Active mixing with Quincke rollers

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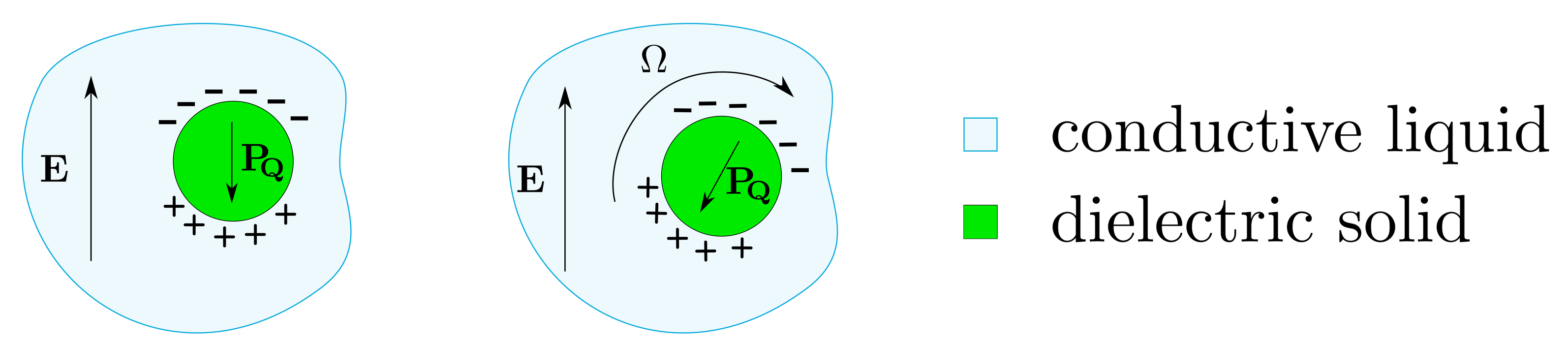
The Quincke effect, from rotors to rollers

Quincke effect: spontaneous rotation of dielectric objects immersed in a conductive liquid in the presence of a DC field E.

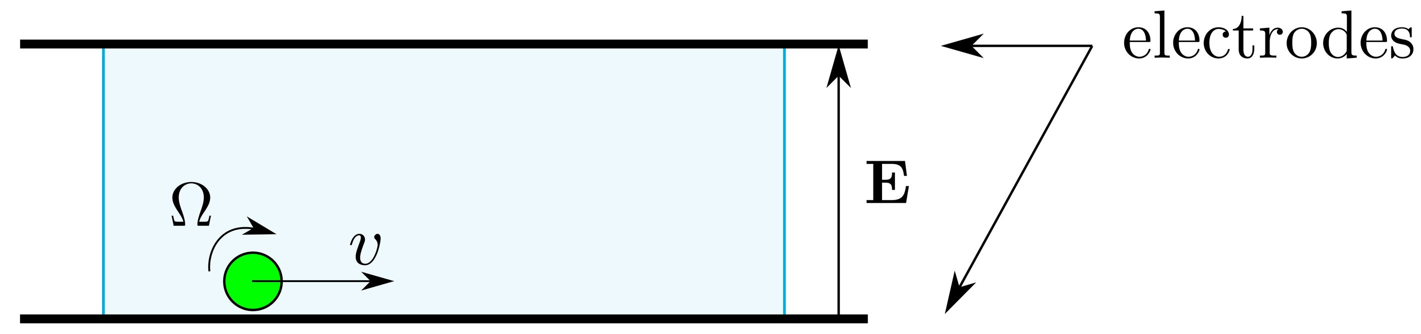
Discontinuity between dielectric constants and conductivities:
$\varepsilon_p \neq \varepsilon_l$, $\sigma_p \neq \sigma_l$ $\rightsquigarrow$ accumulation of charges at the interface, with timescale $\tau = \frac{\varepsilon_p + 2\varepsilon_l}{\sigma_p + 2\sigma_l}$ (p: particles, l: liquid)
$\rightsquigarrow$ electric dipole $\mathbf{P_Q}$, antiparallel to the field.

Above threshold E_Q: net dipole dominated by $\mathbf{P_Q}$ $\rightsquigarrow$ unstable situation
$\rightsquigarrow$ electric torque, balanced with a viscous torque.

Equilibrium state: rotation with finite speed $\Omega = \frac{1}{\tau}\sqrt{\frac{E^2}{E_Q^2} - 1}$

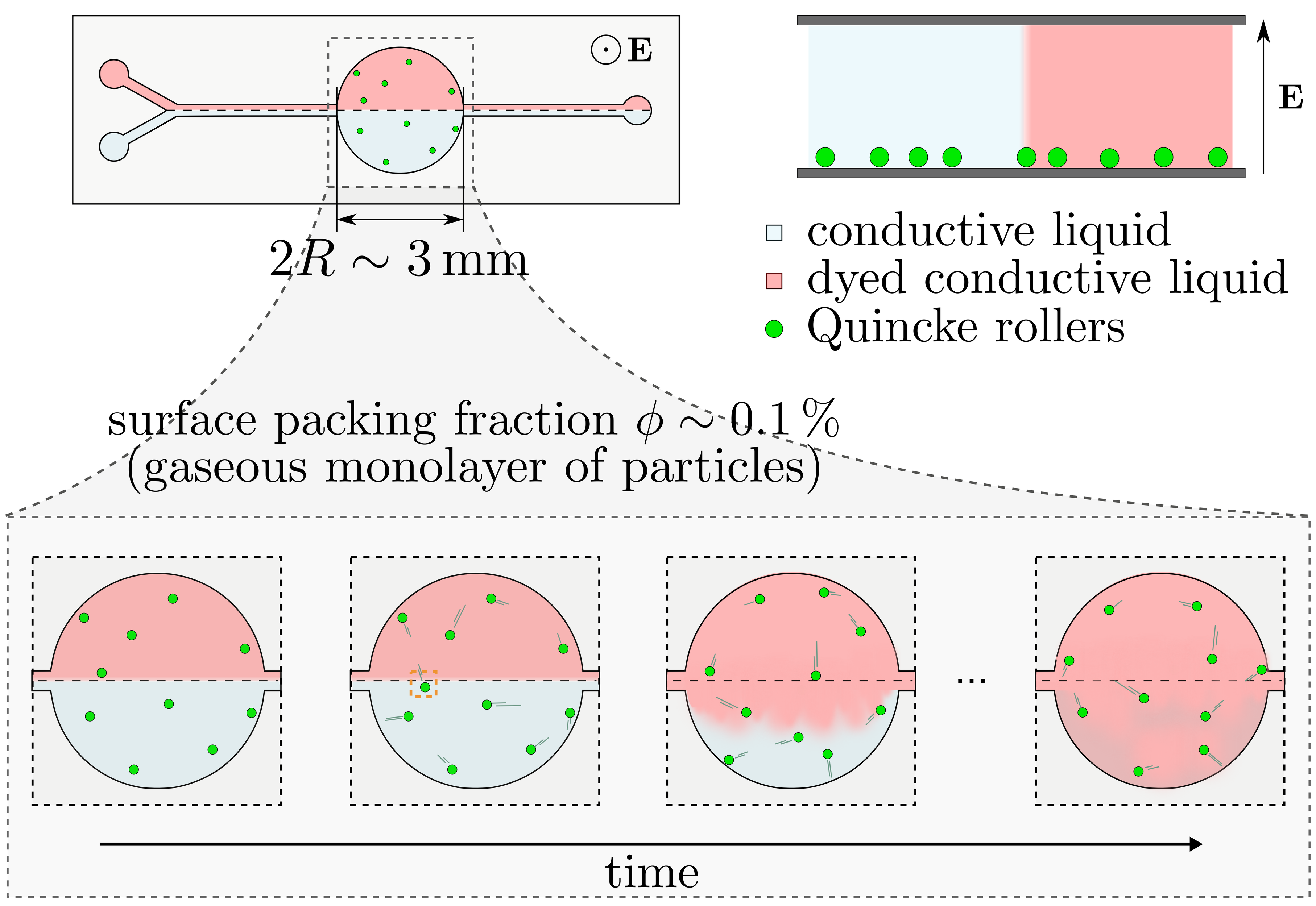


rotation + contact: rolling

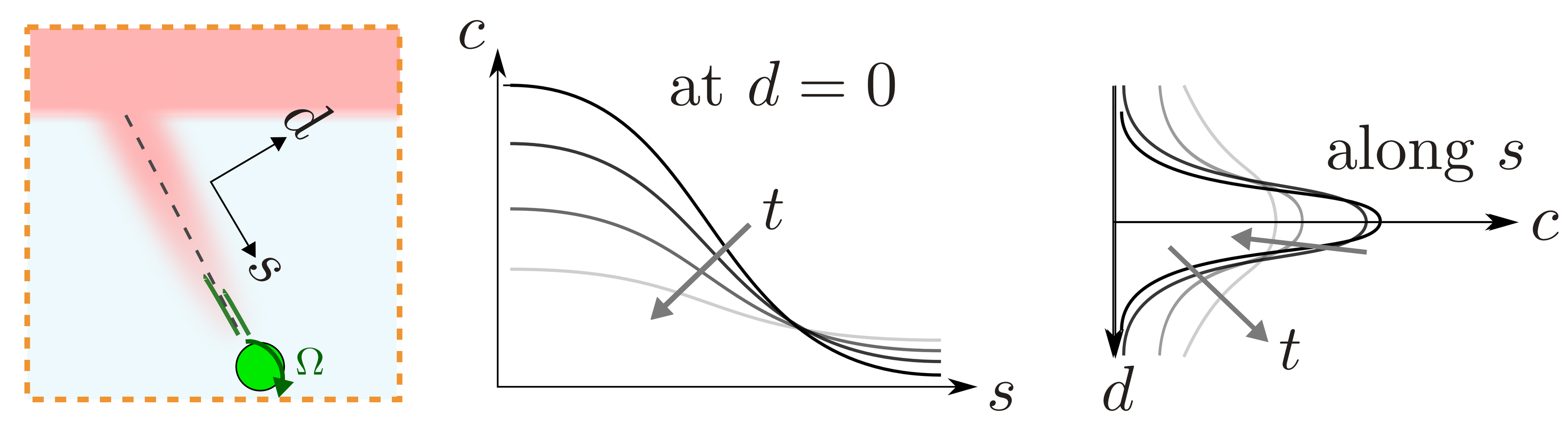


Quincke mixing at the microscopic scale

Mixing: shear + diffusion. Quincke rollers can reach $v \sim 1\,\mathrm{mm\,s^{-1}}$: fast shear at small length scales.
$Re \sim 10^{-3}$: mixing is difficult due to flow reversibility. Particles: break reversibility.

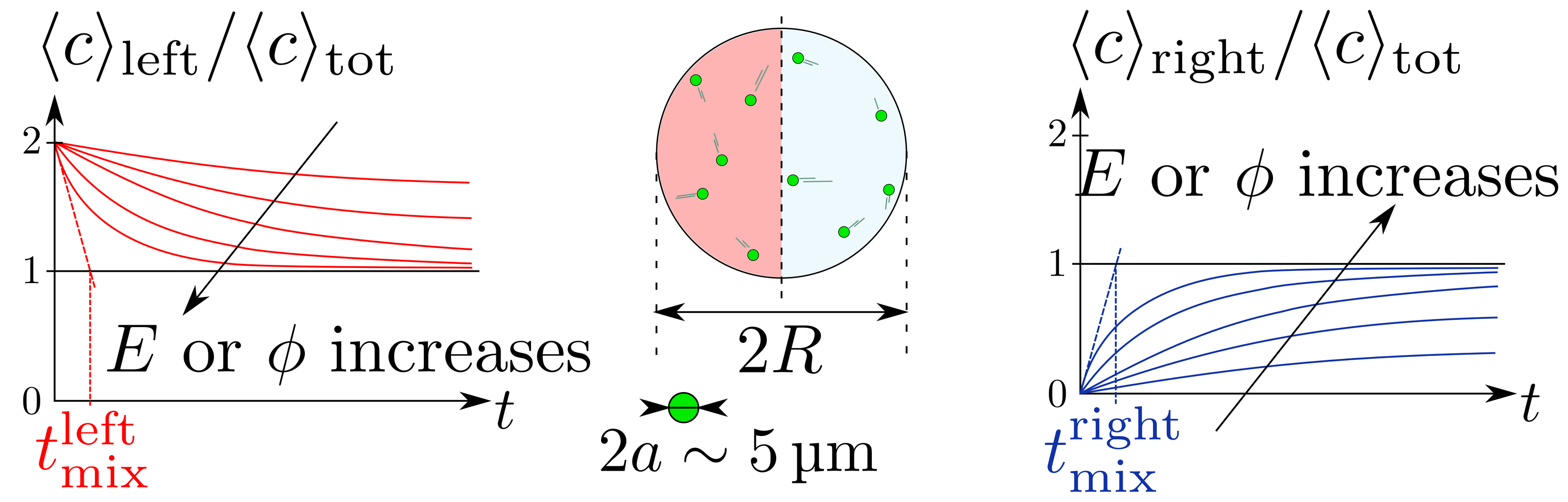


1) concentration profile: interface crossing



liquid advection by rotation

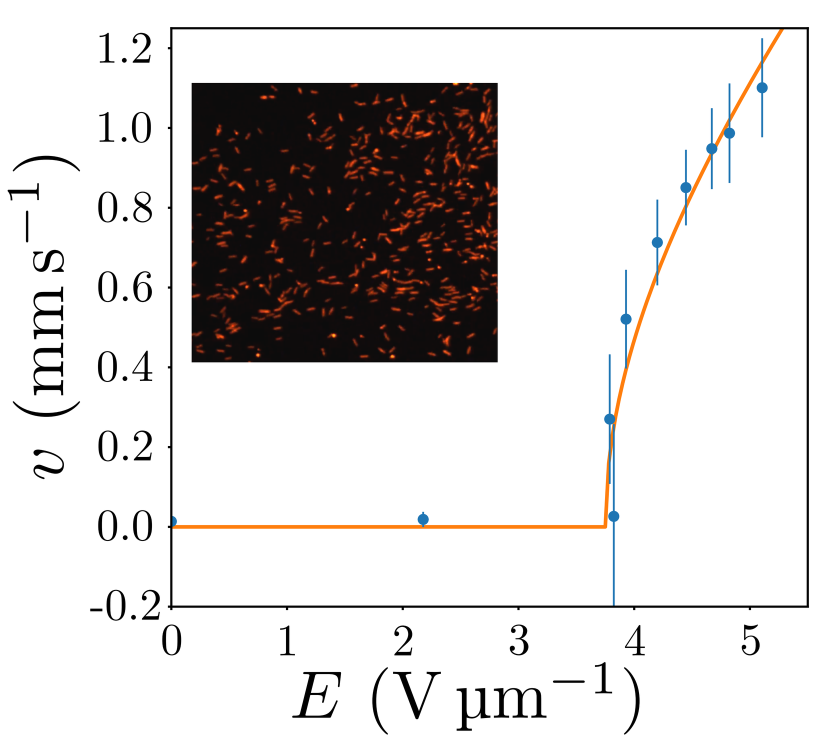
2) average concentration in left or right half cell



Order of magnitude: without shear: $t_{\mathrm{diff}} \sim R^2/D \sim 35\,\mathrm{min}$. With particles: $t_{\mathrm{mix}} \sim \pi a/\phi v \sim 8\,\mathrm{s}$.

Preliminary results and difficulties

Reproducible Quincke effect



Quincke effect: highly sensitive to system characteristics. Problems:

- E_Q depends on ε_p, ε_l, σ_p, σ_l, η, and the liquid's water content,
- dyed versus uncoloured liquid: different ε_l and σ_l, maybe different water content,
- $\sigma_l^{\mathrm{dyed}} \neq \sigma_l^{\mathrm{uncoloured}}$ $\rightsquigarrow$ electrohydrodynamical instabilities.

Need to conduct careful liquid formulation to match dyed and uncoloured liquids.