| ESRF | **Experiment title:** **Spin-resolved magnetic circular dichroism in Co 2p core level photoemission** | **Experiment number:** HE 360/361 |
|---|---|---|
| **Beamline:** 26 | **Date of experiment:** from: 27.3.1998 to: 13.4.1998 | **Date of report:** **26.8.1998** |
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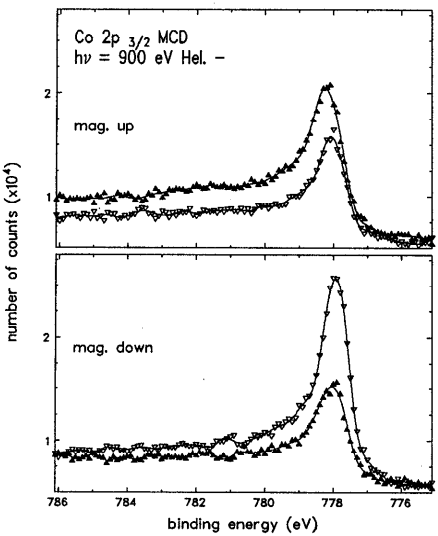
Report:

In the accompanying report [l] we discussed the results of our spin-resolved photoemission study of the Fe 2p level using circularly polarized light at beamline 26. The Fe results showed a dramatic dependence of the spin-resolved spectra on the helicity of the light used for excitation. In particular, the spin polarization integrated over the photoemission peak was strongly affected by reversing the light helicity. In one case this led to a net *majority* spin polarization in the photoemission spectrum, while so far in all experimental investigations a minority spin polarization has been observed. In the same run we have also investigated the 2p spectra of Co and Ni. In this report we concentrate on the results for Co which show a similar behaviour as described in our report for Fe, i.e. a strong dependence of the spin resolved spectra on magnetization for one light helicity.

The experiments were performed at beamline 26 of the ESRF, using our spin-resolving photoelectron spectrometer. Spin analysis was carried out by very low energy scattering off a magnetized Fe(l00) surface grown in a dedicated chamber epitaxially on Ag(100). The Ag substrate and Fe film grown on it were characterized by measuring the reflectivity for electrons with kinetic energies ranging from 0 to 40 eV. These electrons were photoelectrons from the sample, which had passed the photoelectron spectrometer. For calibration purposes we used secondary electrons whose spin polarization is well known. The sample was a thin Co film grown on W(110). This substrate supports growth of Co in hcp structure. Due to the thin film nature of the sample the easy axis of magnetization was in the film plane. The Co film was magnetized by current pulses through a coreless coil close to the sample, and all spectra were taken in remanence. Absorption spectra taken by total yield led to a Co moment close to the bulk moment of Co.

Fig. 1 shows spin resolved Co $2p_{3/2}$ spectra excited by circularly polarized light of negative helicity.

As the magnetic moment of Co is smaller than that of Fe, the exchange splitting between the sublevels of the j=3/2 final state is smaller, and the photoemission lines show less fine structure. For magnetization down, we find a large minority spin polarization of -40%, with the peaks at essentially the same binding energy. For magnetization up, we find a majority spin polarization of +24%. A very unusual finding is the observation that the majority spin peak appears at higher binding energy than the minority spin one. The spin polarization in the high binding energy region is minority for magnetization down and majority for magnetization up. Again, the commonly observed behaviour is a majority spin polarization in the region outside the photoemission peaks. All these unusual findings are consistent with the results for Fe for this light helicity.




A possible explanation of the observed effect is connected to the occurence of circular dichroism in angle-resolved photoemission from non-magnetic solids [2]. If the sample has an intrinsic symmetry axis, this can form a chiral geometry when the helicity of the light and electron emission direction are taken into account, such that the emission intensity in a given direction changes when the light helicity is reversed. If magnetization is introduced, this will lead to a situation where the spectra are not equivalent when both magnetization and light helicity are reversed. For a highly symmetric sample as considered here ( and in the experiment on Fe(ll0) described in the accompanying report) this situation can only arise for non-normal emission. Preliminary calculations [2] display in some respects a trend as observed in experiment, however, the trend is much weaker. Furthermore, one would expect then that the spin-integrated dichroism and in fact the spectra averaged over both magnetizations taken with different light helicities should show significant differences. This is not the case, so it is unclear at present whether the suggested picture is adequate.

As a result of the large change of the spin-resolved spectra with helicity/magnetization reversal, the spin-polarized spectra representing exchange or spin-orbit polarizations are different for the different light helicities. So far all theories lead to the result, that the spectra should be unchanged when both light helicity and sample magnetization are reversed. To clarify the origin of the observed effects, additional experiments in different experimental geometries which could not be performed in this run as well as theoretical studies are desirable.

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[l] C. Bethke et al., previous report.
[2] J. Henk, J. El. Spec. Rel. Phen., in print; and private communication.

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**Report:**

We have studied circular dichroism in 2p excitations of Fe and Co by high resolution spin-resolved core level photoemission. The spin-resolved spectra show strong changes when both helicity and sample magnetization are reversed. This is caused by the interplay between exchange and spin-orbit induced spin polarizations.

Magnetic dichroism in core level spectroscopy has become a widely used technique to investigate magnetic properties in an element-specific way. Phenomenologically speaking, magnetic dichroism occurs when the magnetization of a ferromagnetic sample is collinear with the spin polarization which is induced by *spin-orbit* interaction. This spin polarization is a result of spin-orbit interaction since photon excitation never directly implies a selection rule for the spin, only for the orbital moment and its projection on a quantization axis defined by the experimental conditions. On the other hand, photoelectrons ejected from core levels of magnetically ordered samples are spin polarized due to the *exchange* interaction between the core hole spin and the spin moment of the valence shell under conditions where there is no dichroism. This polarization is always collinear with the sample magnetization. Therefore, the condition for magnetic dichroism can also be stated by saying that magnetic dichroism occurs if exchange and spin-orbit polarization are collinear, or if at least the projection of one on the other is finite. Therefore, it is desirable to investigate magnetic dichroism by spin-resolved photoemission in order to elucidate the mutual influence of these two mechanisms generating spin polarization.

Fig. la shows spin-resolved Fe 2p photoemission spectra obtained with $\sigma+$ circularly polarized light. For both sample magnetizations, one finds the minority spin spectrum at lower binding energy than the majority spin spectrum. Also, the polarization of the peak is of minority type in both cases. This is qualitatively consistent with the results found in linear dichroism [l]. The peaks show some fine structure, which will be

discussed elsewhere. Fig. lb shows the same set of spectra obtained with light of opposite helicity. We expect to find the same set of spectra, if also the sample magnetization is reversed. However, the experimental result is quite different from that. For the σ–/mag. down case, we find an overall minority polarization, however the binding energies of the the two spectra are virtually identical. For the σ–/mag. up case, the minority and majority peaks have different binding energies as in the case for σ+ light, however, the intensities have changes drastically such that there is now a *majority* polarization. The finding of an overall *majority* spin polarization in a core level photoemission spectrum has not been reported before.

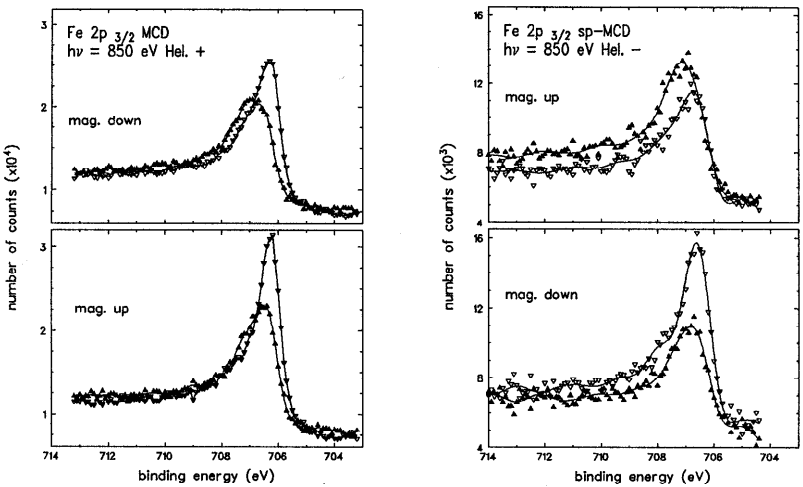


Fig. 1 Spin-resolved Fe 2p3/2 photoemission spetcra excited by circularly polarized light for Fe( 1l0)/W( 110).

The experimental results are not yet fully understood. As mentioned above, spin-orbit interaction causes a spin polarization even in non-magnetic samples. The properties of this polarization have been extensively studied, e.g. for p levels of noble gases. From these studies it is known that the *so-polarization* depends on the angle between light incidence and electron emission, with finite components along all three directions. For emission along the direction of light propagation complete polarization along this direction is observed, such that the other components vanish in this special case. For arbitrary emission, however, the spin polarization in the scattering plane, but normal to the light polarization, as well as normal to the scattering plane are finite. Reversing the light helicity changes the two components of the *so-polarization* which are lying in the scattering plane, i.e. the polar and longitudinal ones. However, the component normal the scattering plane, which we call transverse, is not reversed. We ascribe the observed effect to the interaction of this spin polarization component with the exchange induced effect. An interaction between exchange and spin-orbit induced polarization was suggested by Tamura et al. [2]. in a theoretical study of linear magnetic dichroism in transverse geometry, which in the spin-integrated case measures the same spectrum as circular dichroism. The effect should be observable if a geometry is chosen where the spin polarizations incurred by the two mechanisms - exchange and spin-orbit - are perpendicular to each other. This is partially the case in our experiment for 45” light incidence and normal emission. Analogous results were observed for Co 2p photoemission. In our report on those experiments we discuss an alternative mechanism for the origin of the observed effect. This work was supported by the BMBF under grant no. 05 621 PFA 7.

[l] F.U. Hillebrecht, Ch. Roth, H.B. Rose, W.G. Park, et al., Phys. Rev. B 53, 12 182 (1996).
[2] E. Tamura, G.D. Waddill, J.G. Tobin, and P.A. Sterne, Phys. Rev. Lett. 73, 1533 (1994).