

# Viscosity of Water in Nano-Confinement

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Since the early 1970s there is a notion that water near polar or charged surfaces is somehow ordered or structured, leading to a so called structural component of the disjoining pressure. The first indications came from interpretation of the disjoining pressure isotherms of wetting films of water on hydrophilic substrates [1], while unambiguous experimental proof came through application of the so called Surface Forces Apparatus (SFA) [2-6] showing short range repulsion forces between charged surfaces brought in close proximity ( $< 5\text{nm}$ ), in addition to the double layer repulsion and van der Waals attraction as described by the DLVO theory.

An important question that emerges is if and how the supposed interfacial “structuring” of water affects its local viscosity. In the early 1970’s measurements of the flow velocity of liquid plugs in quartz micro-capillarities driven by a disbalance between the capillary pressure and an applied external pressure revealed an elevated viscosity of water up to 40% in capillarities of  $0.04\ \mu\text{m}$  in radius [7]. These results could not be reproduced in nanometer thin films in the Surface Forces Apparatus (SFA). Different SFA-based measurements indicate that nm thin films have a viscosity equal [6,8] or close to the bulk viscosity of water [9, 10]. In contrary, recent AFM experiments show orders of magnitude increase in the viscosity of water with respect to bulk water in sub-nanometer confinement [11]. In these experiments, the normal and lateral forces of a nano-sized silicon tip approaching a solid hydrophilic surface were simultaneously measured.

In different labs it is attempted to extract data on the viscosity of water from analyzing the capillary filling dynamics of water and aqueous salt solutions in nanochannels. A significantly slower than expected filling in channels with heights in the range of  $10 - 50\ \text{nm}$  [12,13] is found in comparison with the classical Washburn model [14]. The increase of the apparent viscosity in confinement amounts up to approx. 30% in 11 nm channels. A best fit to the experimental data assuming a highly viscous layer next to the hydrophilic channel walls shows that this immobile layer should have a thickness of  $0.9\ \text{nm}$  at each interface, which is in correspondence with the results of ref. [11].

Based on all experimental data available, one must conclude that the question if and how hydration forces are connected to viscosity changes of interfacial water has still not been completely answered.

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