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A new theory of bubble stability: Implications for nanobubbles at surfaces and in bulk solution[1]

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Nanobubbles on hydrophobic surfaces can be imaged using Atomic Force Microscopy and are implicated in the very long-range attraction measured between hydrophobic surfaces. However, the widely accepted theory of bubble dissolution predicts that small bubbles under the influence of Laplace pressure should rapidly dissolve resulting in bubble lifetimes of less than a second.[2] Such short lifetimes should preclude nanobubbles from having an effect on surface force measurements or being observed by AFM,[3] yet nanobubbles are readily observed by AFM and widely implicated in force measurements between hydrophobic surfaces. This has led to a number of attempts at describing their unexpected stability, though no explanation is currently widely accepted. Additionally, nanobubbles have contact angles substantially greater (measured through the more dense liquid phase) than the equivalent macroscopic contact angle. It is clear that nanobubbles at surfaces pose a number of problems that are yet to be resolved. Additionally, recent reports of long-lived nanobubbles in bulk solution add to the mystery. Here we present a new theory describing the stability of nanobubbles. We calculate their lifetimes as a function of gas supersaturation and explain the long lifetimes observed. The same theory predicts that bulk nanobubbles should be stable under certain circumstances. Further, in an extension of this work we explain the difference in contact angle between the nanoscopic and macroscopic measurements and describe in detail the process by which nanobubbles are formed during solvent exchange. Experimental evidence is presented supporting this new approach and showing that this theoretical framework has parallels in other nucleated systems.

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[2]Epstein, P. S.; Plesset, M. S., *Journal of Chemical Physics* **1950,** *18* (11), 1505-1509.

[3]Ljunggren, S.; Eriksson, J. C., *Colloids and Surfaces a-Physicochemical and Engineering Aspects* **1997,** *130*, 151-155.