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Water at the Nanoscale

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ABSTRACT

Knowing the behavior of water in small volumes is essential for the understanding of many processes in biology, tribology, and geophysics. In this seminar we will discuss two different situations: water capillary bridges and sub-nanometer water films. The water bridges provide stability to sand castles, act as transport channels for dip-pen nanolitography and increase adhesion and friction in micro- and nano- devices such as MEMS. The kinetics of capillary condensation and growth at the nanoscale is studied here using friction force microscopy. At 40% relative humidity we find that the meniscus nucleation times increase from 0.7 ms up to 4.2 ms when the temperature decreases from 332 K to 299 K. The nucleation times grow exponentially with the inverse temperature 1/T obeying an Arrhenius law. We obtain a nucleation energy barrier of 7.8*10^{-20}~J and an attempt frequency ranging between 4-250~GHz, in excellent agreement with theoretical predictions. These results provide direct experimental evidence that capillary condensation is a thermally activated phenomenon.

Water confined in sub-nanometer gaps play a crucial role in many biological systems such as ion channels. Here, we report an experiment in which an atomic force microscope tip approaches a flat solid surface in purified water, while small lateral oscillations are applied to the tip. The normal and lateral forces acting on the tip are measured directly and simultaneously as a function of water thickness. We find that, for hydrophilic surfaces, oscillatory solvation forces are present in the last four adjacent water layers where the dynamic viscosity is measured to grow up orders of magnitude in respect to bulk water. The same effects are present for atomically smooth surfaces and slightly rough surfaces. Oscillatory solvation forces have been detected also when the confining flat surface was hydrophobic.

R. Szoszkiewicz and E. Riedo, “Nucleation time of nanoscale water bridges” Phys. Rev. Lett. 85 135502 (2005).

R. Szoszkiewicz and E. Riedo, “Friction forces as a local probe of Phase transitions”, App. Phys. Lett. 87, 033105 (2005).

T.-D. Li, J. Gao, R. Szoszkiewicz, U. Landman and E. Riedo “Behavior of sub-nanometer thick water layers” submitted to Nature.