Spin-Transport Phenomena of Dirac Electrons in Bismuth

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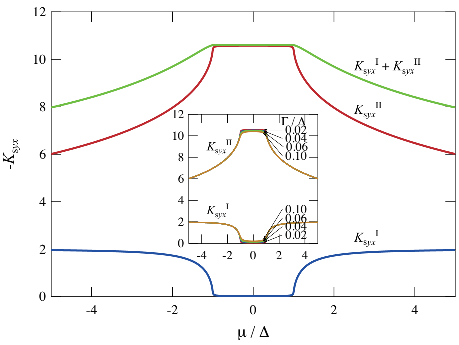
Spin-Hall effect (SHE) is a phenomenon of interest caused by the spin-orbit interaction. The SHE have been investigated in various systems. However, the SHE on bismuth has not been investigated in detail so far, both experimentally and theoretically, although bismuth has the largest spin-orbit interaction among the stable elements.

In this study [1,2], the SHE of fully relativistic (4×4 matrix) Dirac electrons is investigated based on the Kubo formula aiming at possible application to bismuth and bismuth-antimony alloys. It is found that there are two distinct contributions to spin-Hall conductivity, one only from the states near the Fermi energy and the other from all the occupied states. The latter remains even in the insulating state, i.e., when the chemical potential lies in the band-gap, and turns to have the same dependences on the chemical potential as the orbital susceptibility (diamagnetism), a surprising fact. This "duality" will play a crucial role for understanding the long-standing problem: how the transport coefficients relate to the orbital susceptibility [3,4]. These results are applied to bismuth—antimony alloys and the doping dependence of the SHE is proposed.

The present work gives a fully relativistic theory of the SHE not only in insulating but also in conducting state on equal footing for the first time. Also, our results have disclosed that the Dirac electron system will provide another ideal situation for investigating the spin-Hall effect, since it is very simple and gives not only qualitative but also quantitative agreements with experiments on bismuth [5,6].



[1] Y. Fuseya, M. Ogata, and H. Fukuyama: J. Phys. Soc. Jpn. **81** (2012) 093704.
[2] Y. Fuseya, M. Ogata, and H. Fukuyama: J. Phys. Soc. Jpn. **81** (2012) 013704.
[3] R. Kubo and H. Fukuyama: Proc. 10th Int. Conf. Physics of Semiconductors, 1970.
[4] Y. Fuseya, M. Ogata, and H. Fukuyama: Phys. Rev. Lett. **102** (2009) 066601.
[5] Z. Zhu, B. Fauque, Y. Fuseya, and K. Behnia: Phys. Rev. B **84** (2011) 115137.
[6] Z. Zhu, B. Fauque, L. Malone, A. B. Autunes, Y. Fuseya, and K. Behnia: Proc. Natl. Acad. Sci. USA in press.