Angular dependent force fields within single atoms and exchange interactions revealed by force microscopy utilizing quartz sensors

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Frequency-modulation atomic force microscopy (AFM) can be combined with scanning tunneling microscopy (STM), yielding a simultaneous data set for current and average force gradient. The qPlus force sensor [1] allows to perform simultaneous STM and AFM with sub-Angstrom oscillation amplitudes. Ternes et al. [2] have shown that for some metallic contacts, force and current are proportional within a certain distance range such that AFM and STM images should be similar. The figure below [3] shows an example, where combined AFM/STM reveals two strongly distinct aspects of the atomic structure of matter. The gray veil depicts the inverted tunneling current between a CO molecule adsorbed on Cu(111) and a tungsten tip, while the colored surface shows the corresponding force profiles, where the left image corresponds to a W tip oriented in a <100> direction, the right to a <110> direction and the bottom to a <111> direction [3]. Such strong angular dependencies of chemical bonding forces have been observed before for Si tips interacting with Si surfaces [4], W tips interacting with graphite [5] and Ir tips (possibly covered with Cu) interacting with CO/Cu(111) [6]. In the latter two cases, light atoms such as carbon or oxygen interacted with much heavier and much larger metal atoms. A study of the noise limitations of qPlus sensors [7] has led to improved designs that enable true atomic resolution in ambient conditions [8] and highly resolved spin sensitive measurements [9], revealing the antiferromagnetic spin order on the surface of NiO (100) and the distance dependence of the exchange interaction. The magnitude of the exchange interaction is only 1 meV at a decay length of 14 pm.