Cholesteric Liquid Crystals: Flow Properties, Thermo- and Electromechanical Coupling

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5. RECENT DEVELOPMENTS

From an experimental point of view the outstanding development in the area of Lehmann-type effects is clearly the demonstration of the transmembrane transfer of water molecules across chiral liquid crystalline monolayers located at an air-liquid interface by Tabe and Yokoyama (2003). Tabe and Yokoyama observed the formation of patterns such target waves due to the phase winding of the director orientation. They showed that changing the handedness of molecules of the compound leads to a rotation in the opposite direction and that the precession frequency associated with phase winding is proportional to the concentration difference. In addition, they found that the speed of precession is proportional to the inverse of the pitch, that is to the chiral strength. Finally achiral compounds showed no effects in the same geometry under the same external force.

All these experimentally observed Lehmann-type phenomena on monolayers were modeled using macroscopic dynamics by Svenšek et al. (2006). It was shown that a concentration difference across the monolayer leads to a combination of static and dissipative Lehmann-type effects that determines the frequency of director rotation for the phase-winding patterns. The noisy appearance of the experimental observations was modeled by an additive noise source in the resulting macroscopic dynamic equation for the director orientation thus demonstrating the applicability of the concept of macroscopic chirality to a $2 + \varepsilon$ - dimensional experimental system. The figure shows a spiral pattern, which has also been observed experimentally (Prof. Y. Tabe, private communication, 2007).

To show that Lehmann-type effects can arise on many different length scales, Svenšek et al. (2008) analyzed the use of inverse Lehmann effects as a microscopic pump. Both, cholesteric and chiral smectic phases, can be used. Once a spatial pattern such as a phase-winding pattern has been generated, a concentration current or a temperature current arise. These phenomena are consistent with the fact that static and dissipative Lehmann effects are cross-couplings between different variables and thermodynamic forces, respectively. Svenšek et al. (2008) also showed that the measurement of direct as well as of inverse Lehmann effects can be used to disentangle static and dynamic contributions thus allowing to determine the two different types of coefficients (static and dissipative dynamic) separately.

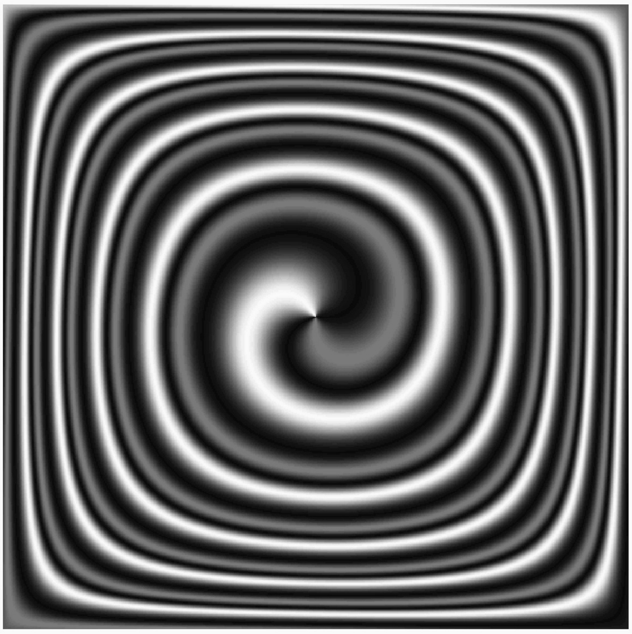

FIG. 1: A spiral pattern without noise. As an initial condition, a defect of strength +1 has been implemented (after Svenšek et al. 2006).

The classical Lehmann geometry (Lehmann, 1900), namely cholesteric droplets in the two phase region near the isotropic - cholesteric phase transition in a temperature gradient has been studied recently in detail experimentally and theoretically by Yoshioka et. (2014) and by Yamamoto et al. (2015). It was demonstrated that the orientation of the cholesteric helical axis with respect to the direction of the temperature gradient leads to qualitatively different phenomena with respect to the rotational motion of the droplet, namely pure director rotation versus barycentric motion (Yoshioka et al., 2014). The crucial importance of incorporating a surface torque into modeling the experimental results was in particular emphasized by Yamamoto et al. (2015). Oswald and Pirkl (2014) (and references therein) studied the influence of an electric field on the orientation of the helix in cholesteric droplets.

Dequidt and Oswald (2007) and Oswald and Dequidt (2008) studied Lehmann effects in compensated cholesteric liquid crystals. In particular in Dequidt and Oswald (2007) it was emphasized that microscopic contributions to the Lehmann effect would be crucial to understand the experimental results. Pleiner and Brand (2010) demonstrated that purely microscopic contributions are unnecessary to explain the experimental results by Oswald and Dequidt when taking into account that the elastic coefficients for linear twist and for the term in the Frank energy quadratic in the twist are not identical.

The formation of phase winding patterns in freely suspended smectic films has been analyzed by Seki et al. (2011) for a film thickness of about ten layers and driven by transmembrane gas flow. These experiments were the first experimental demonstration of Lehmann-type effects in chiral smectic liquid crystals, which had been predicted to occur by Brand and Pleiner (1988).

Quite recently it has been pointed out by Brand et al. (2013) that chiral compounds are not a necessary prerequisite to observe Lehmann-type effects due to macroscopic chirality. The same type of effects is expected to occur for systems composed of achiral molecules as long as these are arranged into liquid crystalline phases of sufficiently low symmetry, which break parity and have C_2 or C_1 symmetry globally, or at least locally. In this case a pseudoscalar quantity can also be constructed. This prediction could be tested, for example, for liquid crystalline phases of low enough symmetry formed by bent-core molecules.

A few years ago Brand and Pleiner (2010) have shown that Lehmann-type effects can also arise when conventional quadrupolar order and tetrahedratic (octupolar) order arise simultaneously. In this case one can have nematic phases of nonchiral D_{2d} symmetry for which a linear gradient term coupling octupolar order and quadrupolar order occurs. This coupling leads to the spontaneous formation of regions of opposite helicity that show Lehmann-type effects. Recently Pleiner and Brand (2014) pointed out that ambidextrous helicity also exists for the lower symmetry nonchiral S_4 nematic phase.

For the area rotato-electric effects there have been two noteworthy developments. Menzel and Brand (2006) analyzed rotato-electric effects in the local description of cholesteric liquid crystals using the director field as a macroscopic variable; they discussed various geometries and the possibility to observe rotato-electric effects as a function of sample thickness. Brand et al. (2013) pointed out the possibility of rotato-electric effects to occur also for liquid crystalline phases of low enough symmetry even for achiral compounds. In addition, they also discussed the various dissipative analogues of rotato-electric effects caused by temperature and concentration gradients in some detail.

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