3

X-RAY MAGNETIC CIRCULAR DICHROISM

F. BAUDELET
Synchrotron SOLEIL, Gif-sur-Yvette, France

X-ray Magnetic Circular Dichroism (XMCD) is an element-specific as well as a symmetry selective probe of microscopic magnetic properties. Using different X-ray energy domains, it is possible to extract information on the spin and orbital polarization of the conduction band or localized orbitals, which are responsible for itinerant or localized magnetism respectively. In the soft X-ray range, atomic calculations reproduce quantitatively the XMCD signal, providing a powerful element-selective magnetometry. In the hard X-ray domain, the theoretical description based on band calculations is more difficult, but magnetic information is currently extracted from XMCD signals.

1. INTRODUCTION

X-ray Magnetic Circular Dichroism is a technique that uses the polarization properties of X-rays to probe microscopic magnetism. Intense linearly or circularly polarized X-rays produced in synchrotron sources have enabled new probes of the magnetic structure of materials to be developed. Magnetic resonant scattering and magnetic X-ray dichroism use linearly or circularly polarized photons [1] with energy near an absorption edge. X-ray Magnetic Circular Dichroism is the difference between left and right circularly polarized X-ray absorption cross-section of a ferromagnetic or ferrimagnetic material.

The interest of using circular polarized light comes from the fact that the magnetic absorption cross-section is directly proportional to $\langle \boldsymbol{M} \rangle$, the mean value of the macroscopic magnetic moment. Two models generally describe magnetism in metals and alloys:

F. Hippert et al. (eds.), Neutron and X-ray Spectroscopy, 103–130.

- The localized model where the electrons responsible for the magnetic moment are quasi-atomic. This model will describe the magnetism of the 4f orbitals in rare earth compounds and d orbitals in some transition metal compounds. These orbitals are probed by "soft X-ray" absorption (< 3 keV).
- The itinerant model where the spin-polarized electrons are considered to be delocalized. In this case the exchange and correlation interactions yield magnetism because of the different filling of the spin-up and spin-down conduction bands. These conduction bands are probed by absorption of "hard X-rays". In that range (2 ⟶ 20 keV) the final states (or the projection of the final states) of X-ray absorption spectroscopy are of *p* symmetry for 3*d* transition metals and of 5*d* symmetry for 4*f* rare earths.

3*d* bands of 3*d* transition metal are an intermediate case. They are usually described by rigid band models with two sub-bands of opposite spin direction, split by exchange energy. 3*d* states are of course delocalized states. Nevertheless the $L_{II\text{-}III}$ absorption edges of 3*d* transition metals (2*p* ⟶ 3*d* transition) are usually described in the literature with good accuracy by atomic models (see section 5).

In the hard and soft energy ranges circular magnetic X-ray dichroism is a selective probe of the element for both the itinerant and localized models of magnetism. The selectivity concerns both the nature of the probed element and the symmetry of the probed band.

In this lecture we will focus on the origin of the XMCD effect in core-hole spectroscopy. Readers not familiar with core-hole spectroscopy can, for example, read the related chapter in reference **[2]**.

2. ORIGINS OF MAGNETIC CIRCULAR DICHROISM

2.1. THEORETICAL ASPECTS ROLE OF THE SPIN-ORBIT COUPLING

The origin of magnetic dichroism can be found in the photon-matter interaction process. In X-ray absorption it is not directly due to the interaction between the transverse field ***B*** of the photon and the spin of the electrons but rather to the interaction between the spin and the orbit, which couples the spin and real space.

Quantum field theory is not mandatory to describe correctly the X-ray absorption process. A semi-classical model may be used, where the atom is quantified and the electromagnetic field of the photons is described by Maxwell's equations.