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Coupling of Magnetic and Ferroelectric Order Parameters in Improper Ferroelectrics

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This talk concerns systems for which the onset of incommensurate magnetic order induces ferroelectricity. I review how Landau theory [1,2] provided a convenient phenomenological explanation of this phenomenon. In the simplest and most frequent scenario, as the temperature is lowered, one first induces collinear incommensurate magetic order. At a lower temperature transition, transverse magnetic components appear and these two different symmetry magnetic order parameters combine to induce ferroelectricity via a trilinear magnetoelectric coupling. I will present several examples of this mechanism, subsequently discussed by Mostovoy[3] within a model of spiral magnetic order. Landau theory also explains [4] a contrasting scenario in which ferroelectric and magnetic can order within a single phase transition as in $RbFe(MoO_4)_2$, whose magnetic spiral contradicts the Mostovoy construction, but which Kaplan[5] has subsequently shown to be consistent with a more complete symmetry analysis of microscopic interactions. Other more exotic higher order magnetoelectric couplings, not easily accessible to an analysis of microscopic interactions, are also possible, especially in the presence of nonuniform magnetic order. I close with a few remarks on microscopic models for magnetically induced ferroelectricity.

[1] G. Lawes *et al.* PRL 95, 087205 (2005).
[2] M. Kenzelmann *et al.*, PRL **95**, 087206 (2005).
[3] Mostotovy, PRL **96**, 067201 (2006).
[4] M. Kenzelmann *et al.*, PRL **98**, 267205 (2007).
[5] T. Kaplan *et al*, PRB **83**, 174432 (2011)