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Surface nanobubbles: Theory, numerics and experiments

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When a solid is brought into contact with water, surface nanobubbles can be formed at the solid-liquid interface. These nanobubbles are small; their height is of order 10nm and their lateral sizes vary from 10-100 nm. Initially, the only proof of the existence of surface nanobubbles was delivered by atomic force microscopy. Later, additional techniques such as infrared attenuated total reflectance have confirmed the existence of gaseous domains on the solid-liquid interface. Before this overwhelming evidence, the existence of surface nanobubbles was controversial because they possess some unusual properties. For example, nanobubbles are surprisingly robust against dissolution by diffusion and Laplace pressure: Instead of the expected lifetime of about a microsecond, nanobubbles are found to survive for several hours and in some cases even several days. Additionally, surface nanobubbles are flatter than predicted by Young's law and are able to resist strong tensile stresses ($\sim$-6 MPa), rather than serving as a nucleation site for a macroscopic bubble. A deep understanding of surface nanobubbles is crucial for practical applications (*e.g.* drag reduction in microfluidic devices) but nanobubbles also pose fundamental questions on the validity of continuum models at the nanoscale. In this talk, we will discuss these open questions in detail by considering theoretical efforts and molecular dynamics simulations. Theoretically, we study the consequences of a pinned contact line. We find that the pinned contact line can explain the long lifetimes and many other nanobubble properties. From molecular dynamics results, we clarify the influence of the gas species on the contact angle. Finally, we will discuss some very recent experimental and theoretical work on the effects of an acoustic field on nanobubbles. We provide experimental data combined with a theoretical analysis and find that the acoustic driving can cause the nanobubbles to grow by rectified diffusion.