Twisted Spin Waves

In 1851, the French scientist Hippolyte Fizeau carried out an experiment where he measured the speed with which light propagates in pipes filled with flowing water. He observed that the light travelling through the moving medium behaves as if it is dragged along by the medium. The magnitude of the effect could only be satisfactorily explained after Albert Einstein introduced his special theory of relativity. Fizeau’s experiment thus provided important support for special relativity.

A similar effect, but with spin waves in a bi-dimensional electron system has been recently discovered by members of the team Nanostructures and quantum systems of the INSP, in collaboration with theoricians of the University of Missouri and the University of York.

Spin waves are studied since a decade in this team. Generally, spin waves are hosted by insulating ferromagnets. Here, they have been studied in a conducting magnetic bi-dimensional electron system: an electron gas confined in a semi-magnetic quantum well. An important property is the structural asymmetry which provides a coupling between the motion of the electrons and their spin. This spin-orbit coupling arises from special relativity. Hence, in this system, three protagonists interplay: the in-plane free motion, the Coulomb-exchange interaction between electrons which builds the spin waves and the spin-orbit coupling. The later can be described by an effective magnetic field operating in the electron’s reference frame. As each electron is sensitive to its own effective magnetic field only, and as this field depends on the electron momentum’s direction and amplitude, we can anticipate that a spin wave, where electrons precess collectively with a deterministic phase, would be quickly destroyed.

However, this naïve picture does not account for the relativistic origin of the spin-orbit coupling. Indeed, in a magnetic conductor, the spin precession coexists with electron motion, oscillating at the same frequency than the spin wave. The spin-orbit coupling converts this motion into spin-currents, mostly perpendicular to the spin-wave wave-vector. This oscillating spin-current lies in the spin-wave reference frame. Thus, contrary to an oscillating magnetic field which would be applied in the laboratory reference frame, this relative spin currents twist the spin-wave phase and not its frequency. Consequently, the spin-wave propagation direction is modified similarly to the Fizeau’s experiment, except that here, the wave propagates in a moving space which belongs to the spin Hilbert space.
Figure 1

a. Spin wave without spin-orbit coupling. Top plane: the Raman process probes the spin wave with wave-vector \( q \) corresponding to a collective spin precession in the quantum well plane, bottom plane: oscillating motion in the momentum space. Fermi circles of majority and minority spins are oppositely shifted.

b. Spin wave with spin-orbit coupling. An oscillating spin-current \( J^z \) appears. The later twist the phases parallel to the direction \( q_\theta \) as if the spin wave was propagating in a moving medium (materialized through the blue wave).

This effect has been evidenced by magneto-Raman spectroscopy, an efficient experimental technique to determine the spin-wave dispersion in electron gases.

As the researchers showed, through this ‘twist’ effect it is possible to control the spin wave propagation, making them go forward, backward or sideways. Controlling spin waves is currently a hot topic in spintronics. The spin-wave twist effect thus may open up new and efficient ways of using spin to encode and transmit information at the nanoscale, like, for example, building lenses or routing devices for spin waves.

Reference

"Spin orbit twisted spin waves : group velocity control"
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