Multiferroics and Magnetoelectric effects

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Introduction

Multifunctionality is one of the keywords in modern materials science, with a star role featured by ***multiferroics*** (i.e. compounds showing more than one of the following long-range orders: magnetic order, dipolar order or spontaneous deformation). Indeed, their many active and competing degrees of freedom give rise to a plethora of phenomena, ranging from exotic magnetic/charge/spin/orbital orders to colossal responses to external fields, thus offering a huge potential for both rich basic physics as well as unprecedented technological applications. In this lesson, I will give an overview on the vaste phenomenology offered by multiferroics and magnetoelectrics [i.e. compounds where a magnetic (electric) field can control ferroelectric (magnetic) properties], both in the bulk phase as well as at (oxides-based) junctions, focusing on the microscopic mechanisms driving multiferroicity and magnetoelectricity. In addition, we will briefly discuss how these complex materials can be modelled, also showing some recent examples where theory and experiments gave a successful interpretation of the physics at play in relevant multiferroics.

Main topics:

- Multiferroics: What are they? Why are they useful? Why are they "complex"? Are they "many" or "few"?

- How to achieve ferroelectricity in transition-metal oxides:

    1. Proper ferroelectricity: the physics of lone-pair

    2. (Electronically driven) Improper ferroelectricity:

        - Spin-ordering driven (spin-spirals, collinear antiferromagnets)
        - Charge-ordering driven
        - Combination of spin- and charge-ordering
        - Examples of prototypical improper multiferroics

- Novel candidates and new mechanisms: manganites, layered materials, ferrites, organic crystals, metal organic frameworks

- Magnetoelectricity: how to control magnetic properties via an electric field and ferroelectric properties via a magnetic field

- Composites: magnetoelectricity at ferroelectric/ferromagnetic interfaces

- Brief overview on the physics of domains and domain walls in ferroic materials (if time permits)

- Challenges and perspectives

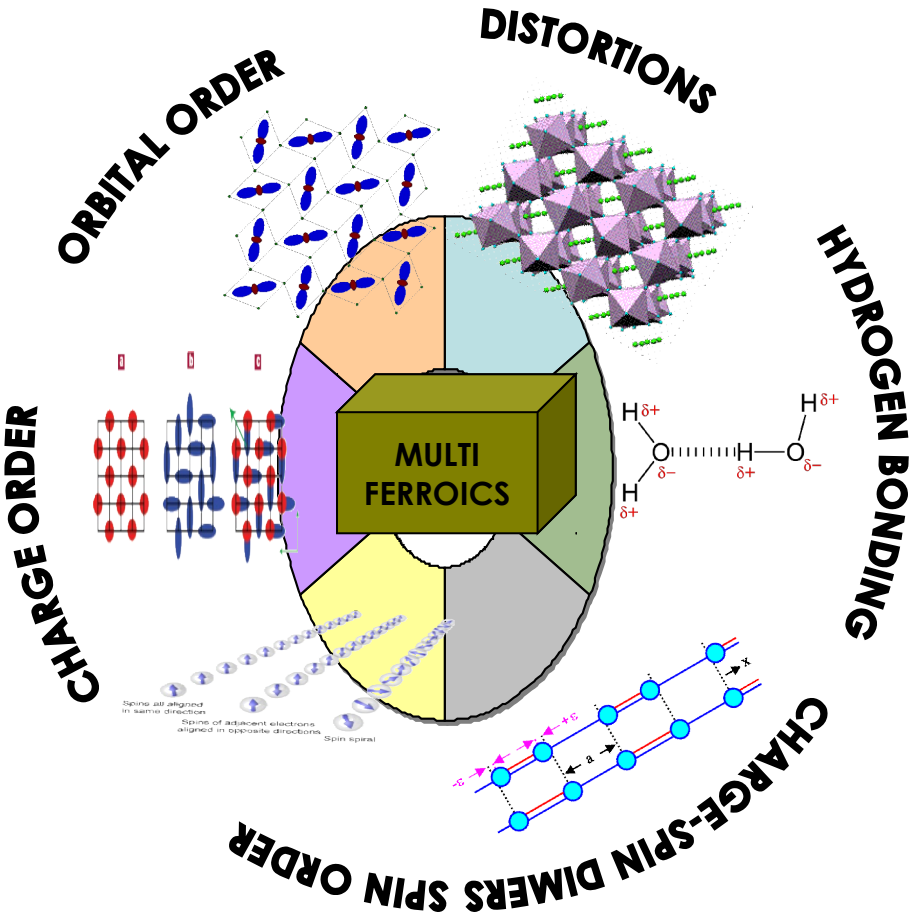

Figure 1: Pictorial representation of the different microscopic mechanisms that can lead to multiferroicity (adapted from Ref. 6)

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