Tiny cause with large effects: the origin of the large magnetoelectric and magnetoelastic effect in $EuTiO_3$

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The magnetoelectric coupling in the perovskite oxide $EuTiO_3$ (ETO) is analyzed within a spin-phonon coupled Hamiltonian. It is shown that the *tiny* magnetostriction which accompanies the onset of antiferromagnetic order at T_N=5.7K induces a *substantial* hardening in the soft optic mode and a drop in the dielectric constant. The reduction of magnetostriction with increasing magnetic field reverses this behavior. While for small fields ferromagnetic order rapidly sets in accompanied by a volume expansion, this is destroyed with increasing fields and a strange paramagnetic state obtained. This exotic observation can be understood as stemming from the interplay between the enhanced oxygen p Ti d dynamical covalency which alters the crystal field at the Eu site and inhibits the virtual transition from $4f^7$ to $4f^6 5d$ responsible for ferromagnetic order.

In addition, it is shown that new thermal expansion experiments at high temperatures are an excellent tool to detect the structural instability in ETO since a pronounced anomaly takes place here. Also this feature is well explained within the polarizability model and evidences that a single model is well suited in describing the exotic behavior of ETO.

Finally, new μSR measurements are described which clearly demonstrate that magnetic domains (most likely fluctuating) exist in ETO at temperatures exceeding the structural instability. From these data a new temperature scale is defined where the fluctuations become more correlated and an increase in their correlation length sets in.