TEXTURE DEVELOPMENT
IN THE SHEAR FLOW OF
NEMATIC SOLUTIONS
OF RODLIKE POLYMERS

Guy C. Berry

www.chem.cmu.edu/berry

Department of Chemistry
Carnegie Mellon University

Zhanjie Tan
Sudha Vijaykumar¹
Beibei Diao²

Mohan Srinivasaro³
Kiyofumi Matsuoka⁴

Present address:
1. Ethicon Endo-Surgery, Inc., Cincinnati, OH
2. du Pont Co., Inc., Buffalo, NY
3. Georgia Tech.
4. Showa Denko KK, Oita, Japan

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Questions on the flow of nematic solutions of rodlike chains in shear flow

• What is the nature of the Director Field?

• Do Line Defects (disclinations) play a role?

• Does the persistence length in dilute solution play a role?

• Do the Frank curvature elasticities and Leslie viscosities play a role?

• Do universal scaling laws for the stress exist?
Birefringence: \[ \Delta n = (\Delta n/c)_o \text{ c S} \]

Magnetic Susceptibility Anisotropy \[ \Delta \chi = (\Delta \chi/c)_o \text{ c S} \]

\[ (\Delta n/c)_o = 1.0, \quad \text{PBZT} \]
\[ (\Delta n/c)_o = 0.6, \quad \text{PPTA} \]

\[ \Delta \chi \propto \Delta n \]

Persistence Length in Dilute Solution

\[ \hat{a}/\text{nm} \]

PBZT \quad > 60
PPTA \quad 30-45
Typical Steady-State Behavior

Anomalous Slow Flow Region I

η_{ss} J_R \dot{\gamma} \approx 1

Log "Shear Viscosity"

Log Recoverable Compliance

Log | "Normal Viscosity"|

Log Shear Rate
"Polydomain" Representation

Quiescent Fluid

Slow Flow

Fast Flow
Late stages of texture coarsening
under the influence of confining surfaces

Lines formed in the wake of a rising air bubble
(bubble moving to left)
Loop Defects relax and disappear very slowly
Collapse of a loop defect
Nematic PBZT Solutions do not align in slow shearing flows

Initial flow of a well aligned nematic solution (PBZT)

\[ \langle \phi \rangle, \text{ deg.} \]

\[ \gamma_{\text{app}} = v_0 t / d \]

\( d = 125 \mu m \) (Filled)

\( d = 250 \mu m \) (Unfilled)
Optical Measurements (Incident light along shear gradient):
Linear Viscoelasticity:

Creep: \[ \gamma(t) = \sigma J(t) = \sigma \{ R(t) + t/\eta \} \]

Recovery on cessation of steady flow: \[ \gamma_R(t) = \sigma R(t) \]
\[ \gamma_R(t) = \gamma_R(\infty) R(t)/R(\infty) \]
\[ R(\infty) = J_s \]

Mesoscopic Theory:

Steady slow flow: \[ \gamma(t) = \dot{\gamma}_{ss} t \]

Recovery on cessation of steady slow flow: \[ \gamma_R(t) = \gamma_R(\infty) H(\gamma_{ss} t) \]
Texture via CD-camera ($\approx 5$ µm resolution, white light)

Photo of turbid-clear transition. Torque = 100,250 dyn cm;

Shear rate calculated at transition: $1.64 \text{ s}^{-1}$
Flow direction from left to right.
Width 1.5 mm; 9.74%, 500µm; .

Steady-state behavior.
\[ \eta (\gamma) \approx -1/2 \]

\[ \gamma_R (\gamma) \approx -2/3 \]

\[ \gamma_s (\gamma) \approx \frac{\eta}{\text{poise}} \]

\[ J (\gamma) \approx \frac{10,000}{\text{dyn/cm}^2} \]

\[ \text{Transmission} \approx \frac{1}{\text{poise}} \]

\[ 0.0001 \leq \gamma/s^1 \leq 10 \]

\[ 0.001 \leq \text{Transmission} \leq 1 \]
Refraction effects observed immediately on start up of moderate flow.

All with no analyzer: a-c show the pattern within 2 s for various polarizations of the incident light; d-f show the patterns at the indicated times after onset of flow.
Transient scattering in a slow flow; 9.74% 500 µm
Top: Before flow,
Bottom: About 10 m into flow —finally went to weak
diffuse scattering in steady state flow
Transient scattering streak observed after 30 min creep in a moderate flow.

Disappeared in steady state moderate flow
Example scattering patterns in steady-state flow, increasing in shear rate from top-left to bottom-right 9.74%; 500µm
Scattering in fast flow.
Torque = 98,000 dyn cm

Scattering at the entry to the fast flow regime
**Tendency for lower range of $L$ and $c/c_{NI}$**

- **Plate Separation**
- **Velocity**
- **Diffuse scatter**
- **Stationary Flow**
- **Scattering along Vorticity**
- **Stria along Flow**
- **No Texture**
- **Slow Flow**
- **Fast Flow**

**Tendency for higher range of $L$ and $c/c_{NI}$**

- **Plate Separation**
- **Velocity**
- **Diffuse scatter**
- **Stationary Flow**
- **Scattering along Vorticity**
- **Stria along Flow**
- **No Texture**
- **Slow Flow**
- **Fast Flow**
The recoil and transmission on cessation of steady-state flow: 12.0%, 200µm
Relation between recoverable strain and optical transmission

Transmission of light during recovery for samples with different deformation histories

Relaxed prior to successive creep
(Lw = 155 nm; c/cNI = 1.71)

High shear rate flow prior to successive creep
(Lw = 155 nm; c/cNI = 1.61)
Scattering pattern after 8 hr relaxation from moderate flow:
Torque in flow = 4,430 dyn cm; 9.74%-500µm
Scattering pattern observed early in the relaxation from a fast flow with a clear texture. The total elapsed time is about 15 min.

The insert at the bottom-right shows the striations and band structure during the stage of well-developed scattering along the flow axis.
Torque in flow: 210,700; 9.74%, 500 µm.
Refraction effects seen in the 16 hr after cessation of a fast flow.
Torque in flow: 100,250 dyn cm; 9.74%, 500µm.
Phase-grating immediately on cessation of Flow with Striations

Vorticity loop observed as phase-grating relaxes
Interpretation:

- There is considerable preferential alignment in flow along the flow direction, but an alternating twist of the director out of the shear plane, and in planes parallel to the surfaces, is imposed on that general alignment;

- The rheological behavior in flow in creep reveals the preferential alignment through an increase in the creep rate (creep acceleration);
Idealized "Chevron" pattern of director field with no out-of-plane distortion

The flow induced alignment is not stable, owing to the twist distortions pervading the sample; an "immediate" elastic retraction along the flow direction produces a phase grating that evolves to defect loops along the vorticity;

The tendency for striation development may be related to the weaker anchoring for twist distortions as compared with splay distortions.