Multiferroics

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At present, the term multiferroic is used in a restricted sense to indicate the coexistence of ferroelectric and ferro-, ferri-, or antiferro-magnetic order. The interplay between these orders has an enormous potential in terms of applications. One of the frequent device concepts illustrating this potential invokes the processing of magnetic information bits by means of electric voltages (instead of currents as in present technologies). This type of devices can be faster since the build-up time associated to the current is reduced and, very importantly, more energy efficient since the heat generated by the currents, and hence the need of its dissipation, is avoided.

The interplay between ferroelectric and magnetic orders is also very interesting from the fundamental point of view. Electricity and magnetism are intrinsically coupled as described by Maxwell's equations. However, the concurrent emergence of ferroelectricity and magnetic order is beyond such a coupling as it implies the synchronism of two collective phenomena of different nature. This possibility relies on the specific behavior of the interacting many-particle system under consideration and the phases of matter that can be promoted in such a setup. From a more chemistry point of view, the subtlety can also be appreciated in the celebrated case of the perovskite compounds. The perovskites provide a large number of systems prone to display either ferroelectric or magnetic order, but very rarely both.

In this lecture, we will address the physics of multiferroics by going through some of the most popular examples of multiferroic materials. The idea is to illustrate the many aspects of this phenomenon by means of well-known and transparent cases. We will follow Khomskii's classification into type-I and type-II multiferroics. In type-I multiferroics ferroelectricity and magnetic order are driven by different mechanisms, and hence set in independently. $BiFeO_3$ and $YMnO_3$ exemplify this class of multiferroics, in which the interplay between the coexisting orders is generally weak —yet $BiFeO_3$ is a single-phase material displaying room-temperature multiferroicity with many interesting features for device applications. In type-II multiferroics, in contrast, ferroelectricity appears directly due to the magnetic order. In consequence, their interplay is strong "by construction." Type-II multiferroicity thus requires, first of all, the emergence of a special type of magnetic structure that breaks space-inversion symmetry at the macroscopic level. Prototypical examples with this property are the non-collinear spin spiral order and the bi-collinear (zig-zag) E-type antiferromagnetic structure, both realized in $TbMnO_3$, as well as collinear antiferromagnetic arrangements of several spin species like in $TbMn_2O_5$. In the lecture, we will consider the mechanisms behind the formation of this special kind of magnetic structures and the different couplings that eventually produce the magnetically-induced electric polarization in these systems.

Literature

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