ESRF	**Experiment title:** **Magnetic hysteresis of Gd and Fe moments in GdHx/Fe multilayers studied by hard X-ray magnetic circular dichroism**	**Experiment number**: HE-1199
Beamline: ID24	**Date of experiment**: from: 19 September 2001 to: 25 September 2001	**Date of report**: 25. 02. 2001
Shifts: 21	**Local contact(s)**: Dr. Olivier MATHON	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

*LEUENBERGER, Frank, *LUEDERS, Ulrike, and *FELSCH, Wolfgang,
I. Physikalisches Institut, Universität Göttingen, Germany;

*NEISIUS, Thomas,
ESRF, Grenoble, France.

Report:

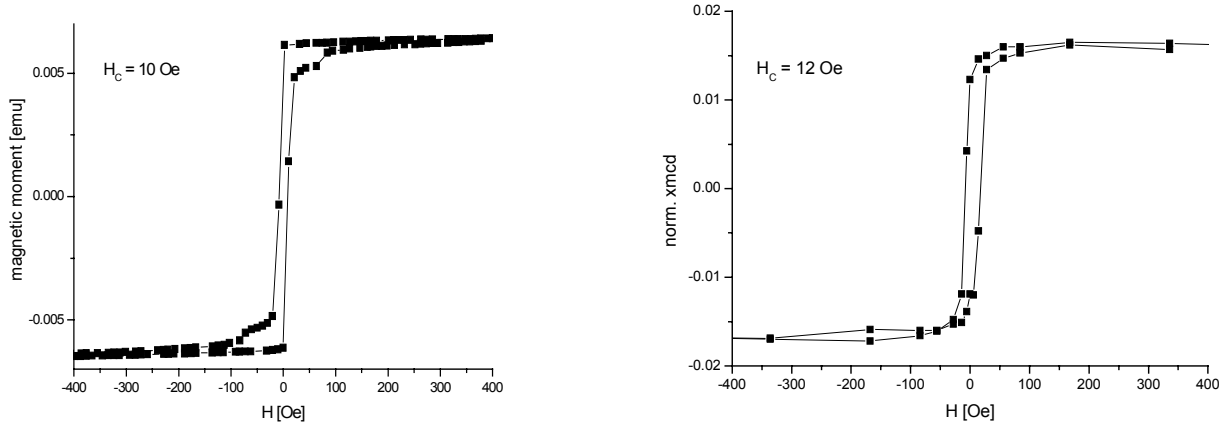
[*General remark:* After the initial setup of the experiment severe technical problems were encountered with the (at that time) new cryostat of the beamline. Blocking of a capillary did not allow to cool down to liquid helium temperature which was a prerequisite of the project. In spite of great efforts of the local contact and the technical experts of the ESRF the problem could not be solved in due time. Therefore, the available continuous-flow cryostat was installed. This limited the lowest temperature to about 13 K (not sufficiently below the Néel temperature of the GdH_x sublayers) and led to vibration noise. Because of these problems and because of a considerable loss of time, only a few measurements could be performed. The proposal will be redeposited in its original form].

Multilayers $[GdH_x/Fe]\times n$ are interesting for the following reasons: As all rare earth metals Gd forms hydrides GdH_x [1]. At $x\approx 2.8$ a metal-to-insulator transition occurs where the metal 5d-state-derived conduction bands are depopulated in favour of low-lying hydrogen-derived valence bands and an energy gap of ~2 eV is formed. Metallic GdH_2 is paramagnetic down to low temperature and orders antiferromagnetically at T_N=20 K. Measurements of the macroscopic magnetisation of the multilayers suggest the presence of a non-collinear spin structure [2]. Experiments of X-ray magnetic circular dichroism (XMCD) we performed at LURE [3] reveal that Fe induces ferromagnetic order in $GdH_{\sim 2}$ above T_N on a length scale of ~15 Å near the interfaces. The average Gd moment is oriented antiparallel to the Fe moment. Magnetic polarisation of Gd is mediated by its 5d band states via hybridisation with the spin-split 3d states of Fe and 5d-4f exchange interaction, similar as in rare-earth transition-metal compounds [4]. With decreasing temperature, on crossing T_N, the XMCD signals at the Gd-$L_{2,3}$ absorption edges that probe the 5d-projected magnetic moment are more and more reduced. In insulating $GdH_{\sim 3}$ sublayers antiferromagnetic oder is considerably diminished when their thickness t_{GdH3} exceeds a threshold: while T_N remains near 20 K for t_{GdH3} = 25 Å as in the metallic phase it is below 5 K at t_{GdH3} = 50 Å. The most remarkable result is, however, that in the insulating phase of the hydride above T_N the Fe-induced magnetic 5d polarisation does not vanish. The amplitude of the Gd-$L_{2,3}$ XMCD signals is decreased by a factor of about two and the decay length in to the $GdH_{\sim 3}$ layers is esentially the same as in metallic $GdH_{\sim 2}$. This points to the introduction of metal-like 5d states into the energy gap near the interfaces of the insulating $GdH_{\sim 3}$ sublayers [3], similarly as in Fe/Ge/Fe and Fe/GaAs/Fe tunnelling structures [5].

In view of the limited time available for the present magnetic hysteresis experiments we decided to concentrate on XMCD measurements at the Gd-L_2 edge. In fact, due to the small Fe-K edge XMCD data collection at that threshold would have required to many acquisitions which was not possible in the special circumstances. Furthermore, we were able to measure on one sample only, the multilayer [GdH_x(50Å)/Fe(16)]×n, for metallic and insulating GdH_x, at temperatures between 16 and 35 K. In the figure below, we compare the hysteresis loop of the multilayer magnetisation for metallic $GdH_{\sim 2}$ measured with a vibrating-sample magnetometer (VSM) with that of the Gd-L_2 XMCD amplitude related to the Gd-5d magnetisation, both at 15 K, i.e. below the Néel temperature T_N of the hydride. While the coercive field H_C is essentially the same the shape of the two curves is distinctly different: Coming from high field H_A the VSM curve switches abruptly at H_C and then gradually approches the reversed magnetisation state as H_A is increased to more negative values. In contrast, the XMCD loop mirrors a more gradual magnetisation reversal for both of its branches. This indicates that the two techniques probe magnetisation reversal in different parts of the multilayers: the VSM data represent the behaviour of the volume, while the XMCD signals are related to the Gd ions at the interfaces. The characteristic difference in shape was observed essentially at all temperatures covered here and, in particular, was preserved in the insulating phase of GdH_x, x≈3. However, the coercive field increased by about a factor of two on crossing the metal-insulator transition, both for the VSM and XMCD loop.

To conclude, we believe that it will be interesting to resume the experiments and to perform additional measurements of XMCD as proposed in our original proposal: at lower temperatures using the new cryostat, also on the Fe-K edge and on multilayers with different sublayer thicknesses. It will be interesting to also perform experiments on field-cooled samples where exchange bias leads to a shift of the VSM hysteresis curves.

[1] P. Vajda in '*Handbook on the Physics and Chemistry of Rare Earths*', Vol. 20, K.A. Gschneidner and L. Eyring Eds., (Elsevier Science 1995).
[2] U. Lueders, Diplomarbeit, Universität Göttingen, 2001.
[3] M. Muenzenberg, Dissertation (PhD thesis), Universitaet Goettingen 2000, (http://webdoc.sub.gwdg.de/diss/2001/muenzenberg/)
[4] M.S.S. Brooks and B. Johansson in '*Handbook of Magnetic Materials'*, Vol. 7, p. 139, K.H.J. Buschow Ed., (North Holland, Amsterdam 1993).
[5] W. H. Butler et al., J. Appl. Phys. **81**, 5518 (1997).



Magnetisation curves of a multilayer [$GdH_{\sim 2}$(50Å)/Fe(16)]×n with metallic $GdH_{\sim 2}$ at 15 K, measured with a VSM (left) and by magnetic circular dichroism at the L_2 edge of Gd (right).