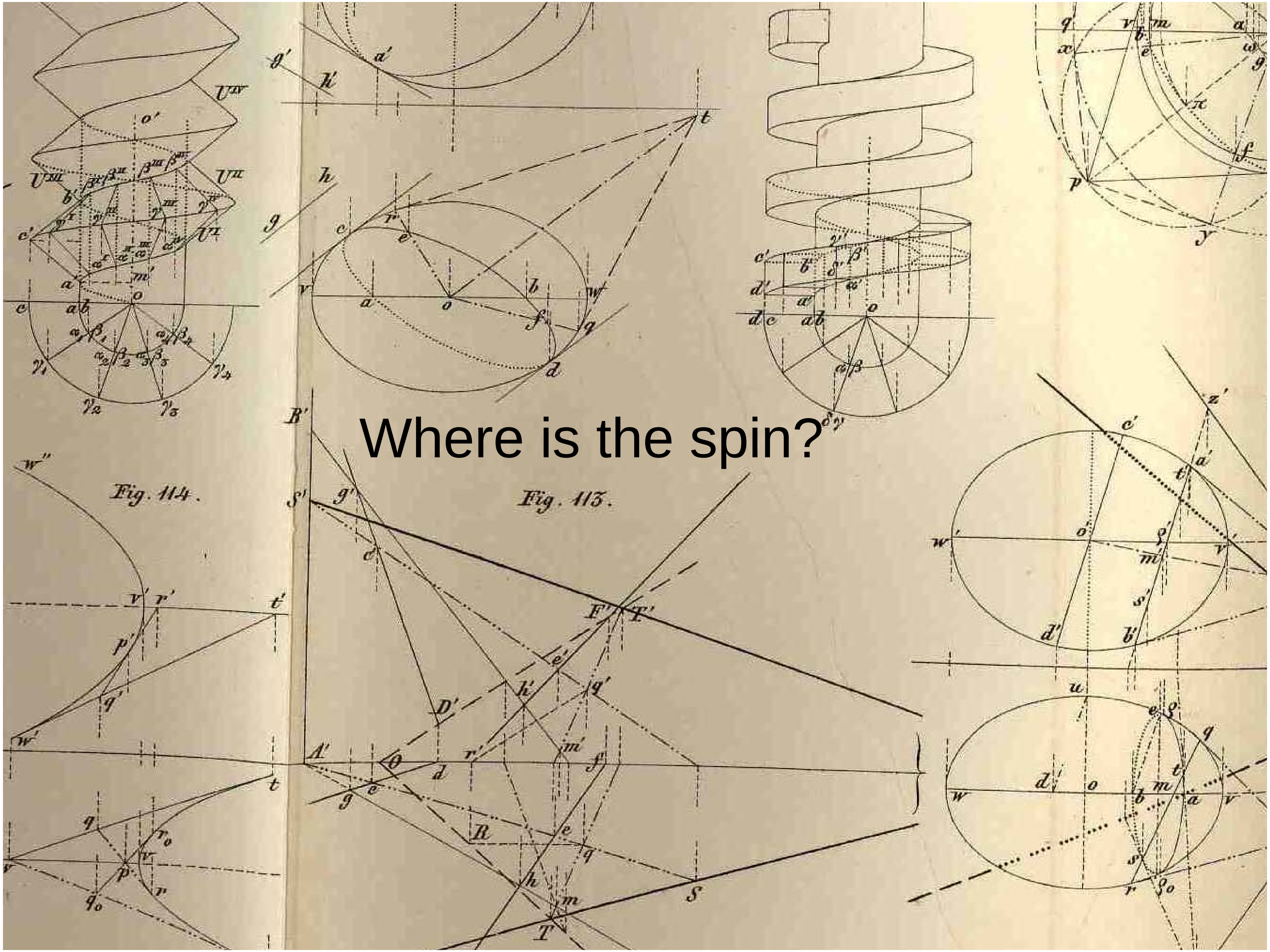
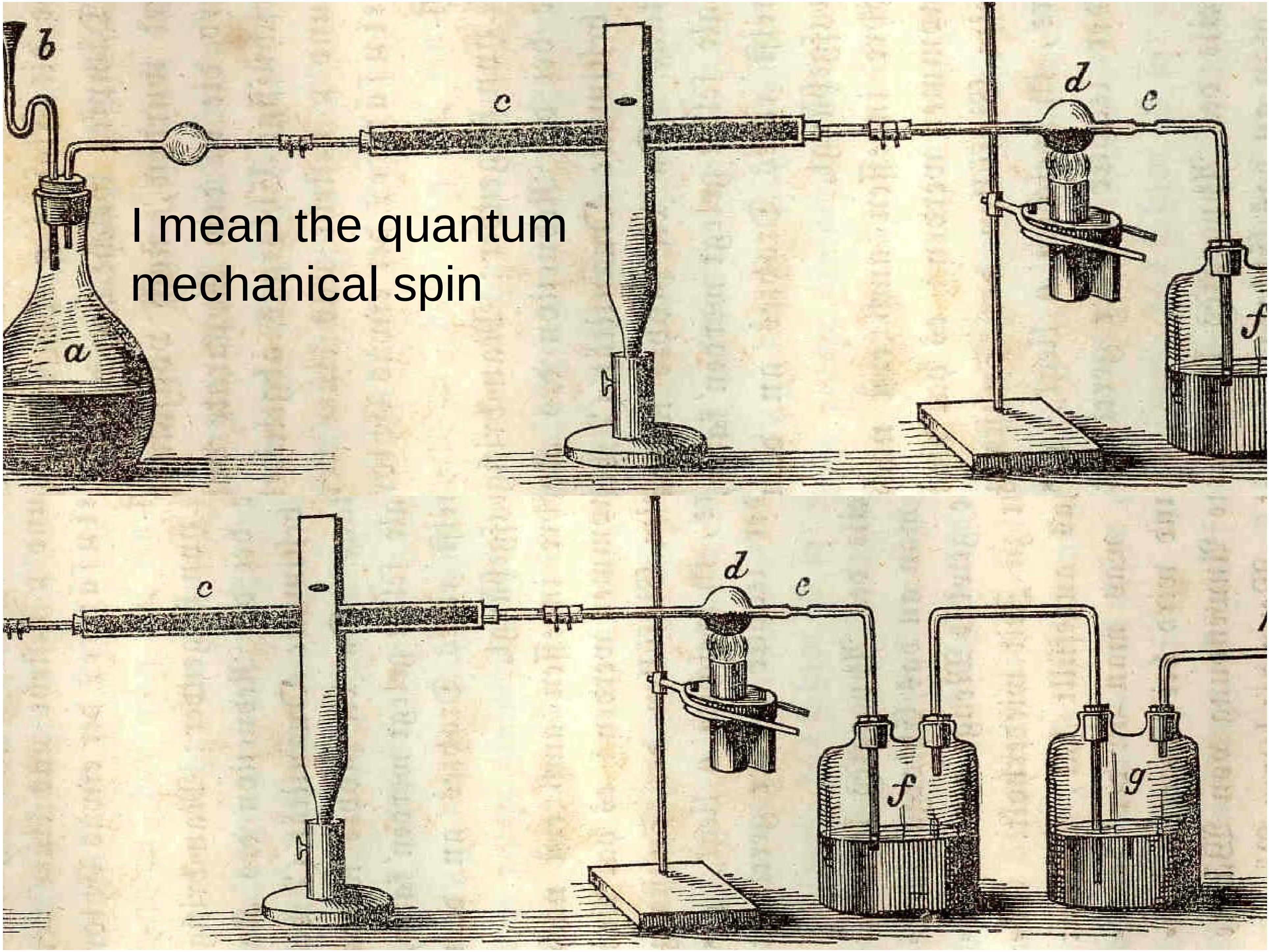
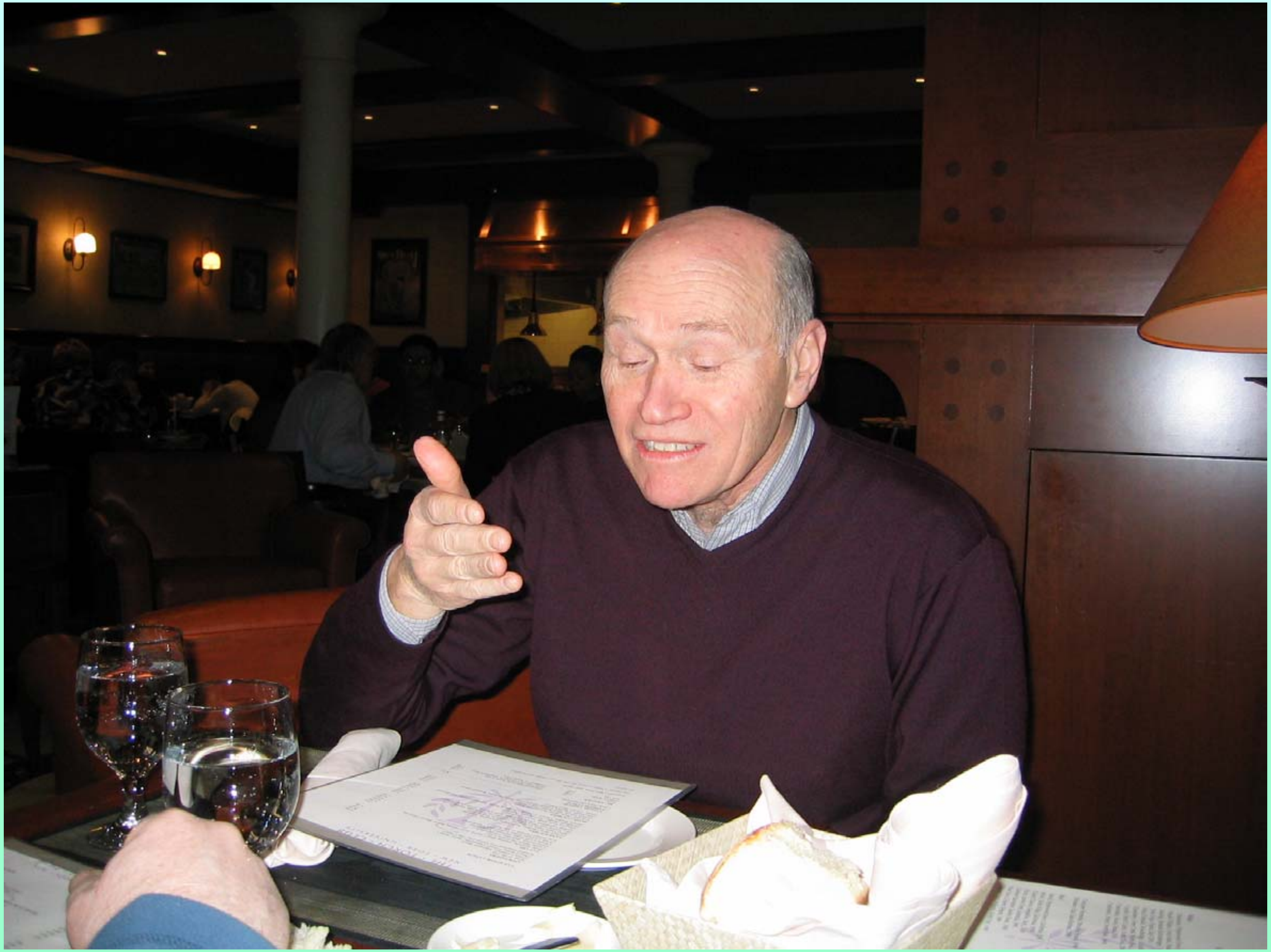
Where is the spin?





I mean the quantum mechanical spin

PML 70 ???

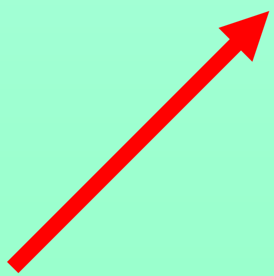


New York, February 18, 2003

PML 70 ???

A ten year old collaboration (1996 – 2006) and battle about:

- where is the spin ?
- what is spin polarization ?



This is the only classical spin I will show in the following!

But first on what we agreed. Actually a lot!

1998

PHILOSOPHICAL MAGAZINE B, 1998, VOL. 78, NOS. 5/6, 549–555

Giant magnetoresistance of repeated multilayers of Cu_3Ni_3 embedded in Cu(100)

C. BLAAS, P. WEINBERGER, L. SZUNYOGH

Center for Computational Materials Science, Vienna, Austria and Institut für Technische Elektrochemie, Technische Universität Wien, Vienna, Austria

P. M. LEVY

Department of Physics, New York University, New York, USA

C. B. SOMMERS

Laboratoire de Physique des Solides, Université de Paris-Sud, Orsay, France

and I. MERTIG

Institut für Theoretische Physik, Technische Universität Dresden, Dresden, Germany

ABSTRACT

The resistivity and giant magnetoresistance (GMR) of $(Cu_3Ni_3)_n$ embedded in Cu(100), for $n \leq 11$, that originates from the electronic structure of these finite, yet otherwise perfect, systems is calculated for currents in the plane of the layers (CIP) by using the Kubo–Greenwood formula for semi-infinite systems and the fully relativistic, spin-polarized screened Korringa–Kohn–Rostoker method. We find that for this particular type of repeated structure the CIP resistivity decreases from about 6 to 2 μΩ cm as the number of repeats increases from 2 to 11, and the CIP-GMR while starting out at 4% for $n = 2$ goes up to 16% at $n = 11$.

1999

Eur. Phys. J. B **9**, 245–250 (1999)

THE EUROPEAN PHYSICAL JOURNAL B

EDP Sciences

On the orientational dependence of giant magnetoresistance

C. Blaas[1,2], P. Weinberger[1,2], L. Szunyogh[2,3], J. Kudrnovský[2,4], V. Drchal[2,4], P. M. Levy[5], and C. Sommers[6,a]

[1] Institut für Technische Elektrochemie, Technische Universität Wien, Getreidemarkt 9/158, 1060 Wien, Austria
[2] Center for Computational Materials Science, Gumpendorferstrasse 1a, 1060 Wien, Austria
[3] Department of Theoretical Physics, Technical University Budapest, Budafoki út 8, 1521 Budapest, Hungary
[4] Institute of Physics, Czech Academy of Sciences, 18040 Praha 8, Czech Republic
[5] Department of Physics, New York University, New York, NY 10003, USA
[6] Laboratoire de Physique des Solides, Université de Paris-Sud, 91405 Orsay Cedex, France

Received 30 November 1998

Abstract. The functional dependence of the giant magnetoresistance (GMR) with respect to the relative angle between the orientations of the magnetization in the magnetic slabs of a trilayer system is calculated by using the Kubo-Greenwood formula for electrical transport together with the fully-relativistic spin-polarized screened Korringa-Kohn-Rostoker method for semi-infinite systems and the coherent potential approximation. It is found that the functional dependence of the GMR is essentially of the form $(1 - \cos\varphi)$.

PACS. 71.20.Be Transition metals and alloys – 72.15-v Electronic conduction in metals and alloys – 75.30.Et Exchange and superexchange interactions

1999

PHYSICAL REVIEW B VOLUME 60, NUMBER 1 1 JULY 1999-I

Ab initio calculations of magnetotransport for magnetic multilayers

C. Blaas and P. Weinberger
Center for Computational Materials Science and Institut für Technische Elektrochemie und Festkörperchemie, Technische Universität Wien, 1060 Vienna, Austria

L. Szunyogh
Center for Computational Materials Science, 1060 Vienna, Austria and Department of Theoretical Physics, Technical University Budapest, 1521 Budapest, Hungary

P. M. Levy
Department of Physics, New York University, New York, New York 10003

C. B. Sommers
Laboratoire de Physique des Solides, Université de Paris–Sud, 91405 Orsay, France
(Received 8 February 1999)

We have used the spin-polarized relativistic screened Korringa-Kohn-Rostoker method for layered systems together with the Kubo-Greenwood formalism and the coherent-potential approximation to describe electrical transport properties of magnetic multilayers. We are able to calculate resistivities and magnetoresistance of model structures with no adjustable parameters by simultaneously determining contributions to the giant magnetoresistance of multilayers coming from both the electronic structure and spin-dependent scattering off impurities. [S0163-1829(99)05125-5]

2001

PHYSICAL REVIEW B, VOLUME 63, 224408

Electrical transport properties of bulk Ni_cFe_{1-c} alloys and related spin-valve systems

C. Blaas
Center for Computational Materials Science, Technische Universität Wien, Getreidemarkt 9/158, 1060 Vienna, Austria

L. Szunyogh
*Center for Computational Materials Science, Technische Universität Wien, Getreidemarkt 9/158, 1060 Vienna, Austria
and Department of Theoretical Physics, Budapest University of Technology and Economics, Budafoki út. 8, 1521 Budapest, Hungary*

P. Weinberger
Center for Computational Materials Science, Technische Universität Wien, Getreidemarkt 9/158, 1060 Vienna, Austria

C. Sommers
Laboratoire de Physique des Solides, Université de Paris-Sud, 91405 Orsay Cedex, France

P. M. Levy
Department of Physics, New York University, 4 Washington Place, New York, New York 10003
(Received 31 July 2000; revised manuscript received 19 December 2000; published 18 May 2001)

Within the Kubo-Greenwood formalism we use the fully relativistic, spin-polarized, screened Korringa-Kohn-Rostoker method together with the coherent-potential approximation for layered systems to calculate the resistivity for the permalloy series Ni_cFe_{1-c}. We are able to reproduce the variation of the resistivity across the entire series; notably the discontinuous behavior in the vicinity of the structural phase transition from bcc to fcc. The absolute values for the resistivity are within a factor of 2 of the experimental data. Also the giant magnetoresistance of a series of permalloy-based spin-valve structures is estimated; we are able to reproduce the trends observed on prototypical spin-valve structures.

DOI: 10.1103/PhysRevB.63.224408 PACS number(s): 75.30.Gw, 75.70.Ak, 75.70.Cn

2002

PHYSICAL REVIEW B, VOLUME 65, 134427

Theoretical evaluation of magnetotransport properties in Co/Cu/Co-based spin valves

C. Blaas
Center for Computational Materials Science, Technische Universität Wien, Getreidemarkt 9/134, 1060 Vienna, Austria

L. Szunyogh
Center for Computational Materials Science, Technische Universität Wien, Getreidemarkt 9/134, 1060 Vienna, Austria and Department of Theoretical Physics, Budapest University of Technology and Economics, Budafoki út. 8, 1521 Budapest, Hungary

P. Weinberger
Center for Computational Materials Science, Technische Universität Wien, Getreidemarkt 9/134, 1060 Vienna, Austria

C. Sommers
Laboratoire de Physique des Solides, Université de Paris-Sud, 91405 Orsay Cedex, France

P. M. Levy
Department of Physics, New York University, 4 Washington Place, New York, New York 10003

J. Shi
Department of Physics, University of Utah, Salt Lake City, Utah 84112
(Received 12 September 2001; published 22 March 2002)

The current-in-plane resistivities and corresponding magnetoresistance ratios are calculated for realistic Co/Cu/Co-based spin-valve samples by applying the Kubo-Greenwood approach together with the fully relativistic, spin-polarized, screened Korringa-Kohn-Rostoker method for layered structures. We study the effects of both alloying in the spacer layers with a selection of $3d$, $4d$, and $5d$ elements as well as different profiles for interdiffusion at the Co/Cu interfaces. On comparing our results to available experimental data we find that both interdiffusion and confinement effects, due to the finite overall thickness of the spin valve, strongly influence the magnetoresistance of spin-valve structures.

DOI: 10.1103/PhysRevB.65.134427 PACS number(s): 75.30.−m, 75.70.Ak, 75.70.Cn

2003

PHYSICAL REVIEW B **68**, 054406 (2003)

Ab initio description of domain walls in Permalloy: Energy of formation and resistivities

S. Gallego,[1,2] P. Weinberger,[1] L. Szunyogh,[1,3] P. M. Levy,[4] and C. Sommers[5]
[1]*Center for Computational Materials Science, Technical University of Vienna, Gumpendorferstrasse 1a, A-1060 Vienna, Austria*
[2]*Instituto de Ciencia de Materiales de Madrid, Consejo Superior de Investigaciones Científicas, Cantoblanco, 28049 Madrid, Spain*
[3]*Department of Theoretical Physics and Center for Applied Mathematics and Computational Physics, Budapest University of Technology and Economics, Budafoki út 8., H-1521 Budapest, Hungary*
[4]*Department of Physics, New York University, 4 Washington Place, New York, New York 10003, USA*
[5]*Laboratoire de Physique des Solides, Université de Paris-Sud, 91405 Orsay Cedex, France*
(Received 18 March 2003; revised manuscript received 22 May 2003; published 7 August 2003)

To determine the formation energy and resistivity for domain walls in permalloy (fcc-$Ni_{85}Fe_{15}$) we use the fully relativistic spin-polarized screened Korringa-Kohn-Rostoker method for layered systems and the corresponding Kubo-Greenwood equation in the context of the (inhomogeneous) coherent potential approximation. We find that the difference in formation energy between 90° and 180° domains becomes very small if the domain wall width increases. Furthermore, we show that regardless of the configuration within a domain wall the in-plane components of the resistivity are larger than in a single domain and, in particular, that the anisotropic magnetoresistance ratio within the domain wall vanishes.

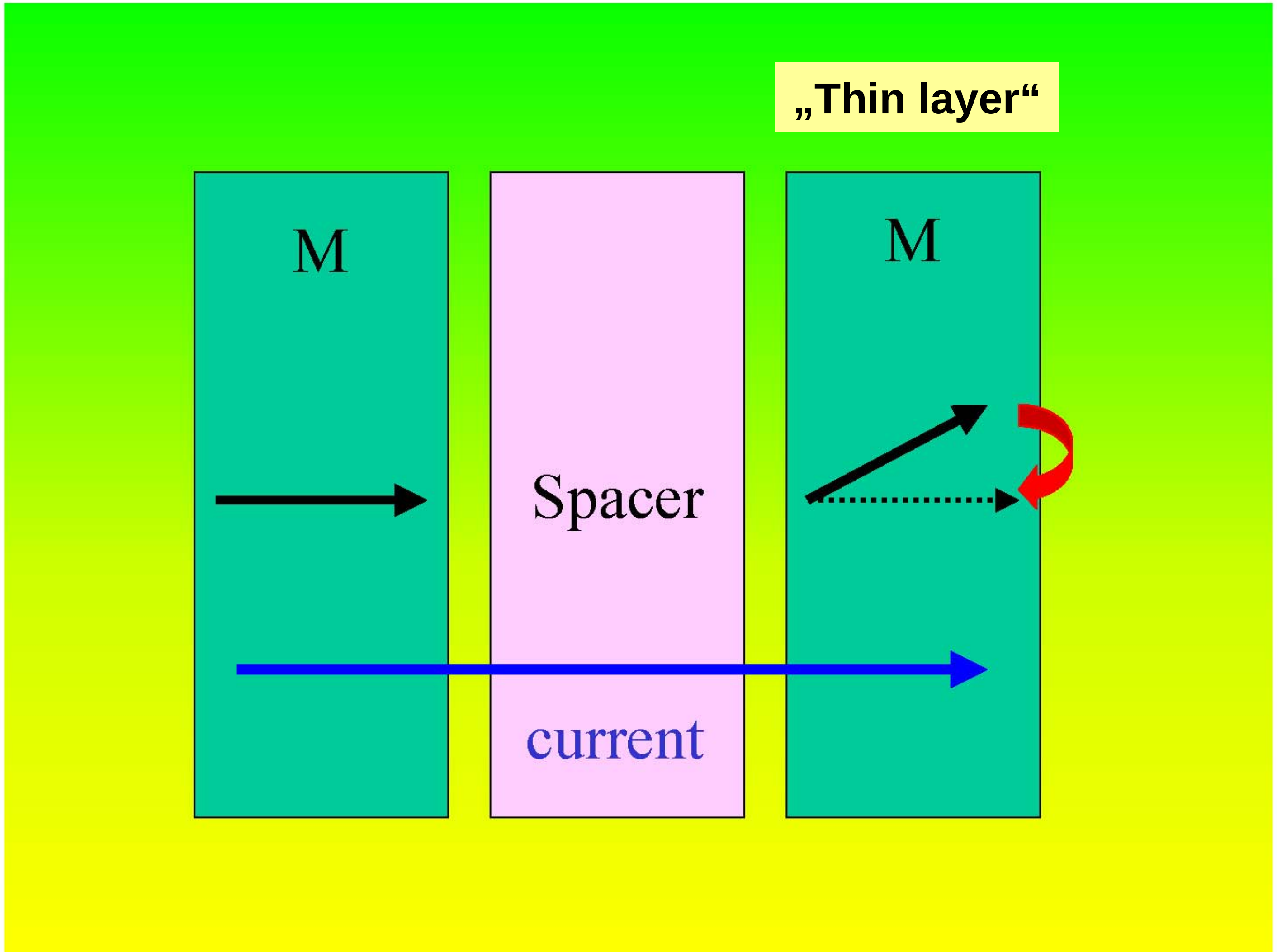
DOI: 10.1103/PhysRevB.68.054406 PACS number(s): 75.30.Hx, 73.22.−f, 75.30.Gw

<u>Our everlasting topic:</u>

Spins, spin-polarization & currents

<u>or (at least at present):</u>

An ab-initio theory of current-induced switching



„Thin layer“
M
Spacer
M
current

Non-relativistic phenomenological set of Landau-Lifshitz & transport equations

$$\frac{\partial n}{\partial t} + \vec{\nabla} \cdot \vec{j} = 0$$

$$\vec{j} = \tilde{\boldsymbol{\sigma}} \vec{E} - D\, \vec{\nabla} \delta n - \vec{\Lambda} \cdot \left(\vec{\nabla} \otimes \delta \vec{m} \right)$$

$$\frac{\partial \vec{m}}{\partial t} + \vec{\nabla} \cdot \overleftrightarrow{J}_{\text{spin}} = \vec{m} \times \vec{B}_{\text{eff}}$$

$$\overleftrightarrow{J}_{\text{spin}} = \vec{\sigma}_{\text{spin}} \otimes \vec{E} - D_{\text{spin}} \left(\vec{\nabla} \otimes \delta \vec{m} \right)^{\text{t}} - \vec{\Lambda}_{\text{spin}} \otimes \vec{\nabla} n$$

$n \equiv n(\vec{r}, t)$: charge density
$\delta n = n - n_{\text{eq}}$

$\vec{j}$: current density

$\vec{m} \equiv \vec{m}(\vec{r}, t)$: magnetization density
$\delta \vec{m} = \vec{m} - \vec{m}_{\text{eq}}$

$\overleftrightarrow{J}_{\text{spin}}$: "spin" current density

$\vec{B}_{\text{eff}}$: internal exchange field

$\vec{E}$: external electric field

$\tilde{\boldsymbol{\sigma}}, D, \vec{\Lambda}$: charge transport coefficients

$\vec{\sigma}_{\text{spin}}, D_{\text{spin}}, \vec{\Lambda}_{\text{spin}}$: "spin" transport coefficients

$\otimes$: tensorial product

t : transposed

$$\overleftrightarrow{J}_{\text{spin}} \simeq (\sigma_{\uparrow} - \sigma_{\downarrow}) \frac{\vec{m}}{m} \otimes \vec{E}$$

$\sigma_{\uparrow(\downarrow)}$: "spin" up (down) conductivity

۳. محاسبهٔ فرکانس امواج اسپین

برای محاسبهٔ فرکانس امواج اسپین در یک فرومغناطیس، معادلهٔ لاندو- لیفشیتز را بر حسب زمان و مختصات فضایی مغناطش M می‌توان به صورت زیر نوشت:

$$\frac{\partial \vec{M}}{\partial t} = \gamma \vec{M} \times \vec{H}_{eff} \quad . \qquad (۱)$$

γ ضریب ژیرومغناطیسی و H_{eff} میدان مؤثر است. H_{eff} شامل میدانهای مختلف اعمال شده بر روی اسپینهای اتمهاست. این میدانها ناشی از انرژی مبادله‌ای به علت تغییرات فضایی مغناطش، ناهمسانگردیهای مرتبه دوم و چهارم، ناهمسانگردی تک جهتی ناشی از انرژی مبادله‌ای در سطح تماس دولایه‌ای، و انرژی زیمن است. در واقع میدان مؤثر به صورت زیر تعریف می شود:

$$\vec{H}_{eff} = \hat{z} H_{0} - \frac{1}{M_S} \nabla_u F_{ani} + \frac{2A}{M_S^{2}} \nabla^{2} \vec{M} + \vec{h}_d \qquad (۲)$$

در این رابطه H_0 میدان خارجی است که در جهت z بر نمونه اعمال می‌شود، M_S مغناطش اشباع، F_{ani} انرژی ناهمسانگردی

This is **not** from Mainmonides‘ famous *Guide for the Perplexed*

but Landau-Lifshitz in Pharsi

$$i\hbar\frac{\partial\psi(\vec{r},t)}{\partial t} = \mathcal{H}_{\mathrm{D}}\psi(\vec{r},t)$$

$$\mathcal{H}_{\mathrm{D}} = c\tilde{\boldsymbol{\alpha}}\cdot\left[\vec{p} - e\vec{A}(\vec{r},t)\right] + \boldsymbol{\beta}m_{\mathrm{e}}c^2 + eV(\vec{r},t)$$

$\vec{A}(\vec{r},t)$	vector potential
$V(\vec{r},t)$	scalar potential
c	speed of light
e	electron charge
m_{e}	electron mass
$\vec{p} = -i\hbar\vec{\nabla}$	momentum
$\boldsymbol{\alpha}_\mu, \boldsymbol{\beta}$	Dirac matrices

Time-dependent Dirac equation

Fully relativistic coupled Landau-Lifshitz & transport equations for a single particle

$$
\begin{cases}
\underbrace{\frac{d}{dt}(\psi^{+}\mathbf{T}\psi)}_{LL-1} + \underbrace{c\nabla\circ[\psi^{+}(\boldsymbol{\alpha}\otimes\mathbf{T})\psi]}_{LL-2} = \underbrace{\frac{e}{m_e}\psi^{+}(\boldsymbol{\Sigma}\times\mathbf{B})\psi}_{LL-3} - \underbrace{\frac{e}{m_e c}\mathbf{E}\psi^{+}\gamma_5\psi}_{LL-4} \\
\underbrace{\frac{d}{dt}(\psi^{+}T_4\psi)}_{T-1} + \underbrace{c\nabla\circ[\psi^{+}(\alpha\otimes T_4)\psi]}_{T-2} = \underbrace{\frac{ie}{m_e}\psi^{+}(\boldsymbol{\Sigma}\cdot\mathbf{E})\psi^{+}}_{T-3}
\end{cases}
$$

$$\mathbf{T} = \beta\boldsymbol{\Sigma} - \boldsymbol{\gamma}_5\frac{\boldsymbol{\pi}}{m_e c}$$

Polarization operator

$$\boldsymbol{\pi} = \mathbf{p} - e\mathbf{A}$$

$$T_4 = \frac{i}{m_e c}\sum_{\mu}\Sigma_{\mu}\pi_{\mu}$$

Some definitions:

$$(\boldsymbol{\alpha} \otimes \mathbf{T}) = \begin{pmatrix} \alpha_x T_x & \alpha_x T_y & \alpha_x T_z \\ \alpha_y T_x & \alpha_y T_y & \alpha_y T_z \\ \alpha_z T_x & \alpha_z T_y & \alpha_z T_z \end{pmatrix} \quad , \quad \boldsymbol{\alpha} \otimes T_4 = \begin{pmatrix} \alpha_x T_4 \\ \alpha_y T_4 \\ \alpha_z T_4 \end{pmatrix}$$

$$\boldsymbol{\alpha} = \begin{pmatrix} 0 & \boldsymbol{\sigma} \\ \boldsymbol{\sigma} & 0 \end{pmatrix}, \boldsymbol{\gamma}_5 = \begin{pmatrix} 0 & -I_2 \\ -I_2 & 0 \end{pmatrix}, \beta = \begin{pmatrix} I_2 & 0 \\ 0 & -I_2 \end{pmatrix}, \boldsymbol{\Sigma} = \begin{pmatrix} \boldsymbol{\sigma} & 0 \\ 0 & \boldsymbol{\sigma} \end{pmatrix}$$

$$\psi(\mathbf{r};t) = \langle \mathbf{r} | \psi(t) \rangle = \begin{pmatrix} \phi(\mathbf{r},t) \\ \chi(\mathbf{r},t) \end{pmatrix}$$

$$\chi(\mathbf{r},t) = \frac{1}{2m_e c} \boldsymbol{\sigma} \cdot \boldsymbol{\pi}\, \phi(\mathbf{r},t)$$

Bispinor representation

Fully relativistic Landau-Lifshitz equation

$$\psi(\vec{r},t) = \begin{pmatrix} \phi(\vec{r},t) \\ \chi(\vec{r},t) \end{pmatrix}$$

$$\chi(\vec{r},t) = \frac{1}{2m_e c}(\vec{\sigma}\cdot\vec{\pi})\ \phi(\vec{r},t)$$

$$\frac{d}{dt}\left[\vec{m}_1(\vec{r},t) + \vec{m}_2(\vec{r},t) + \frac{1}{m_e c}\vec{m}_3(\vec{r},t)\right] + c\vec{\nabla}\cdot\left(\mathcal{J}^{(1)}(\vec{r},t) + \frac{1}{m_e c}\mathcal{J}^{(2)}(\vec{r},t)\right)$$
$$= \frac{e}{m_e}\vec{m}_1(\vec{r},t)\times\vec{B}(\vec{r},t) + \frac{1}{m_e c}\vec{e}(\vec{r},t)$$

$$\vec{m}_1(\vec{r},t) = \left[\phi^+(\vec{r},t)\,\vec{\sigma}\phi(\vec{r},t) + \chi^+(\vec{r},t)\,\vec{\sigma}\chi(\vec{r},t)\right]$$

$$c^{-1} : \mathcal{J}^{(1)}(\vec{r},t) \quad , \quad \vec{e}(\vec{r},t)$$

$$c^{-2} : \vec{m}_2(\vec{r},t) = -2\chi^+(\vec{r},t)\,\vec{\sigma}\chi(\vec{r},t)$$

LL-equation

Omitting all terms of the order of c^{-2}

$$\frac{d}{dt}\left[\vec{m}_1(\vec{r},t)\right] + \vec{\nabla}\cdot\left(\mathcal{J}^{(1)}(\vec{r},t) + \frac{1}{m_e}\mathcal{J}^{(2)}(\vec{r},t)\right) \simeq \frac{e}{m_e}\vec{m}_1(\vec{r},t)\times\vec{B}(\vec{r},t)$$

Non-relativistic limit, $c \to \infty$,

$$\frac{d}{dt}\left[\vec{m}(\vec{r},t)\right] + \frac{1}{m_e}\vec{\nabla}\cdot\left(\mathcal{J}^{(1)}(\vec{r},t) + \mathcal{J}^{(2)}(\vec{r},t)\right) = \frac{e}{m_e}\vec{m}(\vec{r},t)\times\vec{B}(\vec{r},t)$$

$$e.g.:\ \vec{m}(\vec{r},t) = \varphi^{+}(\vec{r},t)\vec{\sigma}\varphi(\vec{r},t)$$

Fully relativistic transport equation

$$\frac{d}{dt}\left\{\sum_{\mu}\frac{1}{m_e c}\left[\phi^{+}(\vec{r},t)\sigma_{\mu}(p_{\mu}-eA_{\mu}(\vec{r},t))\phi(\vec{r},t)+\chi^{+}(\vec{r},t)\sigma_{\mu}(p_{\mu}-eA_{\mu}(\vec{r},t))\chi(\vec{r},t)\right]\right\}$$

$$=c\vec{\nabla}\cdot\mathcal{J}^{(4)}(\vec{r},t)-\frac{ie}{m_e}\sum_{\mu}\left[\phi^{+}(\vec{r},t)\sigma_{\mu}E_{\mu}(\vec{r},t)\phi(\vec{r},t)+\chi^{+}(\vec{r},t)\sigma_{\mu}E_{\mu}(\vec{r},t)\chi(\vec{r},t)\right]$$

$$\mathcal{J}^{(4)}(\vec{r},t)=\left\{\mathcal{J}^{(4)}_{\mu\upsilon}(\vec{r},t)\right\}\ ,\ \mathcal{J}^{(4)}_{\mu\nu}(\vec{r},t)=\sum_{\upsilon}\left[\chi^{+}(\vec{r},t)\sigma_{\mu}\sigma_{\upsilon}[p_{\upsilon}-eA_{\nu}(\vec{r},t)]\phi(\vec{r},t)\right.$$
$$\left.+\phi^{+}(\vec{r},t)\sigma_{\mu}\sigma_{\upsilon}[p_{\upsilon}-eA_{\nu}(\vec{r},t)]\chi(\vec{r},t)\right]$$

$$\lim_{c\to\infty}c\vec{\nabla}\cdot\mathcal{J}^{(4)}(\vec{r},t)=\frac{ie}{m_e}\left[\varphi^{+}(\vec{r},t)(\vec{\sigma}\cdot\vec{E}(\vec{r},t))\varphi(\vec{r},t)\right]$$

Non-relativistic limit

Schematic Landau-Lifshitz & transport equations

$$\frac{\partial \vec{m}}{\partial t} + \vec{\nabla} \cdot \overleftrightarrow{J} = \vec{m} \times \vec{B}_{\mathrm{eff}}$$

„Spin torque term“

Effective field

Effective field:

$$\vec{B}_{\text{eff}} = -\mu_0 \nabla_{\vec{M}} \left(\Delta E_b + F_{\text{J}}\right)$$

$$F_{\text{J}}(t) \simeq - \sum_{k,k'=\text{con,int}} \int d^3r \; d^3r' \int dt' \, \vec{j}_k(\vec{r},t) \; \tilde{\boldsymbol{\chi}}_{k,k'}(\vec{r}-\vec{r}';t-t') \; \vec{j}_{k'}(\vec{r}',t')$$

Twisting energy & Kubo equation

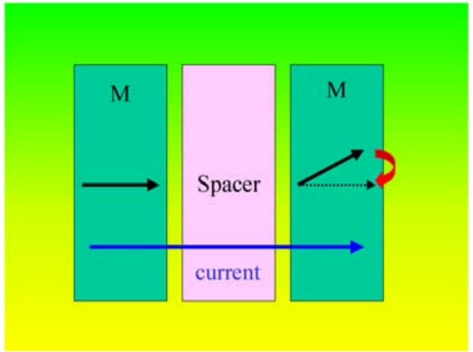
Twisting energy:

$$\Delta E(\Theta;\mathbf{x},m) = E(\Theta;\mathbf{x},m) - \min[E(\Theta;\mathbf{x},m)]$$

$E(\Theta;\mathbf{x},m)$	grand potential
m	number of spacer layers
$\mathbf{x}$	vector of concentrations in case of inhomogeneous alloying

Expansion:

$$\Delta E^{(k)}(\Theta;\mathbf{x},m) = \sum_{s=0}^{k} a_s(\mathbf{x},m)\,(\cos(\Theta))^s$$



$$\sigma_{\mu\mu} = \frac{\hbar}{\pi N_0 \Omega_{at}} Tr\,\left\langle J_\mu Im G^+(\epsilon_F) J_\mu Im G^+(\epsilon_F)\right\rangle$$

μ	$\in \{x,y,z\}$
N_0	number of atoms
Ω_{at}	atomic volume
J_μ	representation of the μ-th component of the current operator
$G^+(\epsilon_F)$	(one-particle) Green's function
ϵ_F	Fermi energy

Mapping on a classic Ohms law

Current

$$I(\Theta;\mathbf{x},m) = \sqrt{\frac{A_0\Delta E(\Theta;\mathbf{x},m)}{\tau(\Theta;\mathbf{x},m)r(\Theta;\mathbf{x},m)}}$$
$$= \sqrt{\frac{\langle A_0\rangle}{\langle\tau(\Theta;\mathbf{x},m)\rangle}}I_0(\Theta;\mathbf{x},m)$$

A_0	unit area
$\tau(\Theta;\mathbf{x},m)$	(minimal) switching time
$I_0(\Theta;\mathbf{x},m)$	reduced current

τ : **Landau-Lifshitz-Gilbert equation for layered systems**

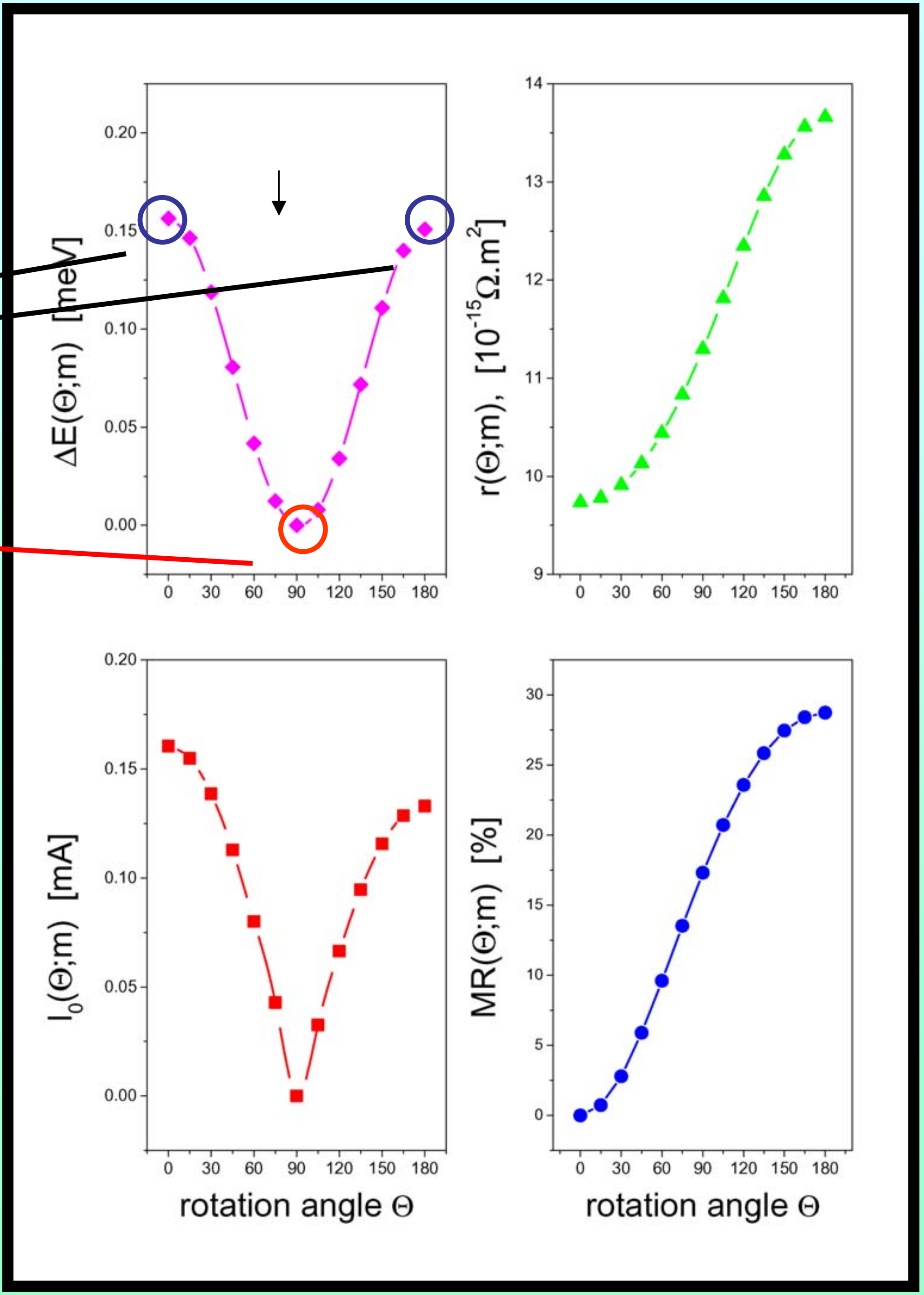
$$\frac{d\vec{n}}{dt} = -\gamma\vec{n}\times\vec{H}^{eff}(\mathbf{x},m) + \alpha\vec{n}\times\left(\vec{n}\times\vec{H}^{eff}(\mathbf{x},m)\right)$$
$$\vec{n} = n_x\vec{e}_x + n_y\vec{e}_y + n_z\vec{e}_z$$

$\vec{n}$	orientation of the magnetization in the
$\vec{H}^{eff}(\mathbf{x},m)$	internal effective field
$\vec{e}_x$, $\vec{e}_y, n_z\,\vec{e}_z$	unit vectors

$Cu/Py_m/Cu_{20}/Py_n/Cu$
m>>n

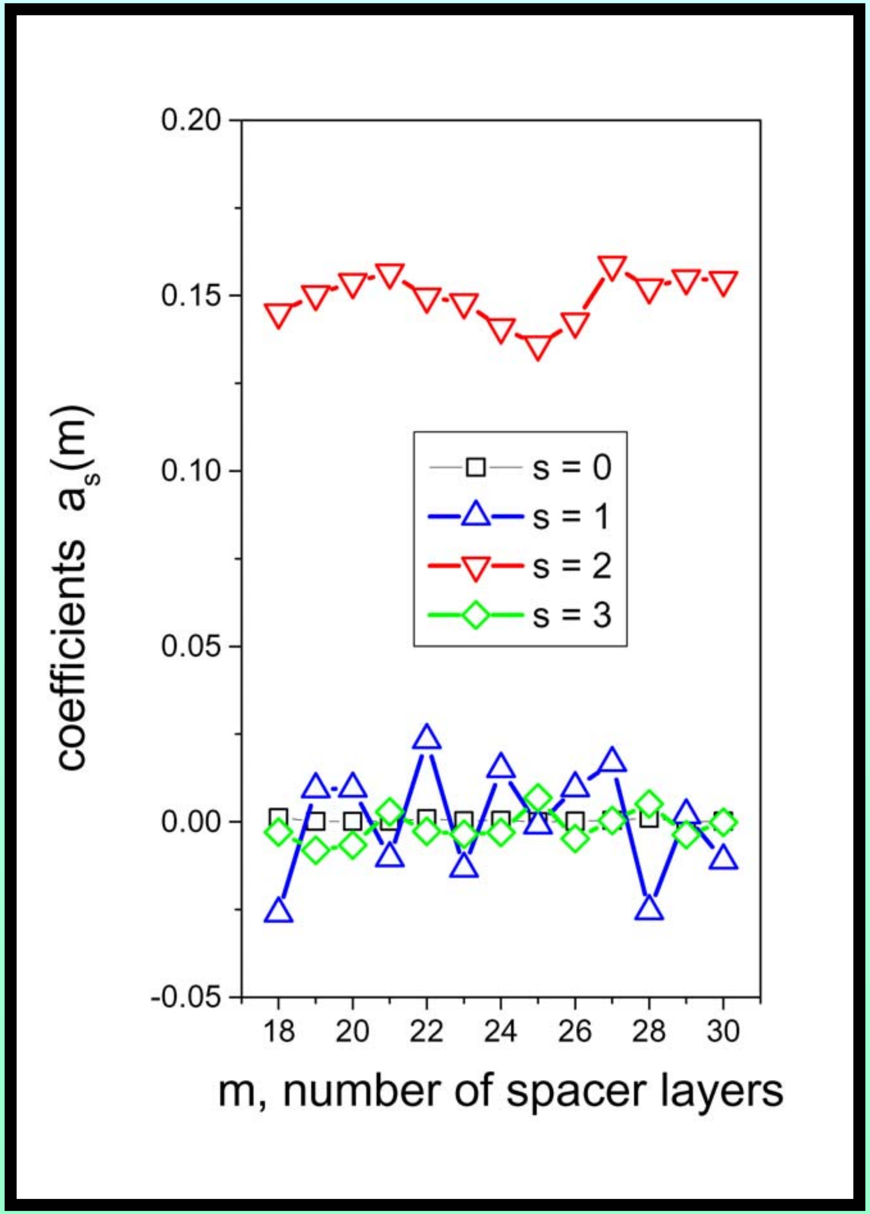
final state

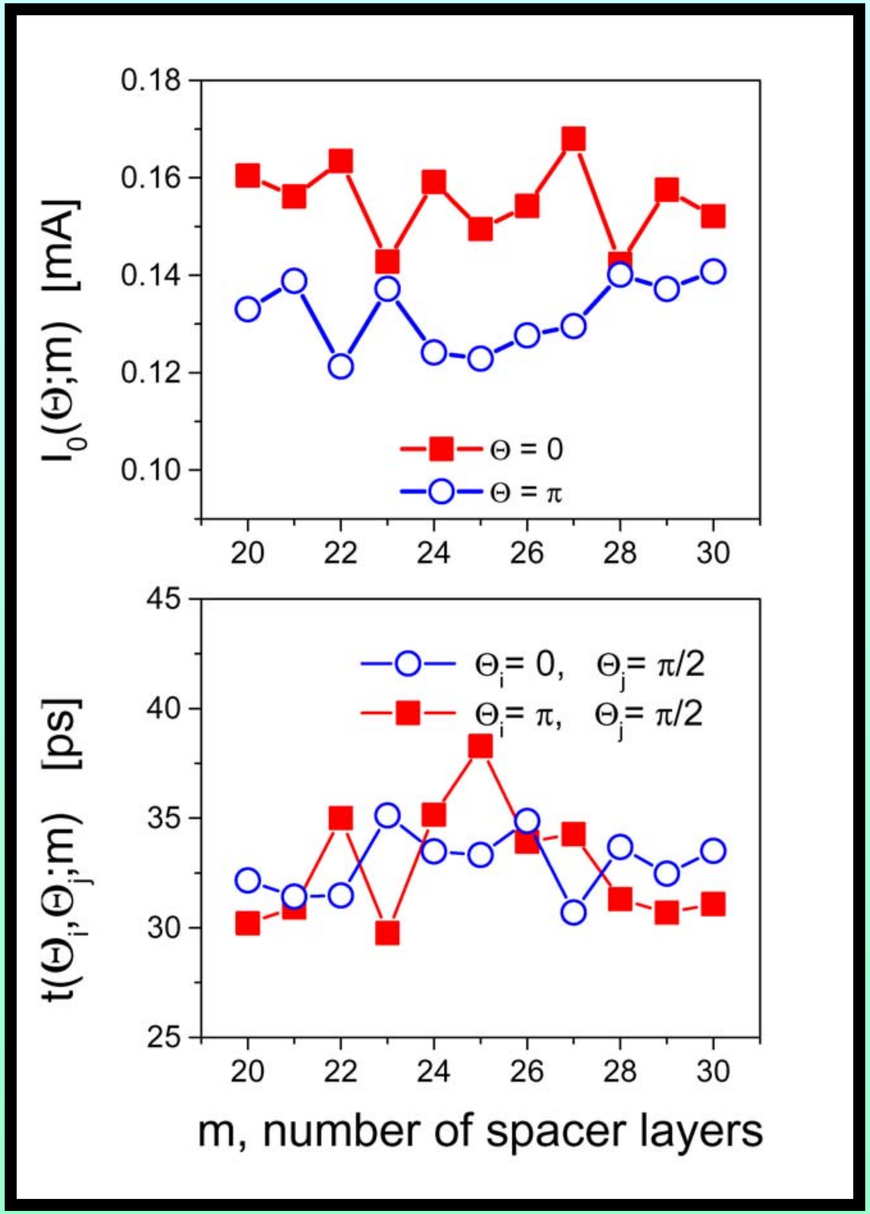
ground state



Reduced current: Mapping on a classical Ohms Law

Expansion coefficients & switching times





Resume

- Sorry, there is still no trace of a classical spin
- if we speak about „spin polarization“, hopefully we now agree on what is meant with this term
- „spin torque“ does have a quantum mechanical counterpart, even in a non-relativistic description
- I think, it is about time for another Pastrami sandwich at Katz!

So then:

... till 120 !!!

(or integer
multiples
thereof)

New York, February 18, 2003