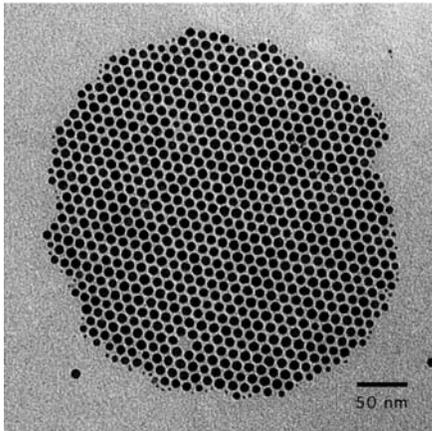


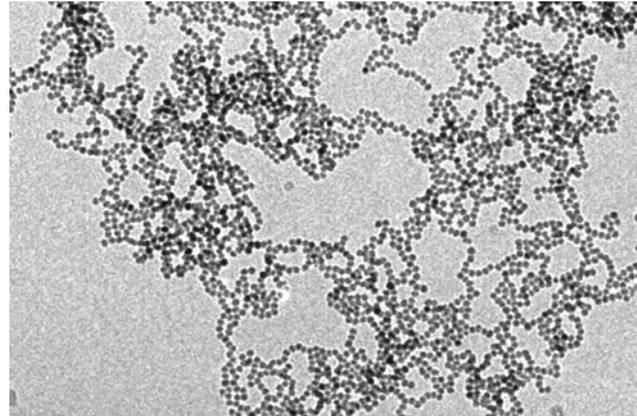
## Self-Assembly of Nanoparticle Structures

Sara A. Majetich  
Physics Department  
Carnegie Mellon University, Pittsburgh, PA 15213-3890

Important issues related to self-assembly include understanding what kind of magnetically interesting structures can be formed, and what are the forces responsible. The forces between particles, and between particles and a surface within a fluid are understood on the micron scale but not on the nanoscale, where for example the notion of an electrostatic double layer surrounding a particle breaks down. There is a need for both experiments and theoretical modeling in order to refine the understanding of these forces, which can then be exploited. Important goals will be the self-assembly of defect-free nanoparticle arrays over macroscopic length scales, which could be useful for data storage media, and the formation of more complex structures, which might be needed in biomedical applications. The ability to study the dynamics of self-assembly will be critical to developing this understanding. Electrophoretic deposition of nanoparticles [1] will enable the nucleation, growth, and melting of nanoparticle arrays to be driven using in an AC electric fields, and SAXS techniques to assess the structural ordering length scale [2].



(a)



(b)

Figure X. (a) TEM image of 9 nm Co nanoparticles in an array self-assembled from a hexane dispersion. (b) TEM image of 10 nm  $\text{Fe}_3\text{O}_4$  nanoparticles in a magnetic gel self-assembled from an aqueous dispersion. The forces guiding self-assembly on this length scale are not now well-enough understood to know how to make arrays of magnetic particles like (a) from aqueous dispersions, even though this could be useful for nanoscale bioassays.

## Understanding and Controlling the Magnetic Coupling of Nanoparticles

With standard surfactant coatings, the spacing between nanoparticles in self-assembled arrays is large enough that magnetostatic interactions dominate exchange. By changing the particle size and spacing, purely magnetostatic ferromagnetism has been observed in these structures [2]. The length scale of the structural ordering is also shown to be important; with a coherence length below  $\sim 300$  nm, the nanoparticle assemblies show spin glass-like behavior, while highly ordered structures act more like bulk ferromagnets [3]. An important research goal is to be able to correlate the structural order and the nanoscale magnetization. SANS results show evidence of multiparticle magnetic correlations, but because large samples are needed these experiments cannot be done on arrays with small numbers of layers. The unusual preference for arrays with an odd number of layers [4] might be understood with information about the layer-by-layer magnetization pattern. This capability would also be useful in evaluating the degree of exchange coupling of nanoparticles, either to each other or to other magnetic structures in nanoscale devices. Here spatial resolution on a length scale comparable to the particle dimensions is desired, as well as the ability to study dynamics on a 100 ps+ time scale. This technique would be extremely useful for nanoscale spintronics, and would also enable a clear differentiation of 0D, 1D, and 2D behavior in the fundamental physics of nanomagnetism.

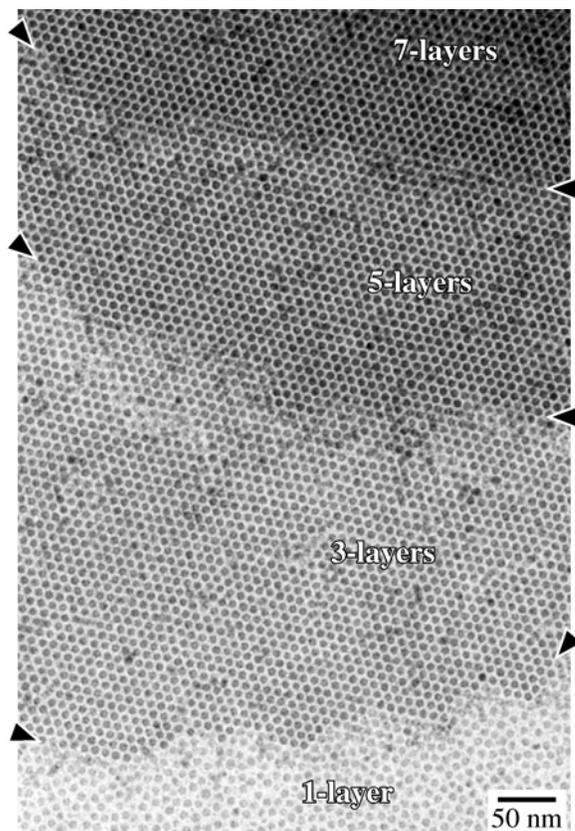


Fig. XX. Array of 6 nm Fe nanoparticles showing an hcp lattice and a preference for an odd number of layers. (Figure from Ref. 4.)

1. M. Giersig and P. Mulvaney, *J. Phys. Chem.* **97**, 6334-6336 (1993).
2. D. Farrell, Y. Ding, S. A. Majetich, C. Sanchez-Hanke, and C. C. Kao, *J. Appl. Phys.* **95**, 6636 (2004).
3. D. Farrell, Y. Cheng, Y. Ding, Saeki Yamamuro, C. Sanchez-Hanke, C.-C. Kao, and S. A. Majetich, *J. Mag. Mag. Mater.* (in press, 2004).
4. S. Yamamuro, D. Farrell, and S. A. Majetich, *Phys. Rev. B* **65**, 224431 (2002).