Winner of the Leen van Wijngaarden Prize 2015

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Dynamics of wetting: From molecular interactions to macroscopic flows

Nothing seems as mundane as a raindrop sliding down a window. However, this type of wetting flows have continued to challenge researchers for decades. The origin of the challenge is that macroscopic hydrodynamics for a moving contact line is not consistent with a no-slip boundary condition at the solid wall, leading to the famous moving contact line singularity. Hence, one needs to invoke nanoscale features of the flow. On top of this, the molecular landscape of the substrate has a dramatic influence on macroscopic features such as the sliding velocity of a raindrop.

We have recently developed detailed experimental and analytical tools to better understand and predict the dynamics of moving contact lines. Of particular interest are so-called dynamical wetting transitions: When moving too fast, drops can break-up into smaller droplets, or air bubbles can be entrained when solid objects enter a liquid bath. Examples of such flows are given in Figure 1, showing situations just prior to the critical speed for the contact line instability. The figures show how the contact line develops extremely sharp V-shaped corners that determine the critical speed for the instability. Besides their intrinsic interest, these flows are at the core of industrial applications like coating and small-scale imaging technologies. In collaboration with ASML and OCE we have in the past years been able to address practical challenges related to the spreading, breakup and coalescence of droplets and bubbles.

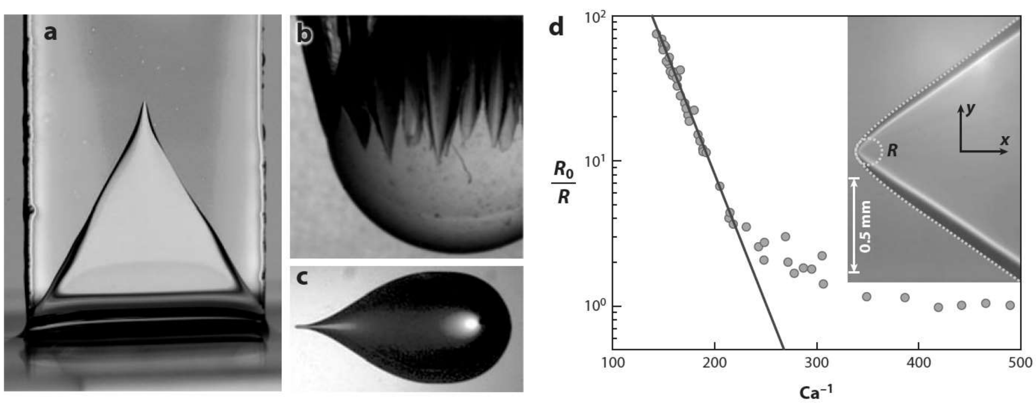

Figure 1. V-shaped contact lines appearing in the context of (a) dip-coating, (b) solid sphere impacting a liquid pool, and (c) sliding drops that exhibit a divergence of the contact line curvature (d).
Taken from Snoeijer & Andreotti, Ann. Rev. Fluid Mech. **45**, 269 (2013). Image b courtesy Lyderic Bocquet, image c courtesy of Laurent Limat.

A peculiar situation arises when the wetted substrate consists of a very soft rubber or gel. The capillary forces due to the droplet will then be able to deform the substrate, giving rise to a “wetting ridge” shown in Figure 2a. The presence of this ridge dramatically changes the classical laws of wetting. At equilibrium, the contact angle follows from a minimization of both capillary *and* elastic free energies. We have shown how this leads to a modification of Young's law for the contact angle. During spreading, the fluid drags the wetting ridge along as it moves over the substrate, inducing strong viscoelastic dissipation inside the highly deformed solid. We have been able to explain how the rheological properties of the solid completely determine the motion of the liquid, and its dynamic contact angle (Figure 2c). Interestingly, we found that above a critical angle the wetting ridge cannot accommodate steady motion: the spreading undergoes an intricate stick-slip motion, during which the contact line slides down the wetting ridge (Figure 2d).

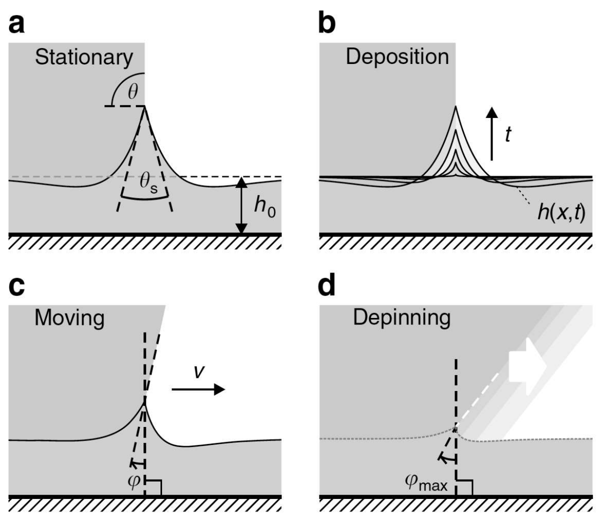

Figure 2. Statics and dynamics of a wetting ridge below a liquid drop on a soft surface. (a) Equilibrium shape of the wetting ridge. (b) Growth of the ridge after droplet deposition. (c) Dynamic contact angle during spreading. (d) Dynamical depinning event, where the contact line slides down the ridge.
Taken from S. Karpitschka, S. Das, M. van Gorcum, H. Perrin, B. Andreotti and J.H. Snoeijer, Nature Communications **6**, 7891 (2015).