Skew scattering, spin Hall effects and muons in spintronics

Abstract: Calculations were made directed to the understanding and control of skew scattering mechanisms for electrons in solids. This is crucial in the search for suitable compounds for the efficient conversion of charge and spin currents to enable future spintronic devices. Theory was developed to understand the magnitude of spin Hall angles measured recently in metallic alloys. In parallel calculations were made to explain the sensitivity of muon spin relaxation to non-equilibrium states of doped semiconductors.

While at the IMR, in the Nojiri laboratory, I continued research directed towards the quantitative understanding of skew scattering phenomena that determine anomalous transport coefficients in the Anomalous and Spin Hall Effects. In the the sign of the spin Hall angle (SHA), i.e. the direction of the induced transverse current was often ignored. This was partly because the primary concern was the small magnitude of the Hall angle, and the search for larger values. As measurements become more systematic, the issue of the sign has became more central; in particular following the report of a very large spin Hall angle of -0.24 at low temperatures in a CuBi alloy. . This result contrasted with previous predictions of a very large Spin Hall Angle, but of opposite sign for Cu doped with Bi impurities. From this discrepancy, it had been claimed in the literature that this could be attributed to none of the conventionally known skew-scattering , side-jump nor intrinsic mechanisms. This would seem to be a serious challenge to our understanding of the Spin and Anomalous Hall effects. By re-examining this issue we showed that in fact a phase shift analysis with the p-orbitals and consistent definitions with quoted experimental results removes any contradiction to a skew scattering mechanism, and thus we restore the possibility of properly microscopic understanding of the effects. There remains a possibly significant difference in the magnitude of the angle and we advanced an explanation[1], backed up with calculation of local electronic structure which showed a significant enhacement by Bi atoms at the Cu surface. This effect of the localization of the impurity state on the surface as shown in Fig 1:

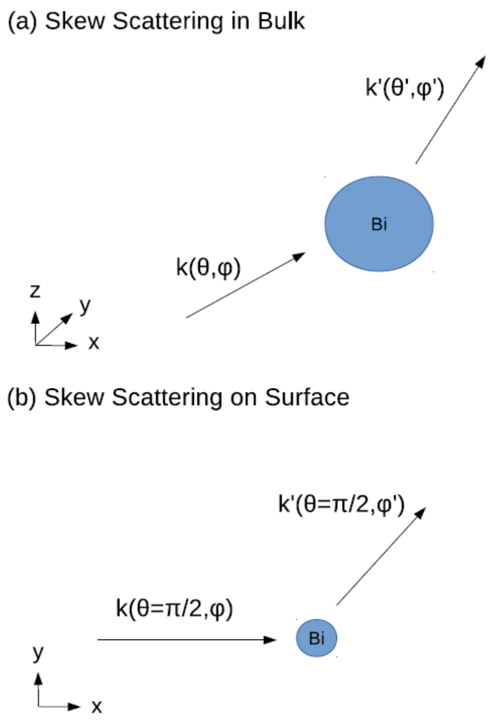

Fig.1 shows schematically the enhanced scattering of Bi impurities on the surface of Cu

hybridization between impurity and surface is shar ply decreased, which factor, combined with the effects of Coulomb correlations enhanced skew scattering.

Recently a small positive spin Hall angle of a few percent, was observed experimentally in nonmagnetic CuIr alloys and attributed predominantly to an extrinsic skew scattering mechanism, which in this case really is opposite in sign to calculations from an extrinsic skew scattering. We therefore reonsidered the SHA in CuIr alloys, with full inclusion of effects of the local electron correlation in 5d orbitals of Ir impurities beyond local density functional methods. In this case the negative angle calculated ignoring such local electron correlation, becomes positive once the correlation U approaches a realistic value. The mechanism can be understood qualitatively as being caused by the redistribution of charge in the local extended impurity state of d symmetry into less correlated s and p extended impurity orbitals. As skew scattering, an interference effect between diffferent scattering channels, is sensitive to shifts in weight this is sufficient to switch the sense of skew scattering from being predominantly in one direction to another. One might then speculate on future ways to control the sign of spin currents by manipulating the occupation number of impurities.

In parallel with this activity we have provided a theoretical explanation for laser-pumped experiments on muon precession performed at J-Parc , that have established that muonium can be a tool in spintronics for following non-equilibrium spin polarizations of the conduction electrons. In n-type GaAs, a puzzling result was that even for the charge state of negatively charge Muonium-, which is the atomic-like state

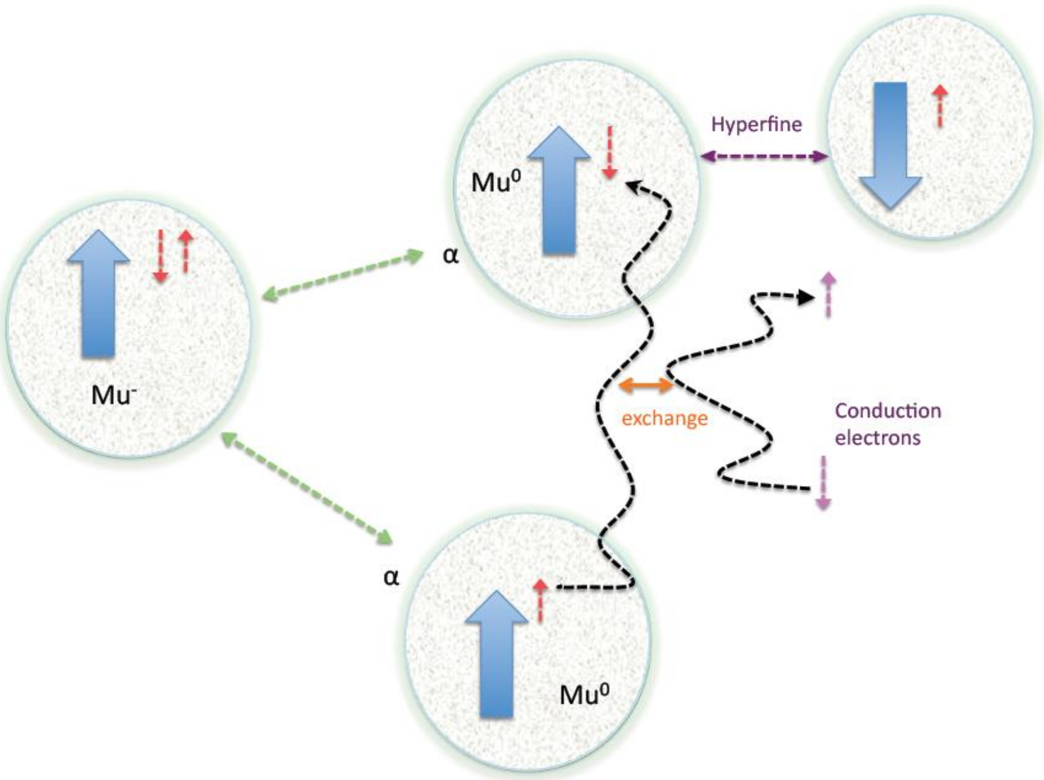

Fig. 2 Schematic theory of muon spin relaxation in negatively charged muonium.

of a positive muon and two bound electrons, there was apparent exchange with conduction electron spins. This is more problematic than previously seen exchange of spin in neutral muonium, as it is difficult to see how spin exchange can occur significantly in what is an spin singlet state of the two electrons. Estimates for the vacuum bound state of muonium give too weak an effect to be relevant to the experiments. We have proposed[2] a mechanism to explain the sensitivity of negatively charged Muonium ions to the spin-polarization of semiconductors in terms of the coherent mixing of charge states induced by hybridization with the semiconducting host. This is shown schematically in Figure 2.

Estimations of the parameters in a model Hamiltonian for different semiconducting hosts allow comparison to scattering times for Silicon and n-type GaAs and the predicted dependence on temperature and doping should lead in the future to tests of the theory..

Keywords: spintronic, magnetic properties, nanowire,

Timothy Ziman ziman@ill.fr

References

[1] B. Gu,, Zhuo Xu, M. Mori, T. Ziman, S. Maekawa,, Sign and Magnitude of Spin Hall Effect in CuBi Alloys submitted (2014) arXiv:1402.3012
[2] B. Gu, M. Mori, T. Ziman, S. Maekawa,, Negatively Charged Muonium as a Detector of Electron Spin Polarization: a Puzzle and a Possible Theory",Jap. Phys. Soc. Conf. Proc. 2 010301 (2014)
[3]Z. Xu, B. Gu, M. Mori, T. Ziman, S. Maekawa,, "Sign change of the spin Hall effect due to electron correlation in nonmagnetic CuIr alloys", submitted to Phys. Rev. (2014) arXiv 1405.7449

Comments:	4 pages, 2 figures
Subjects:	Materials Science (cond-mat.mtrl-sci)
Cite as:	arXiv:1402.3012 [cond-mat.mtrl-sci]