Heat-flux-driven rotation of nematic and cholesteric twisted bipolar droplets

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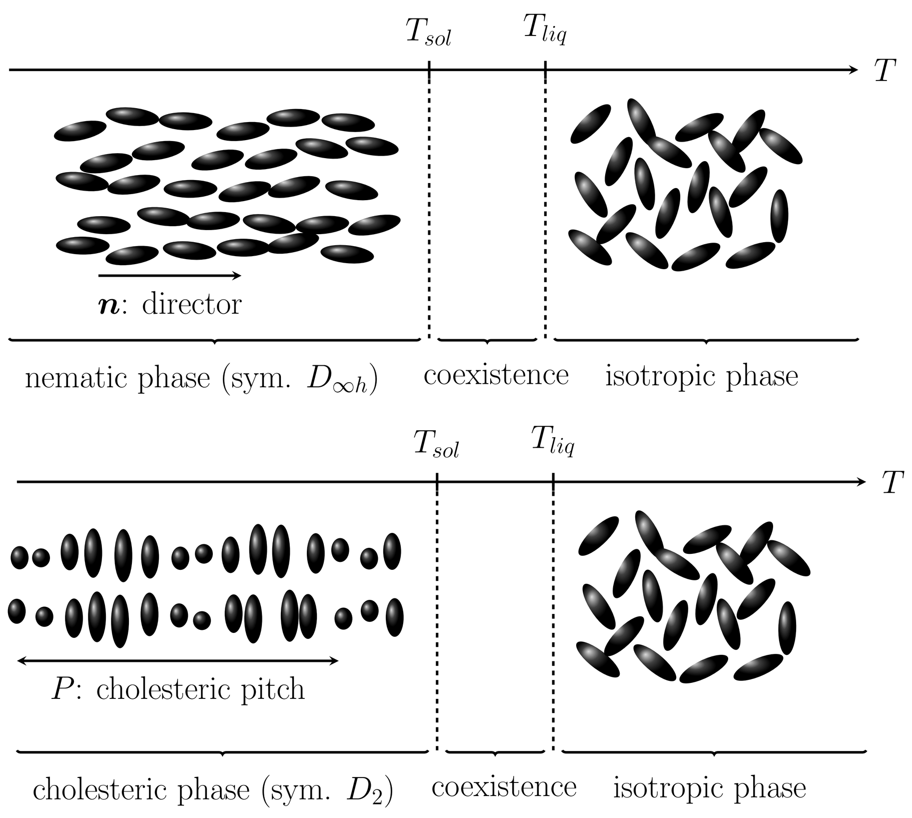
Reminder on the classical Lehmann effect

Structure of nematic and cholesteric phases



nematic phase:

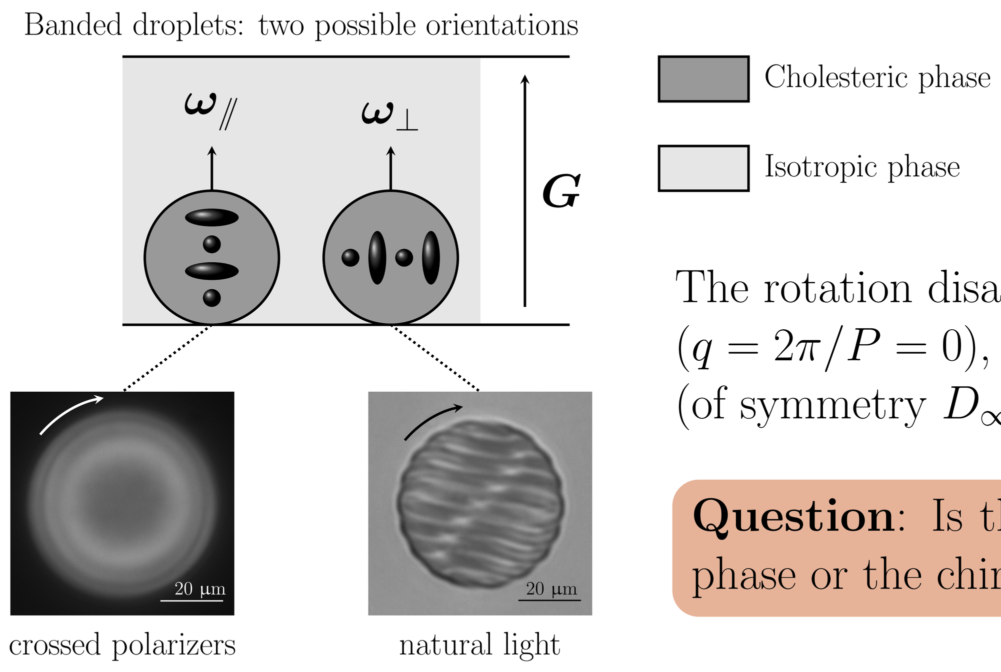
- orientational order
- no positional order

cholesteric phase:

- chiral nematic phase
- spontaneous twist

Rotation of banded droplets in a temperature gradient

First observation (Lehmann, 1900[1]): rotation of the internal texture of cholesteric droplets in coexistence with the isotropic fluid and subjected to a temperature gradient



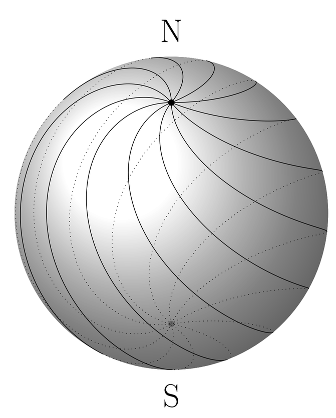
Oswald and Dequidt[2] reproduced in 2008 the Lehmann experiment with banded cholesteric droplets.

The rotation disapears at the compensation point[3] ($q = 2\pi/P = 0$), although the phase remains chiral (of symmetry D_∞).

Question: Is the rotation due to the chirality of the phase or the chirality of the director field?

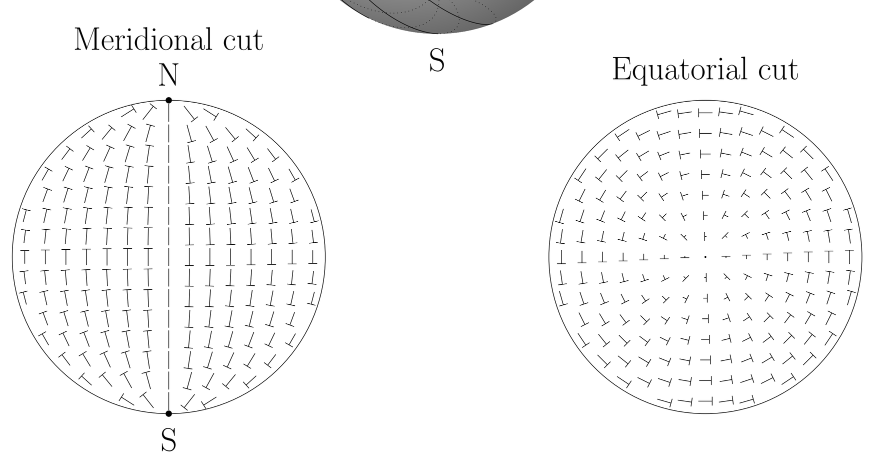
New observations with twisted bipolar droplets

Twisted Bipolar Droplets



Structure characterized by:

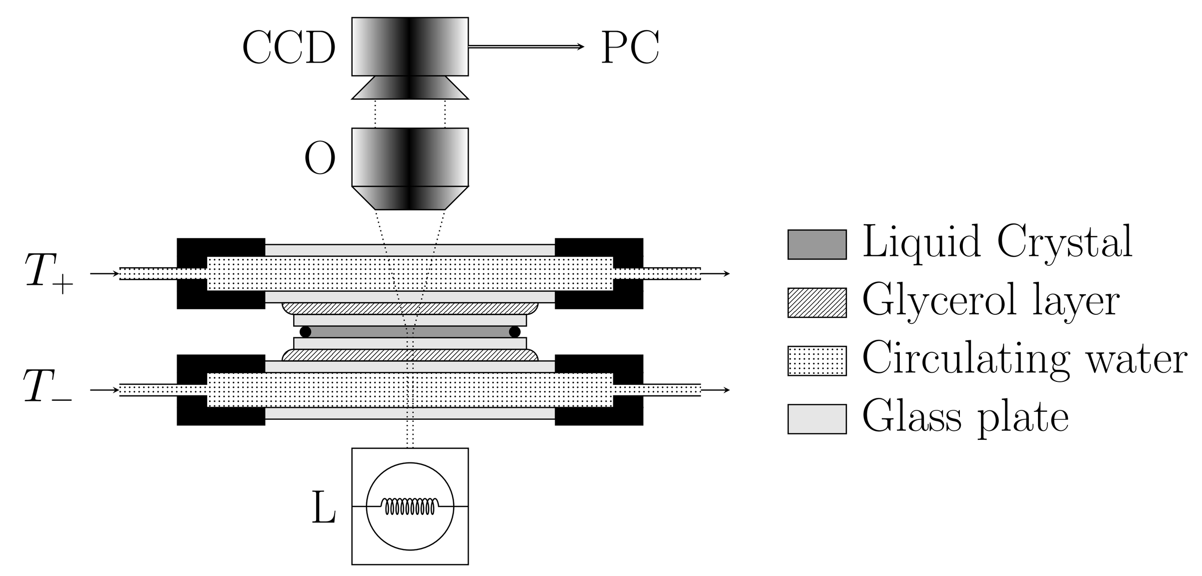
- director tangent to the surface
- two polar defects
- double twist along the NS axis



Equilibrium texture observed in:

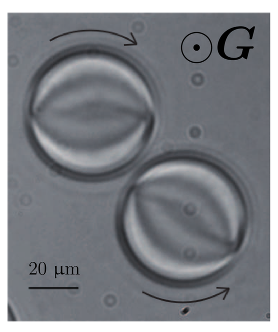
- cholesteric droplets with planar anchoring
- nematic droplets with planar anchoring, providing that the twist deformation has a negligible energy cost

Experimental setup



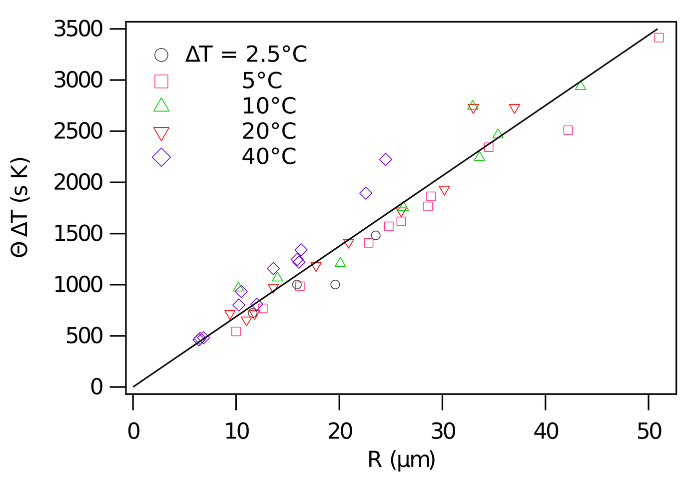
Mean temperature $T = (T_+ + T_-)/2$ and temperature gradient $G = a\,(T_+ - T_-)$ are imposed by two circulating baths.

Results with a nematic lyotropic chromonic mixture (water + 33wt% SSY)



- Achiral phase, with random handedness of the twist inside the droplets
- The sign of the twist fixes the sign of the angular velocity ⇒ **two senses of rotation**
- Angular velocity $\omega = \pm 2\pi/\Theta$ proportional to G

Rotation only due to the twist of the director field



- Akopyan/Zel'dovich thermomechanical torque on the director $\boldsymbol{\Gamma}_{\rm nem} = \boldsymbol{n} \times \boldsymbol{f}_{\rm nem}$, with:

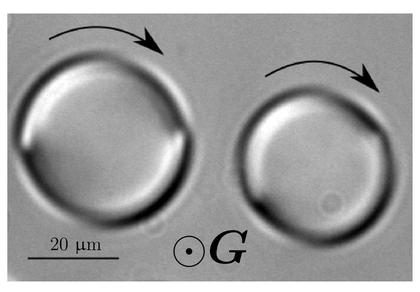
$$\boldsymbol{f}_{\rm nem} = \bar{\xi}_1\,(\nabla\cdot\boldsymbol{n})\,\boldsymbol{G} + \bar{\xi}_2\,([\nabla\times\boldsymbol{n}]\cdot\boldsymbol{n})\,(\boldsymbol{n}\times\boldsymbol{G}) + \bar{\xi}_3\,([\nabla\times\boldsymbol{n}]\times\boldsymbol{n})\,(\boldsymbol{n}\cdot\boldsymbol{G}),$$

- Theoretical prediction without backflow[4]:

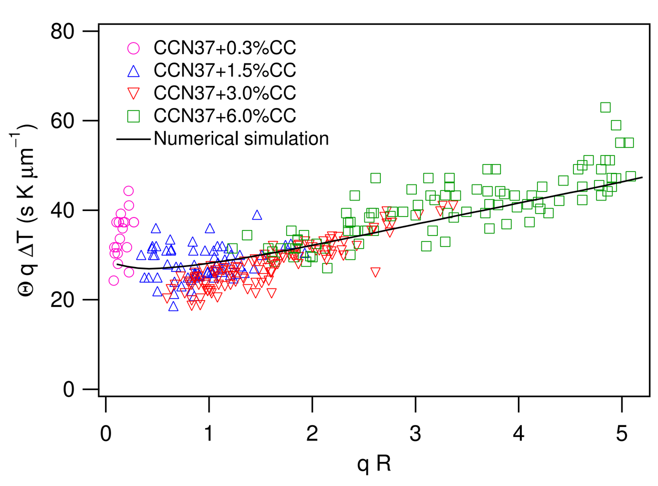
$$-\frac{\gamma_1\,\omega\,R}{G} = \bar{\xi}_1\,I_1[\boldsymbol{n}] + \bar{\xi}_2\,I_2[\boldsymbol{n}] + \bar{\xi}_3\,I_3[\boldsymbol{n}]$$

- Period Θ linear in radius $R \Rightarrow I_i$ independant of $R \Rightarrow$ Strong anchoring
- We computed the values of I_i with a finite element code, and deduced a typical value for the thermomechanical constants: $\bar{\xi} \simeq 80$ pN/K

Results with a diluted cholesteric mixture (CCN37 + CC)



- Chiral phase, with a positive twist inside the droplets
- **Only one sense of rotation**
- Angular velocity poportional to the gradient



- New parameter $q = 2\pi/P$ fixes the twist
- Akopyan/Zel'dovich+Leslie thermomechanical torque on the director $\boldsymbol{\Gamma}_{\rm chol} = \boldsymbol{n} \times \boldsymbol{f}_{\rm chol}$, with:

$$\boldsymbol{f}_{\rm chol} = \boldsymbol{f}_{\rm nem} + \nu\boldsymbol{n}\times\boldsymbol{G}$$

- Simplified model ($\bar{\xi}_1 = \bar{\xi}_2 = \bar{\xi}_3 = \bar{\xi}$):

$$-\frac{\gamma_1\,\omega\,R}{G} = \nu\,J_\nu[\boldsymbol{n}] + \bar{\xi}\,q\,J_\xi[\boldsymbol{n}]$$

- We computed the values of J_ν, J_ξ as a function of qR with a finite element code, and found with a linear regression: $\nu/q \simeq 9.9$ pN/K, $\bar{\xi} \simeq 1.6$ pN/K

Conclusion

- Good qualitative agreement between the experiment and the thermomechanical model
- But **much too large values of** ν/q **and** $\bar{\xi}$, incompatible with the measured values in the homogeneous phase below the coexistence temperature

[1] O. Lehmann, Ann. Phys. **307**, 649 (1900)
[2] P. Oswald, and A. Dequidt, Phys. Rev. Lett. **100**, 217802 (2008)
[3] P. Oswald, Eur. Phys. J. E, **35**, 10 (2012)
[4] J. Ignés-Mullol, G. Poy, and P. Oswald, Phys. Rev. Lett. (to be published)