# Spin dynamics and spin-orbit interactions in magnetic nano-structures

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Abstract

We study the influence of the interplay of spin-orbit interactions and interactions on the dynamics of magnetic structures, such as domain walls and spin currents in alloys different magnetically ordered structures: ferromagnets, antiferromagnets and more complicated magnetic order. We study the interaction of the magnetic order parameter with phonon and photon fields in the search for strong coupling phenomena.

## 1. Research Objectives

Spin-orbit interactions constitute the microscopic mechanism for many key effects in both pure and applied magnetism, involving coupling of orbital and spin degrees of freedom. Many of the useful and interesting effects are limited by their size. In spin-dependent skew scattering, the cornerstone of efforts to produce spin currents, the generated currents are small because the spin-orbit interaction is small in all except the heaviest elements and because the asymmetry depends on higher order interference effects. Ways around this limitation include enhancement by correlations and by resultant resonant scattering effects.In the search for larger effects we can also look to inclusion of scattering of low frequency collective excitations. This lead to examination, for example, of skew scattering effects where there is critical slowing down, the simplest example being that occurring near the Curie temperature of a ferromagnet. Such investigations lead to the discovery of an interesting anomaly and a novel probe of non-linear fluctuations near such a critical point. This suggests that other anomalous effects may occur in glassy systems where the hierarchy of low energy fluctuations may persist over a wider range of temperatures.

Spin-orbit effects are also basic to the effects of crystalline anisotropy in magnetic systems and the coupling between magnetism and lattice effects. Part of the project was to investigate in detail such couplings in, for example, multifunctional materials such as multi-ferroics and in the effects of Dzyaloshinsky-Moriya interactions in domain wall motion. The spin-orbit interaction also causes the magnetoelastic interaction and thereby couples lattice vibrations (phonons) with spin waves (magnons) in magnetic materials. In favourable cases the coupling can be strong and cause remarkable effects. Several experiments motivated us to interpret these couplings and analyse what can be learned from the observations.

## 2. Research Contents

We investigated systematically correlation effects on skew scattering by both impurities in alloys and by collective excitations in various forms of cooperatively ordered solids including ferromagnets, antiferromagnets and magnetic glasses. We were guided by choices of experimental colleagues at the ASRC and elsewhere in order to make direct comparisons. The methods were a combination of state of the art numerical techniques, for example a combined approach of density functional methods and quantum Monte Carlo and simpler Hartree-Fock approximations, and more phenomenological approaches using as input correlations as observed by a variety of experimental techniques for materials, such as neutron scattering, X-ray scattering, and muons, as well as device characteristics. We also studied the effects of magnetoelastic coupling on the transport properties of magnetic insulators such as yttrium iron garnet (YIG).

## 3. Research results

As part of a wider program [1] to understand quantitatively Spin Hall angles in alloys and bulk magnetic solids we analysed [3] of the spin Hall effect in the Cu alloys doped with a series of 5*d* elements, by the combined approach of density functional theory and Hartree–Fock approximation. We found (see Fig.1) that the local correlations in the 5*d* orbitals of the impurities are decisive in determining the sign of the spin Hall angle (SHA).

Fig 1：Predicted Spin Hall with and without 5d correlation.

From Ref.[3]

Including all Correlations and the spin-orbit strengths fully we predict the SHA for each alloy in the series. The signs of CuIr and CuPt are sensitive to perturbation of the local correlations. This observation may suggest mechanisms for controlling the sign of the transverse spin Hall voltage.

We proposed[2] a method to realize diluted magnetic semiconductors (DMSs) with both p- and n-type carriers by choosing host semiconductors with a narrow band gap with starting point the recent observations of Mn-doped $BaZn_2As_2$. By density functional and quantum Monte Carlo simulation, we suggested the possibility of using Mn-doped $BaZn_2As_2$. We also predicted a *nontoxic* DMS, with As replaced by Sb, could have an even higher Curie temperature.

We develop a Boltzmann transport theory for magnon-polarons and determined transport coefficients and spin diffusion length, as shown in Fig. 2.. Magnon polaron formation causes anomalous features in the magnetic field and temperature dependence of the spin Seebeck effect when the disorder scattering in the magnetic and elastic subsystems is sufficiently different. Experimental data by Kikkawa et al. [PRL 117, 207203 (2016)] on YIG was shown to be explained if the acoustic quality is much better than the magnetic quality of the material.

We also organized the 37th Reimei Workshop on Frontiers of Correlated Quantum Matters and Spintronics in conjunction with the DMREF-FCMP

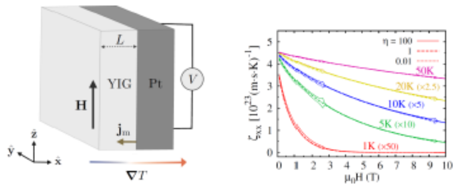


Fig 2：The sample configuration (left) and calculated spin current –temperature curves for diferent in-plane

Symposium, the 37th Reimei meeting on “Mott Transitions and Computational Approaches: was organized in Tokai and Tokyo in conjunction with the Reimei program of Y.Uemura. and we contributed to “Spin Mechanics IV” (39th Reimei) in British Columbia.

## 4. Conclusion

We found new results in the theory of skew scattering from impurities and collectively ordering magnetic systems as summarized in Ref. [1,3]. New ideas were developed in narrow band gap semiconducting systems that may assist in the search for new higher temperatures diluted semiconductors.[2] New concepts in the coupling of magnons and polarons should be important in the burgeoning fields of spin Seebeck devices [4,5]. Apart from the regular collaboration between different members of the Reimei project, there has been great benefit in bringing together people with different perspectives and contacts with different experimental groups – in Tokai, Tohoku, Grenoble and Delft. We organized a joint meeting in Tokyo and Tokai with Y. Uemura’s muon Reimei project .

## 5. References

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