Smectic bubbles, catenoids, foams

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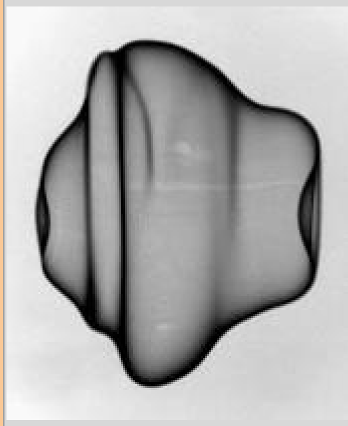
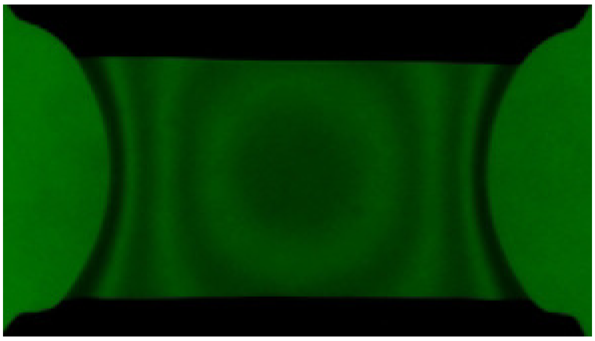
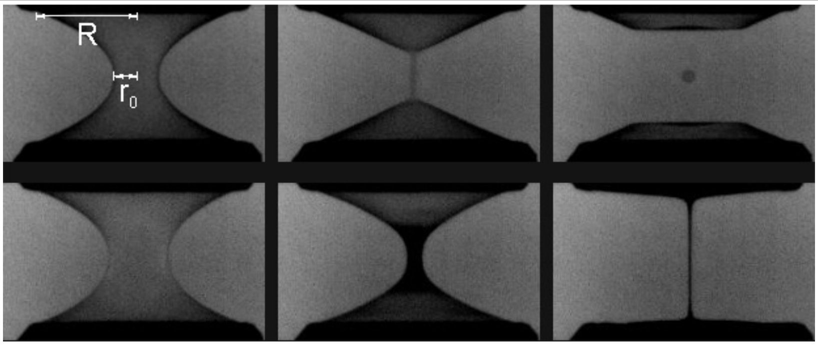


Smectic catenoids

Fluid films that span the gap between two coaxial cylinders adopt a catenoid shape. Catenoid solutions do exist only when their separation does not exeed 1.325.. times the holder radius. When the holders are separated beyond that critical distance, the catenoid pinches off and breaks.



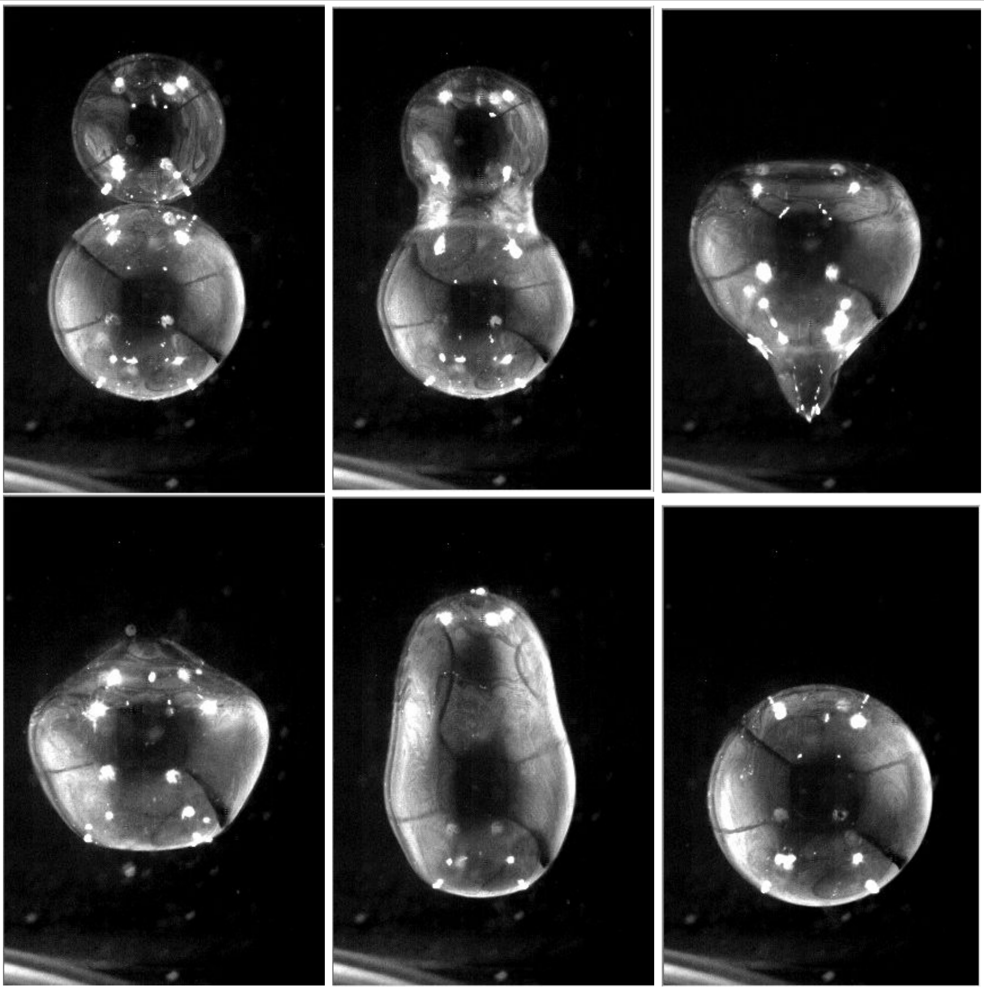
Smectic catenoid film spanning the ends of two coaxial cylinders. The image was taken with green monochromatic light, the uniform film thickness can be determined from the interference fringes in transmission [Müller2006].



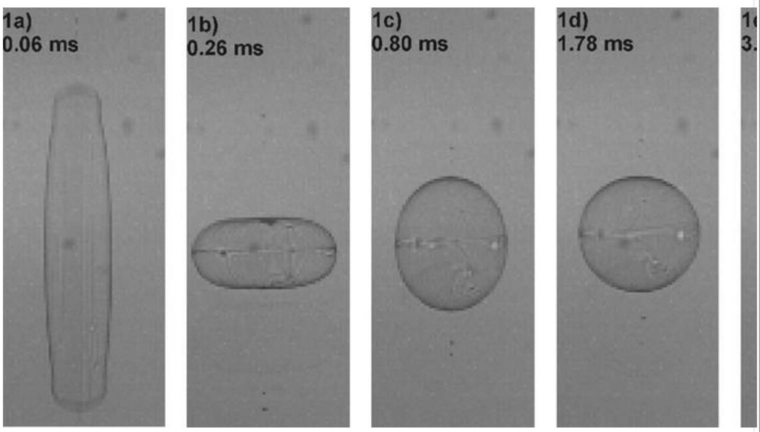
Collapse of smectic catenoids: The upper row shows the standard scenario where the catenoid collapses to an elongated bubble in the middle which later transforms by damped oscillations into a spherical satellite bubble. These satellite bubbles are studied in detail below. The bottom row shows another scenario where the film changes its thickness at the waist, and instead of a bubble, a string is formed that rapidly decomposes into droplets by the Rayleigh-Plateau instability. The catenoid collapse is a complicated dynamic process which involves inertial and viscous forces of the film and the surrounding air [Müller2006]. We utilize the pinch-off of smectic catenoids to produce freely-floating closed smectic films without contact to a meniscus or support [May2012].

Oscillations of bubbles

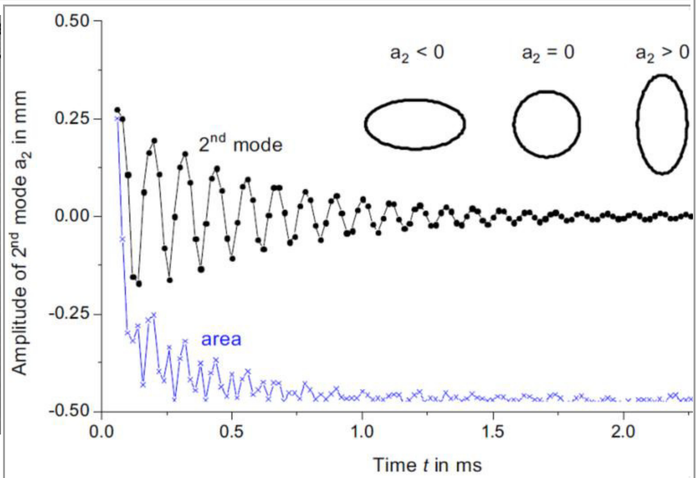
A model for small oscillations of fluid bubbles and droplets has been described by Lamb 1937. Since then, there have been numerous theoretical treatments of oscillations of droplets or bubbles, the theory has been extended to larger amplitudes, viscosities, finite film thicknesses (see Refs. in [Kornek2010]). We observe oscillating soap bubbles and smectic bubbles. Both structures exhibit completely different dynamic properties. While soap bubbles follow the classical models quite reasonably, smectic bubbles perform very different shape changes at small and large amplitude deformations [May2012].



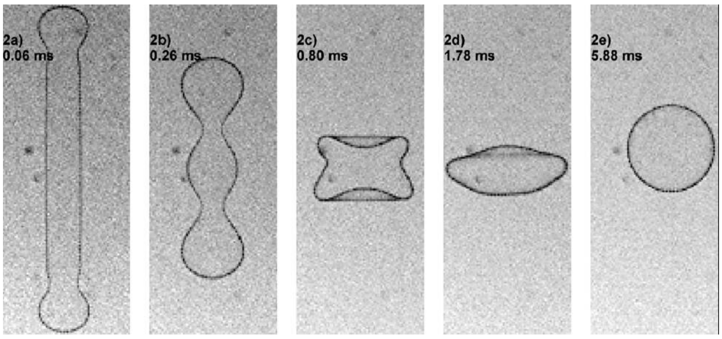
Oscillations of a soap film towards equilibrium after the fusion of two soap bubbles. The length of this image sequence is 0.35 s. The volume of the bubble remains constant, the surface area performs damped oscillations towards the minimum. The bubble shape remains axially symmetric. From a decomposition into the eigenmodes, a numerical analysis was performed and the comparison with numerical simulations was achieved [Kornek2010].



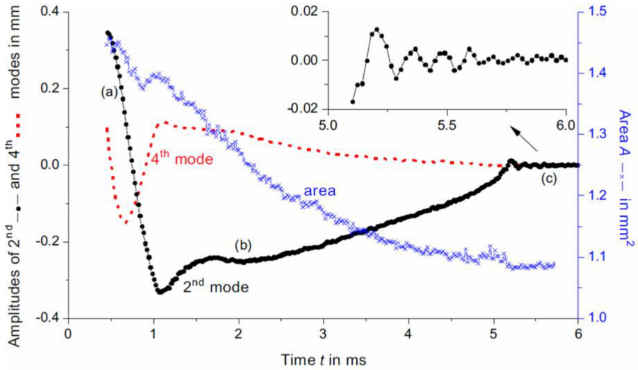
Oscillations of a soap bubble (0.25 mm radius). The analysis of the dynamics is shown in the diagram in the right column [May2012].



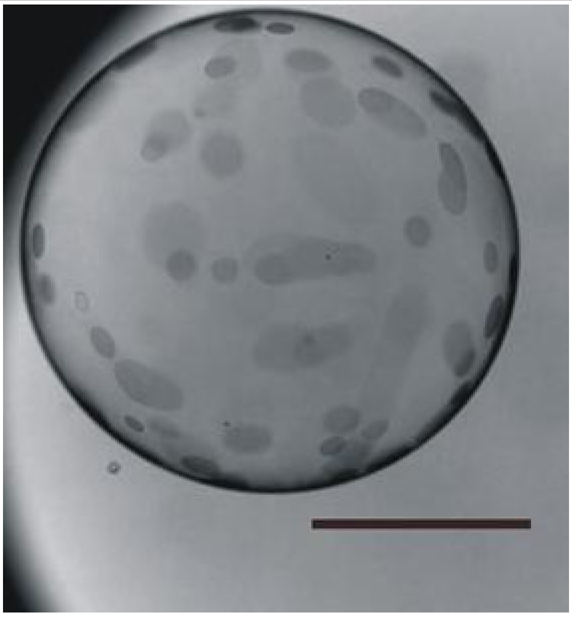
Analysis of the oscillation modes of the soap bubble. After formation, fast capillary driven oscillations are observed in the 2nd mode as well as in the surface area (with twice the frequency of the former). These oscillations are damped, the final state is a sphere [May2012].



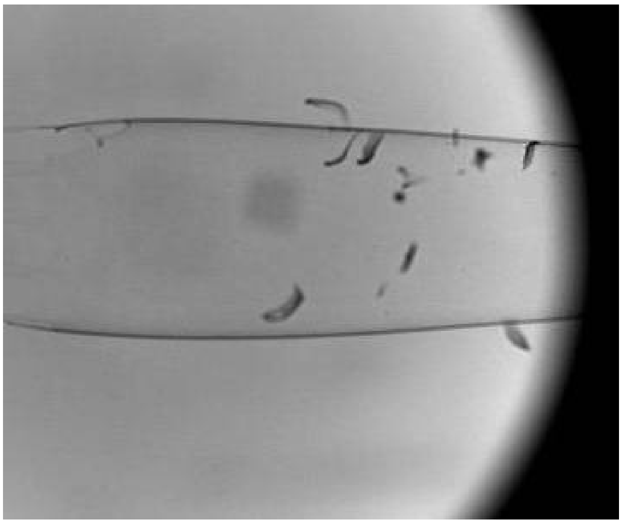
Oscillations of a smectic bubble (0.25 mm radius). The analysis of the dynamics is shown in the diagram in the right column [May2012].



Analysis of the oscillation modes of the smectic bubble. Three phases are found, first a fast relaxation towards a structure with an aspect ratio close to one, then a slow shape transformation at monotonically decreasing surface area, and finally fast capillary driven oscillations [May2012].



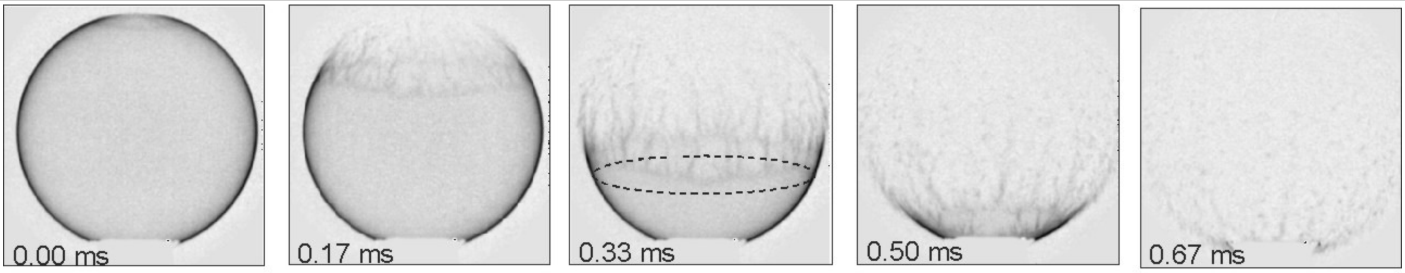
As the reason for the delayed dynamics in the second phase of the soap bubble relaxation, we identify dislocation dynamics and the surface reduction by island formation. The dark spots on the bubble are islands of excess smectic layers that have formed during the relaxation [May2012].



Tubuli can form when the film contracts very fast and excess smectic material must be disposed [May2012]

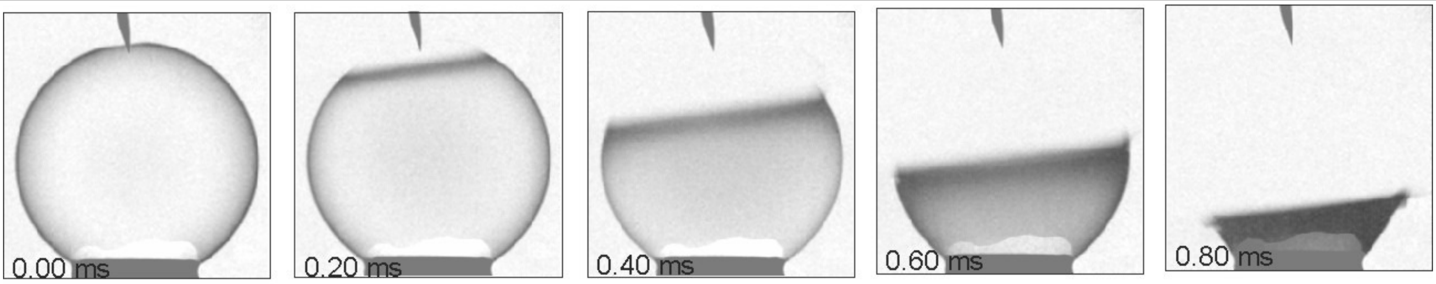
Rupture of thin fluid films

Taylor and Culick proposed half a century ago an equation for the velocity of the rim of an opening hole in a bursting soap film. They predicted a velocity of the rim of $v = (2\sigma/\rho d)^{1/2}$ for a film with tension σ, density ρ and thickness *d*. Smectic films are ideal objects to study the validity of this prediction, since they can be produced with uniform thicknesses, which can be easily determined from interference patterns in transmitted light..



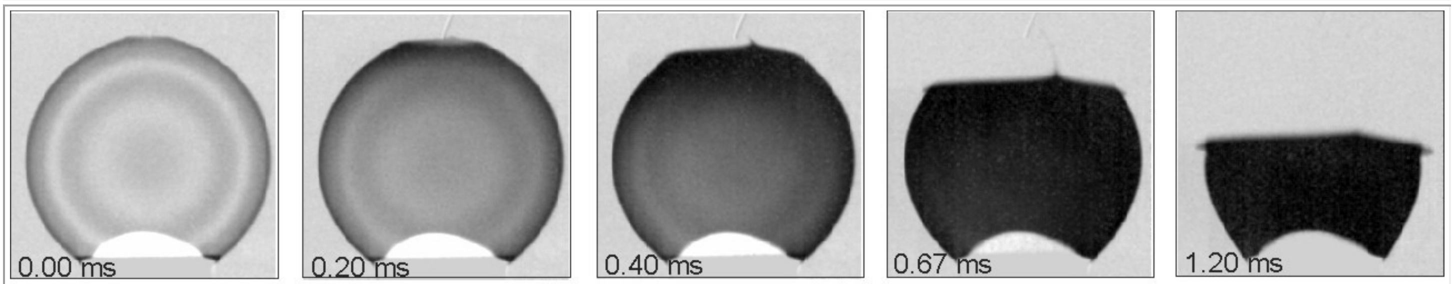
δ = 100 nm

Thin bursting smectic film. Note the filamentation of the rim [Müller2007]. The same instability has been observed also in bursting soap films.



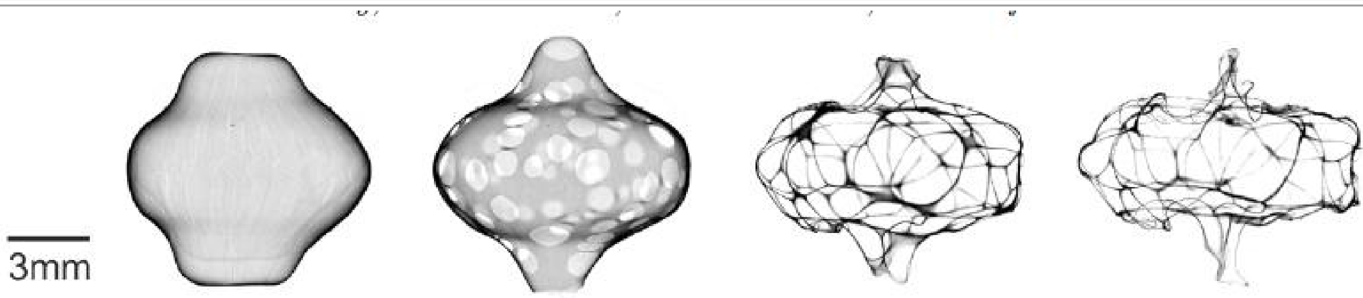
δ = 560 nm

Bursting smectic film of medium thickness. Note the darkening of the film, starting in the vicinity of the rim. We interpret this as scattering of the film which is peristaltically modulated by mechanical waves. This phenomenon is related to the propagation of transversal sound waves ('second sound') in the smectic material [Müller2007,Müller2009PRE]



δ = 1840 nm

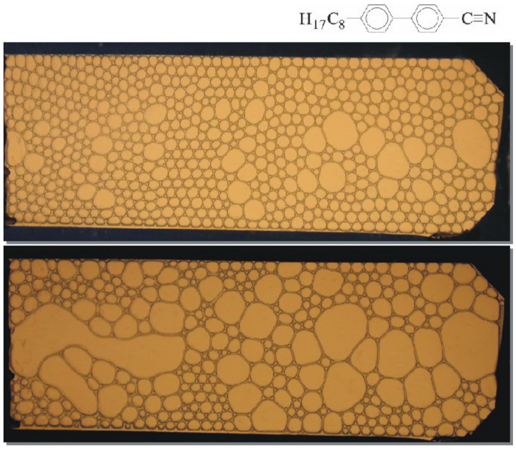
In thick films, one observes the formation of a brim. The rim roughly follows the original bubble periphery, while the remaining film collapses inwards [Müller2007]



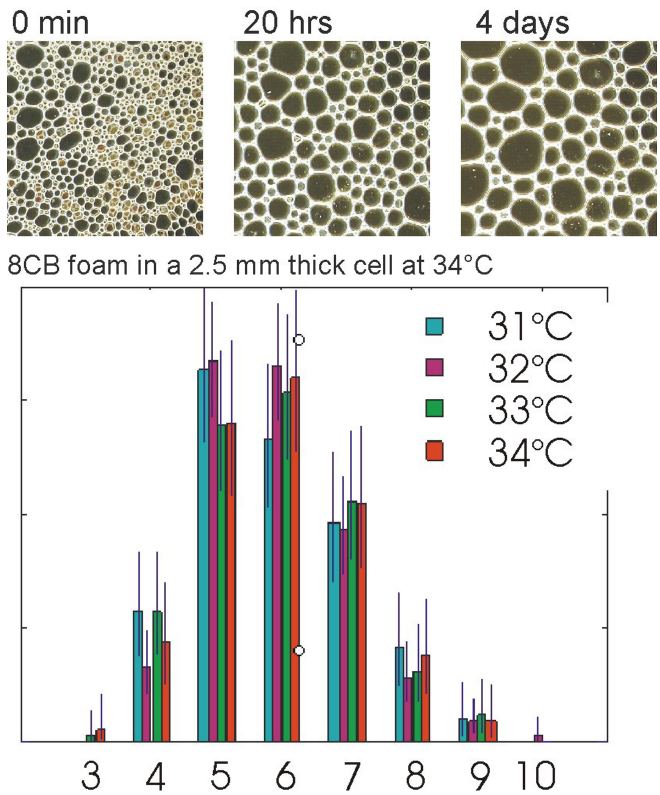
Closed smectic A bubbles can show a different rupture scenario. They burst spontaneously during shape transformations, forming a network of interconnected smectic A filaments which rapidly decompose to droplets as a consequence of the Rayleigh-Plateau instability.

Smectic foams

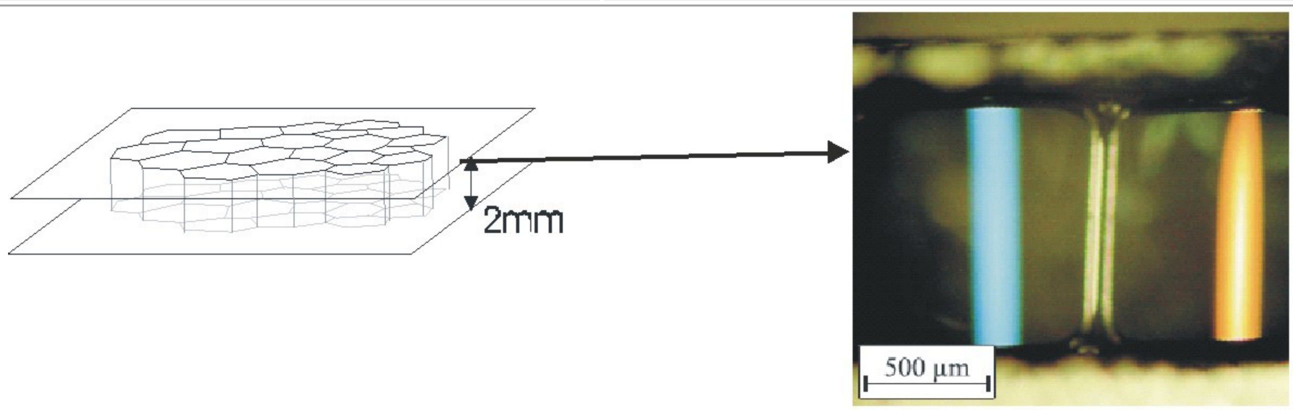
Because of their lamellar inner structure, smectics can form very stable foams. Such foams contain very few percent of liquid, they are mostly composed of entrapped air (dry foams). Smectic foams are much less susceptible to drainage compared to aqueous foams.



Smectic foam of the mesogen 8CB after preparation (top) and after coarsening (bottom). The 2D foam was produced in cells of about 25 mm width.



Coarsening of smectic foam. During coarsening, a universal distribution of n-polygons forms, with a maximum at hexagonal and pentagomal shapes.



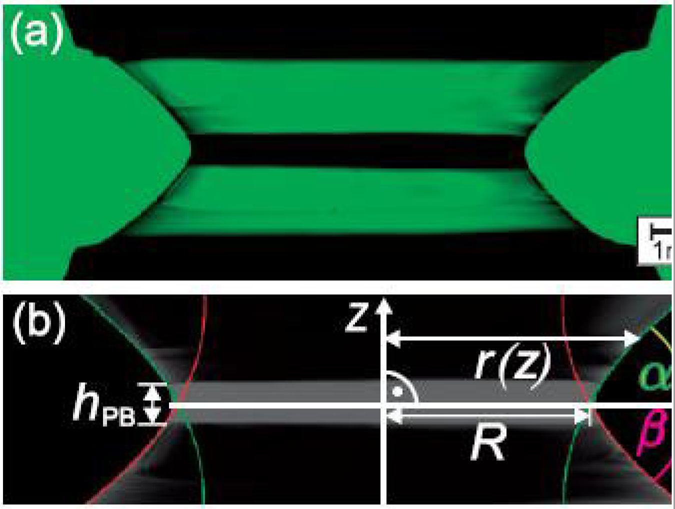
Side view of smectic foam cells. The interference colors reflect the thickness of the individual membranes. Each membrane is uniformly thick, thicknesses are in the optical wavelength range. In the center, a Plateau border is seen.

Natural dry foam has characteristic properties that are general and independent of the material

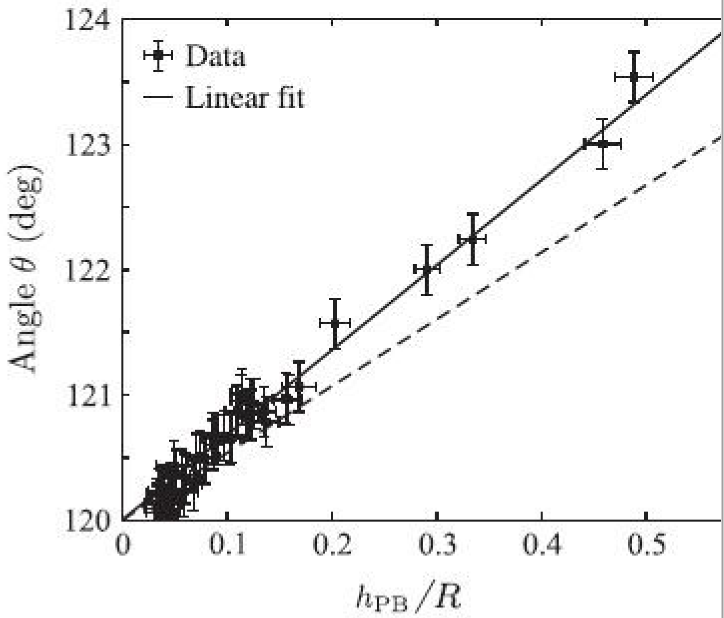
- the general asymptotic distribution function of n-polygons
- the growth/shrinkage rate of cells as a function of the number of neighbors (von Neumann law)
- the dependence of the average cell area on the number of neighbors (Lewis' hypothesis)
- weighted average of the number of edges of neighbors on the number of neighbors (Aboav-Weaire law)
- linear dependence of the average area per foam cell on time (square root dependence of average cell radius)

all these characteristics have been confirmed for smectic foams [Trittel2010]

Negative line tension of Plateau borders



At each connection of three films (Plateau border), the films form angles of 120° to each other in equilibrium. This law results from the force equilibrium of capillary forces at the edge (Plateau's rule). It is valid for dry foam and straight Plateau borders. The decoration of the Plateau borders with a liquid meniscus leads to an additional negative line tension, in that case, the films (e. g. a film in the waist of a catenoid) do not form the 120° angles but can deviate from that rule.



Deviations of the angles θ = α + β from the Plateau rule as a function of the meniscus height, measured for the smectic liquid crystal 8CB [Trittel2011].

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