosol. The electrostatic charge of the liquid and reservoir measured with a Kelvin probe and the charge of the released aerosol measured with a Faraday cup are recorded simultaneously.

Using the setup described in Figure 8, both the electrostatic potential of the nebulizer and the aerosol charge were recorded. Figure 9 shows representative plots for aerosols from deionized water and sodium chloride solution (1 mmol L^{-1}). The nebulizer initial electrostatic potential is < 3 V, when filled with water or with NaCl solution and electric charge detected in the Faraday cup is < 10^{-11} C. On the other hand, when the compressor is turned on during 30 s, both charge and potential are detected, as shown in Figure 9. When deionized water is nebulized, the aerosol shows positive charge while nebulizer displays a negative potential. NaCl solution shows the opposite behavior, forming a negative aerosol and leaving behind positive charge. When gas flow is turned off, no further charge accumulation is detected in the Faraday cup and the electrostatic potential of the nebulizer filled with water

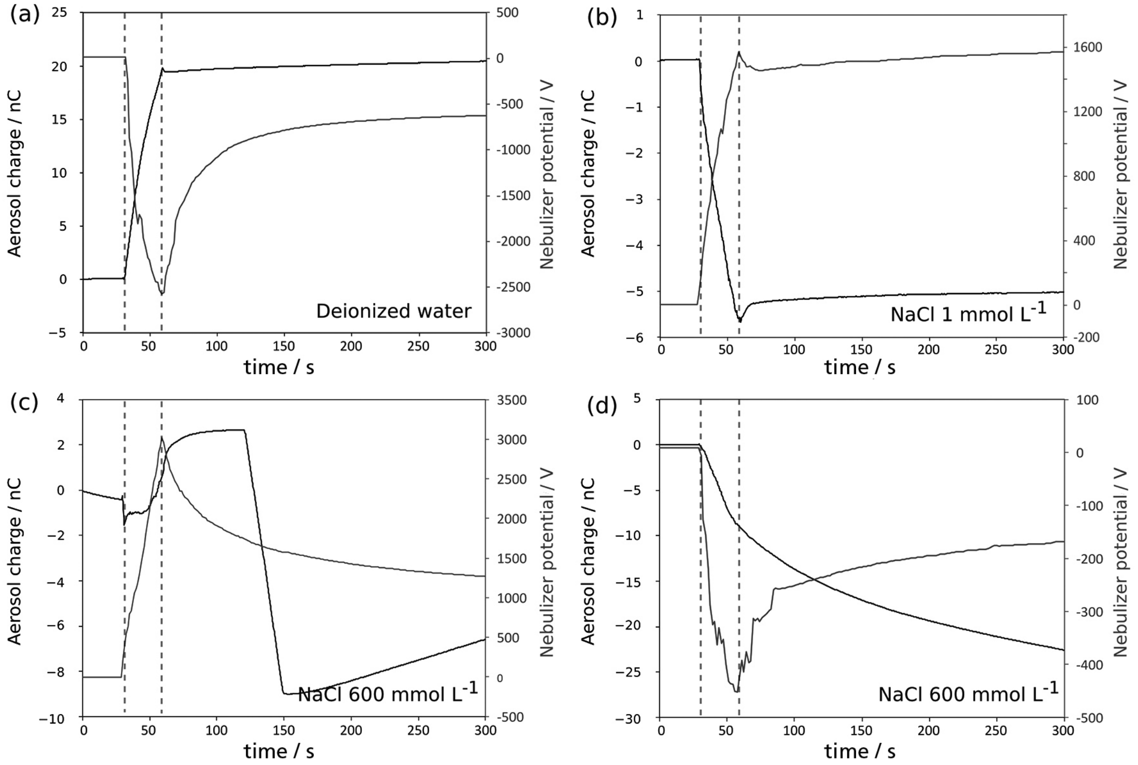

Figure 9. Nebulizer electrostatic potential and charge in the Faraday cup, measured as a function of time when the nebulizer produces aerosol during a short time interval and this is driven towards the interior of Faraday cups. (a) Aerosol from deionized water is positive and the residual water in the nebulizer is negative; (b) sodium chloride solution shows the opposite charging behavior; (c) and (d) random behavior of the concentrated salt solution, chosen out of 14 independent runs. Dashed lines limit the period when the compressor was turned on.

decays from −2500 to −500 V, in five minutes. However, the nebulizer filled with NaCl solution reaches a stable positive electrostatic value, around +1600 V.

Figure 10 shows the electrostatic potential of the nebulizer and charge of aerosol obtained during analogous experiments as in Figure 9, but for different concentrations of NaCl. The electrostatic behavior of aerosol and of the residual liquid is strongly and reproducibly dependent on NaCl concentration. However, using 3.5 wt.% salt concentration, as in seawater concentration, the system behaves randomly: aerosol (or residual water) builds up positive or negative charge during separate runs. These preliminary results are currently being further extended and detailed reports should appear, in the near future.

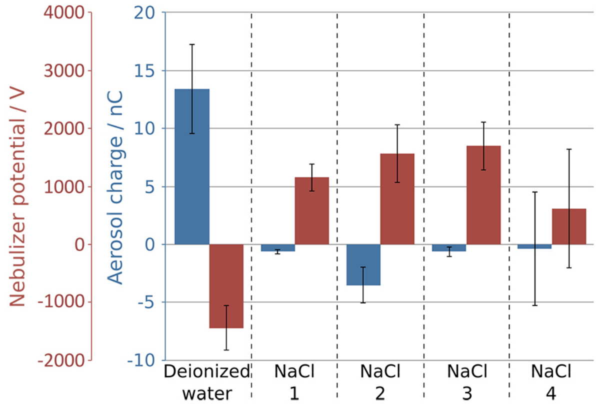

Figure 10. Electrostatic potential of the nebulizer with residual liquid and net charge of aerosol for deionized water and different concentrations of sodium chloride solution. During nebulization, aerosol formed from deionized water has a positive net charge that leaves behind negative charge creating negative potential within the nebulizer. Addition of NaCl at different concentrations (1 = 0.1 mmol L^{-1}; 2 = 1 mmol L^{-1}; 3 = 100 mmol L^{-1}; 4 = 600 mmol L^{-1}) changes this behavior, producing aerosol with a small negative net charge while the nebulizer becomes positive. Sodium chloride at 600 mmol L^{-1} (3.5 wt.%) behaves chaotically: both aerosol and nebulizer carry positive or negative charge, in different runs. Error bars are standard deviations based on at least five independent runs. For 600 mmol L^{-1} NaCl, fourteen experiments were run.

Enlarging current knowledge on aerosol charging phenomena and mechanisms will probably contribute to a better understanding of atmospheric charge formation and stability. Since aqueous aerosols are found in a great number of environments, they can probably contribute to the appearance of the ubiquitous fractal patterns of charge distribution that were detected more than ten years ago in the surfaces of polymers and other common insulators.[74]

3. Prospects

The findings outlined in this account show that water is often non-electroneutral and that it contributes in many ways to impart non-electroneutrality to other substances. Bulk water with excess charge may show many interesting properties but these will likely appear pronouncedly in high surface or interfacial area systems. Important processes like electrowetting, electrospinning and electrostatic coating will probably benefit from these new experimental findings and models for charge build up and dissipation. A challenge now is to devise ways to modify interfacial tension between two liquids by feeding excess charge to interfaces, directly from power supplies and preserving it.

It is now clear that many charging/discharging mechanisms coexist in dielectrics and there is no reason to believe that the complexity of scientific understanding of these phenomena will stop to grow. Understanding electrostatic phenomena is now not possible without considering the associated chemical events and the wealth of singular properties of water, much away from naïve reductionist reasoning.

4. Conclusions

Non-electroneutral water (in any state, pure or mixed with other substances) is spontaneously formed under many circumstances, in natural and anthropic environments and it can be reproducibly obtained in the laboratory, by performing relatively simple experiments.

All the experimental evidence supports the assumption that excess charge carriers in electrified water are ions, especially H^+ and OH^- derived from water itself, but the possibility for imbalance of other ionic solutes cannot be omitted. On the other hand, there is no need to invoke any sort of "space charge" or free electrons to explain electrification phenomena in water.

Water, its vapor, ice, either pure or dissolved, absorbed or adsorbed in various media are found almost anywhere on Earth's surface and also in outer space. On the other hand, experimental results obtained for the past twenty years show that water is effective as an electrifying agent, following adsorption in insulating and metallic solids. This strongly departs from its often-assumed passive role in electrostatic phenomena, acting as a conductor, only. Since most solid surfaces adsorb water, even under low relative humidity, we can expect that adsorbed water adds charge even to seemingly dry particles.

Now, knowing that water contributes to electric charge dissipation but also contributes to electric charge partitioning and build-up under various conditions allows us to give plausible, although still incomplete, descriptions of impressive phenomena like atmospheric electric storms, when electric charge appears in the wide open air, obviously associated with huge masses of water droplets and ice crystals.

Moreover, the electrifying capabilities of water open the way to much additional research on fundamental problems that are also technologically relevant.

One important question is electroneutrality in the environment that is usually assumed but hardly verified. We can now expect many environments to contain localized charge distributed throughout its surfaces, changing the charging state with pressure, temperature and relative humidity. This is especially important in multiphasic solids, where small potential differences between adjacent phases may lead to dangerous potential gradients across the interfaces. The accumulation of electric charge in hydrocarbon fuels has been the source of many accidents with personal and property losses, throughout the world, but this has not been well understood. A new relevant mechanism may be charge partition within the minute amounts of water dissolved in the apolar liquids, whenever these are exposed to moist air.

Finally, a caveat: even though excess charge carried by ions implies the possibility of departure from stoichiometry, this is not to be expected, in most cases, due to the magnitude of the Faraday constant, close to 10^5 C *per* mol of unit charges. We can easily detect 0.1 nC, in the laboratory, or 10^{-15} F. For OH^- ions, this corresponds to 1.7×10^{-14} g, a mass too small to be detected using more or less common balances or other devices for force measurements, including AFM probes.

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Fernando Galembeck*, FRSC, obtained BSc and PhD degrees at the University of São Paulo (USP) and was a postdoc in the Universities of Colorado and California, followed by a stay in Unilever Port Sunlight. He was in the faculty of USP and later became a Professor of Chemistry at the University of Campinas, working on colloids, surfaces, materials and nanotechnology while consulting with industry and advising funding agencies. He is the recipient of Álvaro Alberto and Anísio Teixeira Prizes, the two most important prizes for Brazilian scientists and educators.*

Thiago A. L. Burgo *received his BSc degree (Chemistry) from the State University of Maringá and his PhD from the University of Campinas (2013), working on the triboelectrification of dielectric polymers, where he identified charge carriers and showed for the first time their effects on friction coefficients. Afterwards, he joined the Argonne National Laboratory (Chicago, USA) as a postdoc, investigating the exchange of electric charge at metal-insulator interfaces during friction force fluctuations. His research interests include scanning probe microscopy, electrostatic adhesion, stream electricity and functional materials.*

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