Shear-Induced Buckling Instability in The Lamellar Phase:a Mechanism for Onions Formation?

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We present a model of coupling of shear flow to microscopic degrees of freedom in the lyotropic Smectic A (lamellar phase).This coupling is then shown to produce macroscopic buckling instability unalogous to well known undulation instability appearing in thermotropic smectics under dilatation in the direction perpendicular to the layers.[2]

The lyotropic lamellar phase is experimentally known to become unstable under shear flow.The instability occurs at shear rate $\gamma \sim 1sec^{-1}$ and the so called 'onions' (multilamellar vesicles) are formed[1].

We propose that the instability occurs in two stages.At the first stage,the layers are buckled by shear -induced *microscopic* tension $\sigma \cong \eta_e \dot{\gamma} d$ where η_e is an effective viscosity of the system (which can be very large :$\eta_e \cong 1000\eta_{solvent}$) and d is an interlayer spacing.As the membrane projected area cannot increase (for example,being sandwiched between defects) it has to *buckle* in the direction perpendicular to itself.There is a critical tension however due to energy cost of compression of layers in the buckled state and of bending and expansion of individual layers.Then one is able to calculate the buckling amplitude U_0 and the wavevector k as a function of $\dot{\gamma}$.Denoting K usual smectic bending modulus and B the compressional one ,the result is that the transition occurs at $\sigma_c \cong \frac{T}{Dd}$,where D is the width of a film.For $\sigma - \sigma_c \gg \sigma_c$ we have $k \cong \sigma^{\frac{1}{6}}$, $U_0 k \cong \sqrt{\frac{8\sigma}{3dB}}$.

At the second stage the buckled structure is deformed by shear (by coupling to *nacroscopic* degrees of freedom) nad eventually broken ,resulting in the formation of onions. We speculate that the buckled state will become unstable when the relaxation time of the buckling structure $\tau_c \cong \frac{\eta_e}{Kk^2}$ is shorter than the one needed for shear to deform the structure to a degree that maxima are shifted to the position of neigbouring minima.The estimate is $\dot{\gamma} \cong Kk^2(U_0k)^{-1}$ which gives $\dot{\gamma}_c \sim d^{-a}$ with $7/3 < a < 17/7$ which is consistent with experimental data $a = 2.4 \pm 0.4$[3,1]

[1] D.Roux,F.Nallet and O.Diat,Europhys .Lett.,**24** (1),53 (1993)
[2] N.A.Clark and R.B.Meyer,Appl.Phys.Lett.,**22**,493 (1973)
[3] A.Zilman and R.Granek (to be published)