MAR07-2006-000215

Abstract for an Invited Paper
for the MAR07 Meeting of
the American Physical Society

Intrinsic vs. extrinsic mechanisms of anomalous Hall effect

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Anomalous Hall effect (AHE) in ferromagnets has been a fundamental and intriguing issue in condensed-matter physics. Various mechanisms have been proposed, including the Karplus-Luttinger's band intrinsic mechanism, and extrinsic skew-scattering and side-jump mechanisms. However, the controversy on the mechanism has not been resolved yet. In this talk, a unified theory of the anomalous Hall effect (AHE) is presented for multi-band ferromagnetic metallic systems with dilute impurities [1], using the gauge-covariant formalism for the Keldysh Green's function [2]. In the clean limit, the AHE is mostly due to the extrinsic skew- scattering, and is sensitive to details of impurity potential. When the Fermi level is located around anti-crossing of band dispersions split by spin-orbit interaction, the intrinsic AHE to be calculated ab initio is resonantly enhanced by its non- perturbative nature. Then, an extrinsic-to-intrinsic crossover occurs when the relaxation rate is comparable to the spin-orbit interaction energy. Futher increasing the relaxation rate, a new scaling relation $\sigma_{xy} \propto \sigma_{xx}^{1.6}$ appears in the hopping-conduction regime. Various experimental data on transition-metals and oxcides are understood in terms of this theory [3].

[1] S. Onoda, N. Sugimoto, and N. Nagaosa, Phys. Rev. Lett. **97**, 126602 (2006).
[2] S. Onoda, N. Sugimoto, and N. Nagaosa, Prog. Theor. Phys. **116**, 61 (2006).
[3] T. Miyasato *et al.*, cond-mat/0610324.