Magnetism of nanoparticles: non magnetic metals, core shell, exchange bias

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CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

many thanks to.....

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Outline

I. Nanoscale effects in magnetic materials

-Monodomain regime

-Superparamagnetism

Proximity effects :Exchange bias

II: Nanoscale induced magnetism

-Size effects

-Proximity polarization

-Surface induced magnetism

III. Measurement of nanoscale magnetism

-Traditional magnetometry

-XMCD & Neutrons (brief)

I. Nanoscale effects in magnetic materials

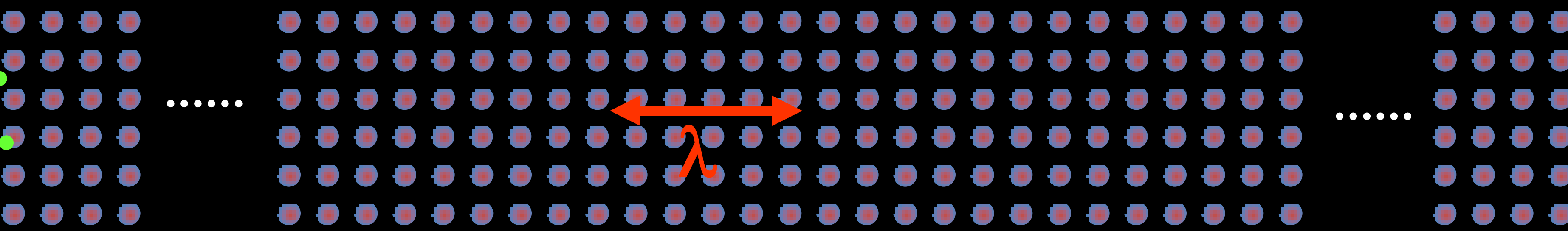
…size matters……

Size effects

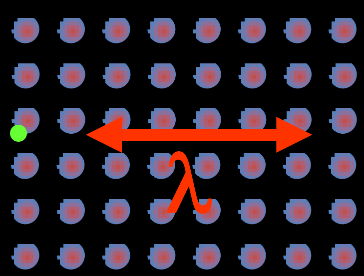
➢NPs has similar size to relavant parameters of physical processes

$$H\Psi = E\,\Psi$$

➢ Macroscopic systems (size>>> λ typical) periodic conditions



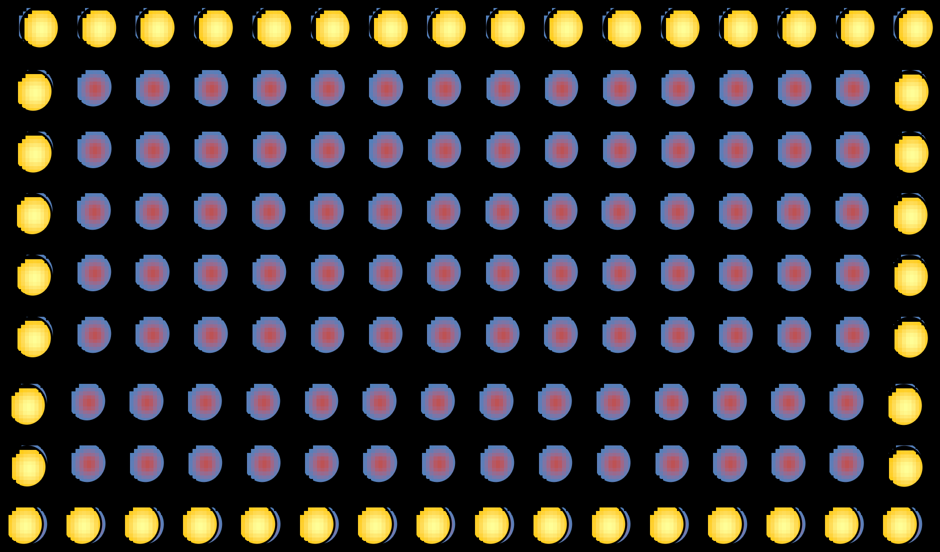
➢NP: Boundary Conditions(size ~ λ typical)

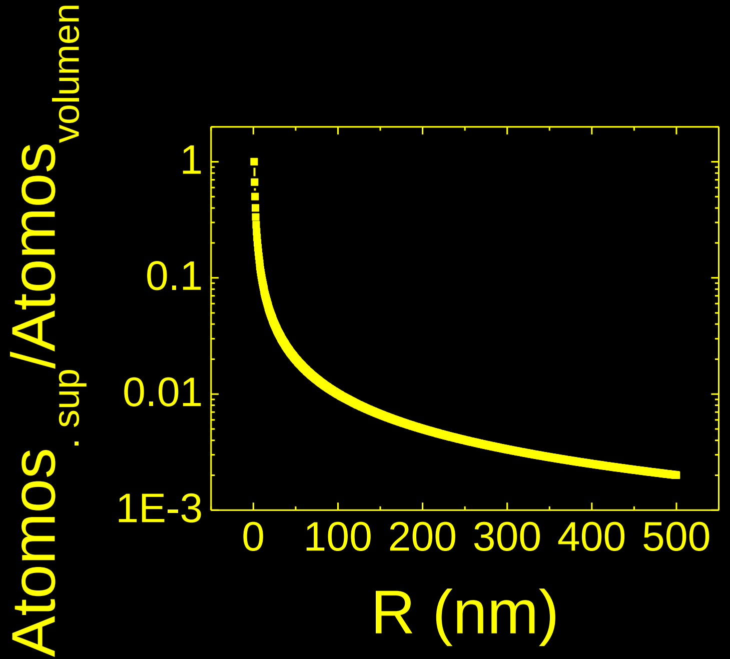


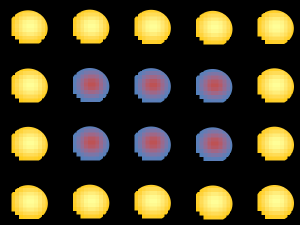
{ Confinement effects

Surface effects

Surface atoms are different to volume ones

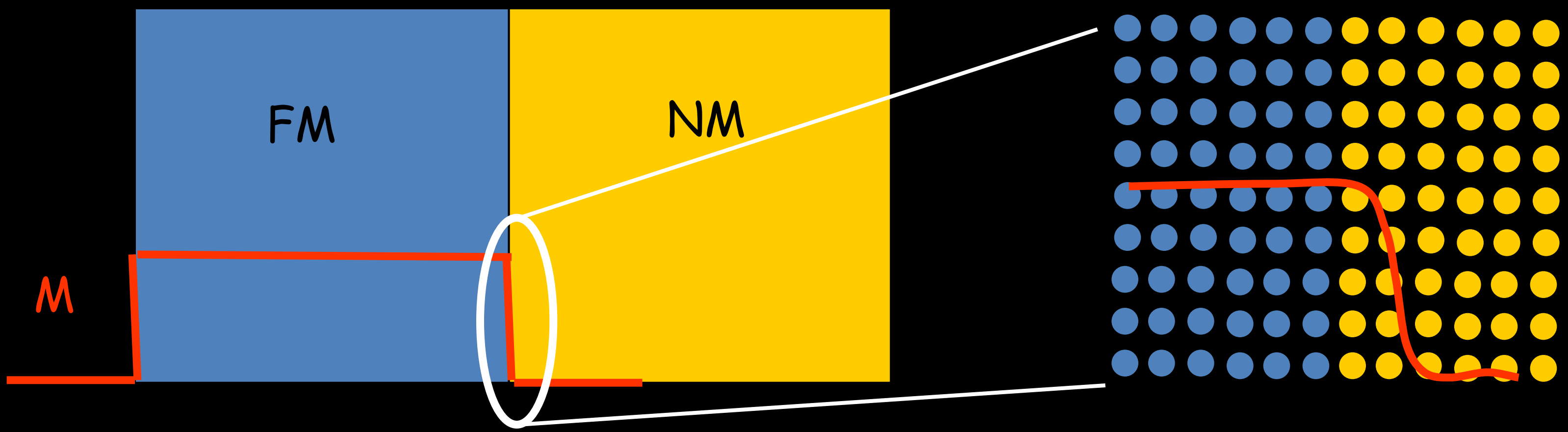






Surface effects

Proximity effects

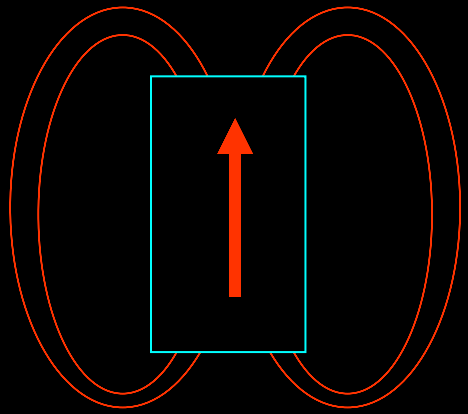


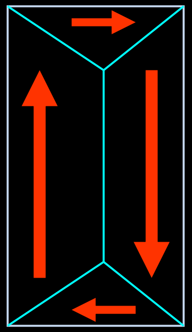
Interaction is of the order of few nanometers

For nanoparticles this region be a significant part of the whole material

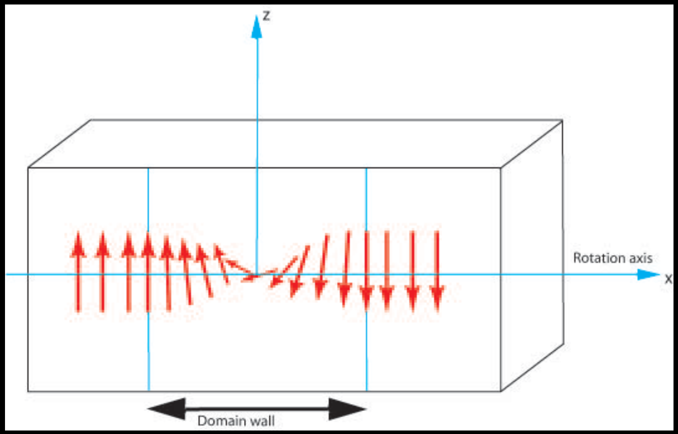
Monodomain regime

Domains decrease the magnetostatic energy





Domains are separated by domain walls

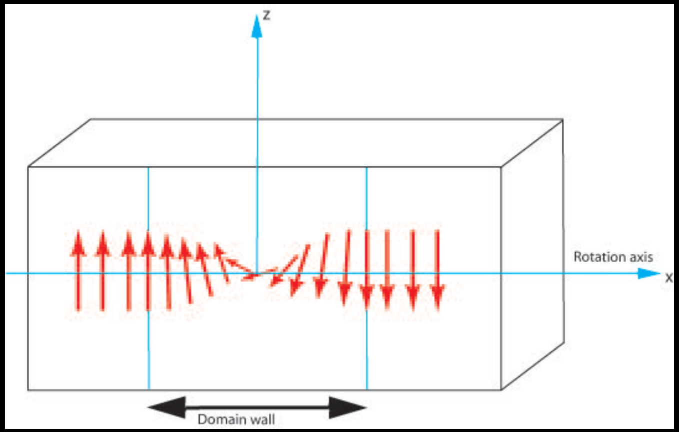


Domain wall width (exchange correlation length) is ~ few nanometers

Monodomain regime

Domains walls have a certain energy

- $\Delta E_{exchange}$
- $\Delta E_{anisotropy}$

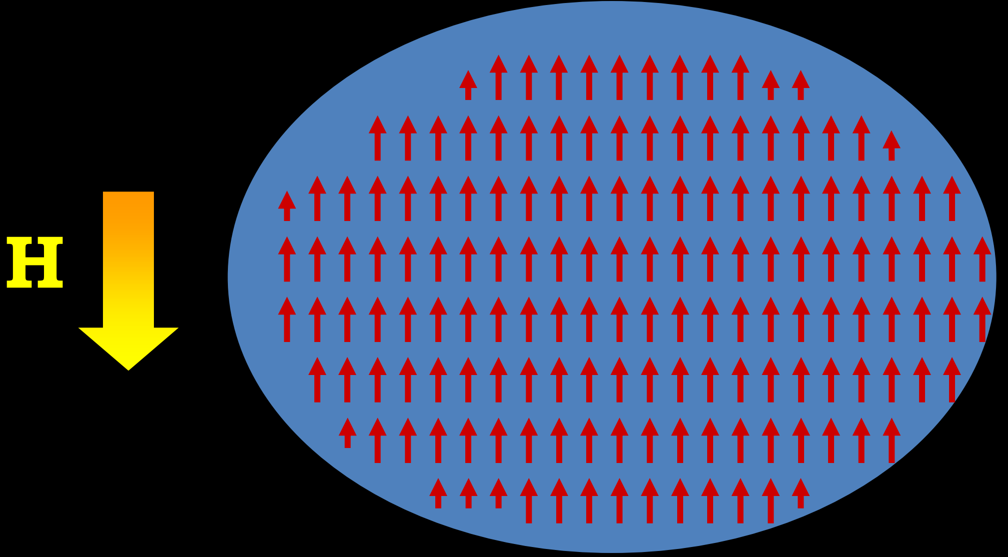


For small nanoparticles is more favourable to have no domains walls

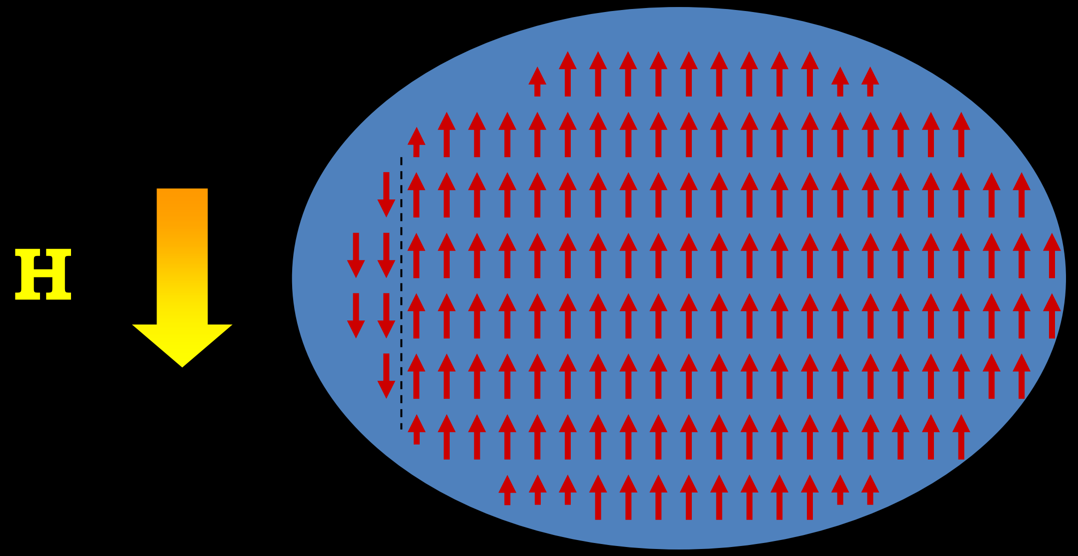
Monodomain regime

Two different mechanisms for magnetization rotation

Coherent spin rotation



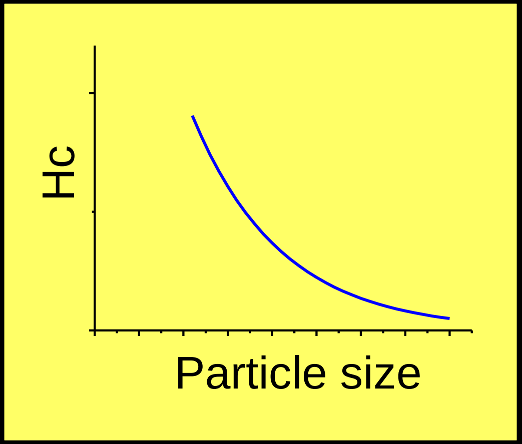
Domain wall motion



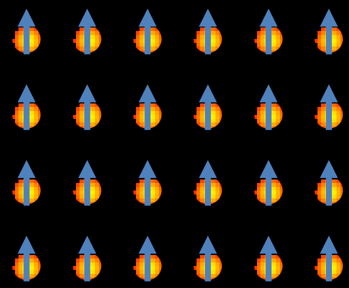
Moodomine regime

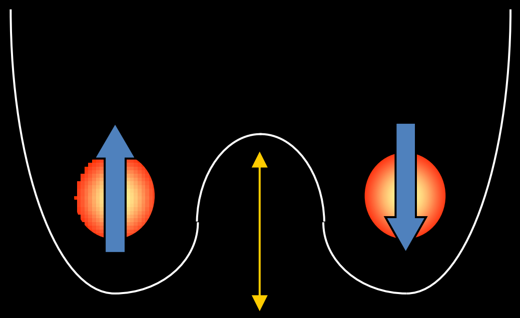
In monodomain nanoparticles there is no domain walls

Increase of the Coercive force



Superparamagnetism





Energy Barrier = KV

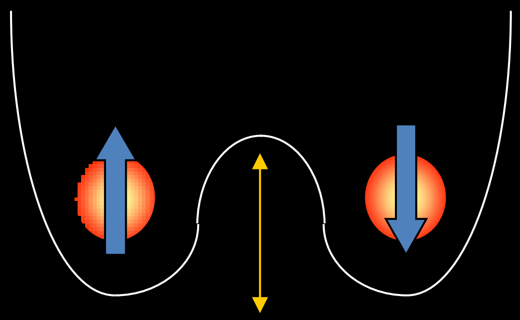
Thermal Energy= $K_B T$

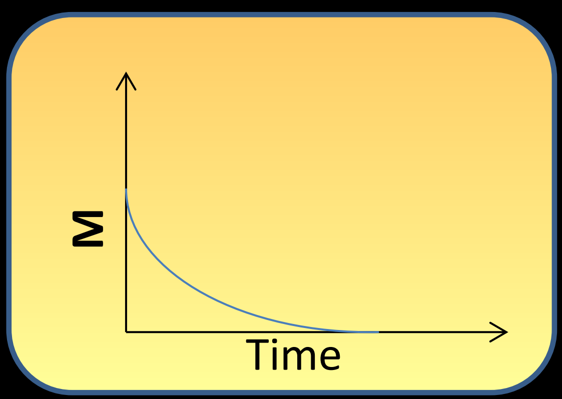
} Relaxation

$$\tau = \tau_0 \cdot e^{\frac{K \cdot V}{k_B \cdot T}}$$

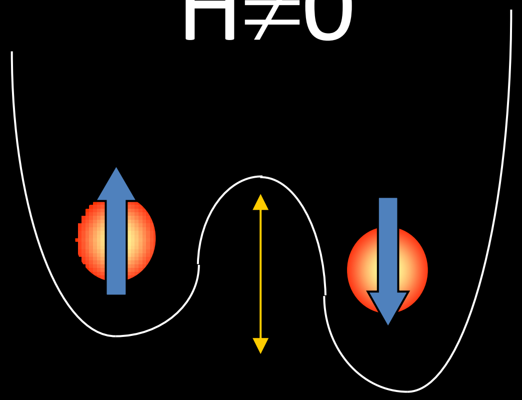
Superparamagnetism

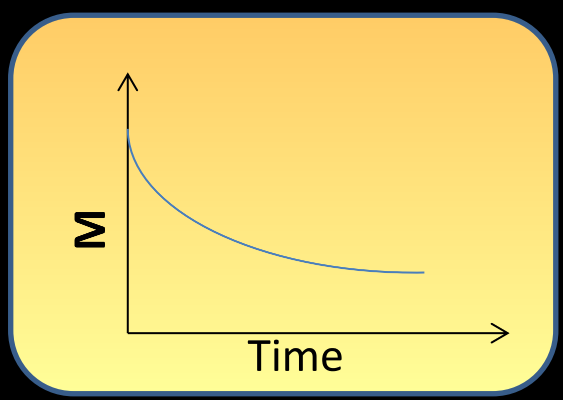
H=0





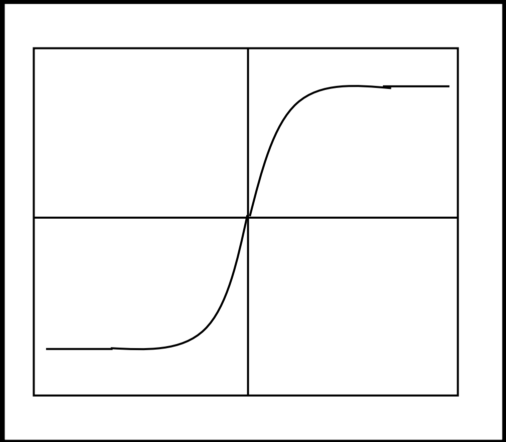
H≠0



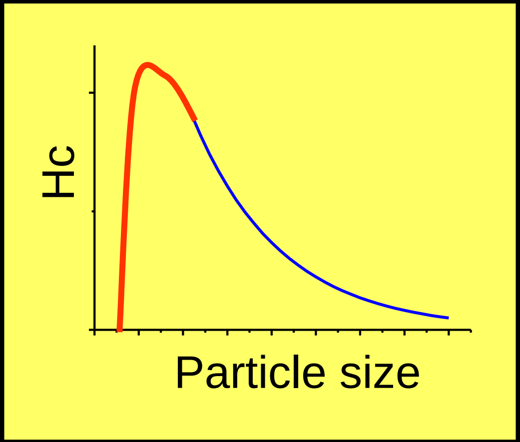


Superparamagnetismo

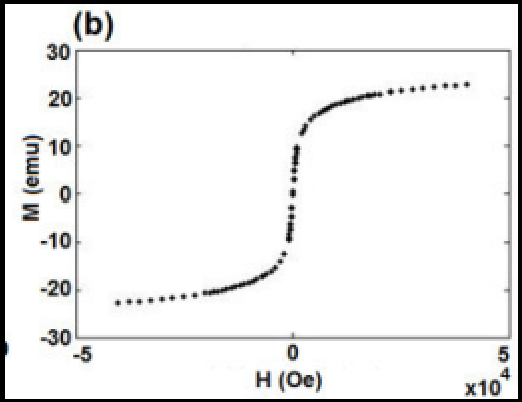
If relaxation time is ~ measuring time



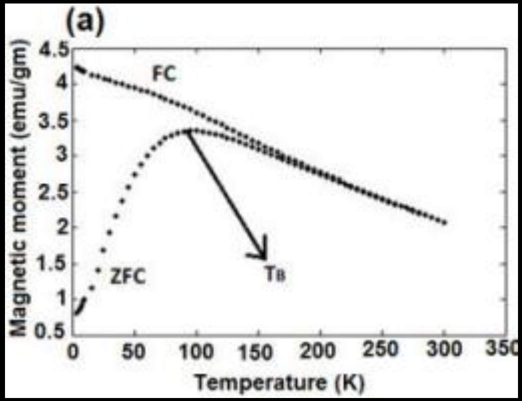
Coercitivity drops
(Big problem for data storage)



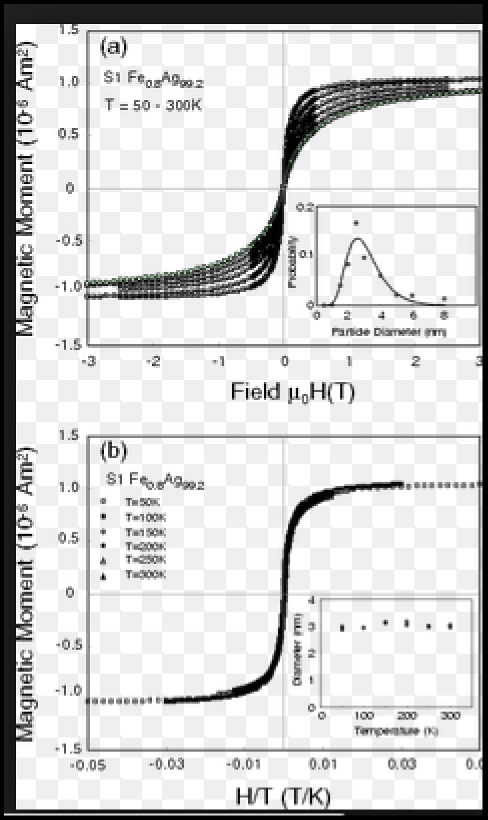
Fingerprints of superparamagnetism



$L(x)=\coth(x)-1/x$



$KV \approx 25\ K_BT$

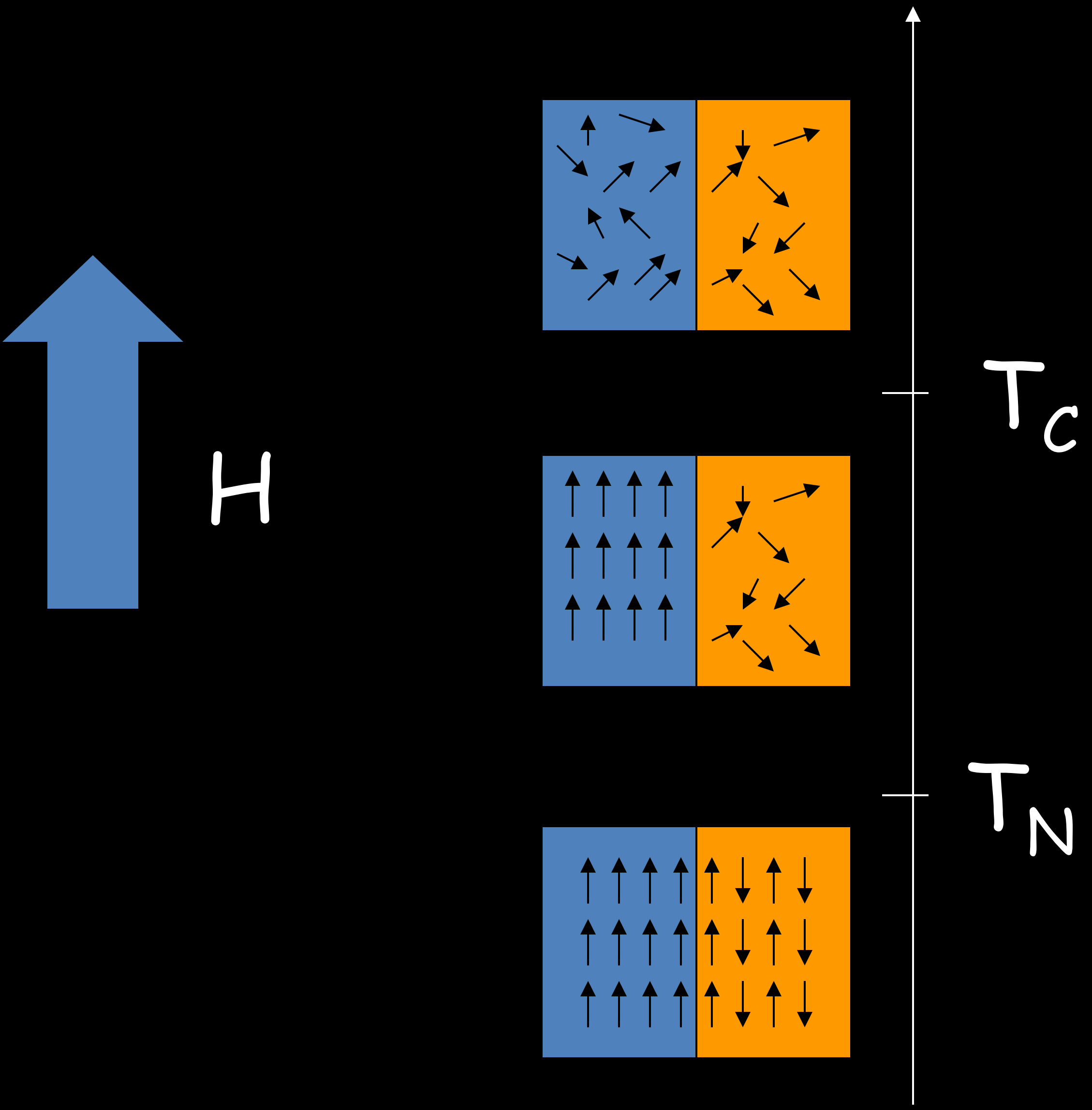


Exchange bias

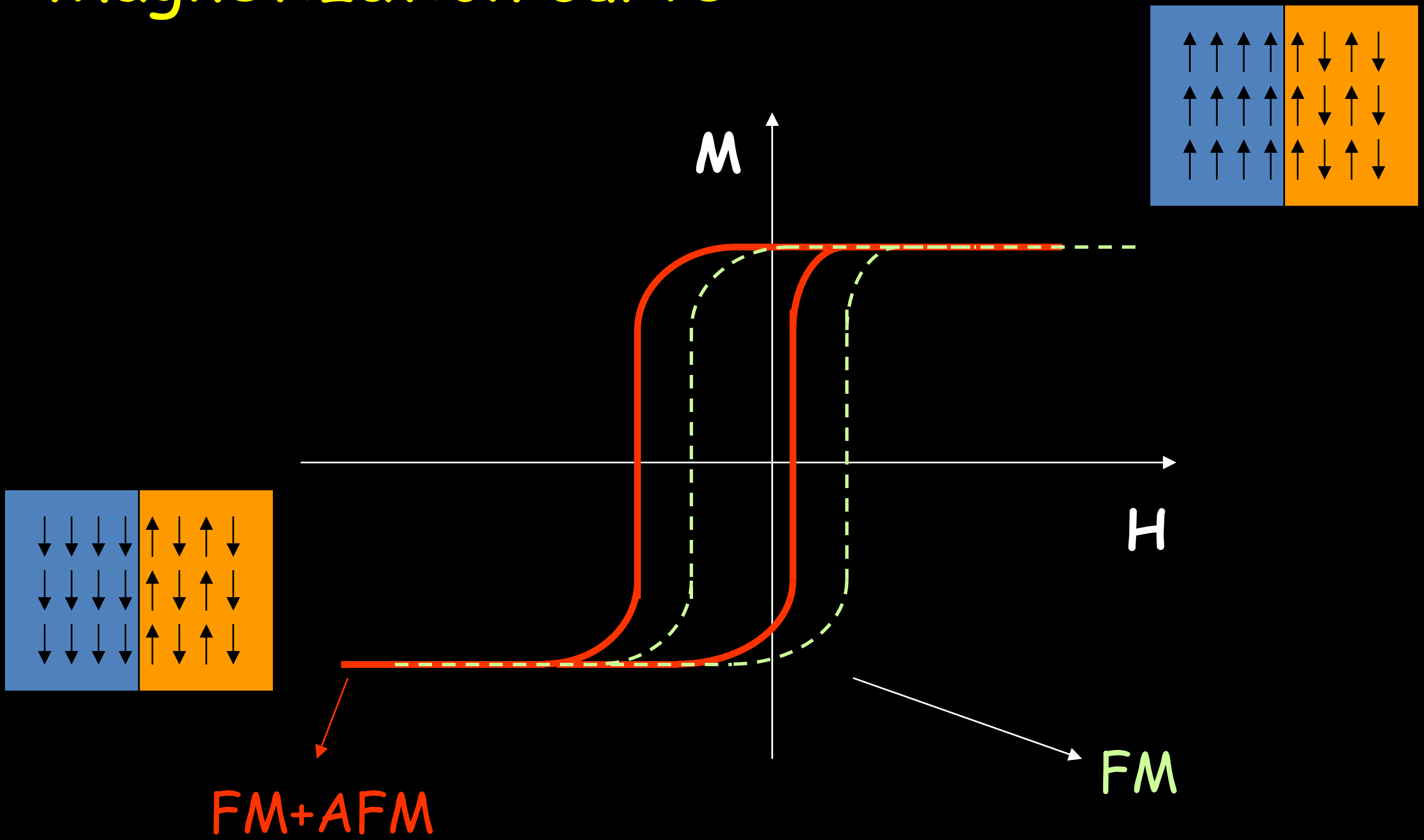
Junction of FM & AFM

$T_C > T_N$

Cooling with field



Magnetization curve



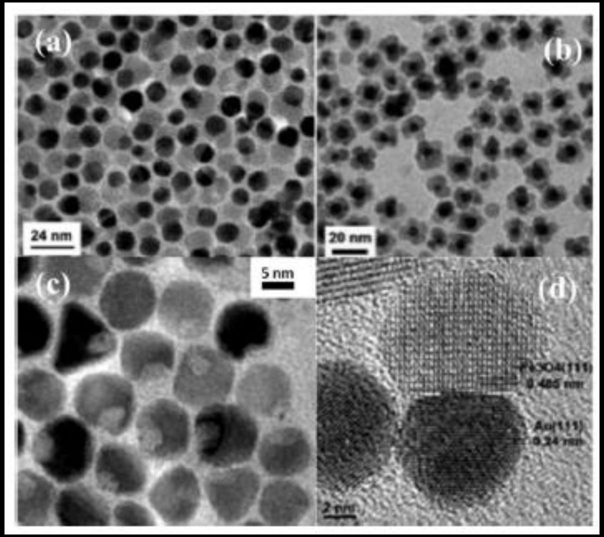
Increase of coercivity

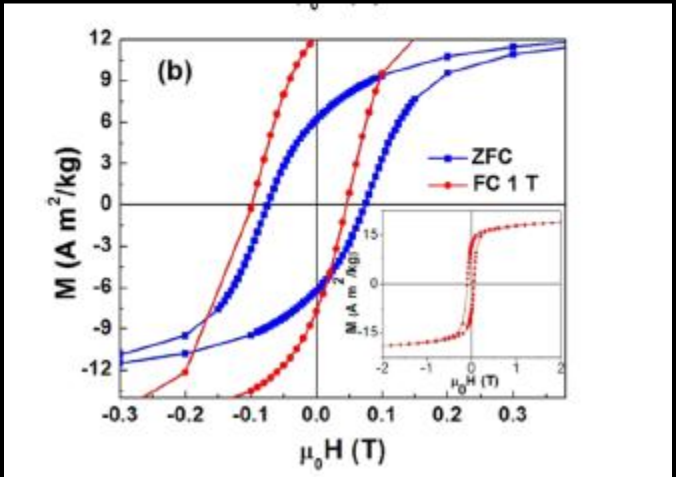
Exchange bias was discovered by W. H. Meiklejohn in 1957

EB is not fully understood

It has been observed in

- ✓ FM/AFM
- ✓ FM/FiM
- ✓ FiM/AFM
- ✓ FiM/FiM
- ✓ FM/disordered layer





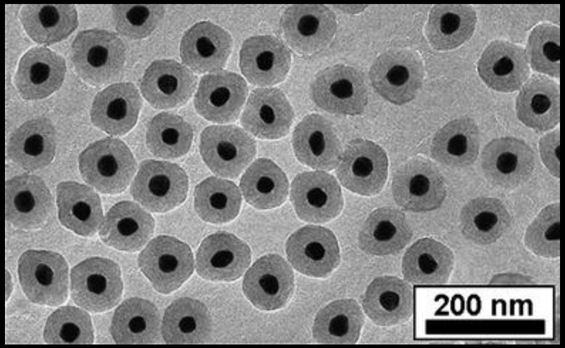
IOP Publishing Nanotechnology

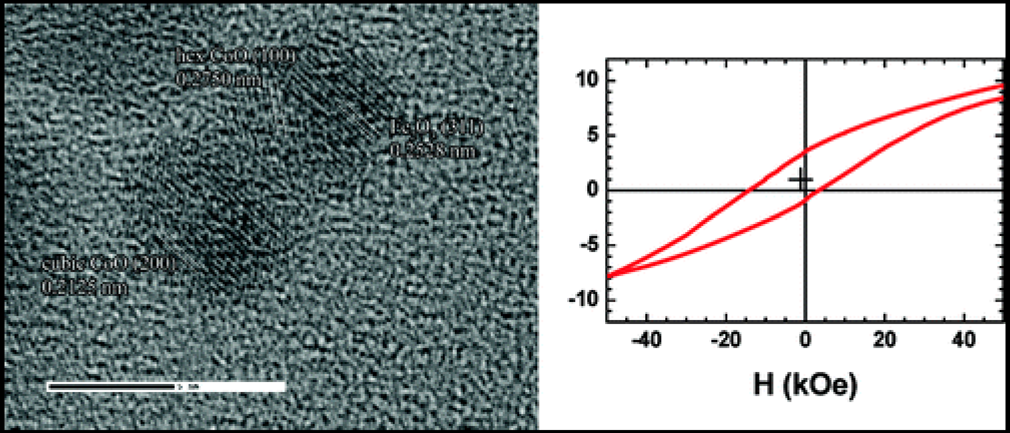
Nanotechnology **25** (2014) 055702 (10pp) doi:10.1088/0957-4484/25/5/055702

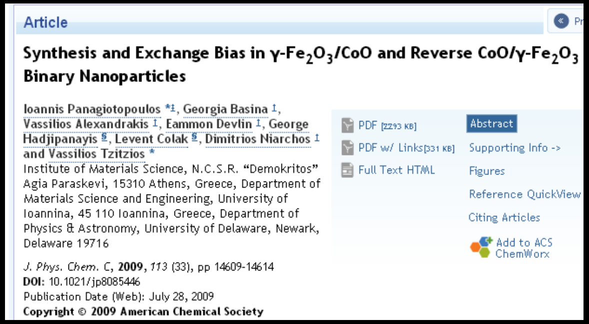
Exchange bias effect in Au-Fe_3O_4 nanocomposites

Sayan Chandra[1], N A Frey Huls[1], M H Phan[1], S Srinath[1,2], M A Garcia[3], Youngmin Lee[4], Chao Wang[4], Shouheng Sun[4], Òscar Iglesias[5] and H Srikanth[1]

Exchange bias in core-shell nanoparticles






Article

Synthesis and Exchange Bias in γ-Fe_2O_3/CoO and Reverse CoO/γ-Fe_2O_3 Binary Nanoparticles

Ioannis Panagiotopoulos *‡, Georgia Basina ‡, Vassilios Alexandrakis ‡, Eammon Devlin ‡, George Hadjipanayis §, Levent Colak §, Dimitrios Niarchos ‡ and Vassilios Tzitzios *
Institute of Materials Science, N.C.S.R. "Demokritos" Agia Paraskevi, 15310 Athens, Greece, Department of Materials Science and Engineering, University of Ioannina, 45 110 Ioannina, Greece, Department of Physics & Astronomy, University of Delaware, Newark, Delaware 19716

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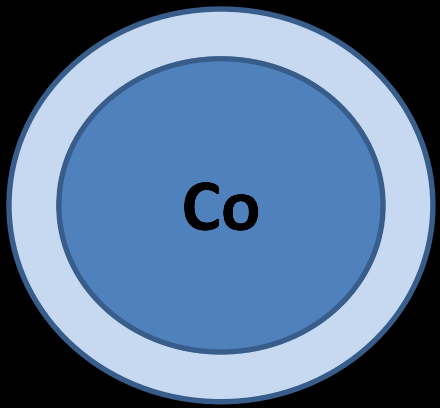
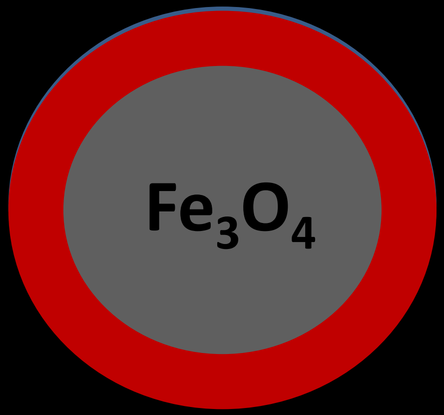
J. Phys. Chem. C, **2009**, *113* (33), pp 14609-14614
DOI: 10.1021/jp8085446
Publication Date (Web): July 28, 2009

Naturally oxidized EB



EB in Co/CoO nanoparticles



EB in $Fe_3O_4/\gamma Fe_2O_3$

EB depends critically on the shell thickness

...some reviews........

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Journal of Physics D: Applied Physics

Journal of Physics D: Applied Physics > Volume 35 > Number 6

Xavier Batlle and Amílcar Labarta 2002 *J. Phys. D: Appl. Phys.* **35** R15 doi:10.1088/0022-3727/35/6/201

Finite-size effects in fine particles: magnetic and transport properties

REVIEW ARTICLE

Xavier Batlle and Amílcar Labarta

Show affiliations

ELSEVIER

Journal of Magnetism and Magnetic Materials

Volume 192, Issue 2, 15 February 1999, Pages 203–232

Exchange bias

J Nogués[a], Ivan K Schuller[b]

ELSEVIER

Physics Reports

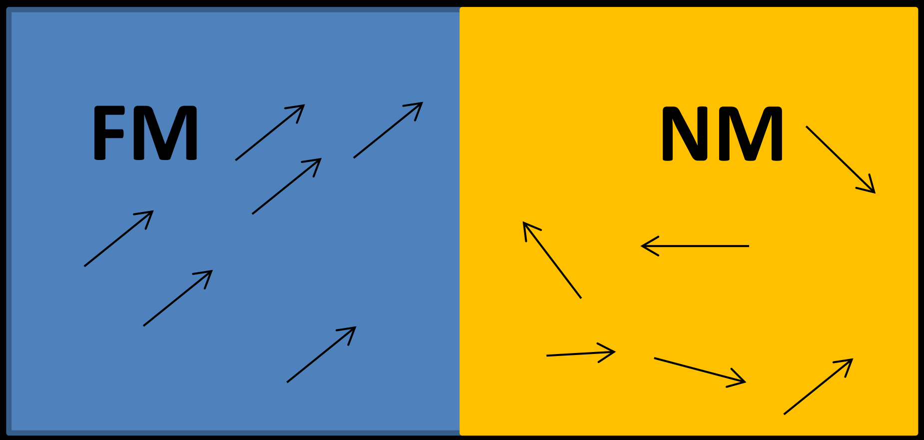
Volume 422, Issue 3, December 2005, Pages 65–117

Exchange bias in nanostructures

J. Nogués[a], J. Sort[a], V. Langlais[b], V. Skumryev[a], S. Suriñach[b], J.S. Muñoz[b], M.D. Baró[b]

II. Nanoscale induced magnetism

Proximity polarization



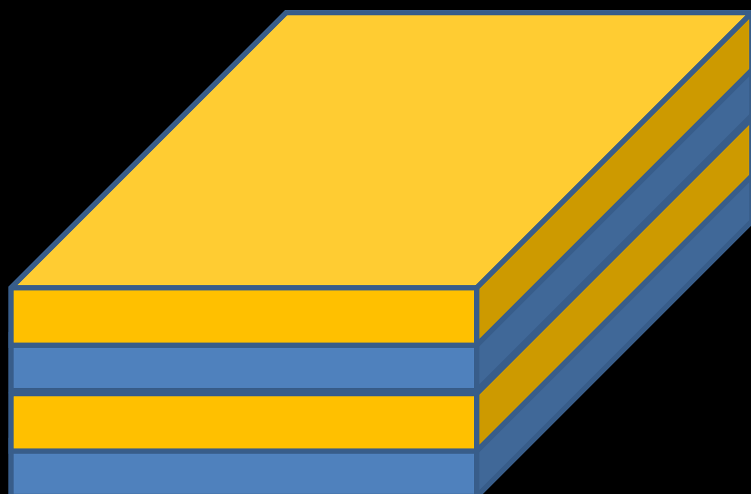
Interface region of the NM will exhibit some magnetic polarization

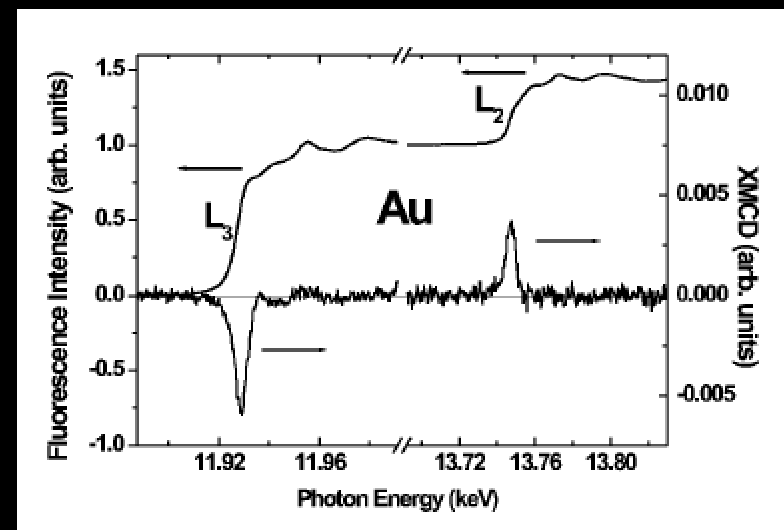
RAPID COMMUNICATIONS

PHYSICAL REVIEW B **69**, 220404(R) (2004)

Magnetic moment of Au at Au/Co interfaces: A direct experimental determination

F. Wilhelm,[1] M. Angelakeris,[2] N. Jaouen,[1] P. Poulopoulos,[3,*] E. Th. Papaioannou,[4,2] Ch. Mueller,[4] P. Fumagalli,[4]
A. Rogalev,[1] and N. K. Flevaris[2]

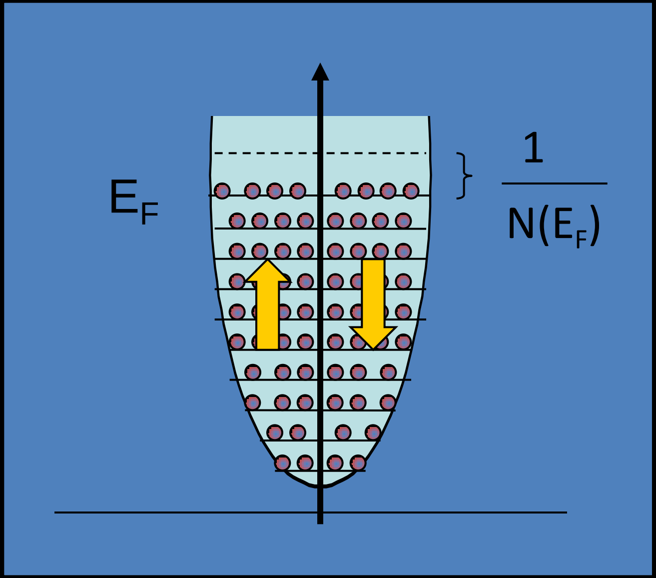




Magnetic nanoparticles

Materials "close to be ferromagnetic"?

Close to satisfy Stoner criterion



To change the spin of one electron:

- Increase of orbital energy $\Delta E=1/N(E_F)$
- Decrease of Exchange energy: I

(Stoner parameter)

Energy balance: $\Delta E=1/N(E_F)-I<0$

$N(E_F)\cdot I>1$ (Stoner criterion)

Ferromagnetism in Pd nanoparticles

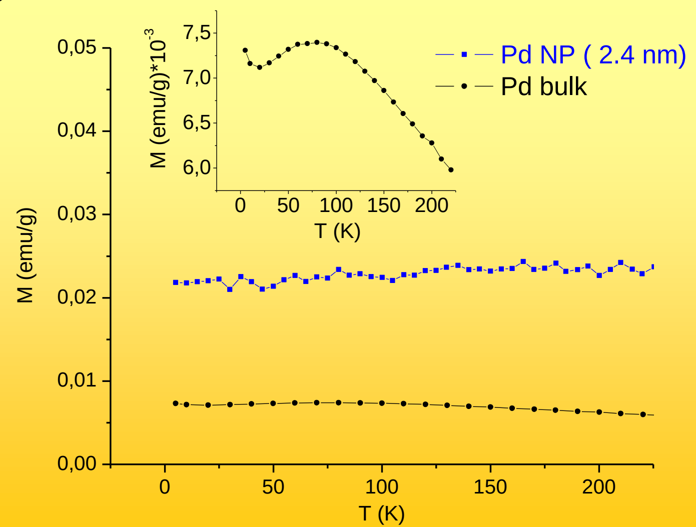
Pd (FCC) is a paramagnetic metal

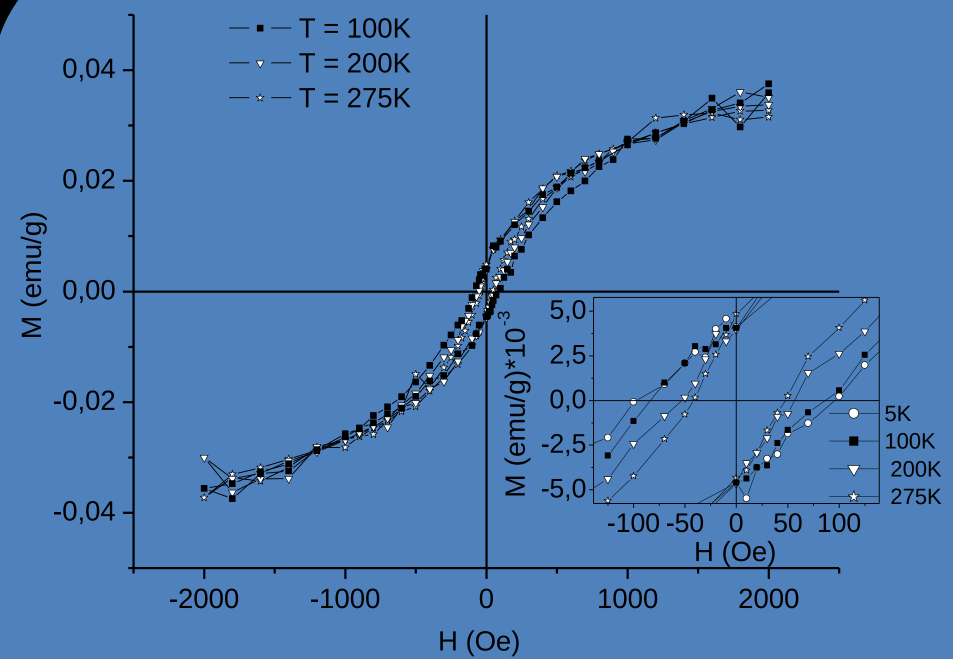
- ➢ $N(E_F)=1.23\ eV^{-1}\ spin^{-1} atom^{-1}$
- ➢ $I = 0.71\ eV$

⇨ **$N(E_F)\cdot I=0.87<1$ (non ferromagnetic behaviour)**

2.4 nm Pd NP exhibit ferromagnetism

Blocking T is over 300 K

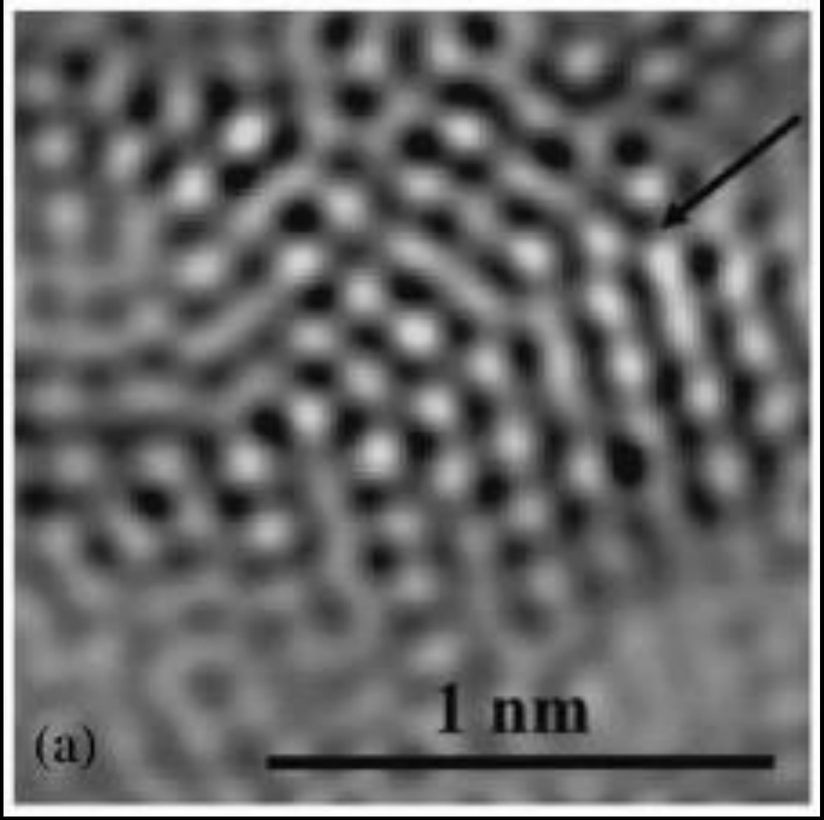


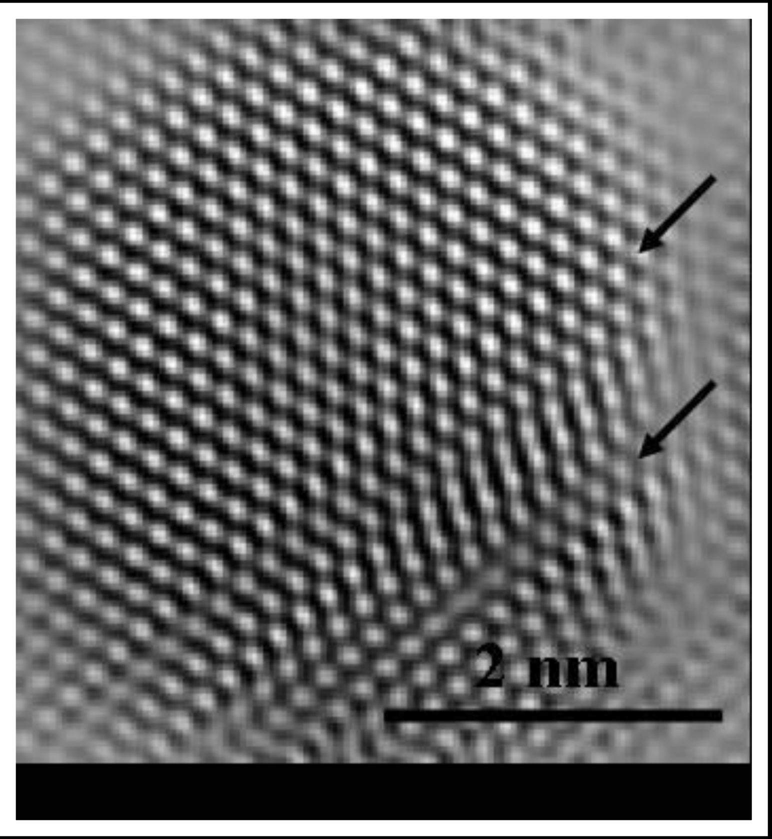


B. Sampedro et al, PRL 91 (2003) 237203

Ferromagnetism in Pd nanoparticles

HREM studies found a large number of twin boundaries





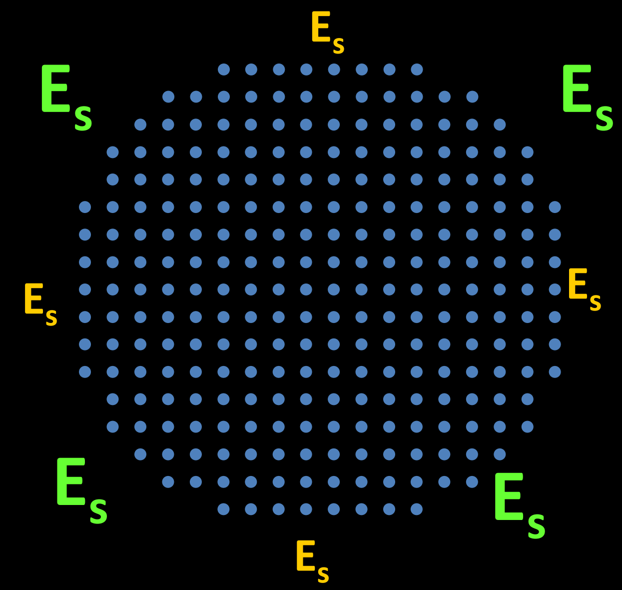
Twin boundaries reduce the energy of the NP

Ferromagnetism in Pd nanoparticles

FCC metals present:

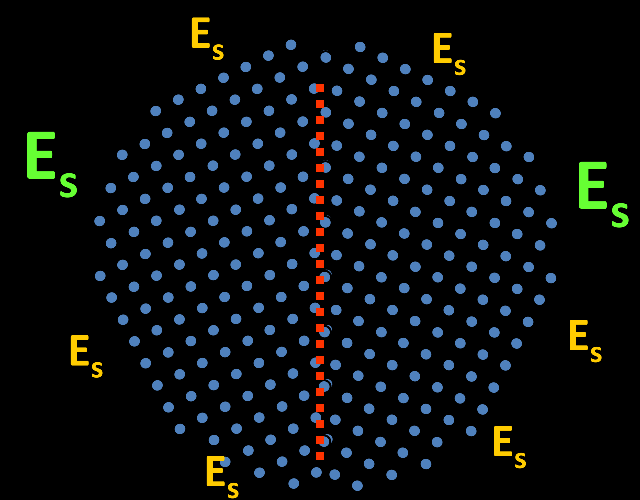
-Highly anisotropic Surface Energy

- Low formation energy for twin boundaries



✓The presence of twin boundaries reduce $E_{Surface}$

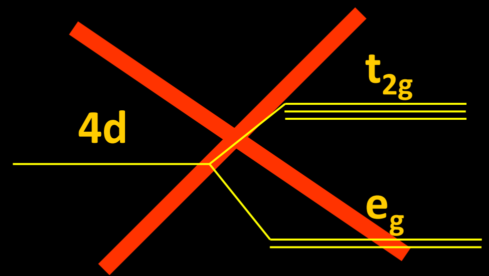
✓The increase of E_{volume} is low



Total energy decreases with twin boundaries

Ferromagnetism in Pd nanoparticles

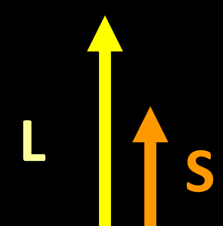
Cubic symmetry splits d levels



At the twin boundaries there is a lack of symmetry →No splitting of the 4d level

Local enhancement of $N(E_F)$

Stoner criterion is satisfied !!



✓Lack of symmetry at the TB blocks the angular momentum

Pd exhibits large spin-orbit coupling→Large K → T_B >300 K

✓Only atoms close to the TB contributes to ferromagnetism → Low M_S (10^{-3} μ_B atom^{-1})

Ferromagnetism in Pt nanoparticles

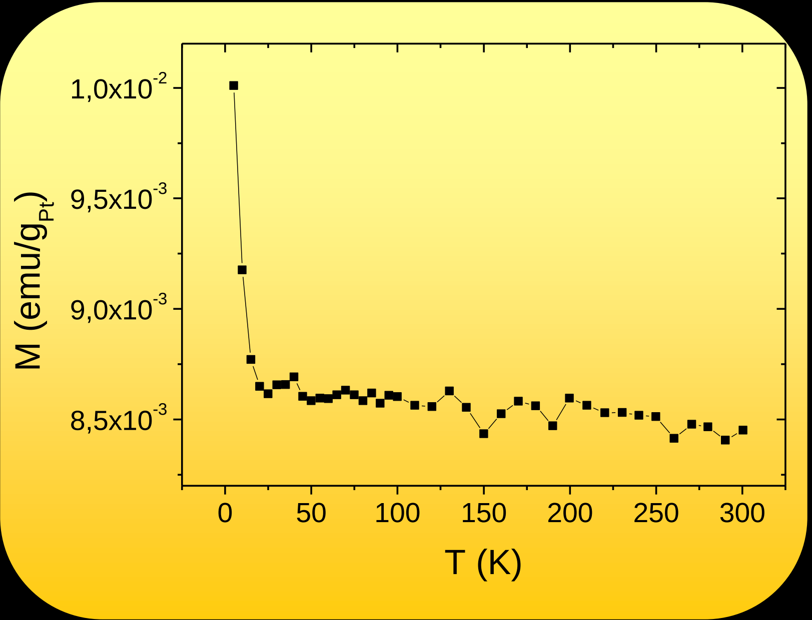
Pt is similar to Pd: - FCC metal

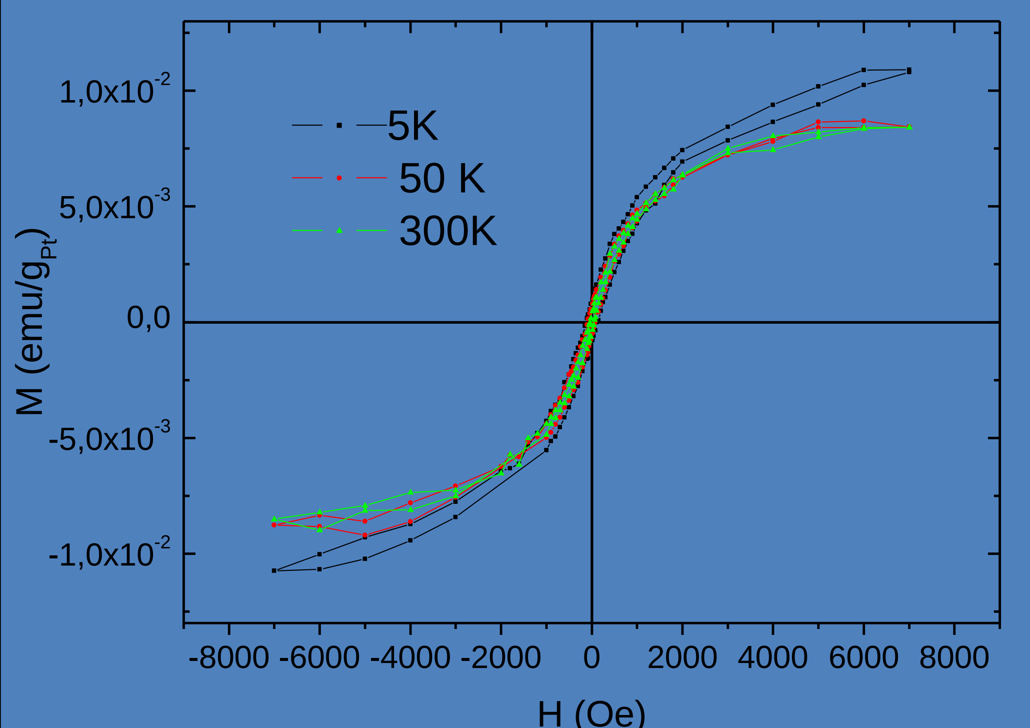
- $N(E_F)=0.9\ eV^{-1}$

- $I=0.85\ eV\ atom^{-1}$

Stoner criterion almost satisfied

2-5 nm Pt NP exhibit FM





Blocking T is over 300 K

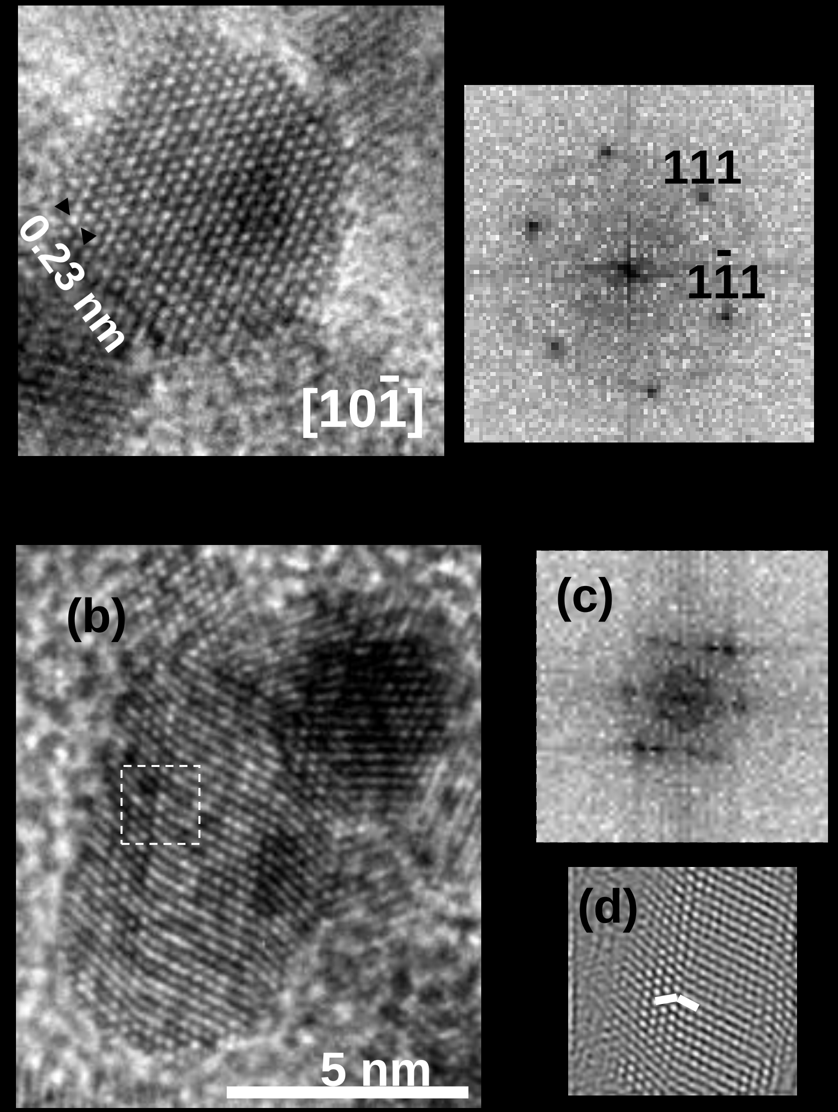
M. A. Garcia et al, *Nanotech.* to be publish

Ferromagnetism in Pt nanoparticles

Pt NP also exhibit:

- a large density of twin boundaries - low M_S.

The same mechanism than Pd



Effects in diamagnetic materials?

What we need for ferromagnetic behaviour?

Magnetic moments

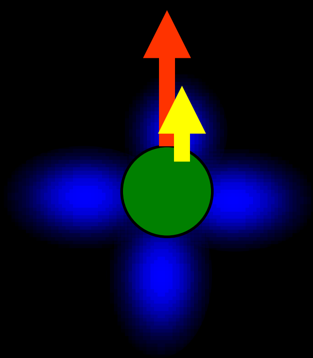
Anisotropy

Exchange interactions

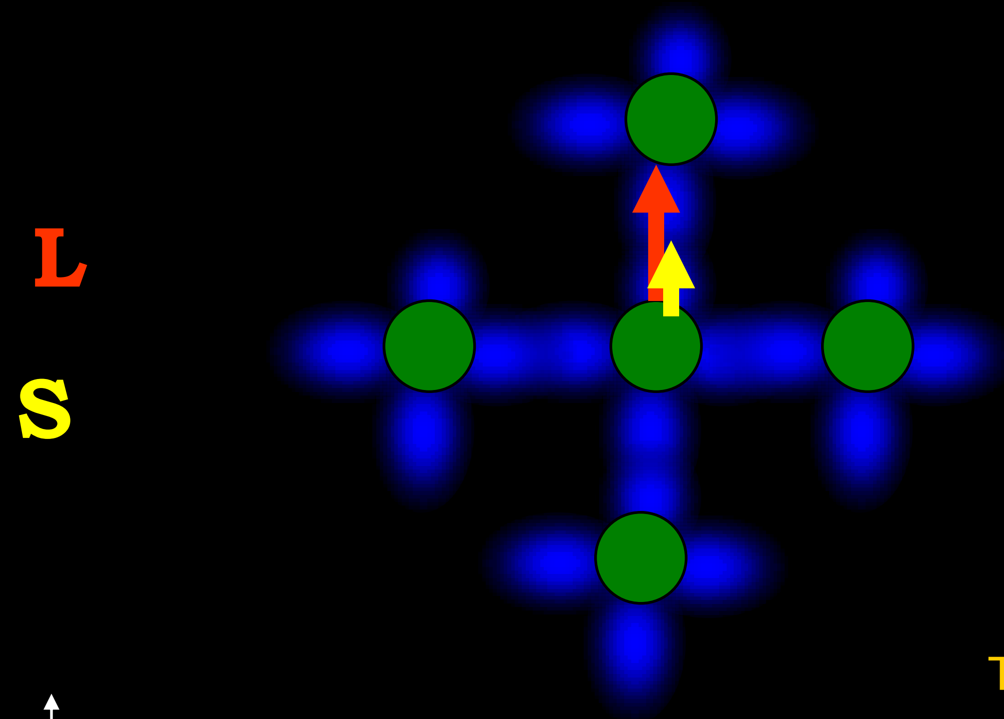
For a single atom

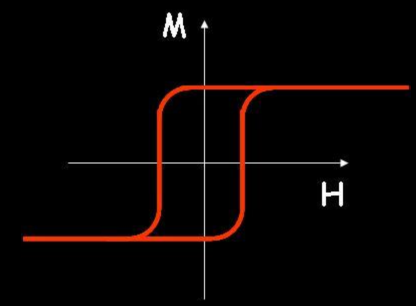
L

S



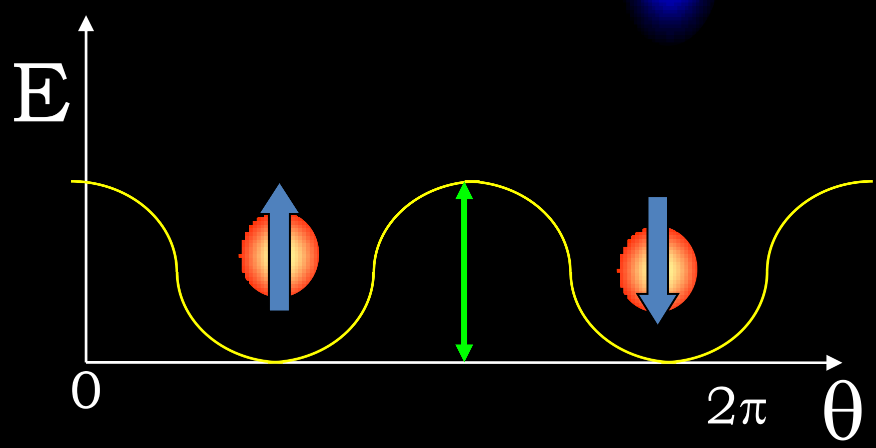
In a solid…….Magnetocrystalline anisotropy





Energy barrier= KV

Thermal energy= $K_B T$



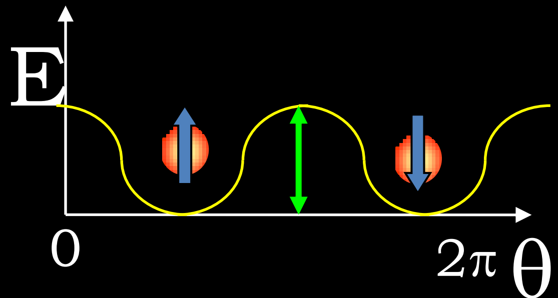
For an atom

KV~ μeV

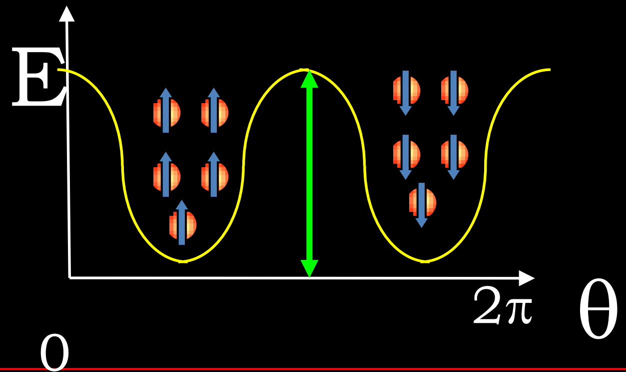
$K_B T$~meV

✓To observe FM we need to increase energy barriers

<u>Exchange:</u> Interaction between magnetic moments tending to keep them aligned



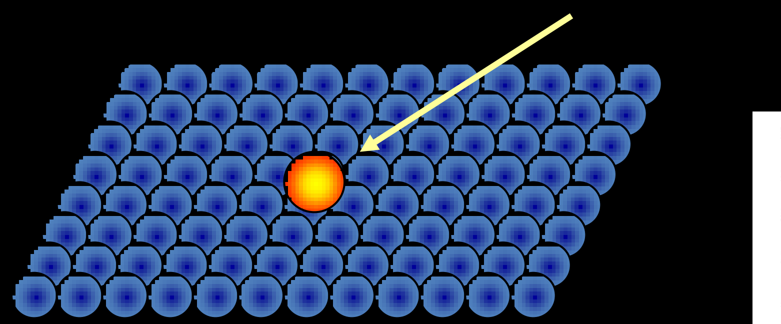
Barrier: E



Barrier n·E

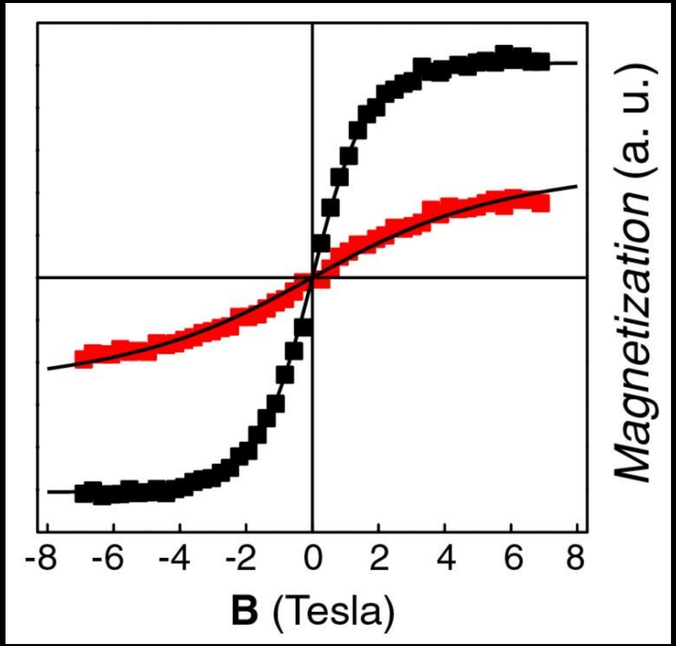
We should need huge anisotropy to observe FM in single atoms

Gambardella, Rusponi et al
Science 300 (2003) 1130

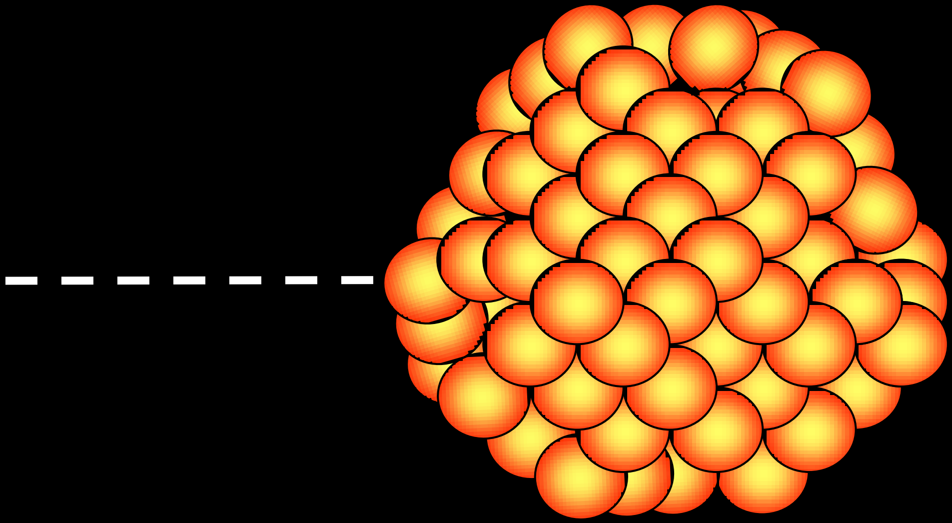


Co-Pt bond blocks Co L →

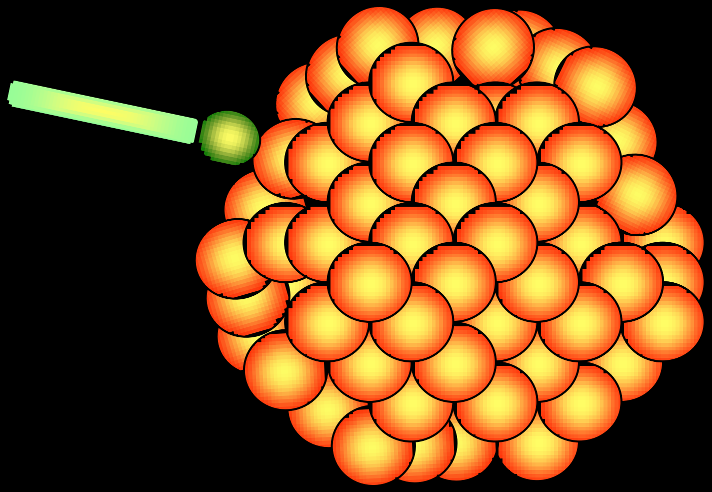
Spin-orbit copling blocks S →

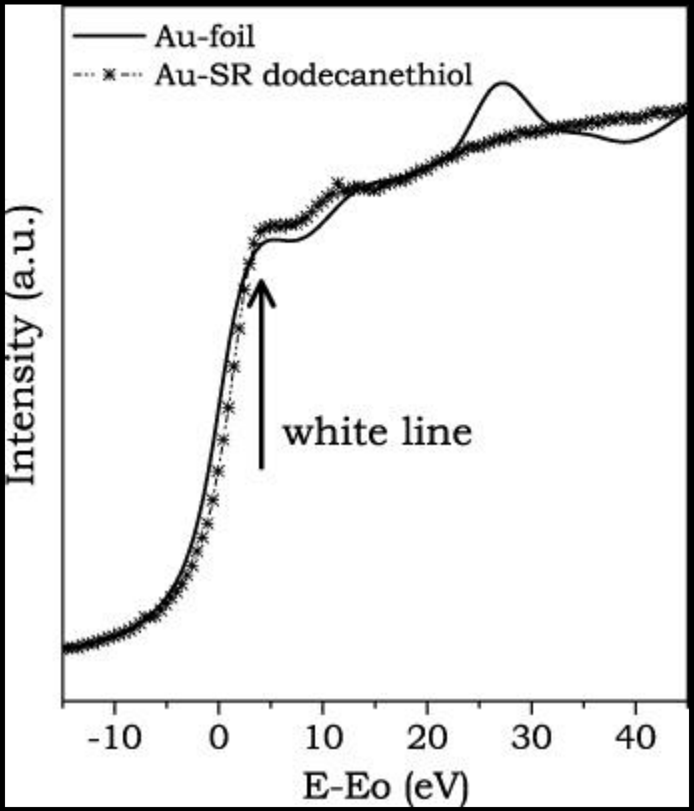


Anisotropy is always increased in surfaces: Symmetry broken



Magnetic moments can be induced by bonds





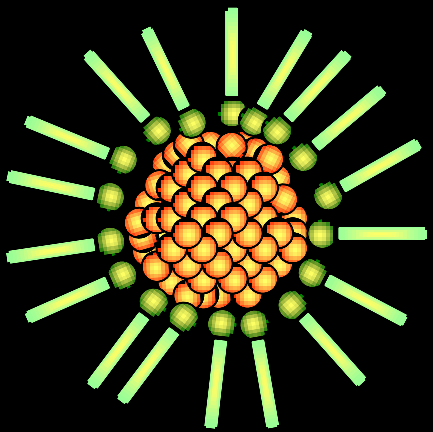
Gold Nanoparticles

- ✓ Holes in 5d orbital via thiol bonding
- ✓ Very large spin-orbit coupling

Two set of samples:

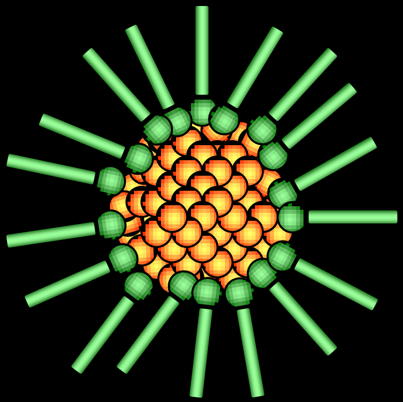
✓Au-NR sample: Gold NPs stabilized by a surfactant (tetraoctyl ammonium bromide).

✓Weak interaction with Au at surface of the NP

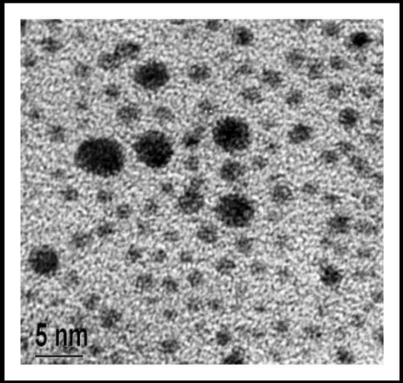


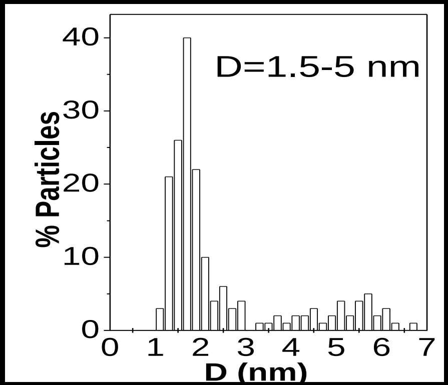
✓Au-SR sample: Gold NPs capped with thiol groups (dodecane alkyl chain)

✓Strong interaction with Au at surface

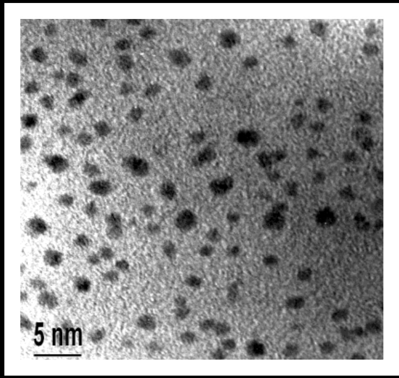


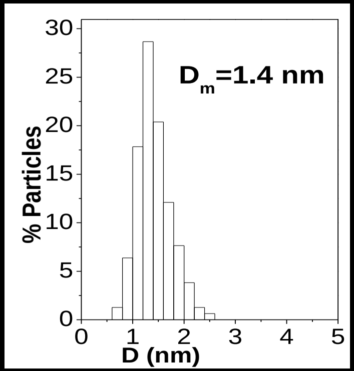
Au-NR



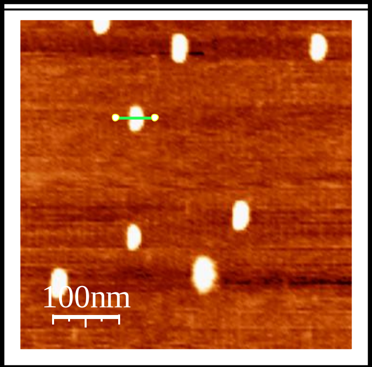


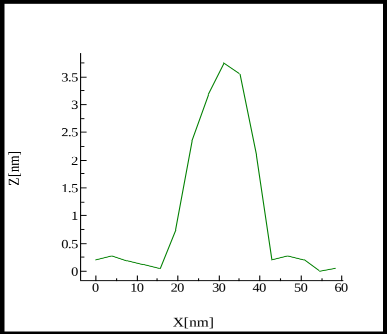
Au-SR





AFM

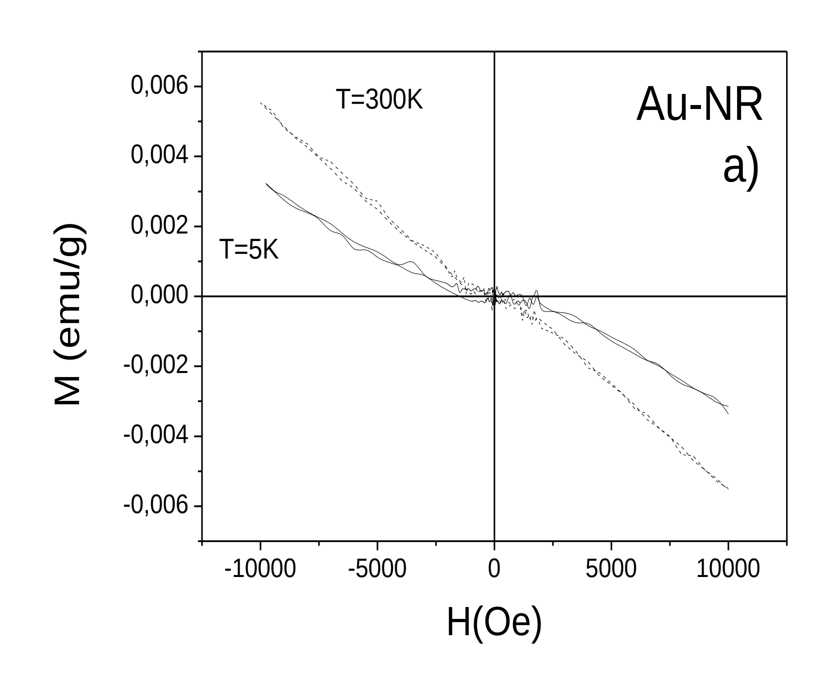


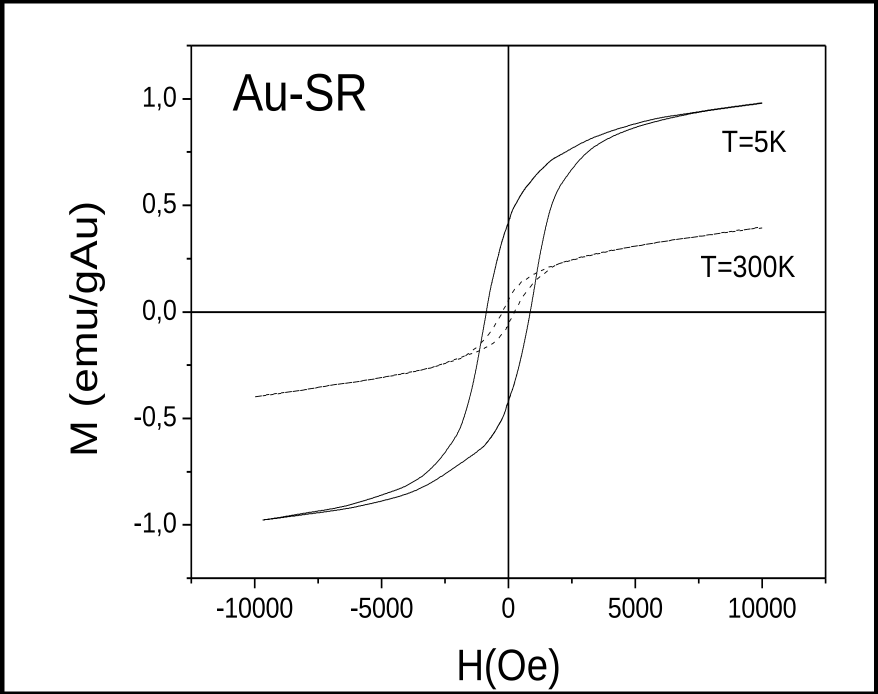


Dispersed NP

Magnetic properties

P. Crespo et al, PRL 93 (2004) 087204

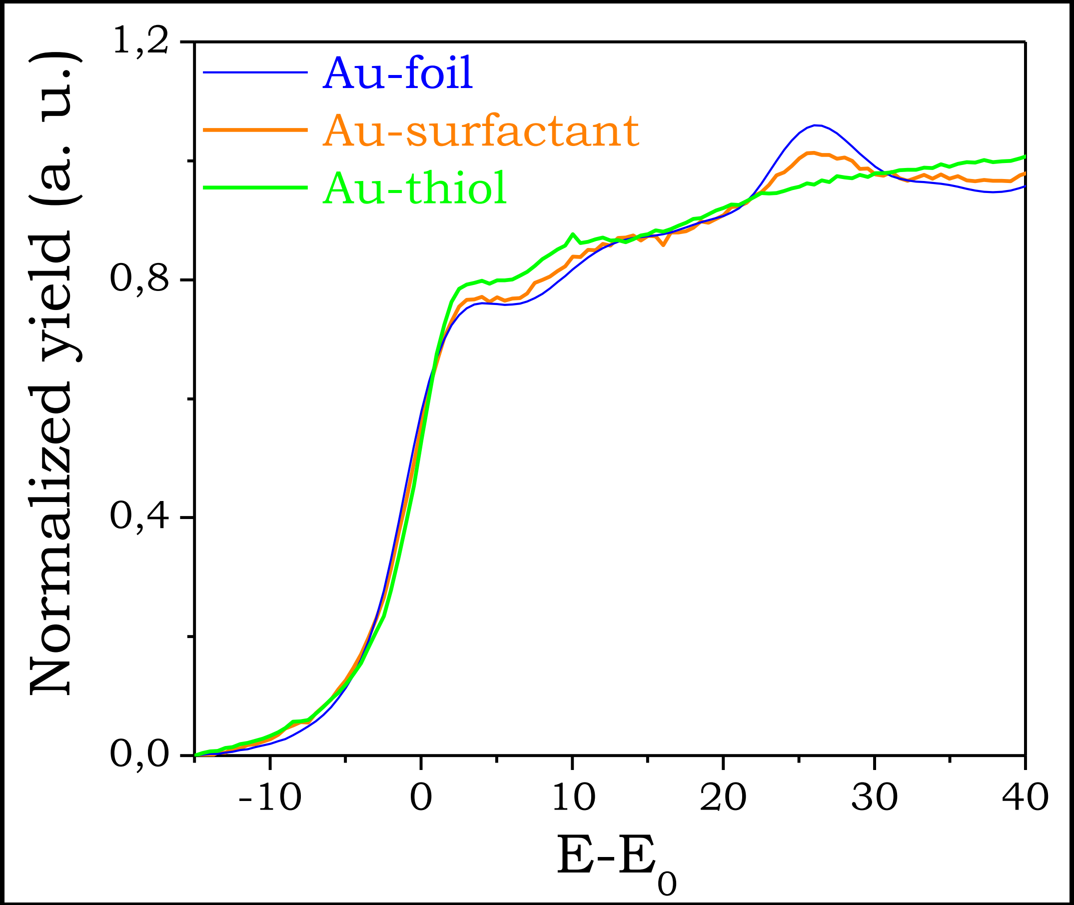


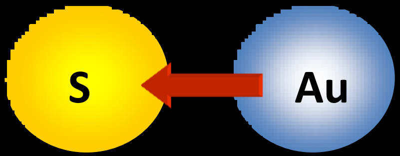


- **NR Samples are diamagnetic (as bulk gold)**
- **SR samples present ferromagnetic-like behaviour up to 300 K**

The capping molecule determines the magnetic behaviour of the NP

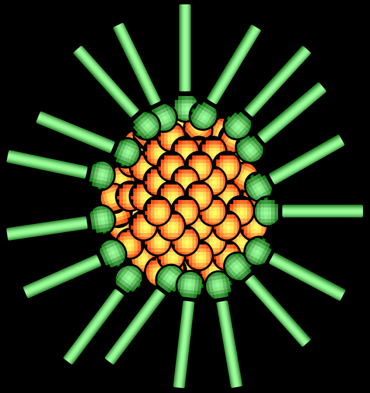
Au L_3 XANES Spectra

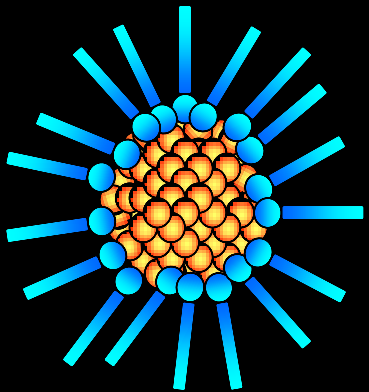


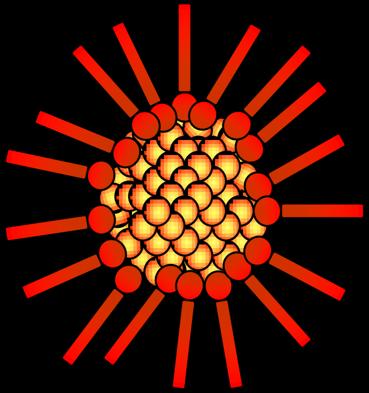


- There is charge transfer from Au(5d) to S(2p).
- Increase of d holes density at the surface Au atoms.

ZnO Nanoparticles







TOPO

Tryoctylphosphine

-O

AMINE

Tryoctylamine

-N

THIOL

Dodecanethiol

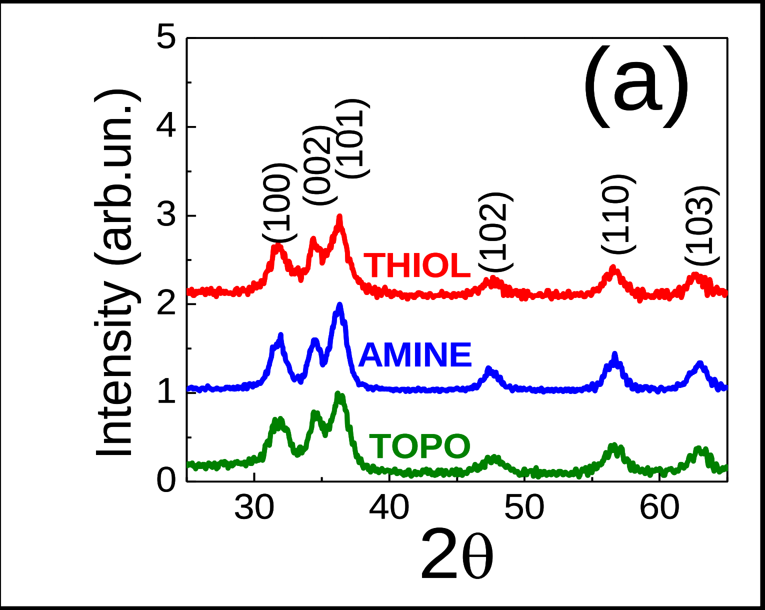
-S

NPs capped with different molecules

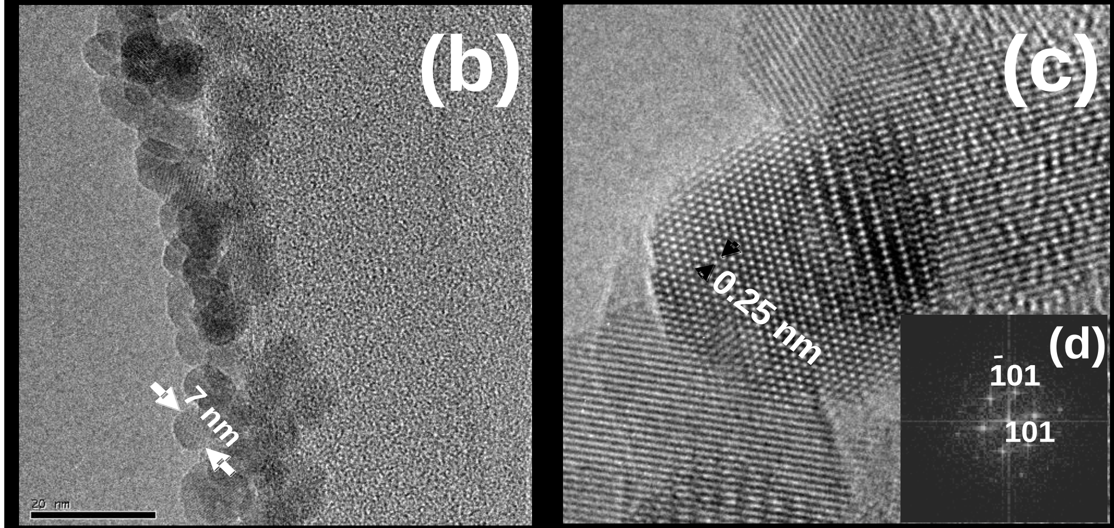
Crystallographic structure does not depend on the molecule

✓ZnO wurtzite structure

✓~10 nm

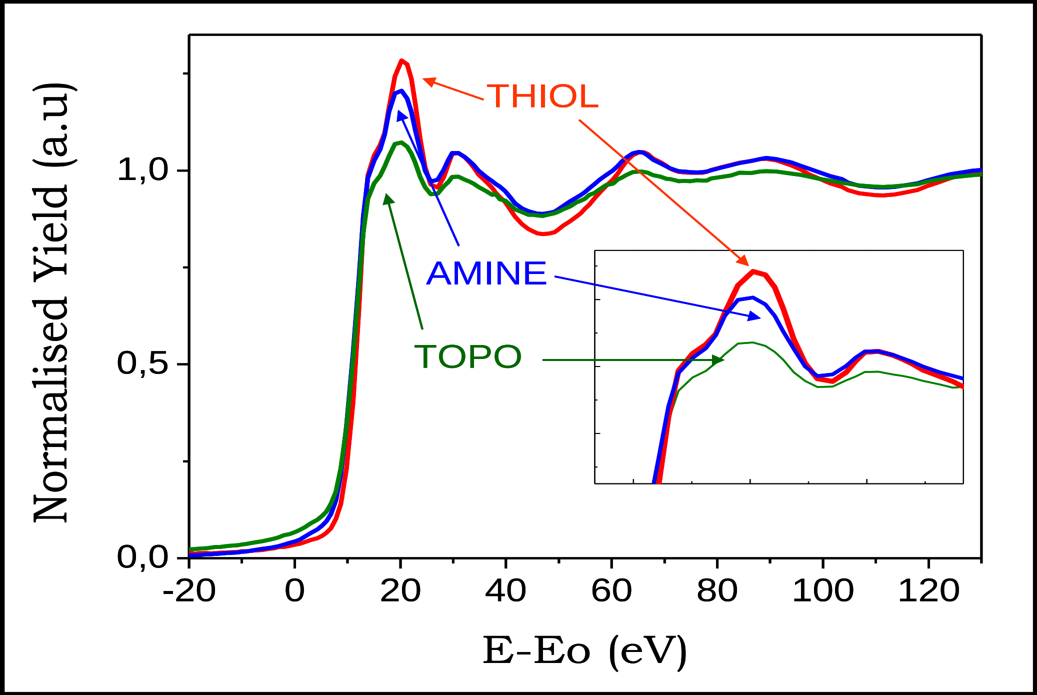


XRD



TEM

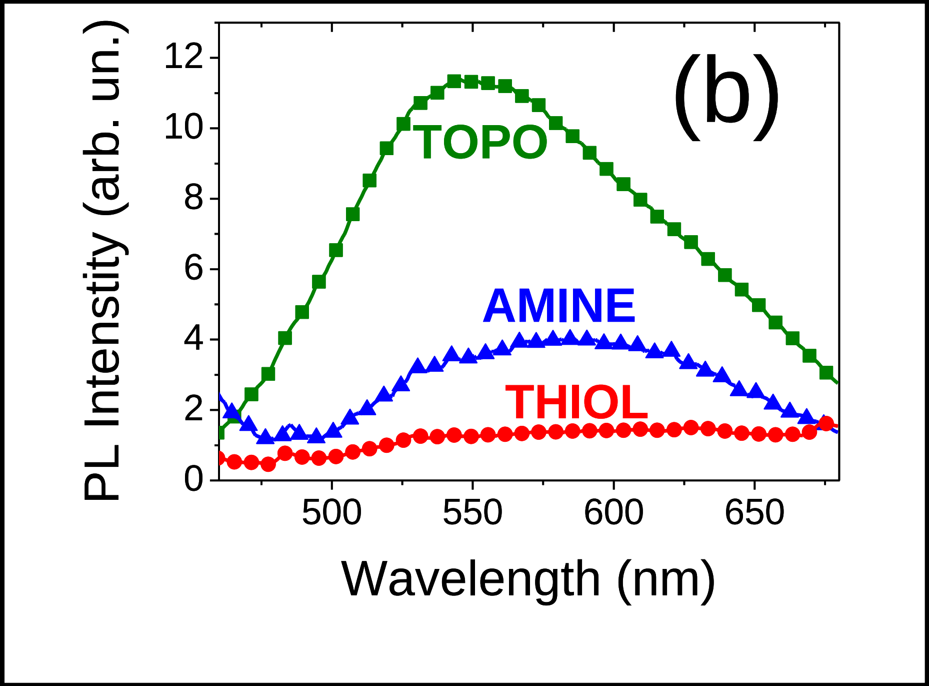
XANES spectra (Zn K-edge)



Different degree of occupation of the Zn outer orbitals depending on the molecule.

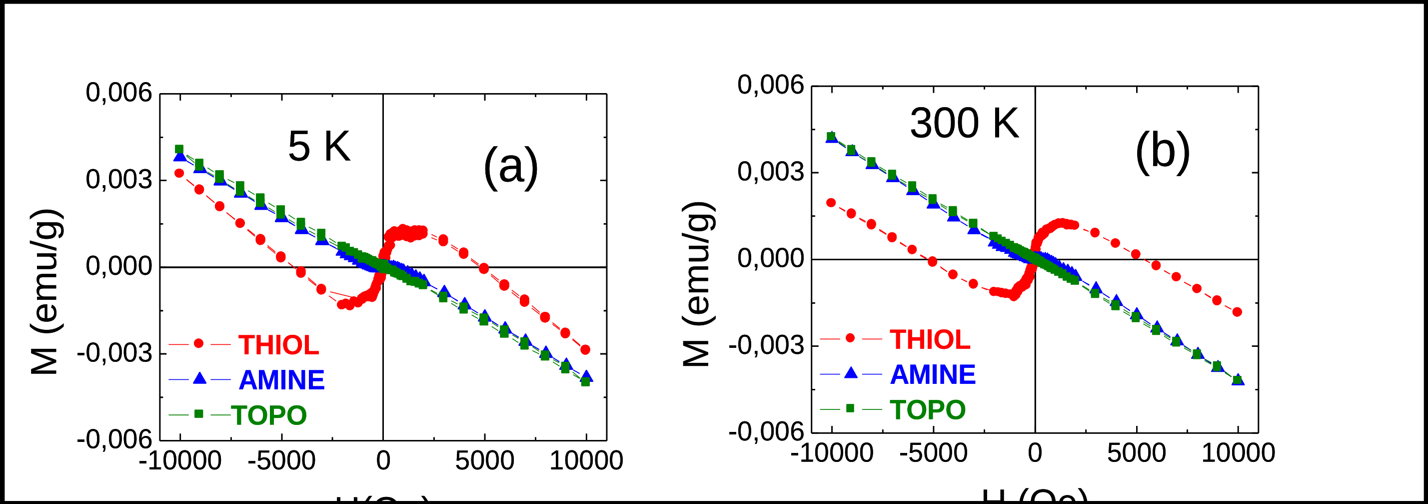
Different charge transfer for each molecule !!

Photoluminescence

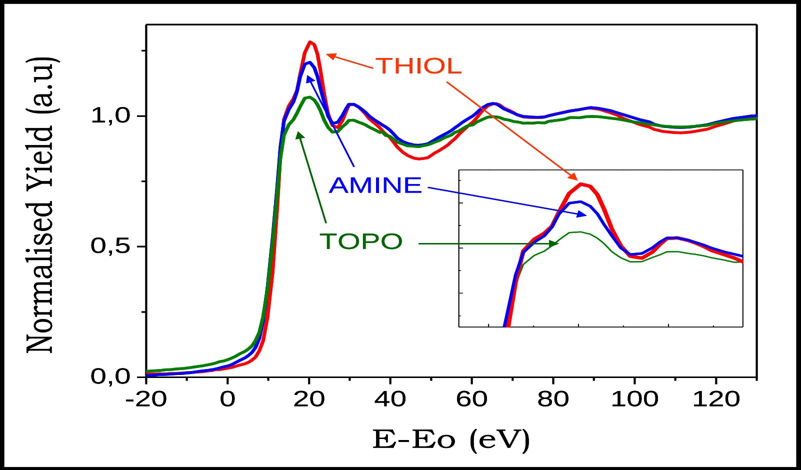


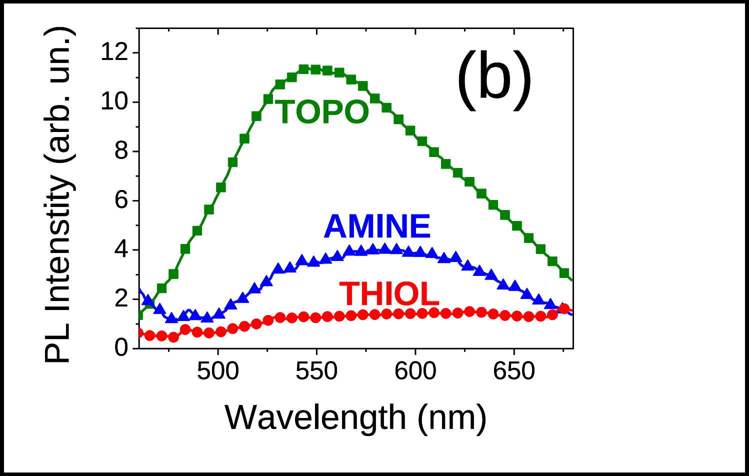
The energy levels are altered by the molecule

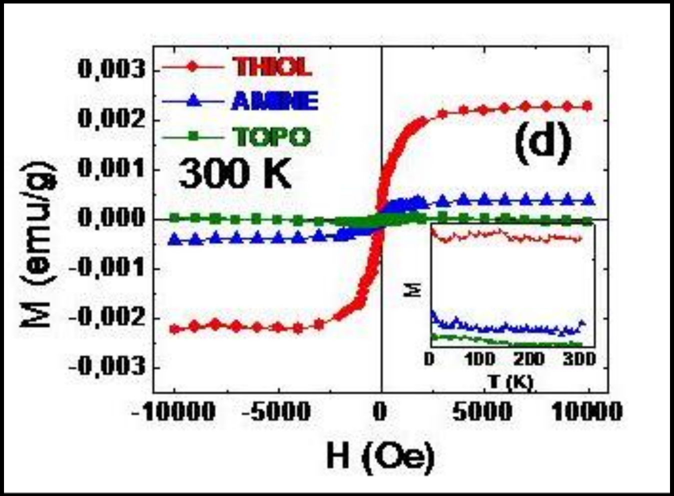
Magnetic Properties



Correlation between structure and magnetism

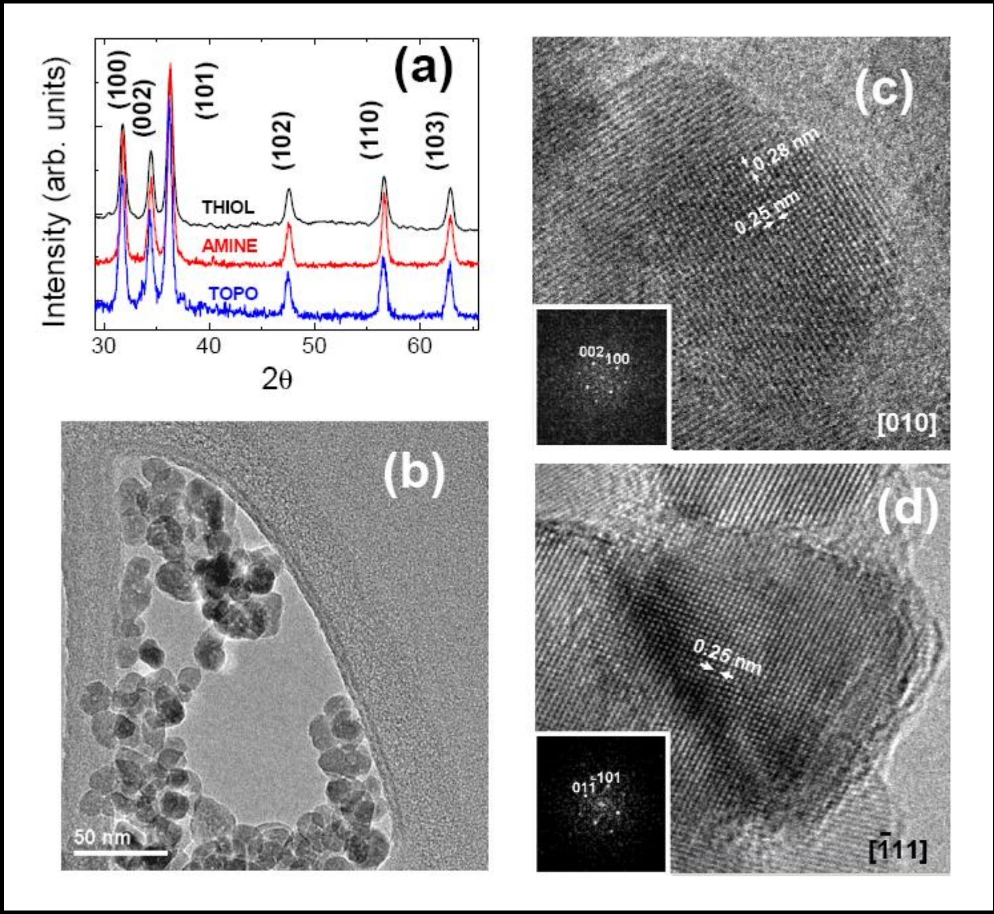




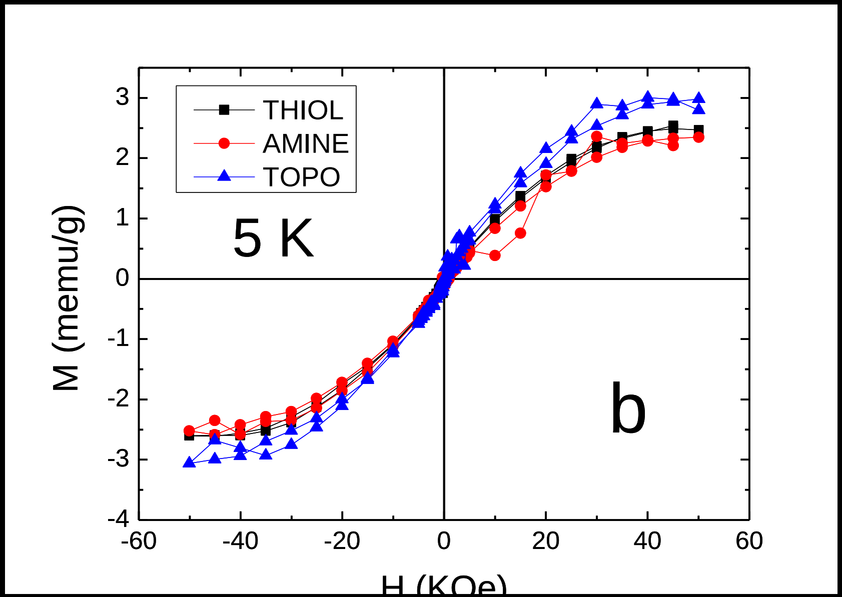


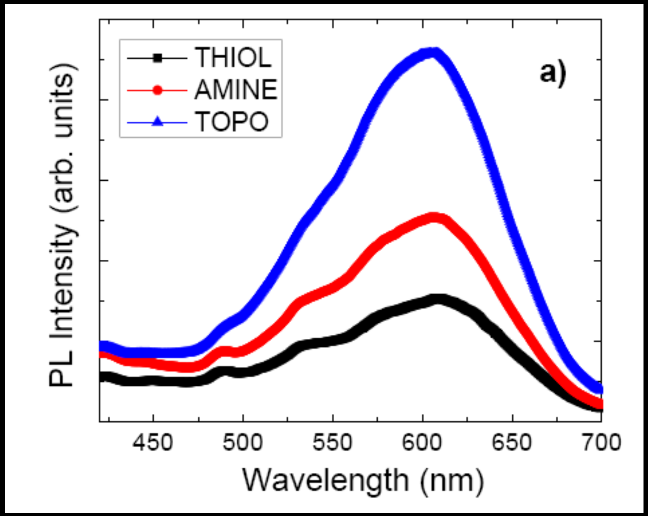
Reproducibility?

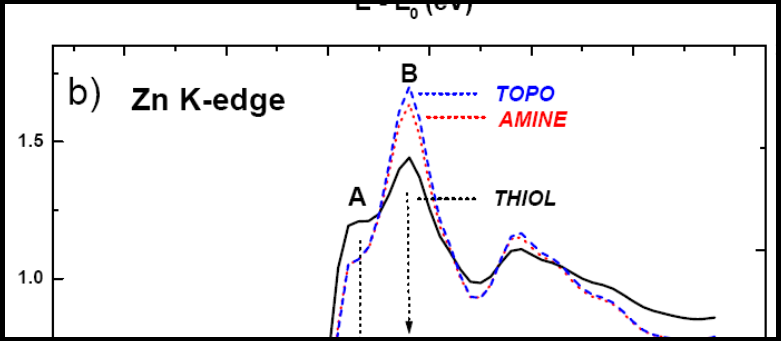
25 nm ZnO NPs



Reproducibility





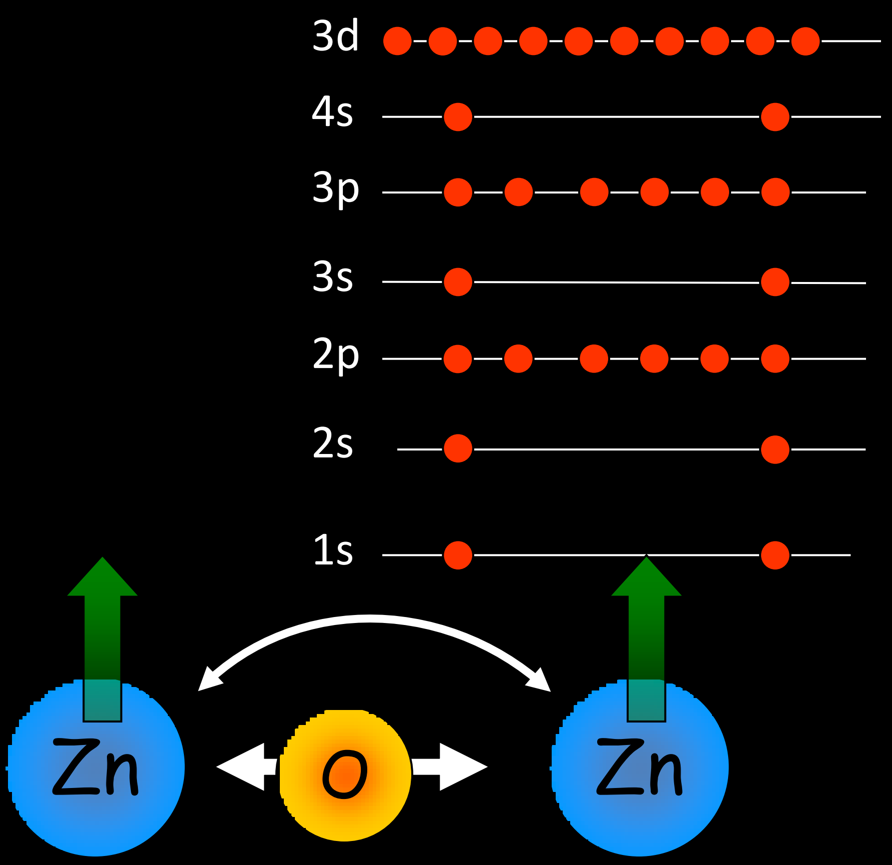


✓Different dependence on the molecule

✓Same correlation electronic structure -magnetism

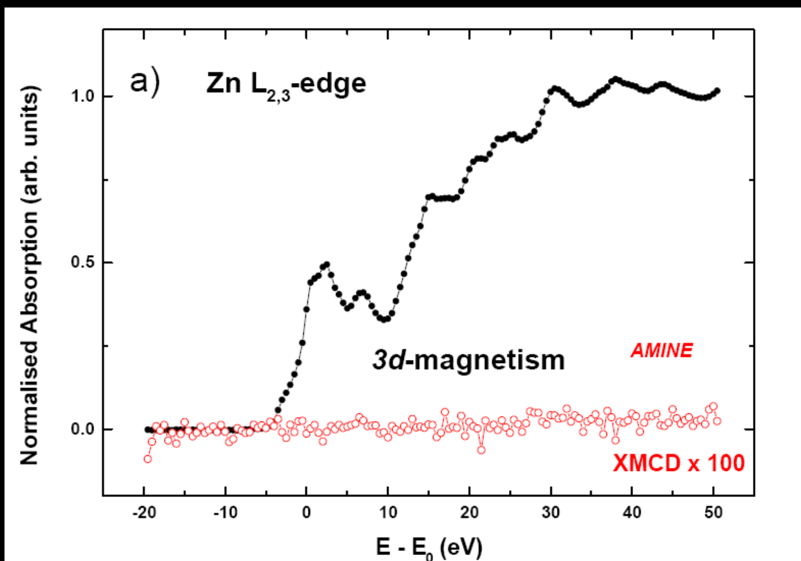
Origin of the magnetism

Magnetism in ZnO (and other 3d oxides) is explained as due to unbalanced 3d holes with some exchange interactions



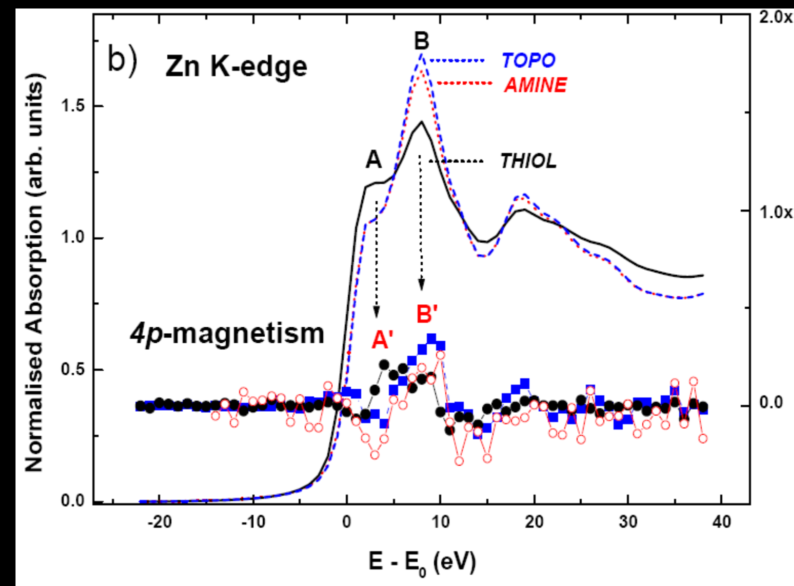
XMCD

XMCD ZnO L_3 edge (2p→3d)

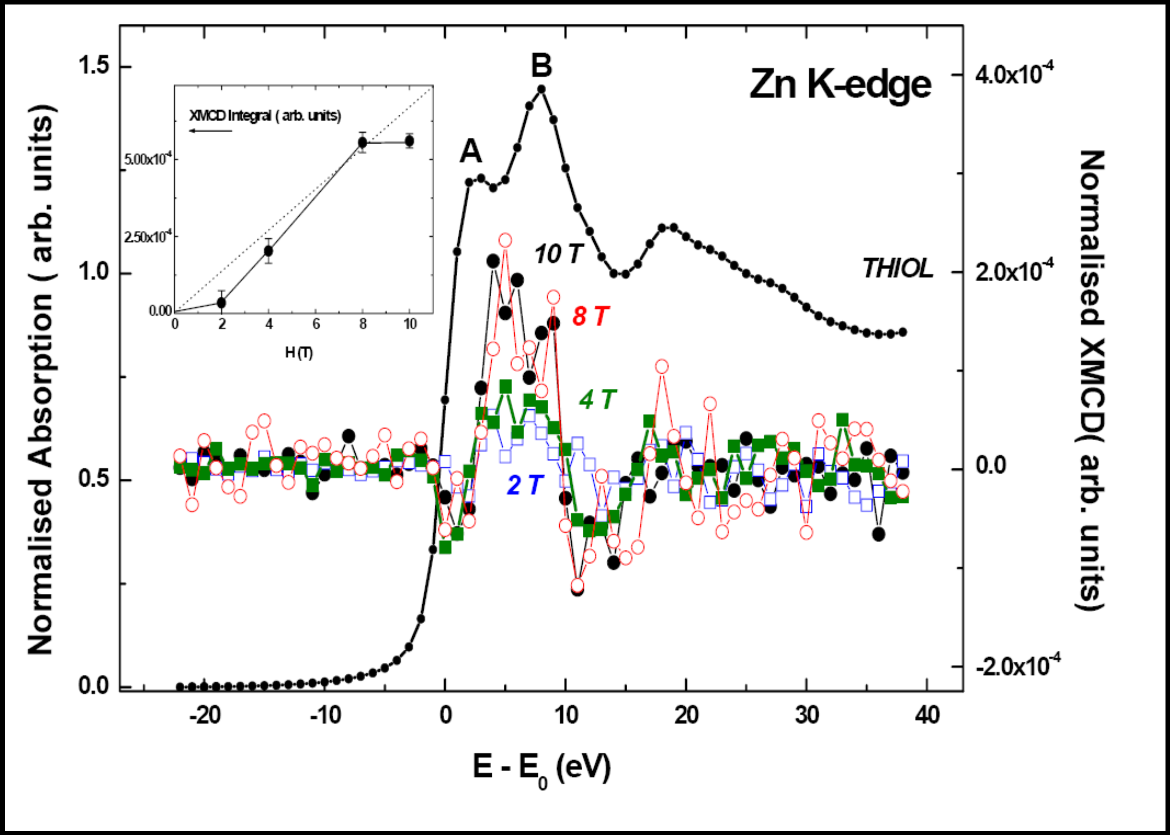


APS

XMCD ZnO K edge (1s→4p)



XMCD



Magnetism is at the 4p -> CONDUCTION BAND

III. Measurement of nanoscale magnetism

VOLUME 91, NUMBER 23 PHYSICAL REVIEW LETTERS week ending 5 DECEMBER 2003

Ferromagnetism in fcc Twinned 2.4 nm Size Pd Nanoparticles

B. Sampedro,[1,2] P. Crespo,[1,2] A. Hernando,[1,2] R. Litrán,[3] J. C. Sánchez López,[3] C. López Cartes,[3] A. Fernandez,[3]
J. Ramírez,[4] J. González Calbet,[1,4] and M. Vallet[1,5]

VOLUME 93, NUMBER 8 PHYSICAL REVIEW LETTERS week ending 20 AUGUST 2004

Permanent Magnetism, Magnetic Anisotropy, and Hysteresis of Thiol-Capped Gold Nanoparticles

P. Crespo,[1] R. Litrán,[2] T. C. Rojas,[2] M. Multigner,[1] J. M. de la Fuente,[3] J. C. Sánchez-López,[2] M. A. García,[1]
A. Hernando,[1] S. Penadés,[3] and A. Fernández[2,*]

Chem. Mater. **2007,** *19,* 1509−1517 1509

Permanent Magnetism in Dithiol-Capped Silver Nanoparticles

Lorenza Suber,* Dino Fiorani, Guido Scavia, and Patrizia Imperatori
CNR-Istituto Struttura della Materia, P.O. Box 10, 00016 Monterotondo St., Italy
William R. Plunkett

ADVANCED MATERIALS

DOI: 10.1002/adma.200601762

New Magnetic Properties of Silicon/Silicon Oxide Interfaces**

By *Gregory Kopnov*, *Zeev Vager*, and *Ron Naaman**

VOLUME 91, NUMBER 22 PHYSICAL REVIEW LETTERS week ending 28 NOVEMBER 2003

Induced Magnetic Ordering by Proton Irradiation in Graphite

P. Esquinazi,* D. Spemann, R. Höhne, A. Setzer, K.-H. Han, and T. Butz
Institut für Experimentelle Physik II, Universität Leipzig, Linnéstrasse 5, D-04103 Leipzig, Germany
(Received 1 July 2003; published 24 November 2003)

APPLIED PHYSICS LETTERS VOLUME 85, NUMBER 26 27 DECEMBER 2004

Magnetism in thin films of CaB_6 and SrB_6

L. S. Dorneles, M. Venkatesan, M. Moliner, J. G. Lunney, and J. M. D. Coey[a)]
Physics Department, Trinity College, Dublin 2, Ireland

JOURNAL OF CHEMICAL PHYSICS VOLUME 118, NUMBER 23 15 JUNE 200

Magnetism induced by the organization of self-assembled monolayers

I. Carmeli
Department of Chemical Physics, Weizmann Institute, Rehovot 76100, Israel

G. Leitus
Department of Material and Interfaces, Weizmann Institute, Rehovot 76100, Israel

R. Naaman[a)]
Department of Chemical Physics, Weizmann Institute, Rehovot 76100, Israel

S. Reich[a)]
Department of Material and Interfaces, Weizmann Institute, Rehovot 76100, Israel

Z. Vager
Department of Particle Physics, Weizmann Institute, Rehovot 76100, Israel

ELSEVIER

Journal of Physics and Chemistry of Solids 65 (2004) 713–717

JOURNAL OF PHYSICS AND CHEMISTRY OF SOLIDS

www.elsevier.com/locate/jpcs

Surprising electronic–magnetic properties of closed packed organized organic layers

Z. Vager[a], I. Carmeli[b], G. Leitus[c], S. Reich[c], R. Naaman[b,*]

Thin films

Unexpected magnetism in a dielectric oxide

NATURE | VOL 430 | 5 AUGUST 2004 |

PHYSICAL REVIEW B **72**, 024450 (2005)

Magnetism in hafnium dioxide

J. M. D. Coey, M. Venkatesan, P. Stamenov, C. B. Fitzgerald, and L. S. Dorneles
Physics Department, Trinity College, Dublin 2, Ireland

Magnetic Properties of ZnO Nanoparticles

M. A. Garcia,[*,†,‡] J. M. Merino,[†,§] E. Fernández Pinel,[†,‡] A. Quesada,[†,‡] J. de la Venta,[†,‡] M. L. Ruíz González,[§] G. R. Castro,[||] P. Crespo,[†,‡] J. Llopis,[‡] J. M. González-Calbet,[†,§] and A. Hernando[†,‡]

NANO LETTERS
2007
Vol. 7, No. 6
1489−1494

INSTITUTE OF PHYSICS PUBLISHING — JOURNAL OF PHYSICS: CONDENSED MATTER

J. Phys.: Condens. Matter **18** (2006) L355–L361 — doi:10.1088/0953-8984/18/27/L01

LETTER TO THE EDITOR

Oxygen-defect-induced magnetism to 880 K in semiconducting anatase $TiO_{2-\delta}$ films

Soack Dae Yoon[1], Yajie Chen[1], Aria Yang[1], Trevor L Goodrich[2], Xu Zuo[3], Dario A Arena[4], Katherine Ziemer[2], Carmine Vittoria[1] and Vincent G Harris[1,5]

Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Solid State Communications 142 (2007) 685–688
solid state communications
www.elsevier.com/locate/ssc

Room-temperature ferromagnetism in nanoparticles of superconducting materials

Shipra, A. Gomathi, A. Sundaresan*, C.N.R. Rao

RAPID COMMUNICATIONS

PHYSICAL REVIEW B **74**, 161306(R) (2006)

Ferromagnetism as a universal feature of nanoparticles of the otherwise nonmagnetic oxides

A. Sundaresan,* R. Bhargavi, N. Rangarajan, U. Siddesh, and C. N. R. Rao

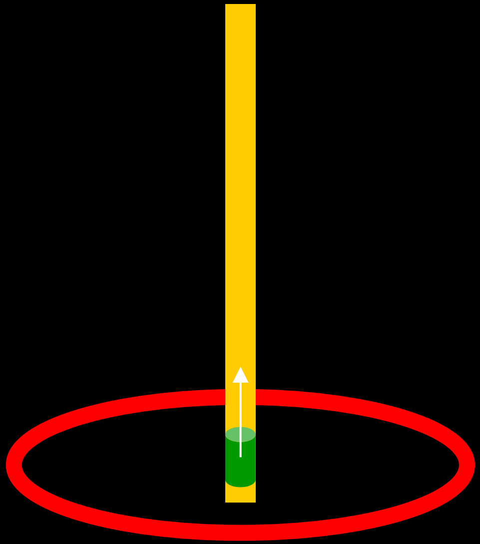
Magnetic measurements with lab magnetometers

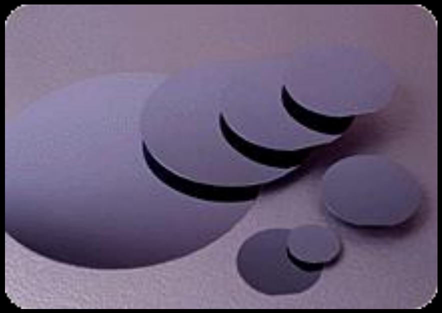
M. A. Garcia

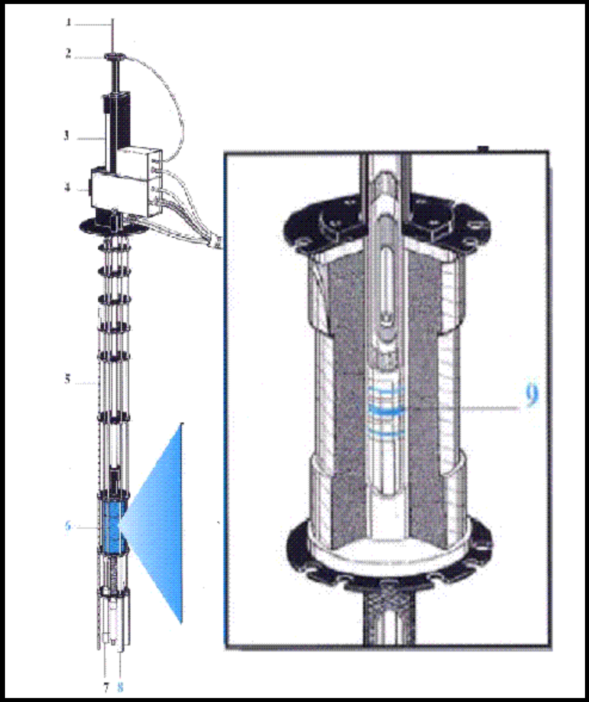
CSIC

Instituto de Cerámica y Vidrio

VSM& SQUID detect **ALL** the magnetic flux across the coil



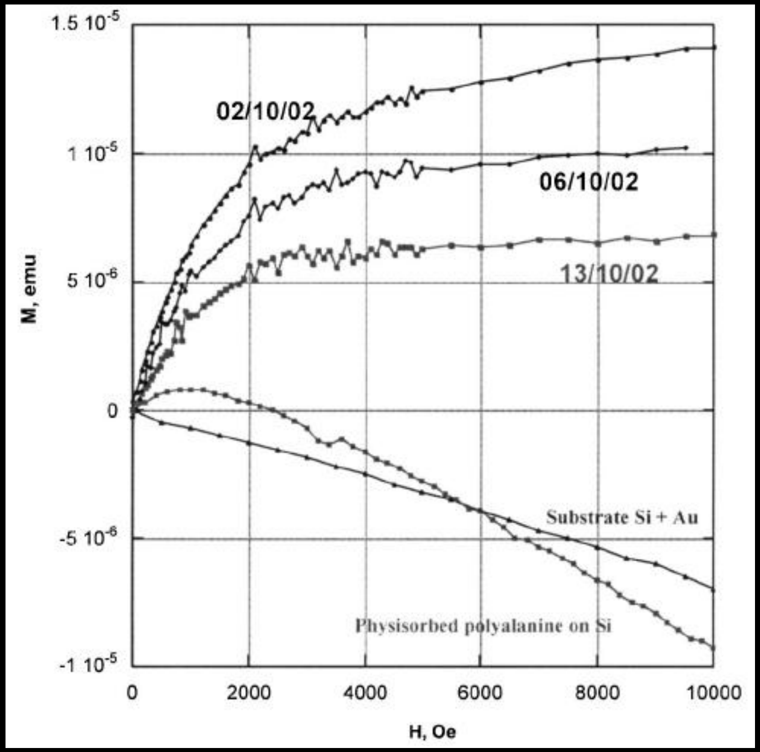




Fe: 220 emu/g

Co: 160 emu/g

Fe_3O_4: 83 emu/g



A 15 μm particle could account for this signal

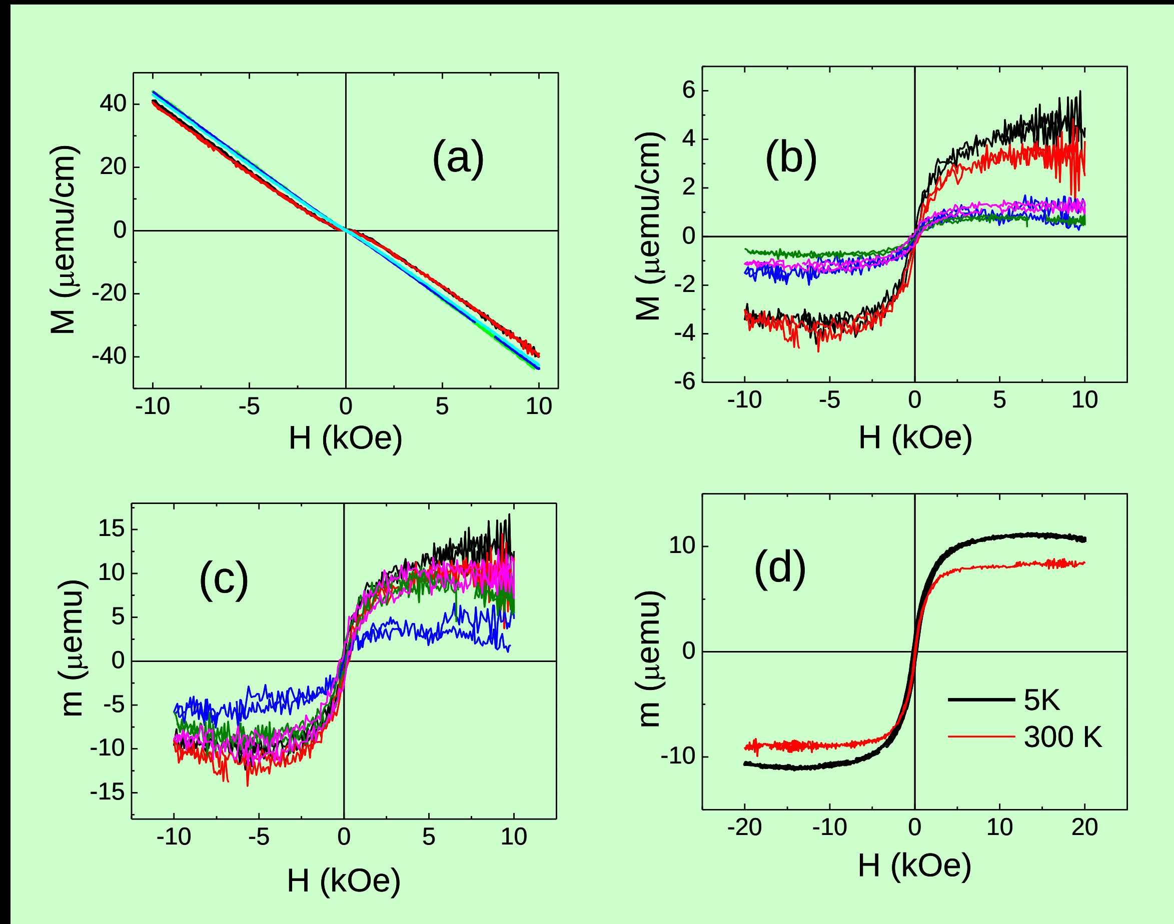
REVIEW

Global Iron Connections Between Desert Dust, Ocean Biogeochemistry, and Climate

bioavailable iron. Although the iron content of soil dust (average, 3.5%) is variable globally,

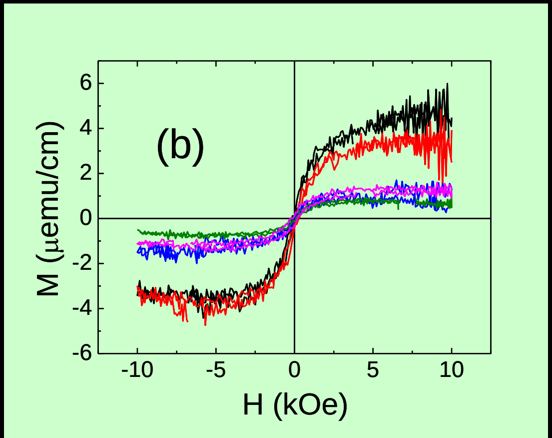
SCIENCE VOL 308 1 APRIL 2005

Kapton tape

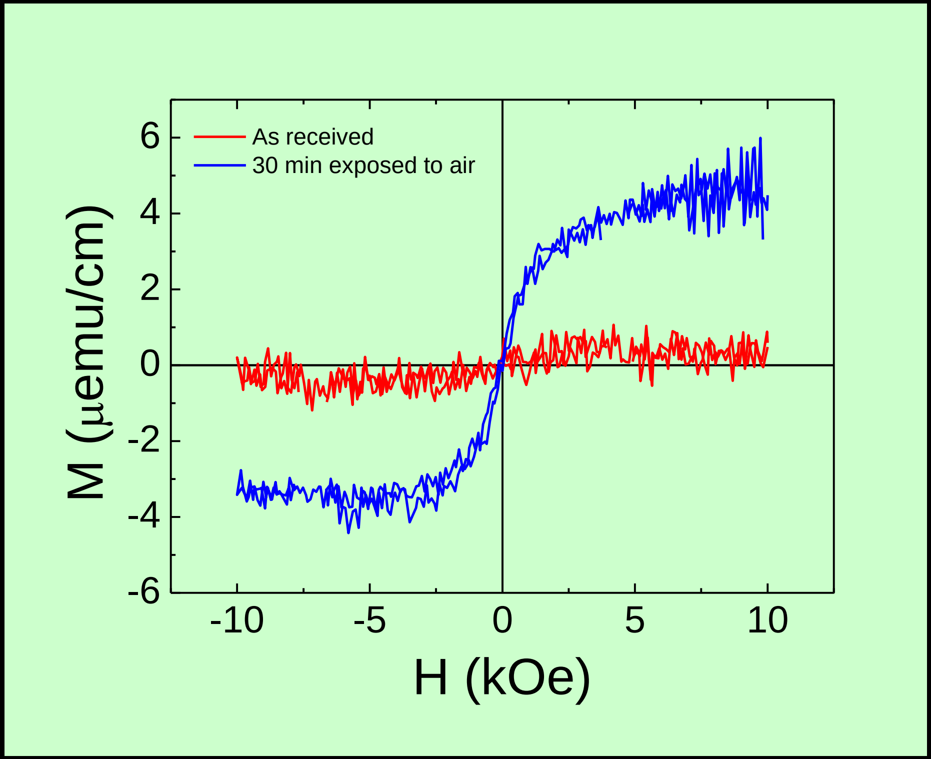


(a)
M (μemu/cm)
H (kOe)
(b)
M (μemu/cm)
H (kOe)
(c)
m (μemu)
H (kOe)
(d)
m (μemu)
H (kOe)
5K
300 K

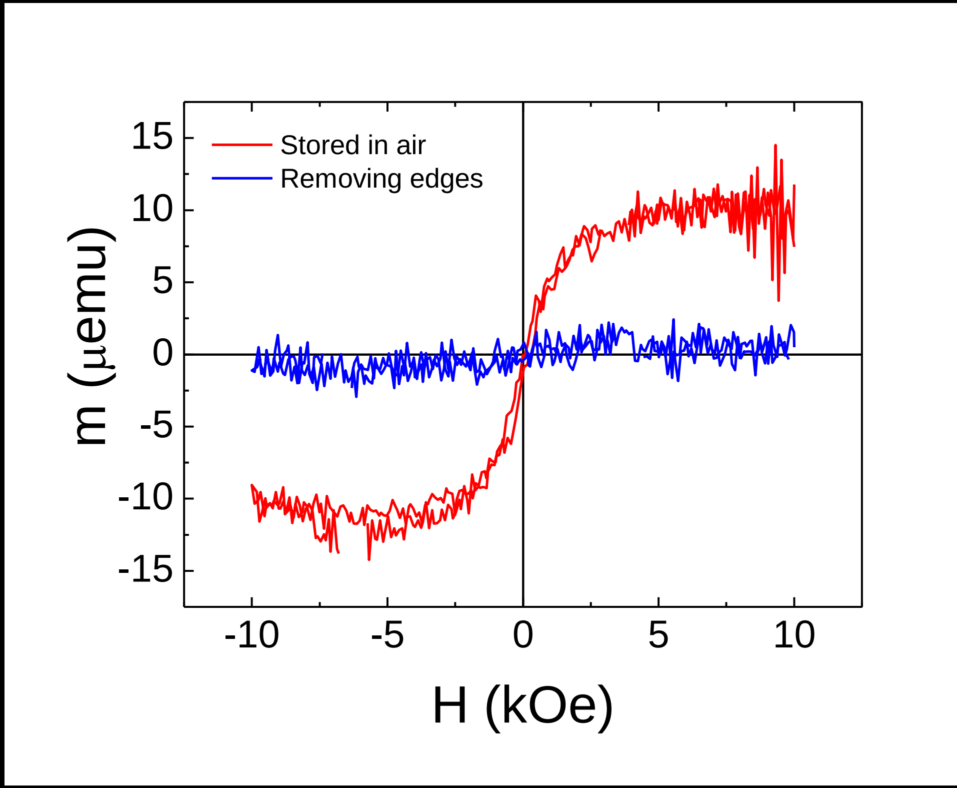
Kapton tape



Kapton tape

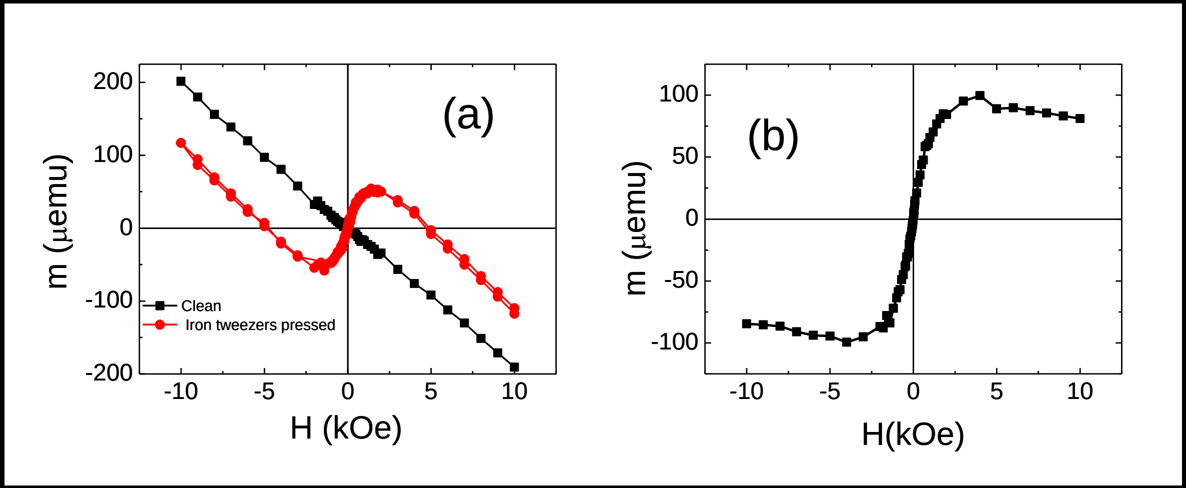

As received
30 min exposed to air
M (μemu/cm)
H (kOe)
6
4
2
0
-2
-4
-6
-10
-5
0
5
10

Kapton tape



Stored in air
Removing edges
m (μemu)
H (kOe)
15
10
5
0
-5
-10
-15
-10
-5
0
5
10

Metallic twizzers



Metallic twizeers

Thin films

Unexpected magnetism in a dielectric oxide

NATURE | VOL 430 | 5 AUGUST 2004

PHYSICAL REVIEW B 72, 024450 (2005)

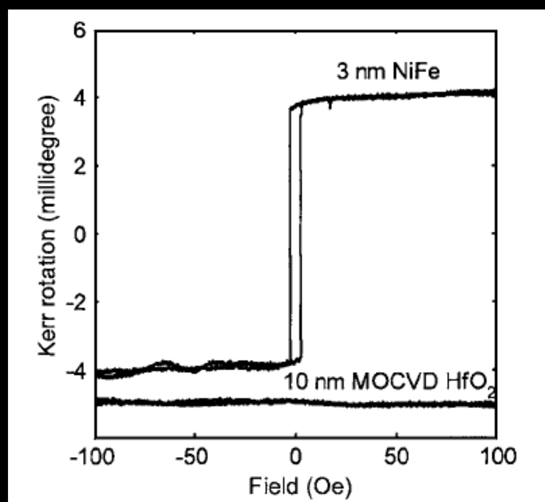
Magnetism in hafnium dioxide

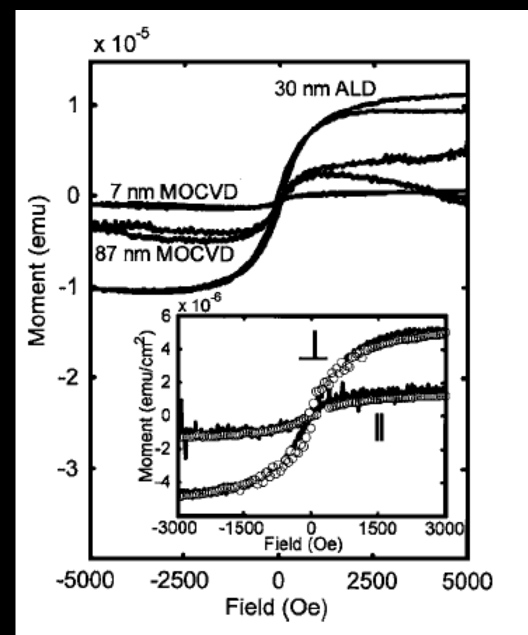
J. M. D. Coey, M. Venkatesan, P. Stamenov, C. B. Fitzgerald, and L. S. Dorneles
Physics Department, Trinity College, Dublin 2, Ireland

APPLIED PHYSICS LETTERS 87, 252502 (2005)

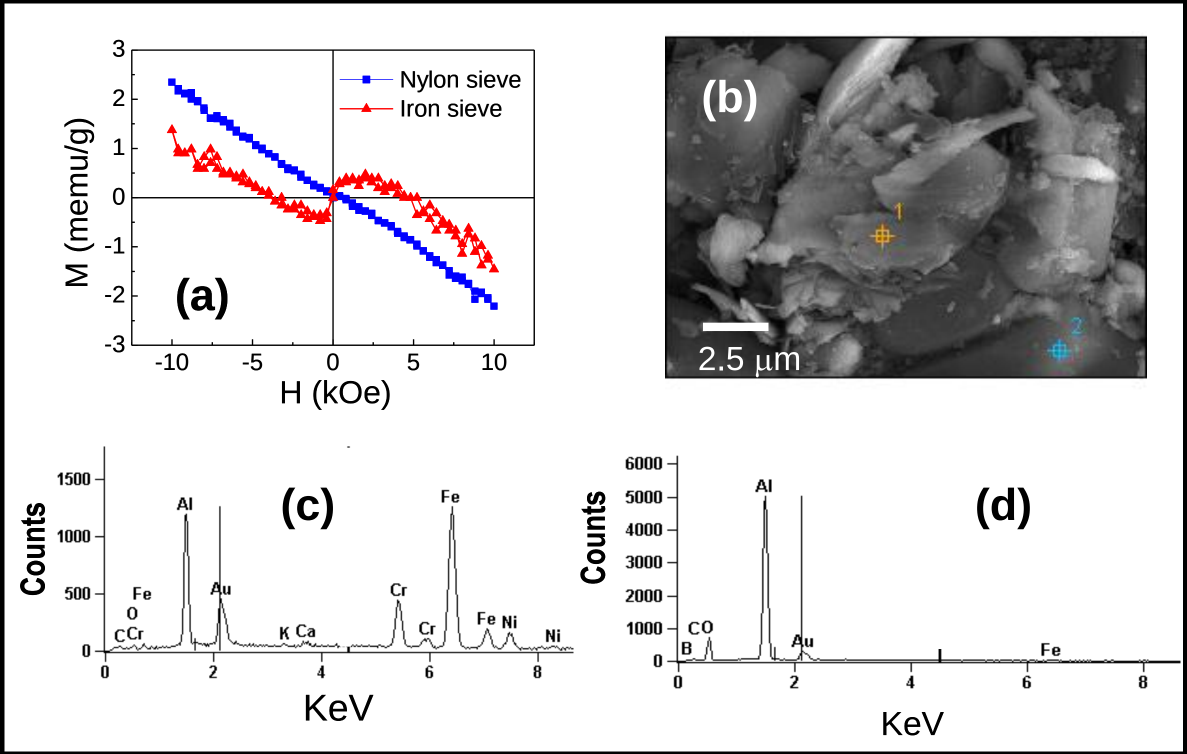
Absence of magnetism in hafnium oxide films

David W. Abraham,[a] Martin M. Frank, and Supratik Guha
IBM Thomas J. Watson Research Center, P.O. Box 218, Yorktown Heights, New York 10598

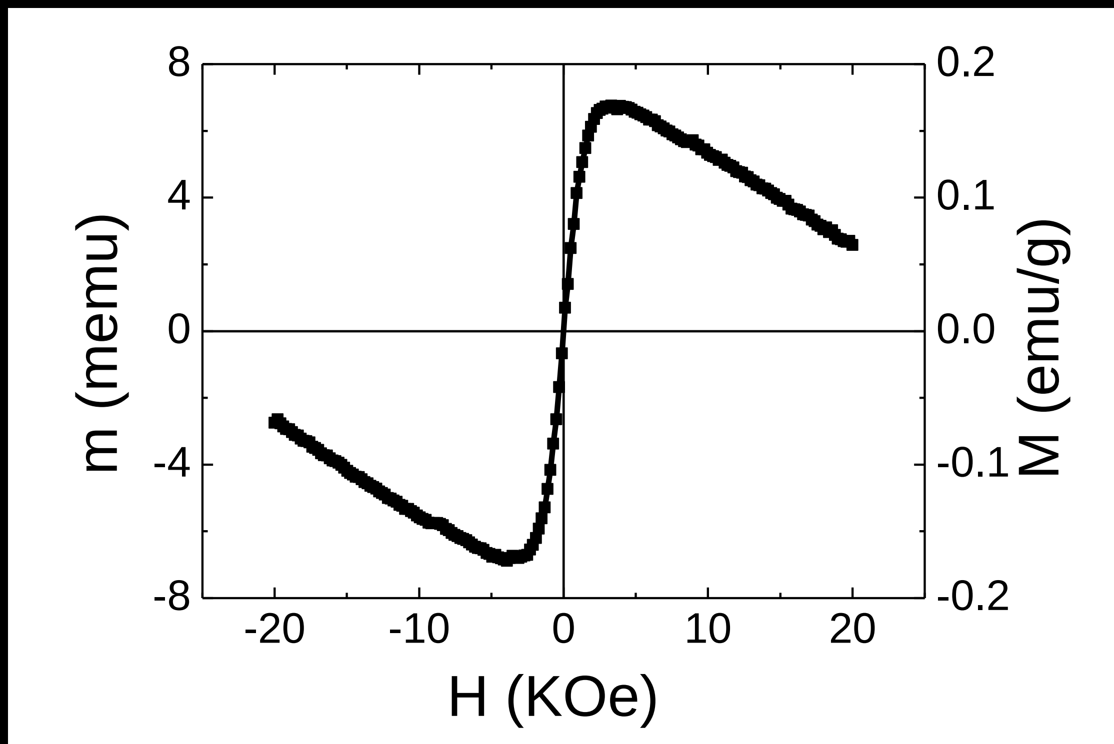




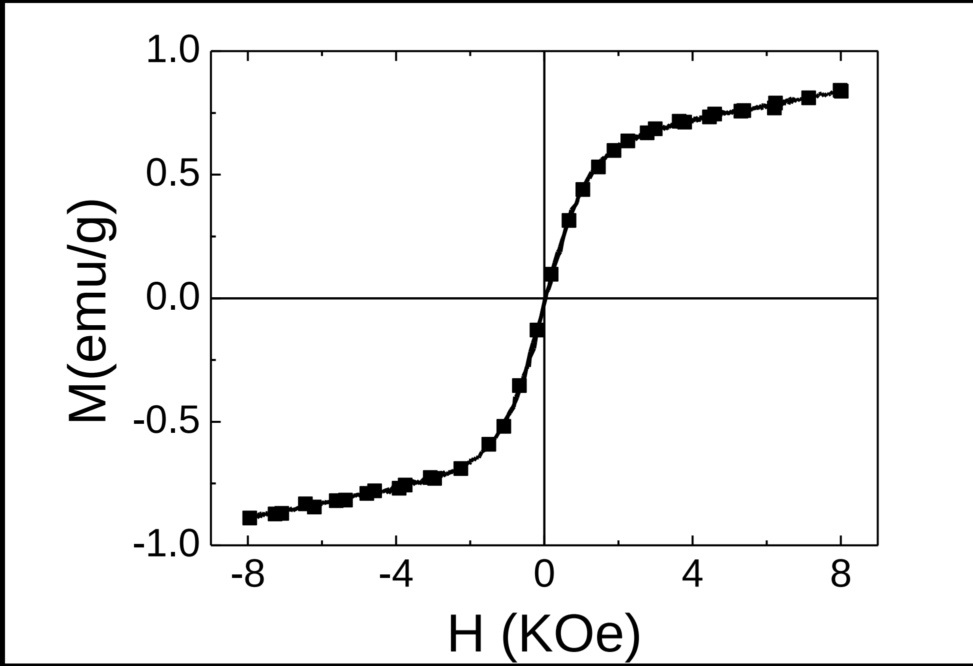
Metallic twizzers



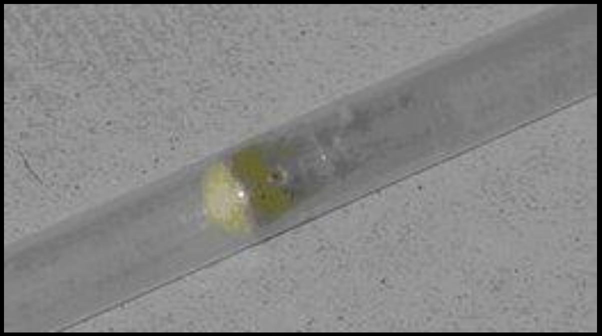
Cotton

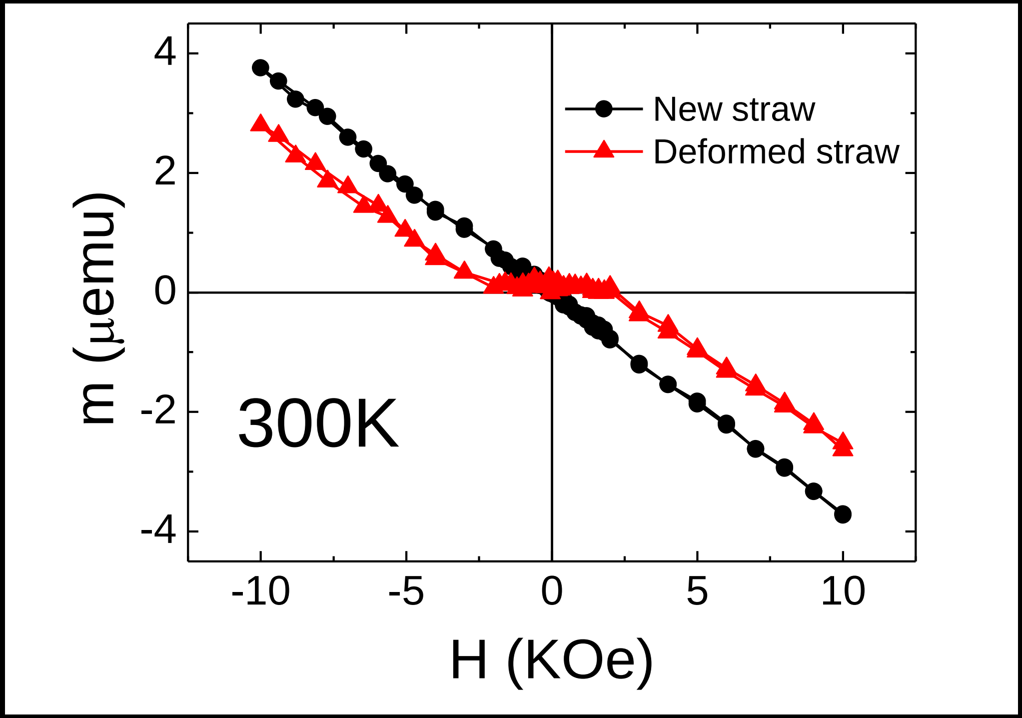


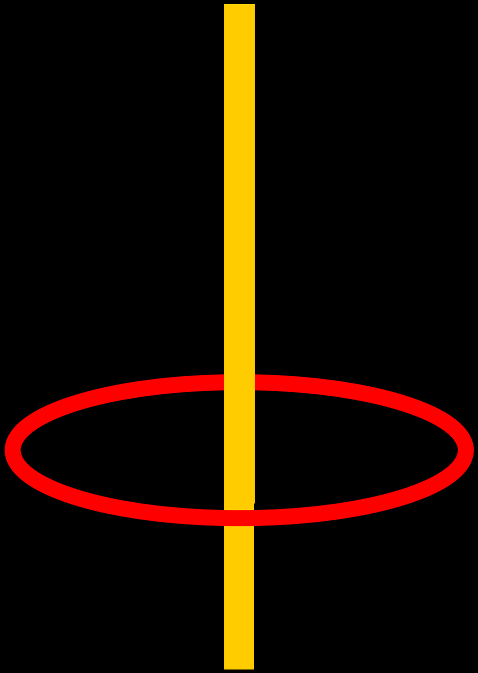
Silver paint



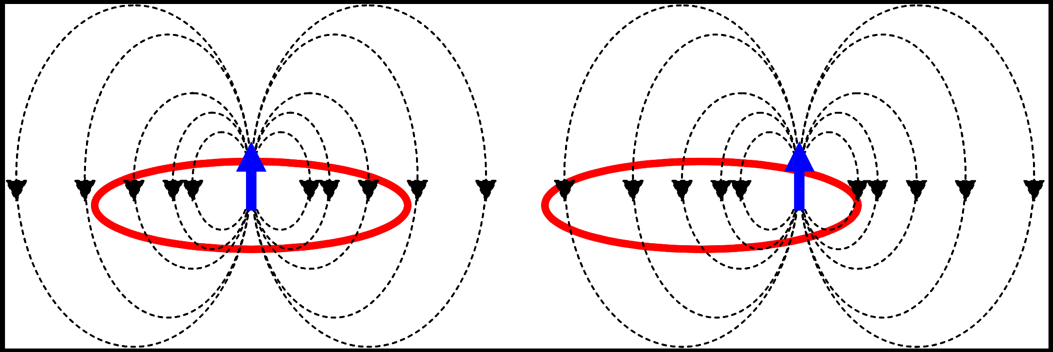
Plastic sampleholders

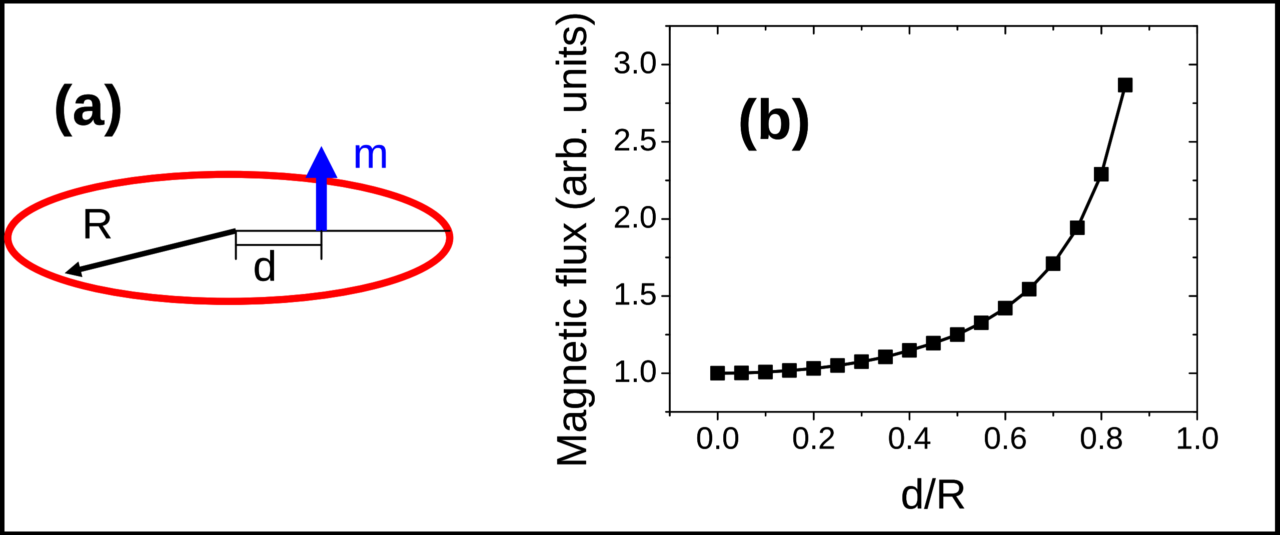




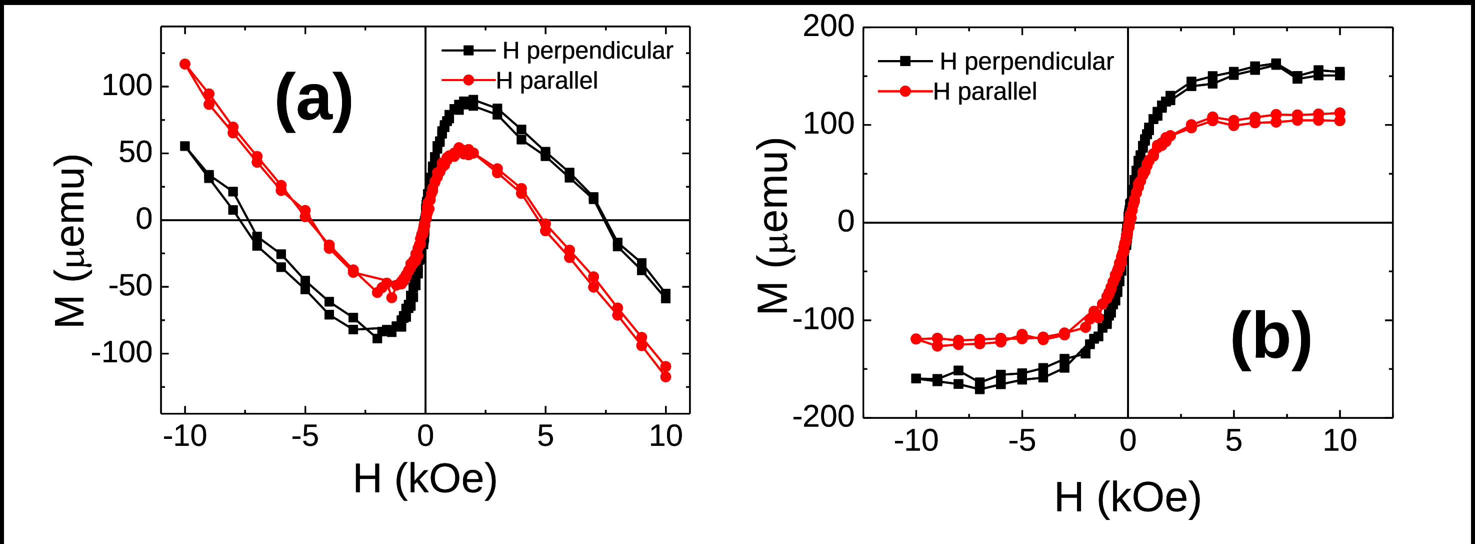


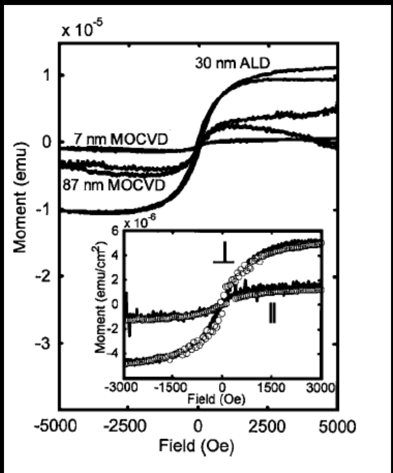
Sample position





Sample position: Anisotropy?





JOURNAL OF APPLIED PHYSICS **105**, 013925 (2009)

Sources of experimental errors in the observation of nanoscale magnetism

M. A. Garcia,[1,2,a] E. Fernandez Pinel,[1,3] J. de la Venta,[1,3] A. Quesada,[3,4] V. Bouzas,[1] J. F. Fernández,[2] J. J. Romero,[2] M. S. Martín González,[5] and J. L. Costa-Krämer[5]

Element specific techniques are required for confirmation

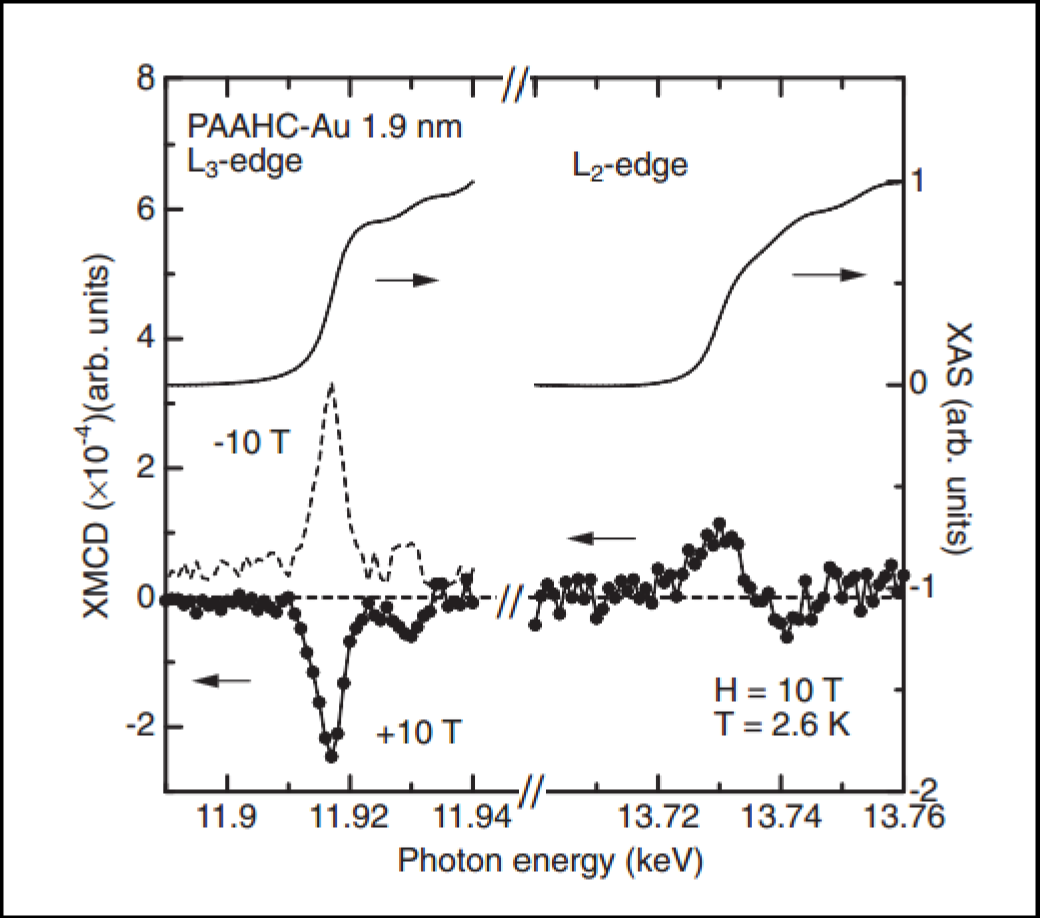
-XMCD

.Neutrons

For reliability

For a better understanding

XMCD in Au Nanoparticles



Y. Yamamoto, T. Miura, M. Suzuki, N. Kawamura, H. Miyagawa, T. Nakamura, K. Kobayashi, T. Teranishi, and H. Hori: Phys. Rev. Lett. 93 (2004) 116801.

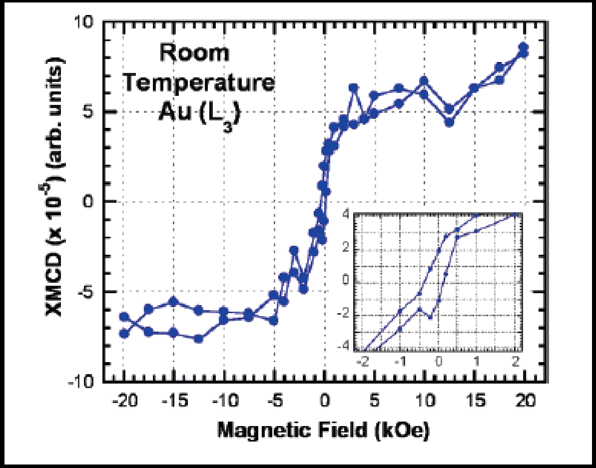
XMCD in Au Nanoparticles

Chemically Induced Permanent Magnetism in Au, Ag, and Cu Nanoparticles: Localization of the Magnetism by Element Selective Techniques

José S. Garitaonandia,[*,†] Maite Insausti,[†] Eider Goikolea,[†] Motohiro Suzuki,[‡] John D. Cashion,[§] Naomi Kawamura,[‡] Hitoshi Ohsawa,[‡] Izaskun Gil de Muro,[†] Kiyonori Suzuki,[||] Fernando Plazaola,[†] and Teofilo Rojo[†]

NANO LETTERS

2008
Vol. 8, No. 2
661−667

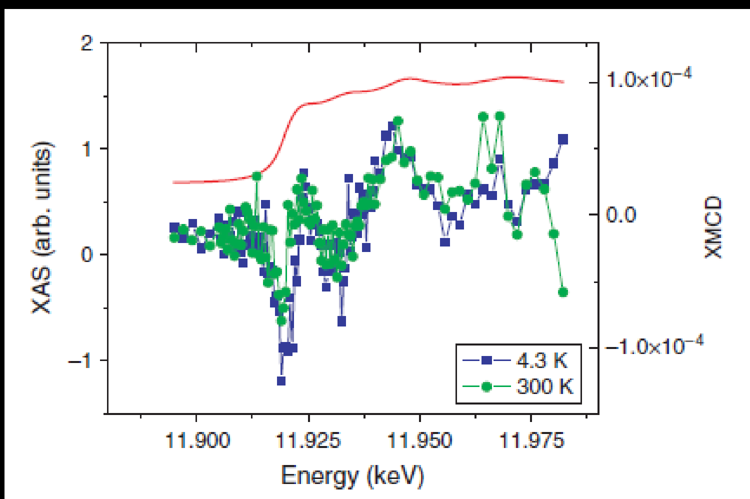


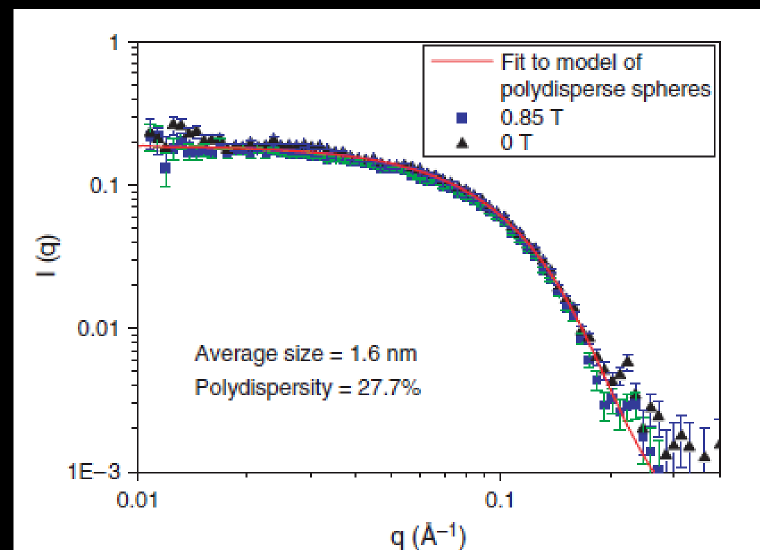
XMCD & Neutrons in Au Nanoparticles

X-ray Magnetic Circular Dichroism and Small Angle Neutron Scattering Studies of Thiol Capped Gold Nanoparticles

J. de la Venta[1,2,*], V. Bouzas[1], A. Pucci[3], M. A. Laguna-Marco[4], D. Haskel[4], S. G. E. te Velthuis[6], A. Hoffmann[5,6], J. Lal[7], M. Bleuel[7], G. Ruggeri[3], C. de Julián Fernández[8], and M. A. García[1]

Journal of Nanoscience and Nanotechnology
Vol. 9, 6434–6438, 2009



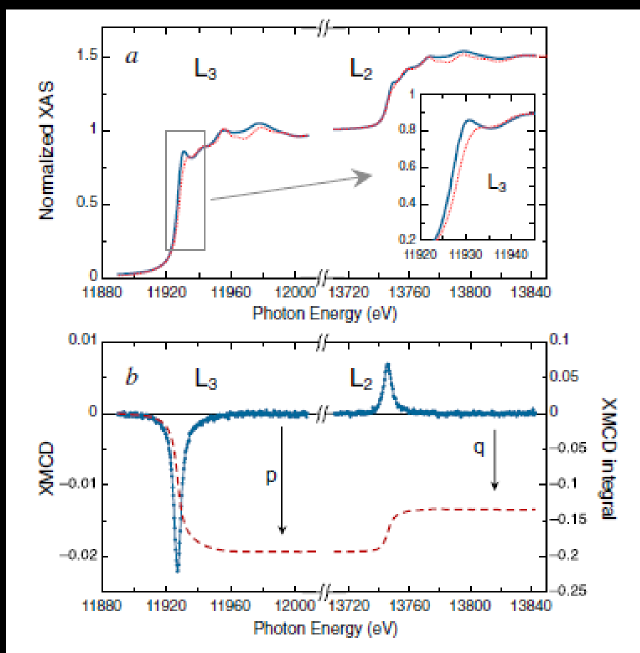


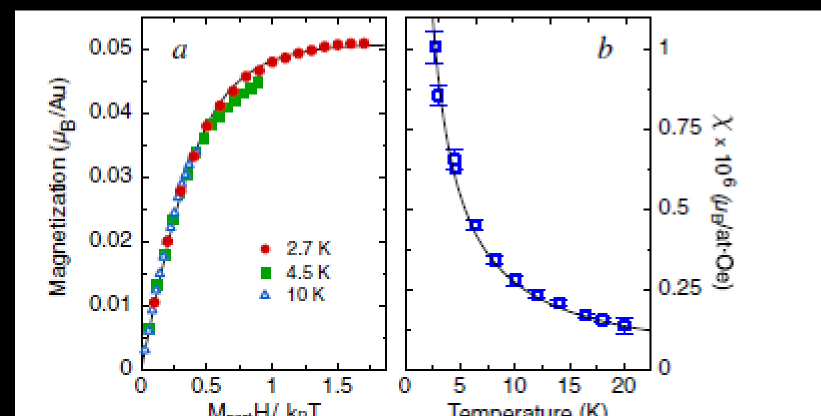
XMCD in Au Nanoparticles

PRL 109, 247203 (2012) PHYSICAL REVIEW LETTERS week ending 14 DECEMBER 2012

Strong Paramagnetism of Gold Nanoparticles Deposited on a *Sulfolobus acidocaldarius* S Layer

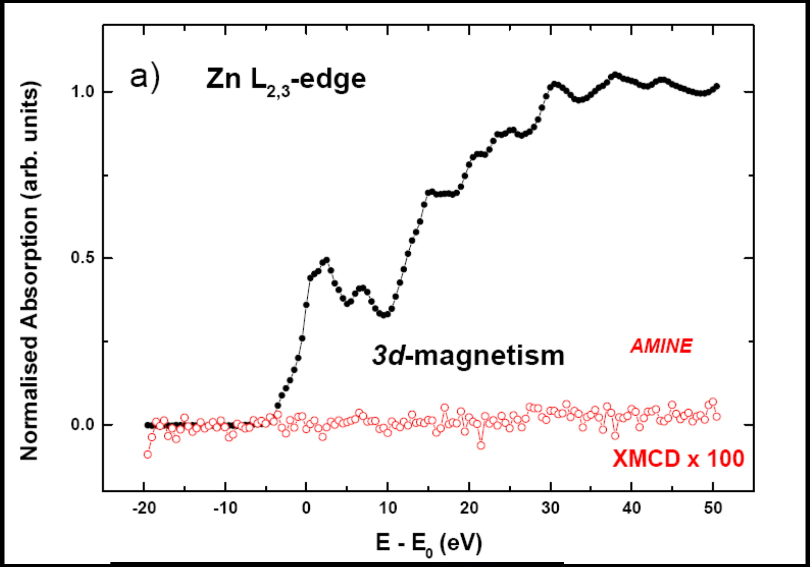
J. Bartolomé,[1,2,*] F. Bartolomé,[1,2] L. M. García,[1,2] A. I. Figueroa,[1,2] A. Repollés,[1,2] M. J. Martínez-Pérez,[1,2] F. Luis,[1,2] C. Magén,[2,3] S. Selenska-Pobell,[4] F. Pobell,[4] T. Reitz,[4] R. Schönemann,[4] T. Herrmannsdörfer,[4] M. Merroun,[5] A. Geissler,[4] F. Wilhelm,[6] and A. Rogalev[6]





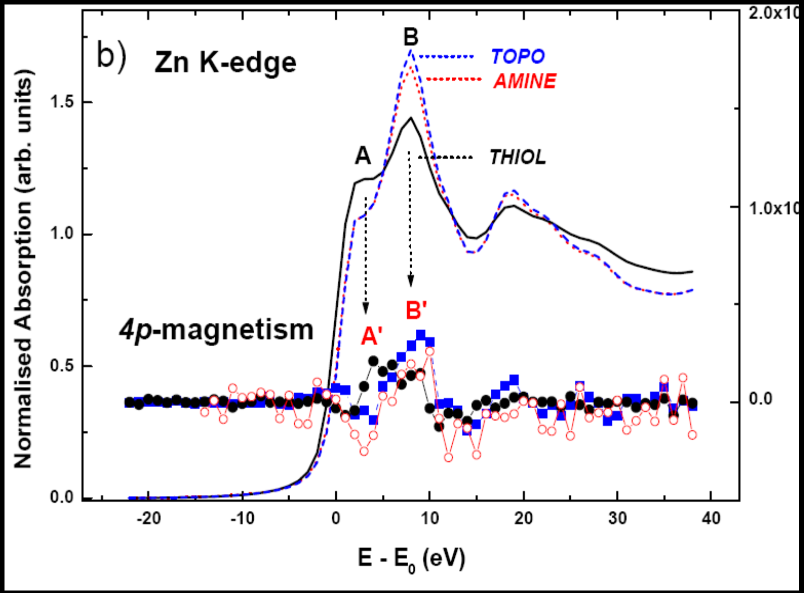
XMCD in ZnO nanoparticles

XMCD ZnO L_3 edge (2p→3d)

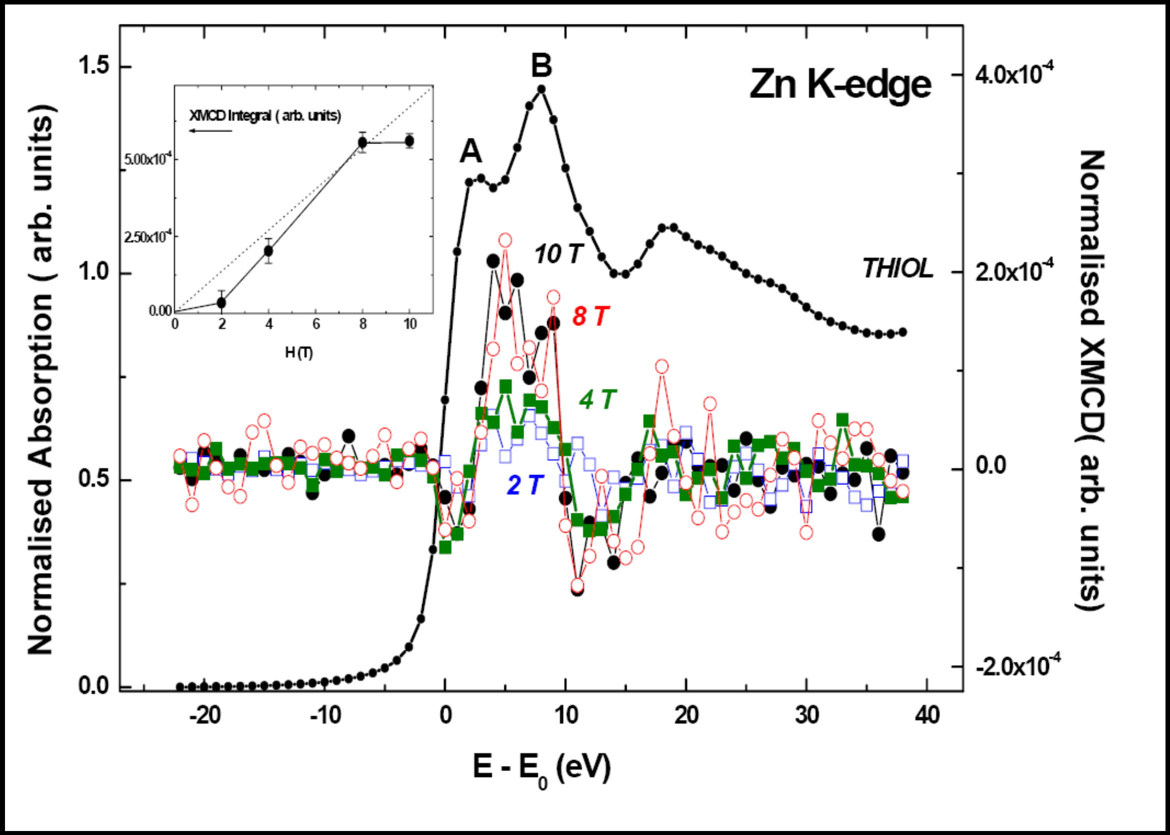


APS

XMCD ZnO K edge (1s→4p)



XMCD



Magnetism is at the 4p -> CONDUCTION BAND

….in summary……

- ✓ *Magnetic materials modify their properties at the nanoscale*

- ✓ *New magnetic effects appear at the nanoscale*

- ✓ *Experimental measurement of nanomagnetism requires specific techniques and protocols.*

…and money came from….

EU 6th FP- Proyecto BONSAI

BONSAI

Sixth Framework Programme

http://www.bonsai-project.eu

Proyecto PIF 2007-50I015

CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS
CSIC

Proyecto FIS-2008-469

GOBIERNO DE ESPAÑA
MINISTERIO DE EDUCACIÓN Y CIENCIA

…..and user programs of:

Argonne NATIONAL LABORATORY

APS + IPNS

ESRF European Synchrotron Radiation Facility

MAGNIFYCO
MAGNETIC NANOCONTAINERS FOR COMBINED HYPERTHERMIA AND CONTROLLED DRUG RELEASE
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