Sphere remains sphere! Moving droplets by electric fields

Liquid bridges play an important role in our everyday life. On the beach we benefit from their stability when we build sand castles, while in some other situations liquid bridges can be annoying, for instance when they stick our hairs together after taking a shower. These bridges exert attractive or repulsive forces on the contacting surfaces, which depend on the wettability of the surface, and may affect the structure of a system. Studying the morphology of liquid bridges in complex geometries is thus relevant in many fields, such as fog harvesting and dropwise condensation, droplet microfluidics, and oil recovery.

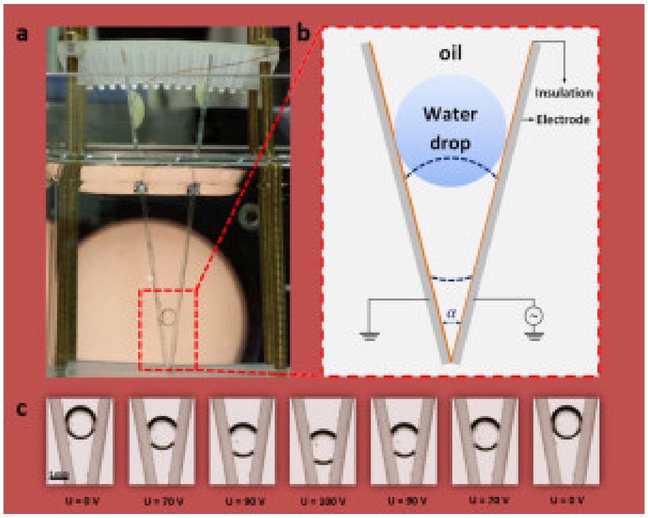

Fig. 1. (a) Experimental setup. The substrates are fixed at an angle using a scaffold, while immersed in a cuvette filled with oil. (b) Cross-sectional schematics of the drop configuration in a wedge before applying voltage (filled shape) and after (dashed contour). (c) Series of images of the droplet, showing its position in the wedge at different voltages.

The shape of liquid drops in constrained geometries, for instance among the sand particles or between fibers can be rather complex. For understanding the droplet's morphology, we can start from a much simpler geometry. A droplet confined in a wedge (Fig.1b) makes a liquid bridge between two non-parallel plates. If the wedge walls are smooth, slippery, water repellant, and also in absence of buoyancy (by matching the density of droplet with surrounding oil), the system is not affected by disturbing forces. Then what would be the shape of the droplet? In such a system, a water droplet in equilibrium always takes the form of a section of sphere, positioned at an equilibrium distance from the wedge apex. Although in the first glance it may look evident, but the equilibrium shape of liquid bridges in such geometries is still an open question in capillarity, even after two centuries history! In a wedge, the shape and more specifically the radius of a spherical droplet depend on the contact angle – the apparent angle which the droplet makes with the surface. It also defines where the droplet is positioned inside the wedge. Therefore a change in the contact angle i.e. wettability of the surface, will result in changing of the droplet’s position. This means a droplet can be manipulated in the wedge. To this end, a method is needed to change the wettability.

We use a unique tool to actively change the contact angle of a droplet on a surface, called “Electrowetting”. The concept relies on applying an electric potential over two insulated electrodes and a conductive droplet in between. Due to the ion attraction and capacitive storage of electrostatic energy, the droplet spreads to increase the contact area with the surface. As a result the surfaces becomes more wetting i.e. the contact angle decreases. The new angle is correlated to the applied voltage (Lippmann relation). Electrowetting is widely used for displays, liquid lenses, and lab-on-a-chip systems. Here we use electrowetting for fundamental science, to analyze the equilibrium shape and position of a droplet inside a wedge under different wettability conditions. In fig.1c a water droplet is shown between two electrodes. As the voltage increases the contact angle reduces, and the droplet approaches the wedge apex. This is a completely reversible process when the voltage is decreased back to zero. We observe that the shape of the droplet is well described by a truncated sphere, which allows us to find a simple correlation between the wettability of the system (tuned by electrowetting) and the position of the drop, by building a geometrical model. A force balance analysis also shows that a truncated sphere droplet does not exert any force on the sidewalls of the wedge, an uncommon situation for constrained droplets!

Appealing for applied science, the geometric constraint and electrowetting can be used to position droplets inside a wedge in a controlled way, without any mechanical actuation. This precise and continuous drop manipulation suggests interesting applications in microfluidics such as on-demand drop generation and liquid flow control.

Publication

On the shape of a droplet in a wedge: new insight from electrowetting.
Baratian D, Cavalli A, van den Ende D, Mugele F
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