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Non-Newtonian rheology in twist-bend nematic liquid crystals

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A number of exciting and relatively recent publications (about ten years ago, compared to more than 100 years of the discovery of the classical liquid crystals) report on a discovery of a new type of equilibrium liquid crystals, termed twist-bend nematics, N_{TB} (see the papers [1–6]). The discovery of N_{TB} nematics opened "Pandora box" with new kinds of modulated liquid crystals (see very influential pioneering works and a few review papers [17–19]). Naturally (as it was the case in great geographical discoveries of 15-th – 17-th centuries) after the first step devoted mainly to observations and structural identifications of new liquid crystals, the interest moves to investigations and exploring of physical properties of these new phases. Since then the N_{TB}, and other modulated nematics is becoming one of the hottest topics in physics of liquid crystals.

Our paper is motivated by two very recent works [20, 21] on rheological studies of the N_{TB} liquid crystals. The authors of these papers found nontrivial non-Newtonian behavior of sheared N_{TB} nematics. At relatively low shear rate ($\dot\gamma \le \dot\gamma_{c1}$) the stress tensor σ created by this shear strain, scales as $\sigma \propto \dot\gamma^{1/2}$. Thus the effective viscosity decreases with the shear rate ($\eta \propto \dot\gamma^{-1/2}$) manifesting so-called shear-thinning phenomenon. At intermediate shear rate $\dot\gamma_{c1} \le \dot\gamma \le \dot\gamma_{c2}$, σ is almost independent of $\dot\gamma$ (a sort of plateau), and at large shear rate ($\dot\gamma \ge \dot\gamma_{c2}$, $\sigma \propto \dot\gamma$), and it looks like Newtonian rheology. The critical values of the shear rate ($\dot\gamma_{c1}$, $\dot\gamma_{c2}$) indicating transitions between dynamical regimes depend on temperature. Above certain temperature T^* (below $N - N_{TB}$ phase transition point T_c, where N stands for conventional nematic state) the behavior becomes pure Newtonian. The aim of this paper is to present theoretical rationalization for the observed in these works [20, 21] results. In what follows we integrate the input from recent works and discussions, however my own contribution to this field will be also presented.

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The main feature which distinguishes the standard nematic N and the twist-bend nematic N_{TB} liquid crystals is a short wavelength modulation of the orientation order $\boldsymbol{\phi}$ presented in the N_{TB} phase. This two component vector $\boldsymbol{\phi}$, orthogonal to the nematic director $\mathbf{n}$ ($\boldsymbol{\phi} \cdot \mathbf{n} = 0$) can be chosen as the order parameter describing $N - N_{TB}$ phase transition. With this vector order parameter in hands one can write the Landau free energy functional.

Recent progress in rheology of the N_{TB} liquid crystals has led to a number of new and exciting experimental results [20, 21]. In the paper we propose a simple heuristic approach to rationalize these new experimental data. The key starting point of our approach is based on a simple observation that the anisotropic viscous properties of the liquid crystals introduce a host of novel phenomena in rheology. We find that at relatively low shear rate ($\dot\gamma \le \dot\gamma_{c1}$) the stress tensor σ created by this shear strain, scales as $\sigma \propto \dot\gamma^{1/2}$. Thus the effective viscosity decreases with the shear rate ($\eta \propto \dot\gamma^{-1/2}$) manifesting so-called shear-thinning phenomenon. At intermediate shear rate $\dot\gamma_{c1} \le \dot\gamma \le \dot\gamma_{c2}$, σ is almost independent of $\dot\gamma$ (a sort of plateau), and at large shear rate ($\dot\gamma \ge \dot\gamma_{c2}$), $\sigma \propto \dot\gamma$, and it looks like Newtonian rheology. Within our theory the critical values of the shear rate scales as $\dot\gamma_{c1} \propto (\tilde\eta_2^0/\tilde\eta_3^0)^2$, and $\dot\gamma_{c2} \propto (\tilde\eta_2^0/\tilde\eta_3^0)^4$ respectively. Here $\tilde\eta_2^0$ and $\tilde\eta_3^0$ are bare coarse grained shear viscosity coefficients of the effective smectics equivalent to the N_{TB} phase at large scales. Our mainly qualitative theory may not have the right numbers for the dynamic shear rate thresholds. However theory predicts the right scaling laws observed in the experiments. Our consideration suggests that the described phenomena and mechanisms can bring about different rheological scenarios worthy of further studies. In this work we have only scratched the surface of this reach subject, focusing only on the most simple questions, which can be answered by calculations "on a back of the envelope".

All obtained results of this work and short discussions of the cited articles (see [1–44]) can be found in the full version of this paper.

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