Spin reorientation in orthoferrites

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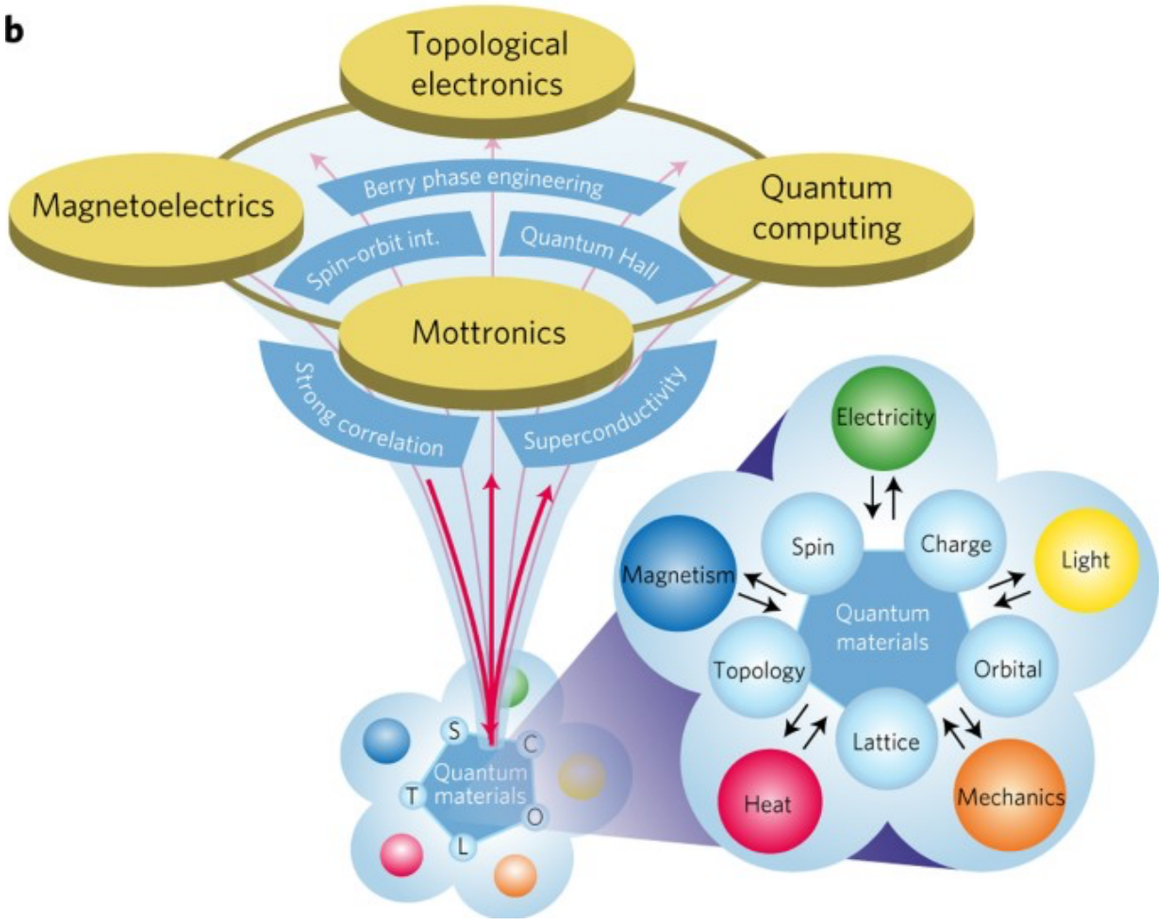
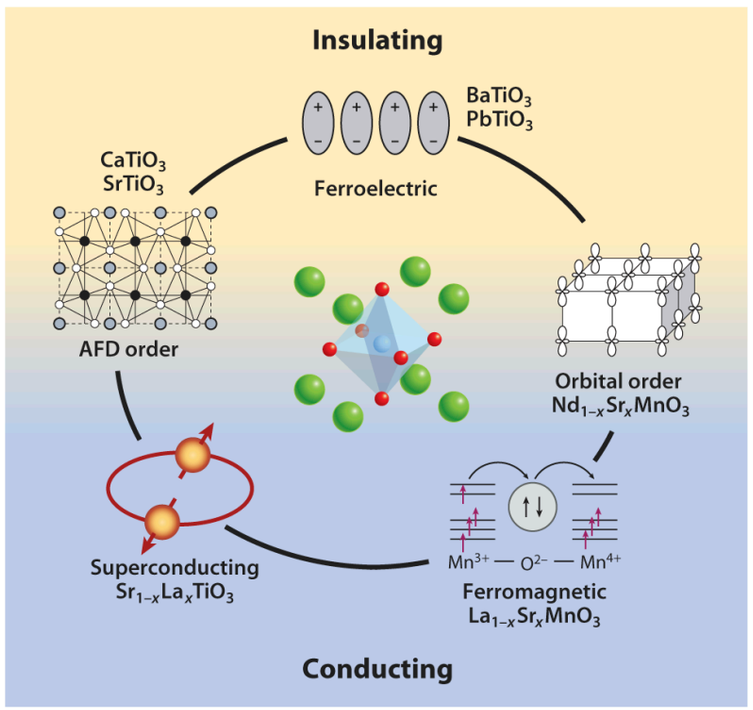
Indian Institute of Technology Roorkee

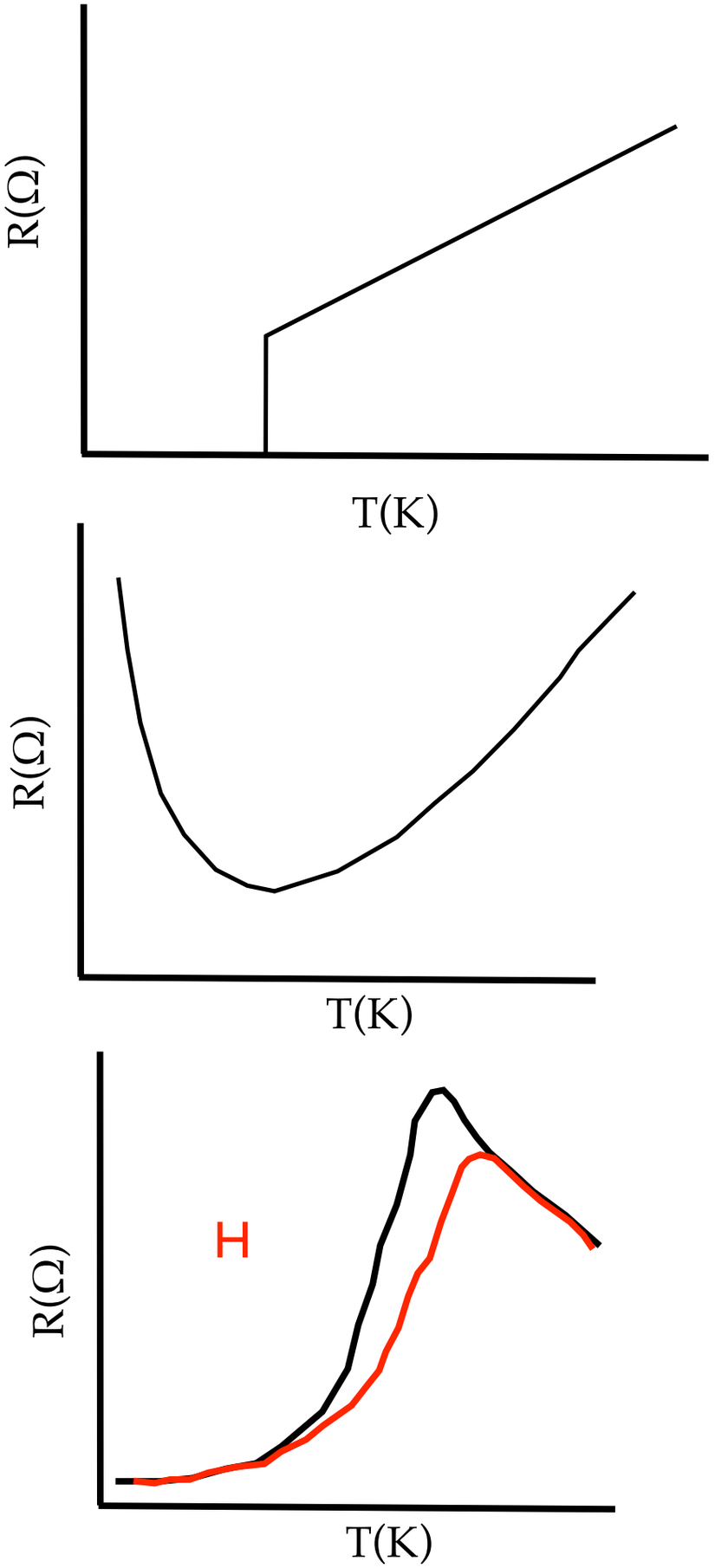
India - JINR Workshop 2023



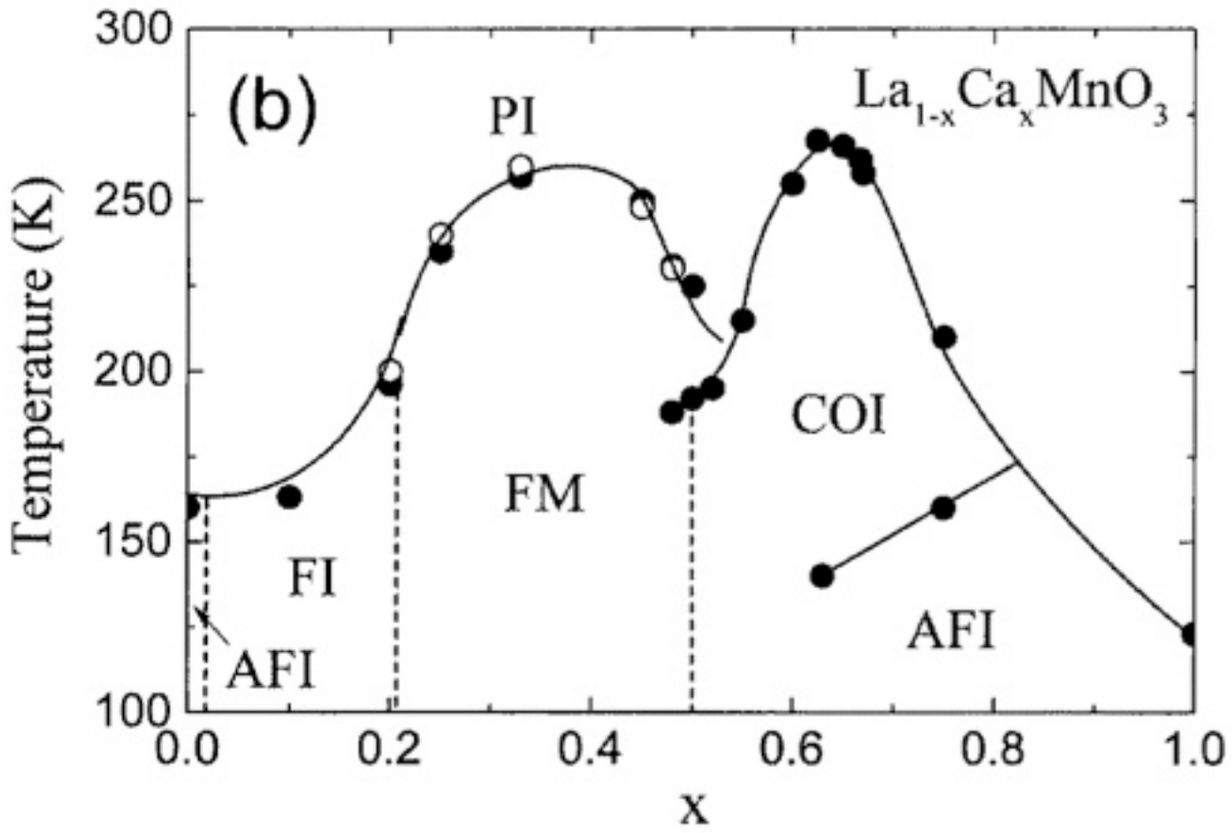
Y. Tokura et al., Nature Materials **13**, 1056 (2017)



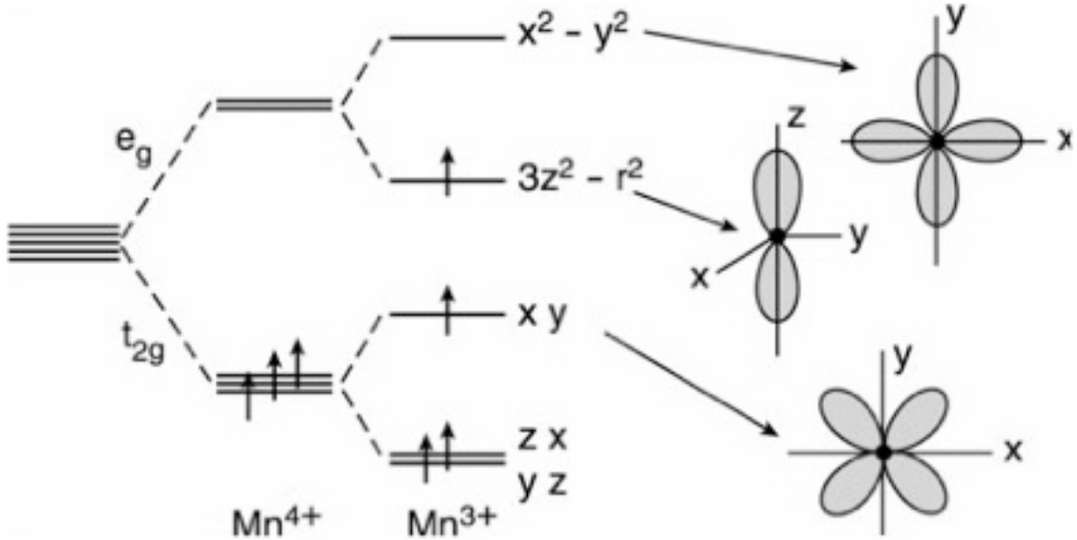
Zubko P, et al. 2011.
Annu. Rev. Condens. Matter Phys. 2:141–65

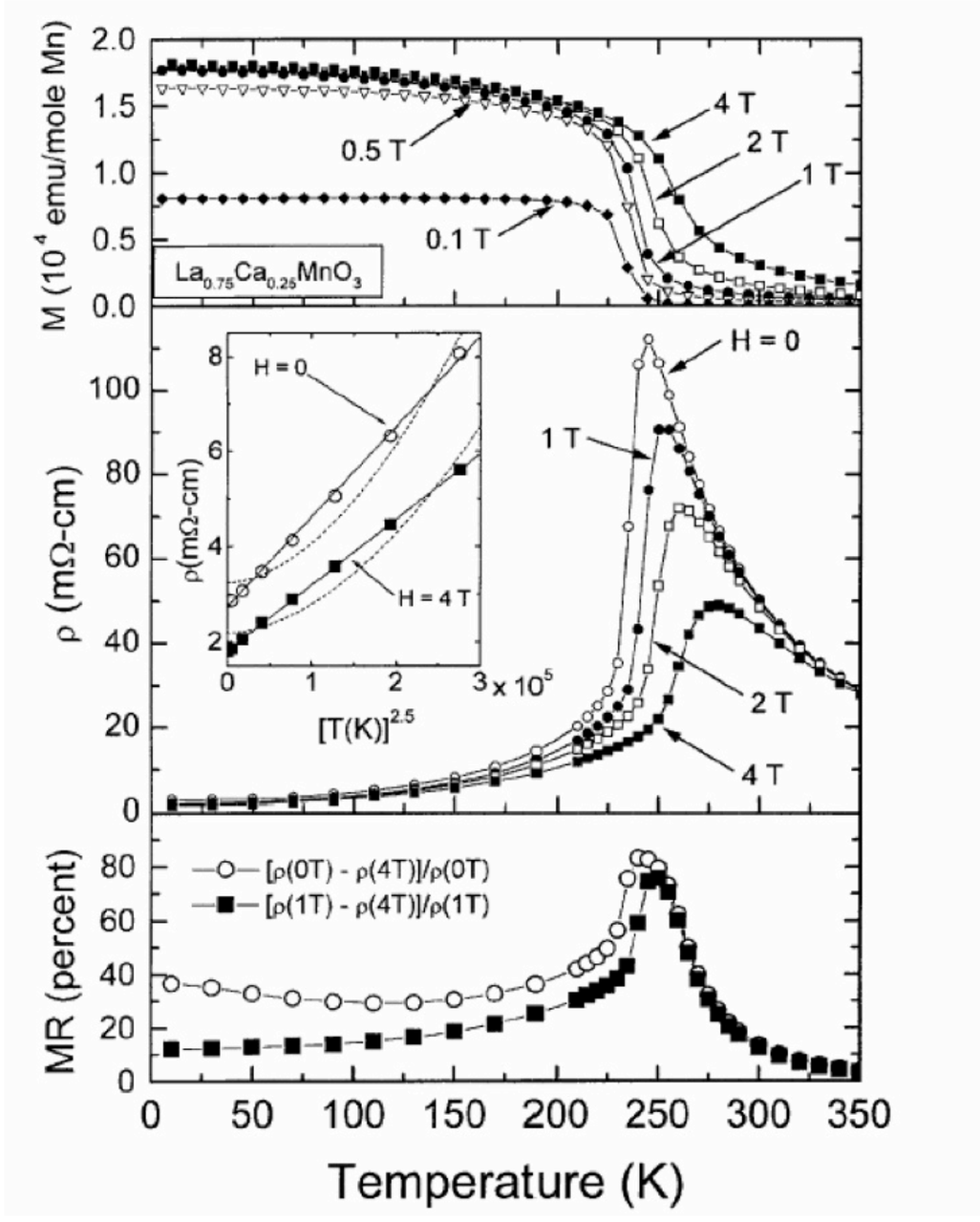


Manganites ($RMnO_3$)



A. Ramirez, J. Phys. : Cond. Matt. 9, 8171 (1997)





Y. Tokura and Y. Tomioka, J. Magn. Magn. Mat. 200,123(1999)

Orthoferrites ($RFeO_3$)

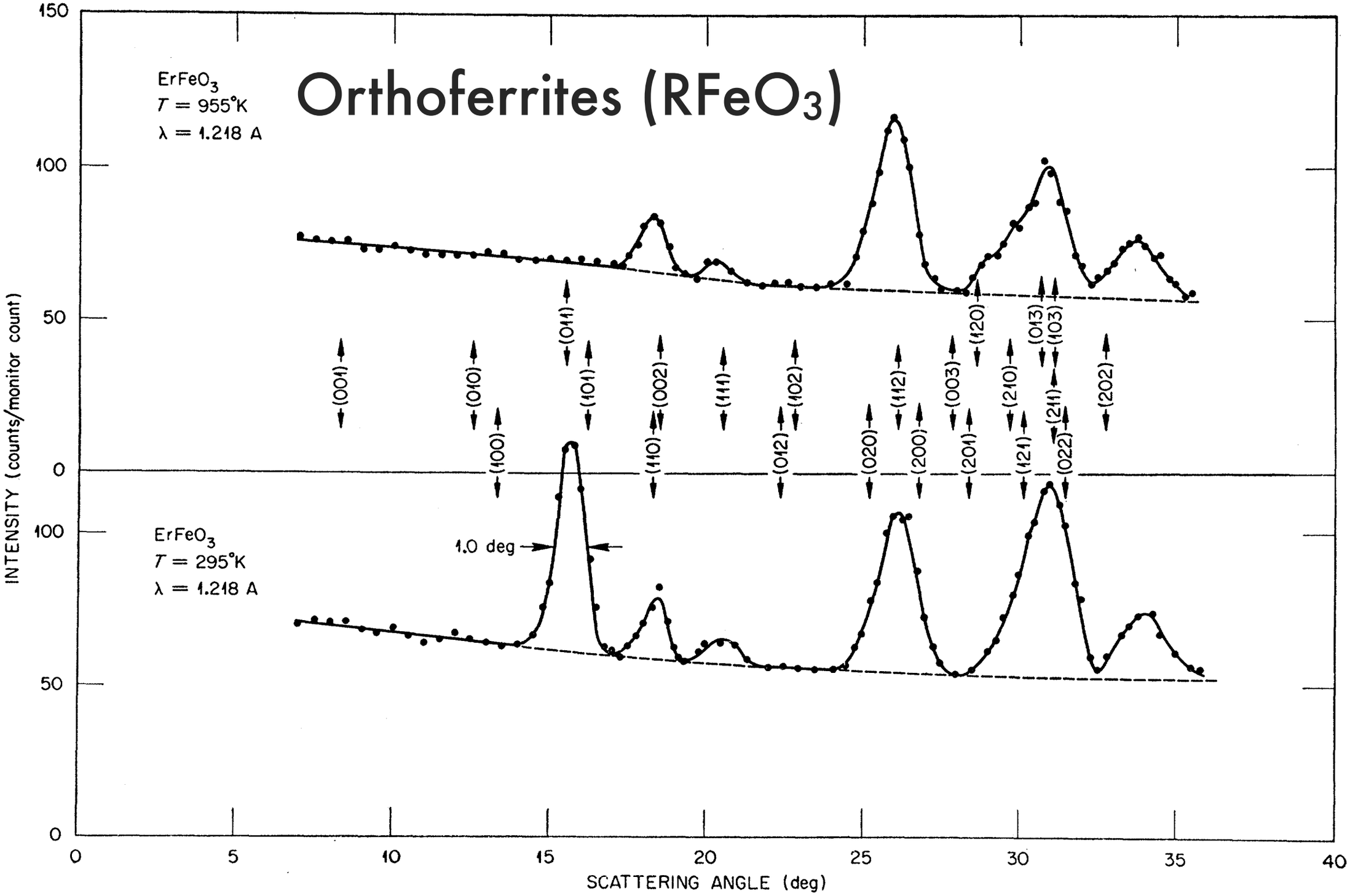


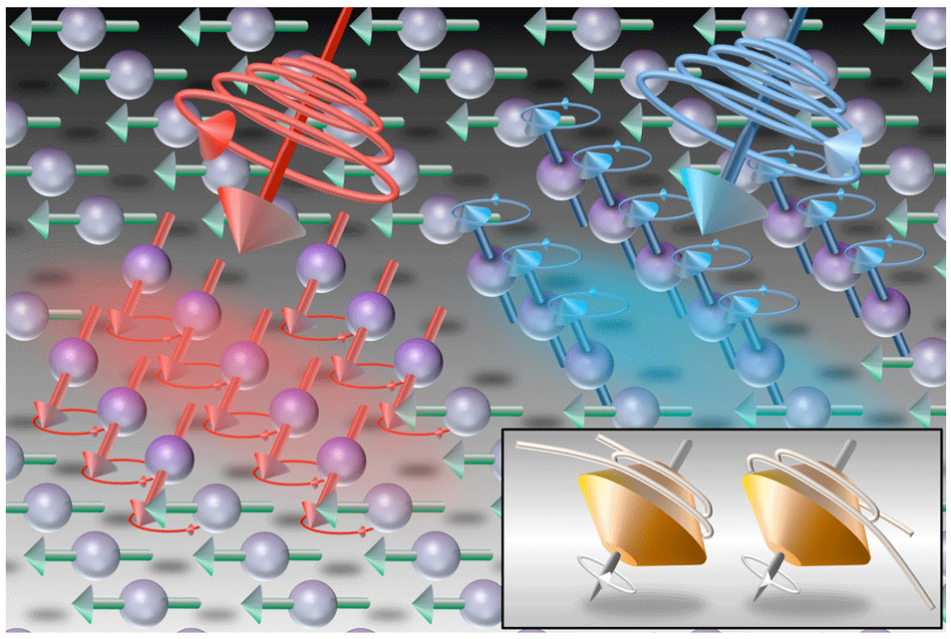
FIG. 1. High-temperature neutron diffraction data for $ErFeO_3$.

PHYSICAL REVIEW VOLUME 118, NUMBER 1 APRIL 1, 1960

Neutron Diffraction Study of the Magnetic Properties of Rare-Earth-Iron Perovskites*

W. C. KOEHLER, E. O. WOLLAN, AND M. K. WILKINSON
Oak Ridge National Laboratory, Oak Ridge, Tennessee

(Received October 16, 1959)



Physics **5**, 41 (2012)

Laser-induced ultrafast spin reorientation in the antiferromagnet $TmFeO_3$

A. V. Kimel[1], A. Kirilyuk[1], A. Tsvetkov[1], R. V. Pisarev[2] & Th. Rasing[1]

[1]*NSRIM Institute, University of Nijmegen, Toernooiveld 1, 6525 ED Nijmegen, The Netherlands*
[2]*Ioffe Physico-Technical Institute, 194021 St.-Petersburg, Russia*

All magnetically ordered materials can be divided into two primary classes: ferromagnets[1,2] and antiferromagnets[3]. Since ancient times, ferromagnetic materials have found vast application areas[4], from the compass to computer storage and more recently to magnetic random access memory and spintronics[5]. In contrast, antiferromagnetic (AFM) materials, though representing the overwhelming majority of magnetically ordered materials, for a long time were of academic interest only. The fundamental difference between the two types of magnetic

The rare-earth orthoferrites $RFeO_3$ (where R indicates a rare-earth element) investigated here are known for a strong temperature-dependent anisotropy[17,18]. These materials crystallize in an orthorhombically distorted perovskite structure, with a space-group symmetry D_{2h}^{16} (*Pbnm*). The iron moments order antiferromagnetically, as shown in Fig. 1, but with a small canting of the spins on different sublattices. The temperature-dependent anisotropy energy has the form[19,20]:

$$\Phi(T) = \Phi_0 + K_2(T)\sin^2\theta + K_4\sin^4\theta \qquad (1)$$

where θ is the angle in the x–z plane between the x axis and the AFM moment **G**, see Fig. 1, and K_2 and K_4 are the anisotropy constants of second and fourth order, respectively. Applying equilibrium conditions to equation (1) yields three temperature regions corresponding to different spin orientations:

$$\Gamma_4(G_x\ F_z):\ \theta = 0,\ T \geq T_2$$

$$\Gamma_2(G_z\ F_x):\ \theta = 1/2\pi,\ T \leq T_1$$

$$\Gamma_{24}: \sin^2\theta = K_2(T)/2K_4,\ T_1 \leq T \leq T_2 \qquad (2)$$

where T_1 and T_2 are determined by the conditions $K_2(T_1) = -2K_4$

PRL **108,** 157601 (2012) Selected for a Viewpoint in *Physics* PHYSICAL REVIEW LETTERS week ending 13 APRIL 2012

Coherent Control of the Route of an Ultrafast Magnetic Phase Transition via Low-Amplitude Spin Precession

J. A. de Jong,[1] I. Razdolski,[1] A. M. Kalashnikova,[2] R. V. Pisarev,[2] A. M. Balbashov,[3] A. Kirilyuk,[1] Th. Rasing,[1] and A. V. Kimel[1]

[1]*Radboud University Nijmegen, Institute for Molecules and Materials, 6525 AJ Nijmegen, The Netherlands*
[2]*Ioffe Physical-Technical Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia*
[3]*Moscow Power Engineering Institute, 111250 Moscow, Russia*
(Received 20 December 2011; published 9 April 2012)

PHYSICAL REVIEW B **84**, 104421 (2011)

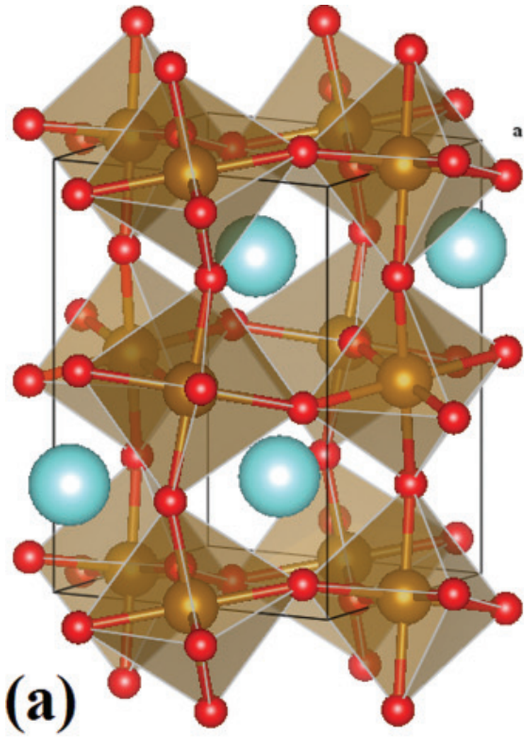
Laser-induced ultrafast spin dynamics in $ErFeO_3$

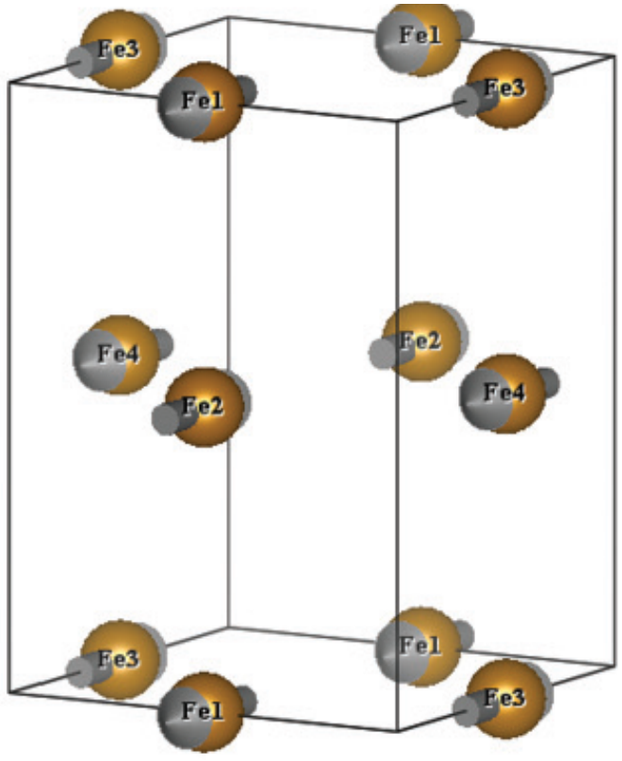
J. A. de Jong,[1] A. V. Kimel,[1] R. V. Pisarev,[2] A. Kirilyuk,[1] and Th. Rasing[1]

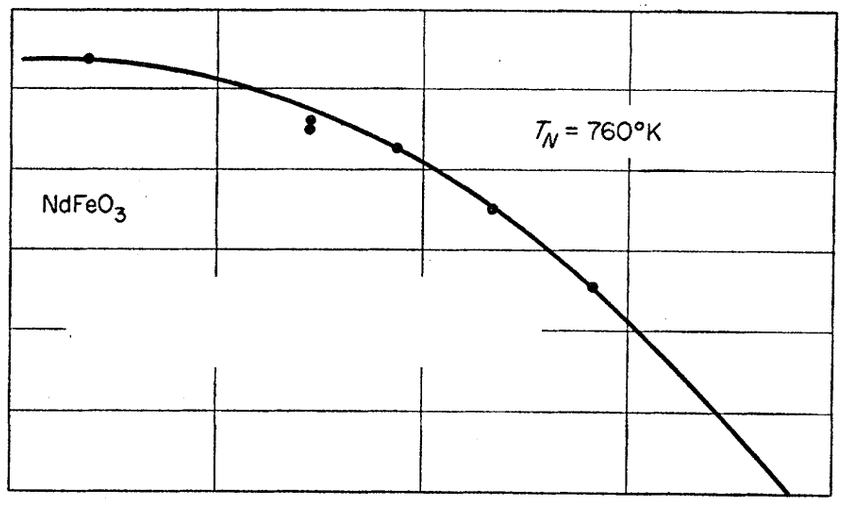
[1]*Radboud University Nijmegen, Institute for Molecules and Materials, NL-6525 AJ Nijmegen, The Netherlands*
[2]*Ioffe Physical-Technical Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia*
(Received 5 July 2011; revised manuscript received 9 August 2011; published 12 September 2011)

- Spin can be manipulated on a time scale of few ps
- Requirement: Temperature induced spin reorientation

$RFeO_3$







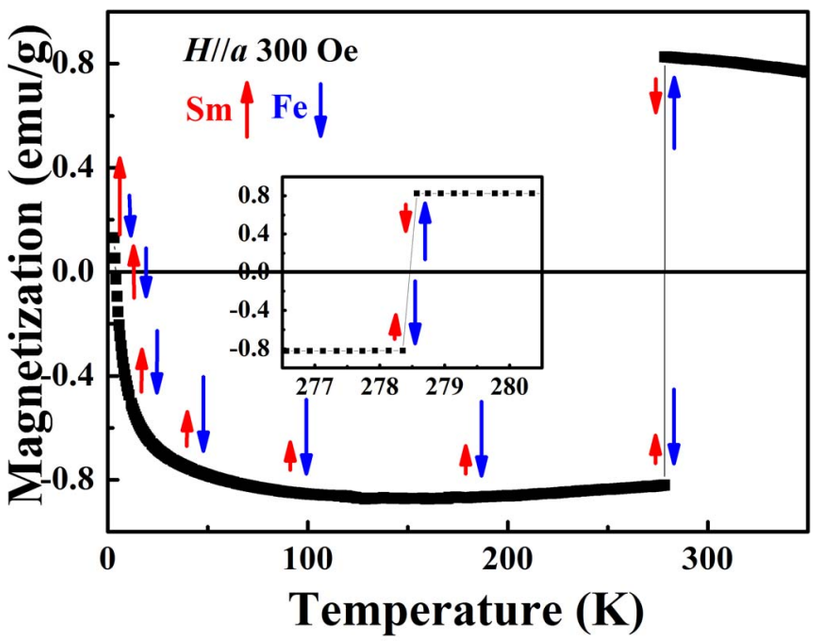
PHYSICAL REVIEW VOLUME 118, NUMBER 1 APRIL 1, 1960

Neutron Diffraction Study of the Magnetic Properties of Rare-Earth-Iron Perovskites*

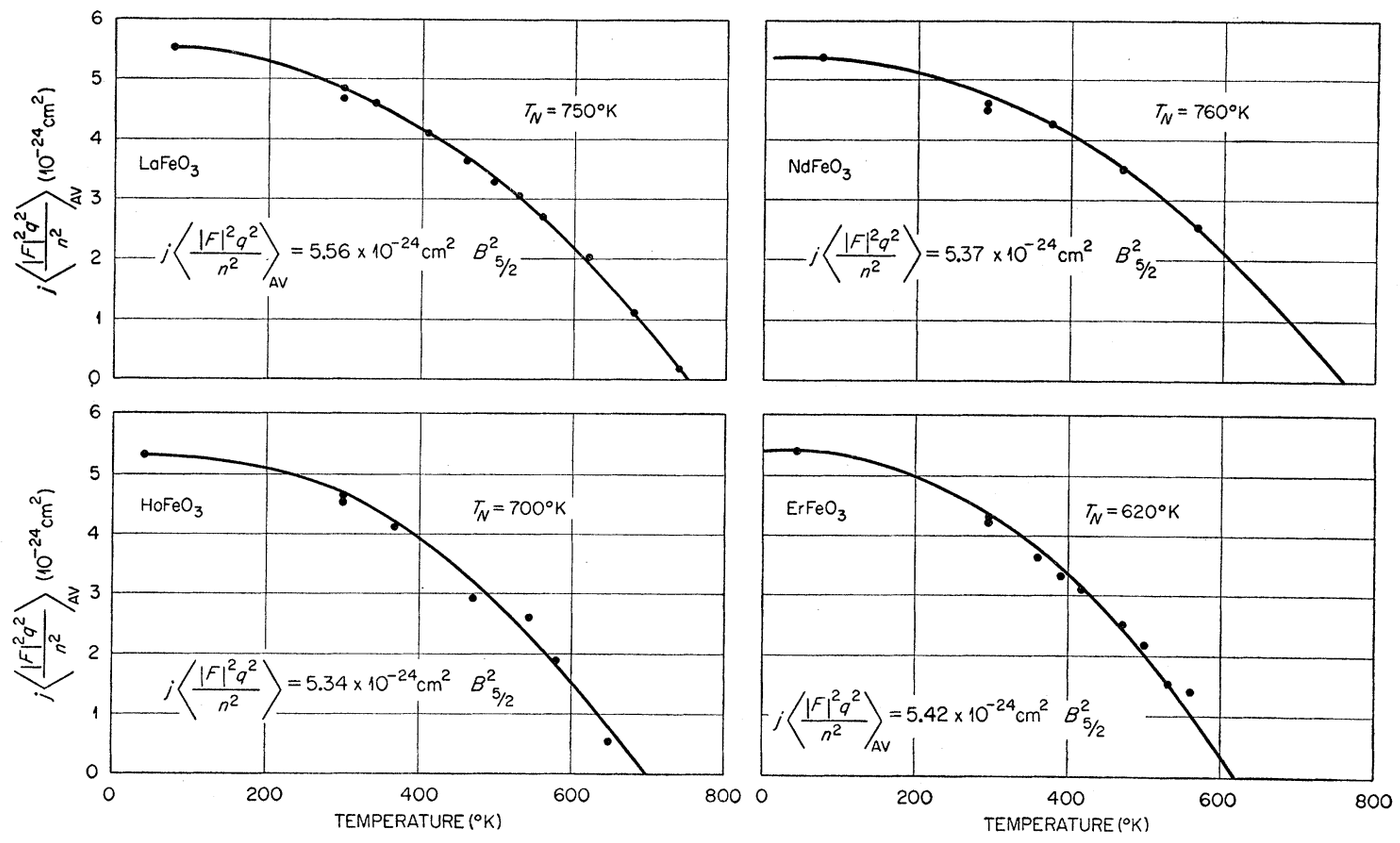
W. C. Koehler, E. O. Wollan, and M. K. Wilkinson
Oak Ridge National Laboratory, Oak Ridge, Tennessee

(Received October 16, 1959)

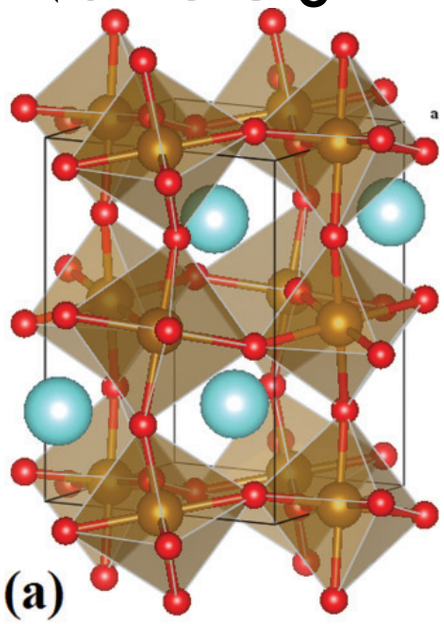
S.J. Yuan et al. Phys. Rev. B **87**,184405 (2013)

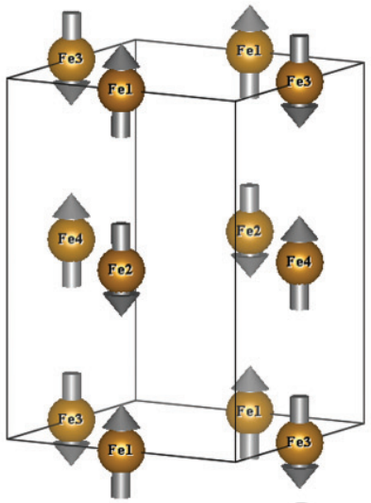


Scientific Reports **4**, 5960 (2012)

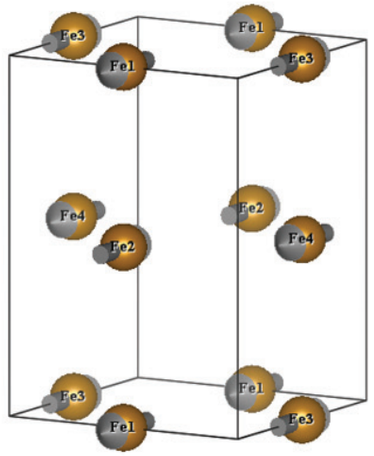


$NdFeO_3$

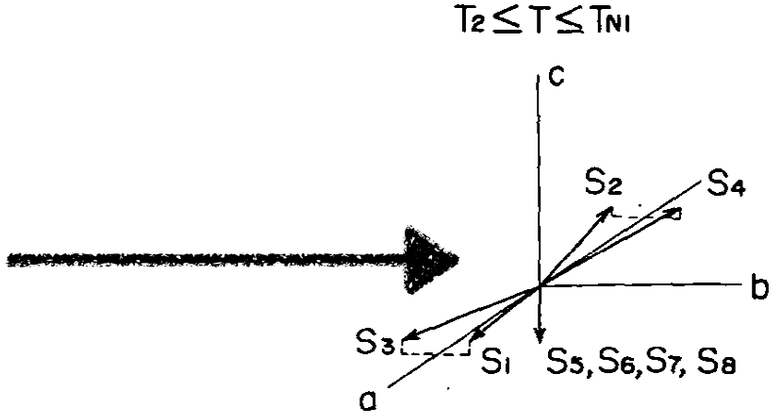




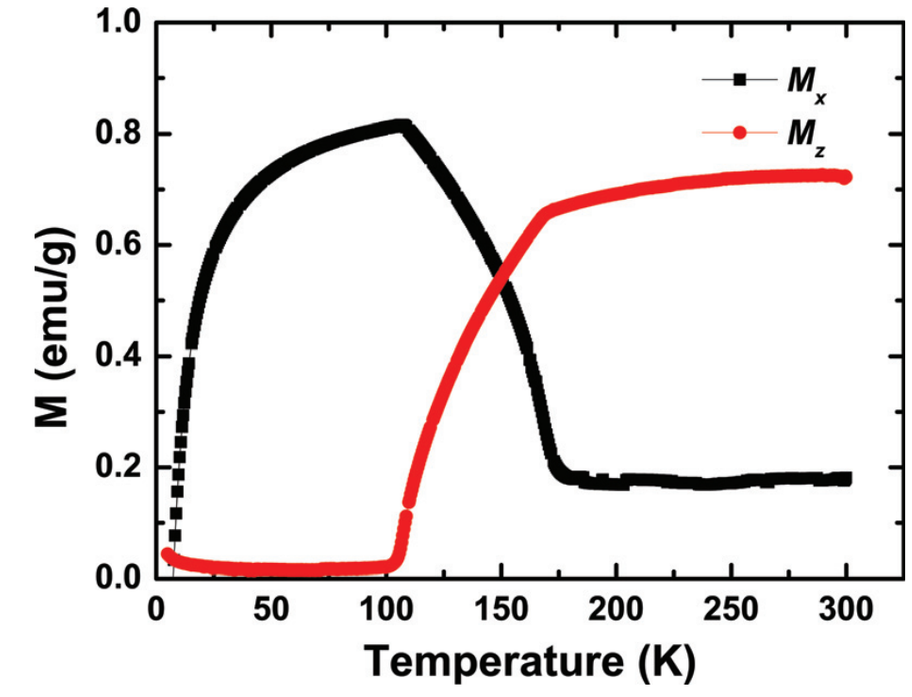
$F_x C_y G_z$

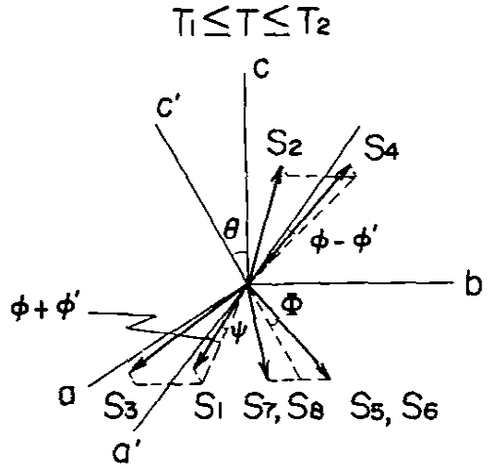


$G_x A_y F_z$



(a)





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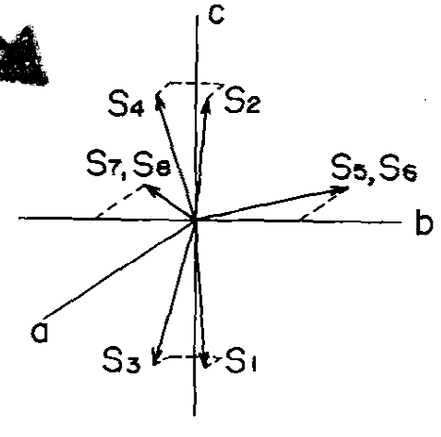


Magnetic properties of NdFeO3 single crystal in the spin reorientation region

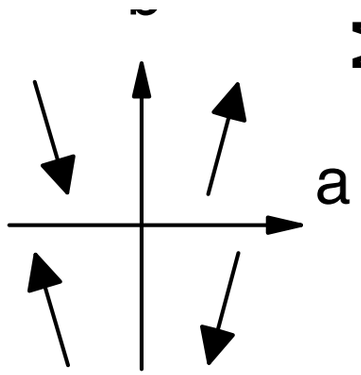
Shujuan Yuan, Yabin Wang, Mingjie Shao, Fenfen Chang, Baojuan Kang, Yosikazu Isikawa, and Shixun Cao

JOURNAL OF APPLIED PHYSICS **109**, 07E141 (2011)

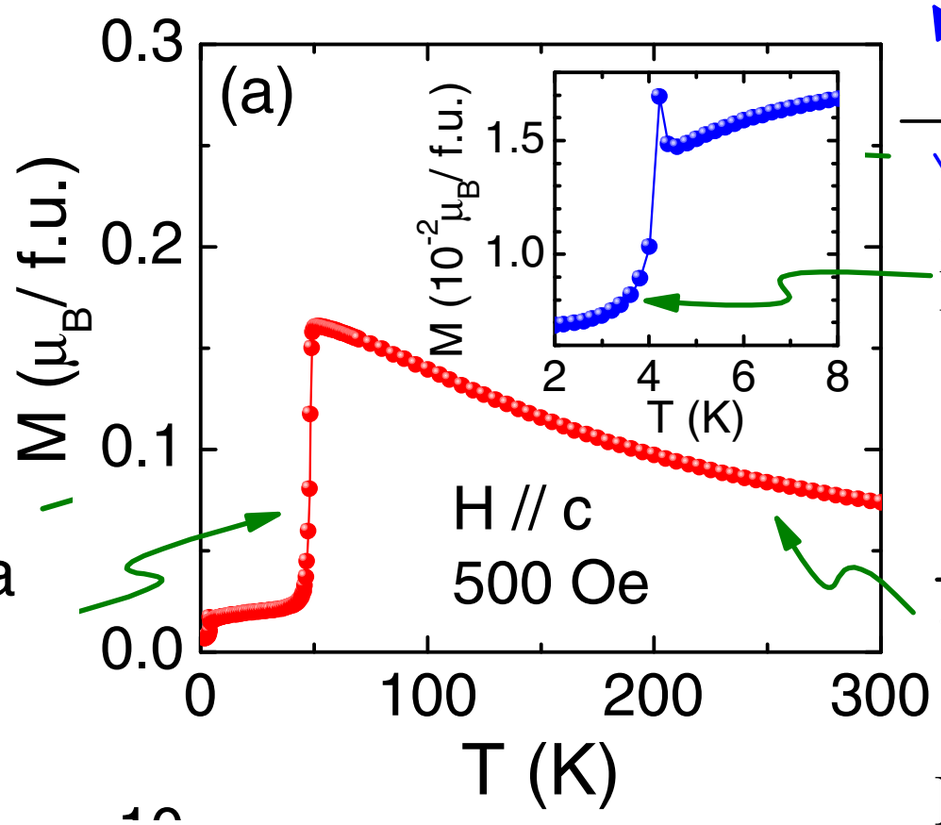
Nd moments orders develops C-type ordering

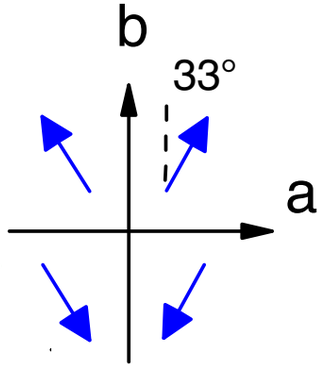
J. Phys. Chem. Solids, 1974, Vol. 35, pp. 479–500.

$DyFeO_3$

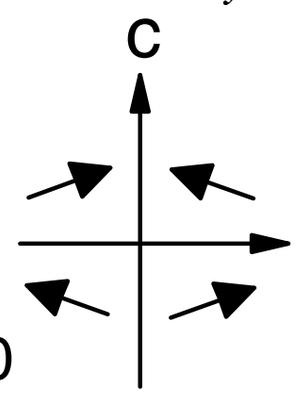


$Fe_{II}: A_x G_y C_z$

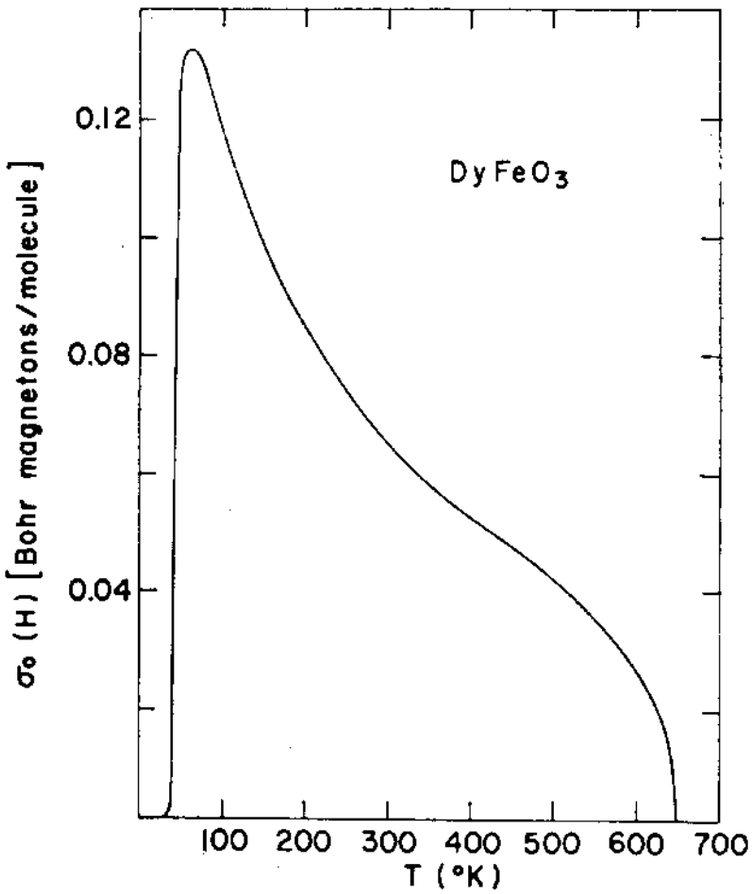




Dy: $G_x A_y$

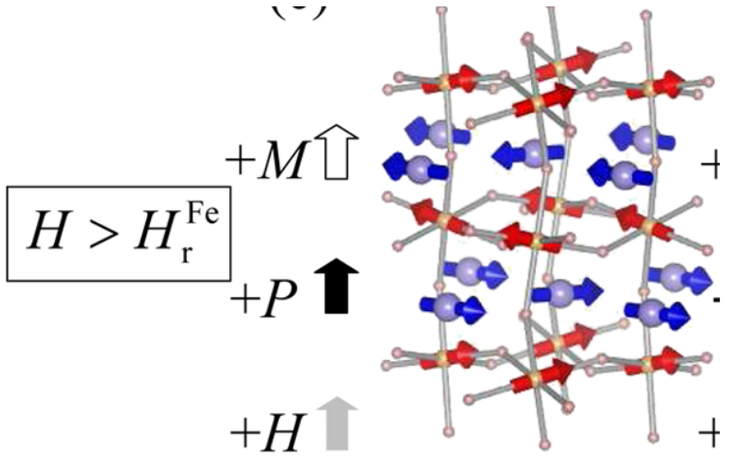


$Fe_I: G_x A_y F_z$

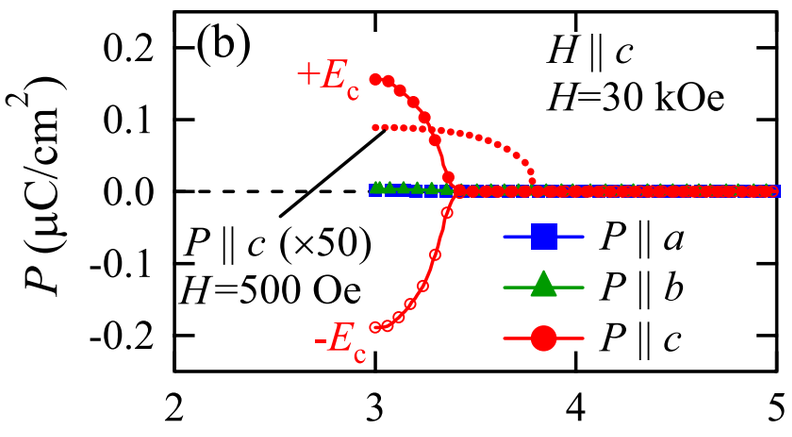


Journal of Applied Physics **39**, 1371 (1968);

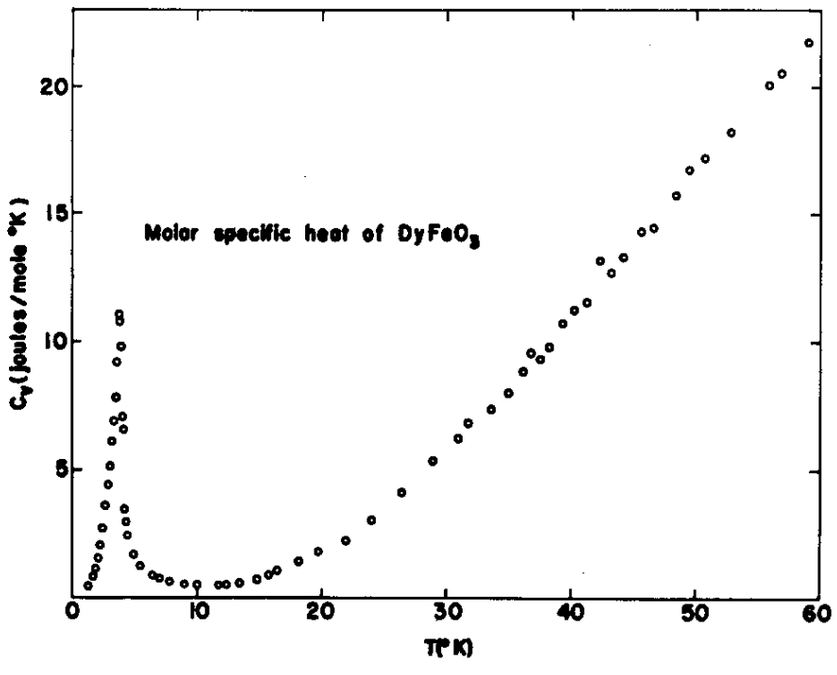
PHYSICAL REVIEW B **89**, 224405 (2014)



$G_x A_y$

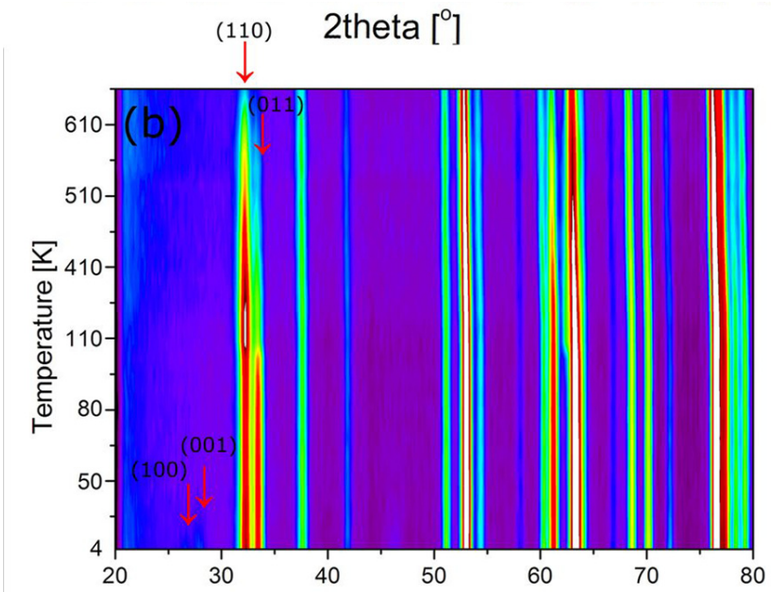


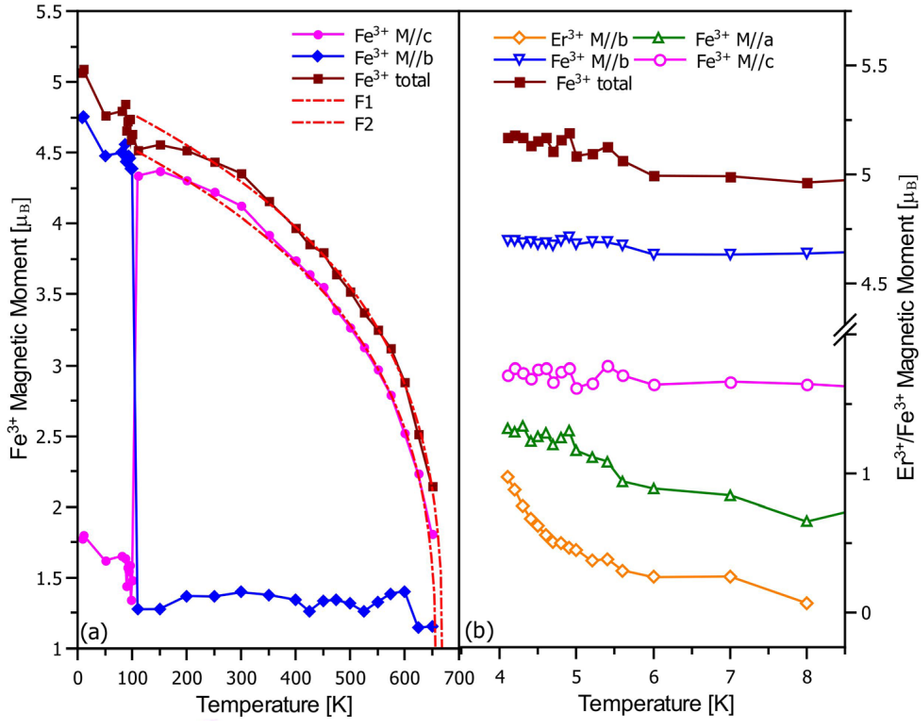
PRL **101,** 097205 (2008)

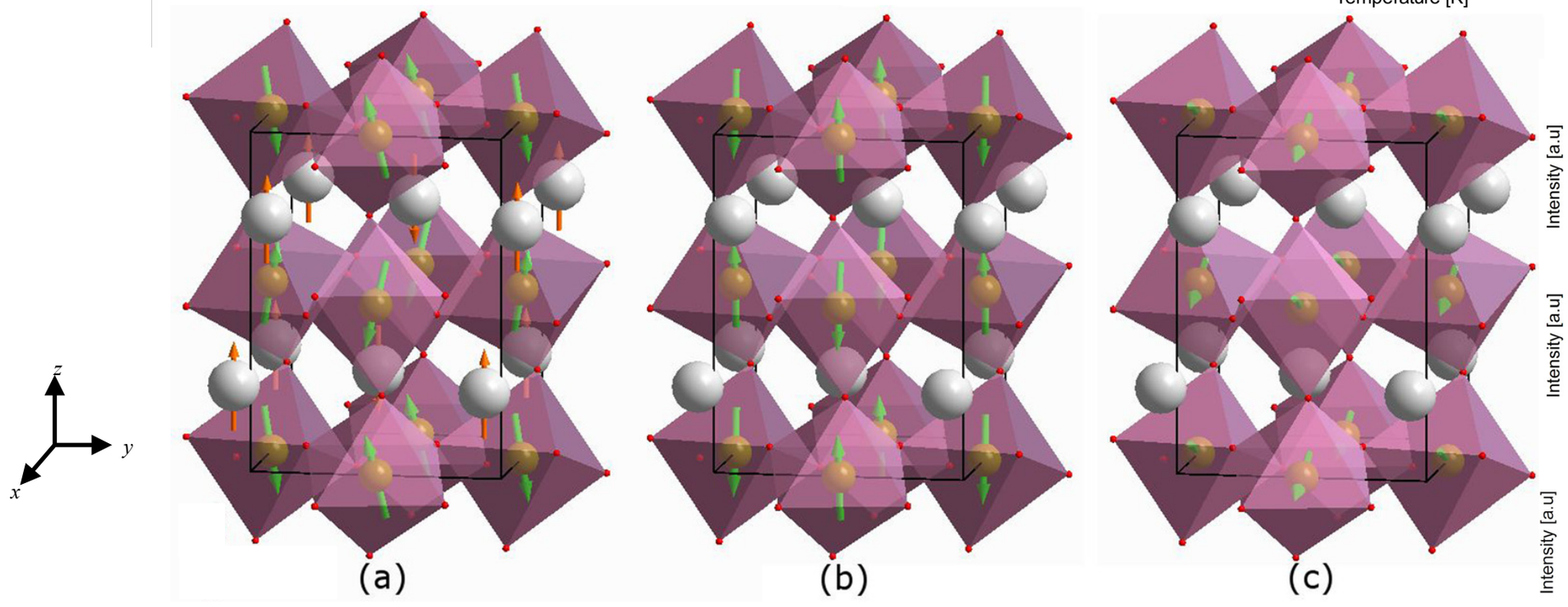


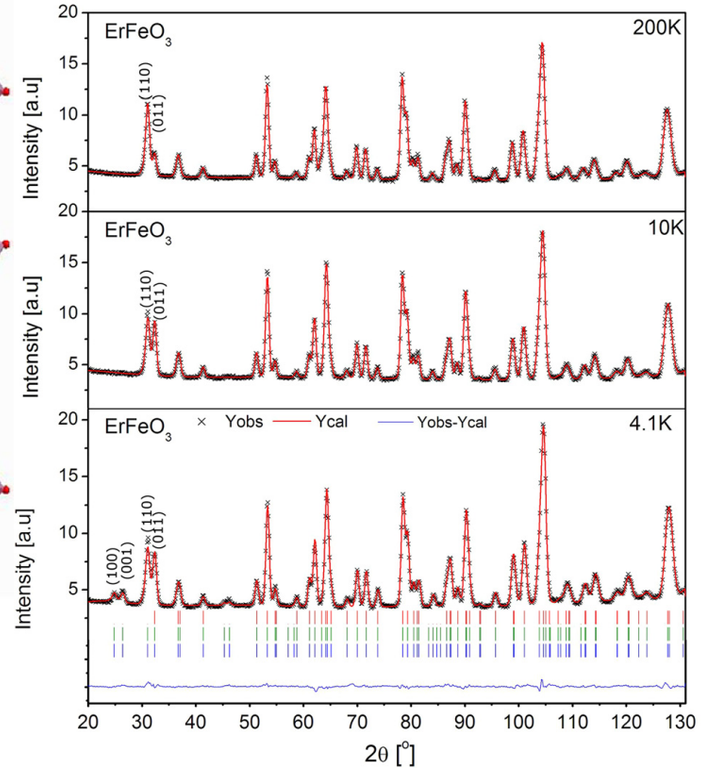
: Journal of Applied Physics **39**, 1367 (1968);

$ErFeO_3$









Er:C_z^R, Fe: $F_x C_y G_z$ $F_x G_z$ $G_x F_z$

T < 4.5 K 4.5K < T < 100 K 110 K < T < 650 K.

JOURNAL OF APPLIED PHYSICS **117**, 164105 (2015)

J. Phys. Chem. Solids, 1974, Vol. 35, pp. 479–500. Pergamon Press. Printed in Great Britain

THEORY OF SPIN REORIENTATION IN RARE-EARTH ORTHOCHROMITES AND ORTHOFERRITES*

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(*Received* 2 *April* 1973)

Abstract—Mechanisms of the temperature-induced spin-reorientation in rare-earth orthochromites (and orthoferrites) are examined. It is concluded that the anisotropic parts of the magnetic interactions between Cr^{3+} (or Fe^{3+}) and rare-earth ions, the antisymmetric and the anisotropic–symmetric exchange interactions, are generally responsible for both the *rotational* and the *abrupt* types of the spin-reorientations. These anisotropic exchange interactions produce an effective field for the Cr^{3+} up-spins in the direction perpendicular to that of these spins and an effective field for the Cr^{3+} down-spins in the direction opposite to the above. These effective fields favor rotation of the Cr^{3+} spins, retaining their original antiferromagnetic configuration. Thus, as the temperature is lowered, this effective field increases due to the increase of the rare-earth magnetization, and when the interaction energy of the Cr^{3+} spins with these effective fields exceeds the anisotropy energy of the Cr^{3+} ion, spin-reorientation takes place. At the beginning and ending of the spin-reorientation a second-order phase-transition occurs. The first-order nature of the *abrupt* spin-reorientation is stressed. Anisotropic exchange interactions between Cr^{3+} and rare-earth ions also play an important role in inducing the *abrupt* spin-reorientation.

- Strong coupling between 4f and 3d electrons
- Anisotropic part of the exchange interaction
- Rare earth ordering observed at much lower temp.

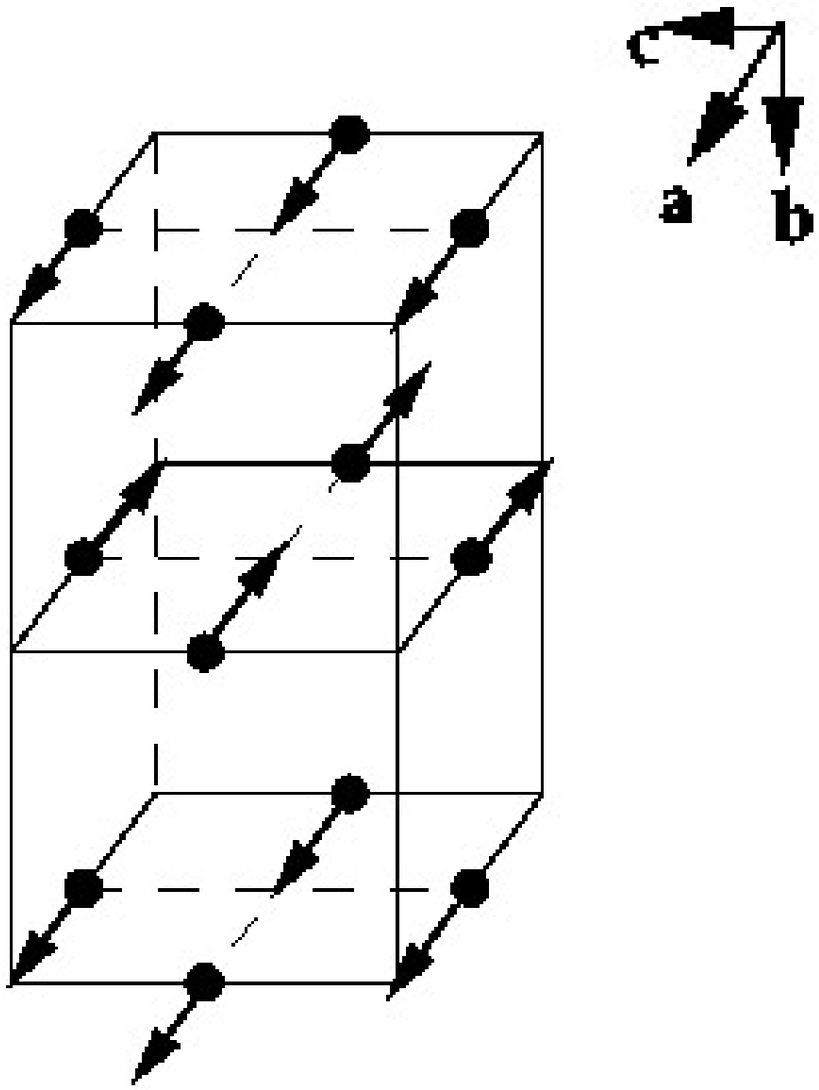
- Role of Rare earth moments ?
- ***Role of the Fe spin canting ?***

$NdMnO_3$

Magnetic structure evolution of $NdMnO_3$ derived from neutron diffraction data

A Muñoz†¶, J A Alonso‡, M J Martínez-Lope‡, J L García-Muñoz§ and M T Fernández-Díaz‖

J. Phys.: Condens. Matter **12** (2000) 1361–1376.

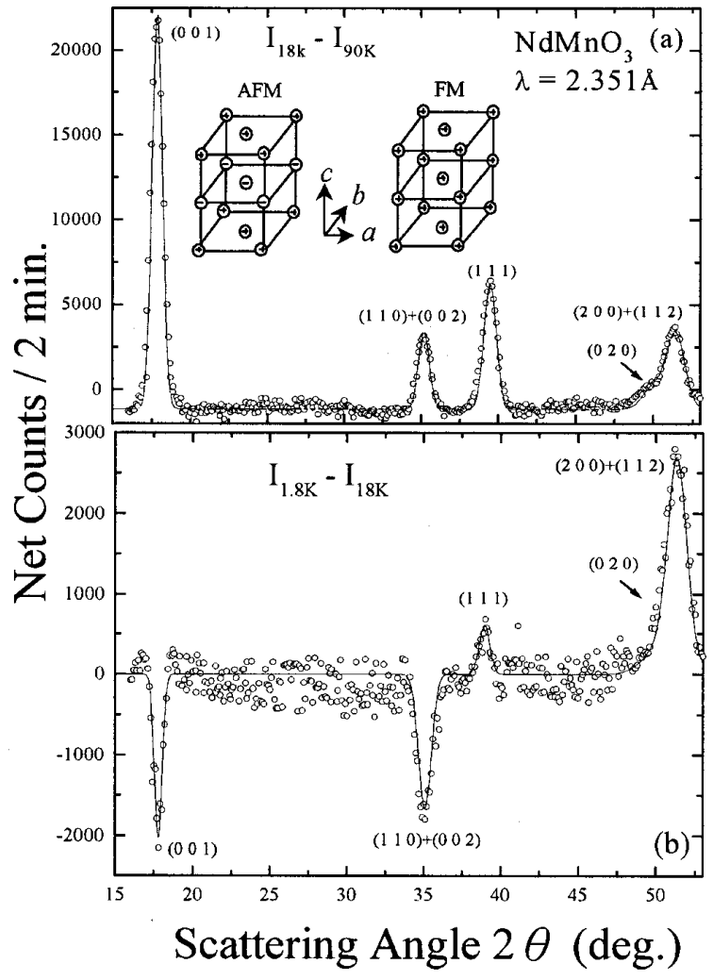


Magnetic structure and spin reorientation of the Mn ions in $NdMnO_3$

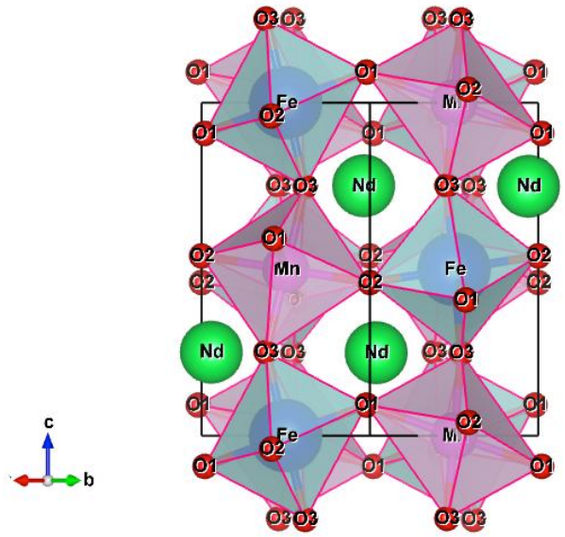
S. Y. Wu, C. M. Kuo, H. Y. Wang, W.-H. Li,[a] and K. C. Lee
Department of Physics, National Central University, Chung-Li, Taiwan 32054

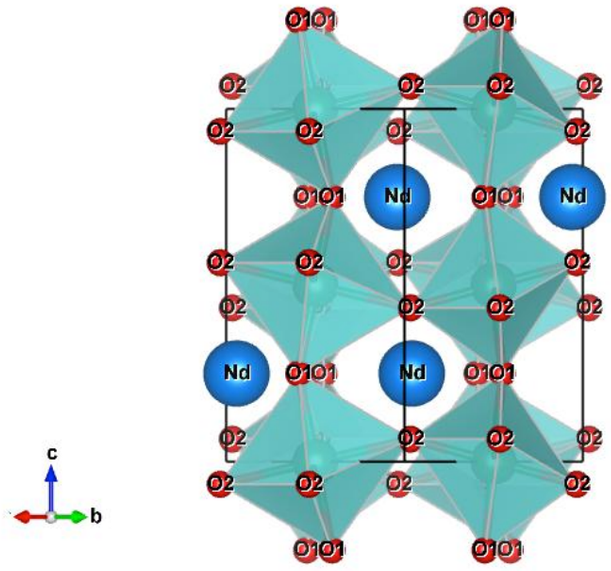
J. W. Lynn
NIST Center for Neutron Research, NIST, Gaithersburg, Maryland 20899

R. S. Liu
Department of Chemistry, National Taiwan University, Taipei, Taiwan 106



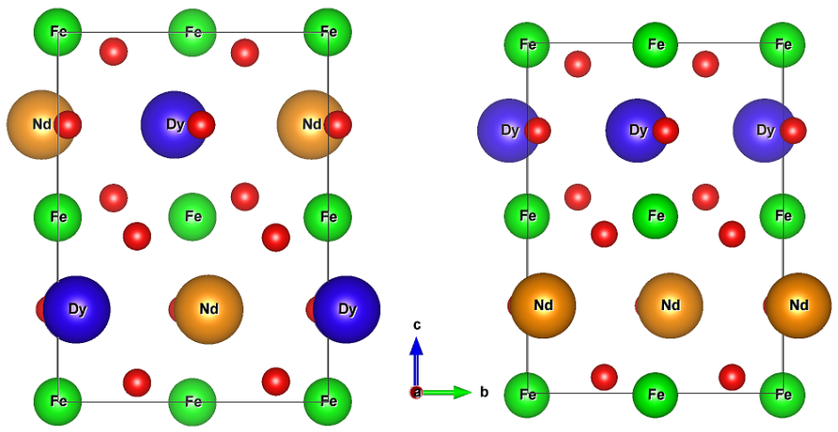
- ***Role of the B site***





$NdFe_{0.5}Mn_{0.5}O_3/Nd_2MnFeO_6$

- ***Role of the A site***

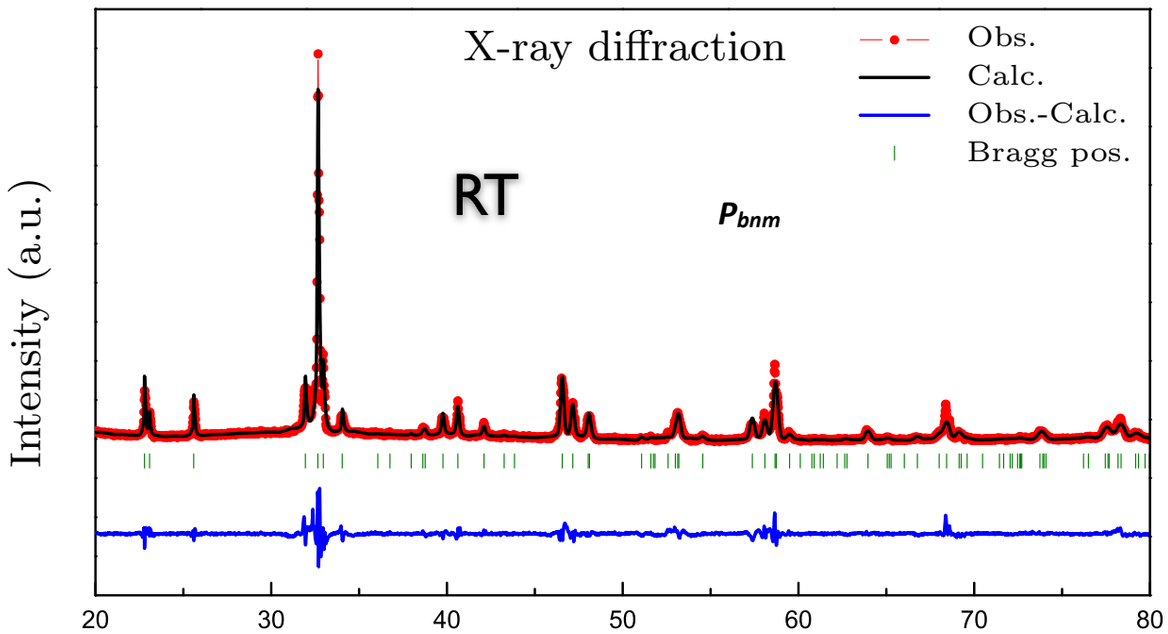


$Er_{0.5}Dy_{0.5}FeO_3$

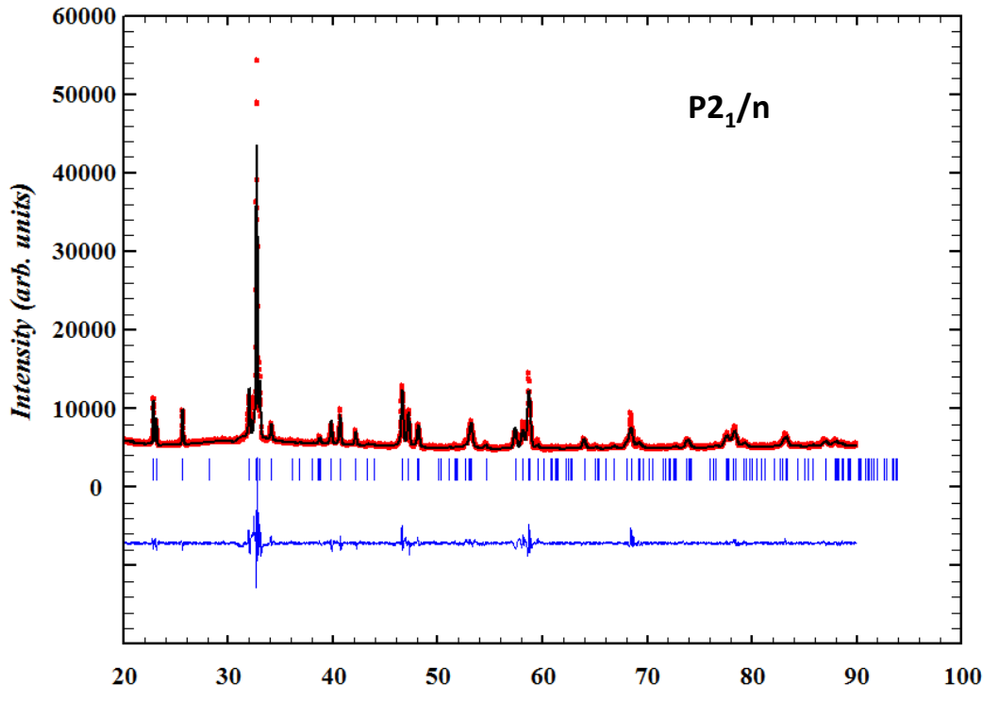
Results

$NdFe_{0.5}Mn_{0.5}O_3/Nd_2MnFeO_6$

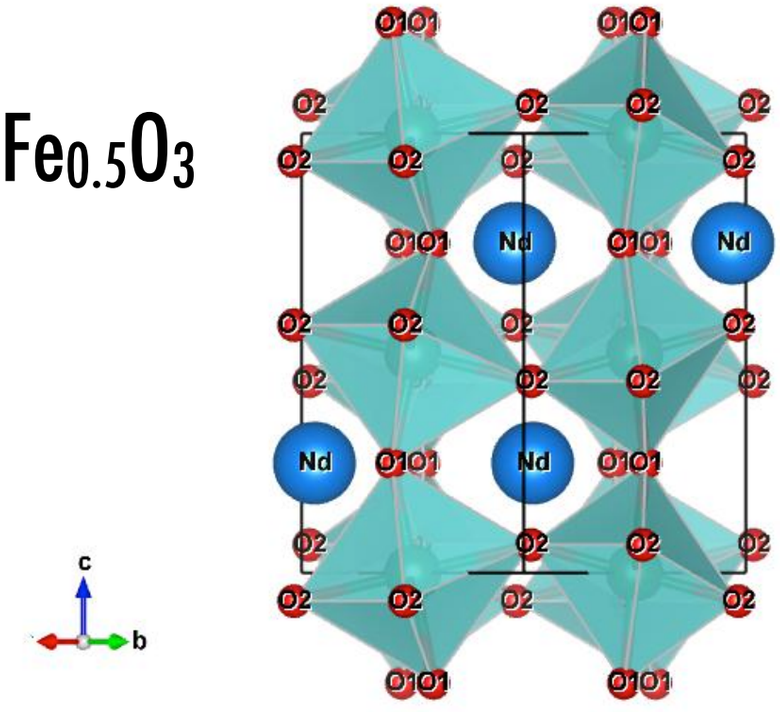
Structural characterization



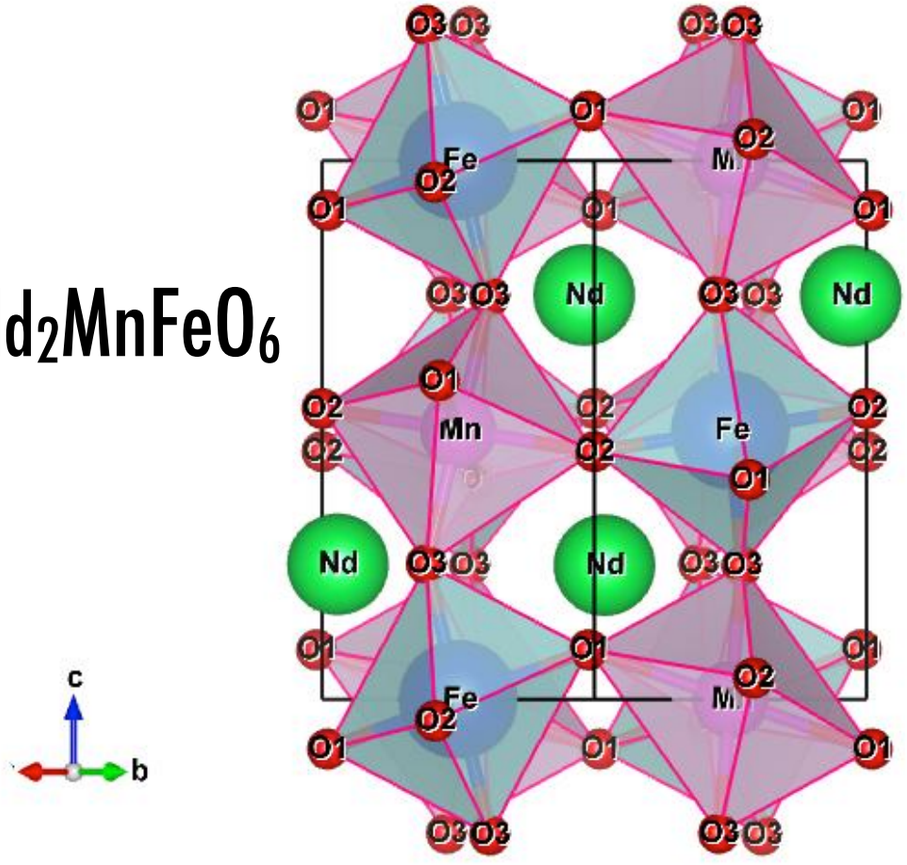
A. Singh et al., Physical Review B 96, 144420 (2017)



$NdMn_{0.5}Fe_{0.5}O_3$

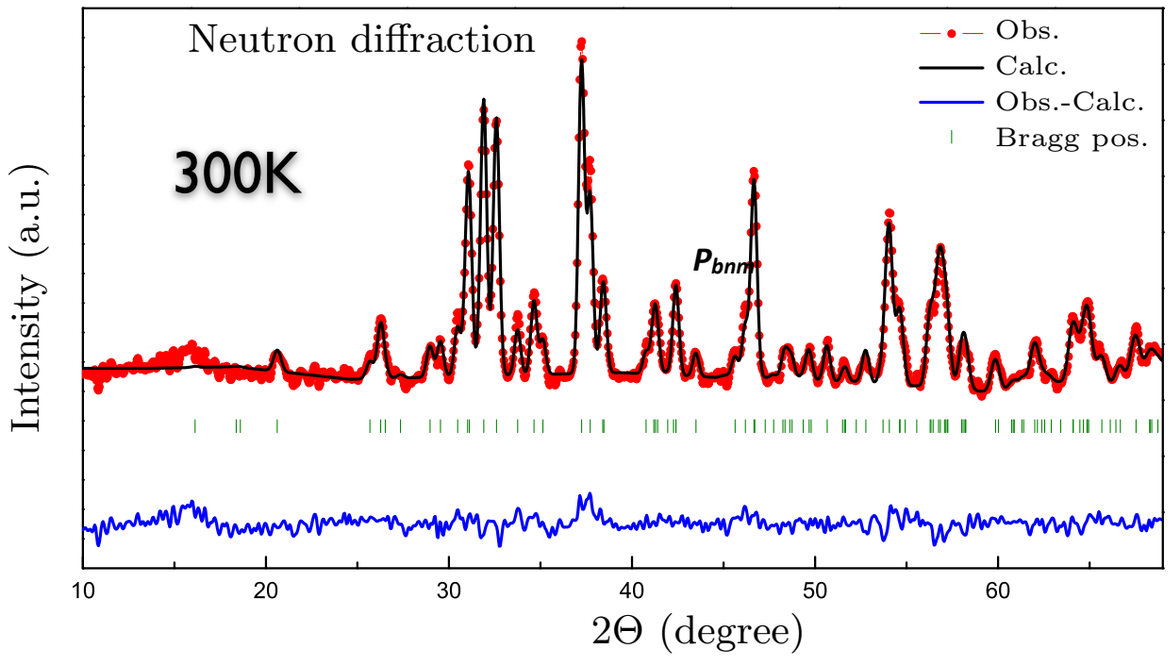


Nd_2MnFeO_6



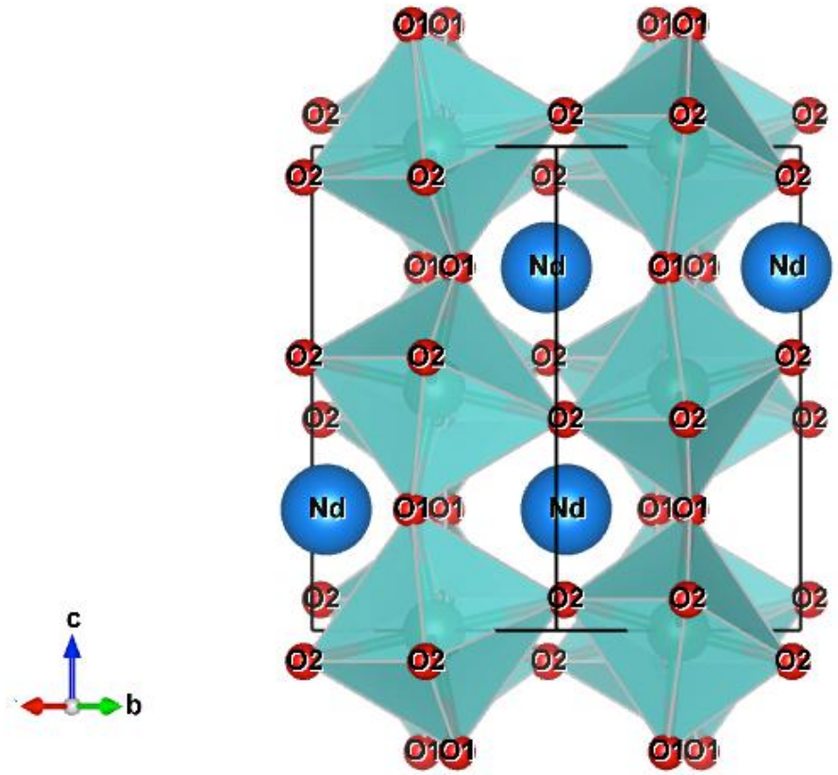
Structural characterization

Neutron diffraction data



A. Singh et al., Physical Review B 96, 144420 (2017)

$NdFe_{0.5}Mn_{0.5}O_3$

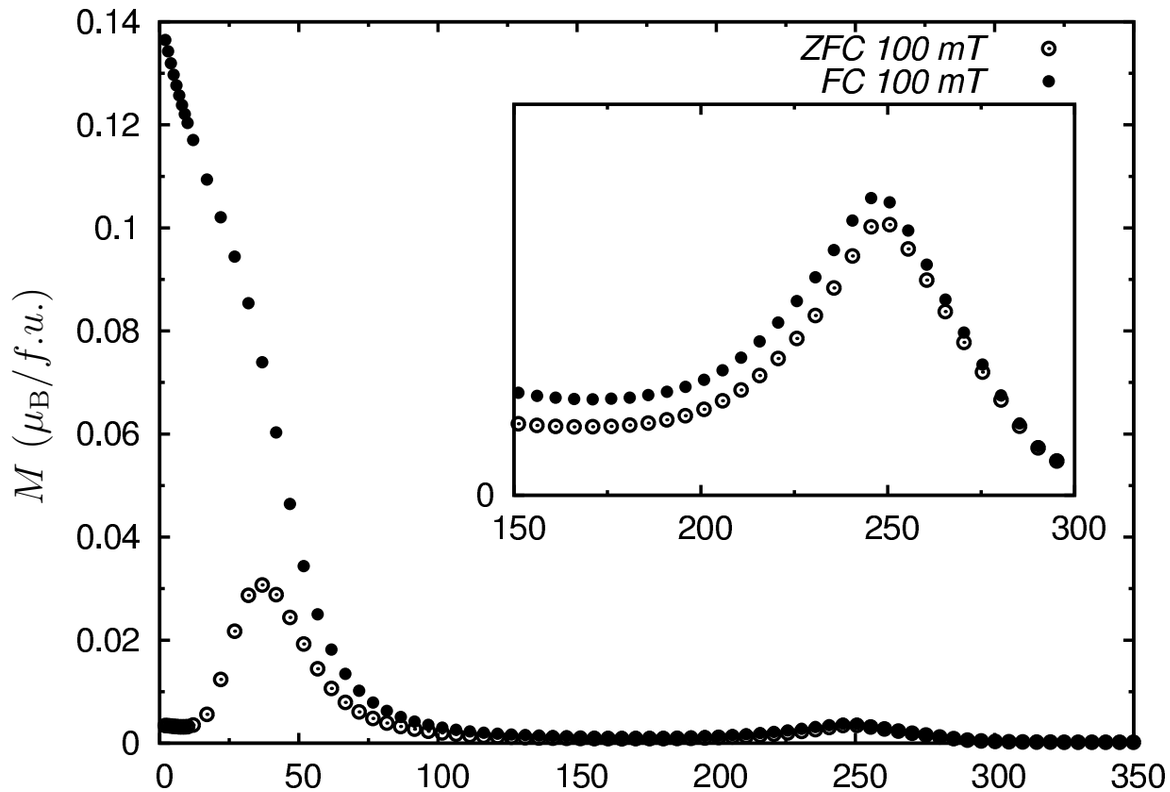


$NdMn_{0.5}Fe_{0.5}O_3$

$NdMn_{0.5}Fe_{0.5}O_3$ crystallizes in orthorhombic crystal structure

Lattice parameters intermediate to $NdFeO_3$ and $NdMnO_3$

Magnetic characterization



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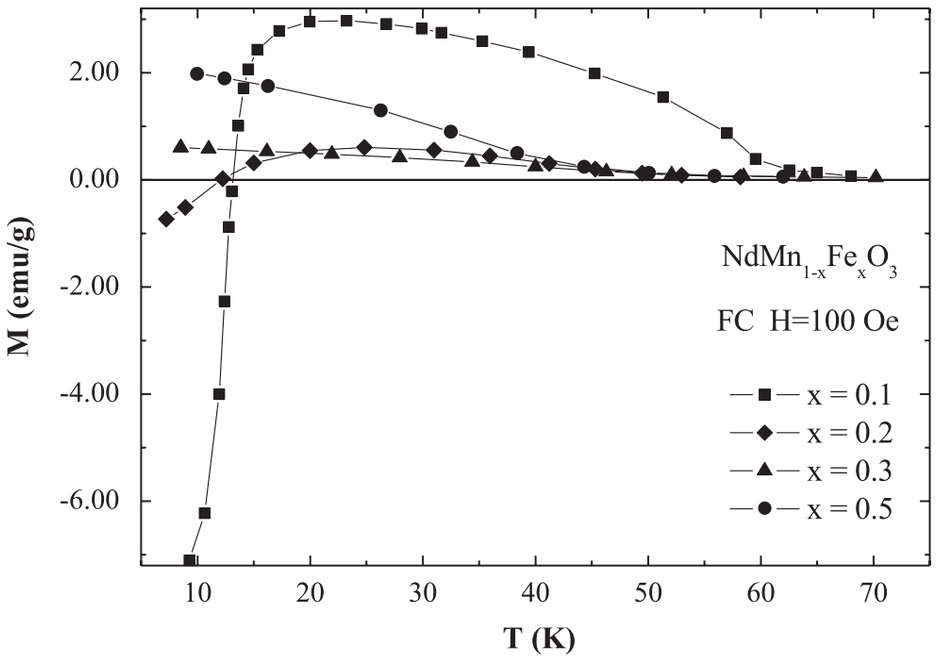

I.O. Troyanchuk et al. J.M.M.M. **312**,470 (2007)

$NdFe_{0.5}Mn_{0.5}O_3$

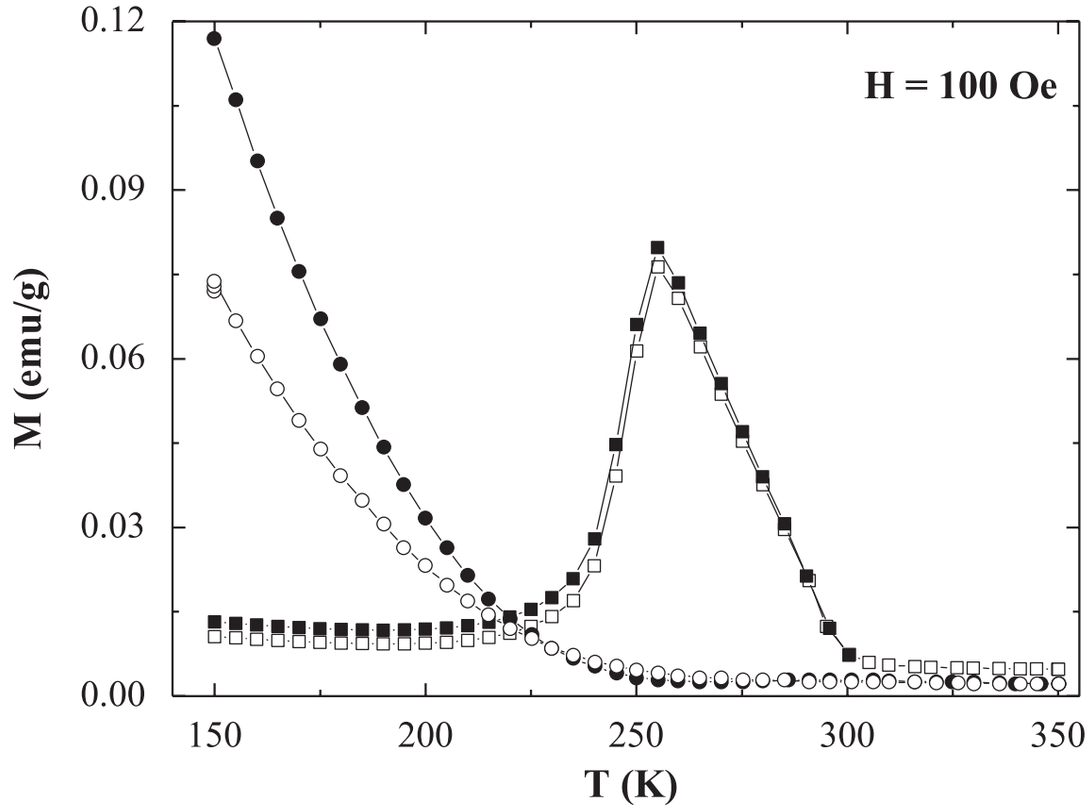

Fig. 4. ZFC (open symbols) and FC (closed symbols) magnetization vs. temperature for $NdMn_{0.5}Fe_{0.5}O_3$ (square) and $LaMn_{0.5}Fe_{0.5}O_3$ (circle).

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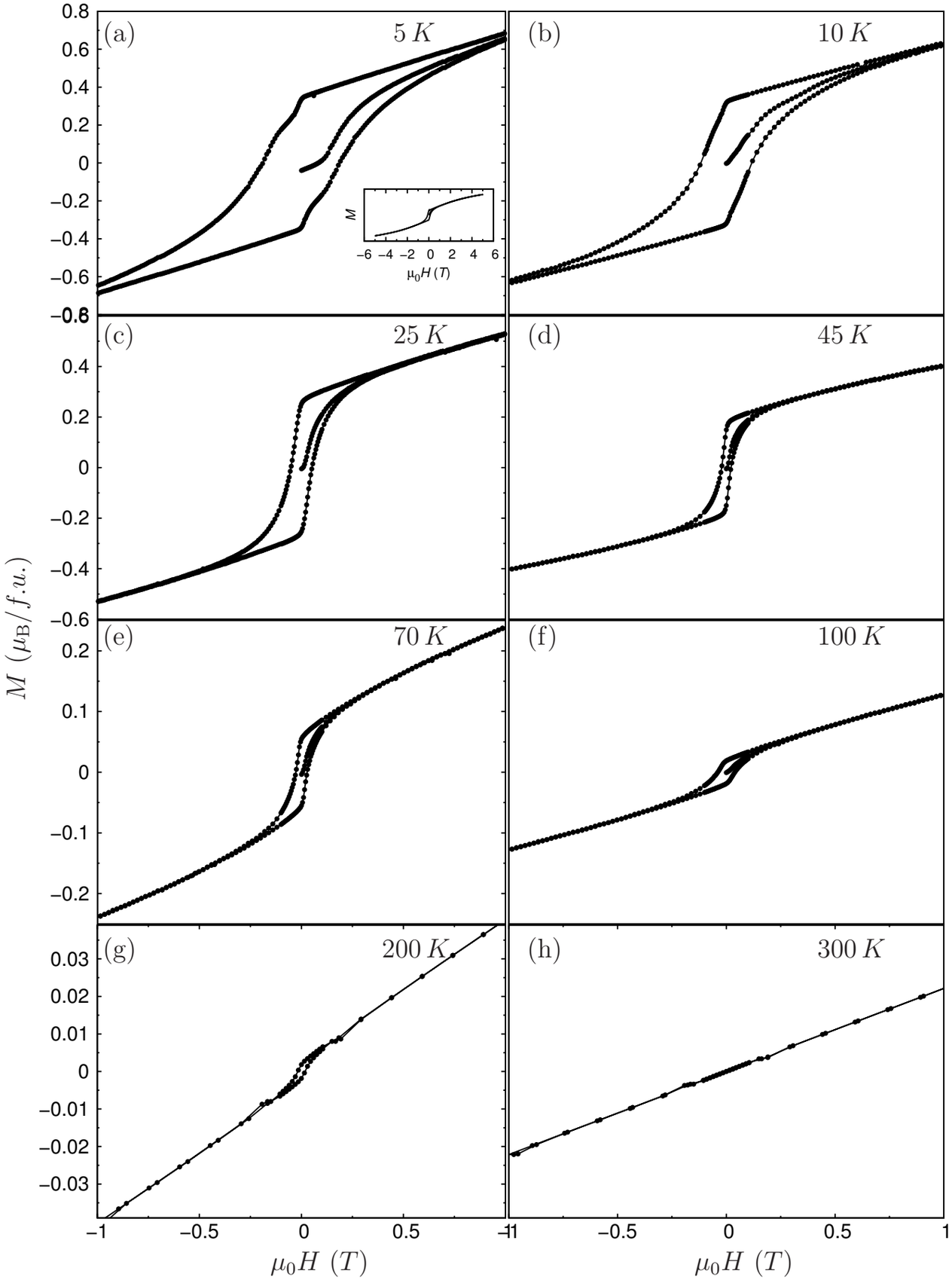
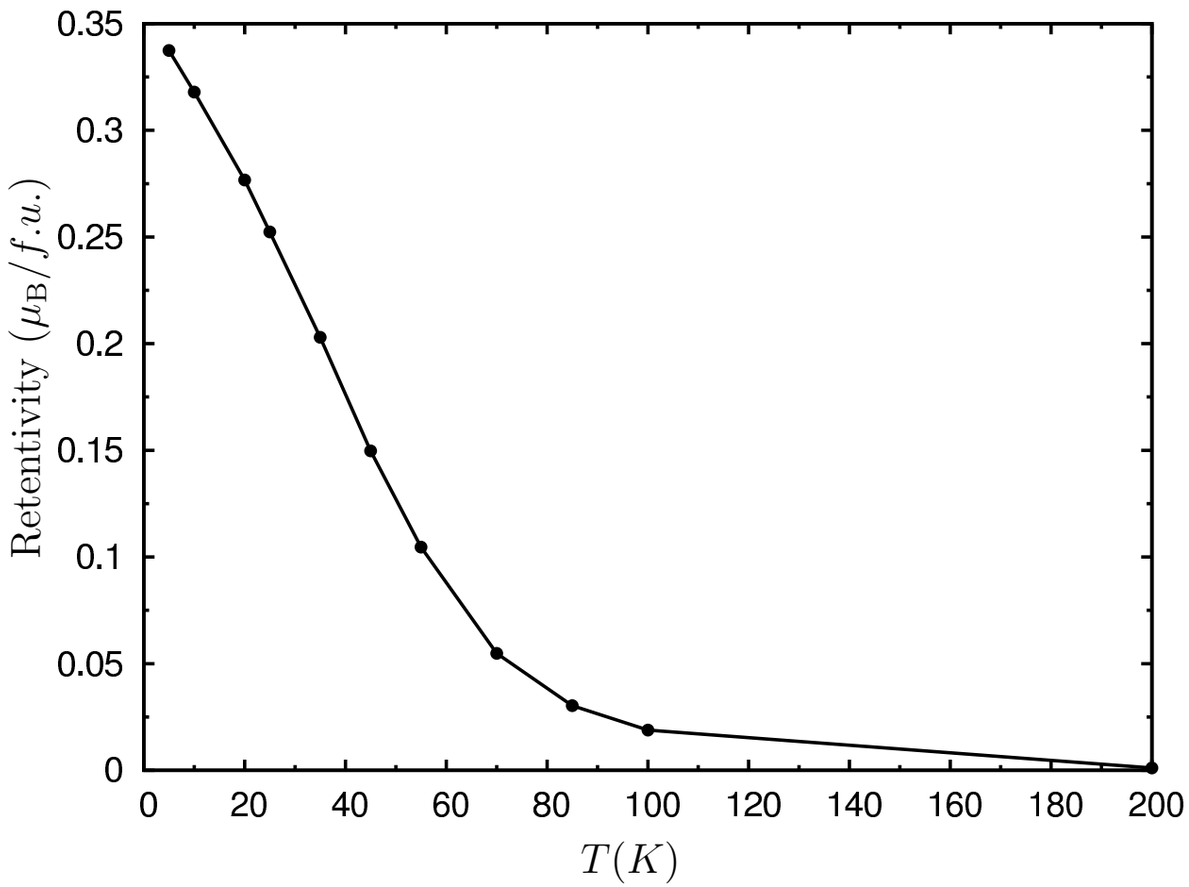
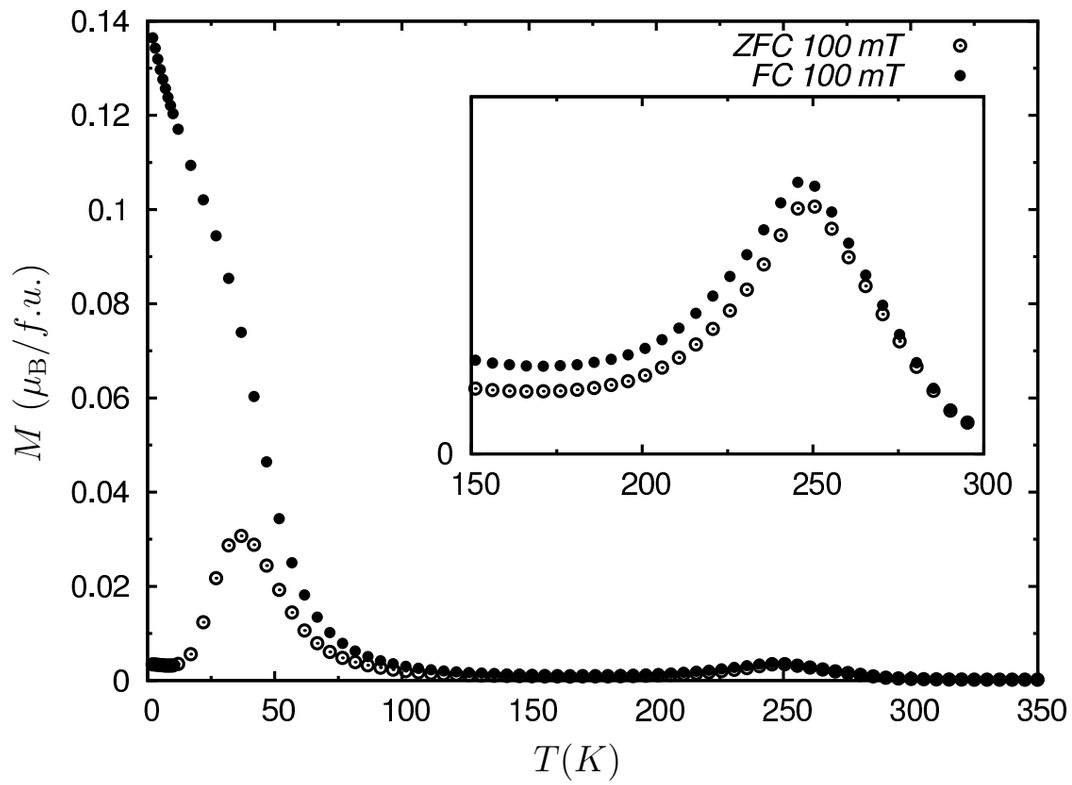
In Fig. 4 the results of $NdMn_{0.5}Fe_{0.5}O_3$ magnetization vs. temperature measurements are demonstrated in FC and ZFC regimes. Near $T = 300$ K the divergence of the curves is observed as result of the spontaneous magnetization appearance. In the temperature interval 220–300 K both ZFC and FC magnetizations demonstrate a wide cusp which has not been observed for $LaMn_{0.5}Fe_{0.5}O_3$ compound. Below 40 K the FC magnetization exhibits a sharp increase probably associated with an appearance of a spin-glass component (Fig. 5). Such a type of anomalous

Magnetic characterization







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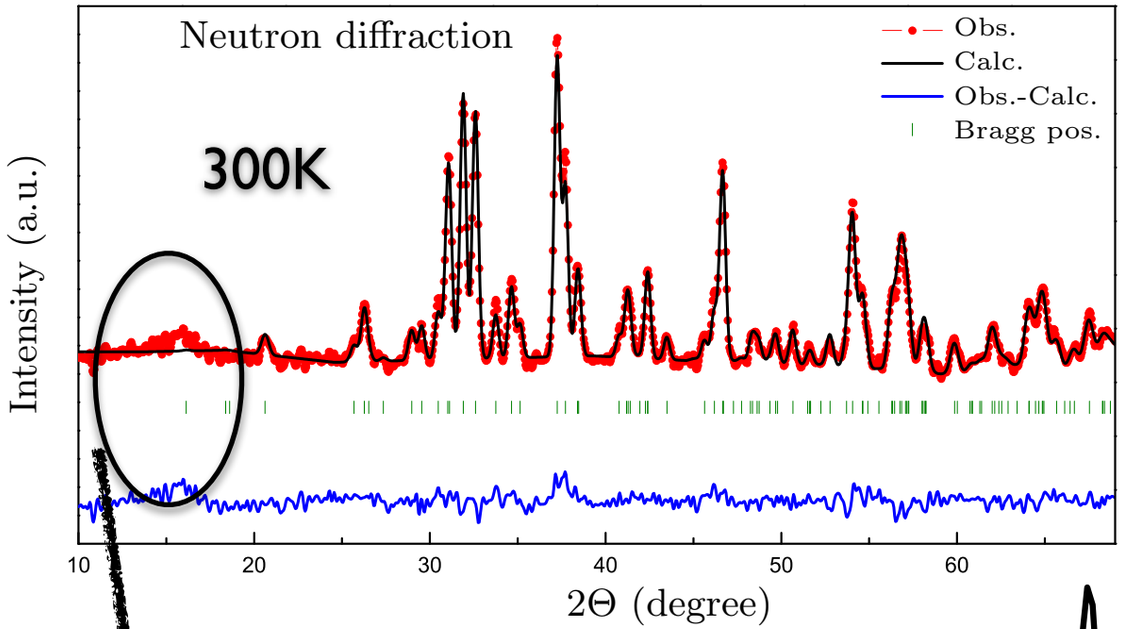
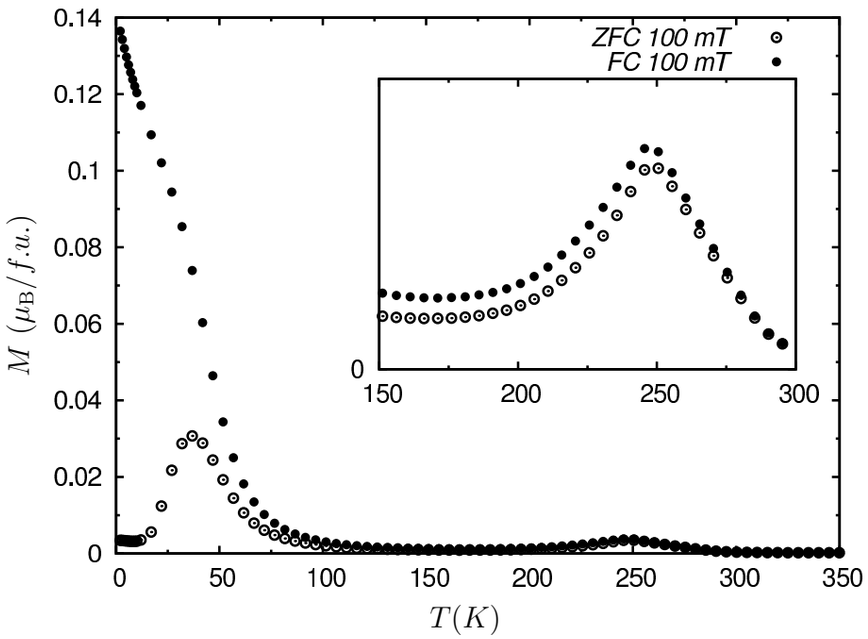
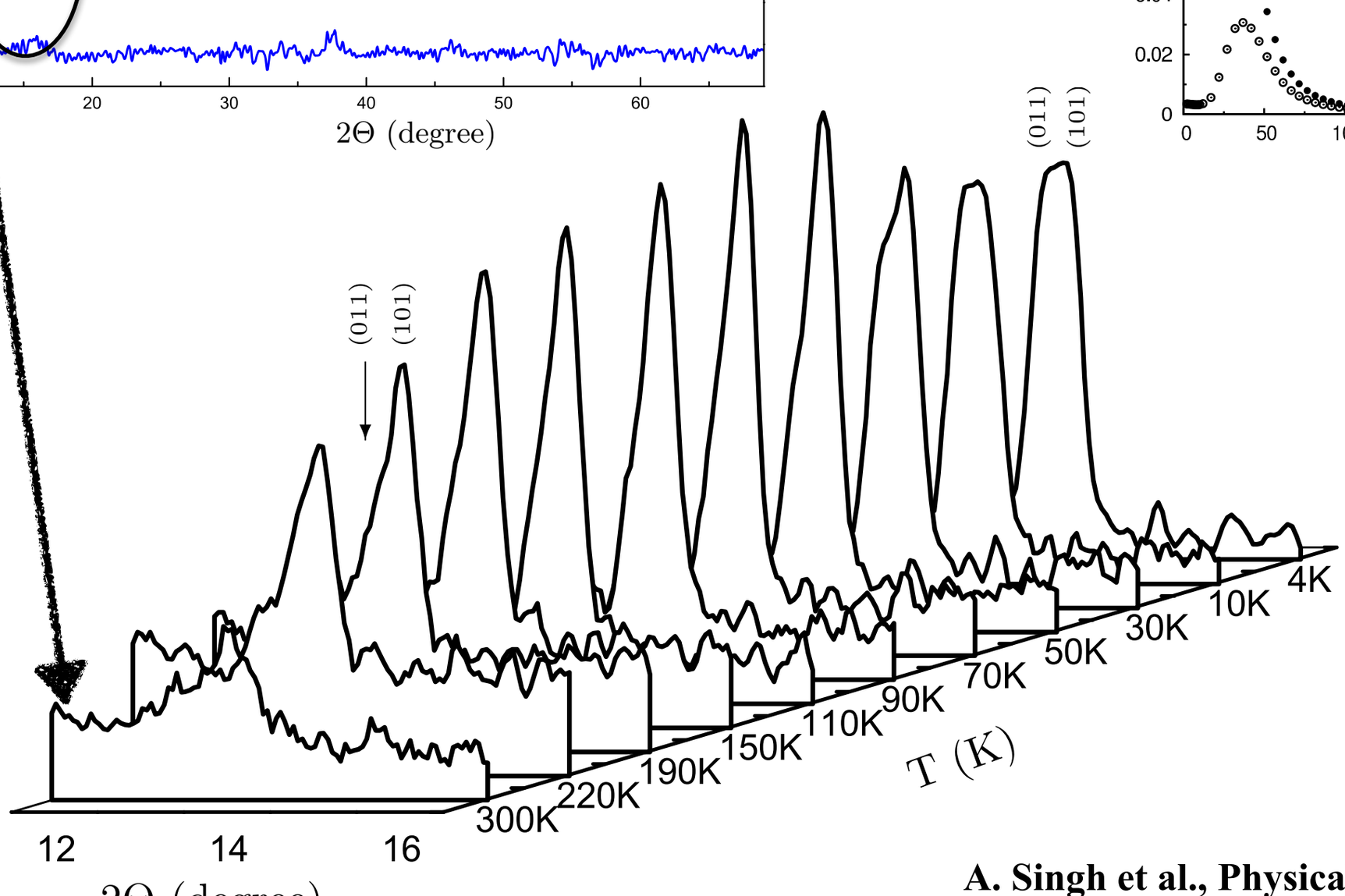
$NdFe_{0.5}Mn_{0.5}O_3$







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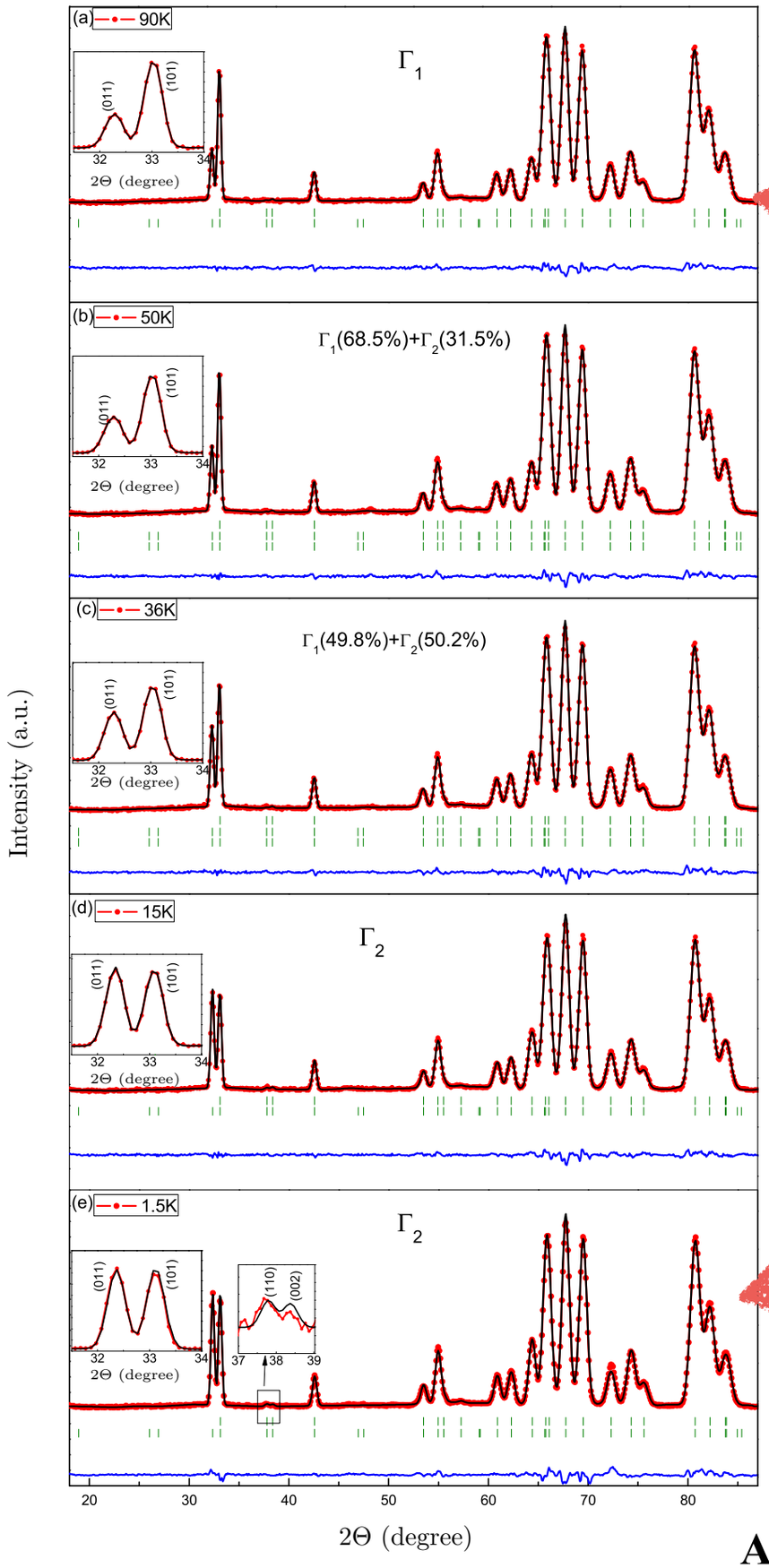
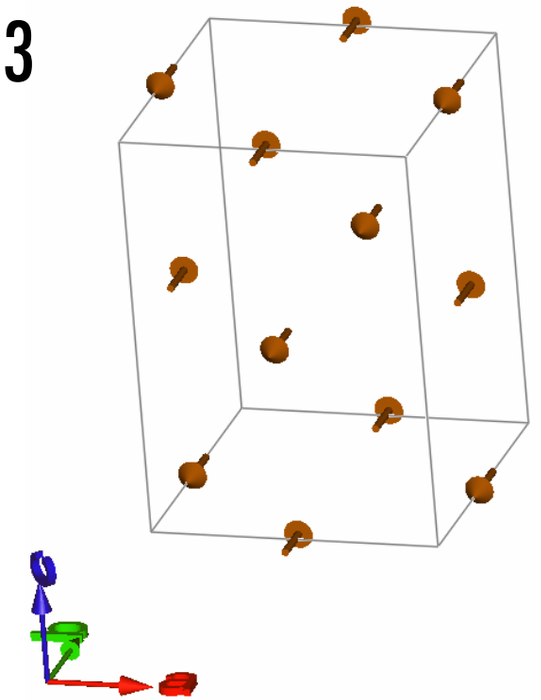
Magnetic characterization | Neutron diffraction



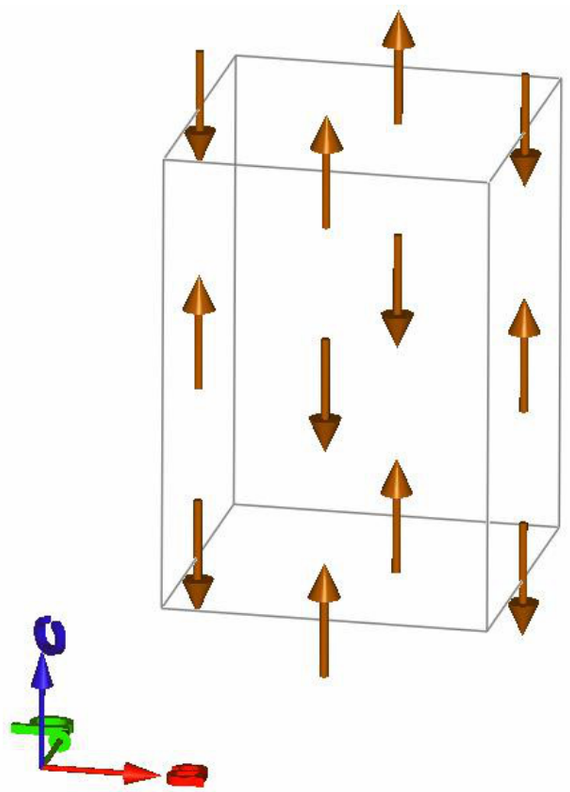
$NdFe_{0.5}Mn_{0.5}O_3$

(a) High temperature magnetic structure



$A_x\, G_y\, C_z$

(b) Low temperature magnetic structure



$F_x\, C_y\, G_z$

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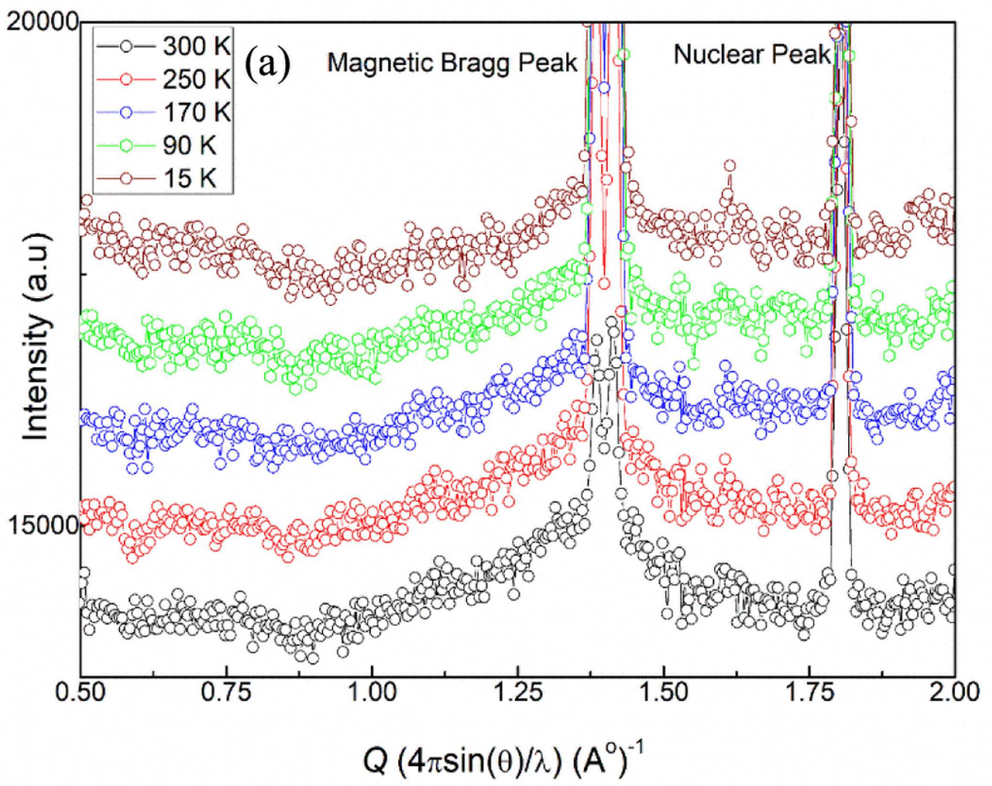
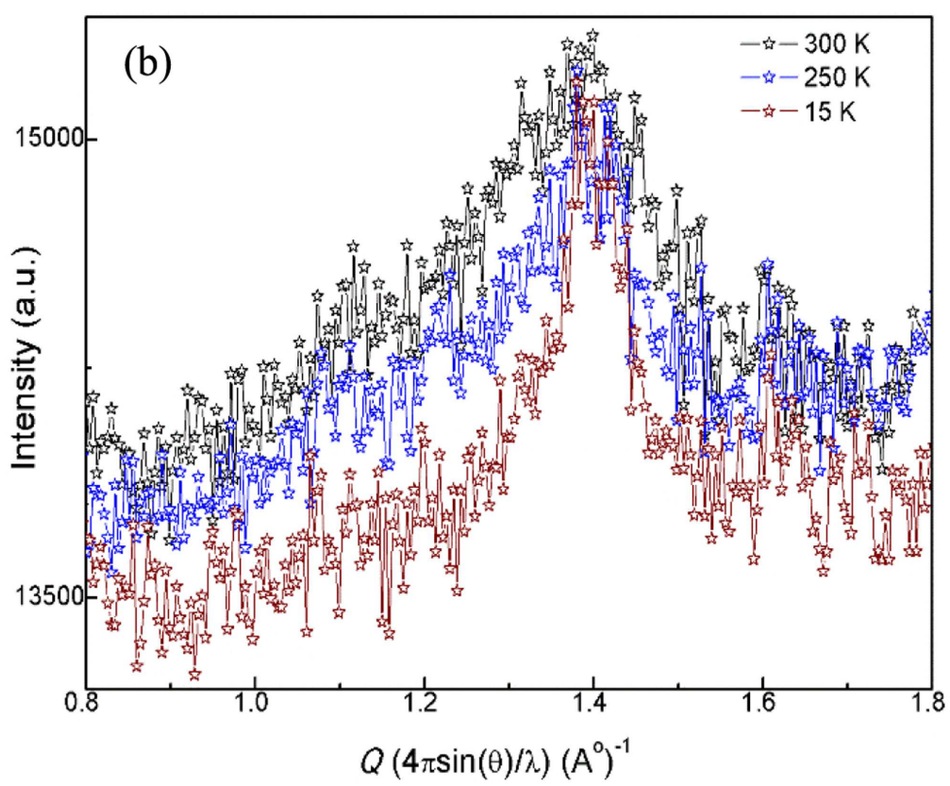
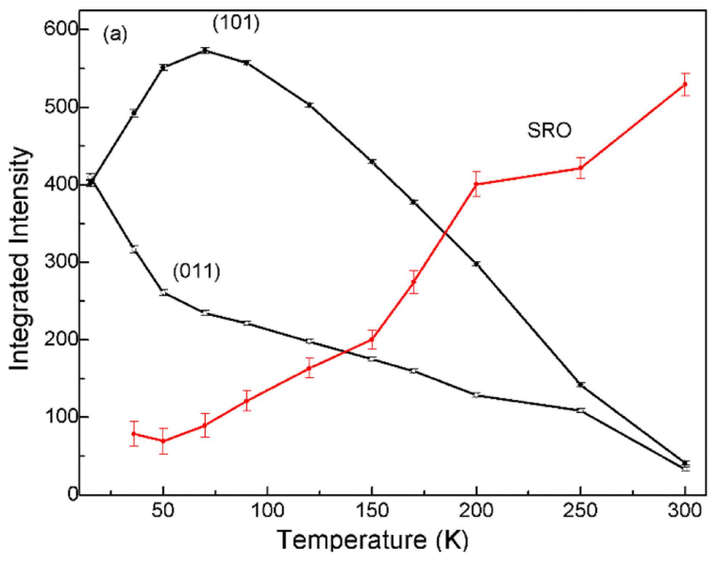
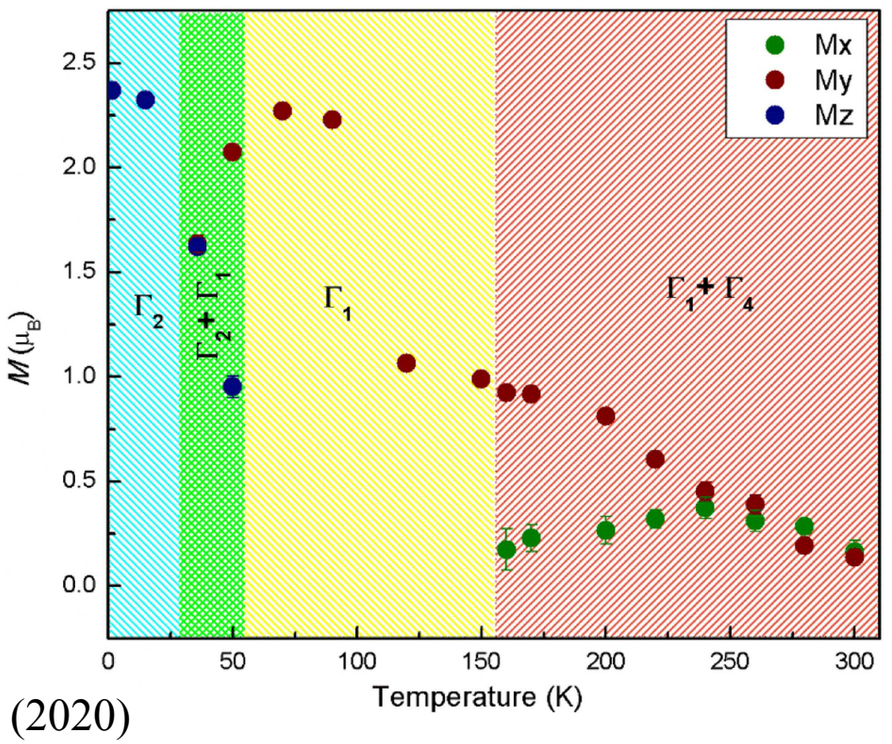
Magnetic characterization

Neutron diffraction









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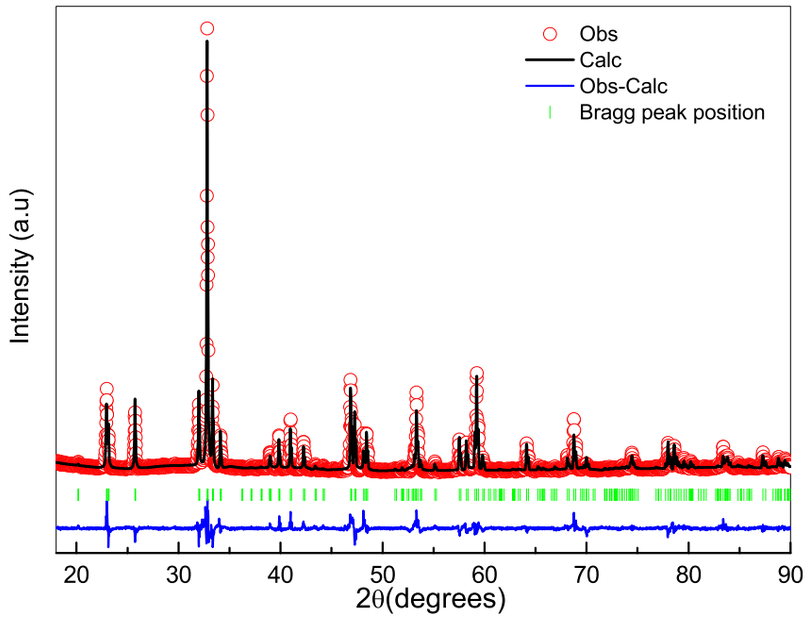
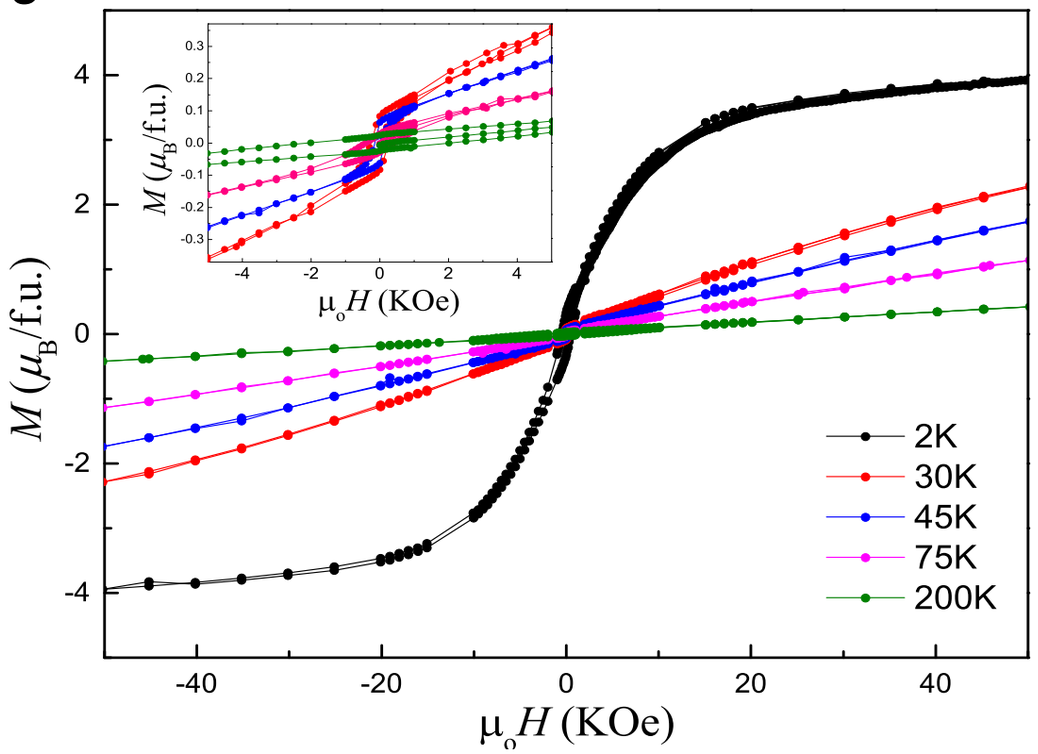
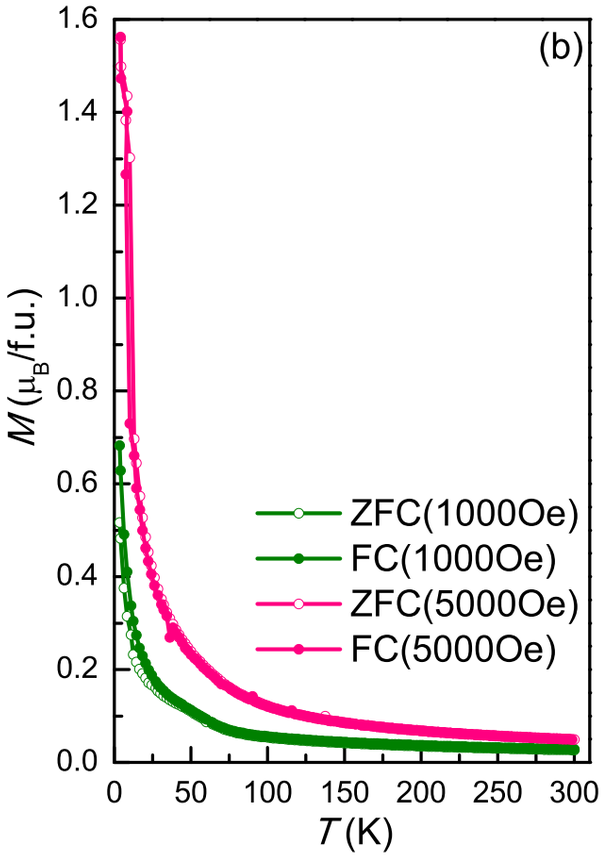
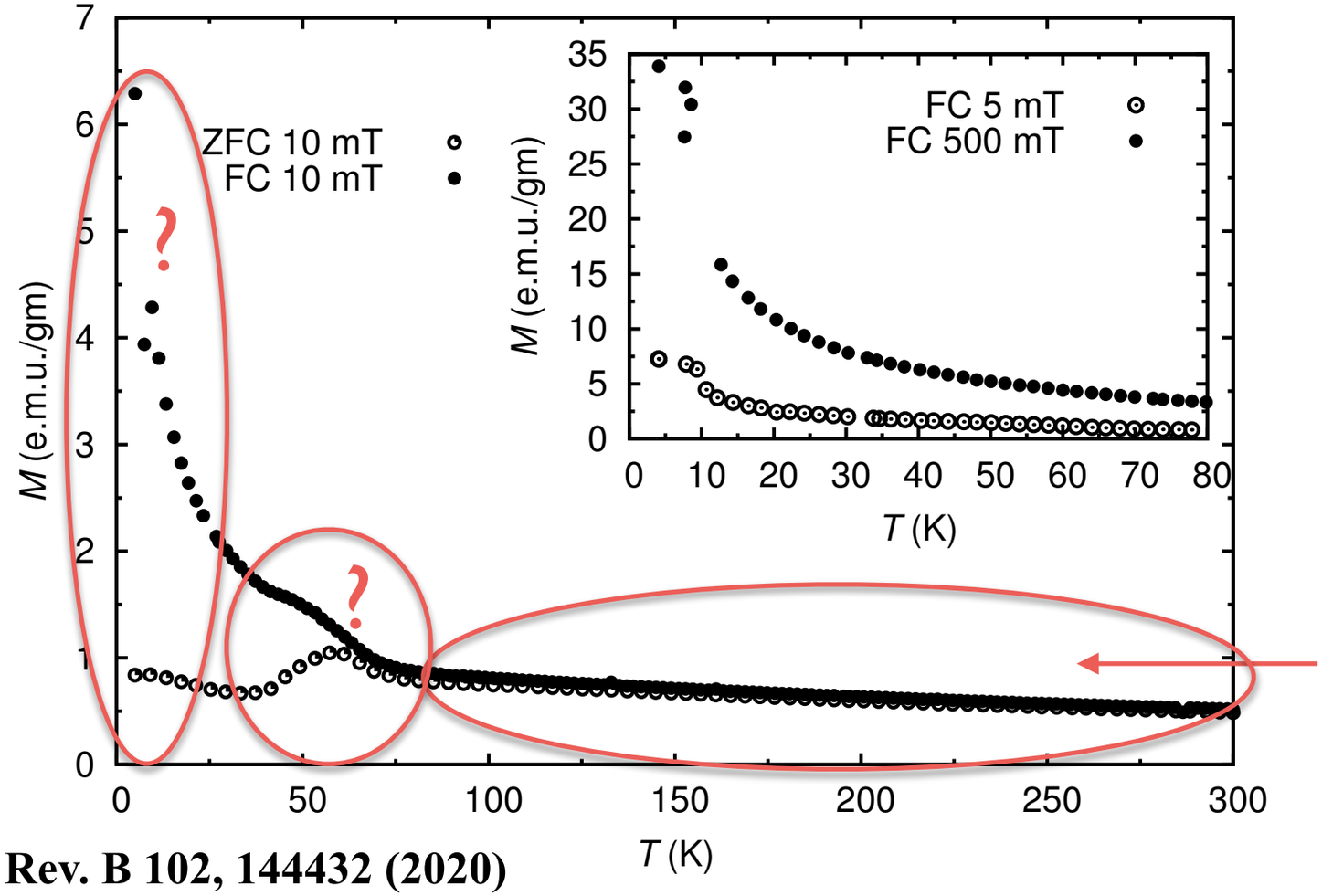
Results

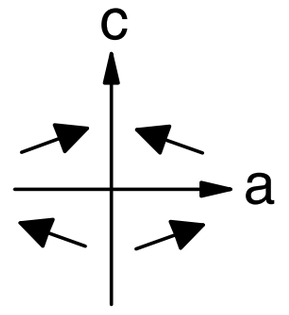
$Nd_{0.5}Dy_{0.5}FeO_3$











Fe_I: $G_x A_y F_z$

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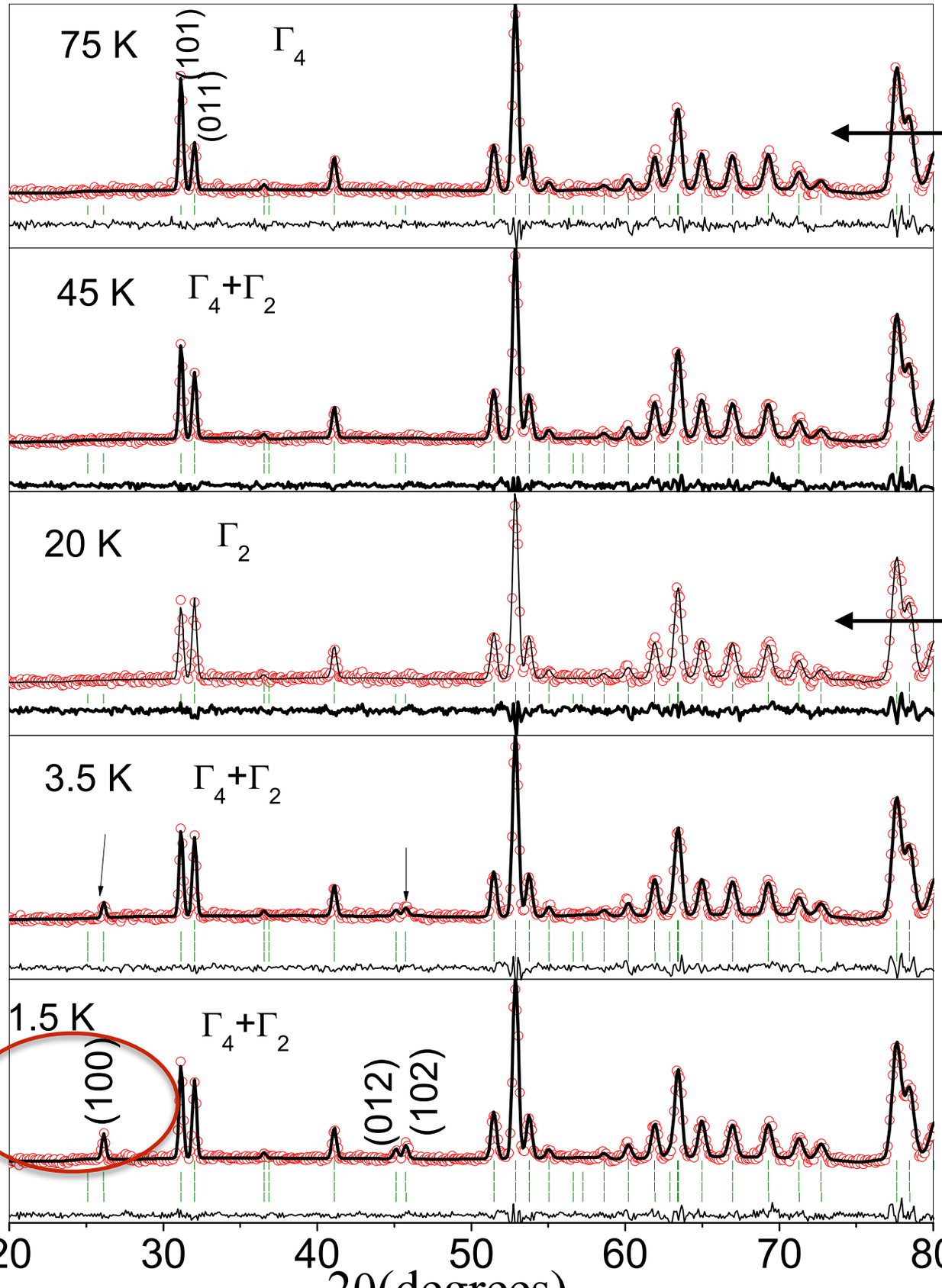
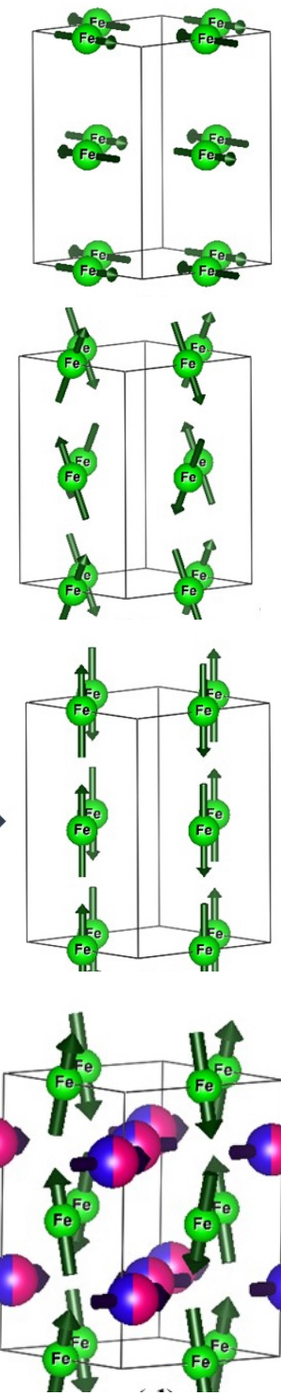
Neutron diffraction

G-41@LLB, Saclay

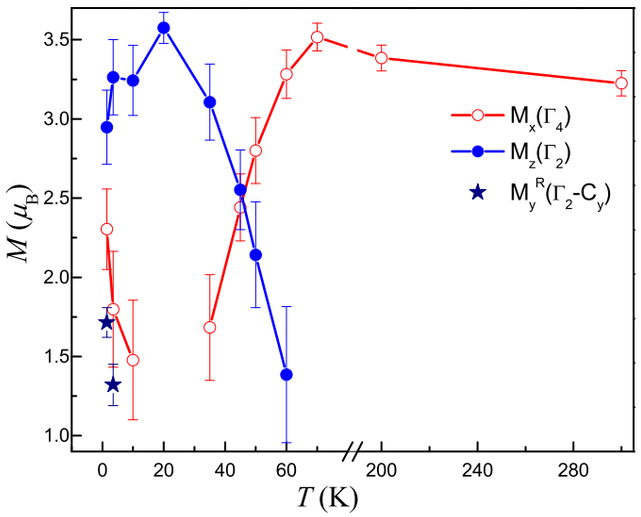
$Nd_{0.5}Dy_{0.5}FeO_3$



Gx Ay Fz



Fx Cy Gz



C_y type ordering of Rare-earth

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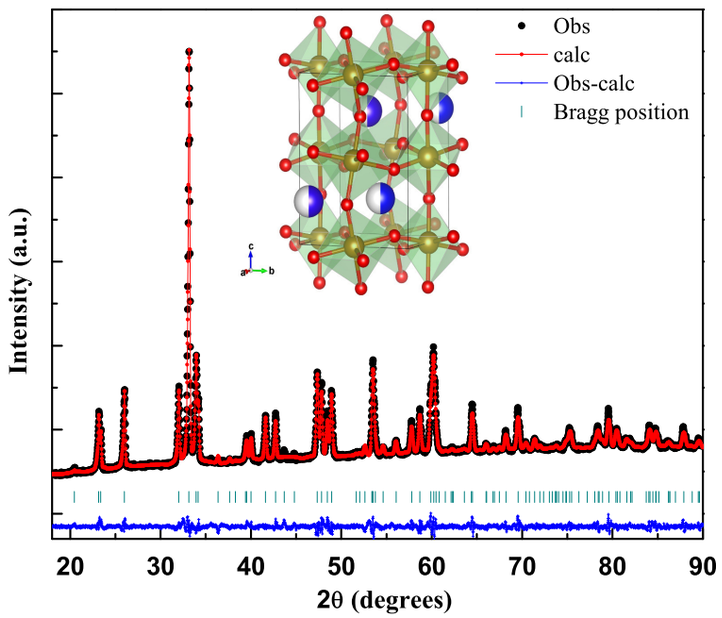
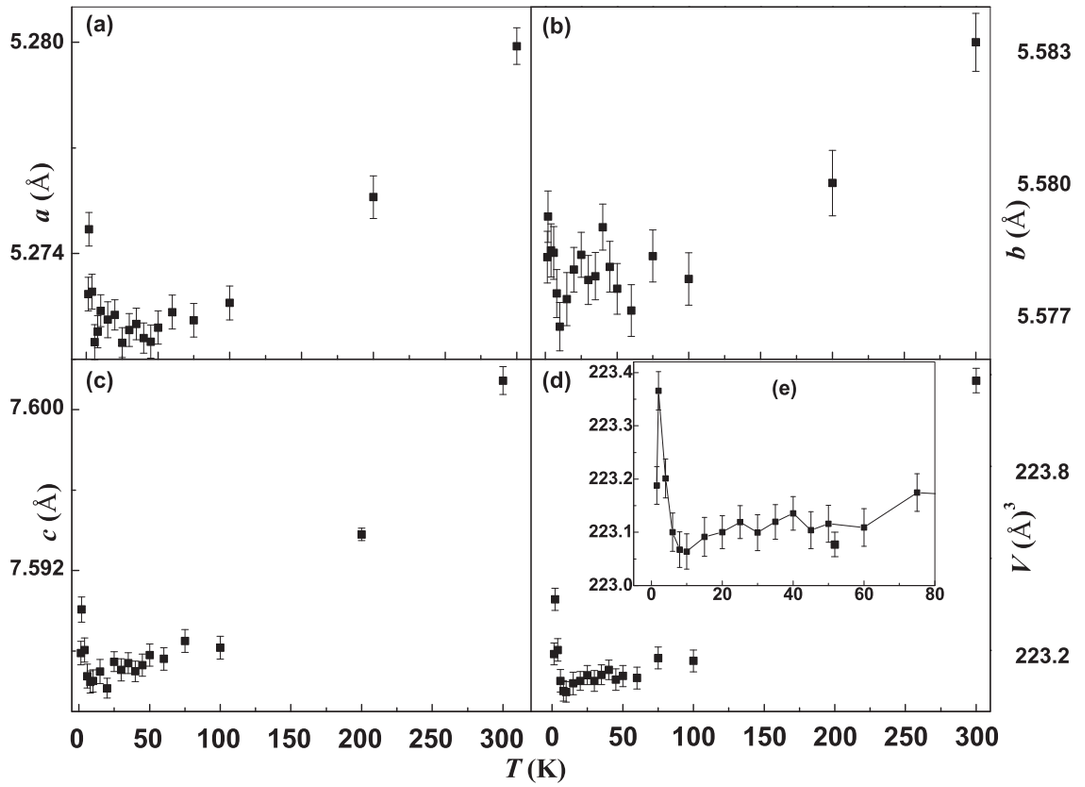
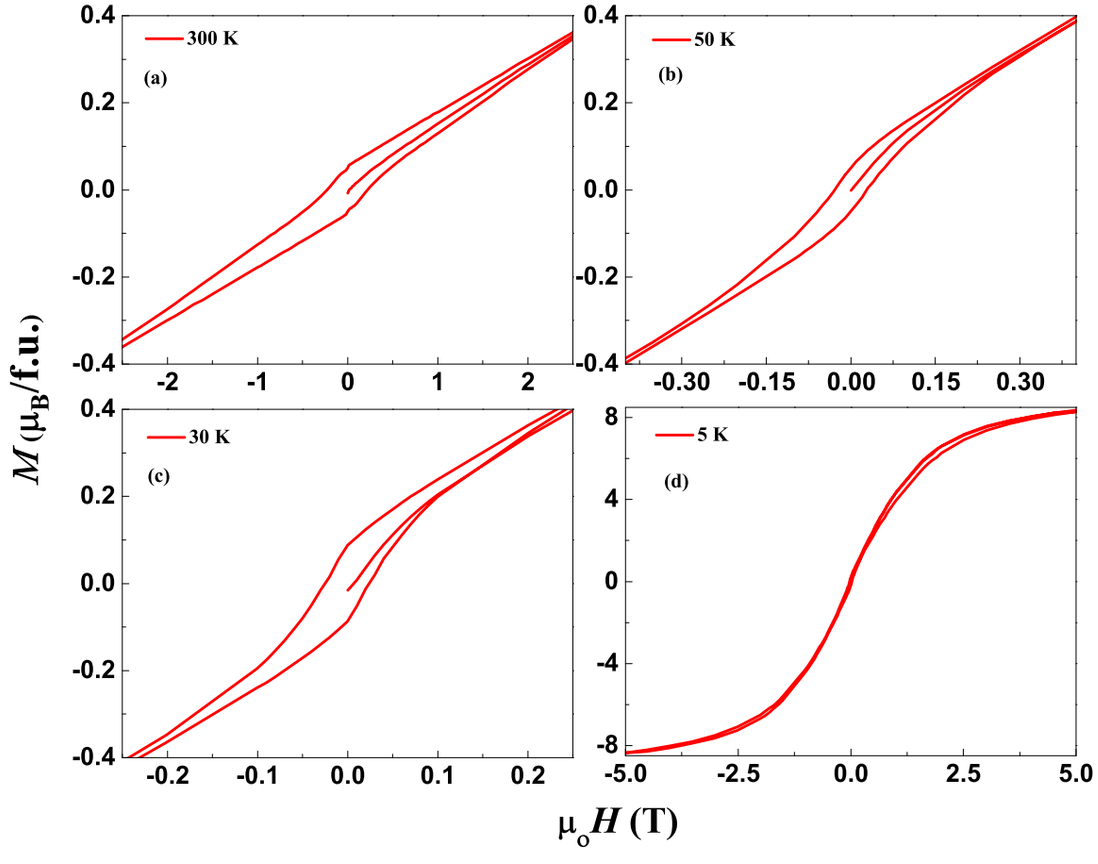
Results

$Er_{0.5}Dy_{0.5}FeO_3$







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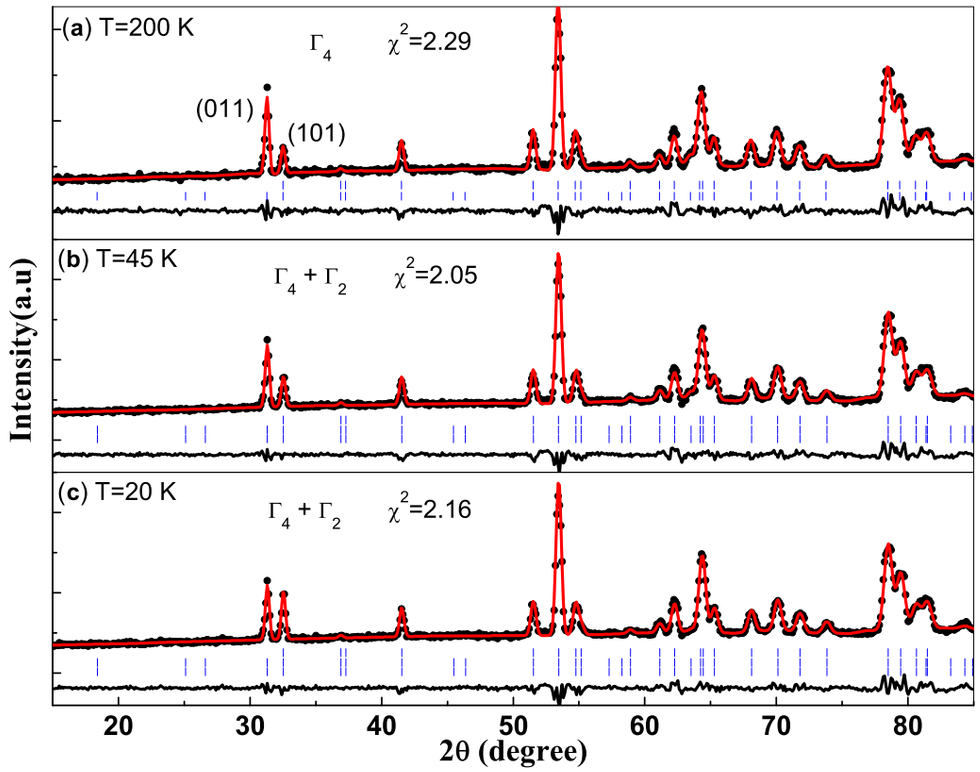
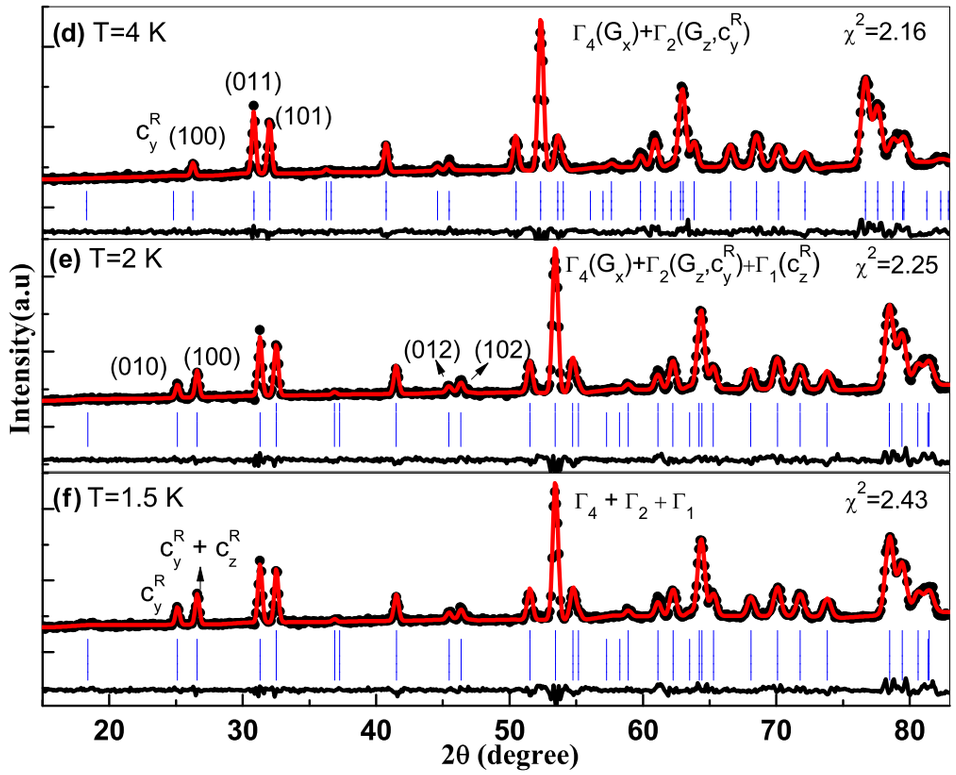
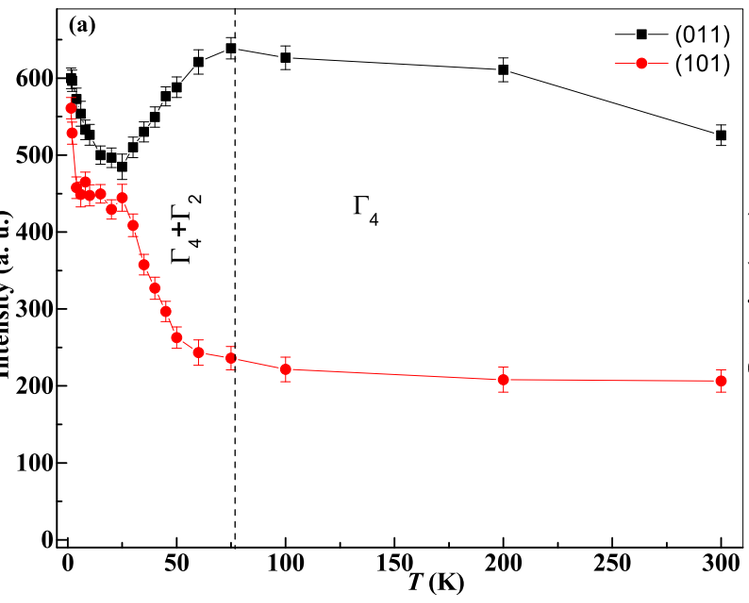
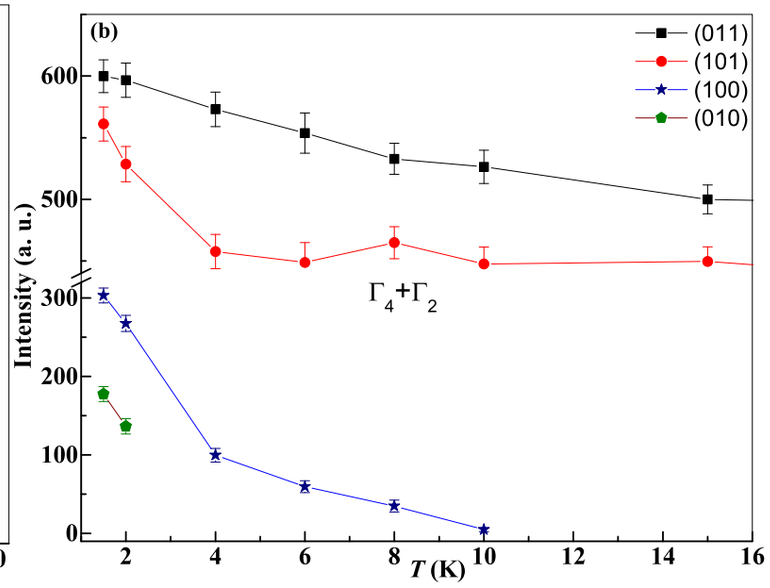
Results

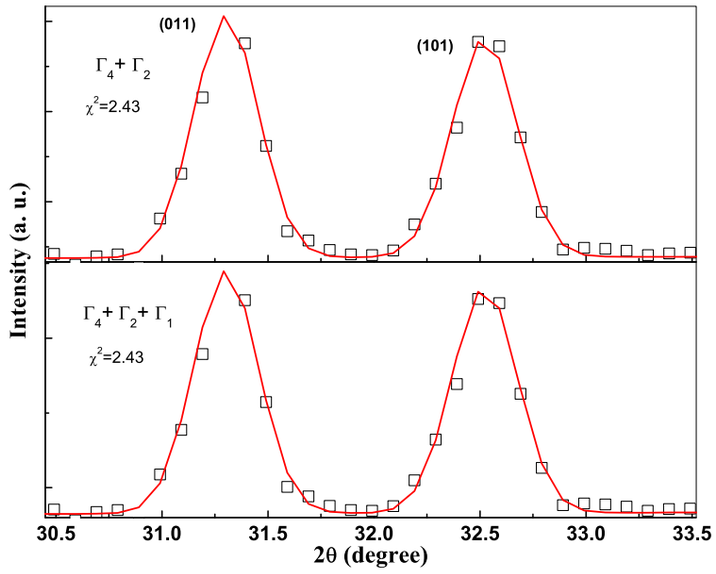
$Er_{0.5}Dy_{0.5}FeO_3$

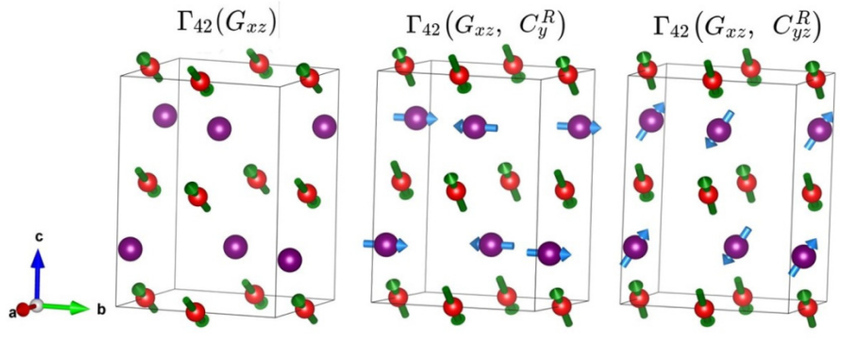












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Conclusions

$NdFe_{0.5}Mn_{0.5}O_3$

- Magnetic properties have similarities to $NdFeO_3$: G type
- ***Ax Gy Cz*** antiferromagnetic structure have T_N ~ 250 K
- <u>No ferromagnetic component in high temperature phase</u>
- ***Ax Gy Cz —> Fx Cy Gz*** spin reorientation (rotational)

$Er_{0.5}Dy_{0.5}FeO_3$

- ***Gx Ay Fz —> Gx Ay Fz+ Fx Cy Gz*** spin reorientation (rotational)
- $C_y + C_z$ type ordering of Rare-earth (Dy^{3+} / Er^{3+})
- Multiple magnetic structures of Fe^{3+} and Dy^{3+} / Er^{3+}
- Anomalous negative thermal expansion associated with rare-earth ordering

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Thank You