Classifying multiferroics: Mechanisms and effects

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Outline

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Definition of Multiferroics

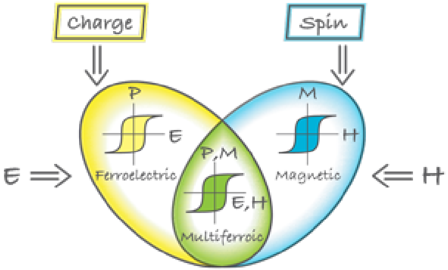

Figure: Combination of ferroelectrics and magnets

What's special about multiferroics?

History

- 1959 *Landau* and *Lifshitz* postulate existence of multiferroics.
- 1970s very little interest
- 2003 *Ramesh et al*: Artificial multiferroics produced
- since then great interest

Reasons for interest

- many applications: Spintronics, different sensors. . .
- basic research

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How to combine ferroelectricity and magnetism

Origin of magnetism

- localized electrons in d or f shells
- exchange interaction $\Rightarrow$ magnetic order

Origin of ferroelectricity

- different microscopic sources
- two types depending on coupling between magnetism and ferroelectricity

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Classification of multiferroics

Types of multiferroics

Type-I:

- weak coupling of ferroelectricity and magnetism
- ferroelectricity at higher T than magnetism
- large **P**
- "old" multiferroics

Type-II:

- strong coupling: polarization changes with **H** field
- ferroelectricity in low-temperature regime
- weak **P**
- "new" multiferroics

Why are multiferroics so rare?

"Mixed" Perovskites

- Perovskites $BaTiO_3$, $Pb(ZrTi)O_3$...
- partially filled *d* shells for magnetism
- empty *d* shells for ferroelectricity
- transition metal ion is shifted ⇒ covalent bond with O (with empty *d* state)
- "d^0 vs. d^n problem"

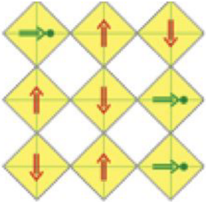

Figure: Ferroelectric d^0 ions and magnetic d^n ions

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Ferroelectricity due to lone pairs

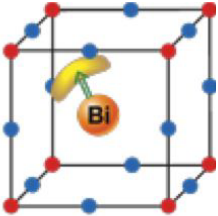

Figure: Lone pairs (yellow) of Bi^{3+}

- realized in $BiFeO_3$, $BiMnO_3$(?)
- outer electrons not in chemical bond

Ferroelectricity due to charge ordering

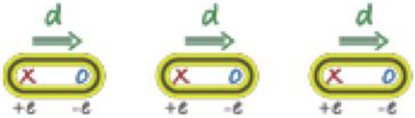

Figure: Inequivalent sites lead to ferroelectricity

- ions with different charge ⇒ different lengths
- or inequivalent bonds due to material structure

"Geometric ferroelectricity"

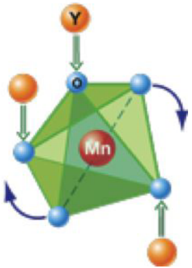

Figure: Mechanism of polarization: Tilting of MnO_5 with magnetic Mn

- formation of dipoles (Y-O)
- not fully understood

Spiral type-II multiferroics

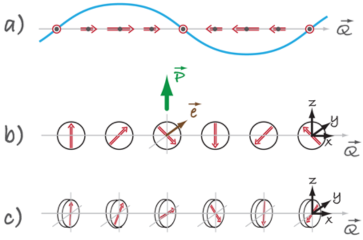

Figure: Spiral spin density wave

Different types of spin density waves (sdw)

- a sinusoidal sdw
- b cycloidal sdw
- c "proper-screw" sdw

Spiral type-II multiferroics

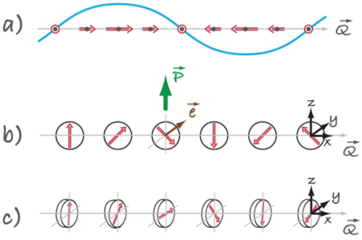

Figure: Spiral spin density wave

Example

$TbMnO_3$

- below 41K sinusoidal sdw
- below 28K cycloidal sdw:
  $\mathbf{P} \sim \mathbf{Q} \times (\mathbf{S_i} \times \mathbf{S_j})$

Collinear type-II multiferroics

- ferroelectricity in collinear magnetic structures
- mostly without spin-orbit interaction
- at low temperatures magnetic ordering $\Rightarrow$ inversion symmetry broken
- another mechanism: Frustrated magnets $\Rightarrow$ polarization

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Summary

- many applications of multiferroics
- two types of multiferroics: depending on coupling of magnetism and ferroelctricity
- many open questions

Todo

- fabrication and study of “artificial” multiferroics
- understanding of basic properties: *Ab initio* calculations
- study of elementary excitations
- ...

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