E304 Introduction to Nano Science & Technology

Unit 9: Nanofluidics

L9.1.4: Surface Effects at the Nanoscale

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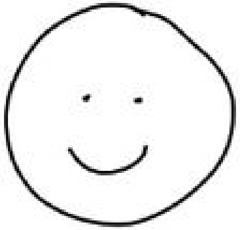
Surface Effects at the Nanoscale

Consider the humble sphere

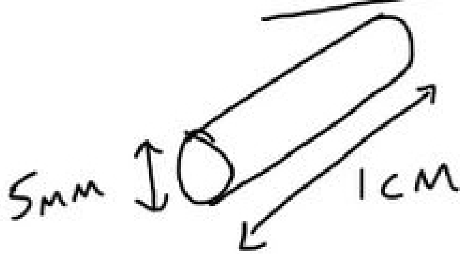


$$SA = 4\pi R^2 \qquad V = \tfrac{4}{3}\pi R^3$$

$$\frac{SA}{V} = \frac{4\pi R^2}{\tfrac{4}{3}\pi R^3} = \frac{3}{R} \Rightarrow R\downarrow \quad \frac{SA}{V}\uparrow$$

Example

PIPE

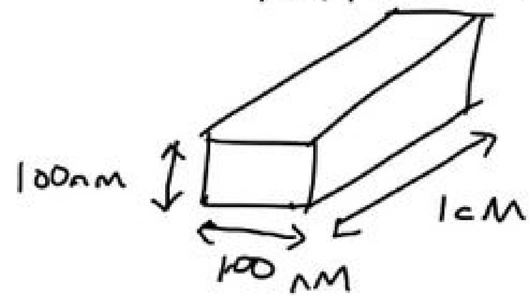


$SA = 1.571\ cm^2$

$V = 0.196\ cm^3$

$SA/V = 800\ m^{-1}$

NANOCHANNEL



$SA = 4 \times 10^{-5}\ cm^2$

$V = 1 \times 10^{-10}\ cm^3$

$\frac{SA}{V} = 4 \times 10^{7}\ m^{-1}$

50000x as large

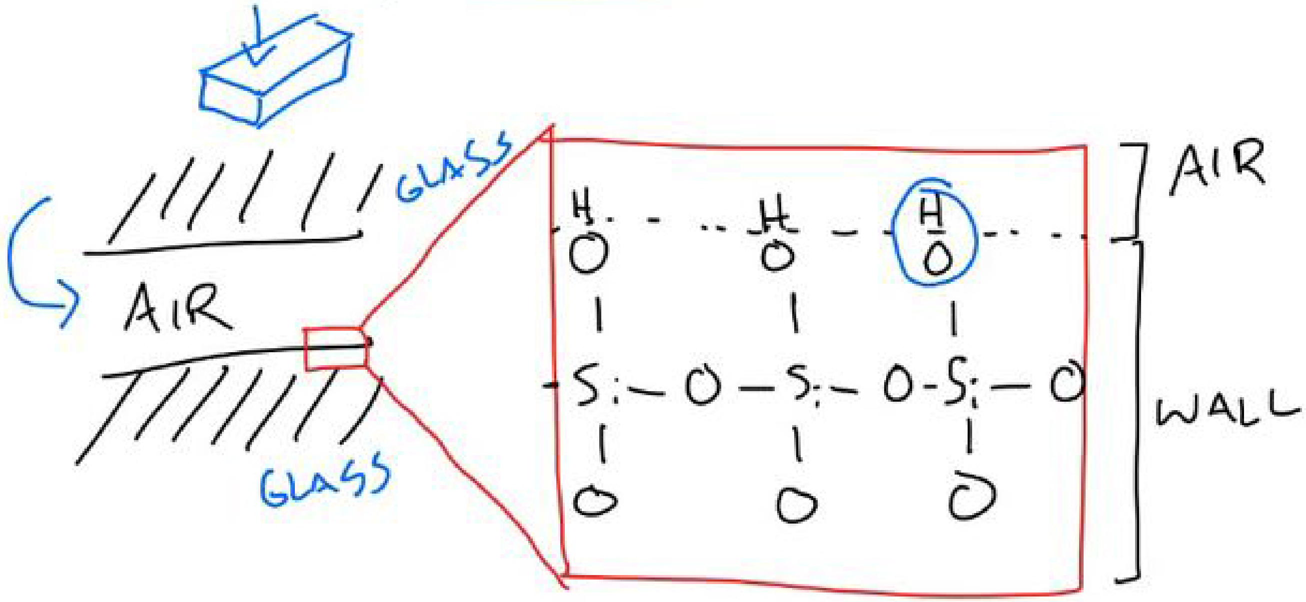
Main point: At the nanoscale, SA/V ratio is huge! ✓

Implications

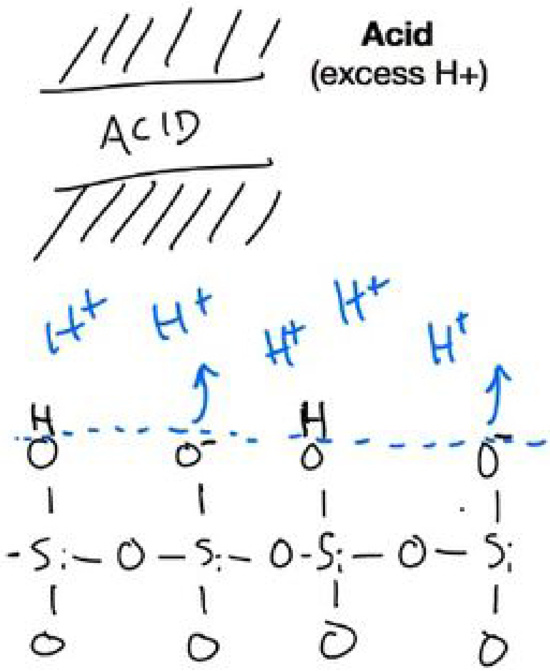
- Surface-based processes are very efficient (absorption, cooling, etc.) ✓
- Surface charge becomes an important factor

Surface Charge in Nanochannels

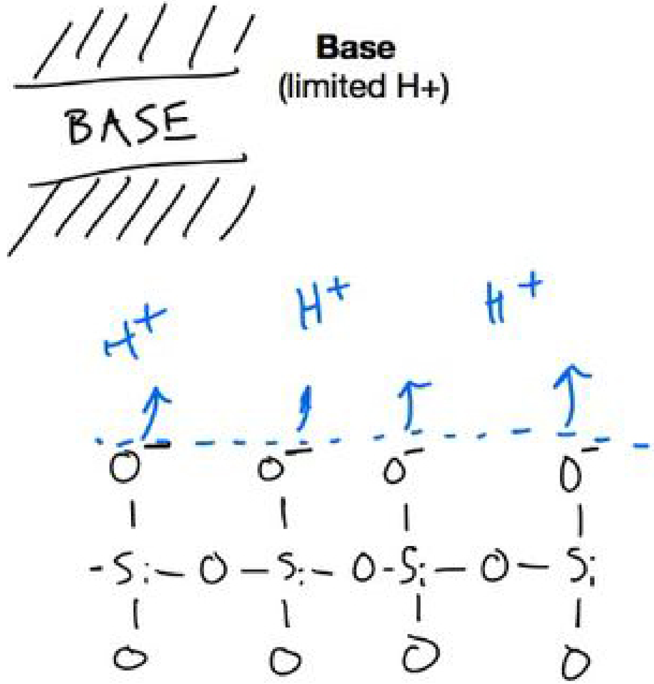
What does the surface of a glass nanochannel look like?



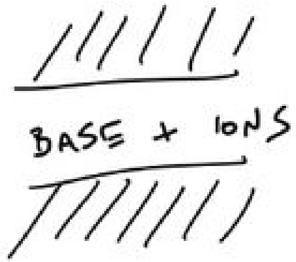
Acid
(excess H+)

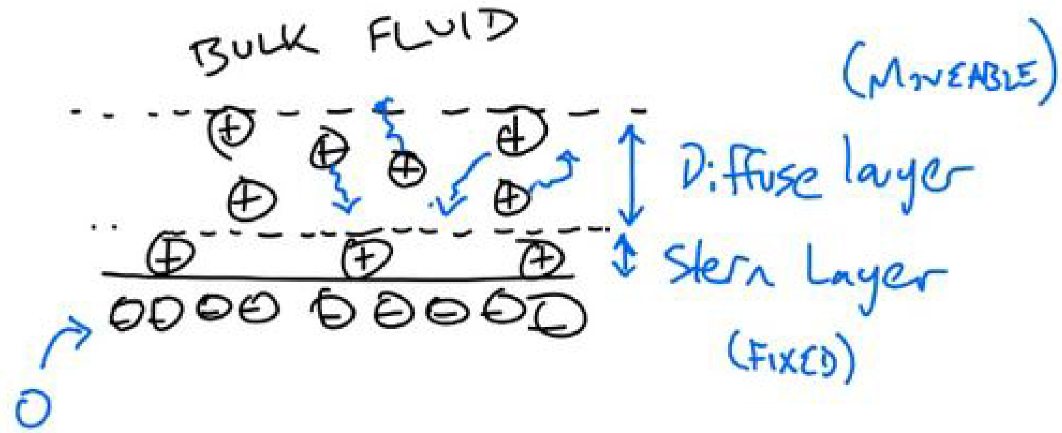


Base
(limited H+)



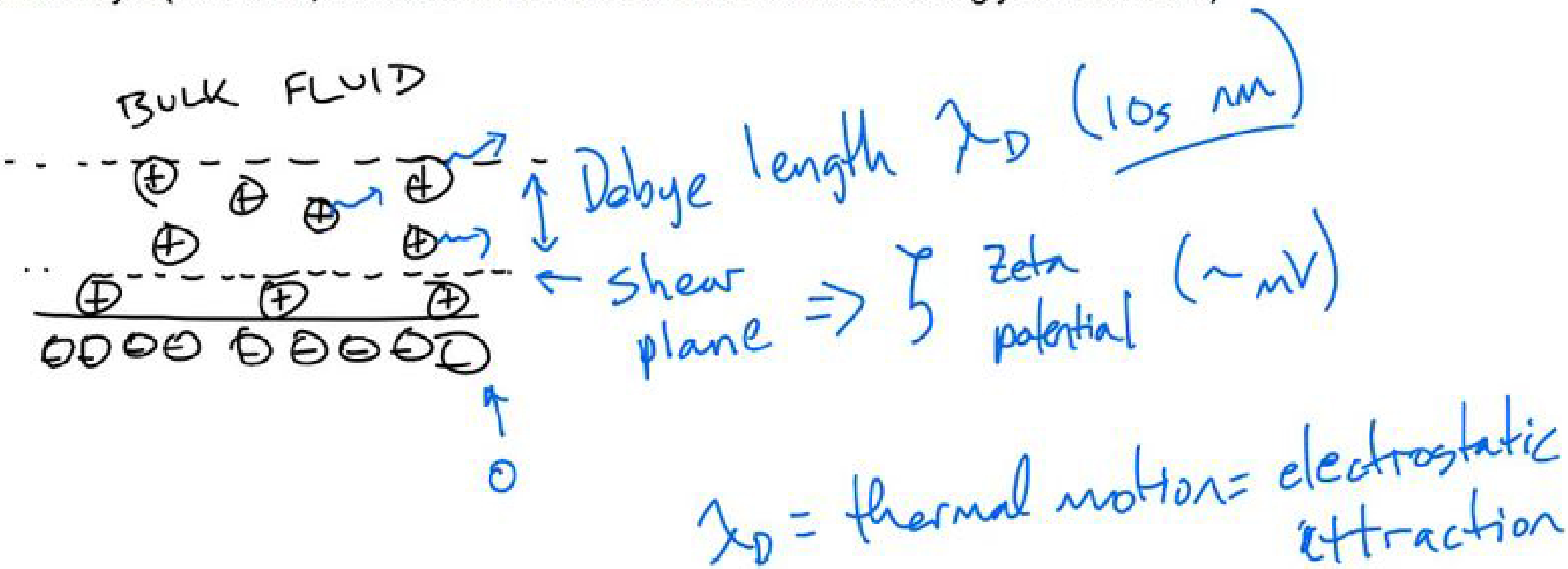
What happens if we put basic water containing salt in a glass nanochannel?





Two layers form:

1. Stern layer (fixed)
2. Diffuse layer (moveable, because ions are too far from wall to be strongly attracted to it)



Debye length

- Extends to where thermal motion of ions = electrostatic attraction to surface
- Depends on several variables (temperature, pH, ions)
- Typical Debye length is ~ 10s of nm
- In nanochannels in particular, the Debye length can occupy a significant fraction of the nanochannel width

Formula for Debye length (assuming a symmetric electrolyte like NaCl)

$$\lambda_D = \sqrt{\frac{\varepsilon_r \varepsilon_0 K_B T}{2 e^2 z^2 n_\infty}}$$

ε_r = relative permittivity

ε_0 = permittivity of free space

K_B = Boltzmann

T = temperature

e = charge of an electron

z = charge of ion

n_∞ = number density of ion far away from