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Intergranular Exchange in Magnetic Nanostructures[1]

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Exchange interactions determine not only atomic-scale properties such as the Curie temperature but are also paramount to the realization of mesoscopic magnetism. Nanoscale exchange reflect the relativistic origin of magnetism. On an atomic scale, interatomic exchange tends to be much stronger than magnetic interactions, but the quadratic wave-vector dependence of the exchange energy makes magnetic interactions competitive on a nanoscale. The corresponding characteristic length scale is $a_o/\alpha = 7.252$ nm, where a_o is the Bohr radius and $\alpha = 1/137$ is Sommerfeld's fine structure constant. In homogeneous solids, the competing relativistic and nonrelativistic interactions determine, for example, the thickness of domain walls. In nanostructures, the situation is more complex, because mesoscopic and atomic exchange effects interfere with structural length scales. This is important in many areas of magnetism, such as permanent magnetism, soft magnetism, spin electronics, and magnetic recording. (For a recent review, see Skomski, J. Phys. CM, vol. 15, 2003, p. R841.) From an atomic point of view, local magnetic moments embedded in an itinerant electron gas are coupled by RKKY-type interactions, whose oscillatory period is determined by the Fermi wave vector k_F. First, RKKY interaction between embedded clusters or particles do not average to zero but actually *increase* with particle size. Second, the low carrier densities of semimetals and semiconductors yield small Fermi wave vectors and nanoscale oscillation periodicities. From a mesoscopic point of view, traditional random-anisotropy scaling amounts to a dimensionless coupling constant A/K_1R^2, but this expression fails to account for important real-structure features. For example, grain boundaries with reduced interatomic exchange give rise to a quasi-discontinuity of the magnetization, create a magnetization perturbation that extends far into the bulk, and modify scaling relations for the coercivity and other quantities. Additional complexity is due to finite-temperature excitations. Nanostructuring has little or no effect on the Curie temperature, but strongly affects the temperature dependence of the coercivity and the magnetization dynamics.

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