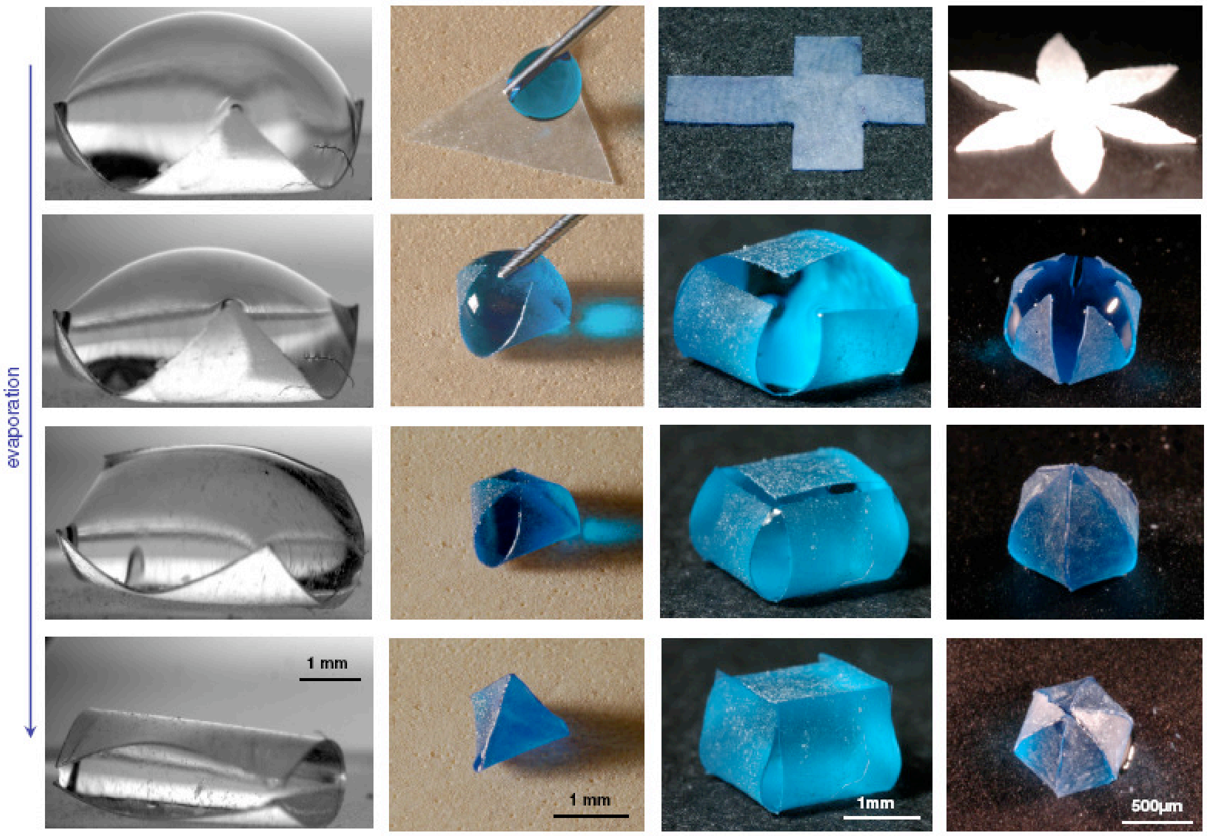
Capillary origami

Charlotte Py [1*], Paul Reverdy [2], Lionel Doppler [1], José Bico [1], Benoît Roman [1] and Charles Baroud [2]
[1] Physique et Mécanique des Milieux Hétérogènes, ESPCI – UMR CNRS 7635 – Université Paris VI – Université Paris VII. Paris, France.
[2] Laboratoire d'Hydrodynamique, Ecole Polytechnique – UMR CNRS 7646. Palaiseau, France.

The hairs of a wet dog rushing out from a pound assemble into bundles: this is a common example of the effect of capillary forces on flexible structures. From a practical point of view, the deformation and adhesion of compliant structures induced by interfacial forces may lead to disastrous effects in micro electro-mechanical systems. However capillarity may also drive the association of such microstructures into well-defined patterns, and thus be used to produce small objects. What happens when a water droplet is deposited on a flexible sheet? Does the sheet spontaneously wrap the droplet? Yes, if driving capillary forces overtake the elastic bending resistance of the sheet.



Our experiments were conducted with polydimethylsiloxane (PDMS) membranes. The PDMS was spin-coated at rotation rates of 1000 to 2000 rpm, leading to layers with thickness in the range 80 to 40 µm. Once the PDMS was cured, a geometrical shape was manually cut from the layer and placed on a superhydrophobic surface. A drop of water was then deposited on the PDMS, and allowed to evaporate. As the water volume decreases, the surface tension of

*present adress: Matière et Système Complexes, Université Paris VII, Paris, France.
email: charlotte.py@paris7.jussieu.fr

the liquid pulls the sheet around smaller volumes, thus increasingly curving it. Sufficiently thin sheets eventually encapsulate the liquid with a shape that depends on the initial cut of the membrane.

The membrane deformation reduces the liquid-air area and thus the surface energy, at the cost of increasing the bending energy. Wrapping of the drop by the membrane occurs when the surface energy is large with respect to the bending energy, which is equivalent to comparing the size L of the membrane with the elastocapillary length, $L_{EC} = \sqrt{B/\gamma}$, where B is the bending rigidity of the membrane and γ the surface tension of the liquid. A 2D model, in which the PDMS sheet is governed by Euler's elastica equations and bent by pressure and surface tension forces at its tip, allowed us to predict the critical length of the membrane above which complete encapsulation of the drop occurs. The theoretical results are in good qualitative and quantitative agreement with our experimental results obtained on square PDMS sheets. The elastocapillary length, and thus the critical length for folding, depend on the membrane thickness as $h^{3/2}$, a scaling favorable to miniaturization since thinner membranes lead to much smaller critical lengths.

In summary, we obtained the self-assembly of millimetric objects through the capillary wrapping of an initially flat surface. Various 3D shapes can be obtained by tuning the initial cut of the membrane : pyramids, cubes or quasi-spheres are obtained from triangles, crosses or flowers shapes, respectively. Since it relies only on standard microfabrication techniques, this process is readily applicable to mass production of micro- or nano-objects.

References :

C. Py, P. Reverdy, L. Doppler, J. Bico, B. Roman, P. Reverdy and C. N. Baroud, Capillary origami: spontaneous wrapping of a droplet with an elastic sheet, *Phys. Rev. Lett.,* 98, 156103 (2007).

*present adress: Matière et Système Complexes, Université Paris VII, Paris, France.
email: charlotte.py@paris7.jussieu.fr