At the frontier between ultrafast optics and magnetism

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Femtomagnetism is a research field that combines magnetism and optics, using femtosecond laser pulses [1]. The main goals are to explore the fundamental mechanisms occurring after short light pulses interact either with electronic spins in condensed phase systems like ferromagnetic metals or with isolated spins. The outcomes are important in several application sectors such as fast recording in magnetic media, magneto-optical sensors, picosecond magneto-acoustics, spintronic systems controlled optically. This lecture reviews several aspects of Femtomagnetism starting from elementary concepts of light matter interaction in magnetic systems [2]. These concepts are used to exemplify a variety of dynamical processes such as the time dependent heating of spins to the Curie temperature [3], the precession and damping of the magnetization [4], the coupling between acoustic pulses and spins [5] or the temporal regime of coherent spin-photon interaction [6].

First we consider the well-known Kerr and Faraday effects that lead to a change of light polarization in a material placed in an external magnetic field. By examining the origin of this effect we show the important role of two processes: the spin-orbit interaction and the exchange interaction. We then consider the case when the electromagnetic field is short enough (femtosecond laser pulses) so that the magnetization dynamics can be decomposed in three main steps. Initially the motion of atomic nuclei or lattice dynamics can be discarded. It leads to the concept of ultrafast demagnetization and the associated raise of spins temperature up to the Curie point, depending on the light pulse intensity. This first process of *light induced demagnetization* occurs in a few hundreds of femtoseconds and involves the spin-orbit and exchange interactions [7]. During the second step the lattice dynamics is important. A *cooling of the spins* accompanied by a partial re-magnetization takes place, during a few picoseconds, due to the interaction between spins and phonons. We then show that the magnetic angular momentum, which direction has been driven out of equilibrium during the heating of the spins, precesses around the effective magnetic field and is further damped with a few hundreds of picoseconds. This third step, named *optically induced magnetic precession*, is the analogous of the ferromagnetic resonance (FMR) except that it is induced by light pulses and observed directly in the time domain while in FMR it is usually induced by high frequency magnetic fields and observed in the frequency domain. Several concrete examples are considered during these three steps.

We finish by coming back on the initial time when the light pulses interact with the spins. It is important for two reasons. Firstly, a coherent interaction between light and spins is present and is due to the spin-orbit interaction. A simple approach, based on the one electron Dirac equation in the presence of an electromagnetic field, is used to understand the main facets of this coherent interaction. It is shown to be important for diffractive magneto-optical devices. Secondly, we extrapolate the coherent regime to the case of spins interacting with a very large laser field during which the relativistic electron dynamics is important.

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