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X-ray Magnetic Circular Dichroism under high magnetic field

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Discovery of X-ray Magnetic Circualr Dichroism (XMCD) ushered in a new era of magnetism research with objectives that previously would have been unattainable. Because of their inherent element and orbital specificity and ability to probe extremely small sample volumes, these spectroscopies have become an indispensable experimental method in studying the magnetism of complex materials. Moreover, derivation of magneto-optical sum rules has greatly strengthened the XMCD, offering a unique capability to deduce from the experimental spectra the orbital and spin contributions to the total magnetic moment carried by the absorbing atom.

So far, XMCD has been extensively used to investigate mainly ferro- or ferromagnetic materials, and only very few studies have been performed on paramagnetic compounds. This is partly because a sufficiently high magnetic field for magnetizing paramagnetic or antiferromagnetic materials was not available at synchrotron facilities. However, a high magnetic field could be the essential parameter to explore new phenomena in materials with important magnetic degrees of freedom. In order to achieve this goal, the external magnetic field has to be comparable with magnitude of the basic magnetic interaction energies, typically above 10 T.

In this contribution we describe recent advances in magnetism research using a high field XMCD station that has been installed at the ESRF beamline ID12 [1]. This station is based on a high vacuum ($< 10^{-7}$ mbar) 52mm cold bore solenoid producing a horizontal magnetic field of 17 Tesla. The power supply is specifically designed to ensure a fast sweep ramping of 2 Tesla/minute. The field homogeneity is better than 0.1% in a 10 mm diameter spherical volume. What is important for XMCD measurements is that for opposite directions of the field the relative difference in amplitudes is smaller than $5x10^{-5}$. The Helium continuous flow cryostat was built in-house to be ”amagnetic”. The absolute value of magnetic susceptibility of parts exposed to the magnetic field, in the zone where it is above 1 Tesla, is of the order of 10^{-5} or less. The temperature on the sample can be set in the range 2.05 K to 325 K with a stability $\Delta T/T < 10^{-3}$. All spectra are measured using total fluorescence yield detection mode using a Si photodiode mounted on a liquid nitrogen shield of the magnet.

This new high field experimental station becomes a unique experimental platform for basic research on magnetism and its performances are illustrated with few selected examples.

Spin Fluctuations of Paramagnetic Rh Clusters [2].

The magnetic moment of Rh clusters with 1.6 nm average diameter embedded in an Al_2O_3 matrix was found to vary linearly with the applied magnetic field. At 2.3 K and under 17 T, the spin magnetic moment amounts to 0.067(2) μ_B per Rh atom. The orbital moment does not exceed 2% of the spin moment. The field induced magnetization was shown to be strongly temperature dependent. This observation is in agreement with a theoretical prediction that in itinerant electron systems, close to the onset of magnetism, the renormalization of the magnetic susceptibility by electron correlations, leads to a Curie-like behavior.

Paramagnetism of Gold Nanoparticles Deposited on a Sulfolobus acidocaldarius S Layer [3].

Magnetic properties of Au nanoparticles deposited on an archaeal S layer studied with XMCD and SQUID magnetometries demonstrate that they are strongly paramagnetic, without any indication of magnetic blocking down to 16 mK. The average magnetic moment per particle is Mpart = 2.36 μ_B. This contribution originates at the particle’s Au 5d band, in which an increased number of holes with respect to the bulk value is observed. The magnetic moment per Au atom is 25 times larger than any measured in other Au nanoparticles.

Quantification of the magnetic exchange via element-selective high-field magnetometry: Co-doped ZnO films [4].

The element specific magnetization curves for 5%, 10%, and 15% Co-doped ZnO epitaxial films with high crystalline perfection have been measured using Co K-edge XMCD. The XMCD(*H*) curves do not saturate up to 17 T evidencing antiferromagnetic exchange between neighboring Co dopant atoms. Angular dependence of XMCD(*H*) in combination with theoretical calculations allow both the next-neighbor exchange *J* and the single ion anisotropy *D* to be determined quantitatively. For 5% and 10% Co doping, *J* = 15 K and *D* = 3 K, whereas for 15% Co doping, these values are reduced to 10 and 2 K, respectively.

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