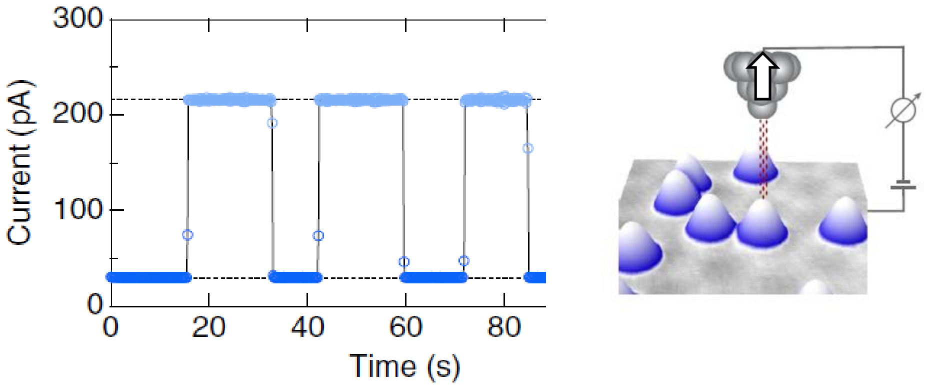
Atom spin polarization

Adapted from M. Pivetta *et al.*: PHYS. REV. X **10**, 031054 (2020); DOI: 10.1103/PhysRevX.10.031054

We are interested in measuring the spin polarization of a magnetic adatom, namely Dy. The spin polarization P is defined as $P = \frac{\rho(up)-\rho(down)}{\rho(up)+\rho(down)}$ where ρ is the density of states for up and down spins. To do that we perform a spin polarized STM experiment using a magnetic MnNi tip, which magnetization is assumed to be perpendicular to the surface and stable over time. We place the STM tip over a Dy atom adsorbed on a surface and we record the time dependence of the tunneling current measured with V_{bias} = 1 mV (with the feedback loop switched off, i.e. with a constant distance between tip and Dy). As shown in figure, the current is bi-stable and assumes two values i.e. I_{low} =30 pA and I_{high} =220 pA.

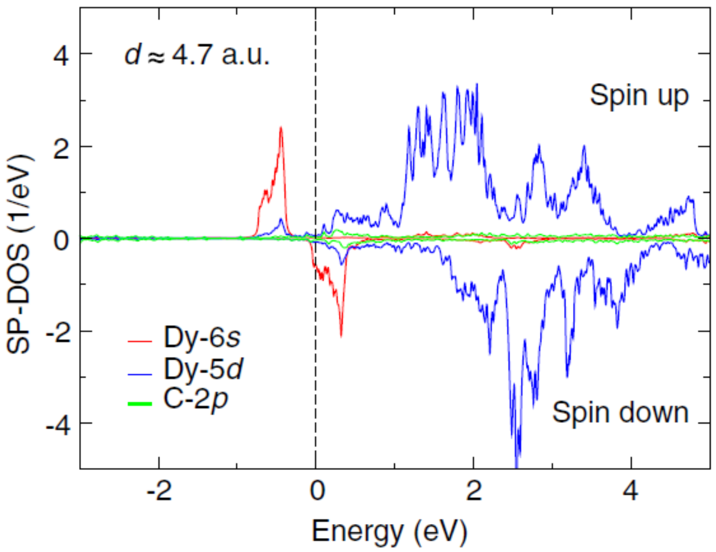


1) Why the current is bi-stable?

2) Demonstrate that the tunnel junction polarization $P_{jun} = \frac{I_{high}-I_{low}}{I_{high}+I_{low}} = P_{atom}\, P_{tip}$

3) Assuming a tip fully polarized, calculate the atom spin polarization

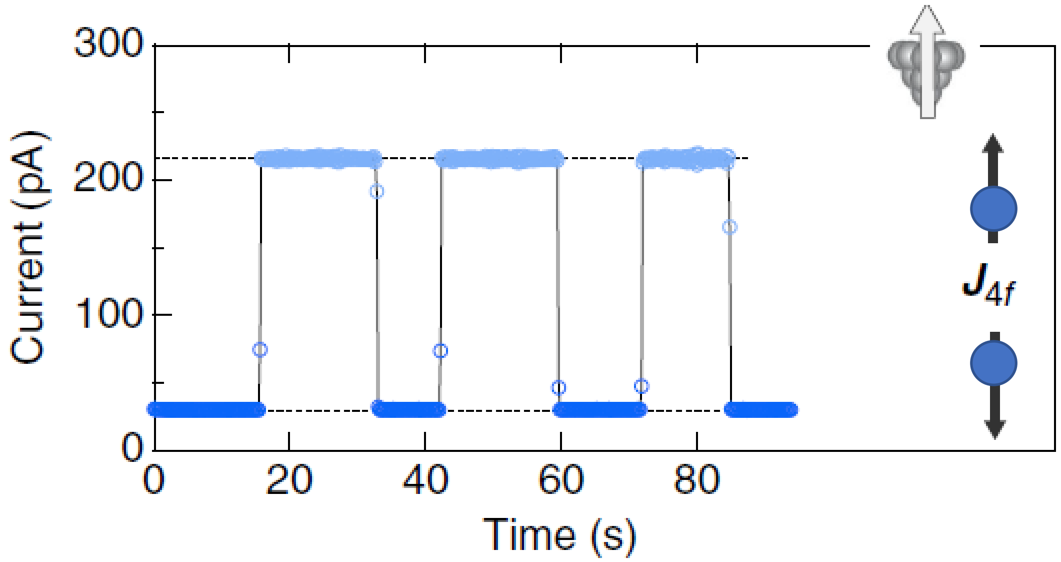
4) Theoretical calculations predict the spin polarized DOS shown in figure. Is this compatible with the experiment?



5) You switch on the feedback loop such that the tip-Dy distance stays constant during the measurement. What is the measured variation in tip-Dy distance that corresponds to the bi-stable current (observed with feedback off)? (Assume a work function Φ=4 eV)

Solution: Atom spin polarization

1) The atom magnetization is not stable over time, but it fluctuates between pointing up and down. Because the tip magnetization is stable over time and pointing for example up, the current is high (low) when the atom magnetization is pointing up (down), corresponding to parallel (antiparallel) alignment of tip and adatom magnetization



2) The tunneling current is given by $I \propto \rho_T \rho_A$

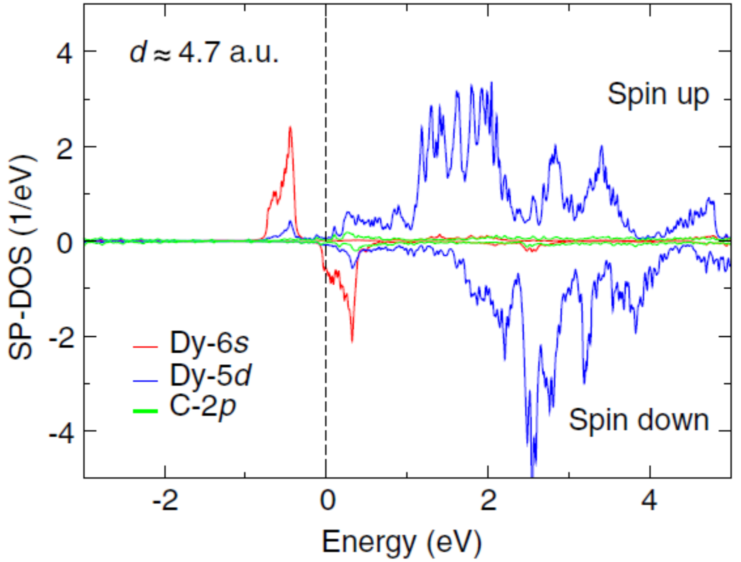
$$\mathrm{I}_{\mathrm{high}} = \rho_T(u)\rho_A(u) + \rho_T(d)\rho_A(d)$$

$$\mathrm{I}_{\mathrm{low}} = \rho_T(u)\rho_A(d) + \rho_T(d)\rho_A(u)$$

$$\frac{I_{high}-I_{low}}{I_{high}+I_{low}} = \frac{\rho_T(u)\rho_A(u)+\rho_T(d)\rho_A(d)-\rho_T(u)\rho_A(d)-\rho_T(d)\rho_A(u)}{\rho_T(u)\rho_A(u)+\rho_T(d)\rho_A(d)+\rho_T(u)\rho_A(d)+\rho_T(d)\rho_A(u)} = \frac{(\rho_T(u)-\rho_T(d))(\rho_A(u)-\rho_A(d))}{(\rho_T(u)+\rho_T(d))(\rho_A(u)+\rho_A(d))} = P_T\,P_A$$

3) From the values in figure we obtain P_{jun} = 76%. Because P_T = 100%, then P_{atom} = 76%

4) The tunneling current has been measured with a V_{bias} = 1 mV, meaning that we are measuring the atom spin polarization very close (1 mV) to Fermi level. The SP-DOS in figure show a strong asymmetry in the number of spin up and down at Fermi level, thus it supports the measurements



5) $I_{high} \propto e^{-2\kappa h_{high}}$

$$I_{low} \propto e^{-2\kappa h_{low}} \propto e^{-2\kappa(h_{high}+d)} \propto I_{high} e^{-2\kappa d}$$

$$d = -\frac{1}{2\kappa} ln\left(\frac{I_{low}}{I_{high}}\right) = -0.49\ ln\left(\frac{30}{210}\right) = 0.95\ \text{Å} \qquad 2\kappa = 1.025\sqrt{\Phi} = 2.05$$