*Beyond Element Specific Magnetism: Magnetic Spectroscopy in the Diffraction Channel*

Daniel Haskel (Argonne National Laboratory)

Inhomogeneities are central to the field of nanomagnetism. Inhomogeneities can be driven by competing interactions at the nanoscale, as is the case of CMR and high Tc superconductors, or artificially introduced through tailored synthesis, as is the case of nanocomposites. Characterization of inhomogeneous systems requires measurements of the chemical, structural and magnetic properties on a phase-specific way. Since x-ray diffraction can isolate coexisting phases by coupling to their different crystal structures, it is desirable to combine resonant x-ray diffraction with nano-beams to image inhomogeneities in real-space by diffraction contrast imaging. Adding circularly polarized x-rays allows for diffraction-contrast, real-space imaging, of structure and magnetic phases to be done simultaneously (by adding and subtracting scattered intensities for opposite helicities of light). The ability to probe chemical, structural and magnetic correlations in a phase-specific way and simultaneously in the same measurement is a key asset of synchrotron based techniques. Resonances add invaluable element-specific information.

Two important areas of research should benefit from these developments. One is that of intrinsically inhomogeneous CMR manganites and high Tc superconductors. In CMR ferromagnetic, metallic regions coexist with anti-ferromagnetic, insulating regions at the nanoscale. In high Tc superconductors nanoscale inhomogeneities in all electronic, magnetic and structural degrees of freedom have been observed. Advanced characterization tools should advanced the quest to determine if these inhomogeneities play an active or passive role in the mechanism of high Tc.
Another important area of research is that of magnetic nanocomposites. One example is that of hard and soft magnetic phases mixed at the nanoscale in the quest to achieve improved permanent magnetic properties. Phase- and element-specific magnetic/chemical/structural characterization should allow detailed investigations of the relevant interactions and guide synthesis efforts.

Finally, site-specificity, in addition to element-specificity, is desirable for understanding the effect of inequivalent atomic environments on magnetic properties. CMR, High Tc, Nd2Fe14B, Sm2Co7, all exhibit inequivalent crystal sites (Mn3+ and Mn4+ in CMR, Cu(1) and Cu(2) in CuO2 planes and chains of high Tc, 2 Nd sites in NdFeB, etc). Resonant diffraction can separate the magnetic contributions of these inequivalent sites.

Figure 1: Coexisting Nd crystalline environments in $Nd_2Fe_{14}B$ permanent magnet (left). Site-specific Nd hysteresis loops (right). The crystalline environment at the Nd(1) site results in its higher stability against demagnetizing fields.

Figure 2: (Left) Schematic of exchange-coupled nanocomposite with hard and soft magnetic phases. Magnetic contributions from Fe atoms in either phase can be separated by  selecting appropriate Bragg diffraction conditions (right) and using circularly polarized x-rays at Fe resonance to couple to their magnetic moments.