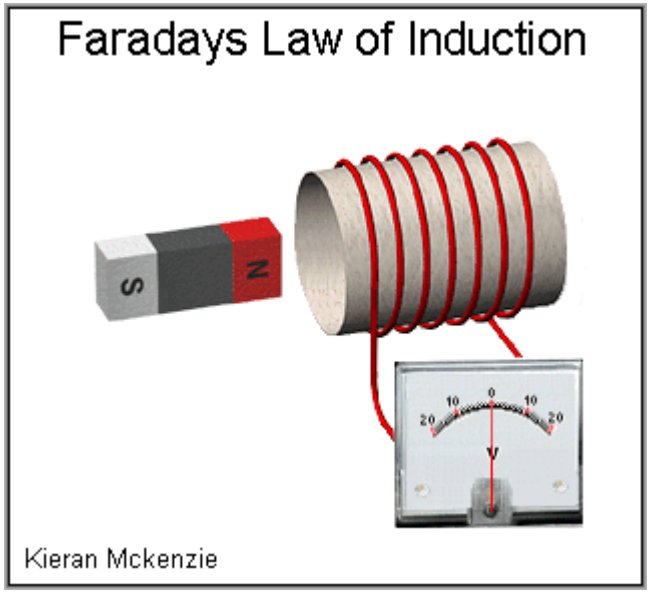
LABORATORY OF
Novel Magnetic Materials

Магнитные наночастицы: свойства и методы изготовления

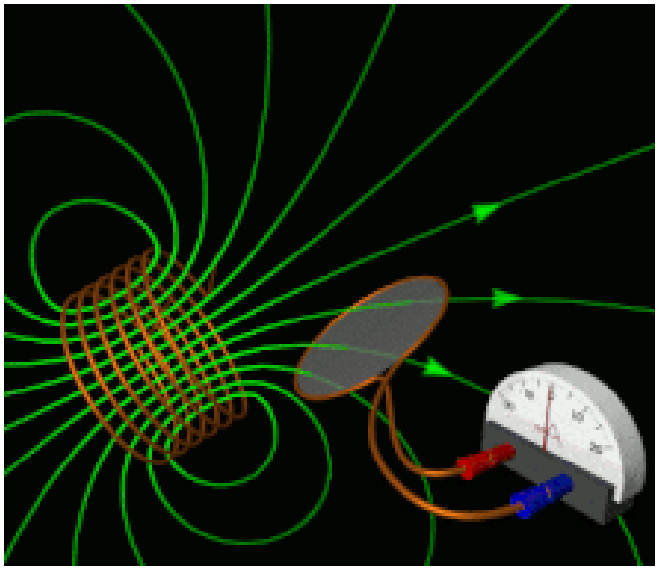
Александр Омельянчик

Балтийский федеральный университет имени Иммануила Канта

Классика

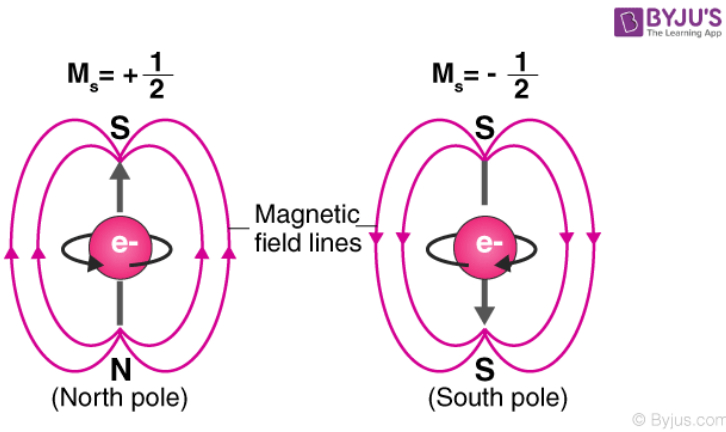


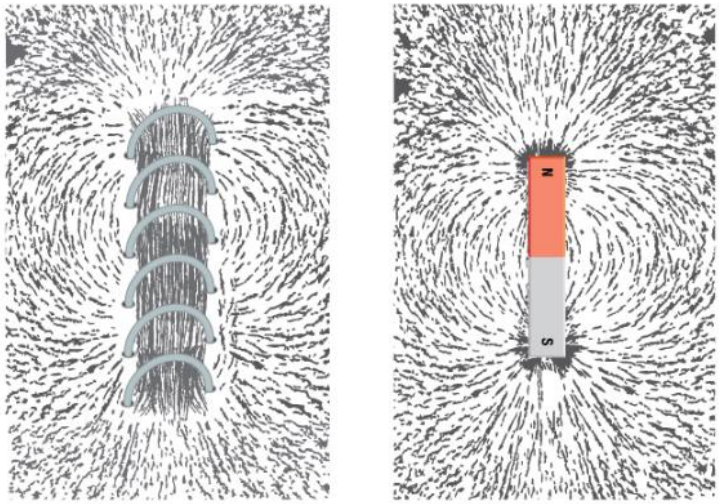
https://en.wikipedia.org/wiki/Faraday%27s_law_of_induction



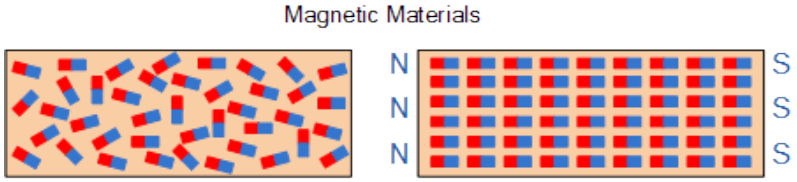
https://mri-q.com/what-causes-magnetism.html

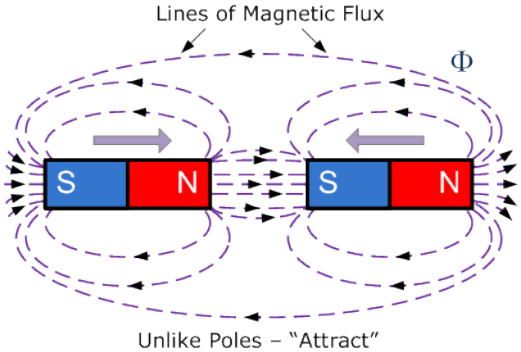
Классика

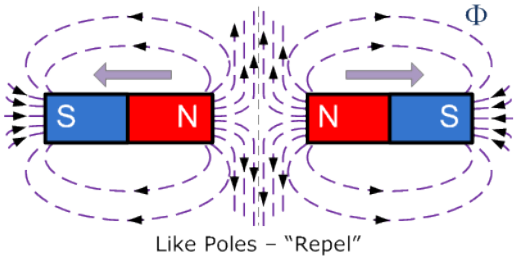




F. Miller and B. H. Dickinson, "College Physics," *Phys. Today*, vol. 12 (1959), pp. 62–64.

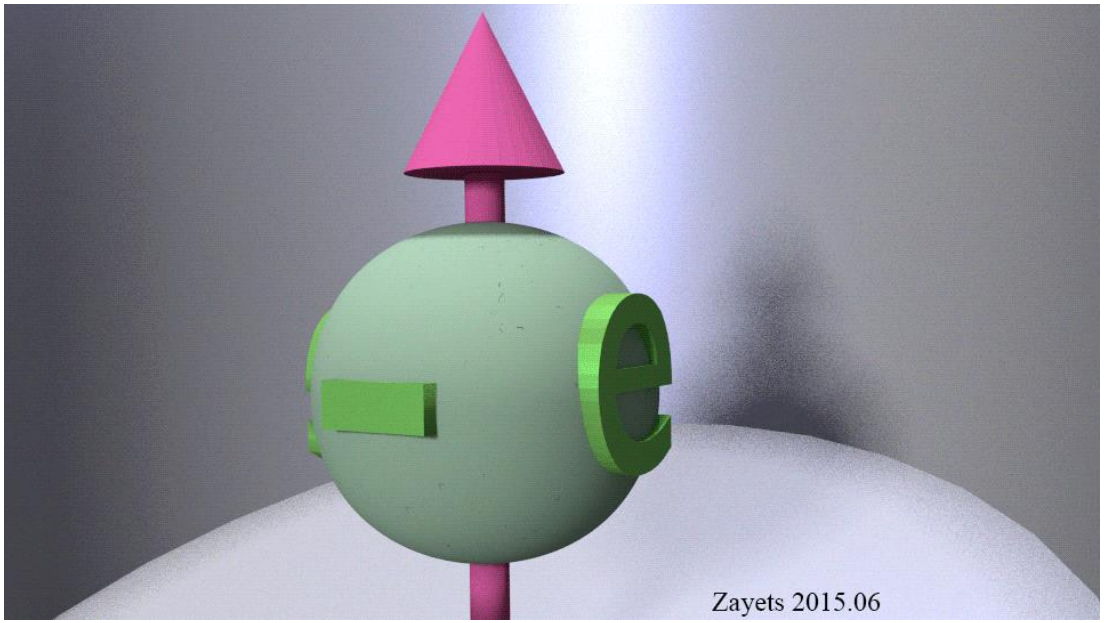






https://www.electronics-tutorials.ws/electromagnetism/magnetism.html

Обменное взаимодействие



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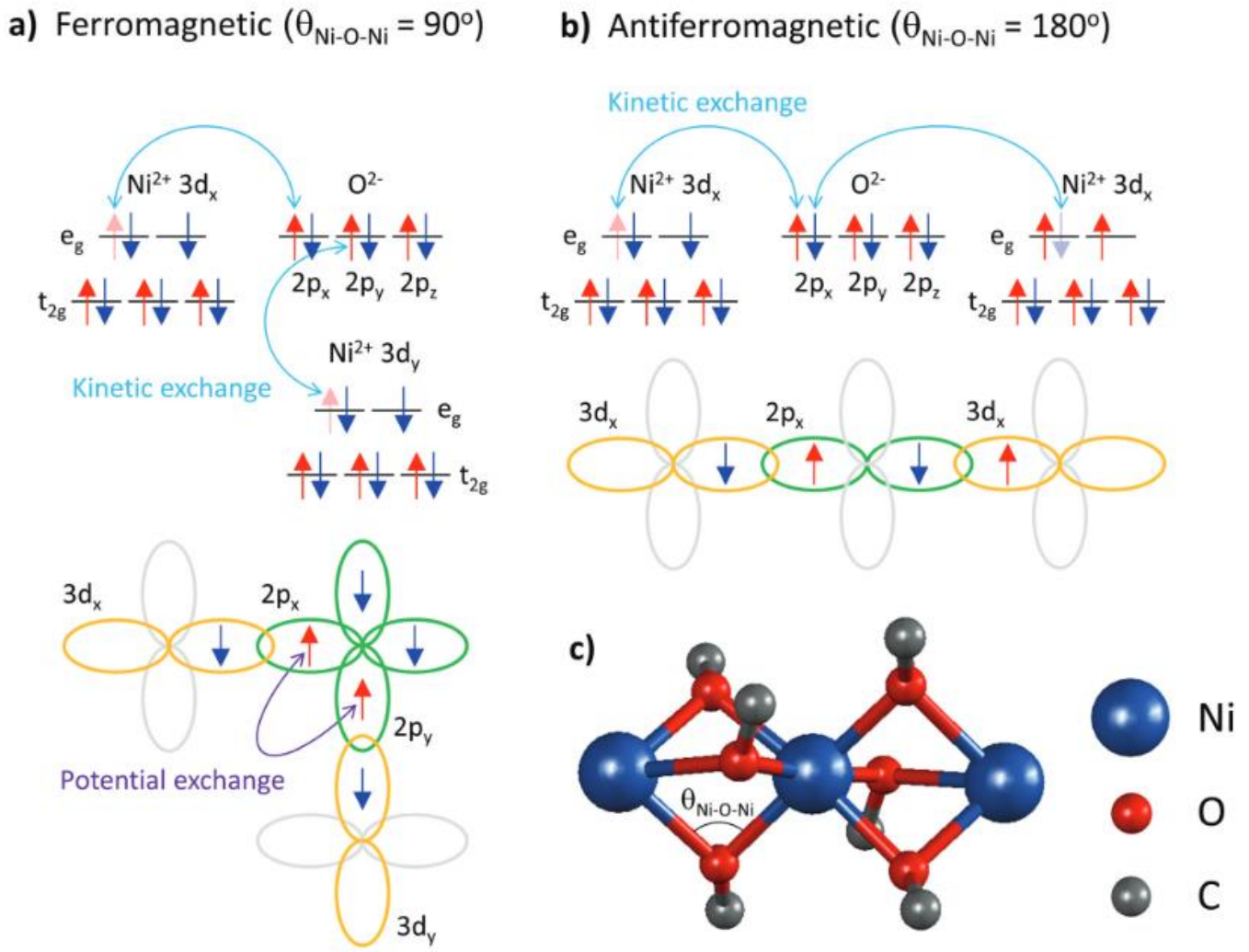
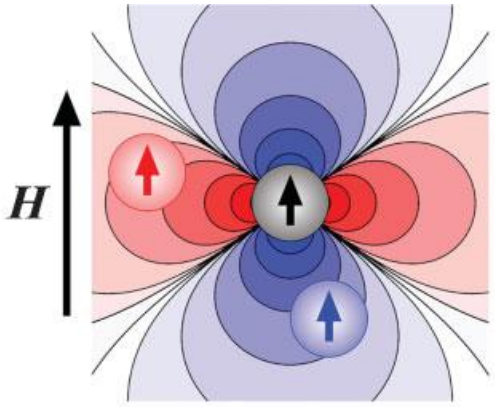
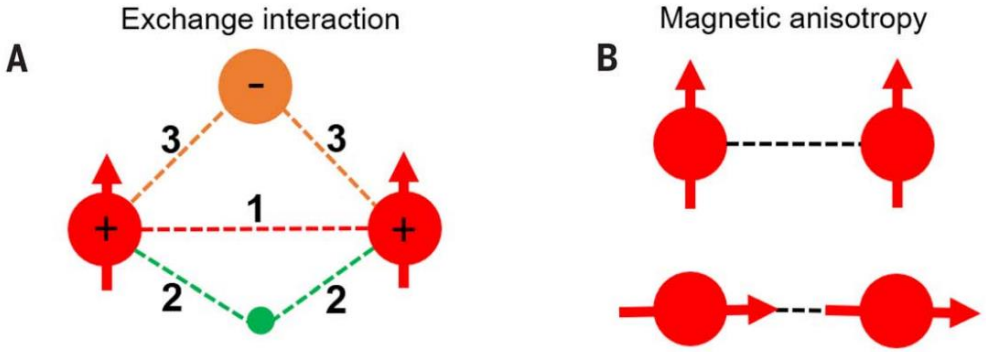


Domanov, Oleg, et al. "Exchange coupling in a frustrated trimetric molecular magnet reversed by a 1D nano-confinement." *Nanoscale* 11.22 (2019): 10615-10621.

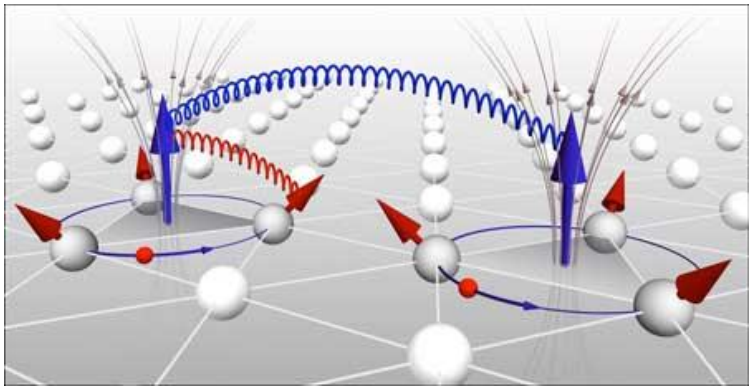
Обменное взаимодействие



Bishop, Kyle JM, et al. "Nanoscale forces and their uses in self-assembly." *small* 5.14 (2009): 1600-1630.

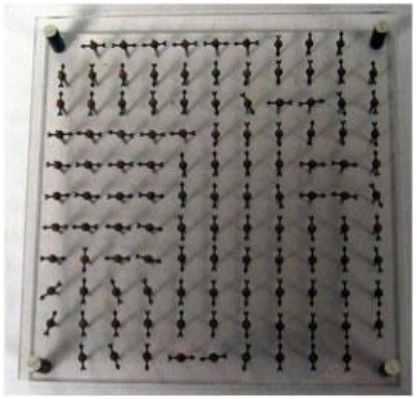


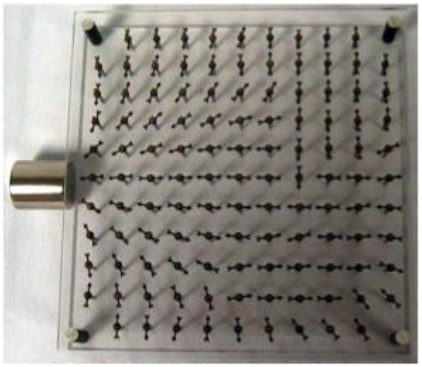
Gong, Cheng, and Xiang Zhang. "Two-dimensional magnetic crystals and emergent heterostructure devices." Science 363.6428 (2019).

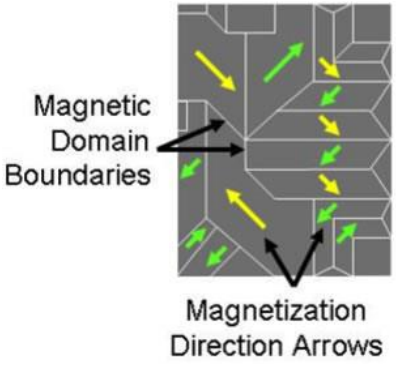


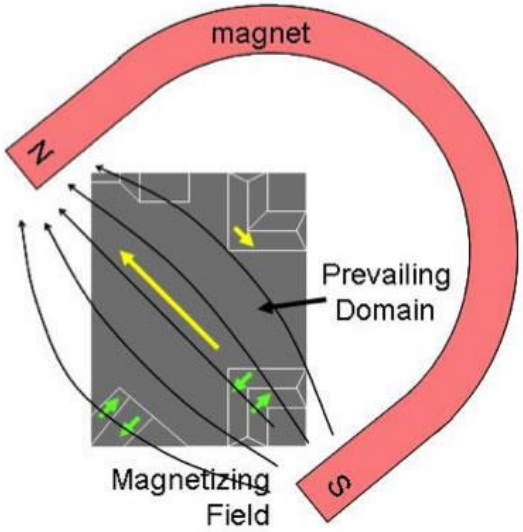
(Image: Forschungszentrum Jülich)

Намагниченность

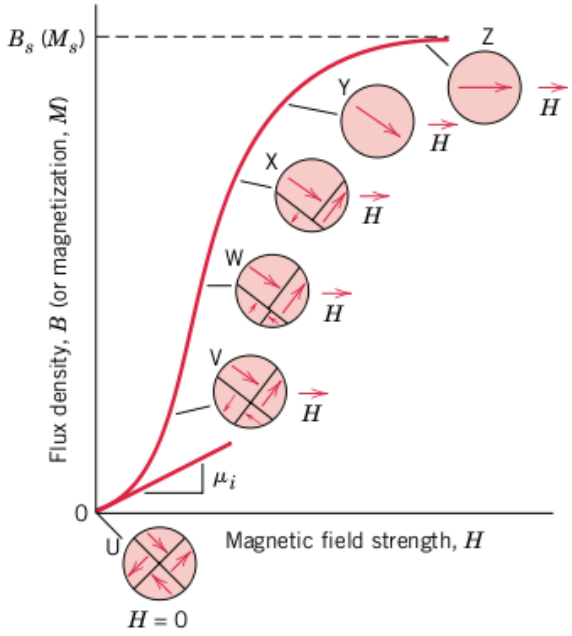






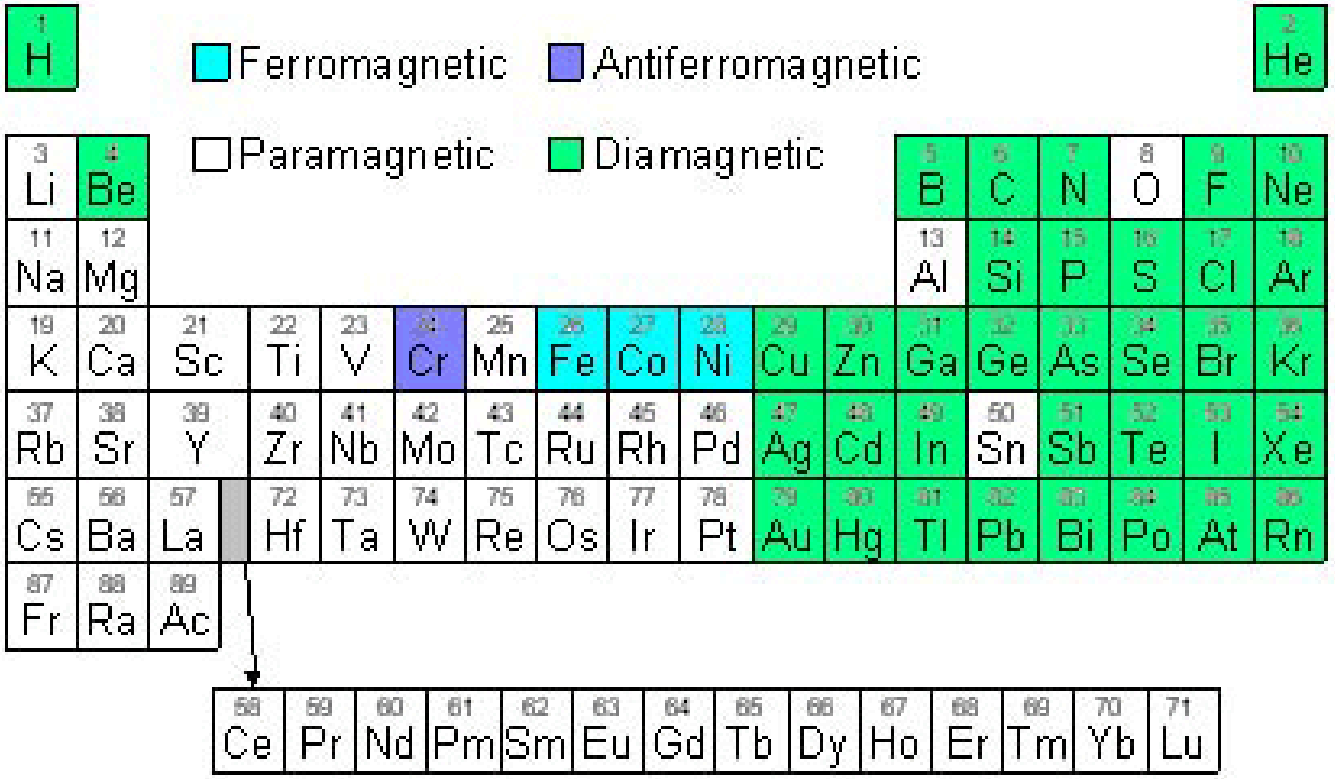


https://ece.northeastern.edu/fac-ece/nian/mom/domains.html



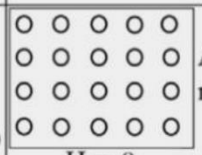
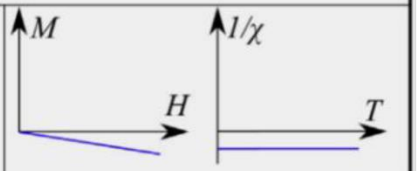
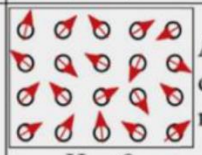
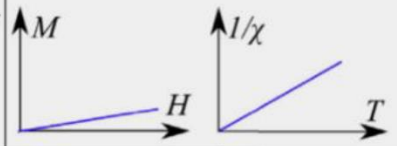
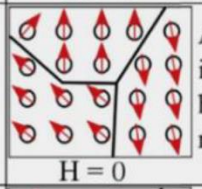
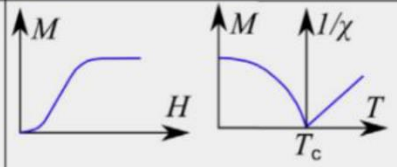
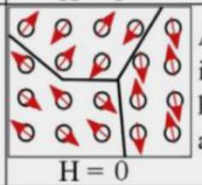
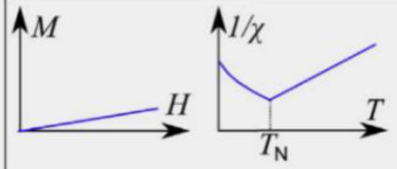
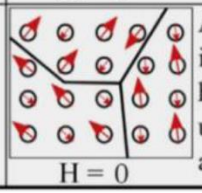
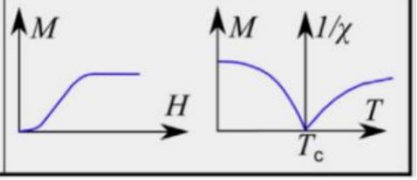
Study of the Structural, Magnetic and Electrical Properties of Magnesium-Cadmium Ferrites
DOI: 10.13140/RG.2.2.21587.63527

Виды магнитных материалов



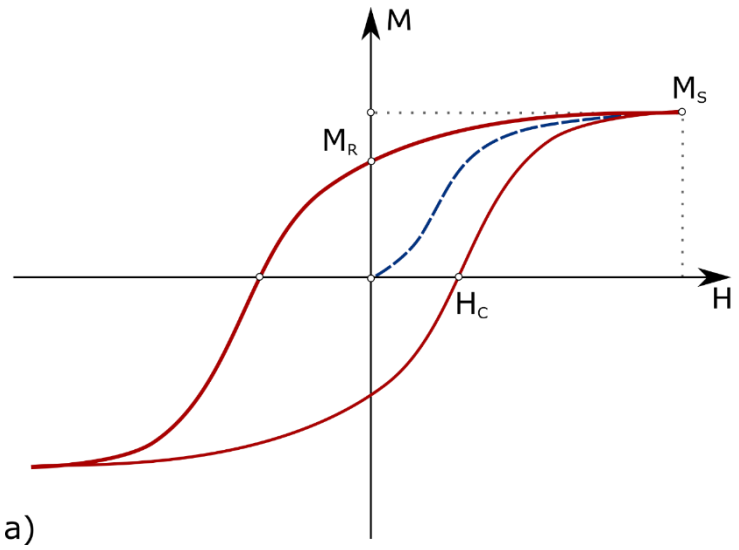
http://www.splung.com/content/sid/3/page/magnetism

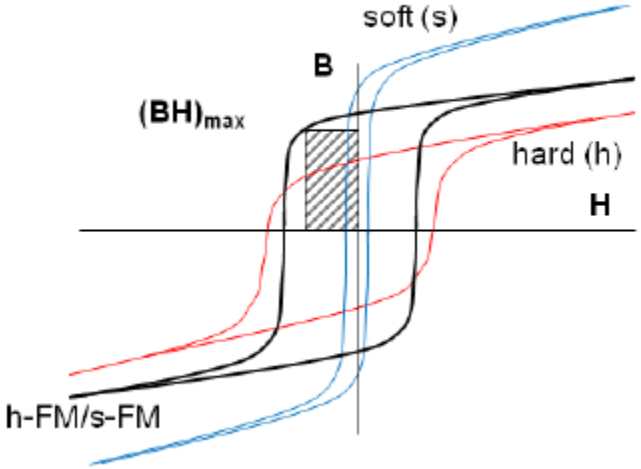
Виды магнитных материалов

Magnetism	Examples	Magnetic behaviour	
Diamagnetism	Bi, Si, Cu, inert gases Susceptibility small and negative (-10^{-6} to -10^{-5})	 Atoms have no magnetic moments.	
Paramagnetism	Al, O_2, MnBi Susceptibilty small and positive (10^{-5} to 10^{-3})	 Atoms have randomly oriented magnetic moments.	
Ferromagnetism	Fe, Ni, Co, Gd Susceptibility large (generally > 100)	 Atoms are organized in domains which have parallel aligned magnetic moments.	
Antiferromagnetism	Cr, MnO, FeO Susceptibilty small and positive (10^{-5} to 10^{-3})	 Atoms are organized in domains which have antiparallel aligned moments.	
Ferrimagnetism	Fe_3O_4, $MnFe_2O_4$, $NiFe_2O_4$ Susceptibility large (generally > 100)	 Atoms are organized in domains which have a mixture of unequal antiparallel aligned moments.	

Nisticò R., Cesano F., Garello F. Magnetic materials and systems: Domain structure visualization and other characterization techniques for the application in the materials science and biomedicine //Inorganics. – 2020. – Т. 8. – №. 1. – С. 6.

Магнитный гистерезис



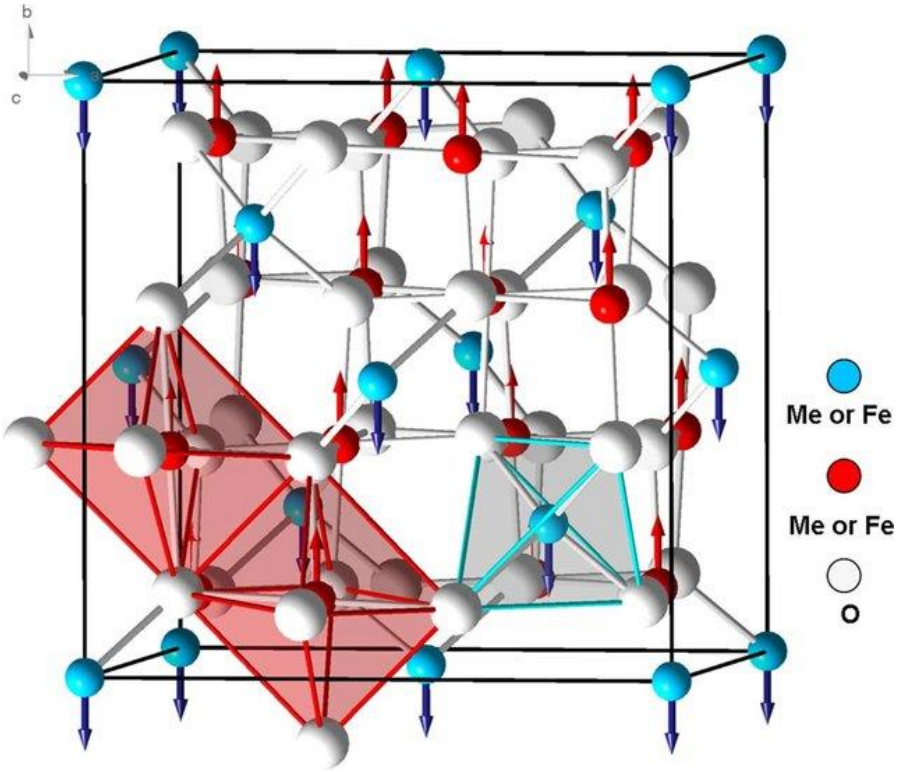


"Advanced Permanent Magnetic Materials"
December 2014
In book: NanomagnetismEdition:
http://www.onecentralpress.com/nanomagnetism/Chapter:
7Publisher: OCP Publishing GroupEditors: J. M. Gonzalez

Шпинель

A lodestone attracting iron filings and nails.

https://nationalmaglab.org/education/magnet-academy/learn-the-basics/stories/magnets-from-mini-to-mighty



Vincent, G. Harris. "Modern microwave ferrites." IEEE Transactions on Magnetics 48.3 (2012): 1075-1104.

Ферриты-шпинели:

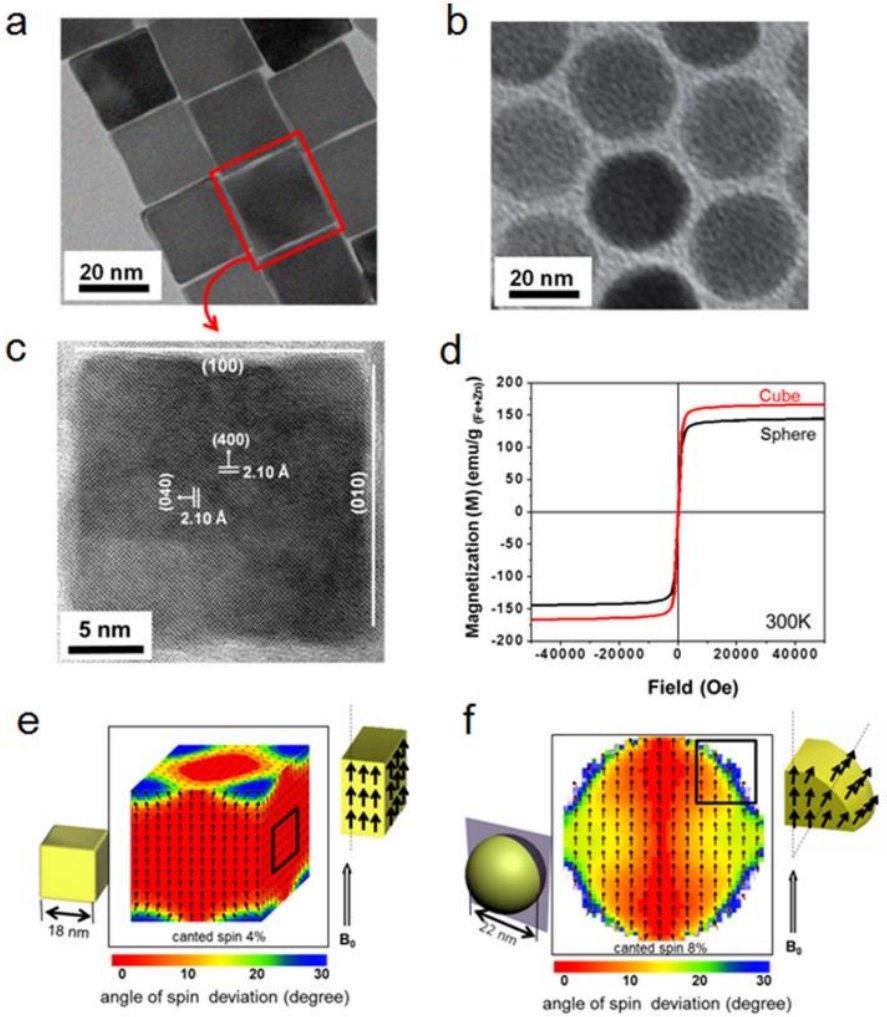
Fe_3O_4 – магнетит = $(Fe^{3+})_8[Fe^{2.5+}]_{16}O_{32}$

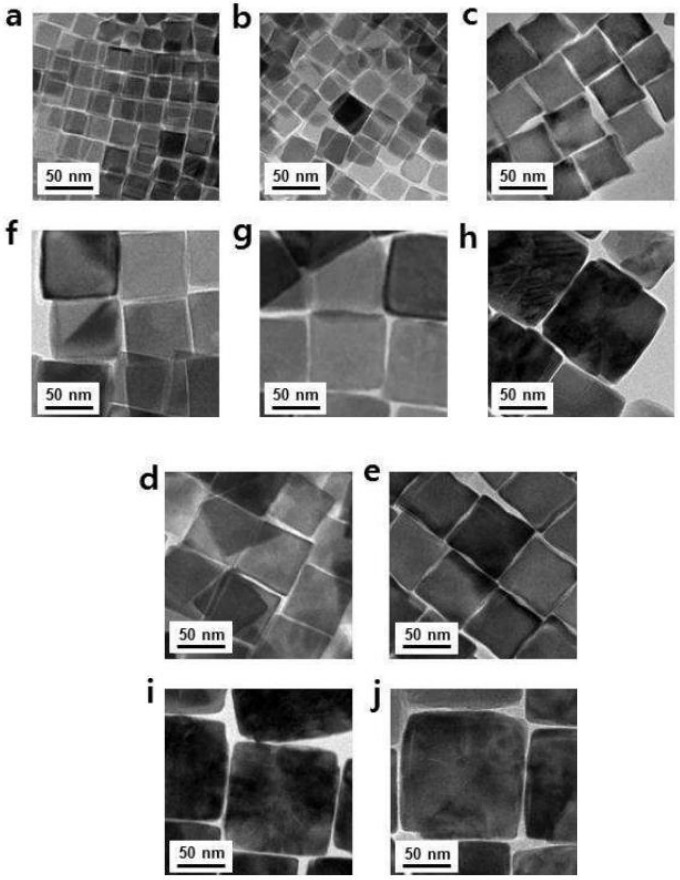
γ-Fe_2O_3 – маггемит = $(Fe^{3+})_8[Fe^{3+}_{5/6}\,\square_{1/6}]_{16}O_{32}$

$CoFe_2O_4$ – кобальтовый феррит = $(Fe^{3+})_8[Fe^{3+}_{1/2}\,Co^{2+}_{1/2}]_{16}O_{32}$

и др. $Me^{2+}Fe^{3+}_2O_4$, где Me^{2+} = Ni^{2+}, Zn^{2+}, Mn^{2+}, Mg^{2+}…

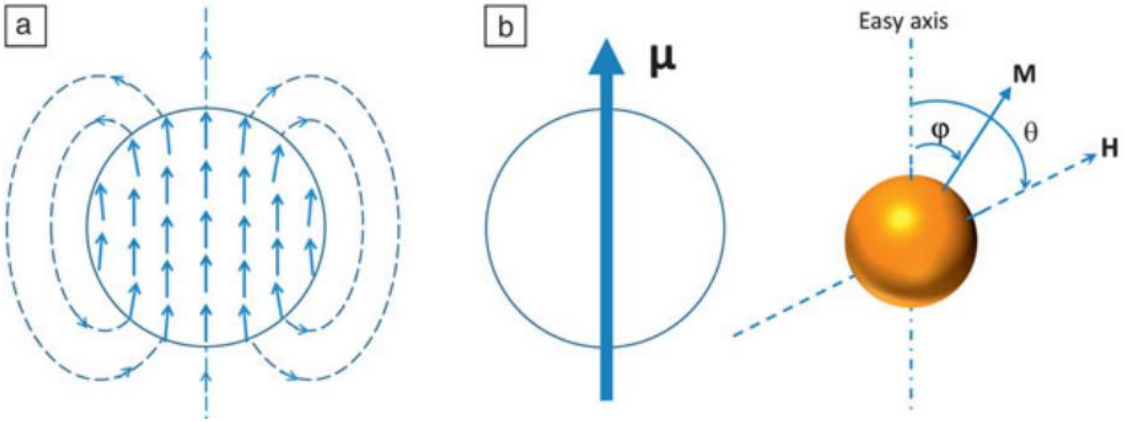
Наночастицы

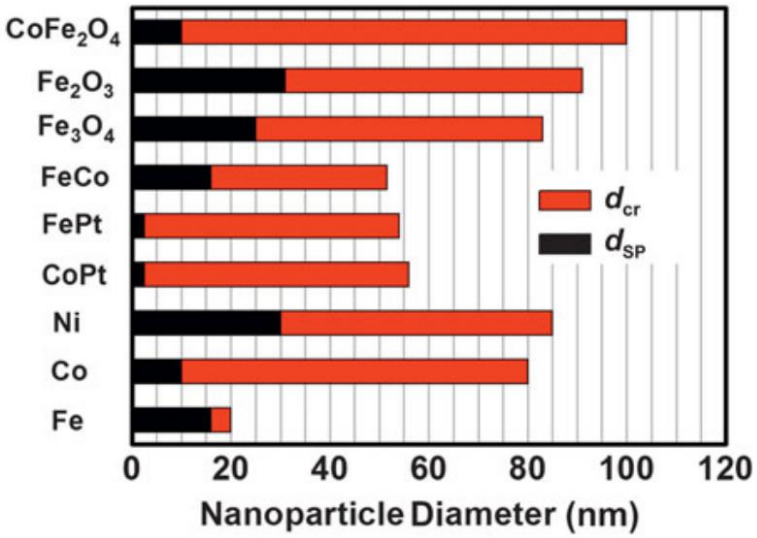




S. H. Noh et al., "Nanoscale magnetism control via surface and exchange anisotropy for optimized ferrimagnetic hysteresis," Nano Lett., vol. 12, no. 7, pp. 3716–3721, 2012.

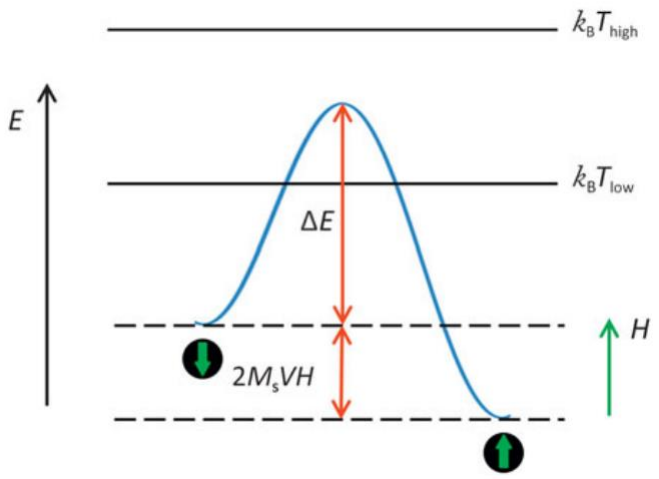
Размерные эффекты

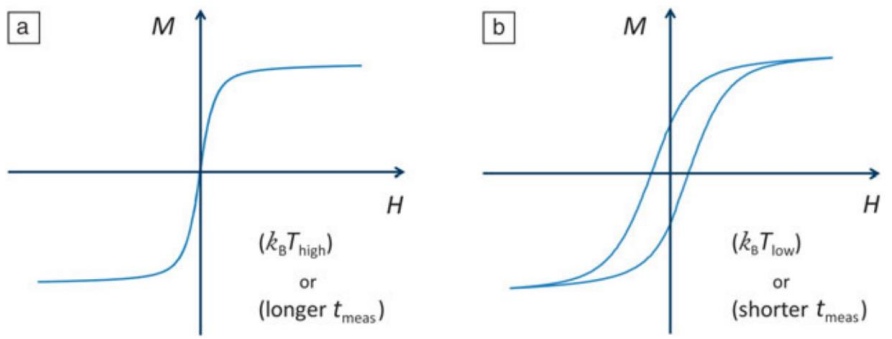




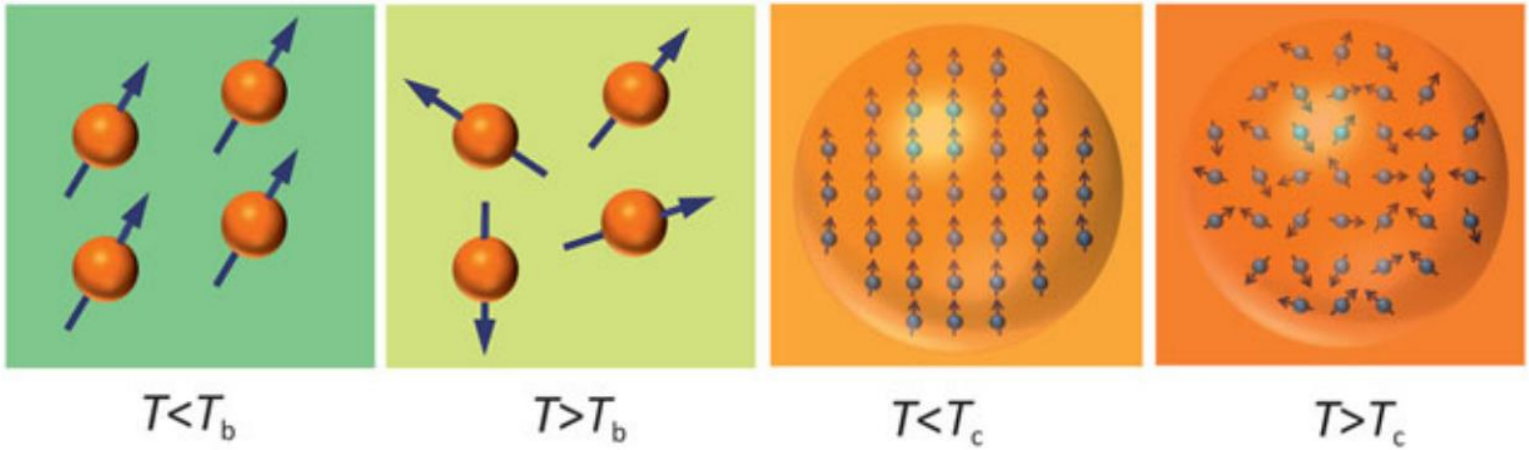
S. A. Majetich, T. Wen, and O. T. Mefford, "Magnetic nanoparticles," *MRS Bull.*, vol. 38 (2013), pp. 899–903.

Суперпарамагнетизм





$\tau = \tau_0 \exp(KV/k_BT)$



S. A. Majetich, T. Wen, and O. T. Mefford, "Magnetic nanoparticles," *MRS Bull.*, vol. 38 (2013), pp. 899–903.

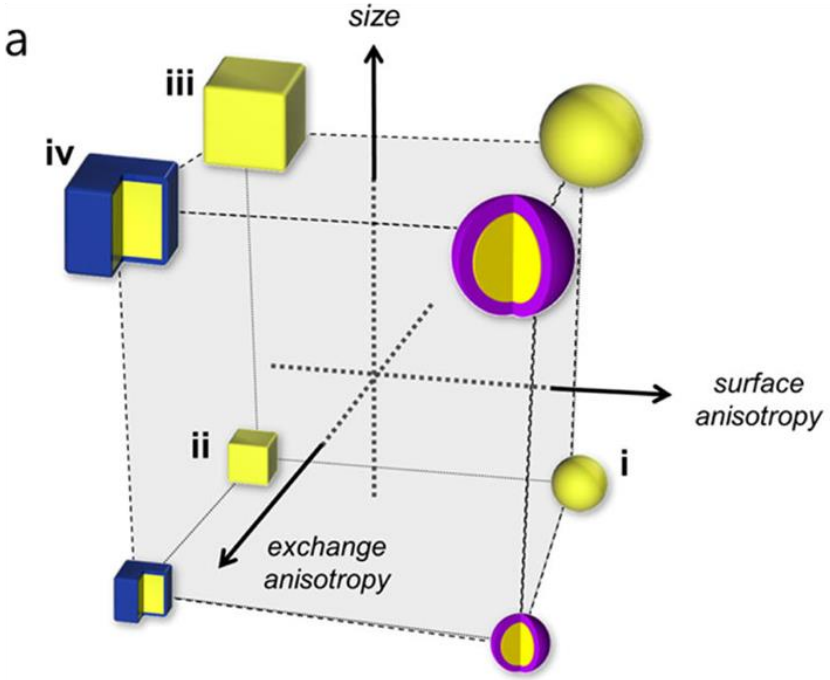
Суперпарамагнетизм

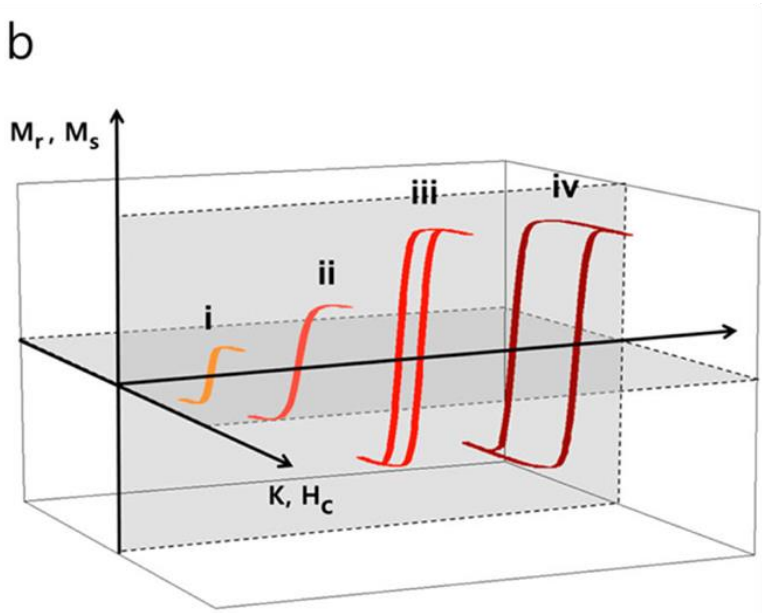
$$\tau = \tau_0 \exp(KV/k_BT)$$

Дизайн материала

Tuning of structure and morphology:
- size (volume)
- shape
- surface

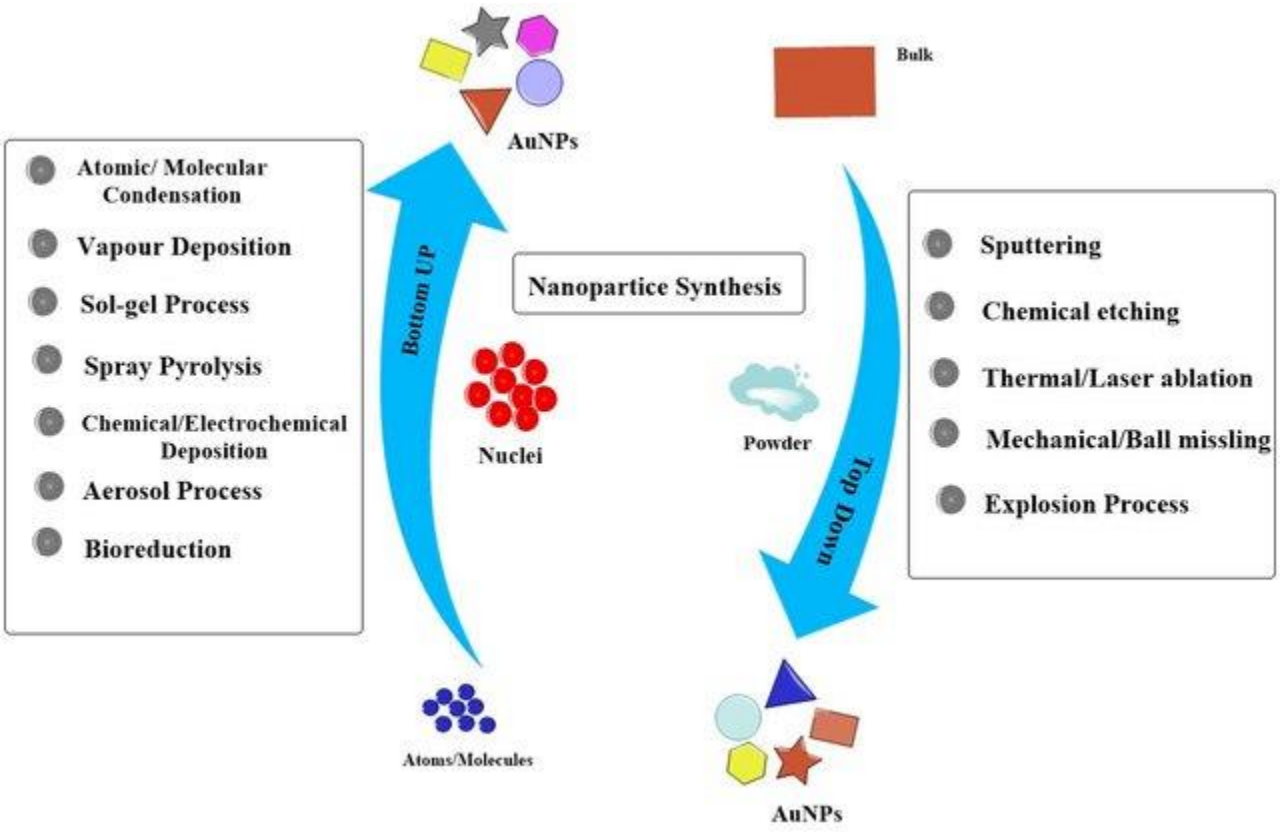
Control of magnetic properties:
- saturation magnetization (M_s)
- remanent magnetization (M_r)
- coercivity (H_c)
- magnetic anisotropy constant (K)





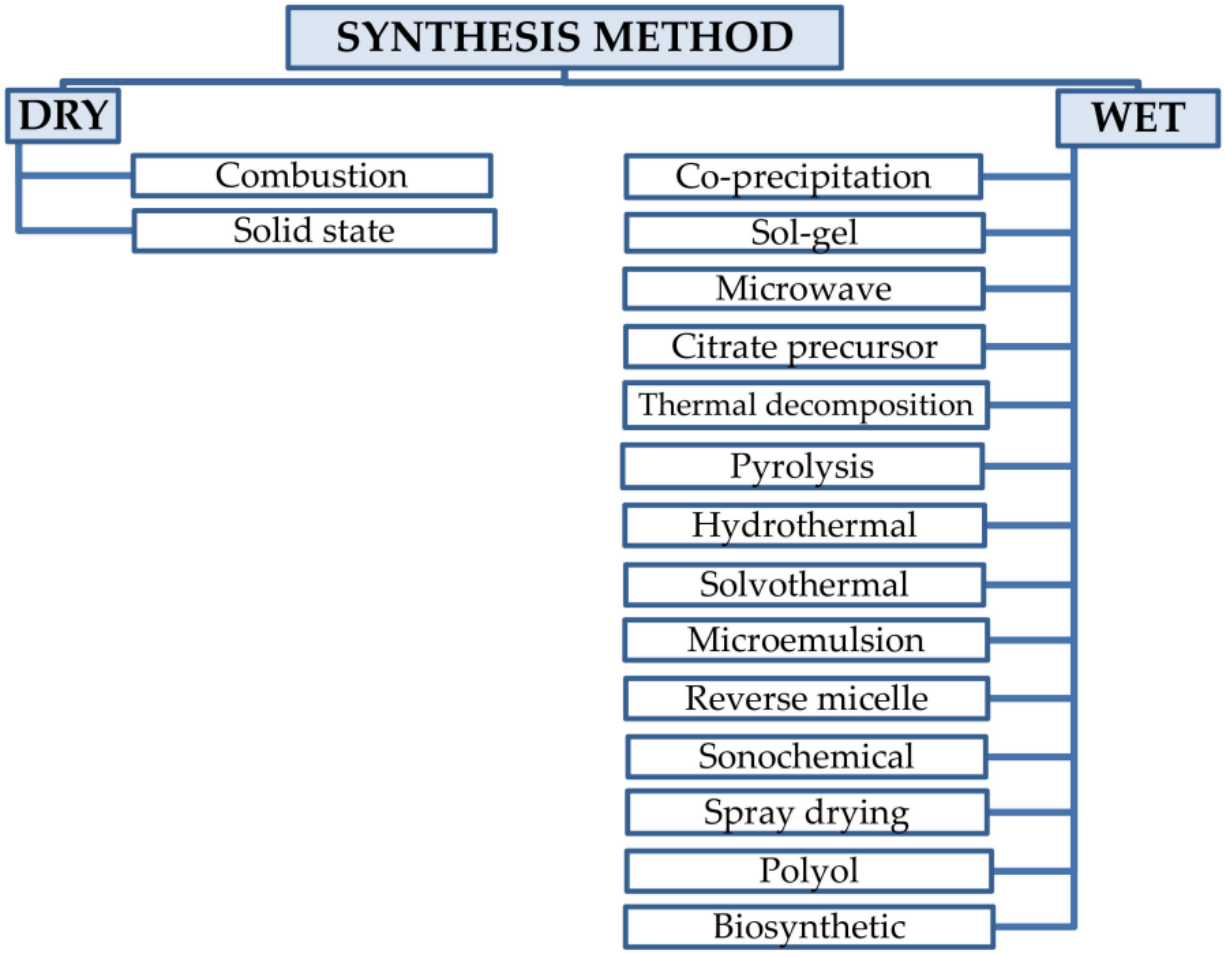
S. H. Noh et al., "Nanoscale magnetism control via surface and exchange anisotropy for optimized ferrimagnetic hysteresis," Nano Lett., vol. 12, no. 7, pp. 3716–3721, 2012.

Методы синтеза



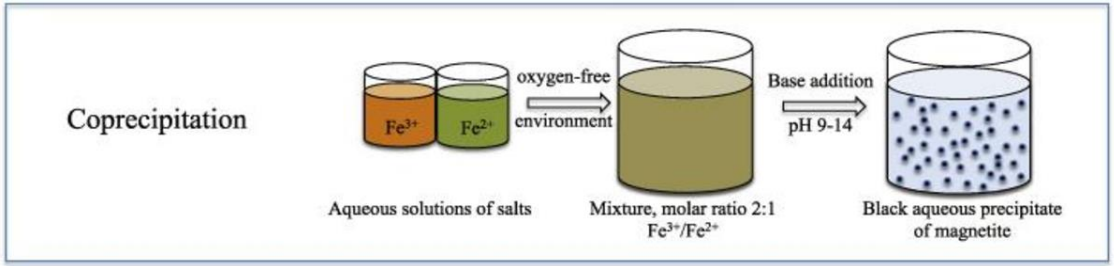
Bozarth, Andrew, Uwe-G. Maier, and Stefan Zauner. "Diatoms in biotechnology: modern tools and applications." Applied microbiology and biotechnology 82.2 (2009): 195-201.

Методы синтеза



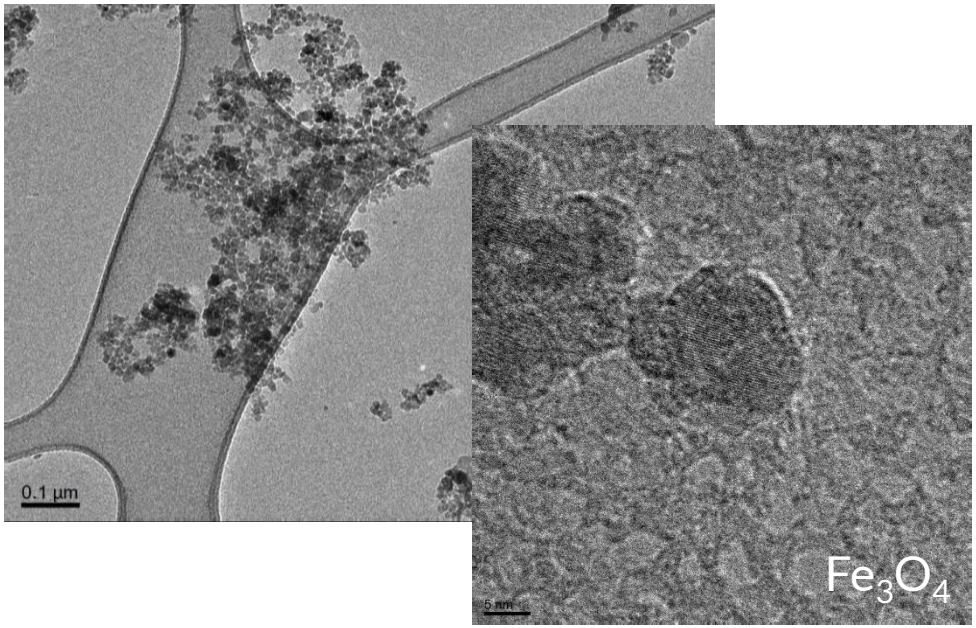
Dippong, Thomas, Erika Andrea Levei, and Oana Cadar. "Recent Advances in Synthesis and Applications of MFe2O4 (M= Co, Cu, Mn, Ni, Zn) Nanoparticles." Nanomaterials 11.6 (2021): 1560.

Соосаждение



$$2Fe^{3+} + Fe^{2+} + 8OH^{-} = 2Fe(OH)_3Fe(OH)_2\ (s) \rightarrow Fe_3O_4\ (s) + 4H_2O$$

Carter, Nicklaus. "Physical properties of iron oxide nanoparticles." (2015).



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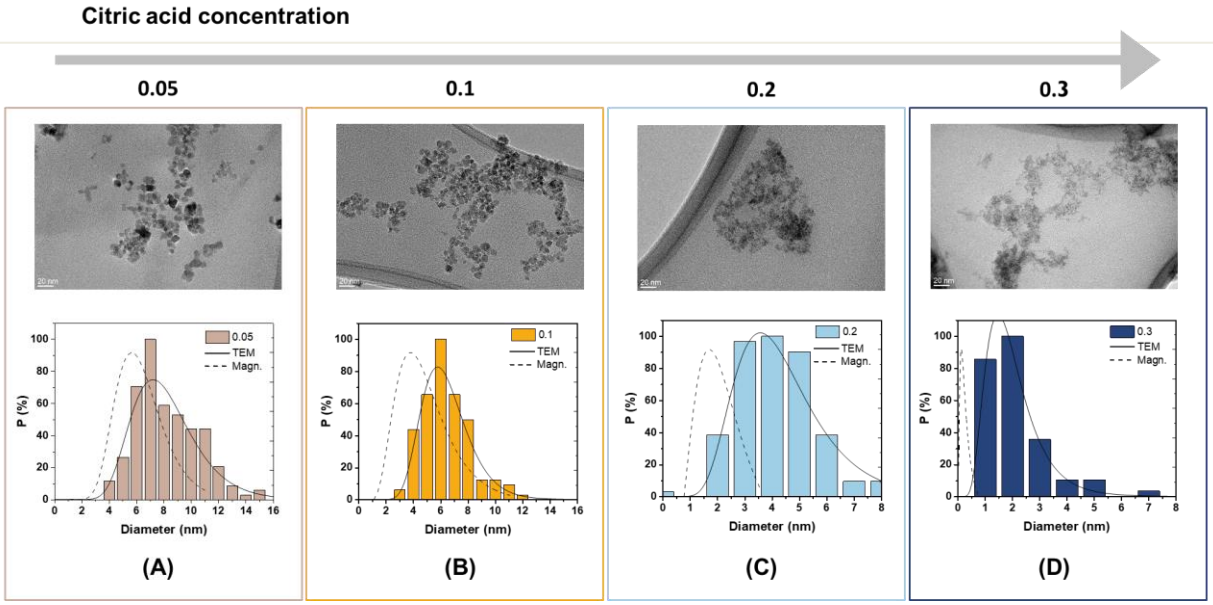
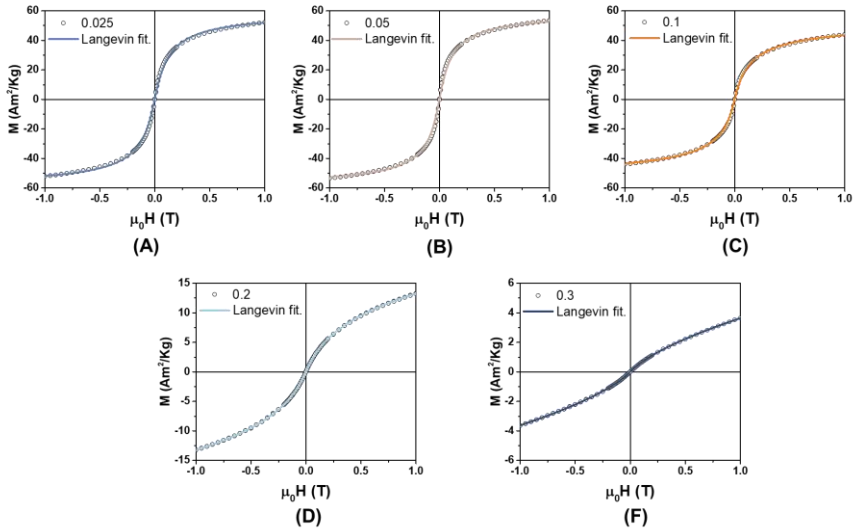
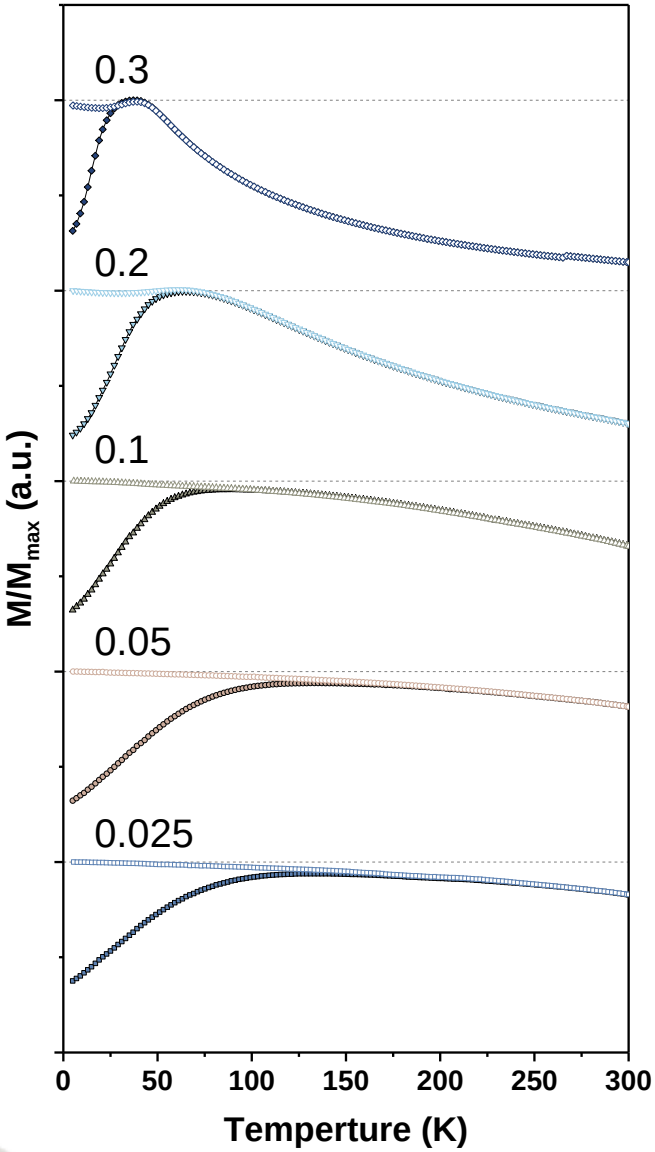
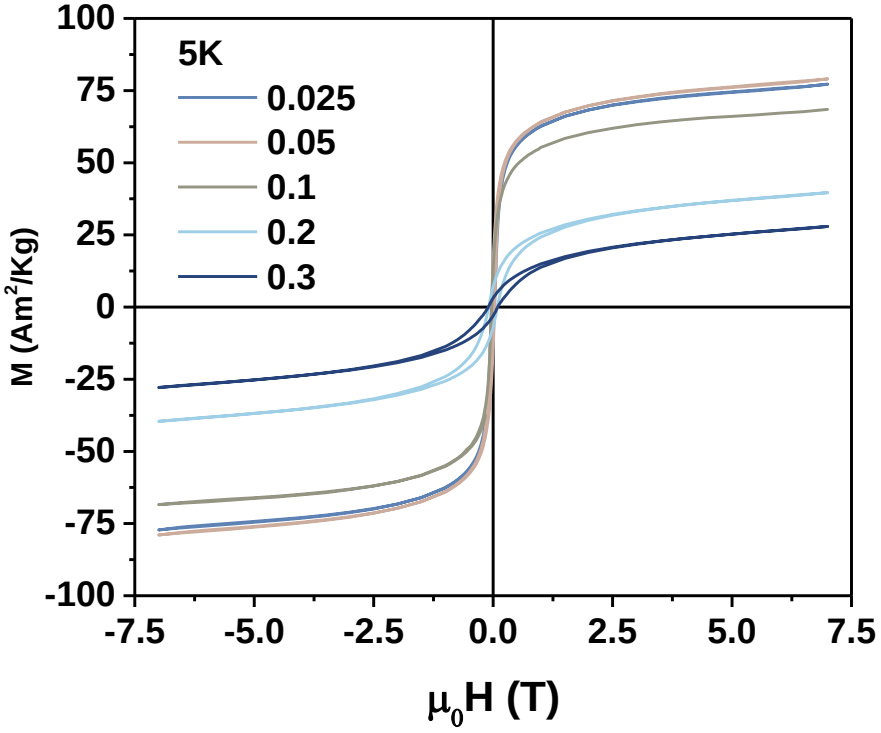




Omelyanchik, A., et al., *Journal of Alloys and Compounds* (2021): 160779.

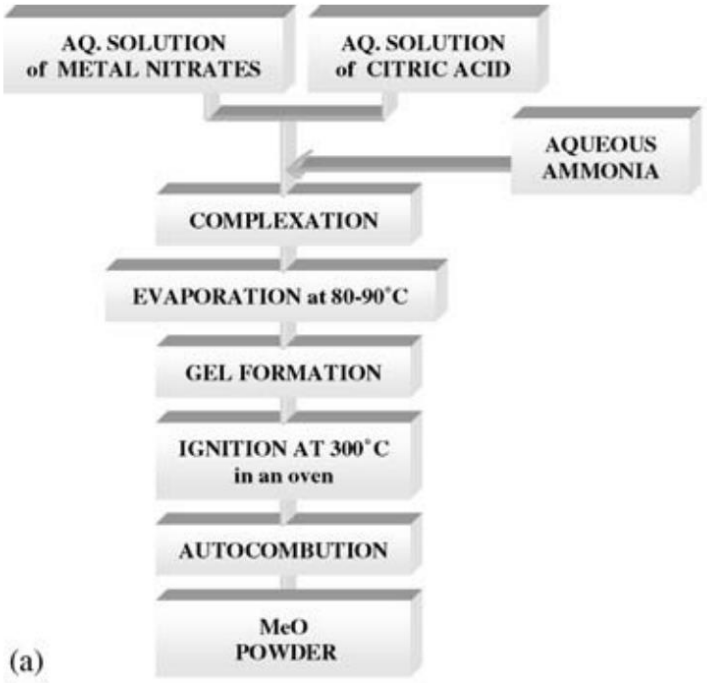
Соосаждение





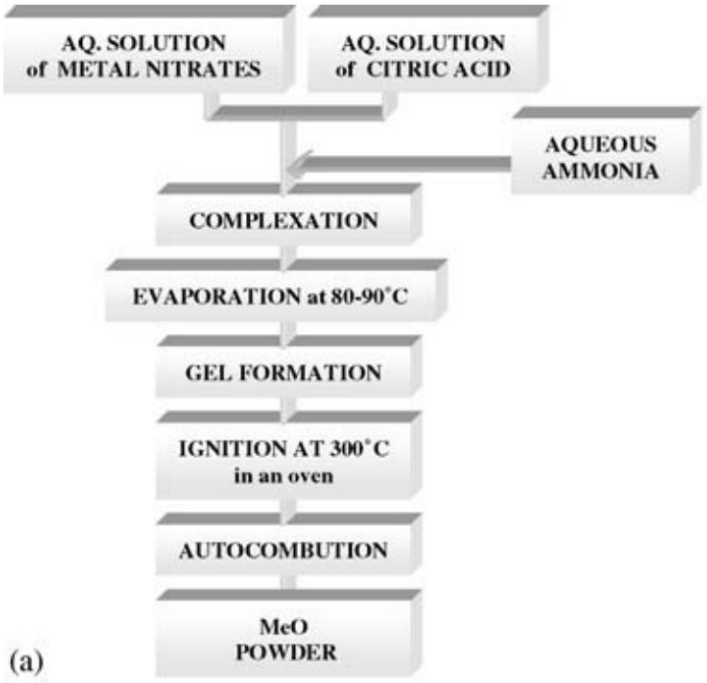
Omelyanchik, A., et al., *Journal of Alloys and Compounds* (2021): 160779.

Золь-гель самосгорание



C. Cannas, A. Musinu, D. Peddis, and G. Piccaluga, J. Nanoparticle Res., vol. 6 (2004), pp. 223–232.

Золь-гель самосгорание



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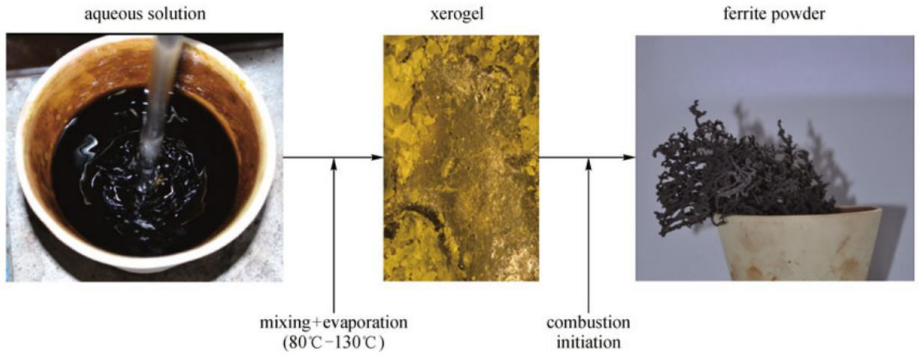

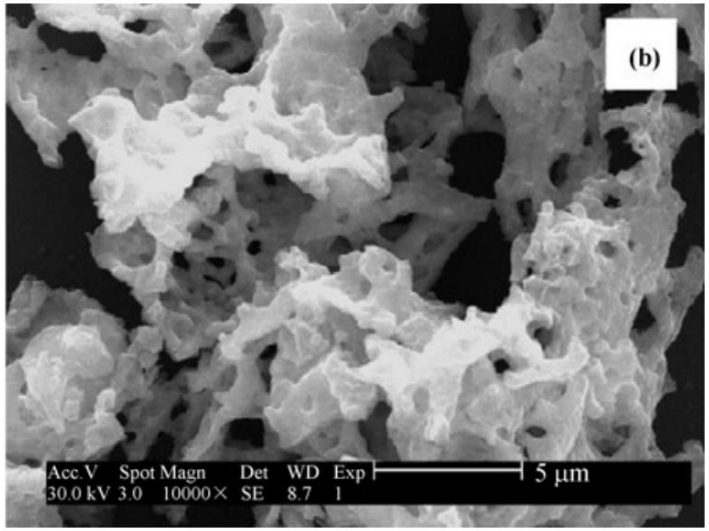

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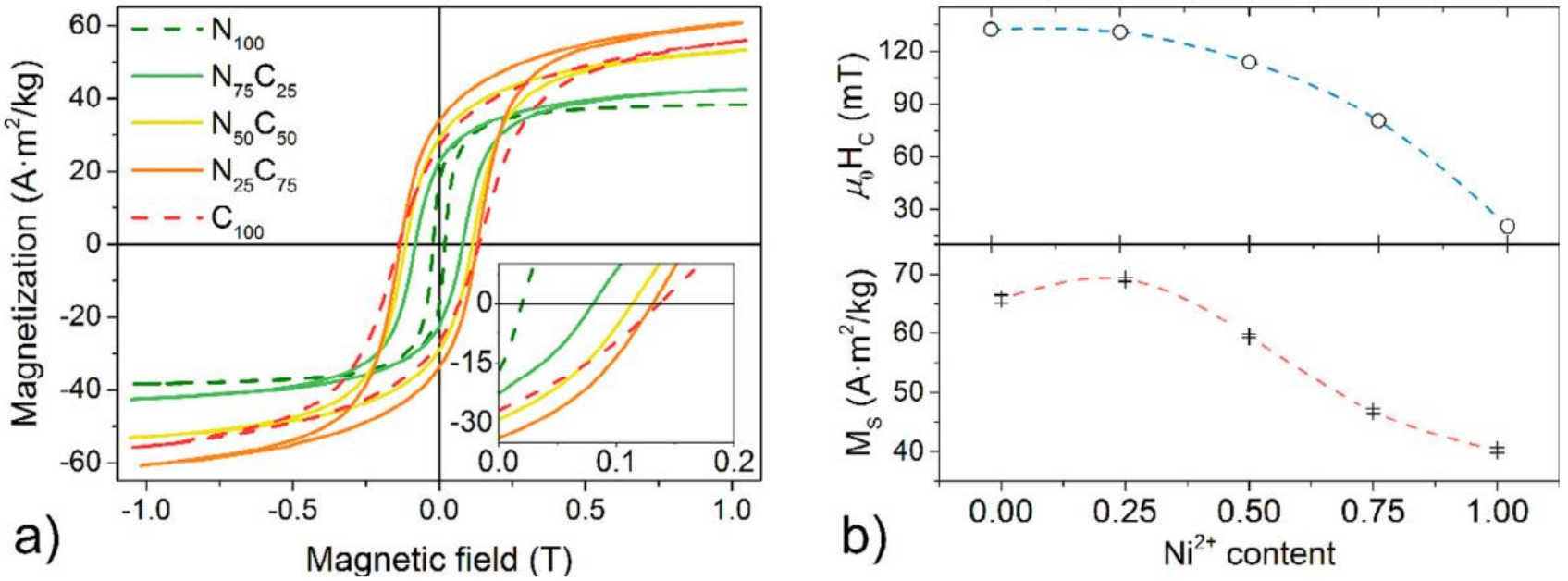
Золь-гель самосгорание

$Ni_xCo_{1-x}Fe_2O_4$



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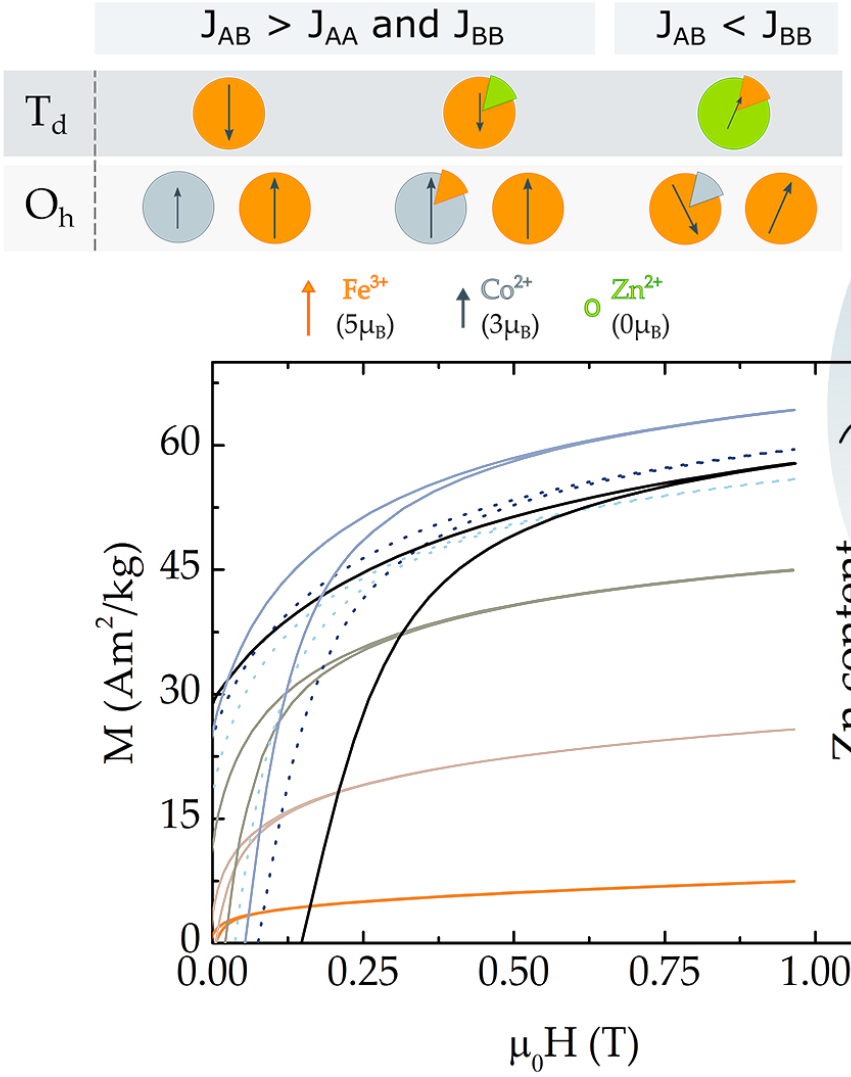
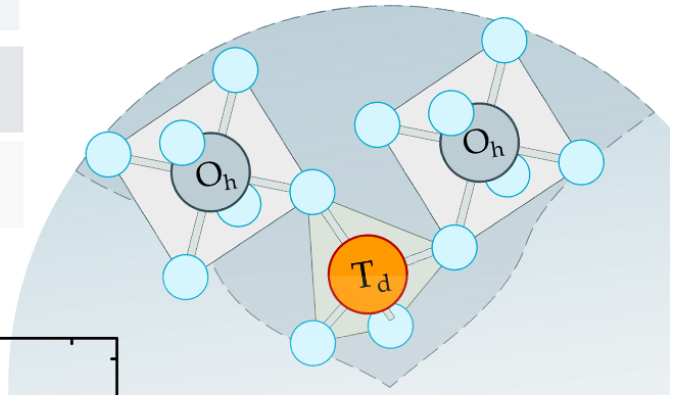
Золь-гель самосгорание





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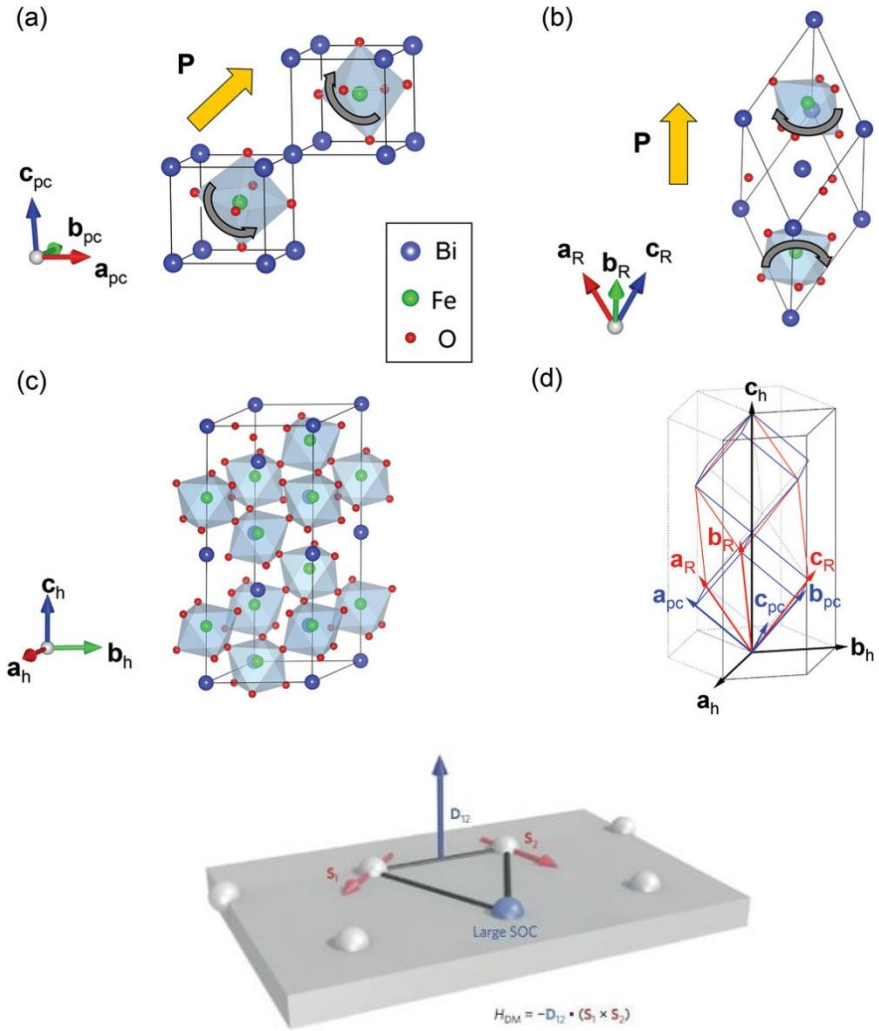
Феррит висмута ($BiFeO_3$)



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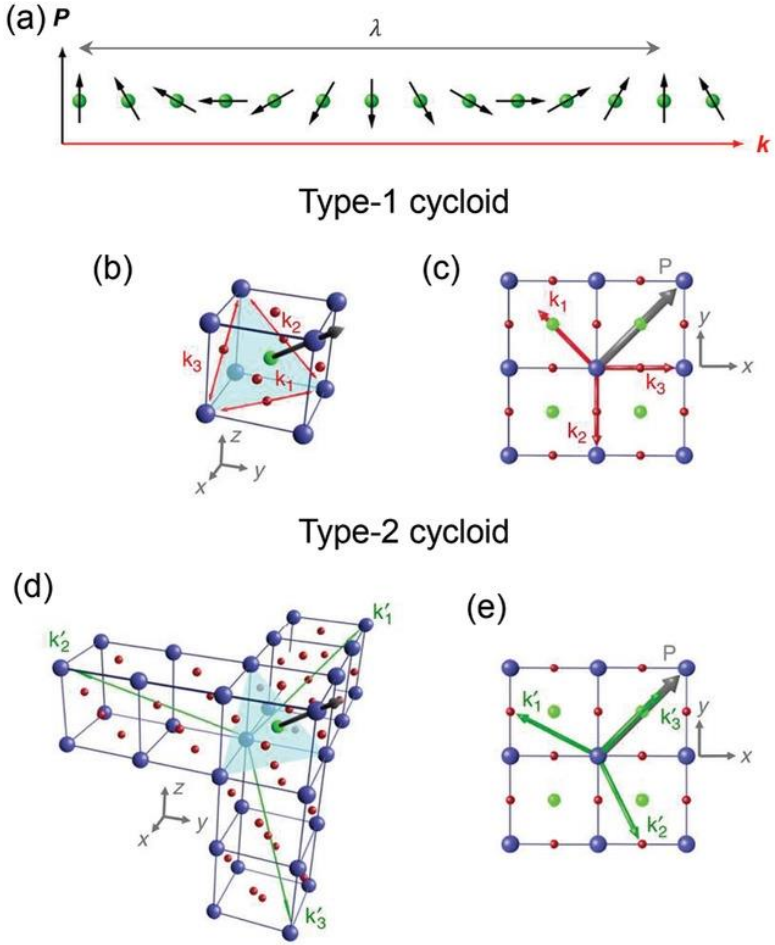

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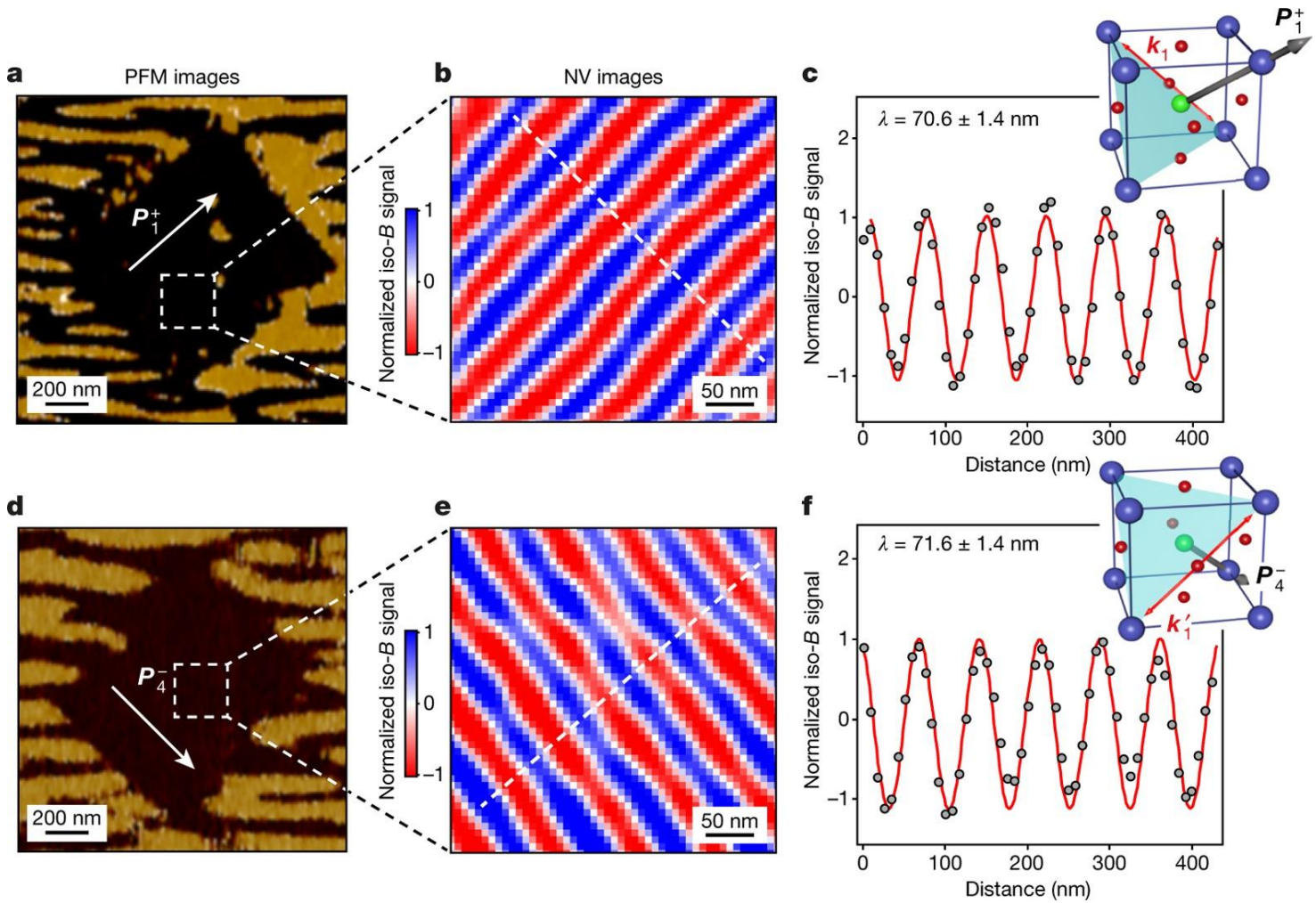

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Я всё.
Спасибо.