ELECTROWETTING

Shake, rattle and roll

A comprehensive theoretical basis for understanding electrowetting is now available. It shows that it is possible to effect drastic shape changes in electrolyte droplets immersed in another (immiscible) electrolyte.

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In 1936, Frumkin, the Russian pioneer of electrochemistry, observed that the shape of a drop of water placed on a solid electrode could be altered by varying the electrode potential: the stronger the polarization, the flatter the drop. This phenomenon, now known as electrowetting, is finding numerous applications, from liquid lenses to moving drops in microfluidic devices. But, as often happens in science, the technological applications have somehow preceded the theoretical understanding of the phenomenon.

Electrowetting is usually explained by considering droplets of an aqueous electrolyte on an electrode and a surrounding medium, which is often an insulating nonpolar oil. The contact angle between the drop and the electrode, and more generally the shape of the drop, simply depends on the forces acting to minimize the contact areas between the respective phases. By polarizing the electrolyte–electrode interface, this contact area is increased and thereby flattens the drop. However, this approach is rather coarse, as it assumes implicitly the creation of net charges in solution upon polarization. Now Charles Monroe et al. writing in Physical Review Letters, present a comprehensive theory of electrowetting in which the polarization at all three interfaces is taken into account.

In most electrowetting-based devices, the system comprises three phases: a metallic electrode, an aqueous electrolyte and an organic solvent. Usually, only the electrode–aqueous-electrolyte interface is polarized, the organic solvent being ion free. In the liquid lenses developed by Variopict (France) or by Philips (The Netherlands), the main advantage is the absence of moving parts to zoom or to autofocus. The liquid lens therefore mimics a human eye, changing its shape to focus the image on a sensing device. Liquid lenses have found various applications in areas such as cameras in mobile phones, surgical endoscopes or the next generation of blue-ray DVD players. Electrowetting can also be used to create displays using light valves. Extreme Photonics (USA) have used electrowetting to move red, green or blue fluorescent oil droplets on windows exposed to an ultraviolet light source, and in this way they obtained emissive devices with greater luminosity than the classical transmissive liquid-crystal displays. Electrowetting may also find applications in electronic papers as it allows rapid manipulation of coloured liquids on a microscale and could therefore be used in the design of fast reflective displays. Moreover, electrowetting is finding many applications in microfluidic chips either to translate solutions in microchannels or to mix solutions.

As illustrated in Fig. 1, if we take into account the presence of ionic charges, not only in the drop but also in the surrounding solution, all three interfaces become polarized. The polarization of an electrode in solution is a familiar concept. However, the fact that liquid–liquid interfaces may be polarized isn’t often considered. Indeed, the interface between two immiscible electrolyte solutions can also be polarized by accumulating charges on either side of the interface. This phenomenon can easily be demonstrated by observing the shape of a hanging drop of one solution in the other as a function of the applied potential. When the interface is uncharged, the drop tends to a spherical shape whereas it elongates on increasing...
the polarization. Interfaces between immiscible electrolytes are interesting because chemical reactivity and adsorption/desorption phenomena can be controlled by the polarization.

Using recent models of charge distribution at liquid–liquid interfaces, the authors did not assume the formation of net charges. Instead they computed the potential distribution in this three-phase system at mechanical equilibrium. The key feature is that neither the solvent nor the electrolyte of the outer solution can mix with that of the droplet. This preserves the electroneutrality of the droplet, which in fact helps to obtain an exact solution to the problem of finding the polarization at the liquid–liquid interface and leads to unusual consequences.

In the coarse model, the droplet can only spread with increasing potential whereas the present study shows that the droplet may spread or contract. It also predicts contact angle saturation (that is complete wetting as a planar thin film) and droplet de-wetting, both of which were observed experimentally. This means that a drop could be stored on a surface, and then released in a flow, which could be envisaged as a novel storage and delivery system for microfluidic applications.

Finally, when water and oil are swapped, the new model predicts some other surprising effects that depend on electrolyte concentrations and dielectric properties of the droplet and the surrounding solution. All of these could be a source of inspiration for experimentalists and, if verified experimentally, the predictions may yield unexpected applications. Considering the recent trends of functionalizing interfaces between immiscible electrolytes with nano-objects, such as metallic nanoparticles, interesting optical and sensing applications will undoubtedly emerge. For example, it is possible to form gold liquid mirrors by adsorbing charged gold nanoparticles at these interfaces. Combined with electrowetting, we can foresee the design of addressable liquid-mirror arrays. This, of course, is just one of the many possible future directions for this field.

REFERENCES