

## Magnetoelectric coupling probed with muon spin rotation

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Multiferroic (MF) materials that exhibit both ferroelectric and magnetic ordering are an important class of materials offering the potential for the design of novel multifunctional devices such as transducers, actuators, sensors and memories. However whilst ferroelectric and magnetic materials are relatively common, very few single-phase multiferroic materials have been reported since the two order parameters (electric and magnetic) tend to be mutually exclusive [1]. The search for new MF materials has primarily centred on BiFeO<sub>3</sub> [2] and complex or frustrated magnetic materials such as TbMnO<sub>3</sub> and YMn<sub>2</sub>O<sub>5</sub> (type 2) [3], even though there are many alternatives that could offer a route to both new physics as well as applications. Whilst the chemistry of perovskites has been well explored over the last few decades, complex oxides and hybrid materials (with structures related to the perovskites), have a rich and largely unexplored chemistry with potential to yield MF materials with commercial impact. In this talk, I will discuss recent muon spectroscopy results from two such alternative materials.

The first of which is a MF based on the tetragonal tungsten bronze (TTB) structure, A<sub>12</sub>A<sub>24</sub>C<sub>4</sub>B<sub>12</sub>B<sub>28</sub>O<sub>30</sub>. The rich diversity of elements that can be incorporated into TTBs allows compositional tuning, which has been exploited for development of new phases of ferroelectrics [4,5]. There are few reports of ME coupling/multiferroic behaviour in TTBs: much of the literature is contradictory and lacks evidence of either ferroelectric or magnetic ordering. With collaborators, measurements of electric polarisation, magnetisation, neutron, muon and RUS on a single sample of Ba<sub>4.32</sub>Dy<sub>0.68</sub>Ga<sub>0.13</sub>Nb<sub>9.87</sub>O<sub>30</sub> have been performed [6]. It was discovered that this material exhibits a strong ME coupling: importantly, it is not strain mediated. Instead, the ME coupling mechanism is probably related to the presence of the spin cant of the non-trivial antiferromagnetism at low temperatures, although some other more exotic scenario cannot yet be discounted. These results will be presented, along with many open questions.

The second class of material is a Metal-Organic Framework (MOF) material, which consist of metal ion centres bridged by organic ligands. This materials class has attracted substantial attention over the past decade thanks to the versatility with which the framework components can be varied [7]. Since different metals and ligands predictably generate particular geometries, MOFs hold great promise for “crystal engineering”. One such family whose magnetic properties have received recent attention has the general structure C(NH<sub>2</sub>)<sub>3</sub>[M(HCO<sub>2</sub>)<sub>3</sub>], where the guanidinium cations (C(NH<sub>2</sub>)<sup>3+</sup>) sit in the pores of a framework of the metal cations M = Mn, Fe, Co, Ni, or Cu, which in turn are connected by formate bridges, in direct analogy with the perovskites ABO<sub>3</sub>. All of these compounds display spin-canted antiferromagnetism. However, while the Mn, Fe, Co and Ni complexes crystallise in the centrosymmetric space group Pnna, the Cu structure belongs to the polar space group Pna2<sub>1</sub> at room temperature as a result of Jahn-Teller distortion about the 3d<sup>9</sup> ion [8]. I will present preliminary studies on the magnetism in the Cu member.

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