OPTIMAL ELECTRO-OSMOTIC FLOW THROUGH NANOCHANNELS

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NAVIER-STOKES EQUATION

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$$\begin{aligned} \nabla \cdot \mathbf{u} &= 0 \\ \rho\left(\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\mathbf{u}\right) &= -\nabla P + \eta_0 \nabla^2 \mathbf{u} + \rho \mathbf{F}, \end{aligned}$$

- $\rho \implies$ Density of fluid
- $\eta_0 \implies$ Shear viscosity of fluid
- $P \implies$ Pressure of the fluid
- $\mathbf{u} \implies$ Streaming velocity field of the fluid flow
- $\mathbf{F} \implies$ External body force applied to generate the flow

NO-SLIP BOUNDARY CONDITION

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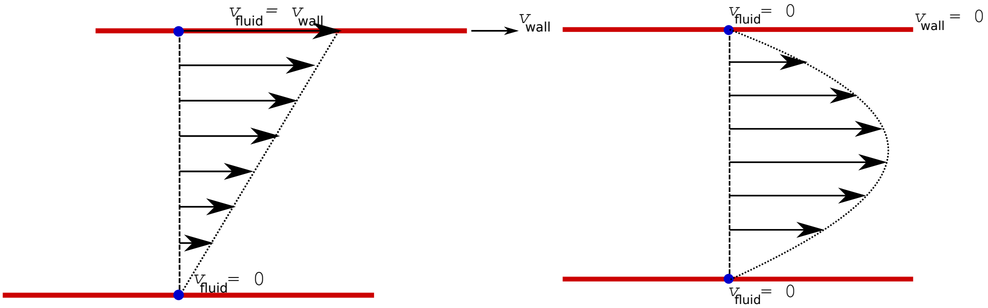

Couette Flow　　　Poiseuille Flow

SLIP BOUNDARY CONDITION

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Nanoscale hydrodynamics

Enhanced flow in carbon nanotubes

Mainak Majumder, Nitin Chopra, Rodney Andrews & Bruce J. Hinds

Table 1 | Pressure-driven flow through aligned MWCNT membrane

Liquid	Initial permeability*	Observed flow velocity†	Expected flow velocity†	Slip length (mm)
Water	0.58	25	0.00057	54
	1.01	43.9	0.00057	68
	0.72	9.5	0.00015	39
Ethanol	0.35	4.5	0.00014	28
iso-Propanol	0.088	1.12	0.00077	13
Hexane	0.44	5.6	0.00052	9.5
Decane	0.053	0.67	0.00017	3.4

MWCNT, multiwalled carbon nanotube. For details of methods, see supplementary information. *Units, cm^3 per cm^2 min bar. †Flow velocities in cm s^{-1} at 1 bar. Expected flow velocity is that predicted from conventional flow.

FLUID FRICTION

- According Navier,

$$\sigma_{xy} = -\xi_0 u_x(z)$$

  - $\sigma_{xy} \implies$ tangential stress exerted by the wall on the fluid,
  - $u_x \implies$ velocity x-component
  - $\boxed{\xi_0} \implies$ $\boxed{\text{interfacial friction coefficient.}}$

Figure: Bust of Claude Louis Marie Henri Navier at the École Nationale des Ponts et Chaussées (Image courtesy: *Wikipedia*)

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- NS equation with slip boundary conditions valid up to channel widths ≈ 1 nm !

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- Electro-osmotic flow (EOF) is an electrokinetic transport process that induces motion to an ionic solution in contact with a charged surface under the presence of an external electric field.

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- Electro-osmotic flow (EOF) is an electrokinetic transport process that induces motion to an ionic solution in contact with a charged surface under the presence of an external electric field.
- The Navier-Stokes equation for analyzing EOF

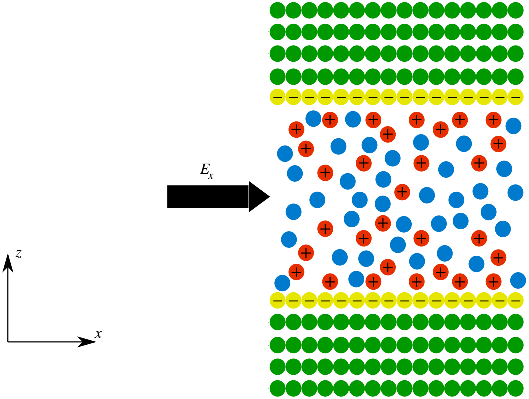
$$\rho\left(\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\mathbf{u}\right) = -\nabla P + \eta_0 \nabla^2 \mathbf{u} + \rho_f \mathbf{E},$$

  - $\rho_f \implies$ Free charge density
  - $\mathbf{E} \implies$ External electric field applied to generate the flow

ELECTRO-OSMOTIC FLOW

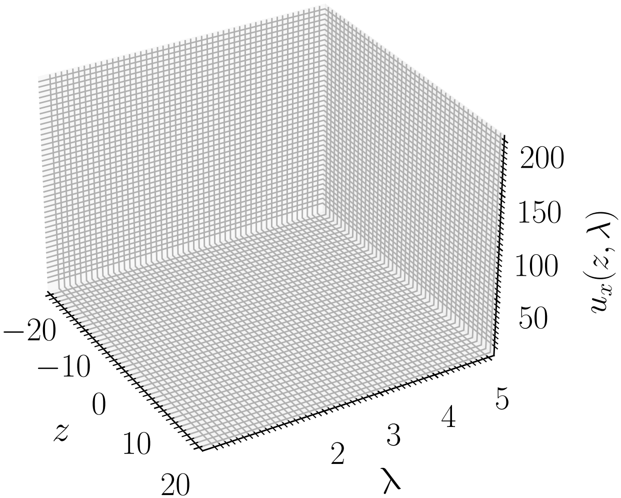
- The governing equation for a fully developed 1-D steady-state EOF, with negligible inertial effects compared to viscous forces

$$\implies \boxed{\eta_0 \frac{d^2 u_x(z)}{dz^2} = -\rho_f(z) E_x}$$



WETTING (HYDROPHILIC) NANOCHANNEL

$$\lambda \propto \frac{1}{\text{ionic conc.}}$$



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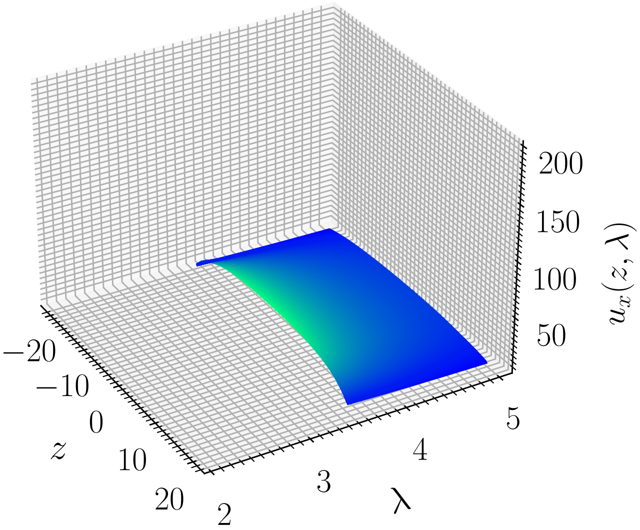

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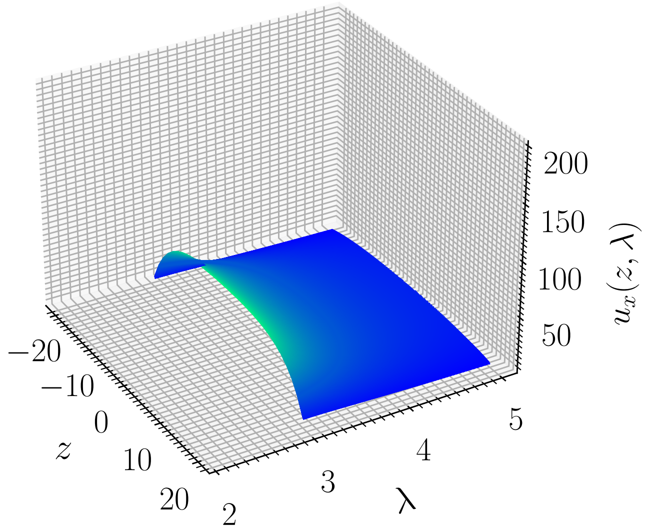

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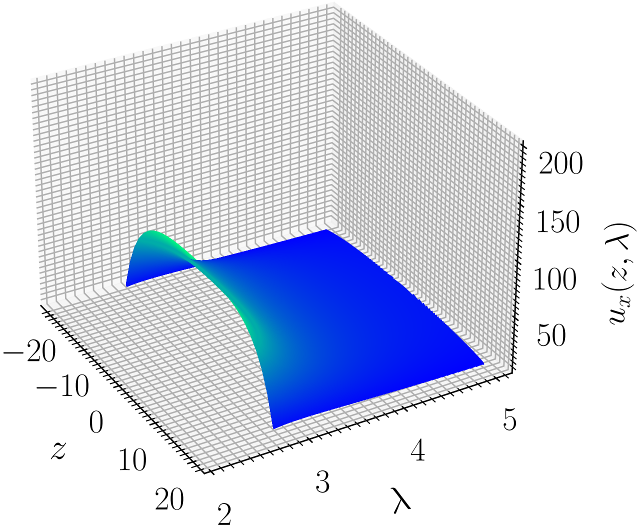

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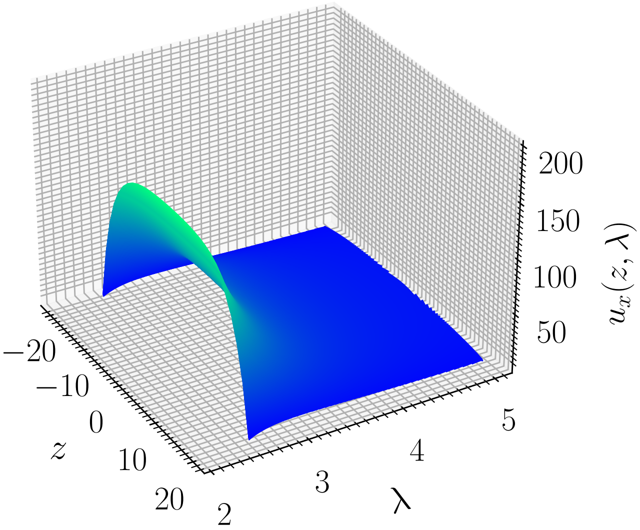
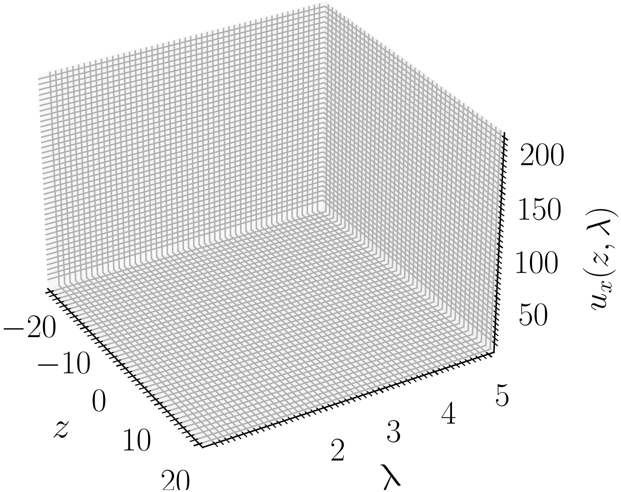


NON-WETTING (HYDROPHOBIC) NANOCHANNEL

$\lambda \propto \frac{1}{\text{ionic conc.}}$



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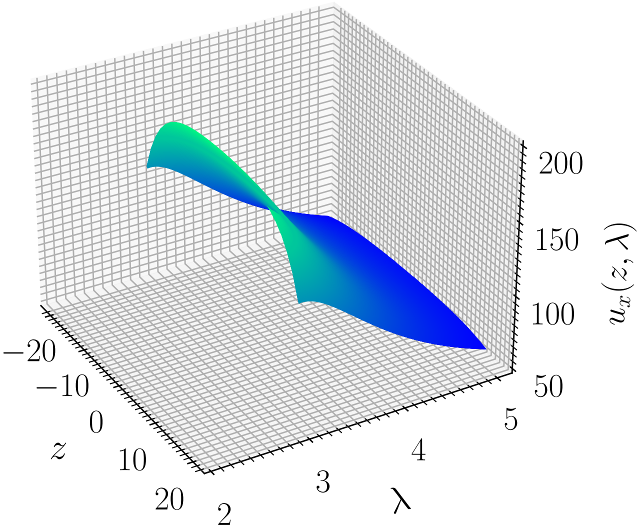

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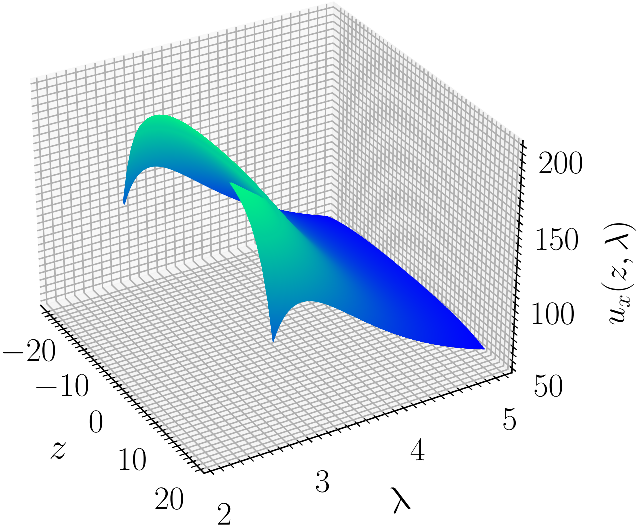

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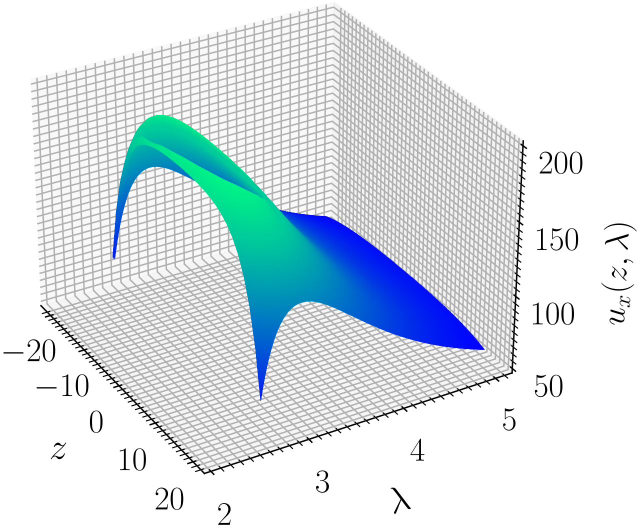

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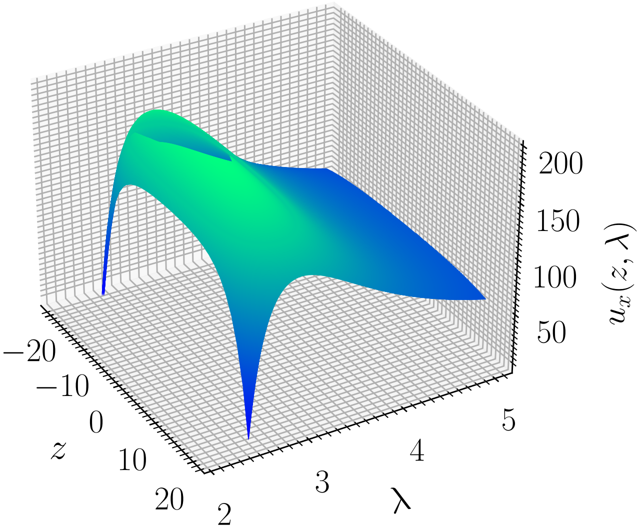
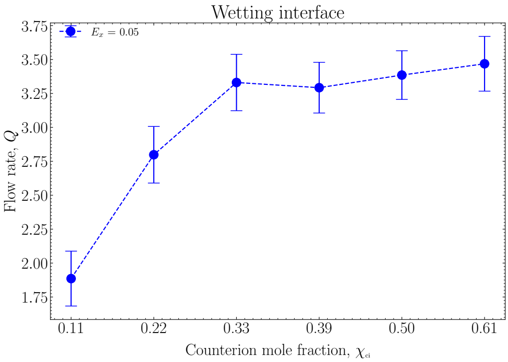
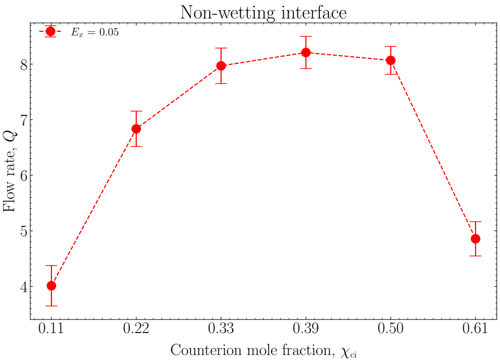


MOLECULAR DYNAMICS SIMULATIONS





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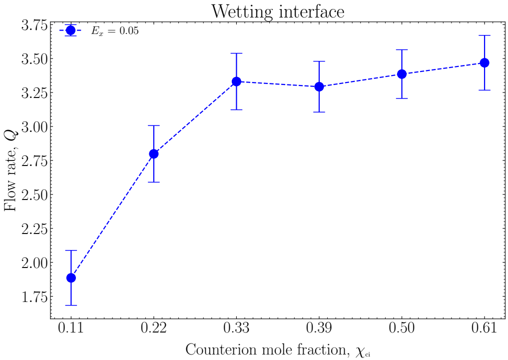

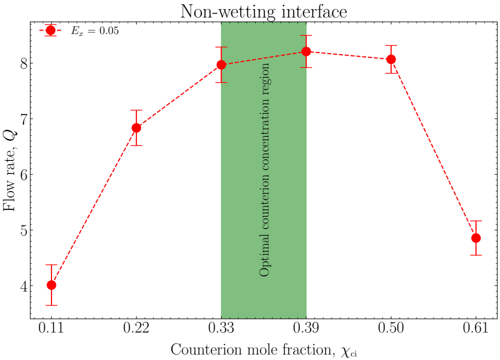

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  - Electro-osmotic pumping does not require any mechanical moving parts such as pumps or valves to transport the fluid.
- Desalination
- Energy storage
- Understanding flow through biological nanochannels

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Optimal Electro-osmotic Flow Through Nanochannels

Thank you!

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