Effect of Strong Confinement on Defect Structures of Cholesteric Blue Phases

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Introduction

• What are “cholesteric blue phases”?
  • 3D orientationally ordered structure due to chirality
  • Bragg reflection in the visible range (color)
  • Optically isotropic (no birefringence)

Typical optical textures of blue phases (platelet)

Introduction

• What are “cholesteric blue phases”?
• How LC molecules are arranged in blue phases?
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Double twist cylinder

http://kikuchi-lab.cm.kyushu-u.ac.jp/kikuchilab/bluephase.html
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Double twist:
  • Energetically more favorable (locally) than single twist

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-1/2 disclination

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Introduction

• What are “cholesteric blue phases”?
  • Arrangement of disclination lines and double twist cylinders
Introduction

• The present study

Structure of a chiral liquid crystal under a strong confinement

BP I
Model and theoretical argument

- Landau-de Gennes theory
  2nd-rank tensor $\chi_{ij}$: orientational order
Model and theoretical argument

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Free energy density in the bulk (after rescaling)

\[
\begin{align*}
\varphi_{\text{bulk}} &= \tau \text{Tr} \chi^2 - \sqrt{6} \text{Tr} \chi^3 + (\text{Tr} \chi^2)^2 \\
\varphi_{\text{grad}} &= \kappa^2 \{(\tilde{\nabla} \times \chi)_{ij} + \chi_{ij}\}^2 + \eta[(\tilde{\nabla} \cdot \chi)_i]^2
\end{align*}
\]

Wright & Mermin, Rev. Mod. Phys. (1989)
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arises from chirality

Rescaled parameters: $\tau$: temperature
$\kappa$: chirality
$\eta = 1$ (one-const. elasticity)

Wright & Mermin, Rev. Mod. Phys. (1989)
Model and theoretical argument

Free energy of surface anchoring (after rescaling)

\[ \varphi_s = \frac{1}{2} w \text{Tr} (\chi - \chi_s)^2 \hspace{1cm} \text{with} \hspace{1cm} \chi_{s\alpha\beta} = S_0 (\nu_\alpha \nu_\beta - (1/3) \delta_{\alpha\beta}) \]
Model and theoretical argument

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homeotrop (normal) anchoring
Model and theoretical argument

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\( w \): anchoring strength

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homeotropic (normal) anchoring

Total free energy (per unit area)

\[ F = \frac{1}{A} \int dx \, dy \left[ \int_0^d dz \left( \varphi_{\text{local}} \{ \chi \} + \varphi_{\text{grad}} \{ \chi; \nabla \} \right) + \varphi_s \{ \chi(z = 0) \} + \varphi_s \{ \chi(z = d) \} \right] \]

\[ \text{bulk} \quad \text{surface} \]
Model and theoretical argument

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Minimized numerically
Model and theoretical argument

Choice of parameters:

\[ \tau = -1, \kappa = 0.7 \]

\[ w = 0.5 \]
Model and theoretical argument

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BP I is stable in the bulk.

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intermediate anchoring
Model and theoretical argument

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Intermediate anchoring

In real units,
Model and theoretical argument

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intermediate anchoring

In real units,

Cholesteric pitch:

\[ 2\pi / q_0 \approx 160\text{nm} \]

strong chirality
Model and theoretical argument

Choice of parameters:
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intermediate anchoring

In real units,
Cholesteric pitch: \[ \frac{2\pi}{q_0} \approx 160\text{nm} \quad \text{strong chirality} \]
Anchoring strength: \[ W \approx 2 \times 10^{-4}\text{Jm}^{-2} \]
Model and theoretical argument

Choice of parameters:
\( \tau = -1, \kappa = 0.7 \)  
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Choice of cell thickness: \( 9 \leq d \leq 18 \)
Model and theoretical argument

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Intermediate anchoring

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Choice of cell thickness: \( 9 \leq d \leq 18 \)

Cholesteric pitch: \( 4\pi \leftrightarrow 160\text{nm} \)

\[ 110\text{nm} \lesssim d \lesssim 230\text{nm} \] strong confinement
Results

Various stable/metastable profiles
Results

Various stable/metastable profiles

Structures similar to bulk BP I
Results

Various stable/metastable profiles

Structures similar to bulk BP I

Structures not expected from bulk BP I
Results

Various stable/metastable profiles
Results

Various stable/metastable profiles

Parallel array of double-helix disclination lines
Results

Various stable/metastable profiles

Two orthogonal arrays of undulating disclination lines
Results

Free energy with the variation of cell thickness $d$
Results

Free energy with the variation of cell thickness $d$

Stable structures:
Results

Free energy with the variation of cell thickness $d$

Stable structures: (smaller $d$)
Results

Free energy with the variation of cell thickness $d$

Stable structures: (smaller $d$) (larger $d$)
Results
Results

Orientational structure of “double-helix disclinations”
Results

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Orientational structure of “double-helix disclinations”

- \( xz \)
- \( yz \)
- \( xy \)

- double-twist cylinders
- disclination lines
Results

Orientational structure of “double-helix disclinations”

- Double-twist cylinders
- Disclination lines
- Double-twist cylinder
Orientational structure of “double-helix disclinations”

- double-twist cylinders
- disclination lines
- double-twist cylinder
- simple orthorhombic lattice
Results
Results

Orientational structure of “undulating disclinations”
Results

Orientational structure of “undulating disclinations”

- double-twist cylinders
- disclination lines
Results

Orientational structure of “undulating disclinations”

double-twist cylinders

disclination lines

double-twist cylinder

simple orthorhombic lattice
Results
Results

Comparison between the two configurations

double-helix disclinations  undulating disclinations

disclination lines

double-twist cylinders
Results

Comparison between the two configurations

double-helix disclinations

undululating disclinations

Close similarities
Results

Free energy with the variation of cell thickness $d$

Stable structures: (smaller $d$) (larger $d$)
Results

Free energy with the variation of cell thickness $d$

Stable structures: (smaller $d$) (larger $d$)

Why?
Results
Results

Why is more stable for smaller $d$?
Results

Why is more stable for smaller $d$?
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Why is more stable for smaller $d$?
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Why is more stable for smaller $d$?

defect rearrangement with smaller thickness
Discussion

Possibility of experimental observation
Discussion

Possibility of experimental observation

TEM with freeze-fracture technique

BP I

Costello et al. PRA (1984)

FIG. 2. As Fig. 1, except that the material was quenched from the blue phase I at 26.5°C to −170°C.
Discussion

Possibility of experimental observation

TEM with freeze-fracture technique

BP I  
Costello et al. PRA (1984)

Confocal microscopy

BP I  
Higashiguchi et al. JACS (2008)

Particle-like excitation in a chiral nematic cell


FIG. 2. As Fig. 1, except that the material was quenched from the blue phase I at 26.5°C to −170°C.
Conclusion
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Defect structures of a chiral liquid crystal under strong confinement were studied numerically.
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Various structures not found before
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Various structures not found before

Interesting examples of frustration (between bulk structures and confinement)
Conclusion
Conclusion

- Future directions
  - Different anchoring (ex. planar)
  - Temperature change
  - Effect of an applied field
  - Optical properties
Conclusion

Confinement can yield far more structures.

BP II-like

hexagonal structure
Conclusion

• References

Conclusion

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Conclusion

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Thank you for your attention!