# Magnetism at Humboldt- and Free-University

Exchance

Coupling

**Klaus Baberschke**

**Institut für Experimentalphysik**
**Freie Universität Berlin**
**Arnimallee 14    D-14195 Berlin-Dahlem    Germany**

A8
Nolting
( A7
Winter )

FREIE UNIVERSITÄT BERLIN

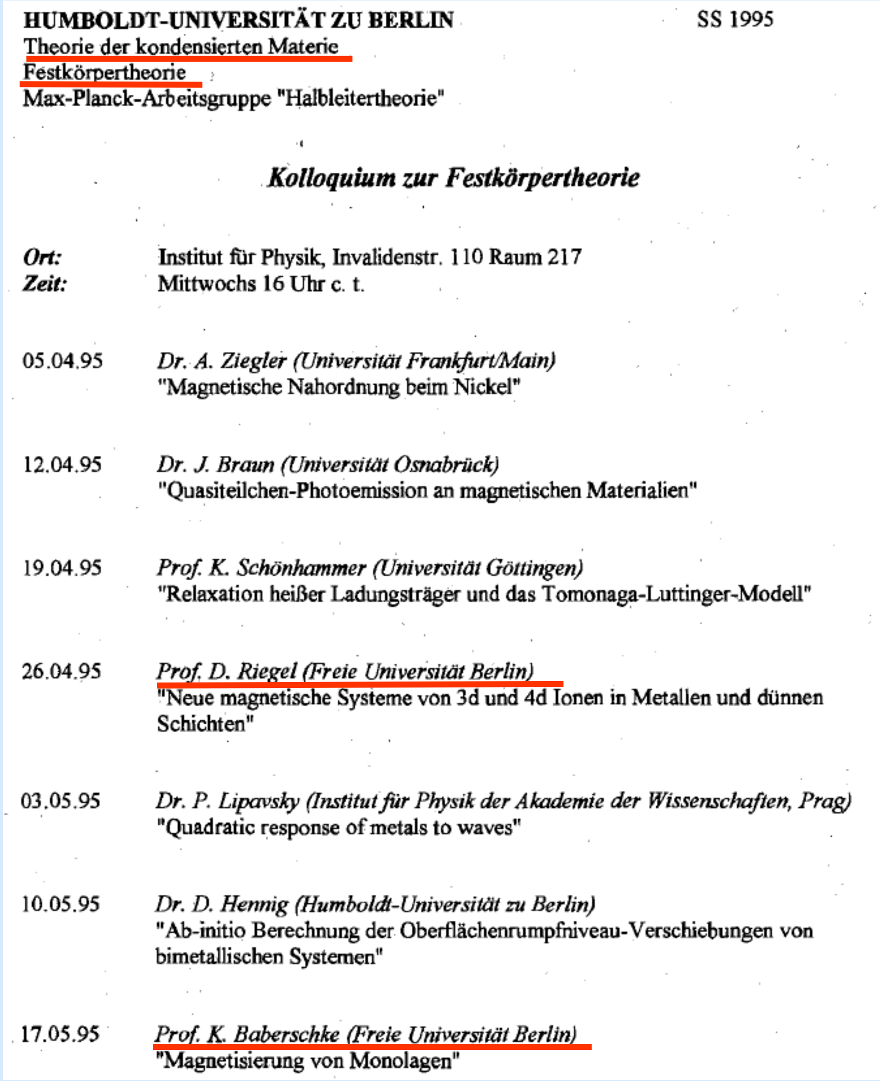
Sonderforschungsbereich 290 **1993 - 04**

Metallische dünne Filme:

Struktur, Magnetismus und elektronische Eigenschaften

A2
Baberschke
( A6
Kaindl )

# 1994: Start Nolting-group @ HUB

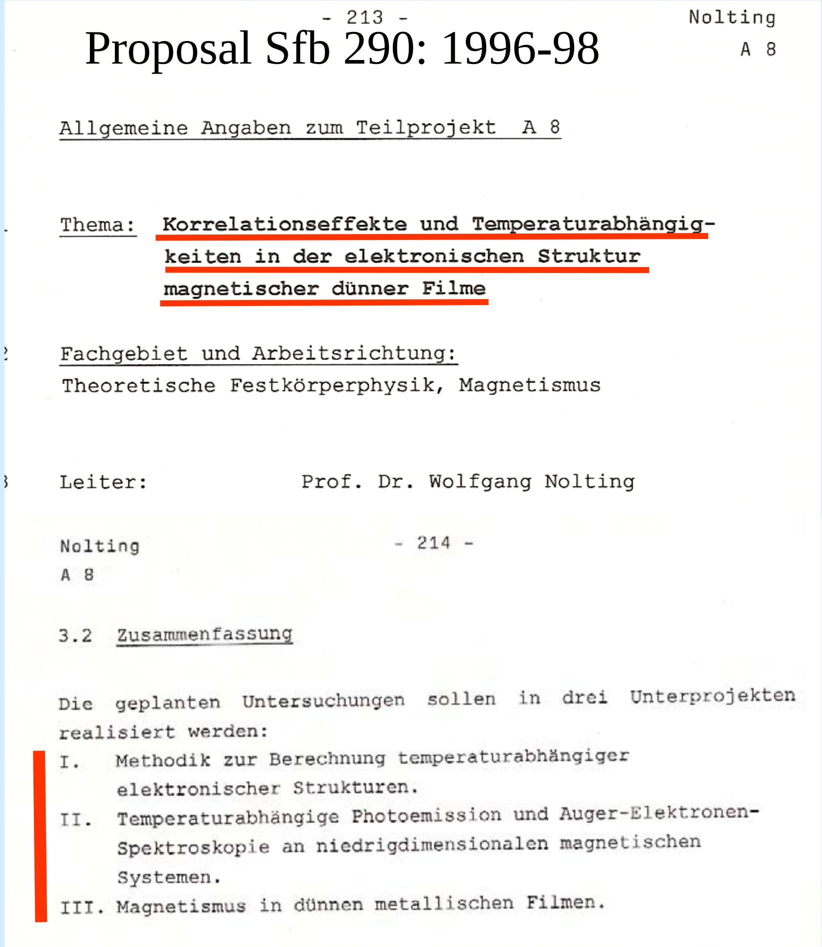


**HUMBOLDT-UNIVERSITÄT ZU BERLIN** SS 1995
Theorie der kondensierten Materie
Festkörpertheorie
Max-Planck-Arbeitsgruppe "Halbleitertheorie"

***Kolloquium zur Festkörpertheorie***

| | |
|---|---|
| ***Ort:*** | Institut für Physik, Invalidenstr. 110 Raum 217 |
| ***Zeit:*** | Mittwochs 16 Uhr c. t. |
| 05.04.95 | *Dr. A. Ziegler (Universität Frankfurt/Main)*<br>"Magnetische Nahordnung beim Nickel" |
| 12.04.95 | *Dr. J. Braun (Universität Osnabrück)*<br>"Quasiteilchen-Photoemission an magnetischen Materialien" |
| 19.04.95 | *Prof. K. Schönhammer (Universität Göttingen)*<br>"Relaxation heißer Ladungsträger und das Tomonaga-Luttinger-Modell" |
| 26.04.95 | *Prof. D. Riegel (Freie Universität Berlin)*<br>"Neue magnetische Systeme von 3d und 4d Ionen in Metallen und dünnen Schichten" |
| 03.05.95 | *Dr. P. Lipavsky (Institut für Physik der Akademie der Wissenschaften, Prag)*<br>"Quadratic response of metals to waves" |
| 10.05.95 | *Dr. D. Hennig (Humboldt-Universität zu Berlin)*<br>"Ab-initio Berechnung der Oberflächenrumpfniveau-Verschiebungen von bimetallischen Systemen" |
| 17.05.95 | *Prof. K. Baberschke (Freie Universität Berlin)*<br>"Magnetisierung von Monolagen" |

## Proposal Sfb 290: 1996-98



- 213 -
Nolting
A 8

Allgemeine Angaben zum Teilprojekt A 8

Thema: Korrelationseffekte und Temperaturabhängigkeiten in der elektronischen Struktur magnetischer dünner Filme

Fachgebiet und Arbeitsrichtung:
Theoretische Festkörperphysik, Magnetismus

Leiter: Prof. Dr. Wolfgang Nolting

Nolting
A 8
- 214 -

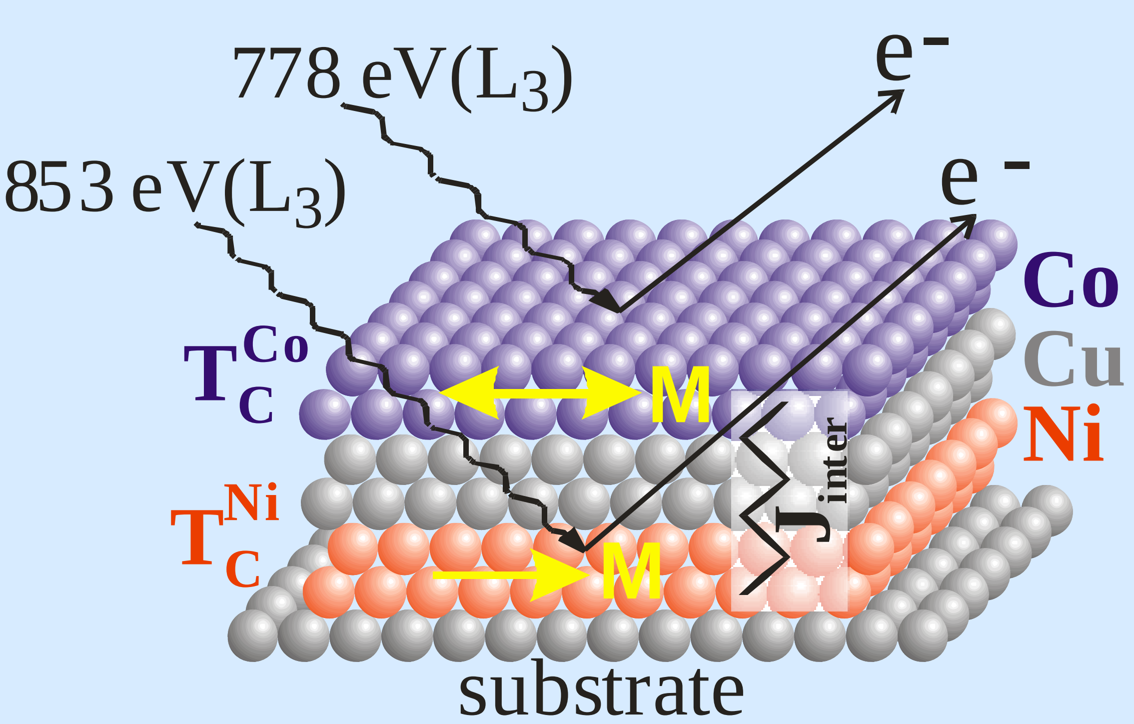
3.2 Zusammenfassung

Die geplanten Untersuchungen sollen in drei Unterprojekten realisiert werden:

I. Methodik zur Berechnung temperaturabhängiger elektronischer Strukturen.
II. Temperaturabhängige Photoemission und Auger-Elektronen-Spektroskopie an niedrigdimensionalen magnetischen Systemen.
III. Magnetismus in dünnen metallischen Filmen.

- Curie – temperatures
- Exchange coupling (physics)
- Exchange coupling (academic)

# FM trilayers, do they have 2 Curie temperatures?

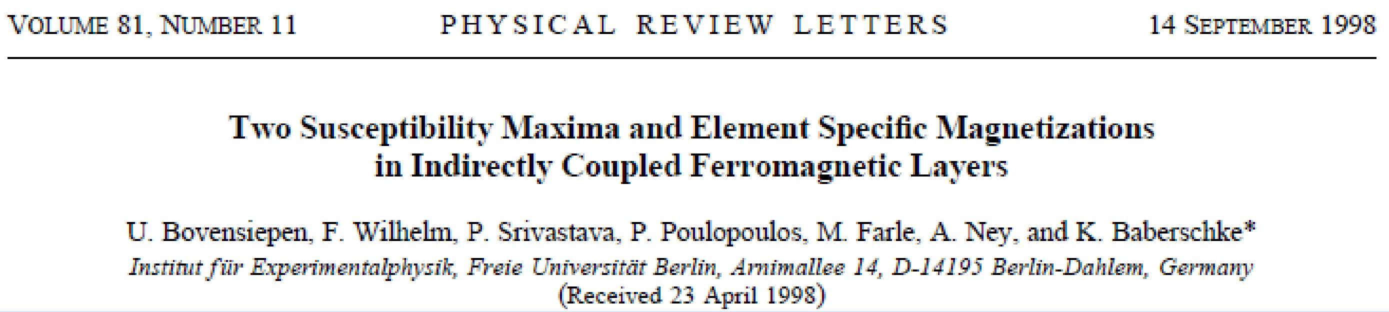


A trilayer is a prototype to study magnetic coupling in multilayers.

What about element specific Curie-temperatures ?

Two trivial limits: (i) $d_{Cu} = 0 \Rightarrow$ direct coupling like a Ni-Co alloy
(ii) $d_{Cu}$ = large $\Rightarrow$ no coupling, like a mixed Ni/Co powder
**BUT** $d_{Cu} \approx 2$ ML $\Rightarrow$ **?**

**Importance of higher order spin-spin correlations in low D.**

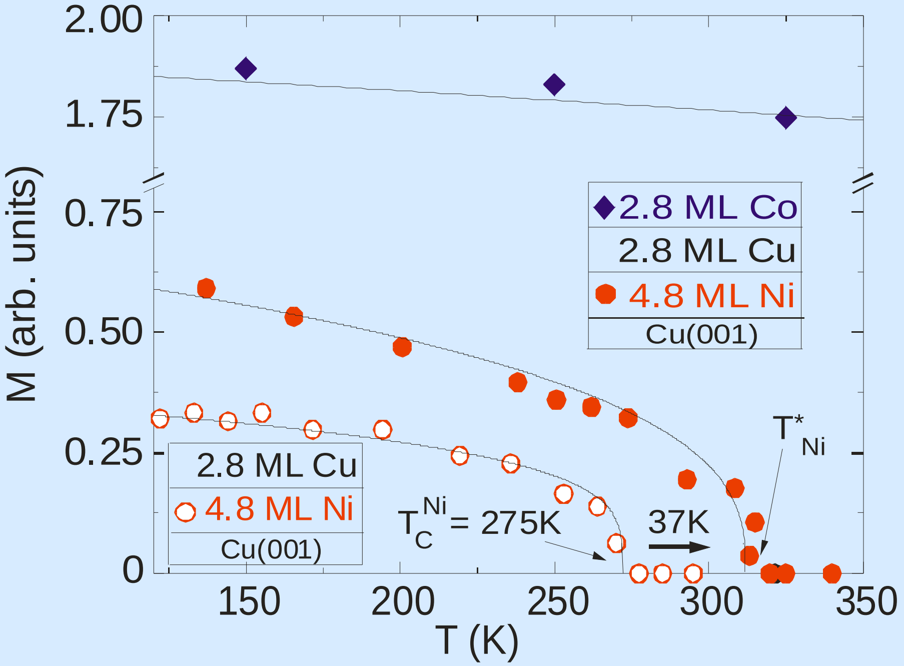


VOLUME 81, NUMBER 11 PHYSICAL REVIEW LETTERS 14 SEPTEMBER 1998

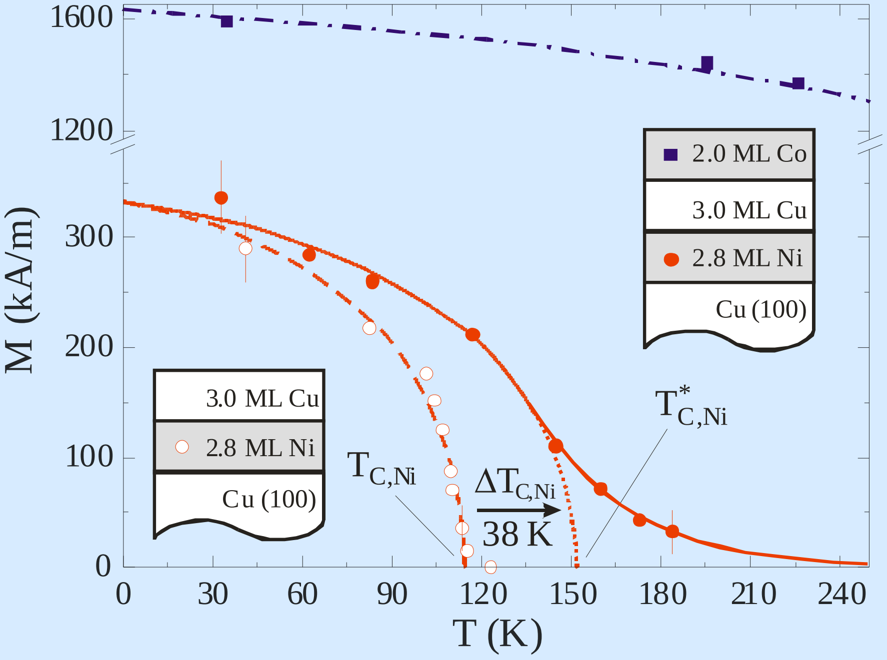
**Two Susceptibility Maxima and Element Specific Magnetizations in Indirectly Coupled Ferromagnetic Layers**

U. Bovensiepen, F. Wilhelm, P. Srivastava, P. Poulopoulos, M. Farle, A. Ney, and K. Baberschke*
*Institut für Experimentalphysik, Freie Universität Berlin, Arnimallee 14, D-14195 Berlin-Dahlem, Germany*

(Received 23 April 1998)

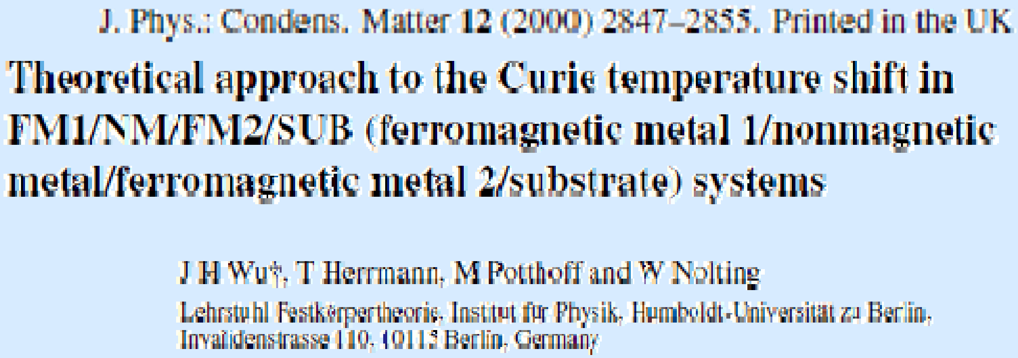


P. Poulopoulos, K. B., Lecture Notes in Physics **580**, 283 (2001)



A. Scherz et al. PRB **65**, 24411 (2005)

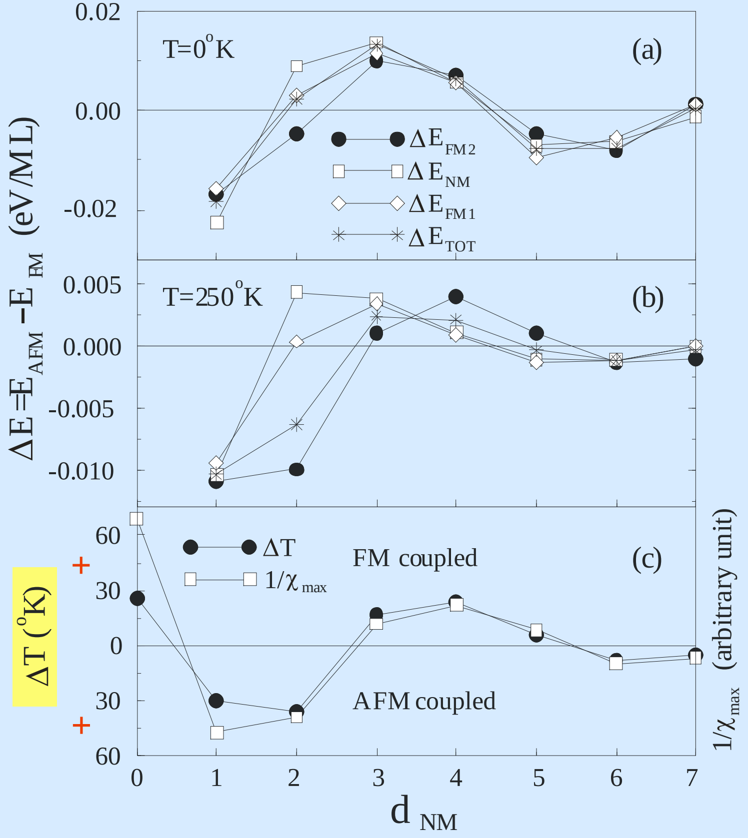
The large shift of $T_C^{Ni}$ can **NOT** be explained by the static exchange field of Co.



J. Phys.: Condens. Matter 12 (2000) 2847–2855. Printed in the UK

# Theoretical approach to the Curie temperature shift in FM1/NM/FM2/SUB (ferromagnetic metal 1/nonmagnetic metal/ferromagnetic metal 2/substrate) systems

J H Wu†, T Herrmann, M Potthoff and W Nolting
Lehrstuhl Festkörpertheorie, Institut für Physik, Humboldt-Universität zu Berlin, Invalidenstrasse 110, 10115 Berlin, Germany



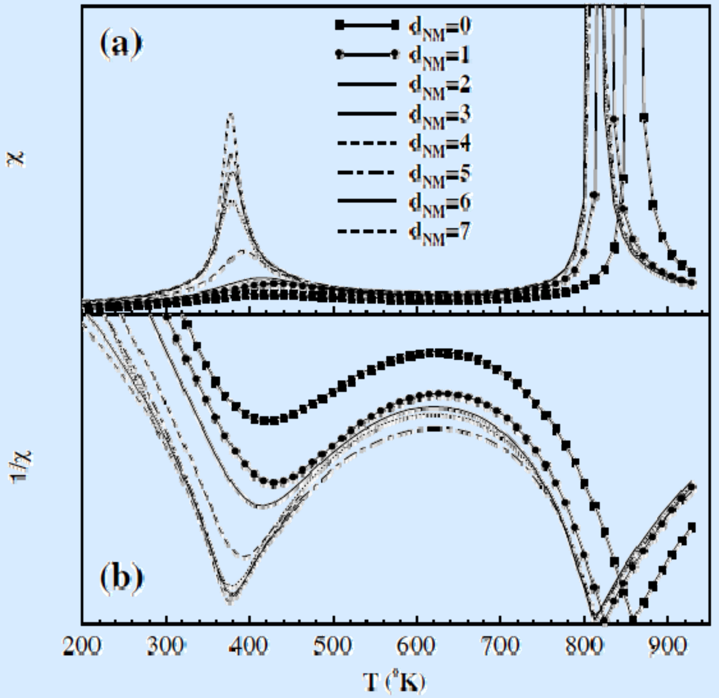
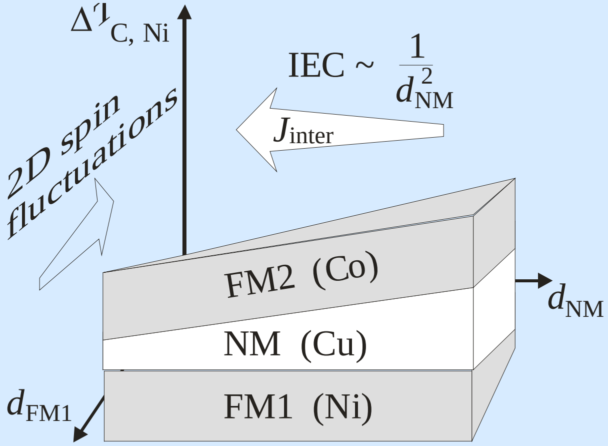
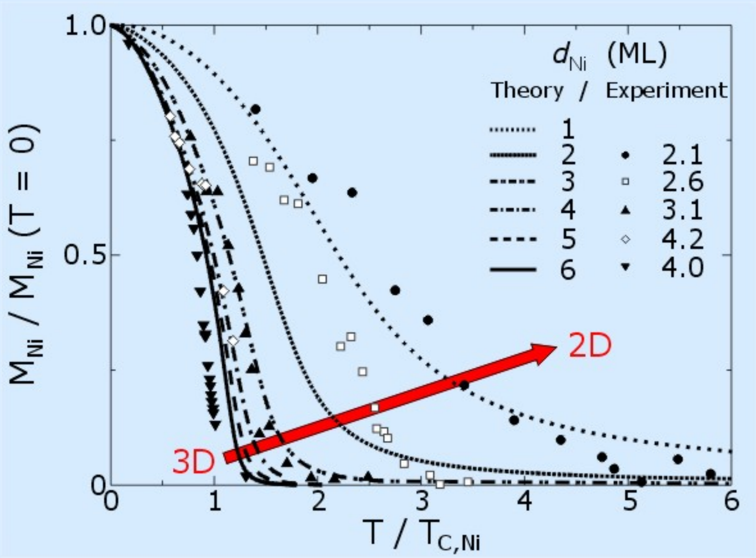


**Figure 3.** The magnetic susceptibility $\chi(T)$ (a) and its inverse (b) as functions of temperature for S1: $2/d_{NM}/4/6$ ($d_{NM} = 0, \ldots, 7$).

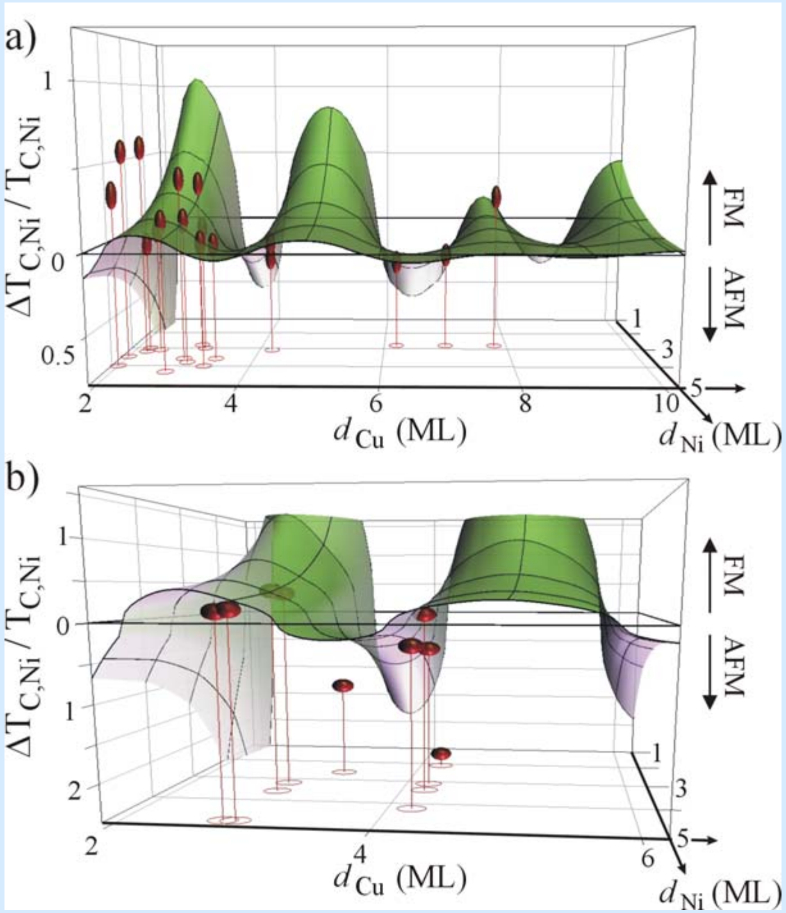
Single band Hubbard model:
“Simple Hartree-Fock ansatz is insufficient
Higher order correlations are needed to explain $T_C$-shift”

# **Evidence for giant spin fluctuations** (A. Scherz, C. Sorg et al. PRB **72**, 54447 (2005))





P. Jensen et al. PRB **60**, R14994 (1999)

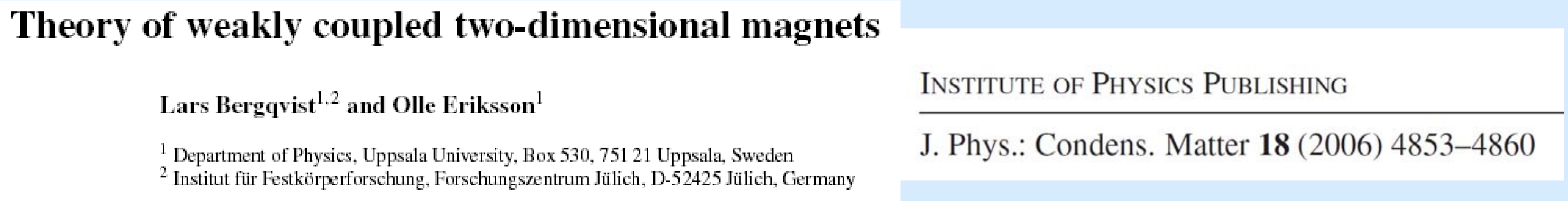


Spin-Spin correlation function $\frac{\partial}{\partial t}\langle\langle S_i^+ S_j^- \rangle\rangle \rightarrow$

$$S_i^z S_j^+ \approx \langle S_i^z \rangle S_j^+ - \langle S_i^- S_i^+ \rangle S_j^+ - \langle S_i^- S_j^+ \rangle S_i^+ + \bullet\bullet\bullet$$

$\longleftarrow$ RPA $\longrightarrow$

$\langle S_i^z \rangle S_j^+$, mean field ansatz (Stoner model) is insufficient to describe spin dynamics at interfaces of nanostructures



# Theory of weakly coupled two-dimensional magnets

Lars Bergqvist[1,2] and Olle Eriksson[1]

[1] Department of Physics, Uppsala University, Box 530, 751 21 Uppsala, Sweden
[2] Institut für Festkörperforschung, Forschungszentrum Jülich, D-52425 Jülich, Germany

INSTITUTE OF PHYSICS PUBLISHING

J. Phys.: Condens. Matter **18** (2006) 4853–4860

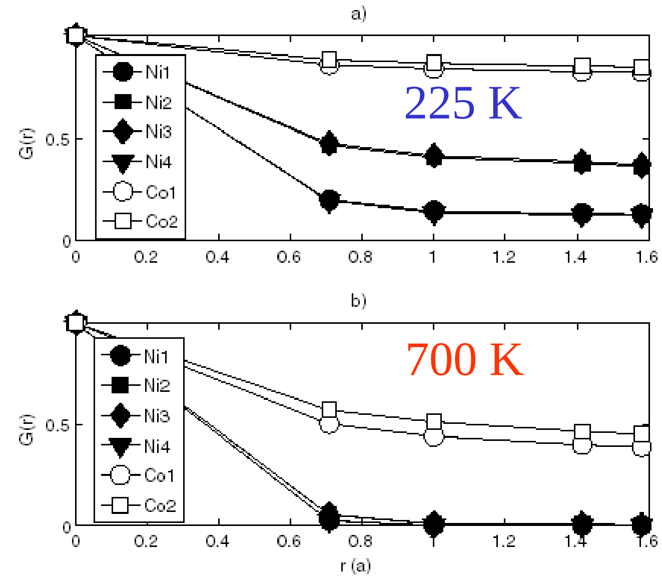


**Figure 5.** The spin–spin pair correlation function in-plane plotted as a function of distance (measured in lattice constants) of the $\mathrm{Ni_4/Cu_3/Co_2}$ trilayer system for (a) $T = 225$ K and (b) $T = 700$ K. The notation of the different layers is the same as in figure 1.

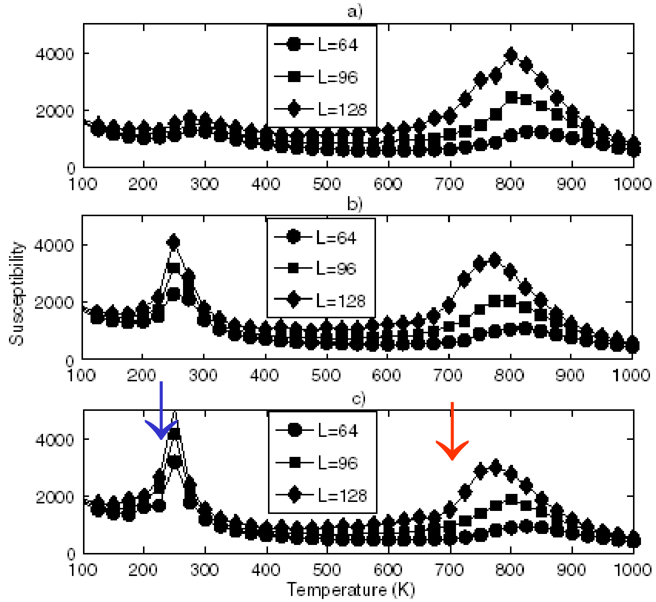
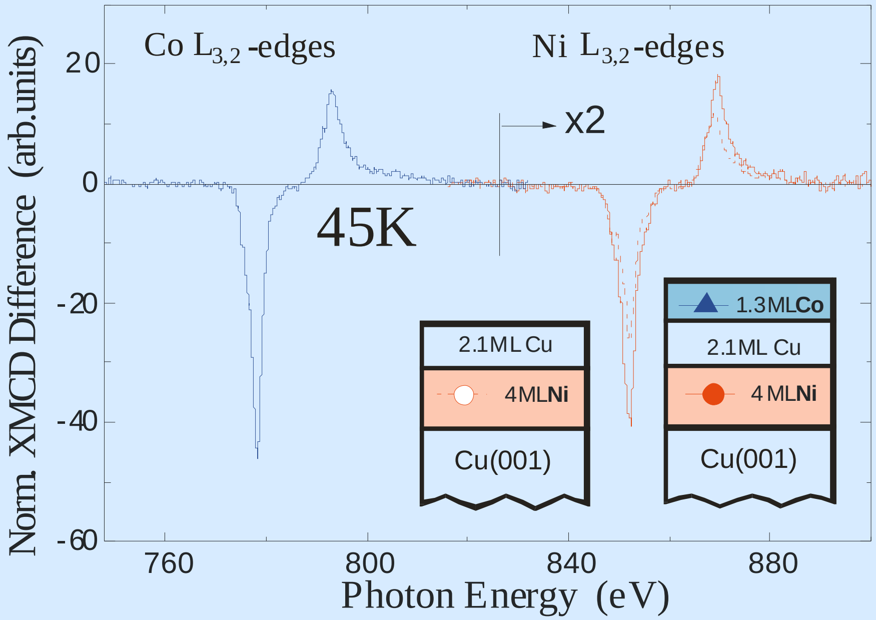


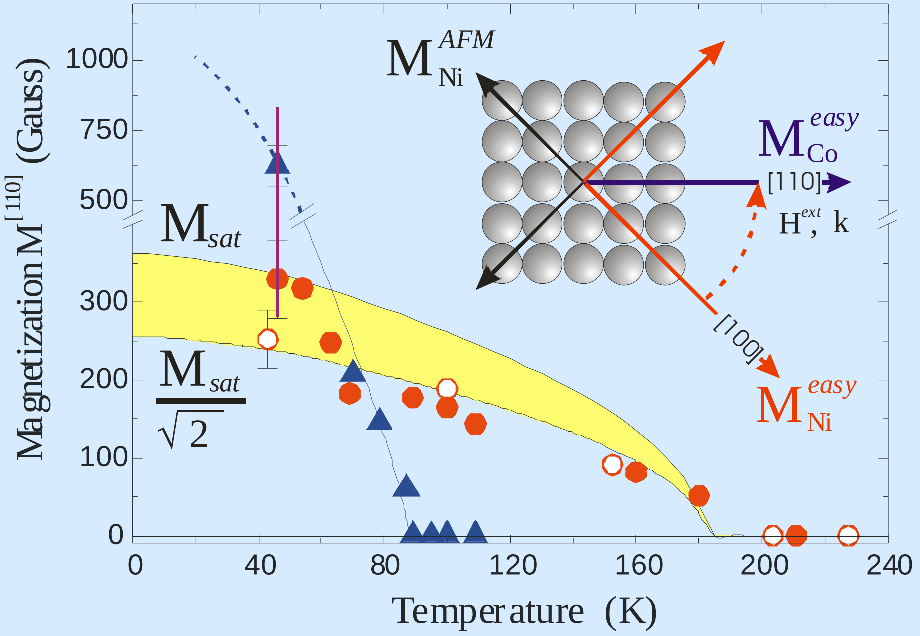
**Figure 4.** Susceptibility of the $\mathrm{Co_2/Cu_n/Ni_4}$ trilayer system for (a) $n = 1$, (b) $n = 2$ and (c) $n = 3$, plotted for three different lattice sizes (number of spins in plane is $L \times L$).

"…the peak at low temperatures is associated with the disappearance of magnetism in the Ni layers … "

"…we come to the conclusion that two distinct temperatures are relevant …and a lower temperature where the Ni spin-spin correction … undergoes an abrupt modification."

# Crossover of $M_{Co}(T)$ and $M_{Ni}(T)$





Two order parameter of $T_C^{Ni}$ and $T_C^{Co}$
A further reduction in symmetry happens at $T_c^{low}$

A. Scherz et al. J. Synchrotron Rad. **8**, 472 (2001)

L. Bergqvist, O. Eriksson J. Phys. Conds. Matter **18** ,4853 (2006)

# Interlayer exchange coupling and its T-dependence.

P. Bruno, PRB **52**, 411 (1995); V. Drchal et al. PRB **60** , 9588 (1999)

N.S. Almeida et al. PRL **75**, 733 (1995)

$$J_{inter} = J_{inter,0} \left[ \frac{T/T_0}{\sinh(T/T_0)} \right] \quad T_0 = \hbar v_F \,/\, 2\pi k_B d$$

$$J_{inter} = J_{inter,0} \left[ 1 - (T/T_C)^{3/2} \right]$$

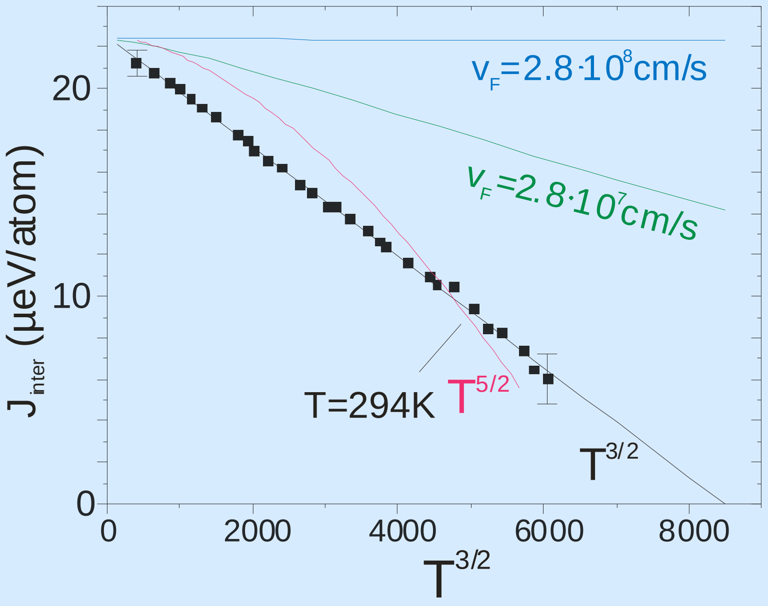
**$Ni_7Cu_9Co_2$/Cu(001)**

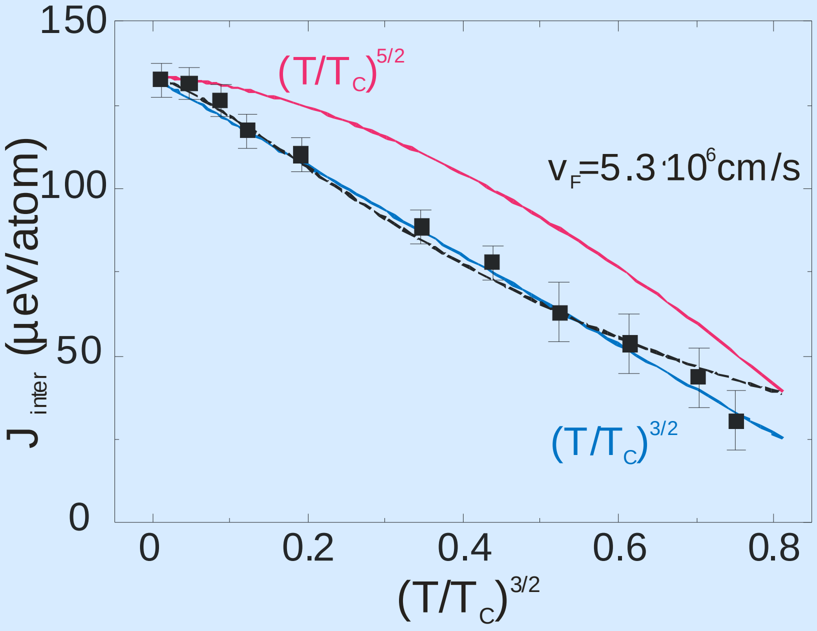
T=55K - 332K

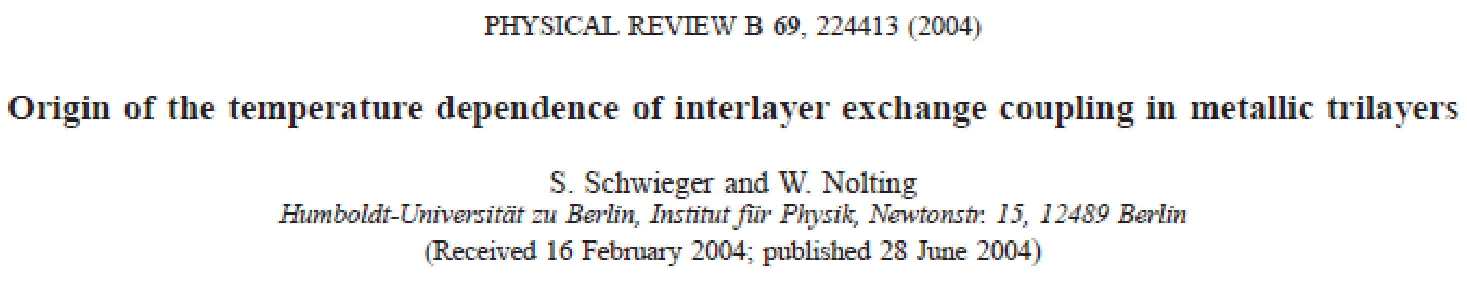
J. Lindner et al.
PRL **88**, 167206 (2002)

**$(Fe_2V_5)_{50}$**

T=15K - 252K, $T_C$=305K





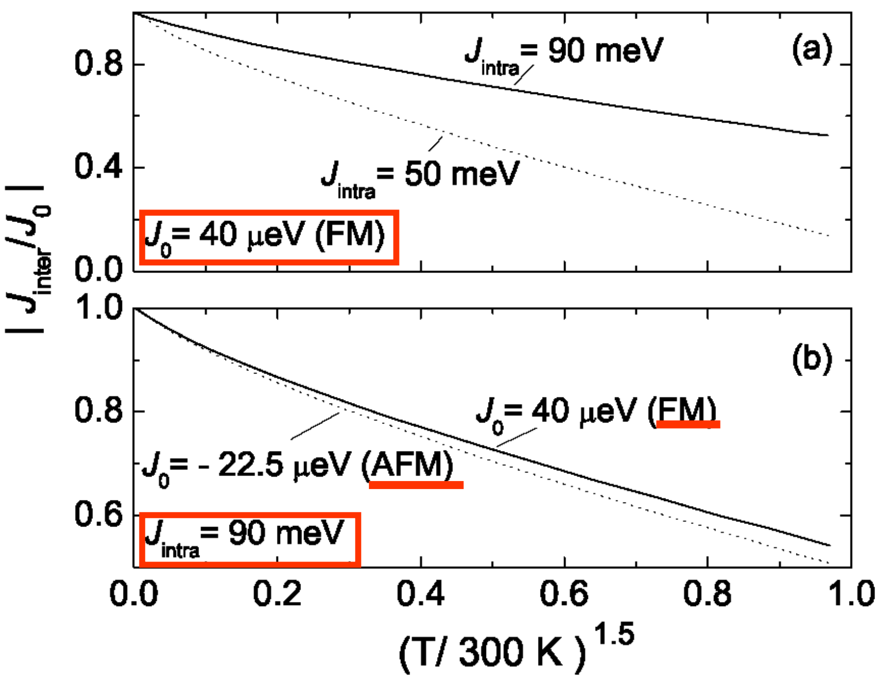


PHYSICAL REVIEW B 69, 224413 (2004)

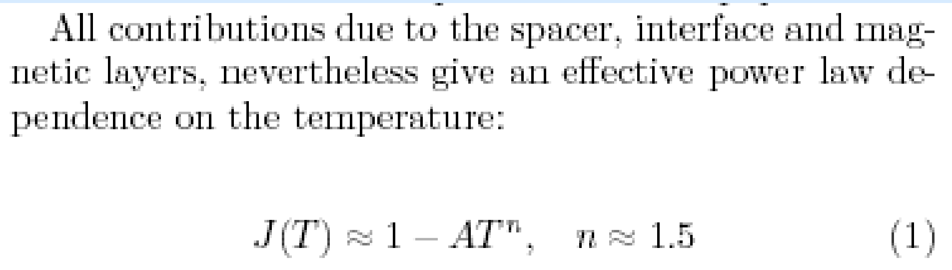
## Origin of the temperature dependence of interlayer exchange coupling in metallic trilayers

S. Schwieger and W. Nolting
*Humboldt-Universität zu Berlin, Institut für Physik, Newtonstr. 15, 12489 Berlin*

(Received 16 February 2004; published 28 June 2004)

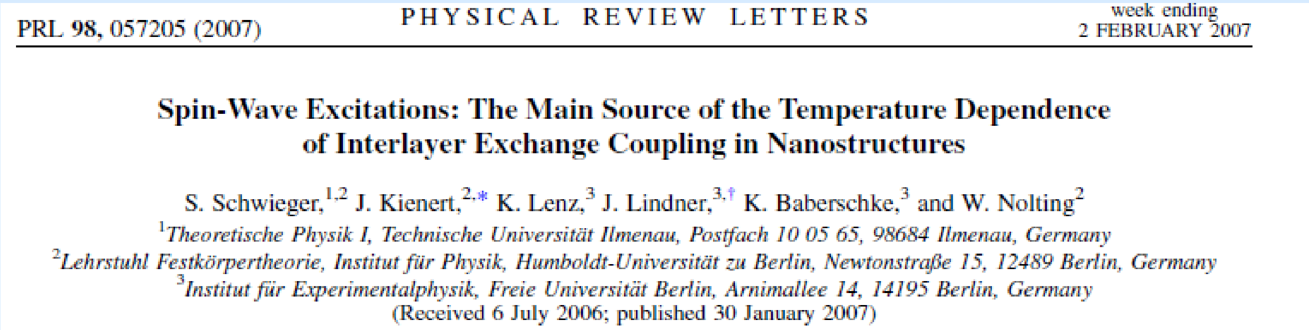


- interface
- electronic band structure
- spin wave excitation



All contributions due to the spacer, interface and magnetic layers, nevertheless give an effective power law dependence on the temperature:

$$J(T) \approx 1 - AT^n, \quad n \approx 1.5 \tag{1}$$



PRL 98, 057205 (2007) PHYSICAL REVIEW LETTERS week ending 2 FEBRUARY 2007

# Spin-Wave Excitations: The Main Source of the Temperature Dependence of Interlayer Exchange Coupling in Nanostructures

S. Schwieger,[1,2] J. Kienert,[2,*] K. Lenz,[3] J. Lindner,[3,†] K. Baberschke,[3] and W. Nolting[2]
[1]Theoretische Physik I, Technische Universität Ilmenau, Postfach 10 05 65, 98684 Ilmenau, Germany
[2]Lehrstuhl Festkörpertheorie, Institut für Physik, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin, Germany
[3]Institut für Experimentalphysik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany

(Received 6 July 2006; published 30 January 2007)

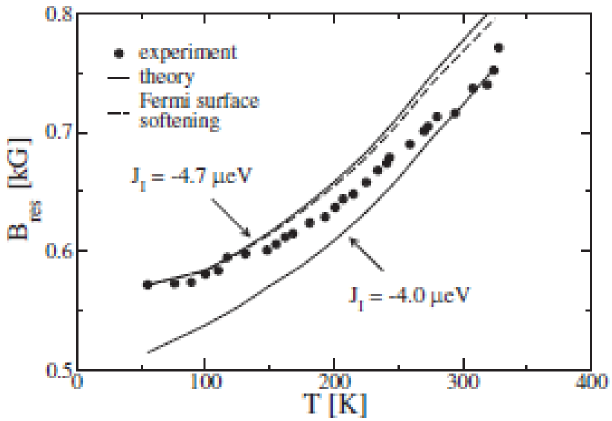
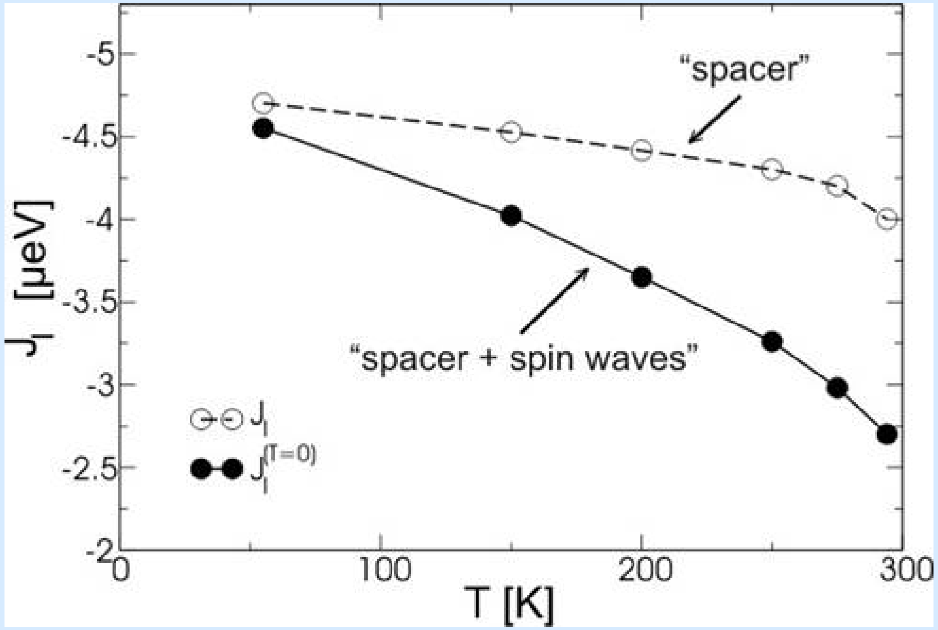
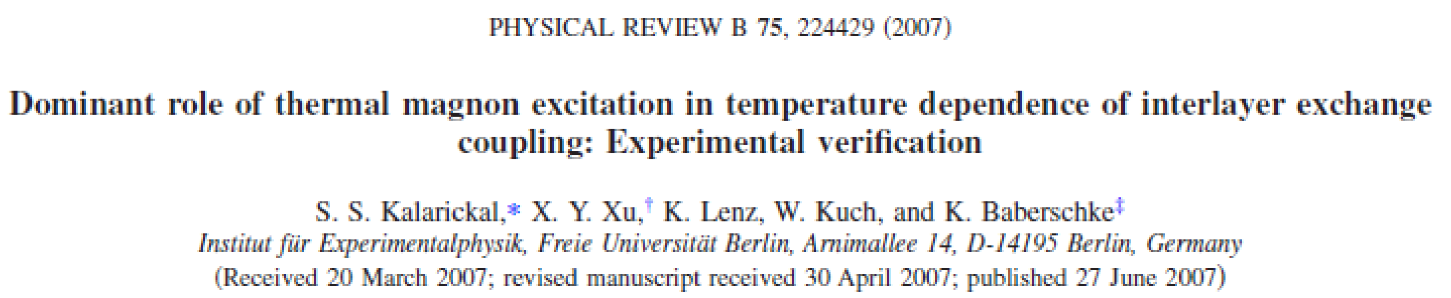


FIG. 4. Resonance field at $\theta_{B_0} = 90°$ as a function of temperature for $Ni_7/Cu_9/Co_2/Cu(001)$. Same parameters for Ni and Co as in Figs. 2 and 3. Solid line: theory considering magnetic contribution only. Dashed line: theory considering magnetic contribution and softening of the Cu Fermi surface [1].



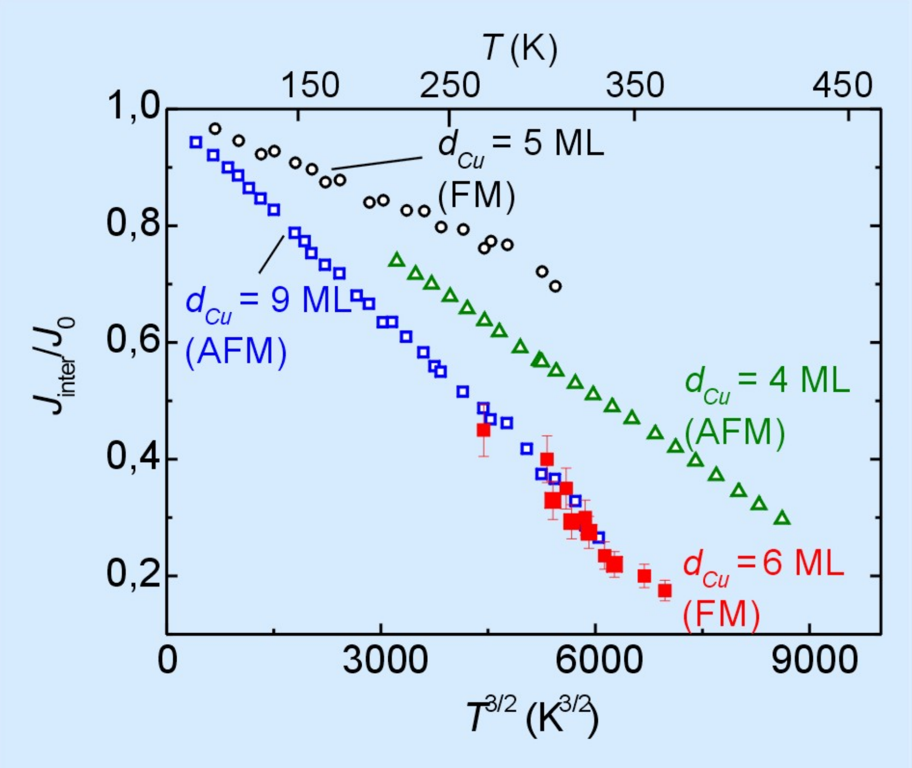


PHYSICAL REVIEW B 75, 224429 (2007)

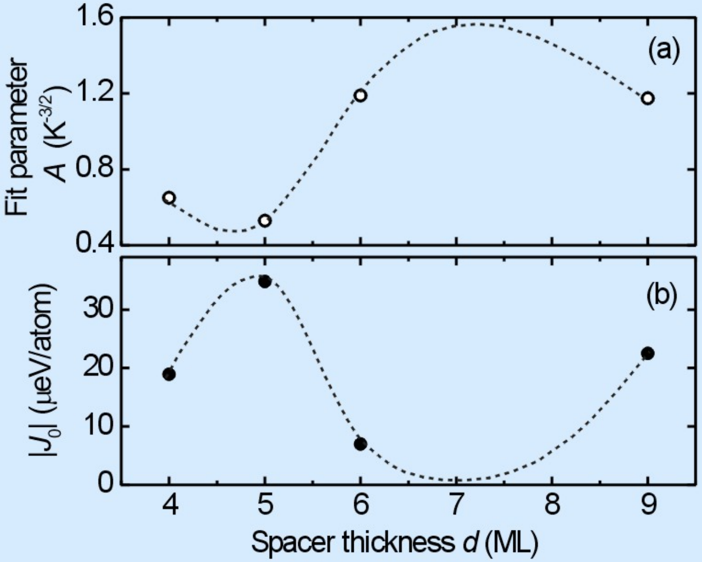
**Dominant role of thermal magnon excitation in temperature dependence of interlayer exchange coupling: Experimental verification**

S. S. Kalarickal,* X. Y. Xu,† K. Lenz, W. Kuch, and K. Baberschke‡
*Institut für Experimentalphysik, Freie Universität Berlin, Arnimallee 14, D-14195 Berlin, Germany*

(Received 20 March 2007; revised manuscript received 30 April 2007; published 27 June 2007)



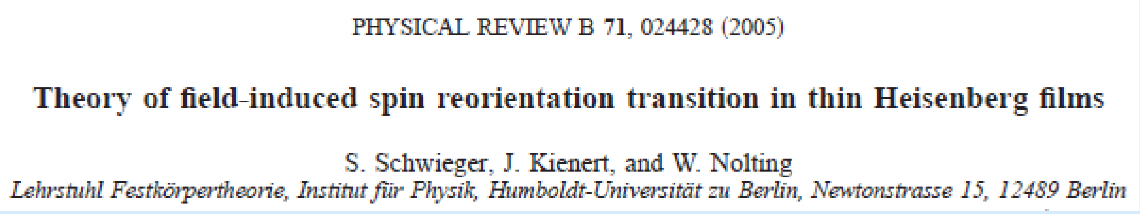
$$J(T) \approx 1 - A(d)T^n \text{, with } n \approx 1.5$$



A(d) ≠ const. (interface)

A(d) ≠ linear function (electronic bandstructure)

A(d) ≈ osc. function (spin wave excitation)



PHYSICAL REVIEW B 71, 024428 (2005)

**Theory of field-induced spin reorientation transition in thin Heisenberg films**

S. Schwieger, J. Kienert, and W. Nolting
*Lehrstuhl Festkörpertheorie, Institut für Physik, Humboldt-Universität zu Berlin, Newtonstrasse 15, 12489 Berlin*

they introduced a z’-coordinate system, to solve the Hamiltonian for arbitrary direction of external field and negative MAE, $K_2$

PHYSICAL REVIEW B 71, 174441 (2005)

**Temperature dependence of interlayer exchange coupling: Spin waves versus spacer effects**

S. Schwieger, J. Kienert, and W. Nolting
*Lehrstuhl Festkörpertheorie, Institut für Physik, Humboldt-Universität zu Berlin, Newtonstrasse 15, 12489 Berlin, Germany*

They solved the FMR equation
**not via free energy (LL equation of motion),**
but calculated explicit the “resonance frequency” (spin-wave mode) as function of external field (quasi dispersion relation).

TEMPERATURE DEPENDENCE OF INTERLAYER…

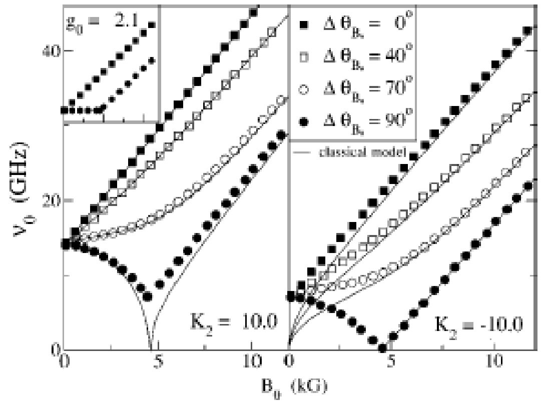


FIG. 1. The resonance frequency as a function of the external field at $T=0$ for different angles between the easy direction and the external field $\Delta\theta_{B_0}$ (symbols). Left panel: positive lattice anisotropy $K_2=10\mu_B$ kG, right panel: negative lattice anisotropy $K_2=-10\mu_B$ kG, inset: dipolar coupling $g_0=2.1\mu_B$ kG. Here and in the following pictures the spin quantum number is set to unity ($S=1$). The results of the classical model are also shown (solid lines).

There is more,
e. g. “Reorientation and $T_c$-shift”
by Körmann et al. 2008 and Rausch et al. 2009

## Willkommen bei der PGzB!

Die 1845 gegründete Physikalische Gesellschaft zu Berlin (PGzB) ist einer der ältesten wissenschaftlichen Vereine in Deutschland. Sie widmet sich der Verbreitung von physikalischer Forschung und Lehre, u.a. durch regelmäßige Vortragsveranstaltungen, unter denen die Max-von-Laue-Kolloquien höchste Bedeutung erlangt haben, sowie durch die Vergabe verschiedener Preise an hervorragende Physiker. Falls Sie die PGzB noch nicht kennen, würden wir uns freuen, Sie demnächst bei einer unserer stets interessanten Veranstaltungen begrüßen zu können

## Frühere Vorstände

| Jahr | Vorsitzender | Stellv. Vorsitzender | Geschäftsführer | Schatzmeister |
|---|---|---|---|---|
| 2008 | Martin Wilkens | Christian Thomsen | Holger Grahn | Wolfgang Gudat |
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| 2006 | Christian Thomsen | Eberhard Jaeschke | Holger Grahn | Wolfgang Gudat |
| 2005 | Eberhard Jaeschke | Wolfgang Nolting | Holger Grahn | Wolfgang Gudat |
| 2004 | Eberhard Jaeschke | Wolfgang Nolting | Heinz-Detlef Kronfeldt | Wolfgang Gudat |
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| 2002 | Wolfgang Nolting | Klaus Baberschke | Heinz-Detlef Kronfeldt | Dominique Barthel |
| 2001 | Klaus Baberschke | Wolfgang Richter | Heinz-Detlef Kronfeldt | Dominique Barthel |
| 2000 | Klaus Baberschke | Wolfgang Richter | Heinz-Detlef Kronfeldt | Dominique Barthel |

1949 - 1974 1975-1999


Physikalische Gesellschaft zu Berlin
Carl Ramsauer Preis
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für hervorragende Doktorarbeiten in Physik und angrenzenden Gebieten an den Berliner Universitäten und Potsdam
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Dr. Jürgen Schmidt, Universit
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8. Juli 2002, 17 Uhr c.t.
Invalidenstr. 42, Hörsaal
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J. Stenger HUB

K. Haberland TUB

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