Symmetry and magneto-transport phenomena

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The phase of matter can be characterized by symmetry and for certain effects, symmetry provides the basic condition to occur. In this lecture, we show how the fundamental concepts of symmetry apply to three key functionalities of spintronic memory devices, namely the retention, reading, and writing of magnetic information. Side by side we compare how the principles apply when considering the more conventional ferromagnetic and the richer antiferromagnetic structures.

Magnetism can and often does lower the symmetry of the crystal, depending on the direction of magnetic moments. It implies that reorientation of magnetic moments can change the electronic structure and by this the total energy. This is the origin of the magnetocrystalline anisotropy energy barrier that supports the non-volatile storage in spintronic memories.

Another example is the ferromagnetic order removing the symmetry protection of the spin-up/spin-down degeneracy of electronic bands. As a result, electrons moving in the unequal spin-up and spin-down bands have different resistivities. In ferromagnetic bilayers this leads to different resistance states for parallel and antiparallel alignments of moments in the two layers and the corresponding giant magnetoresistance effects. Different resistivities in spin-up and spin-down transport channels in a ferromagnet can be also used to filter an unpolarised current passing through the ferromagnetic layer by suppressing one spin-component of the electrical current. The resulting spin-polarized current filtered through such a ferromagnetic polarizer can exert a spin transfer torque on the adjacent ferromagnetic layer and switch its magnetic moment.

In time-reversal symmetric paramagnets, a broken space-inversion symmetry leads to the Kramers degeneracy of states with opposite spins and opposite crystal momenta, while the states at a given crystal momentum can be spin split. As a result, the crystal can develop a net spin polarization in a non-equilibrium, current-carrying state. When these relativistic spintronic effects occur at an inversion-asymmetric interface between a paramagnet and a ferromagnet, or inside a magnetic crystal that lacks inversion symmetry, they can induce a spin-orbit torque. The charge to spin conversion efficiency driving the spin-orbit torque can outperform that of the spin-transfer torque and can be equally efficient in ferromagnets and antiferromagnets.

Lecture topics:

1. Charge-spin coupling fundamentals
    a. Coulomb exchange coupling
    b. Relativistic spin-orbit coupling
2. Symmetry and magnetotransport
    a. Magnetic symmetry groups
    b. Anisotropic magnetoresistance
    c. Anomalous Hall effect
    d. Giant magnetiresistance
3. Symmetry and spin-torque
    a. Spin-transfer torque
    b. Spin Hall effect and spin-oribit torque

Recommended reading:

[1] P. Strange, “Relativistic Quantum Mechanics”, Cambridge University Press 1998.
[2] H. Grimmer, “General relations for transport properties in magnetically ordered crystals“, Acta Crystallographica Section A 49, 763–771 (1993).
[3] J. Sinova et al., “Spin Hall effect”, Rev. Mod. Phys. 87, 1213 (2015).