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INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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SMR/697
8-Mag.Mult.

RESEARCH WORKSHOP ON CONDENSED MATTER PHYSICS
(21 June - 3 September 1993)

WORKING GROUP ON MAGNETIC MULTILAYERS
(9 - 13 August 1993)

INTERFACIAL AND INTERLAYER MAGNETIC COUPLING IN METALLIC SUPERLATTICES

PART II

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MAGNETIC PROPERTIES OF AF/F SANDWICHES AND SUPERLATTICES ✓

1 INTRODUCTION

1.1 $A_m B_n$

$A =$ Fe, Co, Ni $B =$ Cr, Mn

Some [illegible]

D. STOEFFLER; F. GAUTIER
- Prog. Th. Phys. S 101. 139 (1990)
- JMMM 121, 259 (1993)
- Phys. Rev B 44 10389 (1991)
- to be published in the Proceedings of "Magnetism in sys. of reduced dimensionality" [illegible] 1992

1.2 SENSITIVITY OF THE MAGNETIC MOMENTS TO THE MAGNETIC ORIENTATION OF THEIR NEIGHBOURHOOD

- $M(\theta)$ for helicoidal state

  for Cr $M(0 < \frac{19}{20}\pi) = 0$!

- for Mn $M(\frac{3\pi}{5} < \theta < \pi) \sim C^{te}$

2. INTERFACIAL COUPLINGS, $AF_\infty / F_n / AF_\infty$ SANDWICHES

- COLINEAR MAGNETIC DISTRIBUTION
  - P AND AP ARRANGEMENTS FOR Cr/Co, Cr/Ni, Fe/Mn
  - AP ONLY FOR Fe/Cr

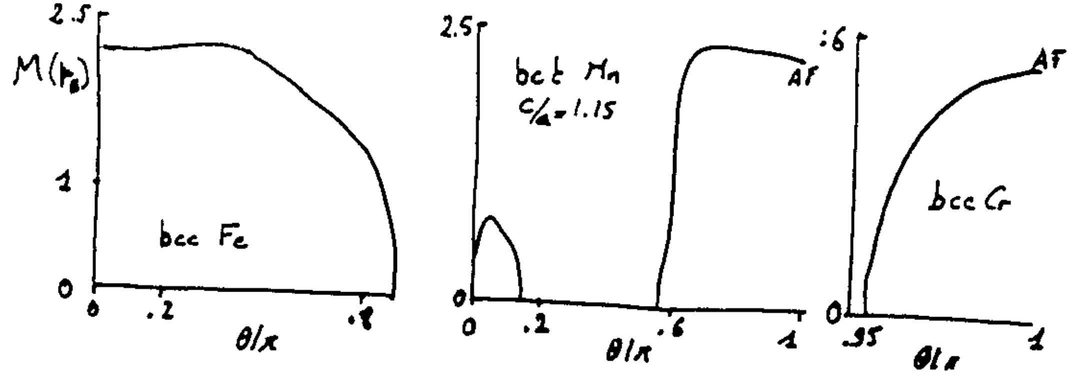
- MAGNETIZATION REVERSAL OF THE Fe LAYER LEADS TO COLINEAR MAGNETIC WALLS IN THE Cr CRYSTALS (UNPINNED MAGNETIC WALLS)

$\delta_w^{Cr} \sim 20$ ML $\qquad \gamma_w^{Cr} \sim 23$ meV

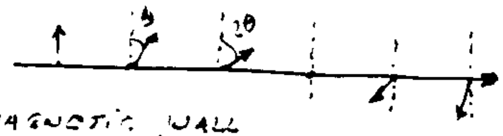
- VARIATION OF THE MAGNETIC MOMENTS DISTRIBUTION WITH RESPECT TO THE Cr / Fe DISORIENTATION.

SENSITIVITY OF THE MAGNETIC MOMENTS TO THE MAGNETIC ORIENTATION

(1)

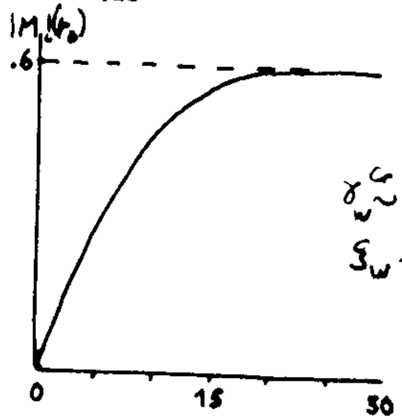


M(θ) θ tilt angle for an helicoidal state



$\theta_i = i\theta$

(2) COLINEAR MAGNETIC WALL



$\gamma_w^{Cr} \sim 19$ meV

$\delta_w \sim 20$ ML

MAGN. MOMENTS FOR COLINEAR WALL IN Cr

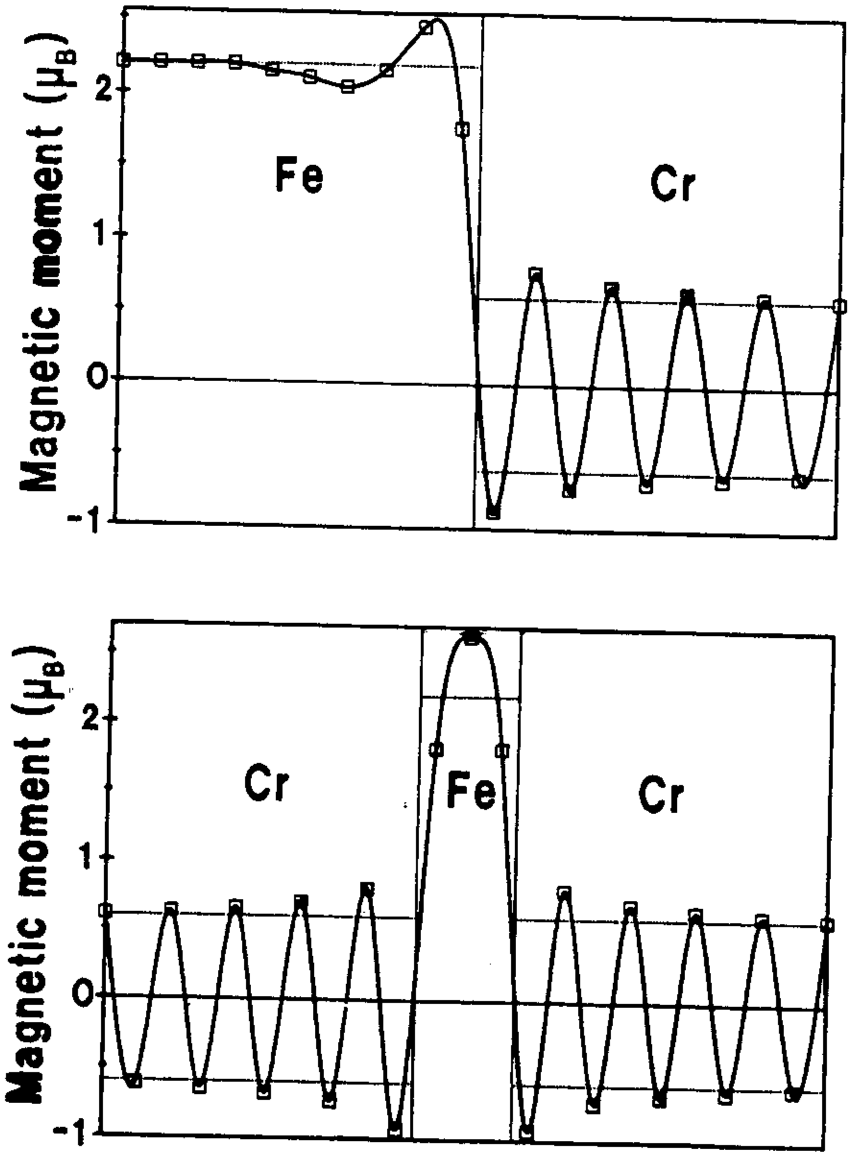
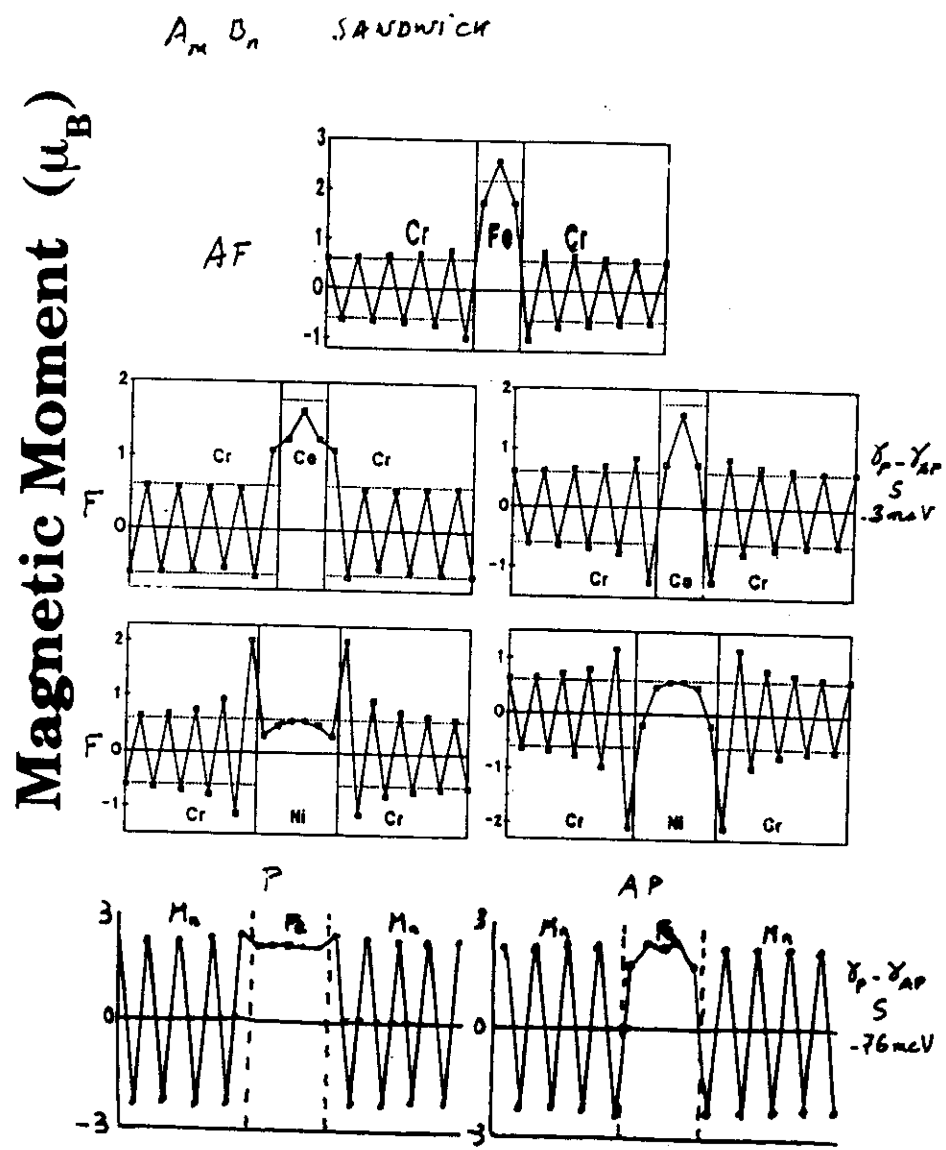
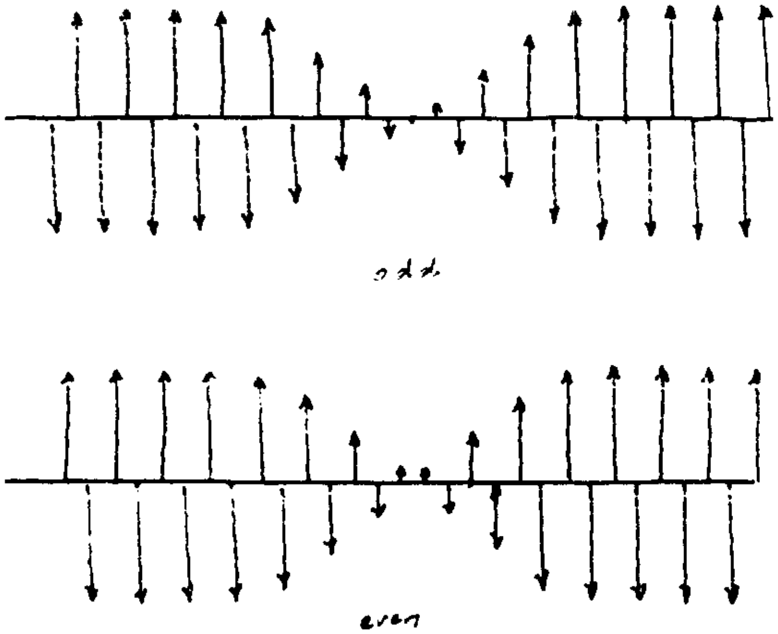


Figure 11. Magnetic moments distributions for a perfect interface between two semi-infinite crystals (upper curve) and for a iron trilayer in chromium (lower curve) with a (001) interface.



MAGNETIC ARRANGEMENTS FOR SANDWICHES

B / A_ B_



COLINEAR MAGNETIC WALL IN A.F.

COLINEAR MAGNETIC WALLS IN Cr

$$E(\{M_i\}) = \sum_i \ell(M_i) + \frac{1}{2}\sum_{i,j} J_{ij} M_i M_j$$

$$\ell(M) = \frac{AM^2}{2} + \frac{BM^4}{4}$$

$$\mu_i = (-)^i M_i \Rightarrow \mu_i^3 + \frac{A}{B}\mu_i - \frac{J}{B}(\mu_{i-1} + \mu_{i+1})$$

A = 608 meV/at   J = 309 meV   B = 28 meV/at

3 $F_\infty / AF_n / F_\infty$ SANDWICHES AND SUPERLATTICES

- THE GROUND STATE IS OBTAINED FOR MAGNETIC DISTRIBUTIONS CONSISTENT WITH THE STRONG INTERFACIAL COUPLING AND THE AF ORDER.

- WHEN THE INTERLAYER Fe MAGNETIC ORDER IS MODIFIED Cr FRUSTRATIONS LEAD TO Cr MAGNETIC MOMENT DECREASE

- CONSTRAINED MAGNETIC WALL

- COLINEAR DISTRIBUTIONS

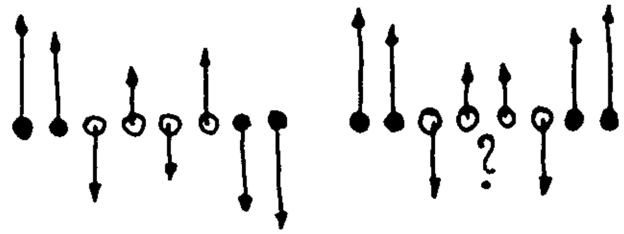
- STABILITY OF THE NCS vs C.S.

- QUADRATIC vs BIQUADRATIC CONTRIBUTIONS

F/AF/F MULTILAYERS AND SANDWICHES

$Fe\, Cr_n\, Fe$
$Fe\, Mn_n\, Fe$

AF F



n = 4

● Fe ○ Cr

the F interlayer magnetic arrangement gives rise to a frustration of the Cr AF order for even n values

Distribution of the magnetic moments amplitudes and directions ?

Structure of the constrained magnetic wall in the AF spacer ?

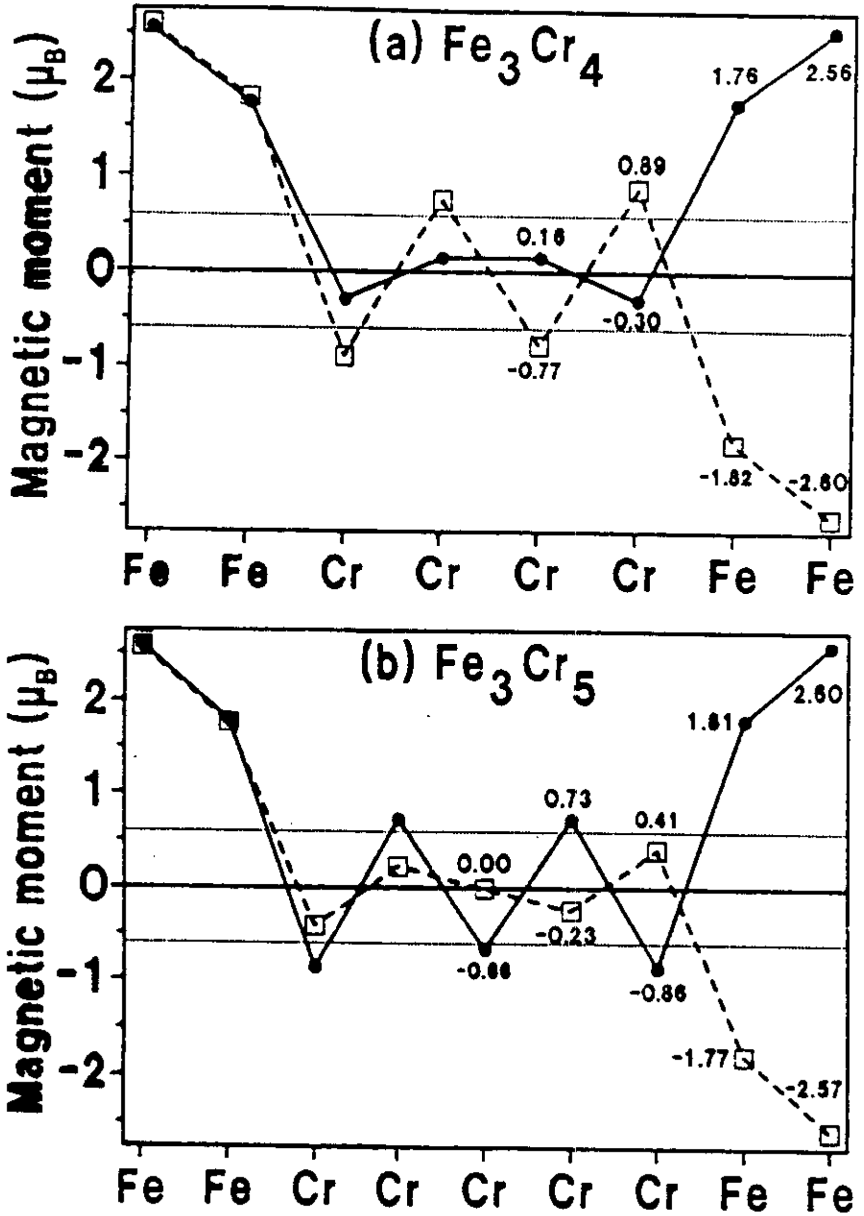


Figure 9. Magnetic moments distributions for (a) Fe_3Cr_4 and (b) Fe_3Cr_5 in the Ferromagnetic (F) (full line) and AntiFerromagnetic (AF) (dashed line) cases.

The GROUND STATE IS AF FOR EVEN n_{Cr}
F " ODD "

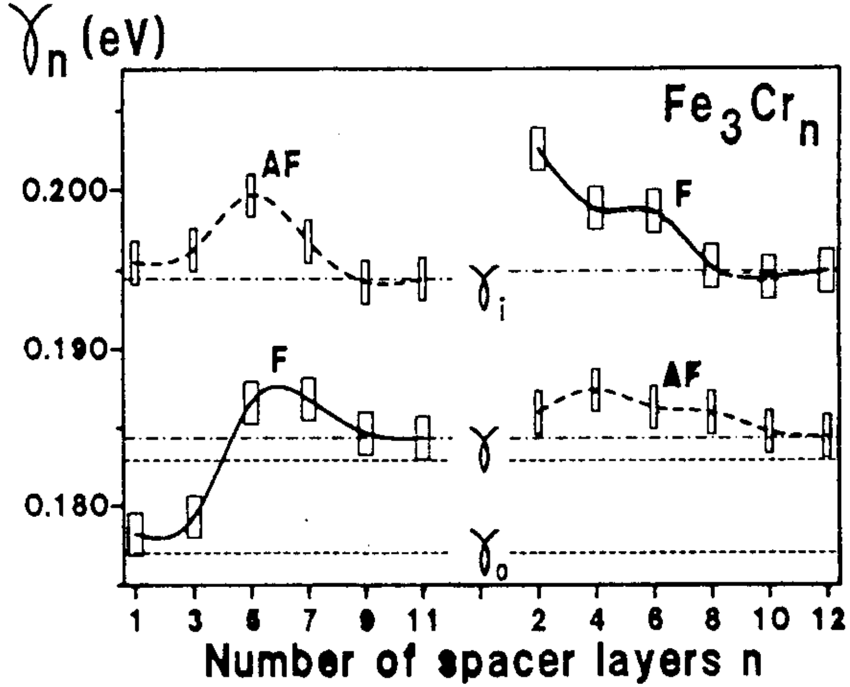
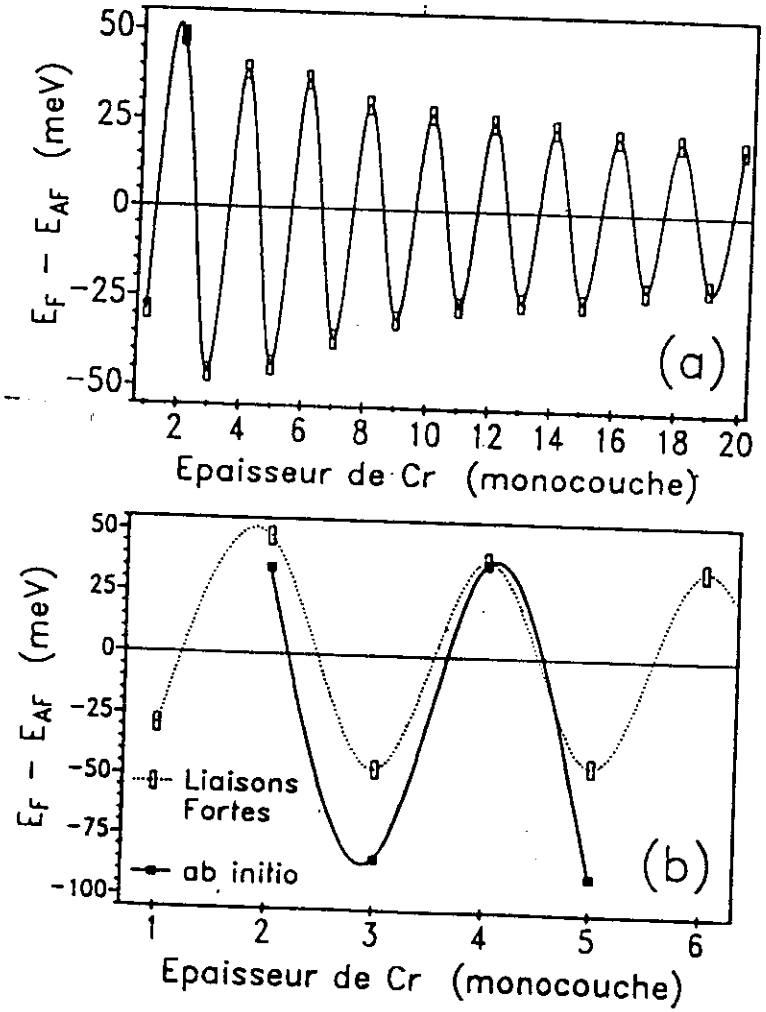
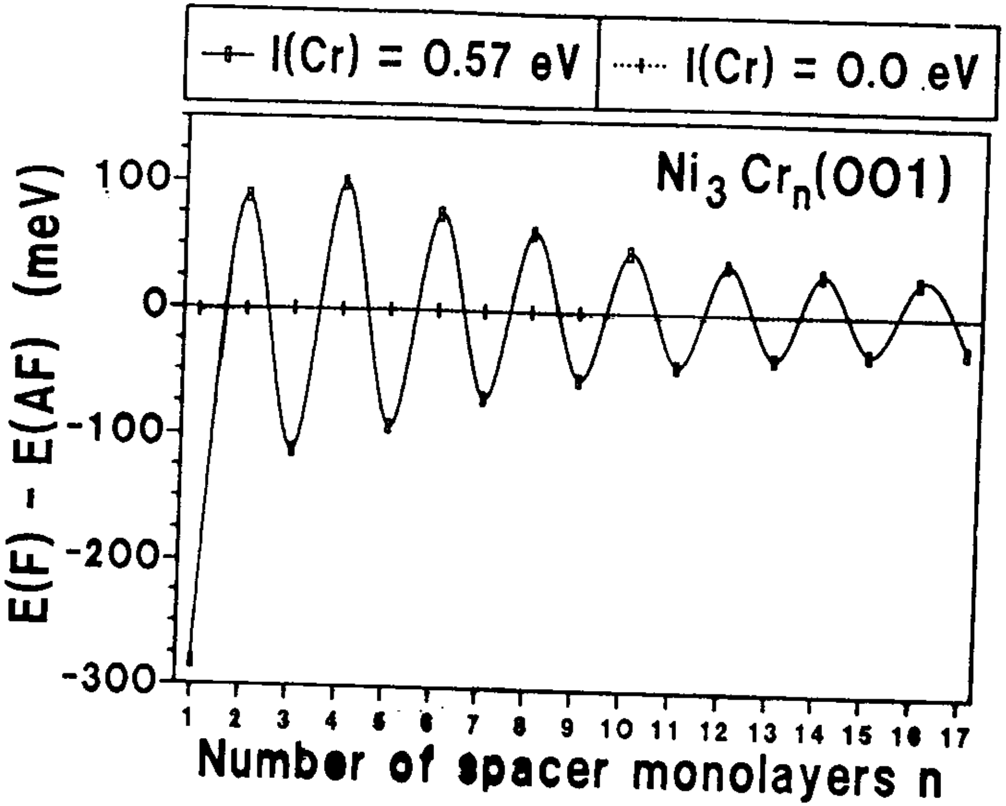


Figure 12. Interface energy γ_n as a function of the spacer thickness parity for the F and AF cases. The dash-dotted lines gives approximately the limits γ_i (i = even or odd) for $n \to \infty$. The dashed lines give the interface energies γ_0 for a perfect Fe/Cr(001) interface between two semi-infinite crystals and for a perfect iron trilayer in chromium $Cr/Fe_3/Cr(001)$.

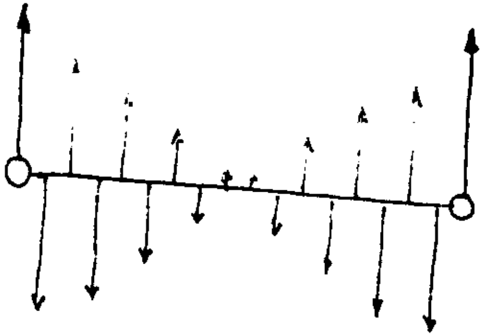
WITHOUT DEFECT $\gamma_n^F \to \gamma_n^{AF}$ $n \to \infty$

WITH DEFECT $\gamma_n^F \sim \gamma^{AF}$

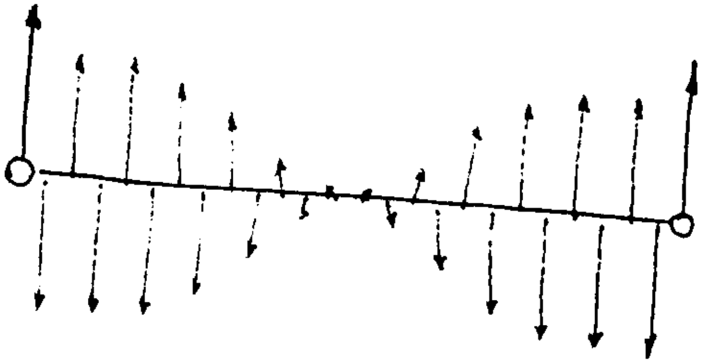




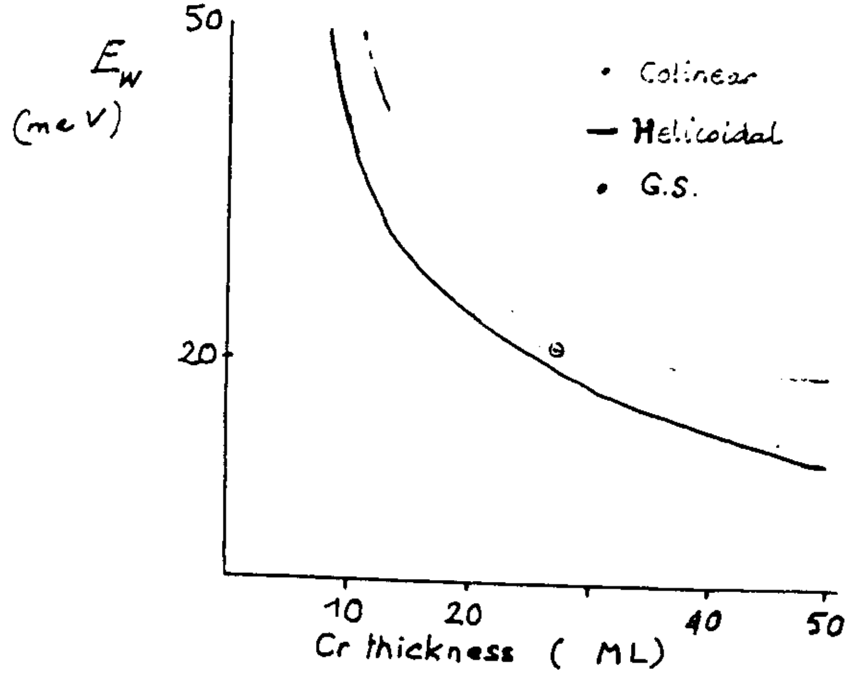
▯ LF (Stoeffler + F.G. 1990)



CONSTRAINED COLINEAR MAGNETIC WALL

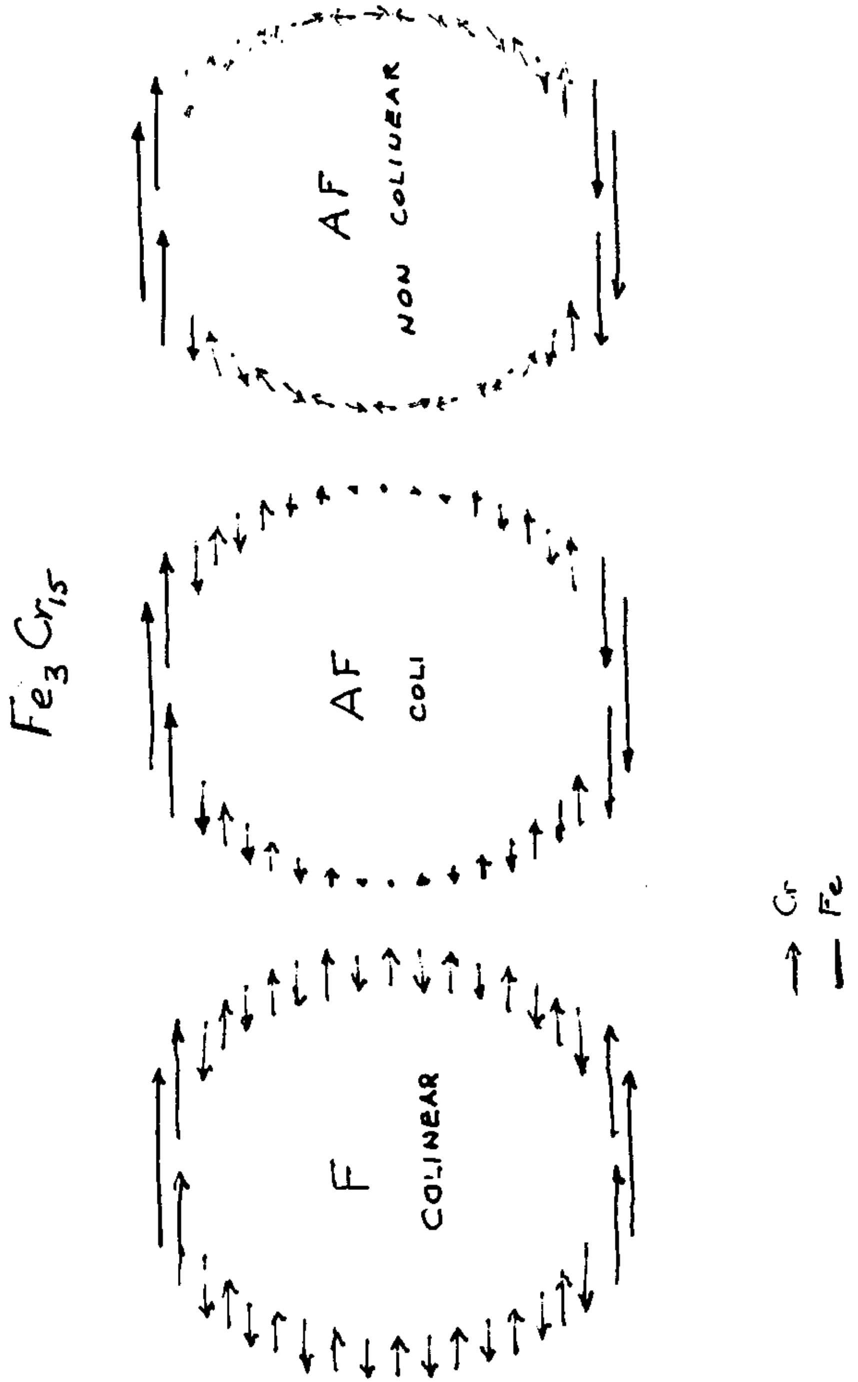


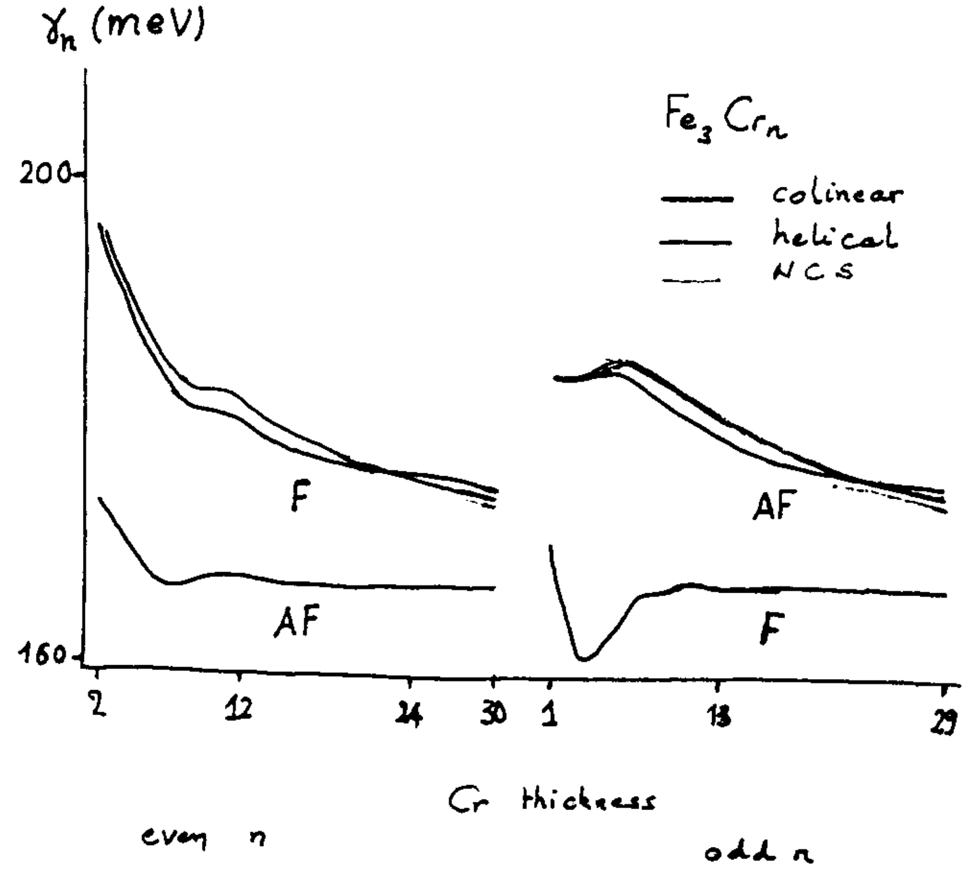
NON COLINEAR MAGNETIC WALL with strong reduction of the moments at the center of the film



$Fe_{\infty}\, Cr_n\, Fe_{\infty}$

A cross over between colinear and helicoidal walls occurs for $n_c = 27$ ($\theta = \pi$)

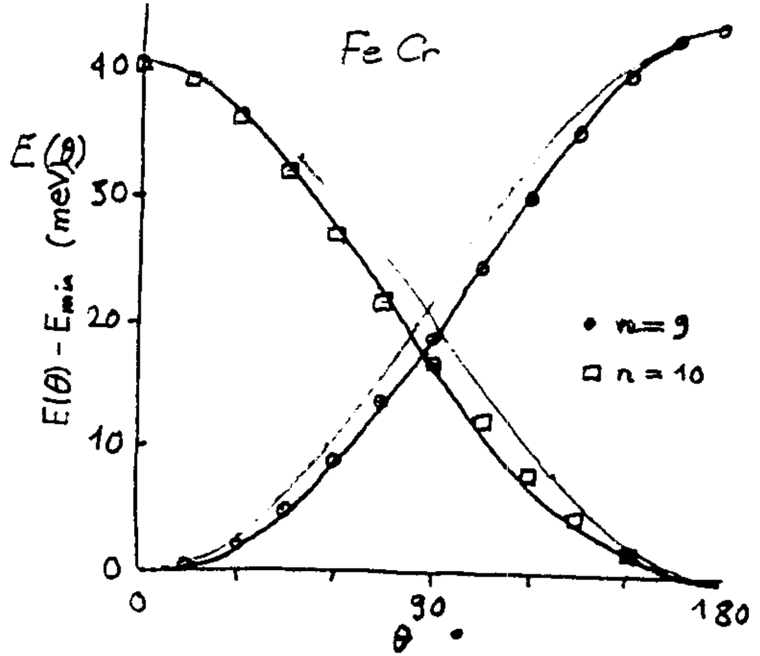




$$\gamma_n = (E(A_m B_n) - m E_A^\circ - n E_B^\circ)/2$$

QUADRATIC AND BIQUADRATIC

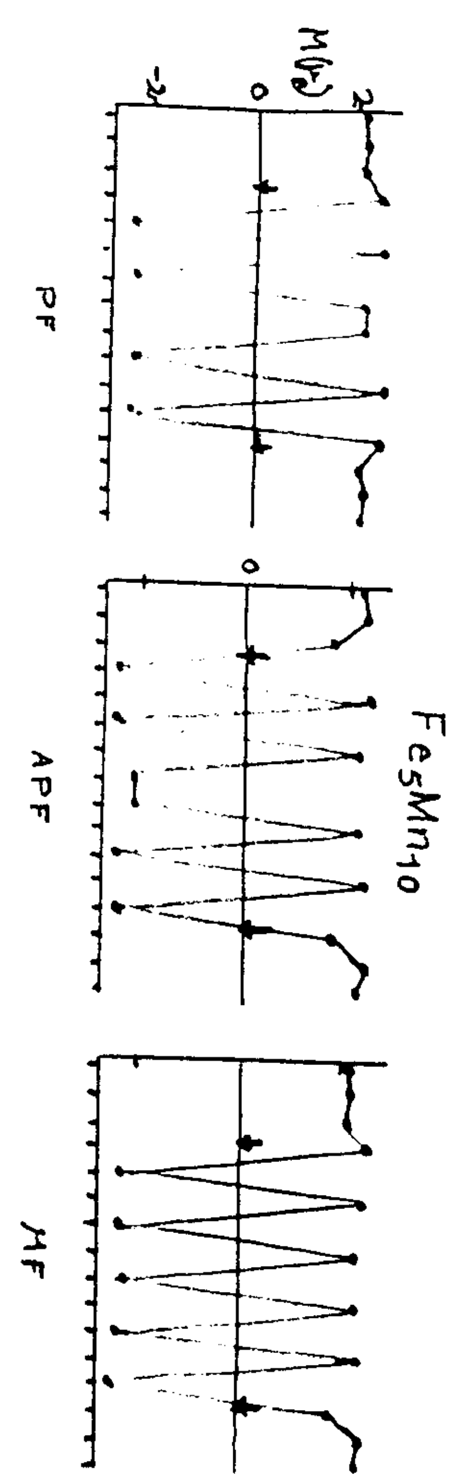
COUPLINGS

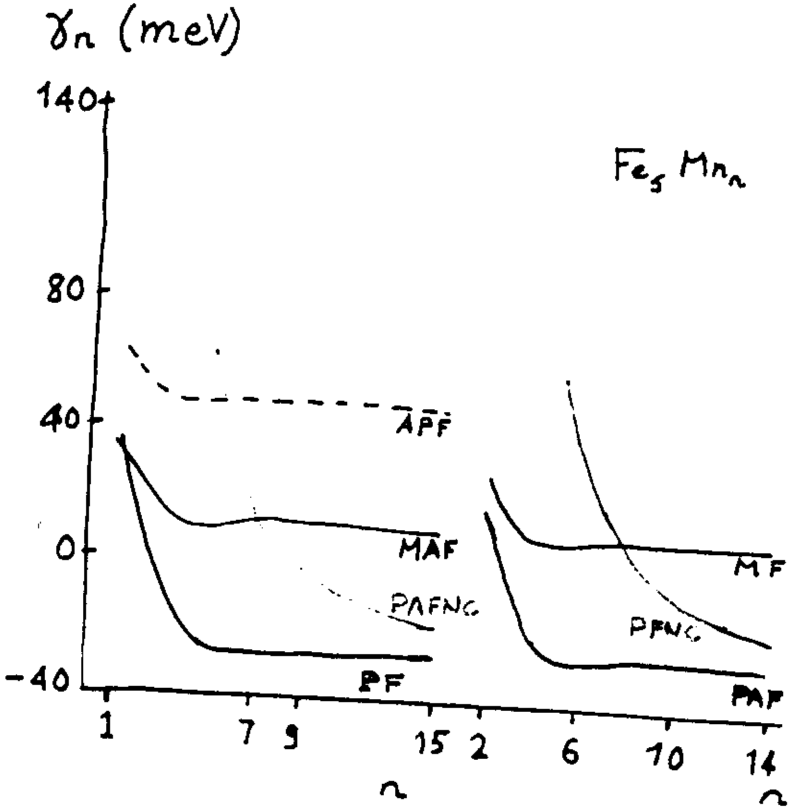


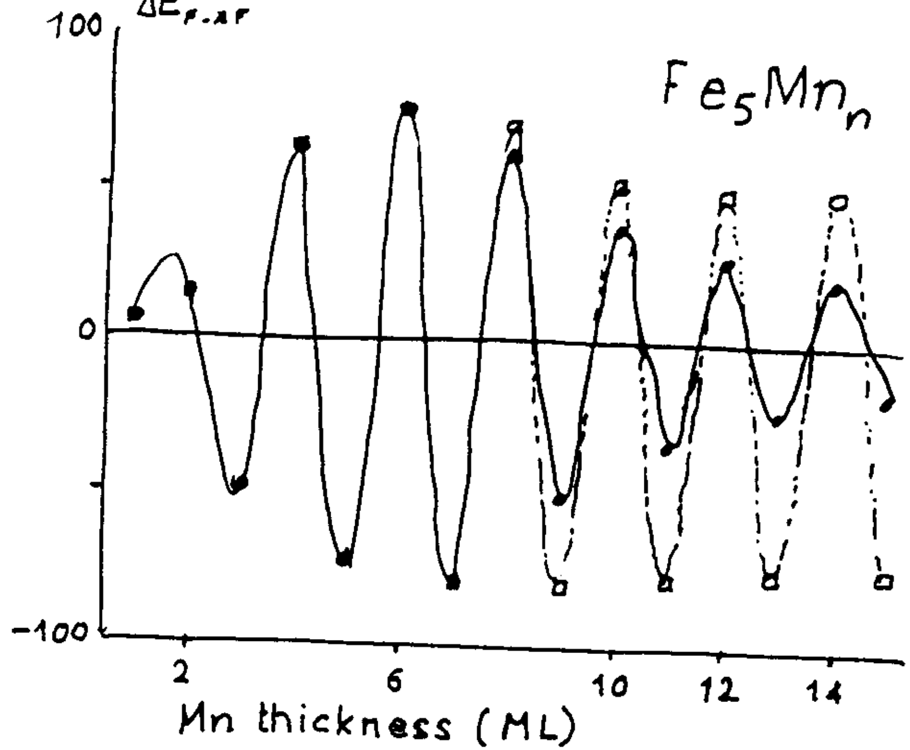
$$\Delta E(\theta) = \Delta E_0 + \alpha \cos\theta - \beta \sin^2\theta$$

$\beta > 0$

$\beta / |\alpha| \sim 15\,\%$







$n_c = 7$

--- COLINEAR

— NON COLINEAR

{ P parallel, AP antiparallel, M mixed } interfacial coupling

{ F, AF } interlayer magnetic arrangement

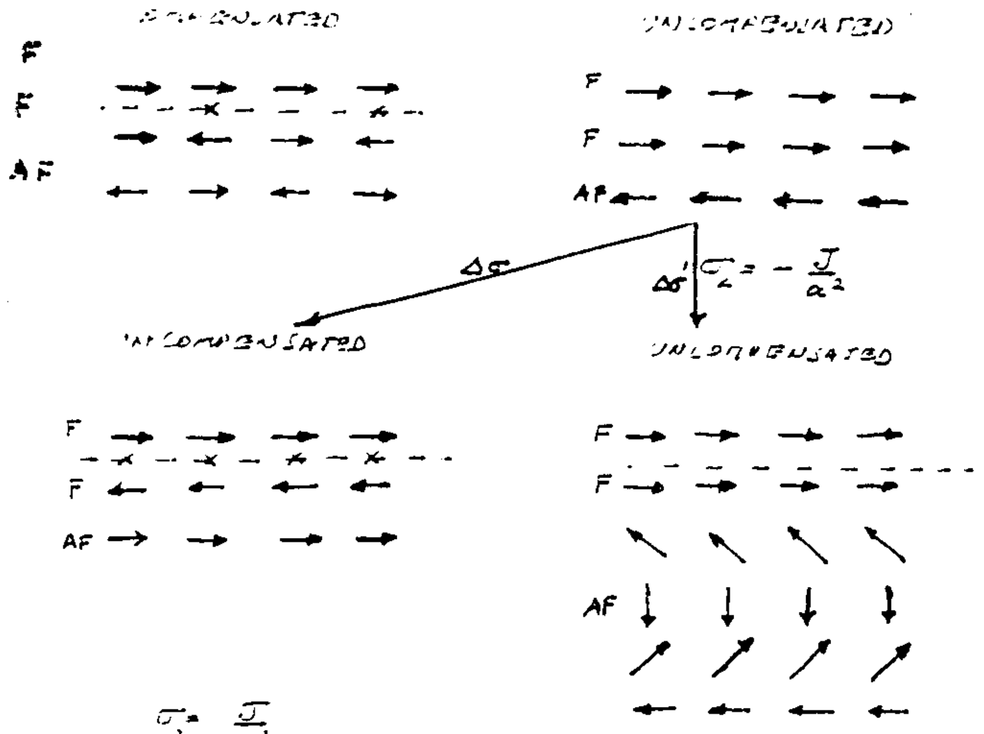
NC non colinear.

EXCHANGE OF STABILITY BETWEEN COLINEAR AND NC

4 NON IDEAL INTERFACES AND EXCHANGE ANISOTROPY FOR F/AF INTERFACES

- EXCHANGE ANISOTROPY AND PINNED MAGNETIC WALLS (Malozemoff)
- HERE WE CONSIDER AF/F/AF SANDWICHES
- FOR Cr/Fe INTERFACES THERE IS NO PINNED MAGNETIC WALLS AT THE INTERFACES WHEN THEY ARE PERFECT
- FOR NON IDEAL INTERFACES SUCH A PINNING CAN EXIST AND $\Delta\gamma$ CAN BE REDUCED TO SOME meV/at.

⇒ ENERGY NEEDED TO REVERSE THE FERRO MAGN % AF MAGN



$\sigma_3 = \frac{J}{a^2}$

$\sigma_4 = -\frac{J}{a^2} + 4\sqrt{AK}$

$A \sim \frac{J}{2}$ AF

K_A

1 → 3 $\quad \Delta\sigma = \frac{2J}{a^2}$

2 → 4 $\quad \Delta\sigma' = 4\sqrt{AK}$

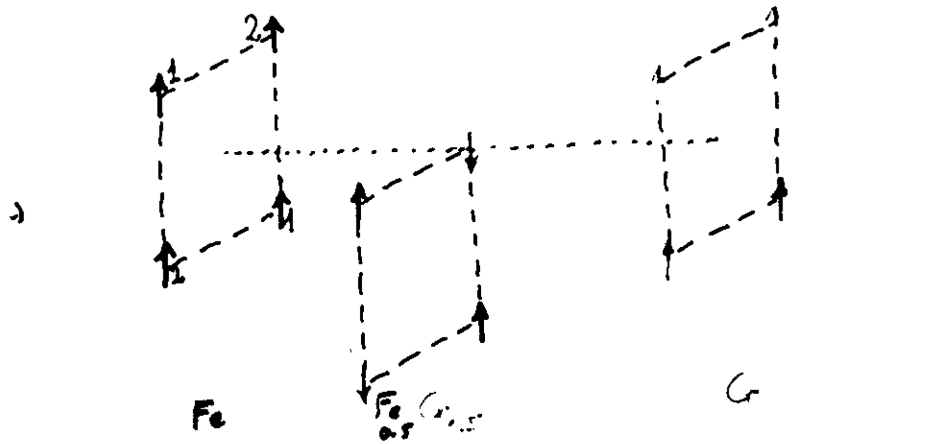
EXCHANGE ANISOTROPY FIELD

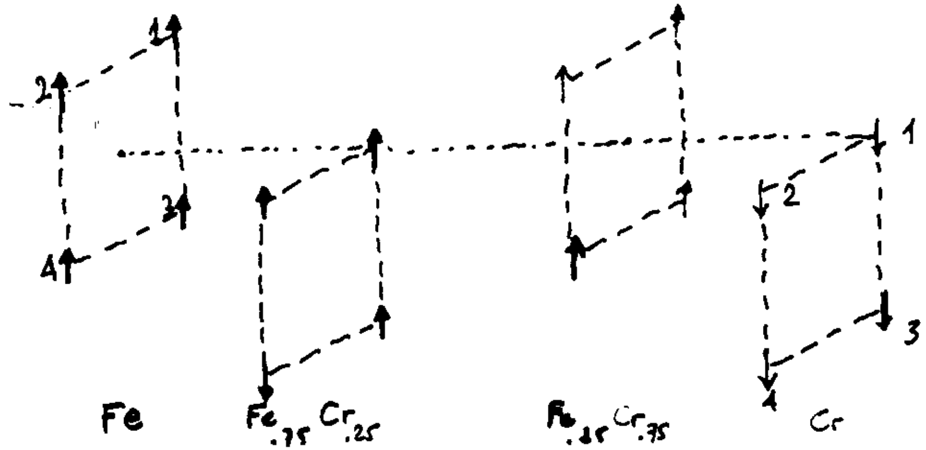
$$H_E = \frac{\Delta\sigma}{2 M_s t_F}$$

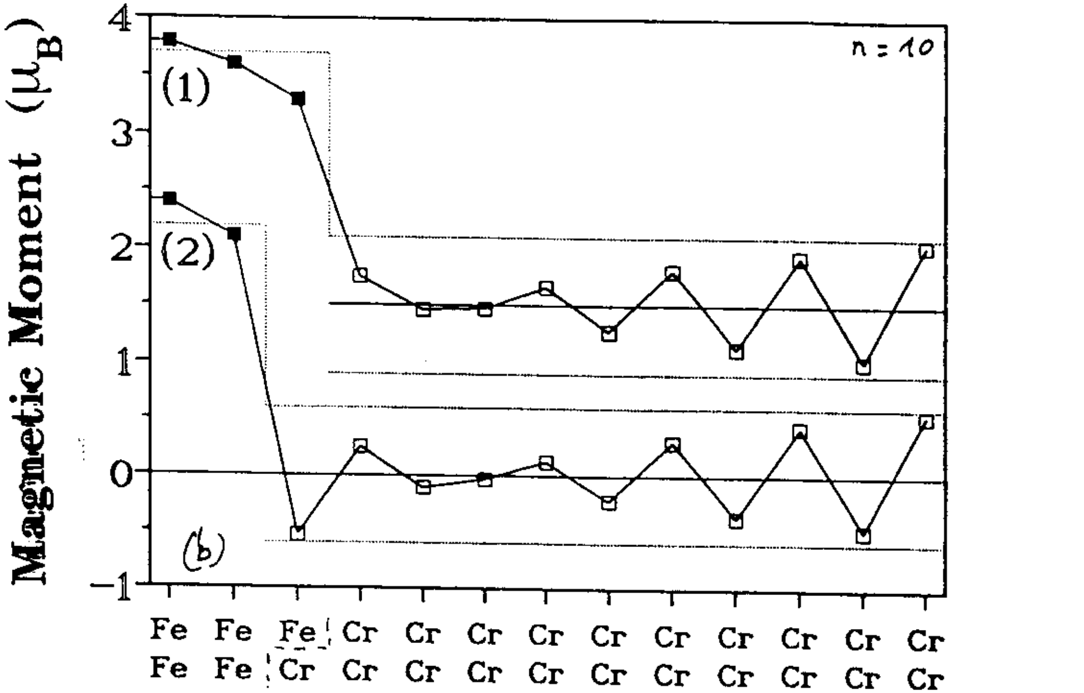
M_s MAGNETIZATION
t_F THICKNESS
FERROMAGNET

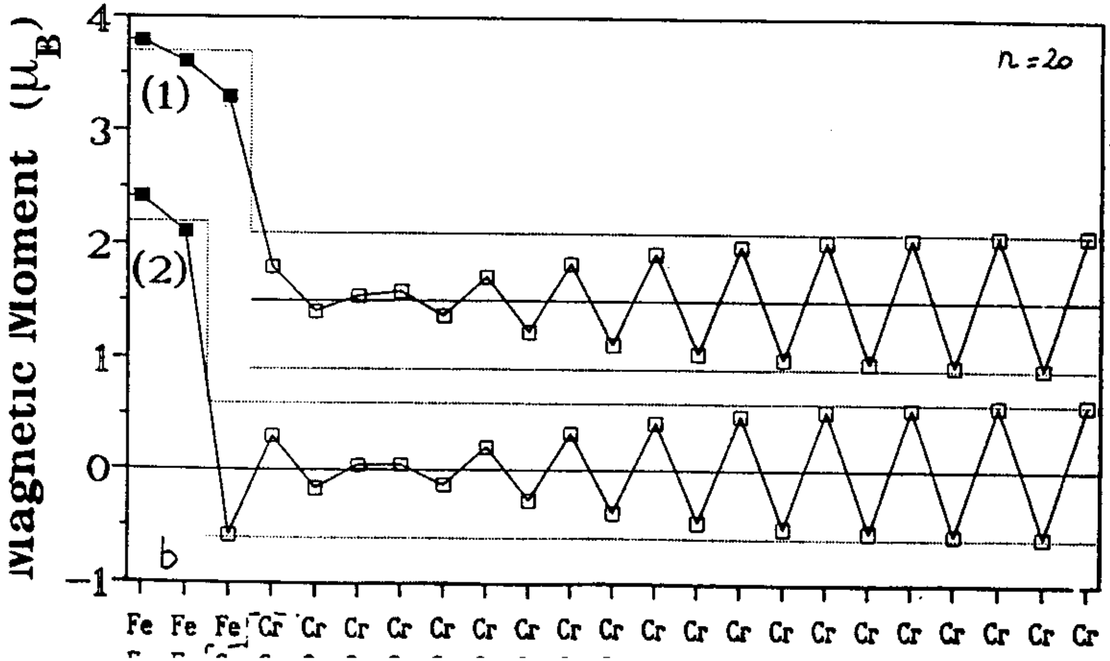
- Ti de l'ordre de grandeur de J a priori

SANDWICH Cr/Fe5/Cr
PINNING OF A MAGNETIC INTERFACIAL DEFECT

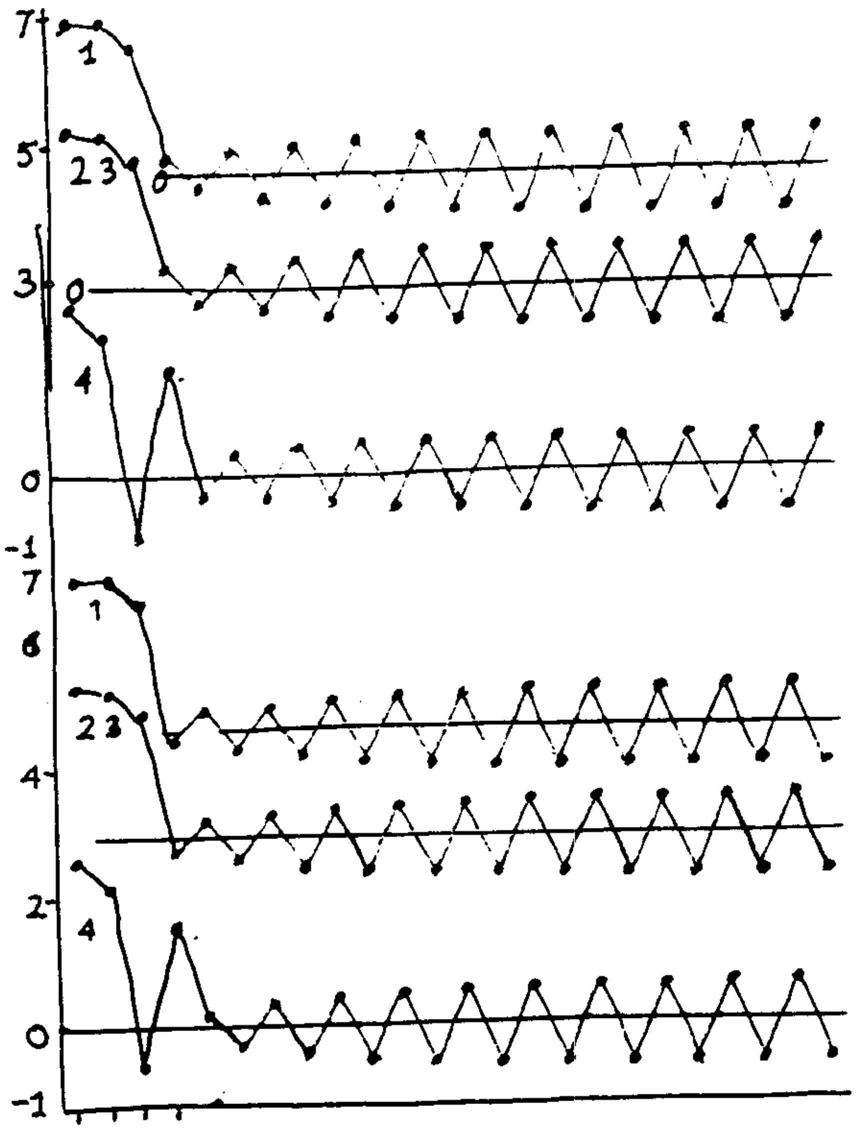








$Cr_{\infty}\ Fe_5\ Cr_{\infty}$

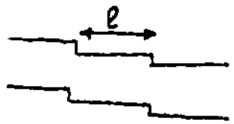


I. O. C (b) $[Fe_{0.75}\,Cr_{0.25}][Fe_{0.25}\,Cr_{0.75}]$

- THE MAGNETIC MOMENTS DISTRIBUTIONS ARE SIMILAR
- EXCHANGE ANISOTROPY ~ 1 meV / at

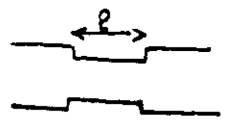
5. IMC AND INTERFACIAL IMPERFECTIONS

- STEPS



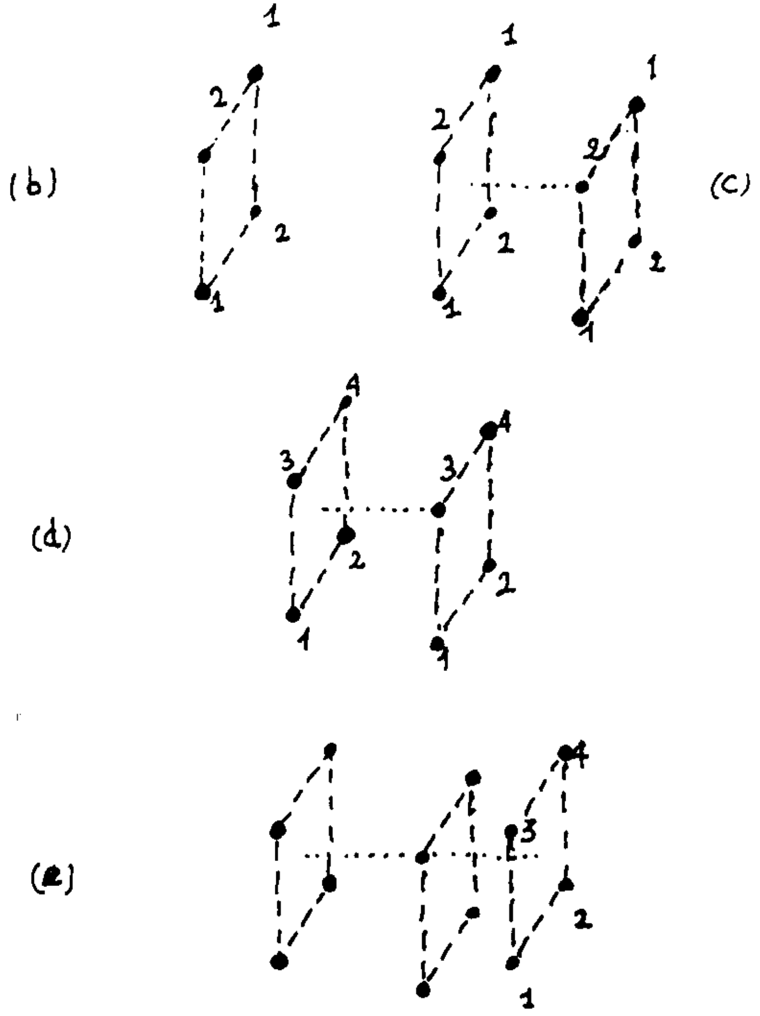
ex Co Ru

- ROUGHNESS



- INTERFACIAL ORDERED COMPOUNDS (at. scale) can strongly reduce the IMC own magnetic frustrations.

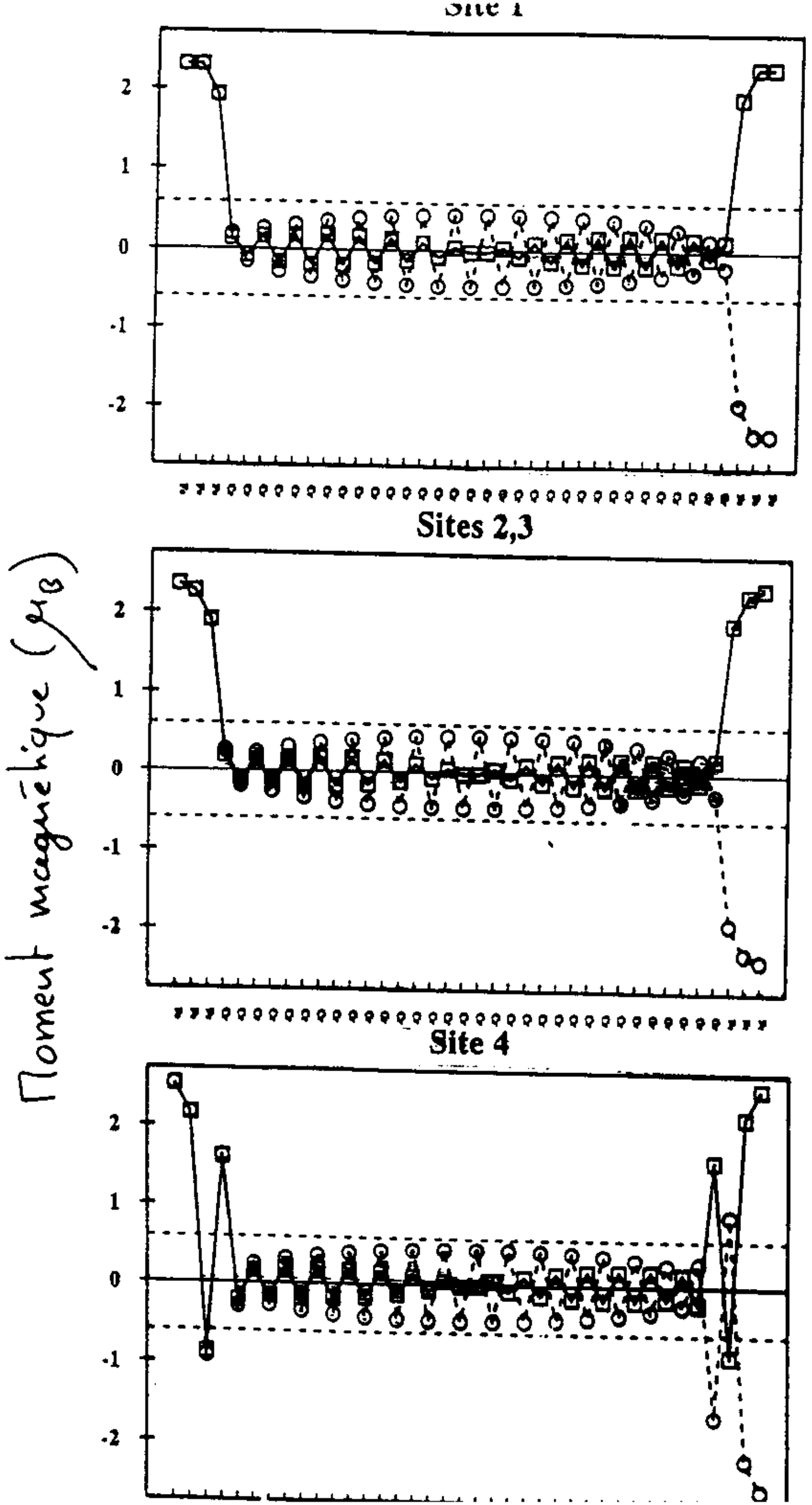
Fe Cr OK



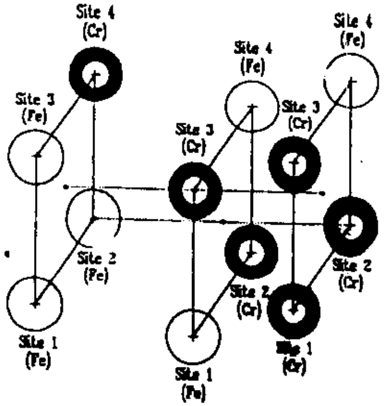
I.O.C.

Cas d.

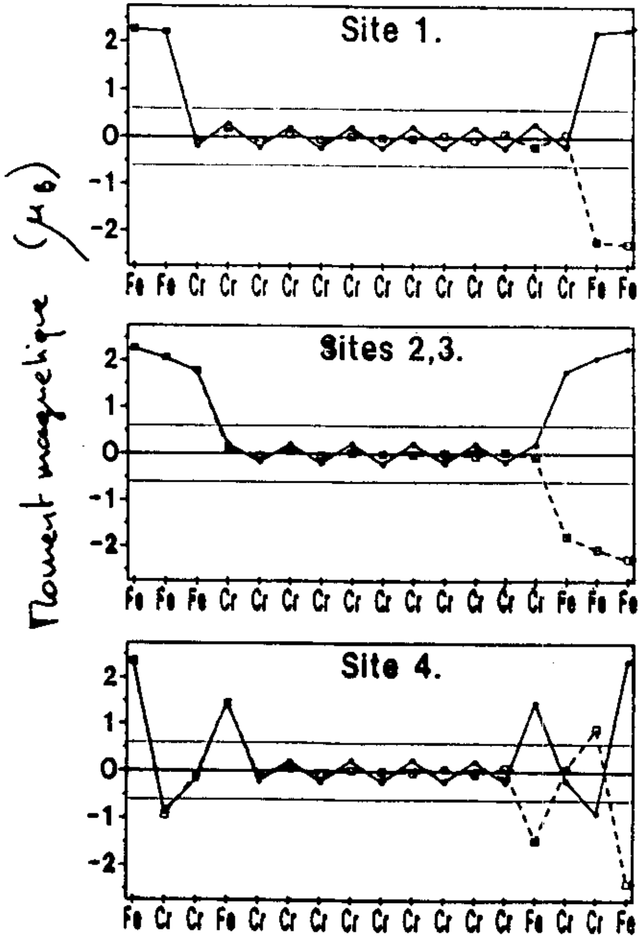
(n= 30)

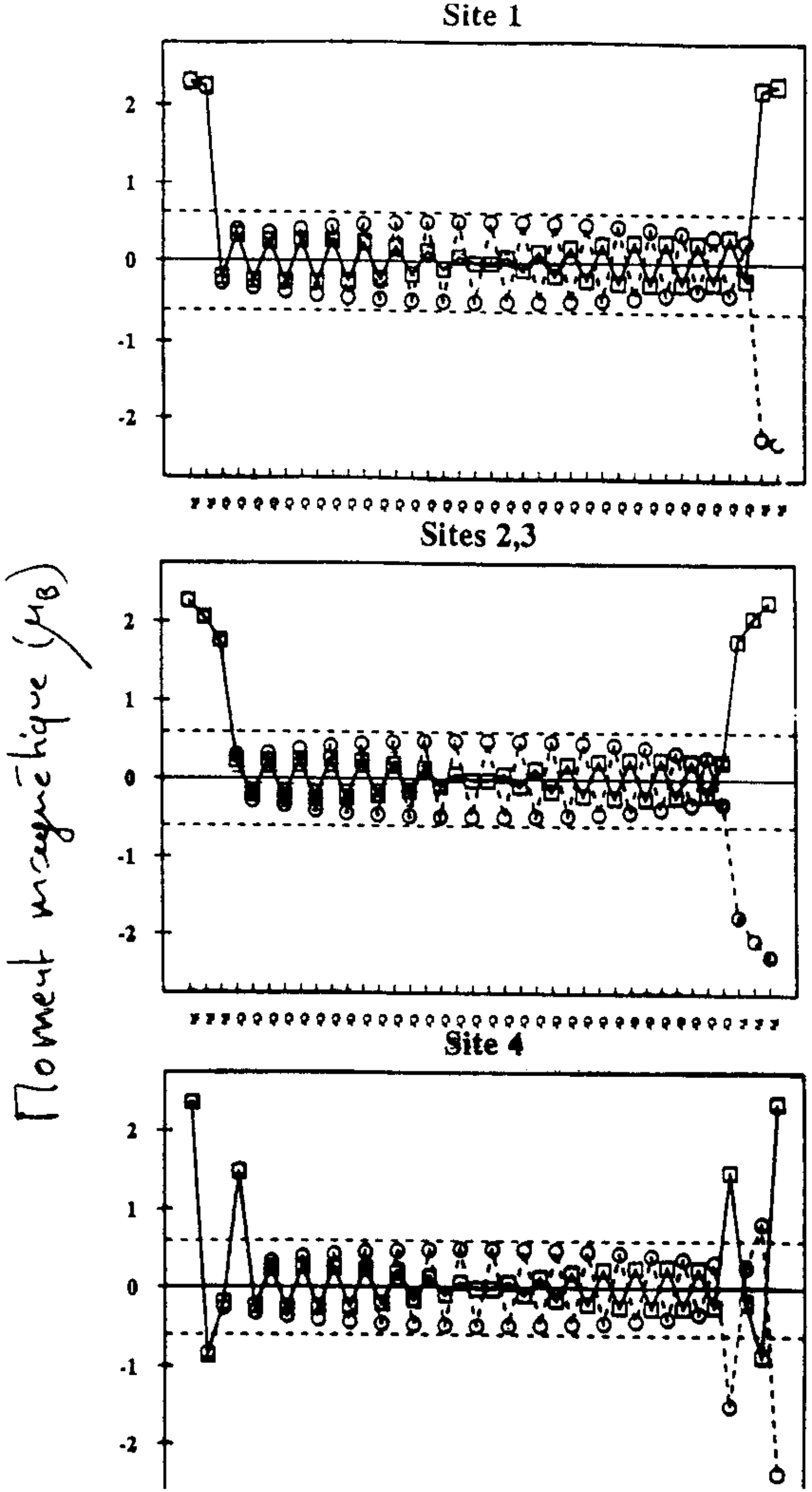


e.

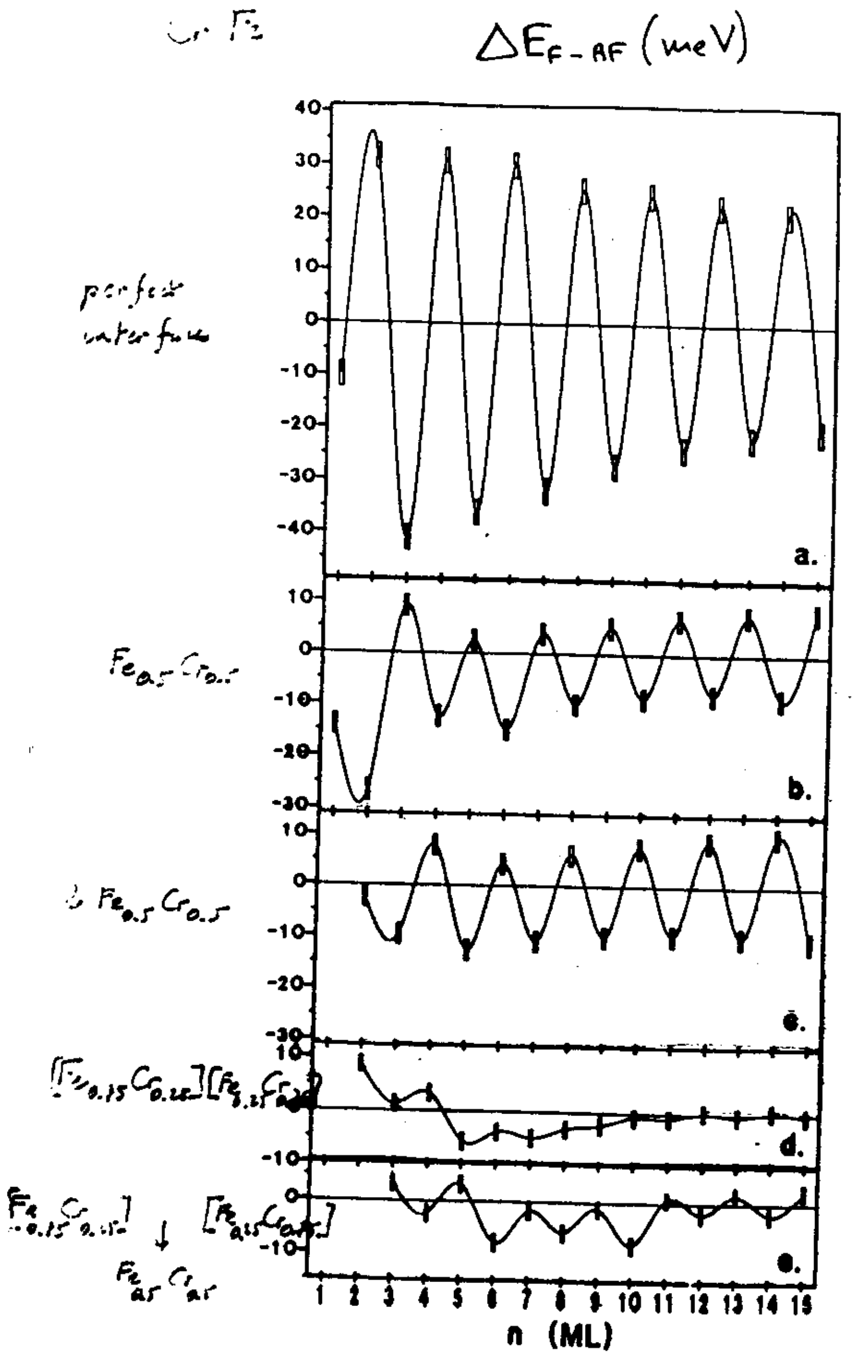


[Fe75% Cr50%
/ Fe50% Cr50%
/ Fe25% Cr75%]





Cas e.
(n = 30)



ΔE_F-AF (meV)
a.
b.
c.
d.
e.
n (ML)