Microrheology

“what I won’t be talking about…”

Active microrheology:
measure nonlinear material properties

TMS & J. Brady

Interfacial Microrheology

E. Weeks
E. Furst

(Si Young Choi, UCSB)

Measure interfacial viscosity & elasticity
Many microfluidic applications...

- Inkjet printers
- Chemical reactors
- Hazard detectors
- Heat management
- Biomedical devices
- Optical devices
- Analytical systems

**Single cell analysis**

- Hong et al. (04)

**DNA separation**

- Huang et al. (02)

**fundamental studies**

- Rodd et al. (04)

- Cholban et al. (04)

**fuel cells**

200 μm
“Engineering on the pore scale”

Unifying theme:

‘Design’ effective porous media with e.g. geometric or surface anisotropies

M. Narovlyansky
G. Whitesides
Electrokinetic separations

Mixture of particles
(proteins, colloids, DNA fragments, etc.)
Electrokinetic separations

Fastest particles in ‘rear’ must outrun slowest in ‘front’ for separation
Electrokinetic separations

Fastest particles in ‘rear’ must outrun slowest in ‘front’ for separation

Long initial plug:
long track, slow separation

Narrow plug:
short track, quick separation
Electrokinetic injection

Ideally: inject narrow, long, sharp plug across separation channel for subsequent separation
Why the mushroom?

• Analyte follows electric field lines
Why the mushroom?

• Analyte follows electric field lines
• Electric field lines *not* confined to channel intersection...
Idea: ‘sculpt’ E field by ‘designing’ porous channels

Chou, Austin et al. (2000)

Feichtner & Cummings (2003)
Long injections: field leakage
Long injections: *field leakage*

A few field lines at the edges do traverse partitions...
How many field lines leak?

Field strength within jth partition

\[ E_j \approx E_\infty \frac{w - 2(j - 1)(p + q)}{2L} \]

Total fraction leaking through partitions on each side (N partitions total)

\[ \frac{\Delta h}{w} \approx \frac{Nq}{8L} \]

Remaining field lines confined
Sheath flow: restrict analyte to confined fields
Separations & repetitive injections

Fluorescein/5’-Carboxyfluorescein separation

Clean, repetitive 2Hz injections

--multidimensional separations,
--isolation/purification of rare species
Elegant little devices...

Balagadde & Quake (05)

Hanson et al (02)

Hong et al (02)

Song & Ismagilov (03)
...with a dirty little secret

Balagadde & Quake (2005)

What if you need to carry one around?

*e.g. ‘microfluidic pacemaker’*
Ions ‘screen’ charges

screening length $\lambda_D$ varies from $\sim 1 - 10^3$ nm
**Electro-osmosis:** field drives flow

Charge Cloud \(~1-10\) nm

`slip` velocity (conveyor belt) \( u_s = -\frac{\epsilon \zeta}{\eta} E \)
Induced-Charge Electro-Osmosis around conducting bodies
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\[ \mathcal{U}_S \sim \frac{\varepsilon E_0^2 a}{\eta} \sim 1\text{mm/s} \]

AC or DC fields
nonlinear – higher ‘\( \zeta \)’

Levich (62)
Gamayunov, Dukhin, Murtsovkin (86)
Squires & Bazant, JFM (04)
Bazant & Squires, PRL (04)
Induced-Charge Electro-Osmosis around conducting bodies

AC Electric field:
300 Hz, 100 V/cm
250 μm gold-coated post

J. Levitan, MIT
Asymmetric coating – asymmetric flow
dielectric coatings suppress induced charge

'Swims' toward coated end
Pumps toward clean end

Squires & Bazant, JFM (06)
ICEP motion of half-metallic colloids

Electric field:
200 V/cm
10 kHz field
North-South

Beads orient perpendicular to field
Swim towards insulating (bright) end

Andy Pascall, UCSB
Applications

Local AC micropump

- AC field – steady flow, no reactions
- Large field with small potential

Helical asymmetry: Spinning body

- Aligns perp. to field
- Rotates steadily
- ‘rotary motor’?
High-pressure EOF pumps

\[ Q_E \sim \frac{\epsilon \zeta V}{\eta L} A_{pump} \]

\[ Q_p \sim \frac{\Delta p r_{pore}^2}{\eta L} A_{pump} \]
High-pressure EOF pumps

\[ Q_E \sim \frac{\varepsilon \zeta V}{\eta L} A_{\text{pump}} \]

\[ Q_p \sim \frac{\Delta p r^2}{\eta L} A_{\text{pump}} \]

require:
• high \( V \)
• high \( \zeta \)
• small pores

\( 10kV -- 100 \text{ atm} (!) \)
High-pressure ICEO pumps

Potential applied across channel height $h$

$$\Delta p_{\text{ICEO}} \sim \epsilon \frac{V^2 L}{h^2 r_{\text{pore}}}$$

10 V ICEO pump $\sim$ 1-100 atm (!)

Ongoing: Andy Pascall, UCSB
ICEO flows around metal colloids

Levich (62), Gamayunov, Dukhin, Murtsovkin

AC electro-osmosis

Ramos, Green, Gonzales, Ajdari

EHD flows around oil drops

Taylor (66)

AC colloidal self-assembly

Ristenpart & Saville
Asymmetric bodies - asymmetric flow

fore-aft: swims towards blunt end
left-right: swims towards pointed end

Qualitative observations: Gamayunov, Murtsovkin, Mantrov (87, 90)
relevent for ‘nano-bar-codes’ as well (Santiago, Shaqfeh, Saintillain, Rose)
Translation and Rotation under AC fields...

Odd perturbations: Translation
• parallel or perpendicular to field

Even Perturbations: Rotation
• conductor aligns with/against field
‘Design’ colloidal swimmers:

$P_3 + P_2 = \text{result}$

All axes align with field, swims along field towards blunt end

$P_3 + P_2 = \text{result}$

$P_2$ aligns with field, ‘swims’ perp. to field towards sharp end
Strong shear in screening cloud

$u_s \sim 1 \text{mm/s}$

$\lambda_D \sim 1 \text{nm}$

$\dot{\gamma} \sim 10^6 \text{s}^{-1}$

$\tau \sim \text{kPa}$

Can we exploit this?
Liquid interfaces can flow

Liquid metal surface

\[ \frac{U_{\text{liq}}}{U_0} = 1 + 4 \frac{\mu_w}{\mu_m \lambda_D} \frac{b}{\lambda_D} \]

Naively expect 10^3-10^4 times faster...

Adverse effects:
- surface conduction
- charge convection
- inertia
- surfactants
Asymmetric solid/liquid electrode

Net flow from liquid to solid
Preliminary Experiments

With G. Soni, C. Meinhart (UCSB)

(Liquid) Gallium Eutectic

(Solid) Titanium Electrode 200µm

1 mM KCl solution
Evaporated Titanium Electrode
25 V/cm, 500Hz field applied

(annoying) bubble
Preliminary Experiments  With G. Soni, C. Meinhart (UCSB)

QuickTime™ and a decompressor are needed to see this picture.

1 mM KCl solution
Evaporated Titanium Electrode
25 V/cm, 500Hz field applied