Dynamic Force Spectroscopy in Vacuum and Fluids – Theoretical Considerations

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Use of the atomic force microscope (AFM) in quantitative force measurements inherently requires a relation connecting the observed deflection properties of the cantilever to the interaction force. In static mode, this relation is trivial and has facilitated its wide-spread use. Despite its simplicity, the jump-into-contact instability of the cantilever can restrict its application in the measurement of attractive short-range forces. Dynamic force spectroscopy overcomes this limitation, but introduces significant complexity to the interpretation and extraction of quantitative force data. In this talk, I shall present a theoretical discussion of some fundamental properties of dynamic force spectroscopy with specific regard to the interpretation and unequivocal determination of force data at arbitrary oscillation amplitudes.

One dynamic mode that has received wide-spread attention is frequency modulation atomic force microscopy (FM-AFM). This mode utilizes the change in resonant frequency of a cantilever to detect variations in the interaction force between cantilever tip and sample. While implementation of the technique is well established, interpretation of the resulting frequency shift in terms of an interaction force remains problematic. In this talk, I shall present simple yet accurate formulas that enable the interaction force and energy to be determined directly from the measured frequency shift. In contrast to previous analytical results, these formulas are valid for any oscillation amplitude and interaction force, and are therefore of wide-spread applicability in frequency modulation dynamic force spectroscopy. The validity of the formulas will be demonstrated along with a comparison to experimental measurements.

Due to its relevance to biological and colloidal systems, there is growing interest in the application of dynamic force methods to fluid systems. While operation in fluids presents no conceptual difficulty in static mode, additional complexity arises in dynamic measurements since the dynamic properties of the cantilever are strongly dependent on the surrounding fluid. Consequently, I shall also present results of a detailed theoretical investigation of the dynamic properties of AFM cantilevers in fluids. This will include discussion of the behavior of AFM cantilevers in proximity to a surface, as typically required in force spectroscopy studies, and their behavior far from a surface. The implications of this fundamental study to dynamic force spectroscopy shall be discussed.