Stabilization of Magnetic Moments in Nanoparticles by Magnetic Dipole-Dipole Interactions

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We have studied sub-monolayer films of spherical magnetic nanoparticles (Fe_3O_4) with a UHV VT AFM/STM. The particles, capped with oleic acid and having a narrow size distribution, were prepared by wet chemical methods and deposited by a simple drop-casting procedure on an HOPG substrate. Non-contact mode AFM measurements show that large islands of nanoparticles (single layer) were formed. MFM measurements with a magnetic tip scanning the surface at a distance of 50-60 nm show that on top of the islands the interactions are dominated by long-range attractive forces. This conclusion is supported by spectroscopy measurements that were taken on top of the islands (measuring the frequency shift as a function of the tip-sample distance). The attractive interactions can be understood in terms of the small coercivity of the magnetite particles and the high magnetic field of the tip. Spectroscopy measurements performed along the edges of the islands of nanoparticles, i.e. close to but significantly outside the islands, on the contrary clearly show repulsive interactions. Since the coercivity of the nanoparticles is far too small to explain these observations, we conclude that magnetic interactions between the nanoparticles are responsible for stabilizing the magnetic moments inside the nanoparticles. Apparently, on the edge of an island of nanoparticles, this stabilization is sufficiently strong to prevent the magnetic dipoles from reorienting themselves. On the basis of simple energy considerations, we propose that magnetic dipole-dipole interactions are responsible for the stabilization.