Tiny cause with huge impact: polar instability through strong magneto-electric-elastic coupling in bulk $EuTiO_3$

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Multiferroic materials with combined polar, magnetic, and elastic orderings are at the forefront of scientific research in view of their complex interactive couplings: magnetic order can be tuned by strain and an electric field, polar order can be triggered by a magnetic field and strain, and elastic properties are controlled by a magnetic and/or an electric field. Such materials are desirable for multiple applications. Even though the phenomenon of multiferroicity has been predicted long ago [1], its realization remains rare for rather simple reasons: typically polar order is achieved when a transition metal d0 configuration is combined with highly polarizable anions, whereas magnetic order relies on a finite dn configuration. Obviously these two requirements yield a certain incompatibility for the coexistence of the two phenomena which have been tried to overcome by combining magnetic layers with polar ones, by growing composites, and via strain engineering [2, 3]. Even though a rather large number of materials have been shown to exhibit the desired properties, the coupling between magnetic and polar order is either very weak, or the spontaneous polarization/magnetization appears at low temperature only and remains too small to be of technological interest. Here we propose a new strategy to achieve strong magnetic-polar coupling by deriving the soft mode frequency of $EuTiO_3$ as a function of its lattice parameters which exhibits unusual, yet very small temperature dependencies at high and low temperatures [4, 5]. Specifically we develop a route of how to induce ferroelectric order in bulk $EuTiO_3$ (ETO) by combining experimental results with theoretical concepts. We show that marginal changes in the lattice parameter of the order of 0.01% have a more than 1000% effect on the transverse optic soft mode of ETO and thus easily induce a ferroelectric instability.

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