Switching dynamics and bistability in blue phase devices

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Outline

• Introduction: Liquid crystals
• Motivations
• Dynamical equations
• Switching dynamics, anchoring conditions, bistability
• Conclusions
A liquid crystal is a phase of matter with properties in common between liquids and solids.
Blue phases

www.physorg.com/news129997960.html
Liquid crystal device

- Technological applications: Screens, digital clocks, mobiles, e-books....
- Improvements: viewing angle, bistable behaviour, decrease in switching times

Hydrodynamic and electric field effects in blue phase devices

“Twisted nematic displays” (used for the construction of flat panel monitors)
Dynamic equations for liquid crystals

\[ \partial_t \rho + \partial_\alpha \left( \rho u_\alpha \right) = 0 \]

\[ \rho \partial_t u_\alpha + \rho u_\beta \partial_\beta u_\alpha = \partial_\beta P_{\alpha\beta} + \partial_\beta \left[ (\xi - 2\eta/d) \delta_{\alpha\beta} \partial_y u_y + \eta \left( \partial_\alpha u_\beta + \partial_\beta u_\alpha \right) \right] \]

\[ (\partial_t + \mathbf{u} \cdot \nabla) \mathbf{Q} + \mathbf{S} (\mathbf{W}, \mathbf{Q}) = \Gamma \mathbf{H} \]

- \( \rho (\mathbf{r}, t) \) Total density
- \( \mathbf{u} (\mathbf{r}, t) \) Velocity field
- \( P(\mathbf{Q}) \) Pressure tensor
- \( H(\mathbf{Q}) \) Molecular field
- \( Q_{\alpha\beta} = \left( n_\alpha n_\beta - \frac{1}{3} \delta_{\alpha\beta} \right) \) Order parameter
- \( W_{\alpha\beta} = \partial_\beta u_\alpha \) Velocity gradient tensor

Equations are solved by using a hybrid lattice Boltzmann method *

Equilibrium properties

\[ f = \frac{A_0}{2} \left( 1 - \frac{y}{3} \right) Q_{\alpha\beta}^2 - A_0 \frac{y}{3} Q_{\alpha\beta} Q_{\beta\gamma} Q_{\gamma\alpha} + \frac{A_0 y}{4} \left( Q_{\alpha\beta}^2 \right)^2 \]

\[ + \frac{K}{2} \left( \partial_\alpha Q_{\beta\gamma} \right)^2 + \frac{K}{2} \left( \varepsilon_{\alpha\gamma} \partial_\gamma Q_{\delta\beta} + 2q_0 Q_{\alpha\beta} \right)^2 \]

\[ - \frac{\varepsilon}{12\pi} Q_{\alpha\beta} E_\alpha E_\beta + \varepsilon_{fl} Q_{\alpha\beta} \left( E_\alpha \partial_\gamma - E_\gamma \partial_\alpha \right) Q_{\beta\gamma} \]

\[ + \varepsilon_{fl} \left( \partial_\beta Q_{\alpha\beta} \right) E_\alpha + \frac{1}{2} W_0 \left( Q_{\alpha\beta} - Q_{\alpha\beta}^0 \right)^2 \]

\[ P_{\alpha\beta} = -P_0 \delta_{\alpha\beta} - \xi H_{\alpha\gamma} \left( Q_{\gamma\beta} + \frac{1}{3} \delta_{\gamma\beta} \right) - \xi \left( Q_{\alpha\gamma} + \frac{1}{3} \delta_{\alpha\gamma} \right) H_{\gamma\beta} + \]

\[ 2\xi \left( Q_{\alpha\beta} + \frac{1}{3} \delta_{\alpha\beta} \right) Q_{\gamma\varepsilon} H_{\gamma\varepsilon} - \delta_\beta Q_{\gamma\varepsilon} \frac{\delta F}{\delta \partial_\alpha Q_{\gamma\varepsilon}} + Q_{\alpha\gamma} H_{\gamma\beta} - H_{\alpha\gamma} Q_{\gamma\beta} \]

\[ H = -\frac{\delta F}{\delta Q} + \left( \frac{1}{3} \right) \text{Tr} \frac{\delta F}{\delta Q} \]

Defect dynamics in a BPI cell

Anchoring effects

Homogeneous anchoring

Homeotropic anchoring

Confined blue phases

Periodic

Homeotropic

Homogeneous

Bistable liquid crystal device

- Existence of two stable states in absence of an applied electric field: each of the bistable states is metastable and is retained after the field is switched off. This fact eliminates the need of having a constant electric field to keep the system in the ‘‘on’’ state, hence sharply reducing energy consumption.

- Energy saving devices (no voltage for fixed images) : e-book, e-newspapers...

- Portable devices: less electronics, less weight, small size

Experimentally realized bistable devices: Zenithal bistable device (DERA), CNRS laboratories, Hewlett Packard laboratories (Bristol), surface stabilazed Cholesteric textures (SSCT) and many others.
Bistability in a BPI cell

Conclusions

• BPI device: Disclinations twist up and pin to the boundary. Upon switching off the field part of the network deforms and the zero field configuration is not recovered.
• A device that show a bistable behaviour has been proposed. The dyamical schedule of the applied electric field is fundamental to observe bistability. Twisted rings and double-helix disclinations can be selected by varying the electric field.

Perspectives

• What if a flexo-electric field is considered?
• Active systems: droplets, cells, bacteria, dna, etc…
Flexoelectricity

Flexoelectricity is the generation of a spontaneous polarization in a liquid crystal due to a deformation of the director, or conversely, the deformation of the director due to an applied electric field (R. B. Meyer Phys. Rev. Lett. 22, 918 (1969)).

An applied field will induce a splay distortion as the molecular dipole aligns along the field lines. An electric field in the opposite direction will induce a different distortion.

Flexoelectric blue phase