How much force is needed to move a single atom with a scanning tunneling microscope tip?

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We comparatively determine the forces required to move an ionic (bromine) atom and a metallic (silver) atom on a Ag(111) surface at 4.6 K using a scanning-tunneling-microscope tip. The minimum lateral forces of 50 pN and 55 pN to move the bromine and silver atom, respectively, are determined from the tip-atom distance and the force vector angle relationship. An ionic contribution entails a stronger total tip-atom force for the bromine atom (478 pN) whereas a weaker force is measured for the silver atom (337 pN) at 1.3 Å tip-atom distance. This experiment employs a variety of STM manipulation techniques in a systematic manner to execute the novel measurement technique. The atomistic force measurement scheme can also be used to explore and quantify various interactions, such as magnetic, van der Waals and covalent interactions, between atoms and molecules. Thus, it opens an exciting avenue of STM applications for a quantitative measurement of the tip-adsorbate forces for atoms, molecules and biological systems with an atomic precision.

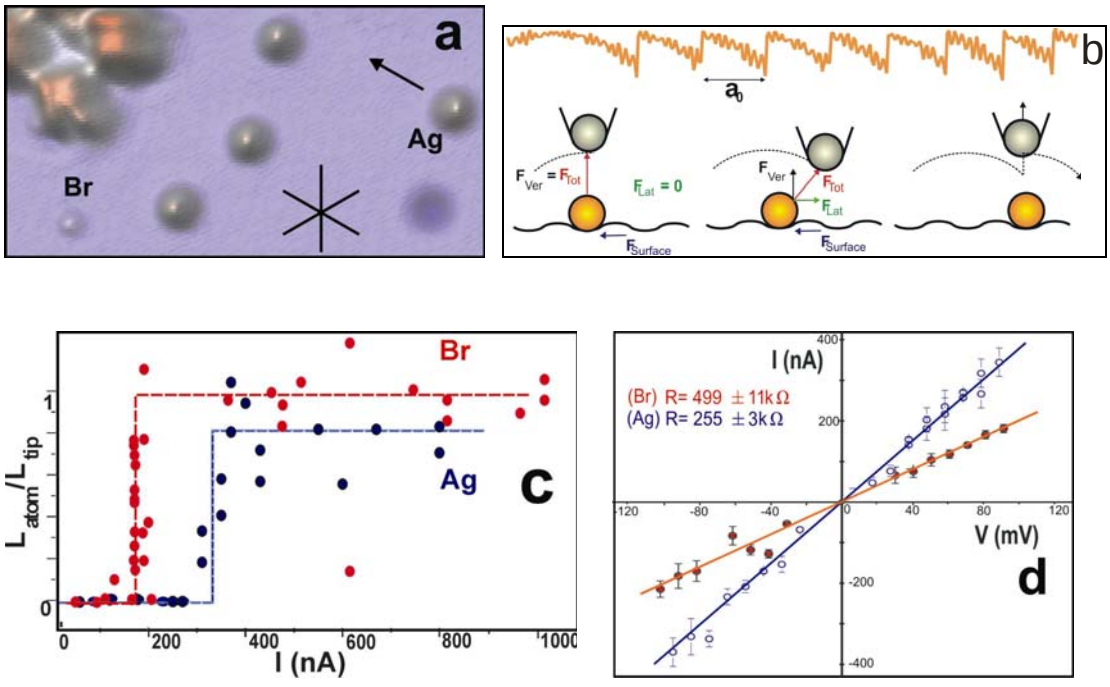

Figure 1 (a) An STM image showing TBrPP-Co molecules (top left corner), an extracted Br atom (bottom left) and four silver atoms (right). The star-shaped cross and the arrow indicate the surface close-packed directions and the atom manipulation path, respectively. Image size=116 Å x 63 Å, V = 990 mV, I = 37 nA, (b) An illustration of the force components involved in lateral manipulation along with a lateral manipulation signal obtained during measurements, (c) Determination of threshold current for each voltage used in manipulation, (d) Threshold resistance plots for Ag and Br atoms.