

# A Universal Relation in NC-AFM, STM, and Atom Manipulation

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The imaging mechanism for both NC-AFM and STM can be explained as a process of making and breaking of chemical bonds between the tip and the sample. Based on that concept, we find a universal relation between tunneling resistance  $R$  and attractive atomic force  $F$  [1]:

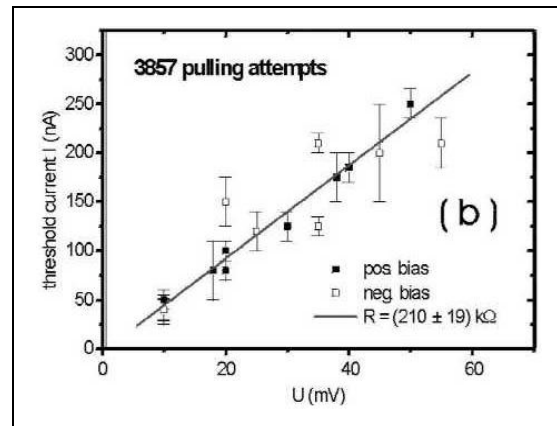
$$R = R_K \frac{f \kappa^2}{\rho_S \rho_T F^2}, \quad (1)$$

where  $R_K \approx 25.812 \text{ k}\Omega$  is von Klitzing's constant,  $\kappa$  is decay constant,  $\rho_S$  is sample DOS,  $\rho_T$  is tip DOS (both at Fermi level), and  $f \approx 1$  is a dimensionless factor depending on tip geometry. Recently, Eq. (1) was tested against NC-AFM experiments, and was partially verified [2,3]. That relation was also applied to interpret the bias dependence of NC-AFM images [4].

The primary mode of atom manipulation is **pulling** [5,6]. If the chemical bond is its mechanism (rather than van der Waals or electrostatic forces), and  $E$  is the energy barrier for the adatom to overcome, according to Eq. (1), the tunneling resistance  $R$  corresponding to energy barrier  $E$  is

$$R = R_K \frac{f}{\rho_S \rho_T E^2}. \quad (2)$$

Eq. (2) explains the **threshold tunneling resistance** discovered experimentally. It is clearly independent of the magnitude and sign of bias voltage (see  $\rightarrow$  Fig 1b of Ref. [6]). Because  $E$ ,  $\rho_S$ , and  $\rho_T$  can be derived from independent experiments (e.g., surface diffusion) or first-principle computations, following Eq. (2), the threshold tunneling resistance can be **estimated or predicted quantitatively**.



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