Lecture 10

Flow at nanoscale.

Why Nanofluidics

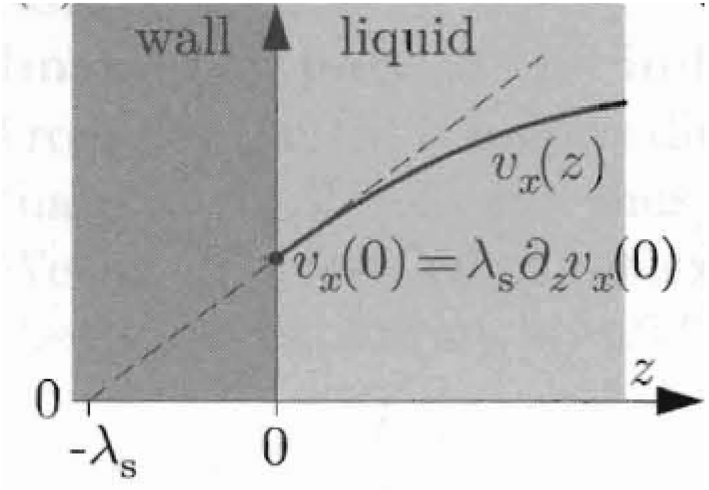
- Nanofluidics are already used for long time in various applications: nanoporous membranes, gels and molecular filters, but not well understood
- with current advances in micro/nanofabrication we can produce systems with channels as small as molecules, down to 1-10nm.

No-slip boundary condition at nanoscale

- Minor deviation from the non-slip boundary condition can have an important effect on nanoscale.
- More general Navier boundary condition (suggested back in 19th century!):
  - for a wall at y=0:

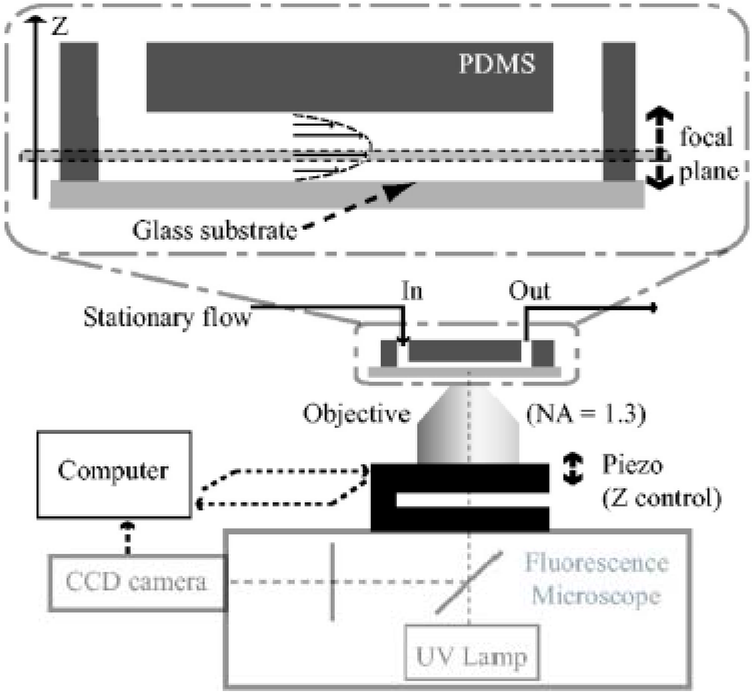
$$u(0) = \lambda_x \frac{\partial u}{\partial y}$$

slip length, the distance behind the boundary, where the tangent intersect the axis



Measurements of flow profile ín nanochannels

- PIV technique with 50nm fluorescent particles



lens stepping 50nm

P. Joseph and P.Tabelling, Phys.Rev. E 71, 035303 (2005)

Measurements of flow profile ín nanochannels

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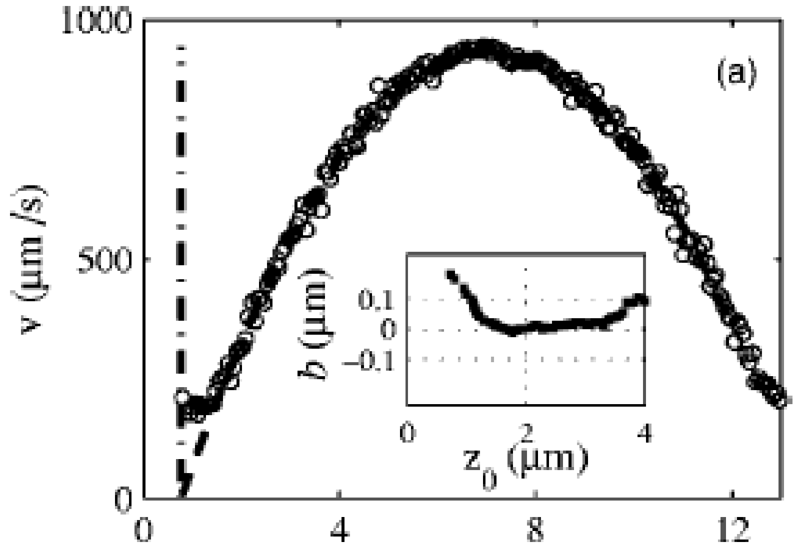
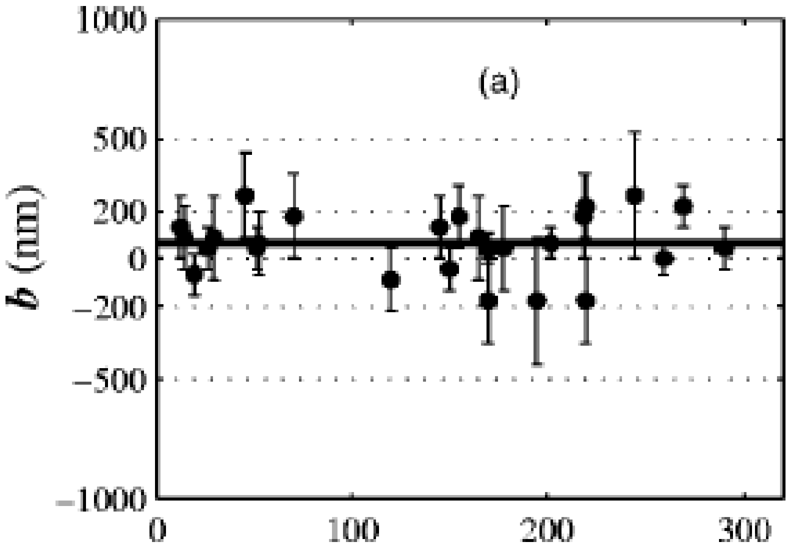
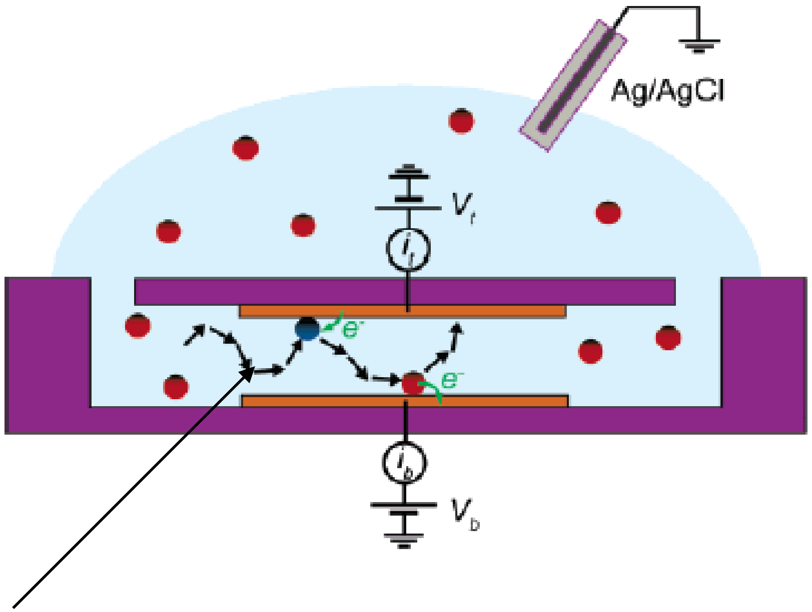




- Flow profile nicely fits as a parabola (Poiseuille flow)
- Measured slip length: $\lambda_s = 50nm \pm 50nm$
- Assuming 50nm slip length will lead to reduction of hydraulic resistance
  - for 10um channel by 3%,
  - for 1um channel by 23%
- Larger values of slip length observed sometimes are related to gas bubble layer formed on the wall

Mesoscopic fluctuation of concentration of the molecules of interest

- As soon as the number of molecules of interest gets sufficiently small statistical fluctuation can become large

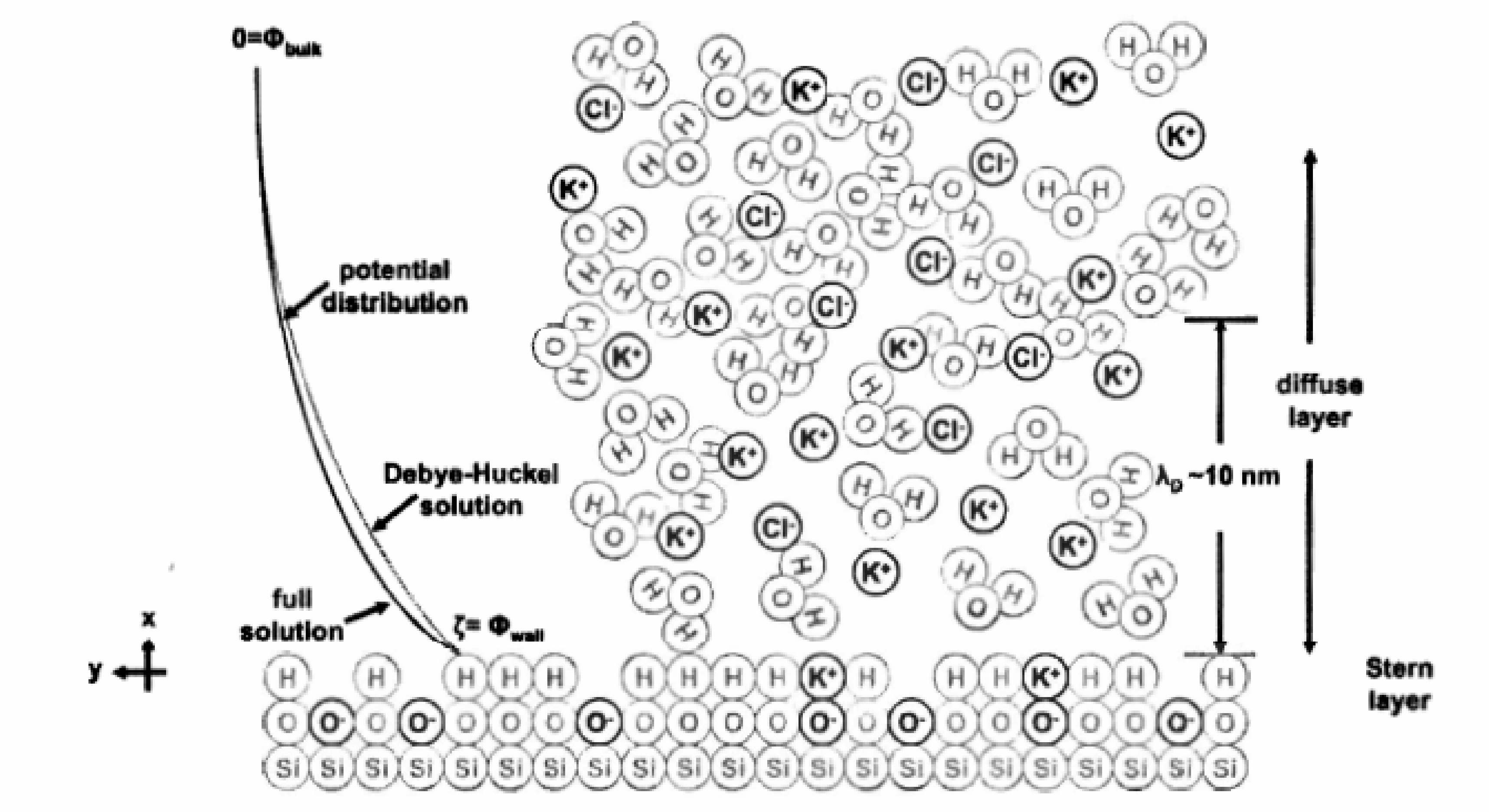


a molecule of ferrocenedimethanol

M. A. G. Zevenbergen, D. Krapf, M. R. Zuiddam, and Serge G. Lemay, Nanoletters 7, 384 (2007)

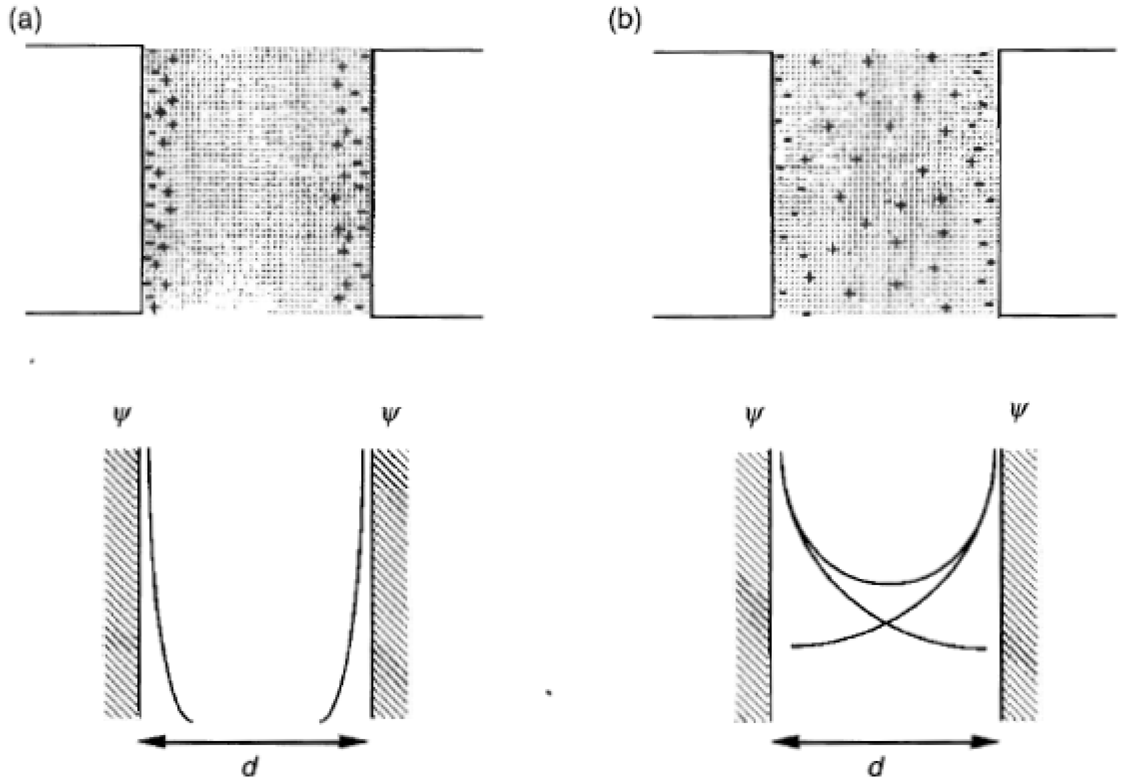
Origin of electroosmosis

- Structure of the solid (silicon) - liquid (electrolyte) interface



Flow through nanopores

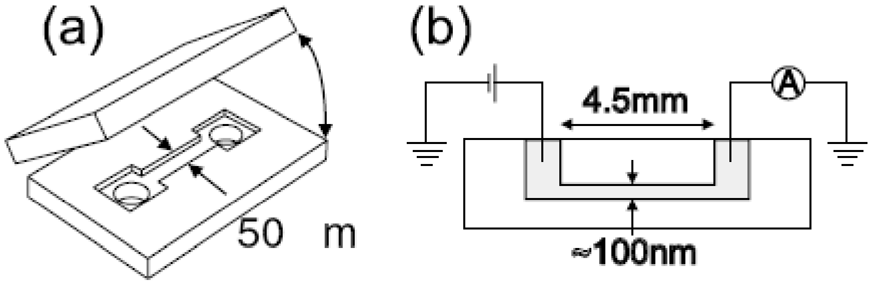
large channel: $d \gg \lambda_D$ nano channel: $d \leq \lambda_D$

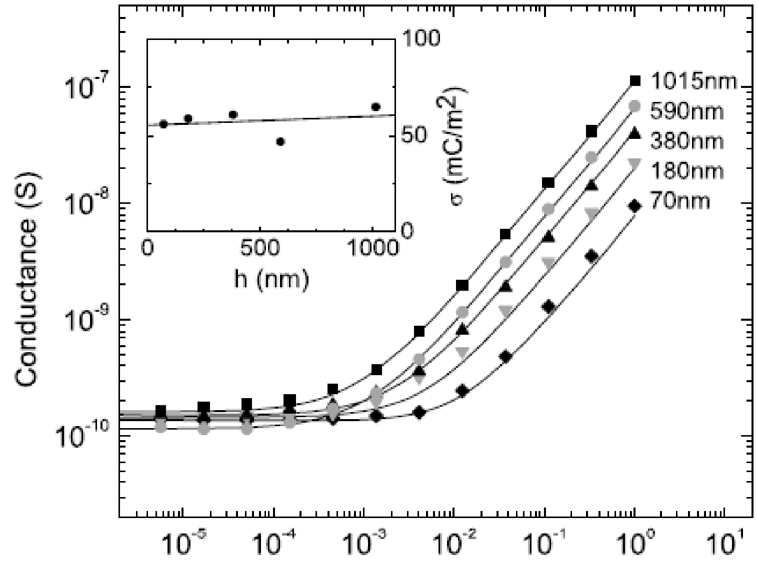


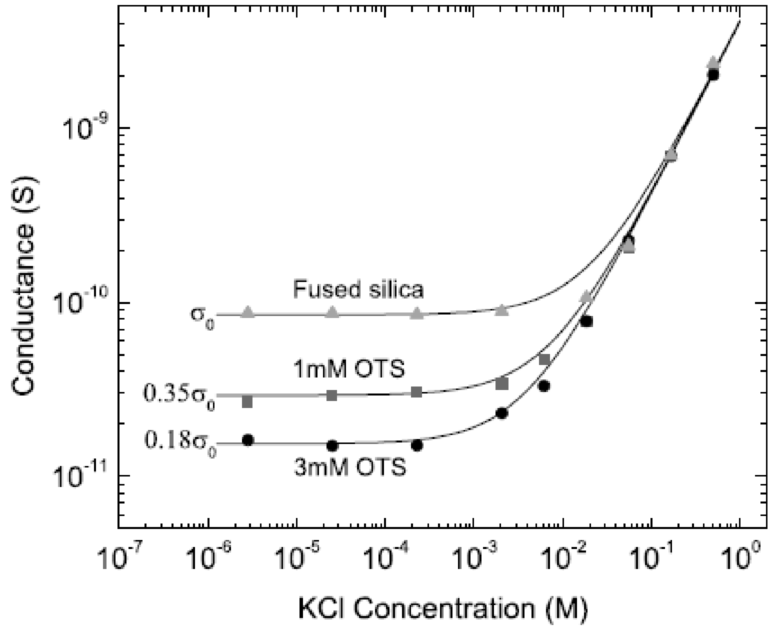
- when the double layers overlap a pore will predominantly contain ions of one sign (here anions)
- this leads to higher conductance, limited transport of e.g. proteins etc.

Surface-charge governed transport

- Mobile counter ions in charged double layer dominate transport at low ionic concentration in small channels



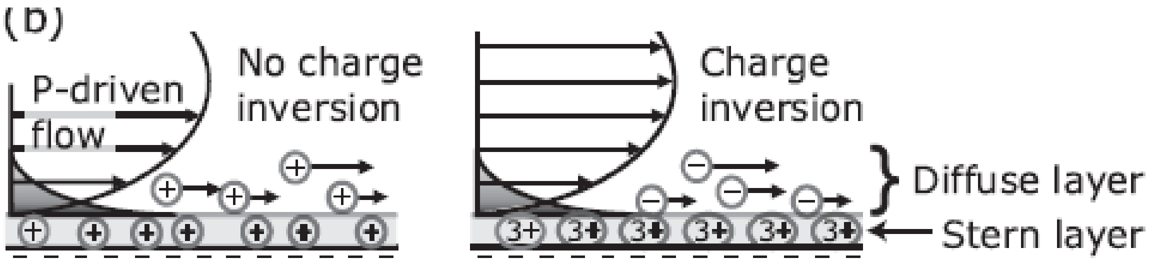


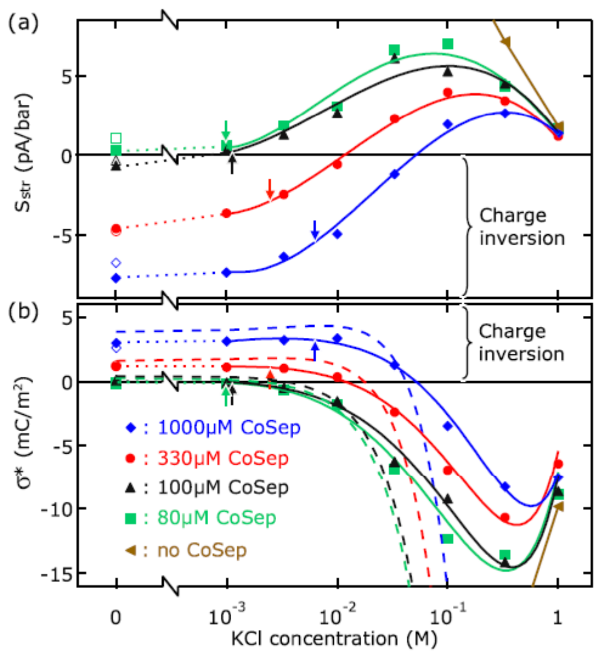


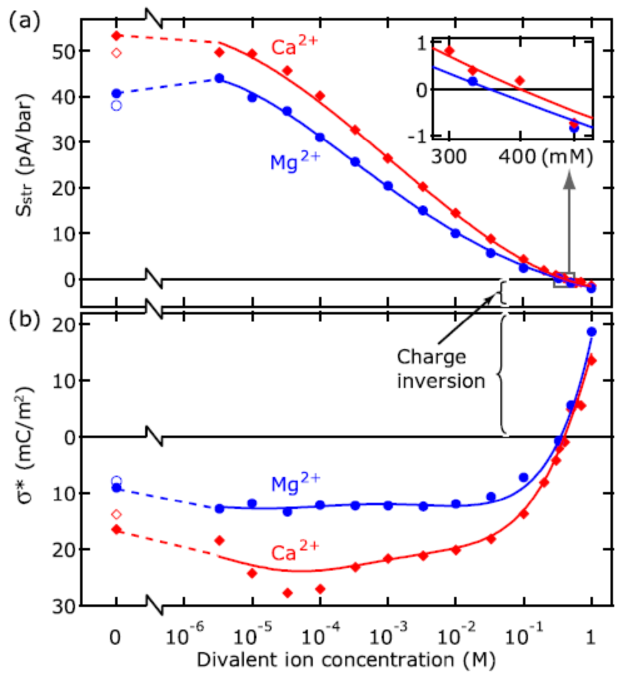
Derek Stein, Maarten Kruithof, and Cees Dekker, Phys.Rev.Lett. 93, 035901 (2004)

Charge inversion

- Multivalent ions adsorbed on the walls can lead to charge inversion of the diffuse layer

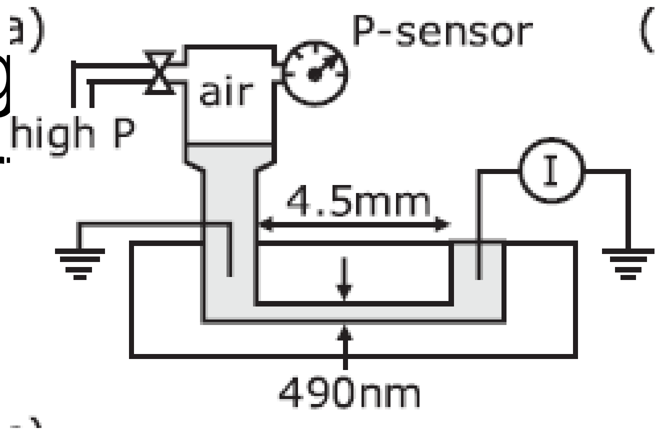






Streaming currents

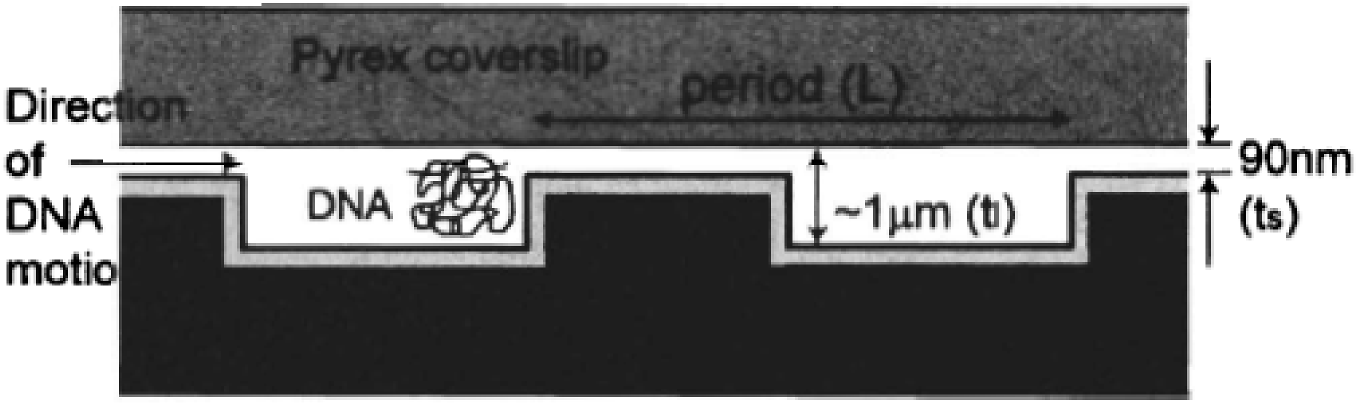
- The origin of streaming current effect: transpor diffuse layer ions by pressure



Biomolecule separation using nanochannels

- Polymeric molecules like DNA and RNA form a “blow” in solution with the radius of gyration (Rg). E.g. for λ-DNA (48.5 kbp), Rg~0.7μm
- To pass through the filter pore smaller than Rg, force to overcome the entropic force is required

Entropic trapping device

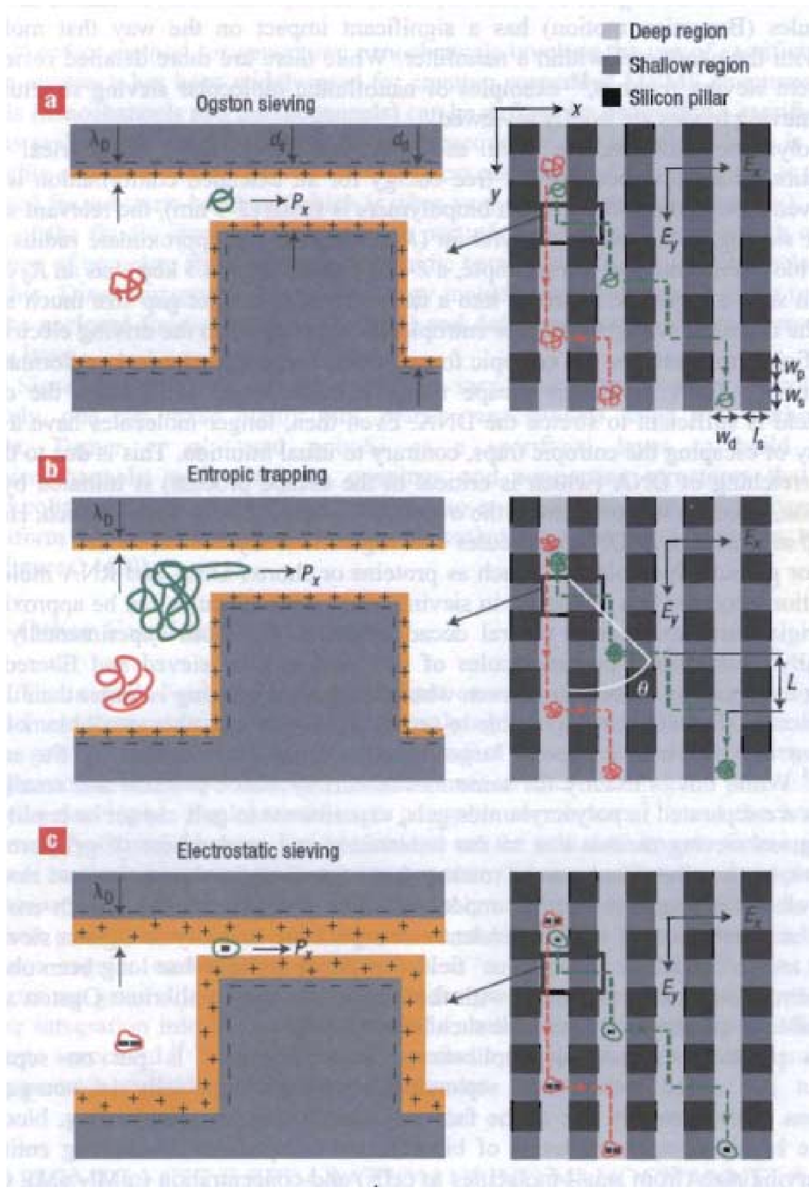


- The large is the gyration radius of a molecule the more surface contact it will make and the faster it will escape from traps

Han J, Turner S.W., Graighead H.G., Phys.Rev.Lett. 83, 1688 (1999)

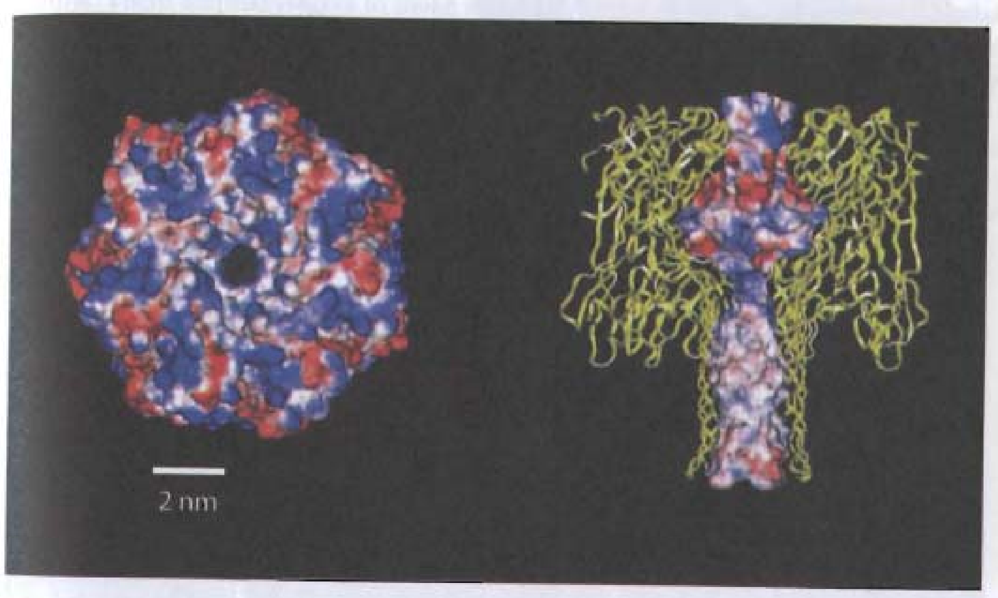
Main sieving modes in nano-filters

- **Ogston sieving**: applies to molecules smaller than nanofilter gap
- **Entropic trapping**: applies to long polyelectrolytes (longer than persistence length)
- **Electrostatic sieving**: Debye length comparable with the channel size, charge selective transport

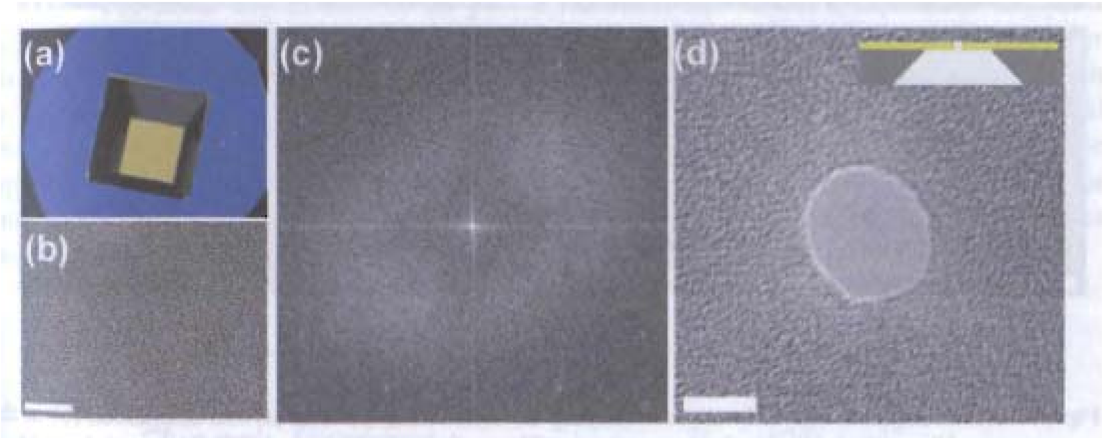


Nanopores: key to DNA sequencing?

- Fabrication of a single nanopore
  - α-Hemolysine protein nanopore

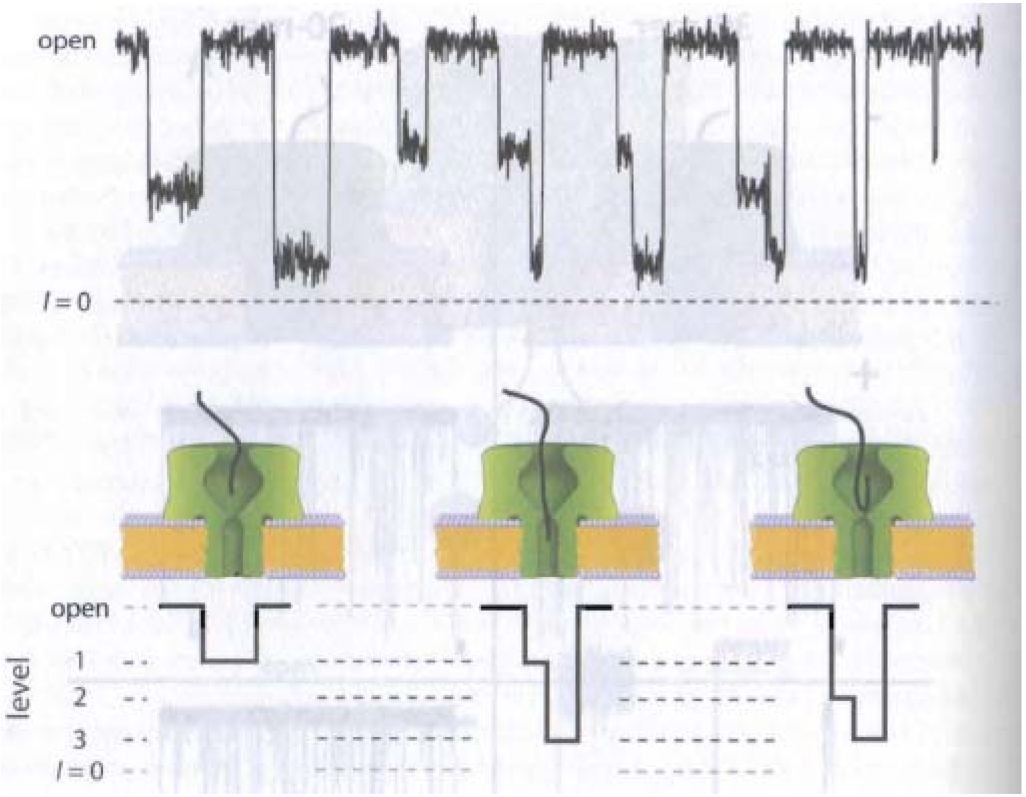


  - Microfabricated nanopore



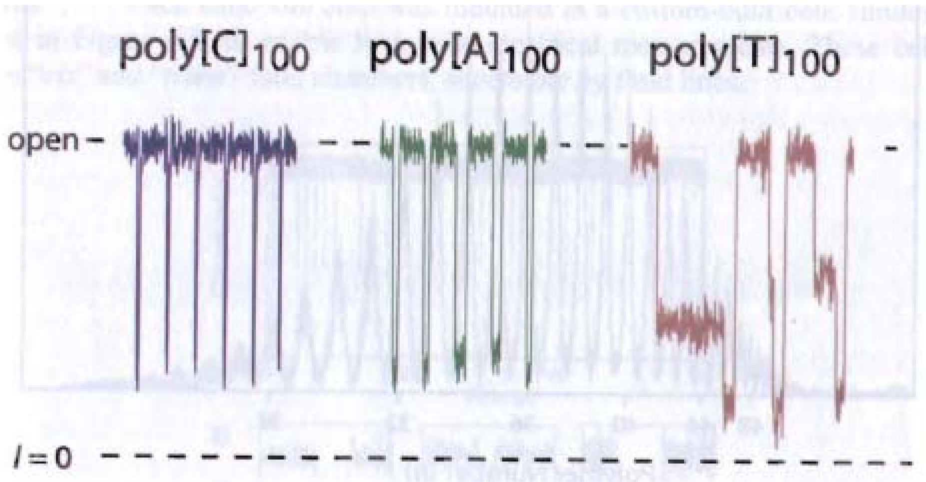
Nanopores: key to DNA sequencing?

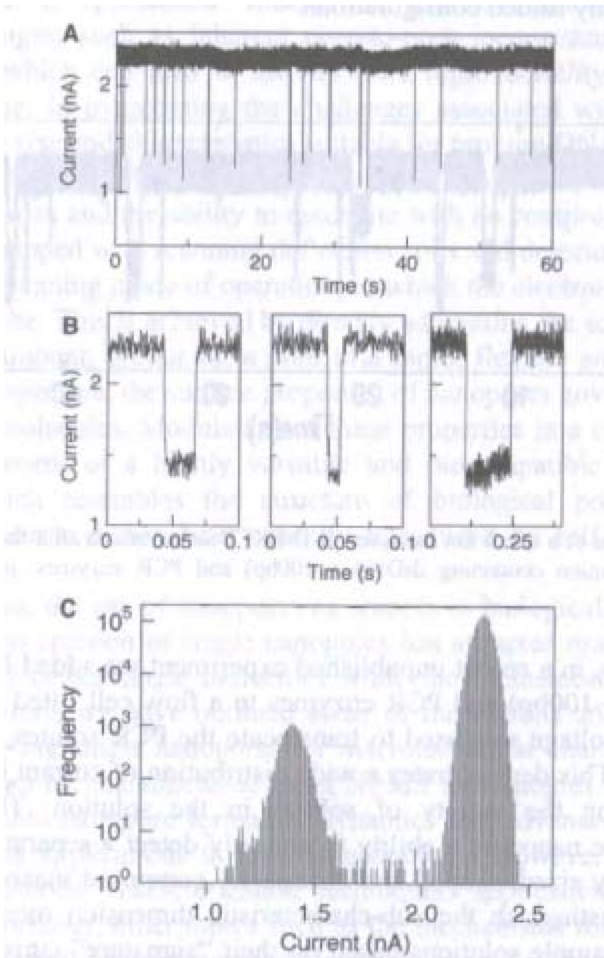
- Channel blockage due to translocation of molecules



Nanopores: key to DNA sequencing?

- Sequence recognition during translocation:





Translocation through hemolysine pore

Translocation through solid state pore