The future of magnetic tape relies on a continuing rate of increase in data density while maintaining the current (or better) competitive advantage in cost.

The current limiting factors seem to be track density, bit density, and tape thickness.
Track density and bit density are limited by NOISE.

Thinner, Smoother, More Ordered Magnetic Layer!
Thinner, Smoother Magnetic Layer

Wiest, Hawkins, et al.

D. T. Johnson, et al.

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Magnetic dispersions are non-Newtonian and viscoelastic.

\[ \tau = \mathbf{F} \left\{ \gamma_{[0]}(t, t'), S \right\} \]
Ordered Magnetic Layer


Mean Field Model

Bhandar and Wiest, *J. Rheol.* (submitted)

Assume:

- Anisotropic Hydrodynamic Drag
- Maier-Saupe Steric Interaction
- Magnetic Mean Field

Order Parameters:

\[ J = \langle u \rangle \quad S = \langle uu - \frac{1}{3} \delta \rangle \]

Evolution of \( J \) and \( S \):

\[ \frac{\partial J}{\partial t} + v \cdot \nabla J = \ldots \]

\[ \frac{\partial S}{\partial t} + v \cdot \nabla S = \ldots \]
Order Tensor & Parameter

\[ S = \left\langle uu - \frac{1}{3} \delta \right\rangle \]

\[ S = 3 \sqrt{\frac{9}{2} \text{tr}(S \cdot S \cdot S)} \]

\( S = 1 \): perfect prolate order

\( S = -1/2 \): perfect oblate order
No Flow and No Magnetic Field

Order Parameter, $S$

$A = 0.5 \, N$

$B = N$

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STABLE

Prolate

UnSTABLE

Oblate

$N + B$

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Shear Flow (no Magnetic Field)
Shear flow and Magnetic Field
Comparison With Rheological Data

\[ \eta (\text{Pa s}) \]

\[ \gamma (1/\text{s}) \]

\[ \lambda = 75 \text{s} \]

\[ \sigma = 0.1 \]

\[ L = 125 \text{nm} \]
Theoretical/Modeling: Closure Approximations

\[ \langle uuuu \rangle = \langle uu \rangle \langle uu \rangle \]

- Failure to predict director tumbling and other modes of particle orientation

\[
\langle uuu \rangle = \frac{1}{|J|} JJJ + \left( \frac{1-|J|}{5} \right) \left\{ \delta J + J\delta + (\delta J)^\dagger + 5 [SJ + JS + (SJ)^\dagger] - 2 [\delta S \cdot J + J \cdot S\delta + (\delta S \cdot J)^\dagger] \right\}
\]

- Spurious Solutions of Non-linear Evolution Equations?
Numerical Integration of Diffusion Equation

\[
\frac{\partial f}{\partial t} + \frac{\partial}{\partial \mathbf{u}} \cdot \left[ (\kappa \cdot \mathbf{u} - \kappa \cdot \mathbf{uuu}) f \right] - \frac{\sigma}{6\lambda} \left( \frac{\partial}{\partial \mathbf{u}} \cdot \frac{\partial}{\partial \mathbf{u}} f + \frac{1}{kT} \frac{\partial}{\partial \mathbf{u}} [\Phi^{M-S} + \Phi^{mag}] f \right) = 0
\]

Representation in terms of spherical harmonic functions:

\[
f(\mathbf{u}, t) = \sum_{l=0}^{\infty} \sum_{m=-l}^{l} b_{lm} Y_{l}^{m}(\mathbf{u})
\]

where \( b_{lm} \) are complex.

Use properties of spherical harmonics to get:

\[
\frac{\partial}{\partial t} b_{lm} = \mathcal{S}(b_{l'm'}, N, \mathbf{H}, \kappa)
\]

Larson and Ottinger (1991)
Experiments:

• Rheometry
  with Alan Lane and Meihua Piao

• cryo-VSM
  field, no flow
  with Dave Nikles

• Rheo-SANS
  flow, no field
  with Gary Mankey, NIST

• Co-axial Shear Magnetometry
  flow and field
  with Duane Johnson
Angular Dependence of Remanence
(with Dave Nikles)

Angular dependence of parallel remanence ($M_p$) and transverse remanence ($M_t$)
Rheo-Neutron Scattering
(with Dave Nikles, Gary Mankey and NIST)

Simultaneously measure order and rheological properties in shear flow.

Co-axial Shear Magnetometry  
(with Duane Johnson)

Measure susceptibility in flowing dispersion (with or without constant magnetic field in flow direction) to infer order parameter.
Why?

If any of these predictions are true, can we:

use the results to identify the appropriate combination of orienting field and flow,

so as to modify tape production processes in order to obtain

Thinner, Smoother, More Ordered Magnetic Layers

(without costing any more).