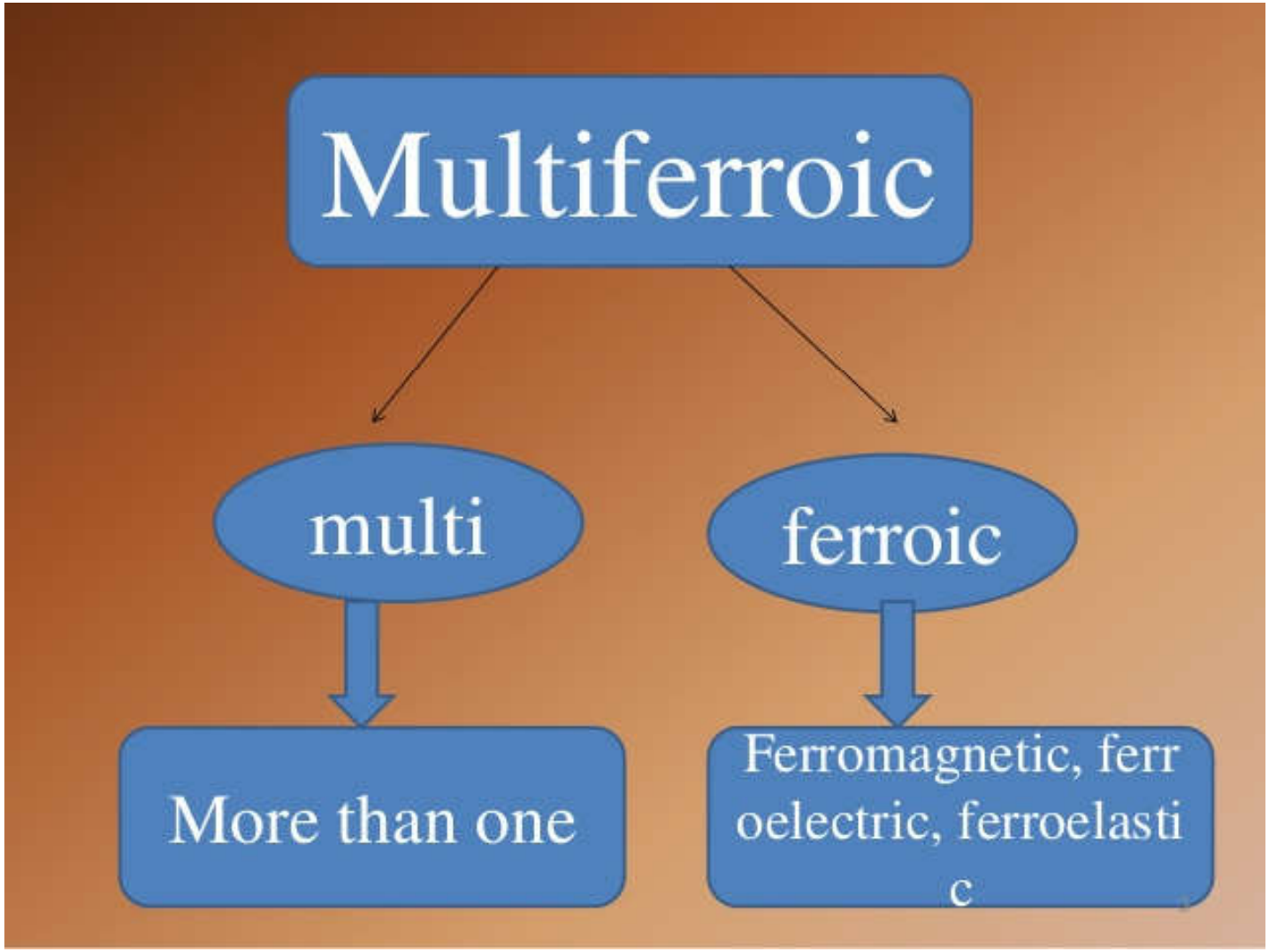
18PYB101J-Electromagnetic Theory, Quantum Mechanics, Waves and Optics

Module 2 Lecture-15

Multiferroic Materials

Multiferroic Materials



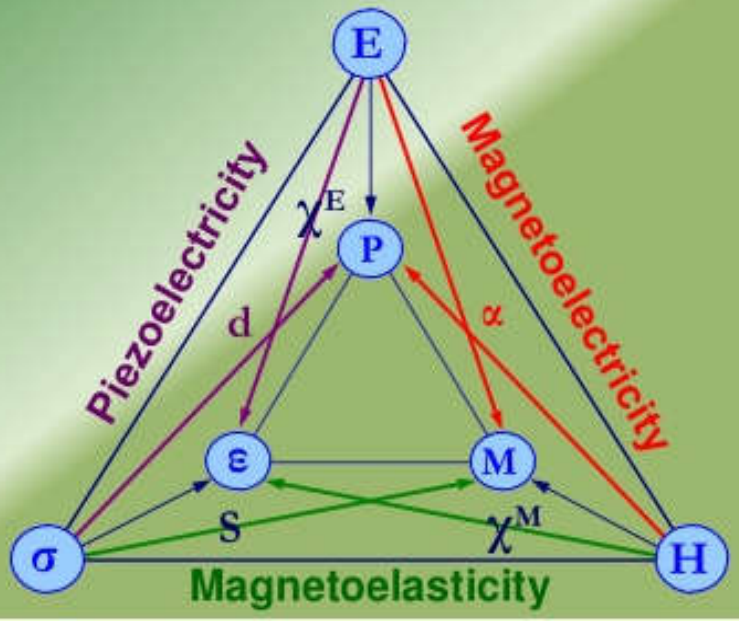
Multiferroics are defined as materials that exhibit more than one of the primary ferroic properties in the same phase:

- ferromagnetism – a magnetisation that is switchable by an applied magnetic field
- ferroelectricity – an electric polarisation that is switchable by an applied electric field
- ferroelasticity – a deformation that is switchable by an applied stress

While ferroelectric ferroelastics and ferromagnetic ferroelastics are formally multiferroics, these days the term is usually used to describe the *magnetoelectric multiferroics* that are simultaneously ferromagnetic and ferroelectric.

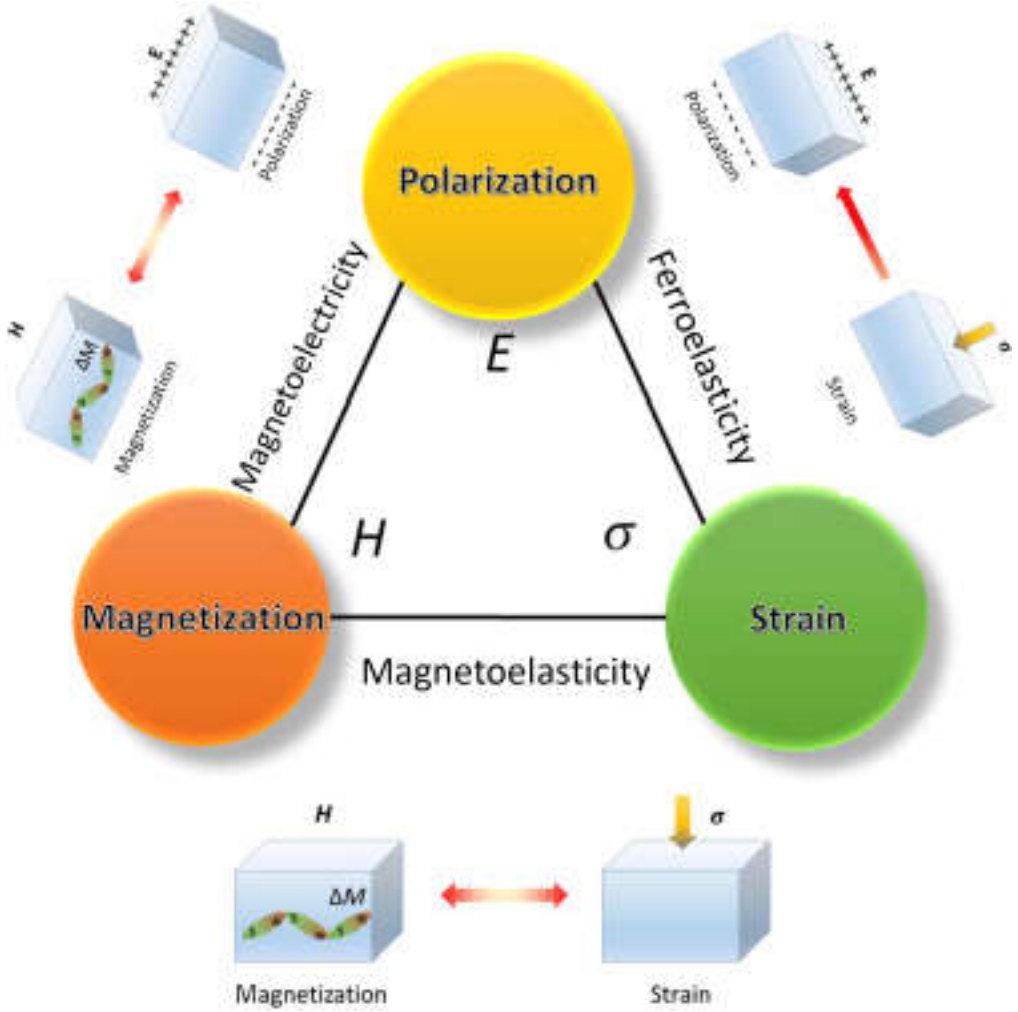
Multiferroic Materials

- Multiferroic → Materials possess two or more of the following
  - (Anti-)Ferromagnetism, (Anti-)Ferroelectricity, (Anti-)Ferroelasticity
  - Coupling between order parameters



N. A. Spaldin and M. Fiebig, Science **309**, 391 (2005).

Multiferroics



Types of Multiferroics

Multiferroics can be divided into two groups:

1. Type-I Multiferroics
2. Type-II Multiferroics

Type-I Multiferroics:

➢This type of multiferroics are older, more numerous and are good ferroelectrics. In these materials the ferroelectricity and magnetism occur at different temperatures and arise from different mechanisms.

➢In these materials, the coupling between magnetism and ferroelectricity is unfortunately weak. Different origin of ferroelectricity and magnetism in type-I multiferroic are mostly due to different active subsystems of a material.

Types of Multiferroics

Type-I Multiferroics:

- There is a certain coupling between breaking time reversal symmetry, breaking spatial inversion symmetry, ferroelectric order parameter, magnetic order parameter in such type-I multiferroics.
- In these materials, ferroelectricity can have a number of possible microscopic origins.
- For example: $BiFeO_3$ with the ferroelectric transition temperature T_c higher than the Neel transition temperature T_N.

Types of Multiferroics

Type-II Multiferroics:

- Due to the recent discovery of a novel class of multiferroics, there is a biggest excitement as ferroelectricity exists only in a magnetically ordered state and is caused by a particular type of magnetism.
- A nonzero electric polarization occurs in the low temperature phase. For example $CuFeO_2$ with $T_c = T_N$.
- The magnetic and/or electric polarization of the barrier controls the current driven through a magnetic tunnel junction (MTJ) with a multiferroic tunnel barrier.

Types of Multiferroics

Type-II Multiferroics:

➢Multiferroic tunnel junction (MFTJ) is referred to the junctions with a multiferroic tunnel barrier.

➢The use of a multiferroic material as a tunnel barrier and ferromagnetic materials as leads in MFTJs would lead to 8 possible resistive states of such junctions.

Some common Multiferroic with their T_C, T_N and Polarization

material	T_{FE} (K)	T_M (K)	P($\mu C\ cm^{-2}$)
$BiFeO_3$	1103	643	6.1
$YMnO_3$	914	76	5.5
$HoMnO_3$	875	72	5.6
$TbMnO_3$	28	41	0.06
$TbMn_2O_5$	38	43	0.04
$Ni_3V_2O_8$	6.3	9.1	0.01

Multiferroic Materials

Applications

- Spintronics Devices (that includes a spin-based transistor)
- Information Storage Devices (magnetic tape, floppy disk etc)
- Spin Valve (device consisting of two or more conducting magnetic materials, that alternate its electrical resistance)
- Quantum Electromagnets (electromagnets are wire coils or loops, which tend to be bulky and difficult to fabricate)
- Microelectronic Devices (MOSFETs, Bipolar Transistor etc)
- Sensors (measures a physical quantity and converts it into a signal which can be read by an instrument)

Thank you