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(9 - 13 August 1993)

THEORY OF NEGATIVE MAGNETORESISTANCE IN MAGNETIC METALLIC MULTILAYERS

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These are preliminary lecture notes, intended only for distribution to

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"THEORY OF NEGATIVE MAGNETORESISTANCE IN MAGNETIC METALLIC MULTILAYERS"

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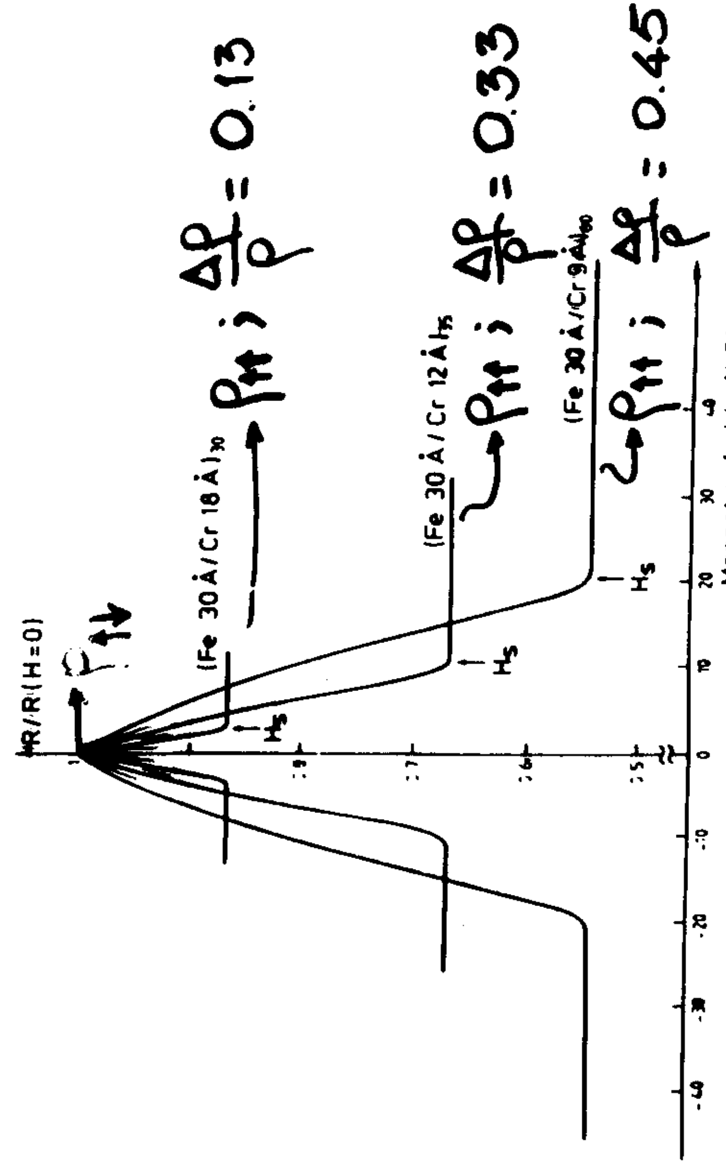


Magnetoresistance of three Fe/Cr superlattices at 4.2 K. The current and the applied field are along the same [110] axis

$$\frac{\Delta\rho}{\rho} \equiv \frac{\rho_{\uparrow\downarrow} - \rho_{\uparrow\uparrow}}{\rho_{\uparrow\downarrow}}$$

$$= \frac{\sigma_{\uparrow\uparrow} - \sigma_{\uparrow\downarrow}}{\sigma_{\uparrow\uparrow}} \quad ,$$

SÈMI-CLASSICAL.

ONLY QUANTUM EFFECTS:

1) FERMI-DIRAC DISTRIBUTION
2) REFLECTION - TRANSMISSION COEFFICIENTS AT THE INTERFACES
3) EXCHANGE SPLITTING: SPIN-UP AND SPIN-DOWN ELECTRONS EXPERIENCE DIFFERENT POTENTIALS

NO QUANTUM INTERFERENCE EFFECTS.

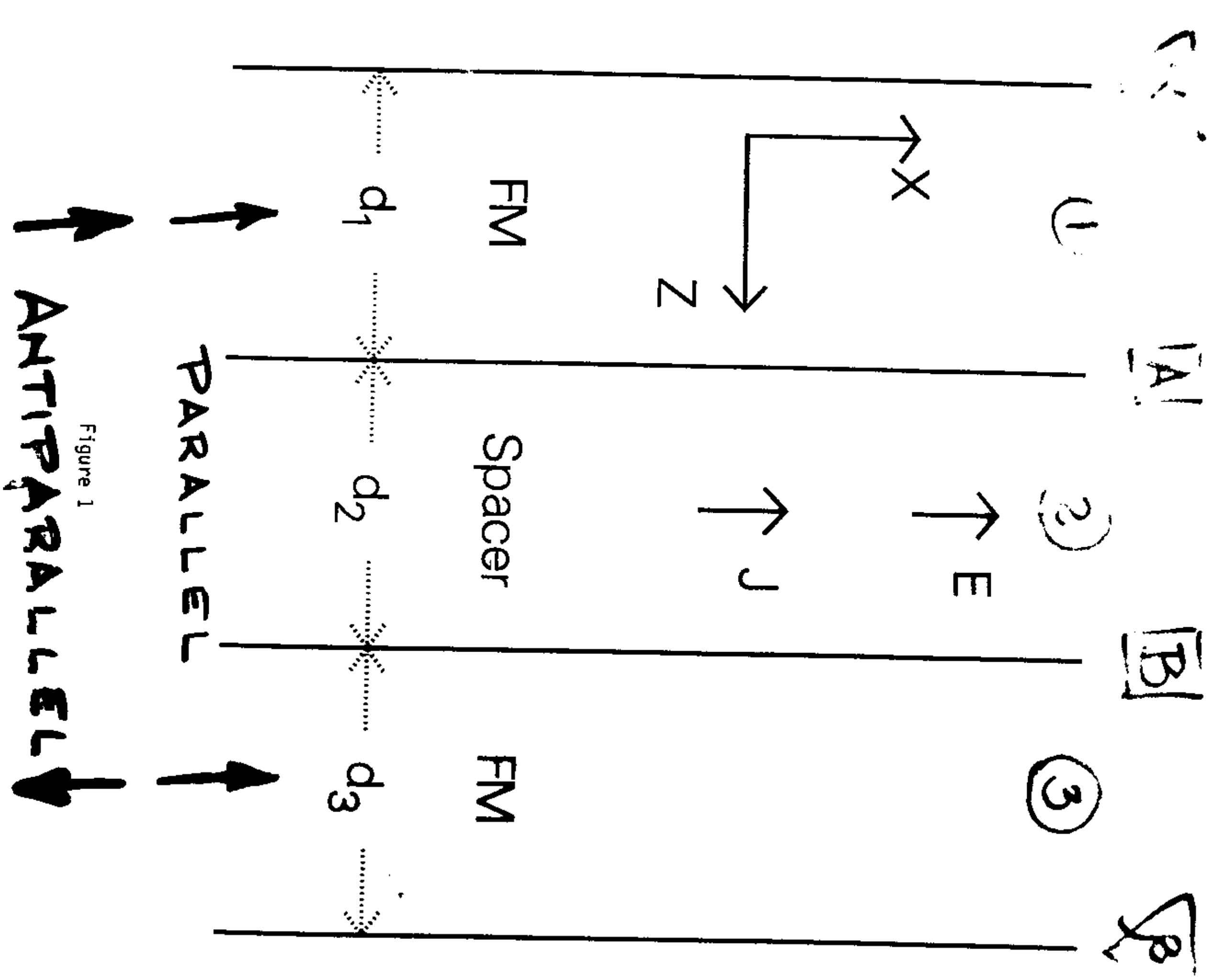


Figure 1

$$f_{i\sigma}(\mathbf{v},z) = f^{0}_{i\sigma}(\mathbf{v}) + g_{i\sigma}(\mathbf{v},z) \quad ,$$

$$\frac{\partial g_{i\sigma}}{\partial z} + \frac{g_{i\sigma}}{\tau_{i\sigma}\, \mathrm{v}_z} = \frac{|e|E}{m_{i\sigma}\, \mathrm{v}_z} \frac{\partial f^{0}_{i\sigma}}{\partial \mathrm{v}_x} \quad ,$$

$$g_{i\sigma}^{\pm}(\mathbf{v},z) = \frac{|e|\tau_{i\sigma}E}{m_{i\sigma}} \frac{\partial f^0(\mathbf{v})}{\partial v_x} \left\{ 1 + F_{i\sigma}^{\pm}(\mathbf{v}) e^{\mp \frac{z}{\tau_{i\sigma}|v_z|}} \right\} ,$$

$$g_{1\sigma}^{+} = P_{\alpha\sigma}\, g_{1\sigma}^{-} \quad \text{at} \quad z = 0 \quad ,$$

$$g_{3\sigma}^{-} = P_{\beta\sigma}\, g_{3\sigma}^{+} \quad \text{at} \quad z = d \quad ,$$

$$g_{1\sigma}^{-} = S_{A\sigma} R_{12\sigma}\, g_{1\sigma}^{+} + S_{A\sigma} T_{21\sigma}\, g_{2\sigma}^{-} \ ,$$

$$\text{at} \quad z = d_1 \quad ;$$

$$g_{2\sigma}^{+} = S_{A\sigma} R_{21\sigma}\, g_{2\sigma}^{-} + S_{A\sigma} T_{12\sigma}\, g_{1\sigma}^{+} \ ,$$

$$\text{at} \quad z = d_1 \quad ;$$

$$g_{2\sigma}^{-} = S_{B\sigma} R_{23\sigma}\, g_{2\sigma}^{+} + S_{B\sigma} T_{32\sigma}\, g_{3\sigma}^{-} \ ,$$

$$\text{at} \quad z = d_1 + d_2 \quad ;$$

$$g_{3\sigma}^{+} = S_{B\sigma} R_{32\sigma}\, g_{3\sigma}^{-} + S_{B\sigma} T_{23\sigma}\, g_{2\sigma}^{+} \ ,$$

$$\text{at} \quad z = d_1 + d_2 \quad .$$

$$J_{xi\sigma}(z) = -|e| \left(\frac{m_{i\sigma}}{h}\right)^3 \int \mathrm{v}_x \, g_{i\sigma}(\mathbf{v}, z) \, d^3\mathbf{v}$$

$$\sigma = \frac{1}{E\,d} \sum_{i=1}^{i=3} \sum_{\sigma=\uparrow,\downarrow} \int J_{xi\sigma}(z) \, dz.$$

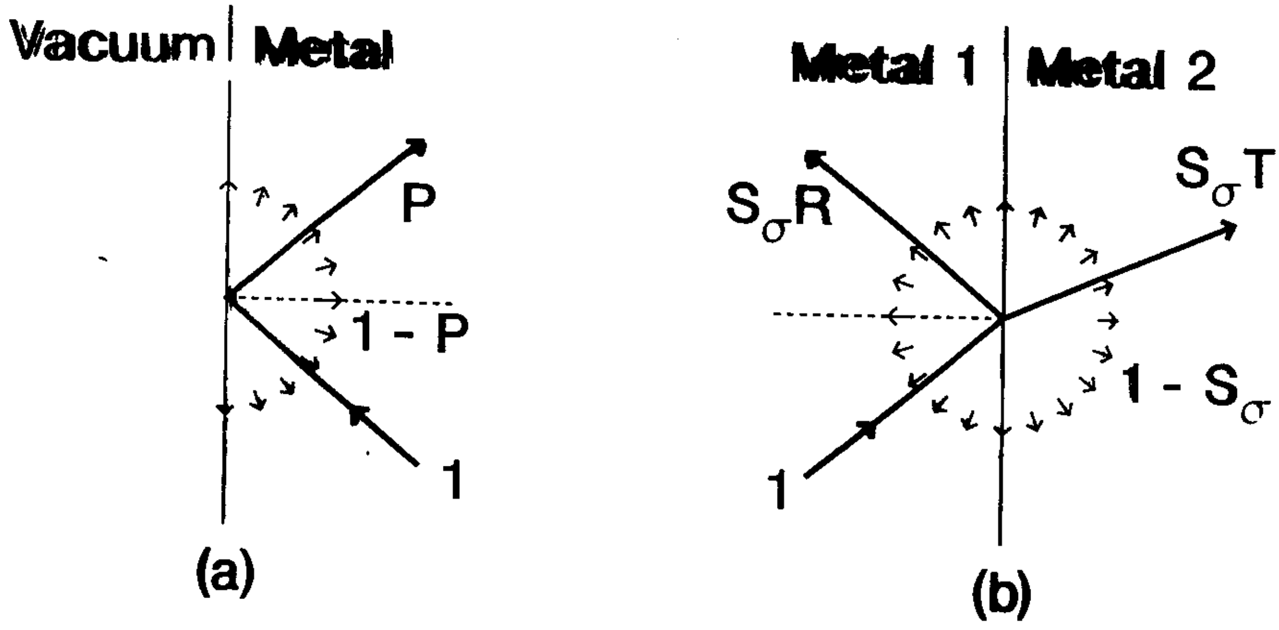


Figure 2

3 geometric parameters:

$$d_1 \quad , \quad d_2 \quad , \quad d_3 \quad ;$$

6 electronic parameters:

$$m_M \quad , \quad m_m \quad , \quad m_S \quad ,$$

$$V_M \quad , \quad V_m \quad , \quad V_S \quad ;$$

3 sample bulk parameters:

$$\tau_M \quad , \quad \tau_m \quad , \quad \tau_S \quad ;$$

4 free-surface parameters:

$$P_{\alpha M} \quad , \quad P_{\alpha m} \quad , \quad P_{\beta M} \quad , \quad P_{\beta m} \quad ;$$

4 interface parameters:

$$S_{AM} \quad , \quad S_{Am} \quad , \quad S_{BM} \quad , \quad S_{Bm} \quad .$$

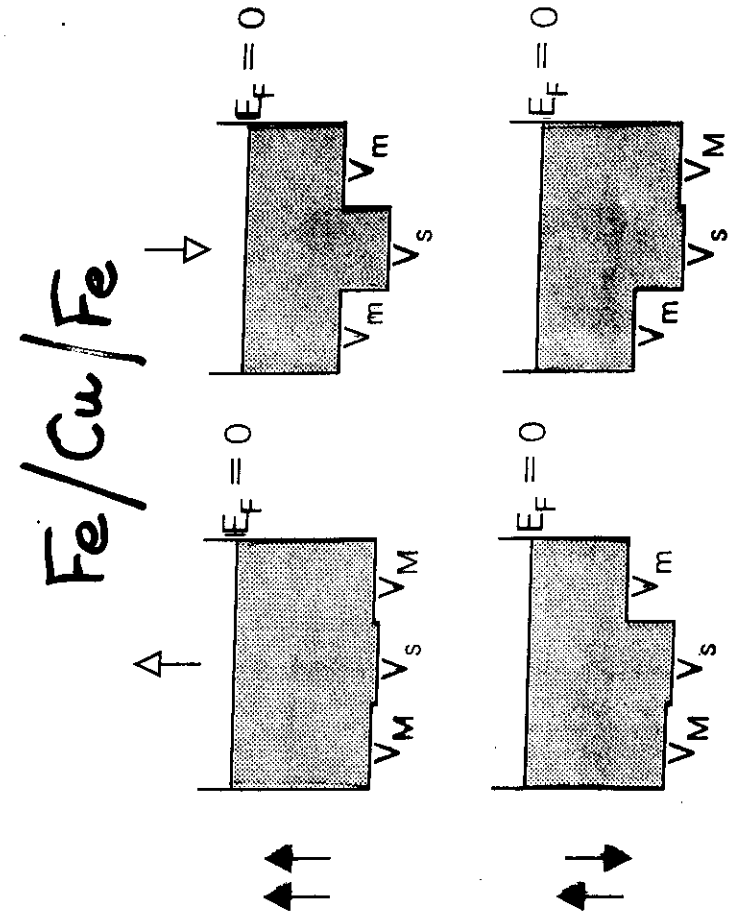


Figure 3

A TRILAYER

$$| \; d_1 \; | \; d_2 \; | \; d_3 \; |$$

VACUUM F_1 S F_3 VACUUM

WITH PERFECT REFLECTION AT THE OUTER SURFACES IS <u>EXACTLY</u> EQUIVALENT TO AN INFINITE MULTILAYER SAMPLE

$$\ldots | d_2 | 2d_1 | d_2 | 2d_3 | d_2 | 2d_1 | d_2 | \ldots$$

S F_1 S F_3 S F_1 S

$\longleftarrow$ PERIOD $\longrightarrow$

$\therefore \; P = 1 \Longrightarrow$ INFINITE MULTILAYER SYSTEM

CHEMICAL COMPOSITION

Fe/Cr/Fe OR Fe/Cu/Fe — CHEMISTRY

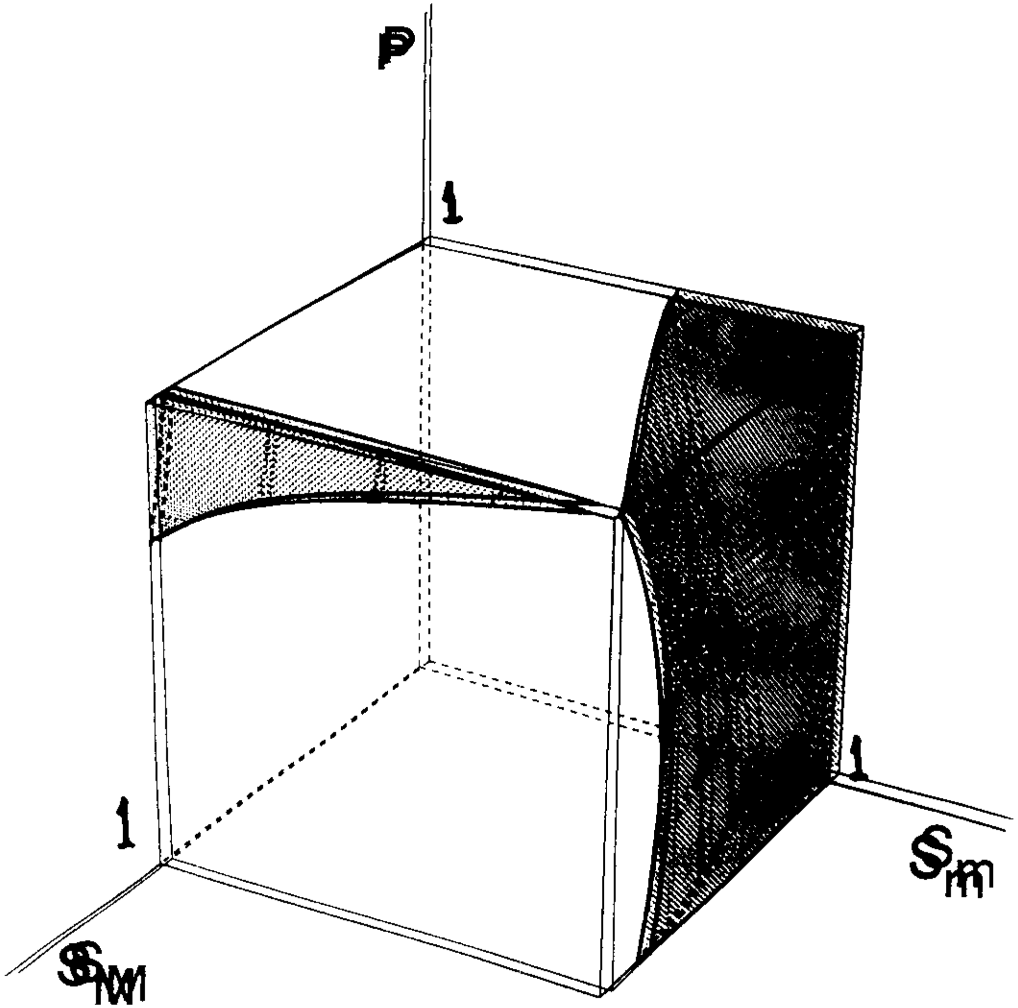
$d_1 = d_3 = \boxed{d_F}$ $d_2 = \boxed{d_S}$ — GEOMETRY

$\tau_M = \tau_m = \tau_S = \boxed{\tau}$ — PURITY

$P_{\alpha M} = P_{\beta M} = P_{\alpha m} = P_{\beta m} = \boxed{P}$ — QUALITY OF SURFACES

$S_{\alpha M} = S_{\beta M} = \boxed{S_M}$

$S_{\alpha m} = S_{\beta m} = \boxed{S_m}$ — QUALITY OF INTERFACES

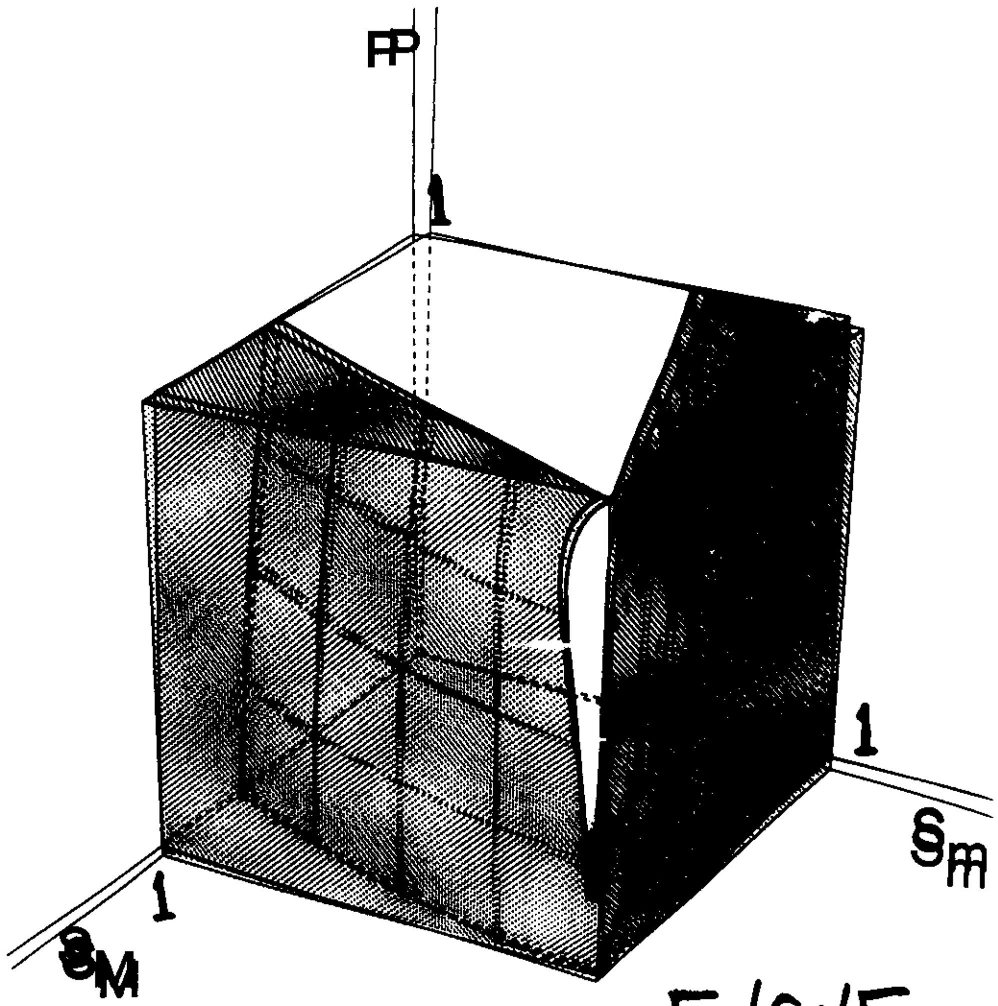


Fe/Cr/Fe

$d_s = d_F = 10$ Å

$\tau = 5 \times 10^{-13}$ s

Figure 4



Fe/Cu/Fe

$d_s = d_F = 10$ Å

$\tau = 5 \times 10^{-13}$ s

Figure 5

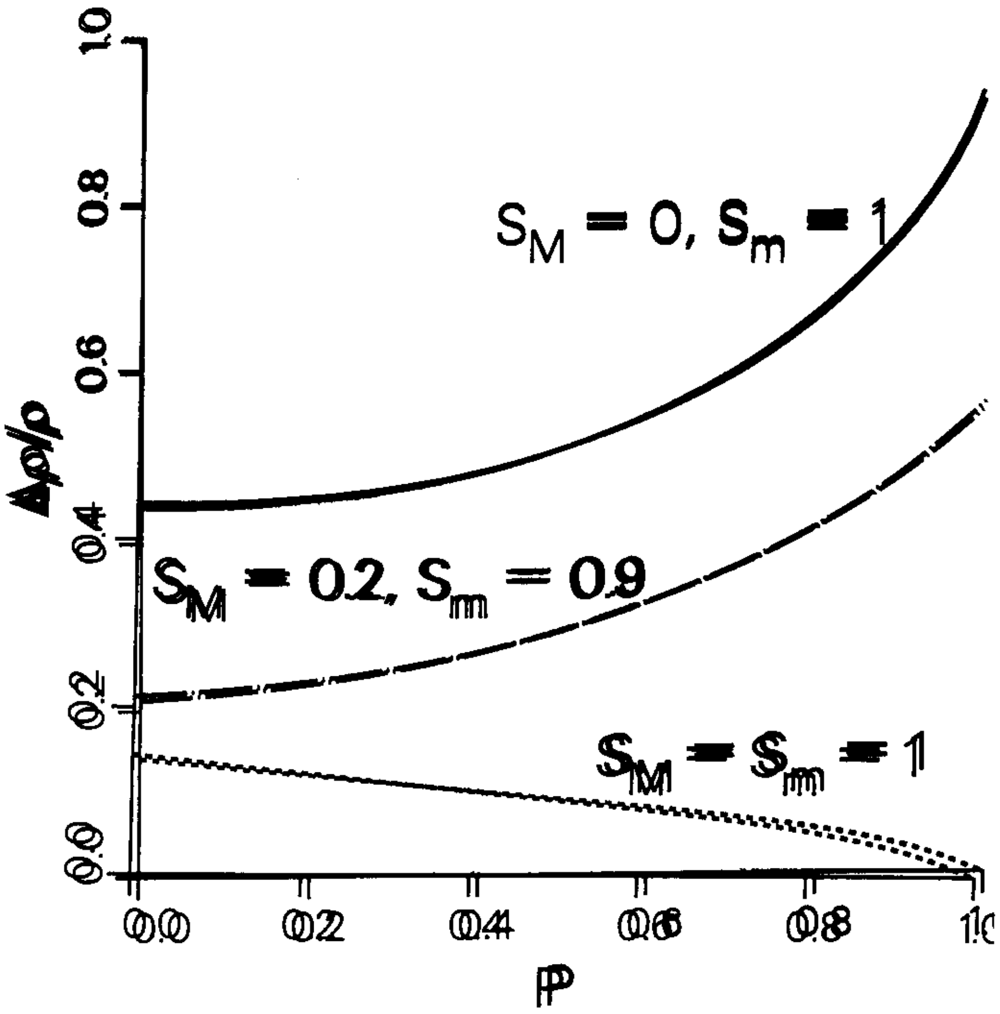


Figure 6

$\tau = 5.0 \times 10^{-13}$ s.
$d_F = d_S = 10$ Å

Fe/Cr/Fe

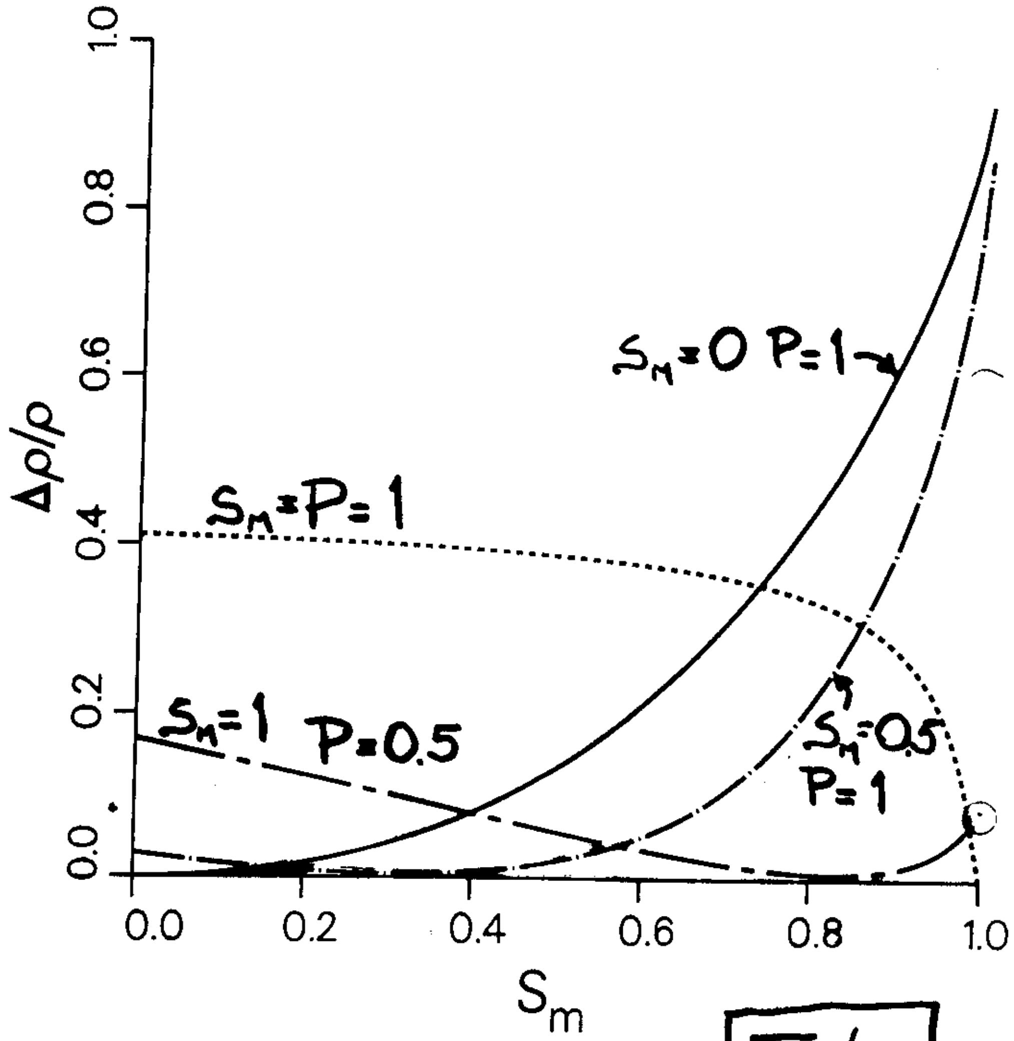


Figure 7

Fe/Cr

$\tau = 5.0 \times 10^{-13}$ s.
$d_F = d_S = 10$ Å

3

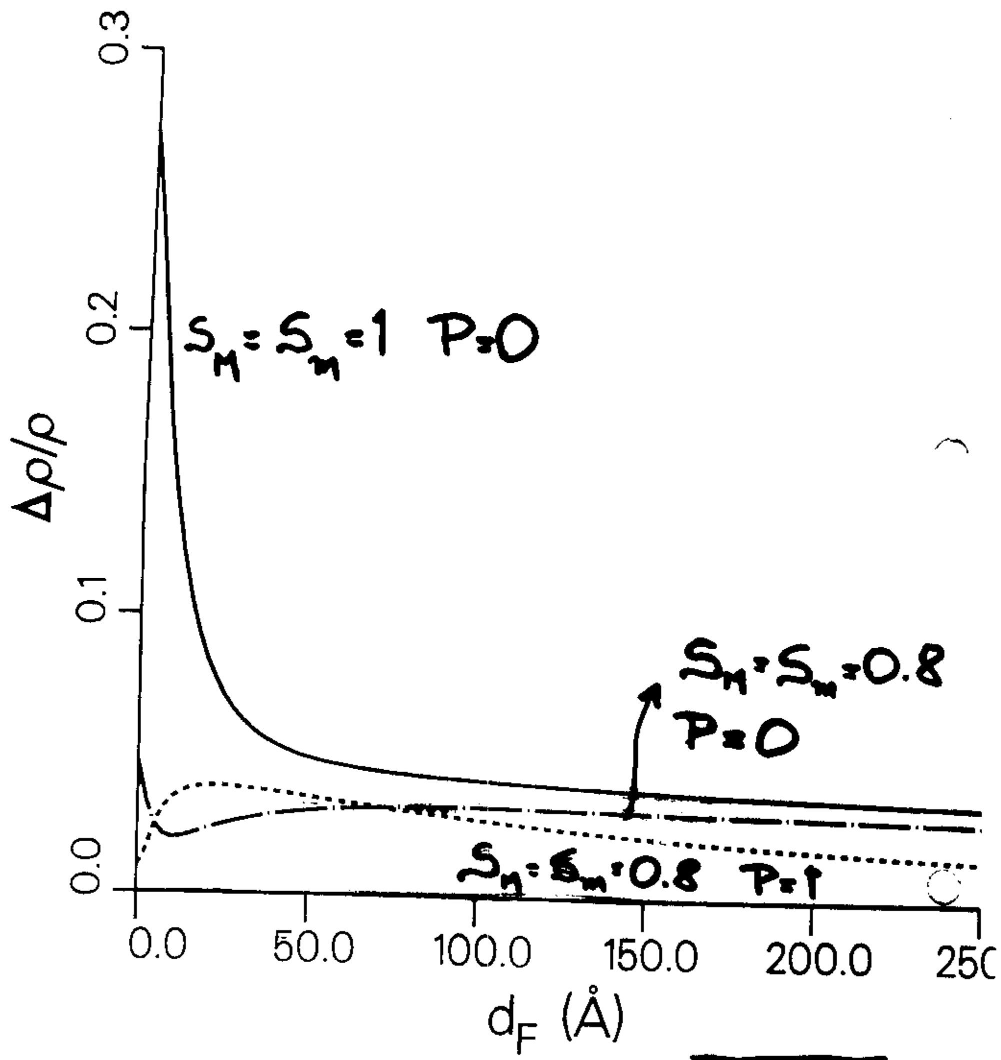


Figure 8

$\boxed{\text{Fe/Cr}}$

$d_s = 10\,\text{Å}$

$\tau = 5.0 \times 10^{-13}\,s$

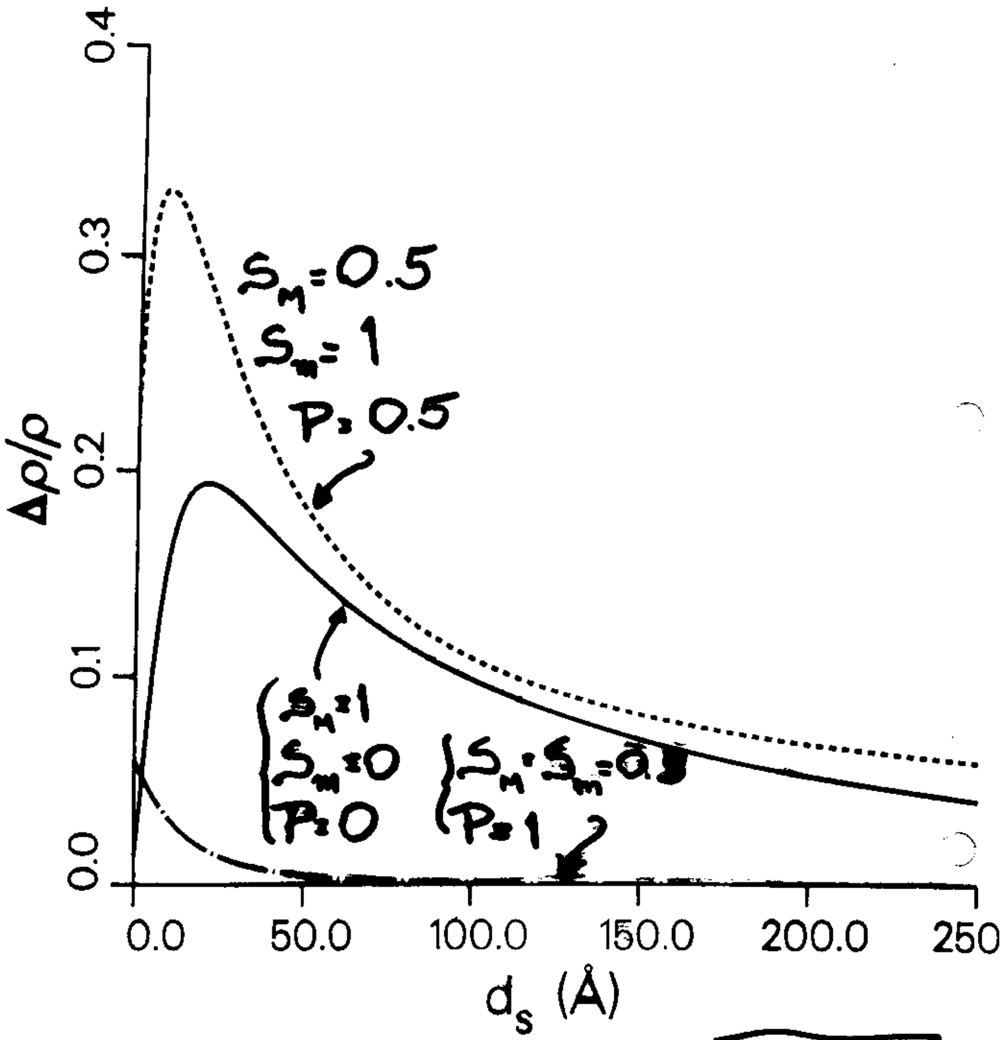
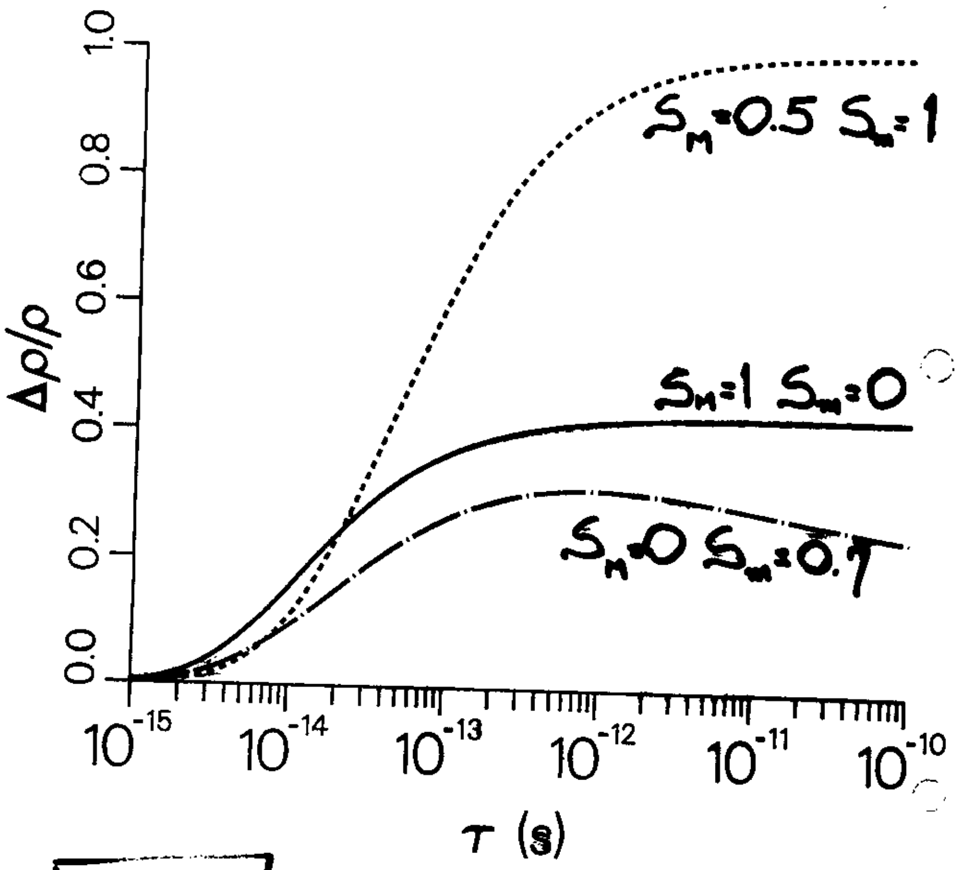


Figure 9

$\boxed{\text{Fe/Cr}}$

$d_F = 10\,\text{Å}$

$\tau = 5.0 \times 10^{-13}\,s$



Fe/Cr

Figure 10

$d_s = d_F = 10\,\text{Å}$

$P = 1$

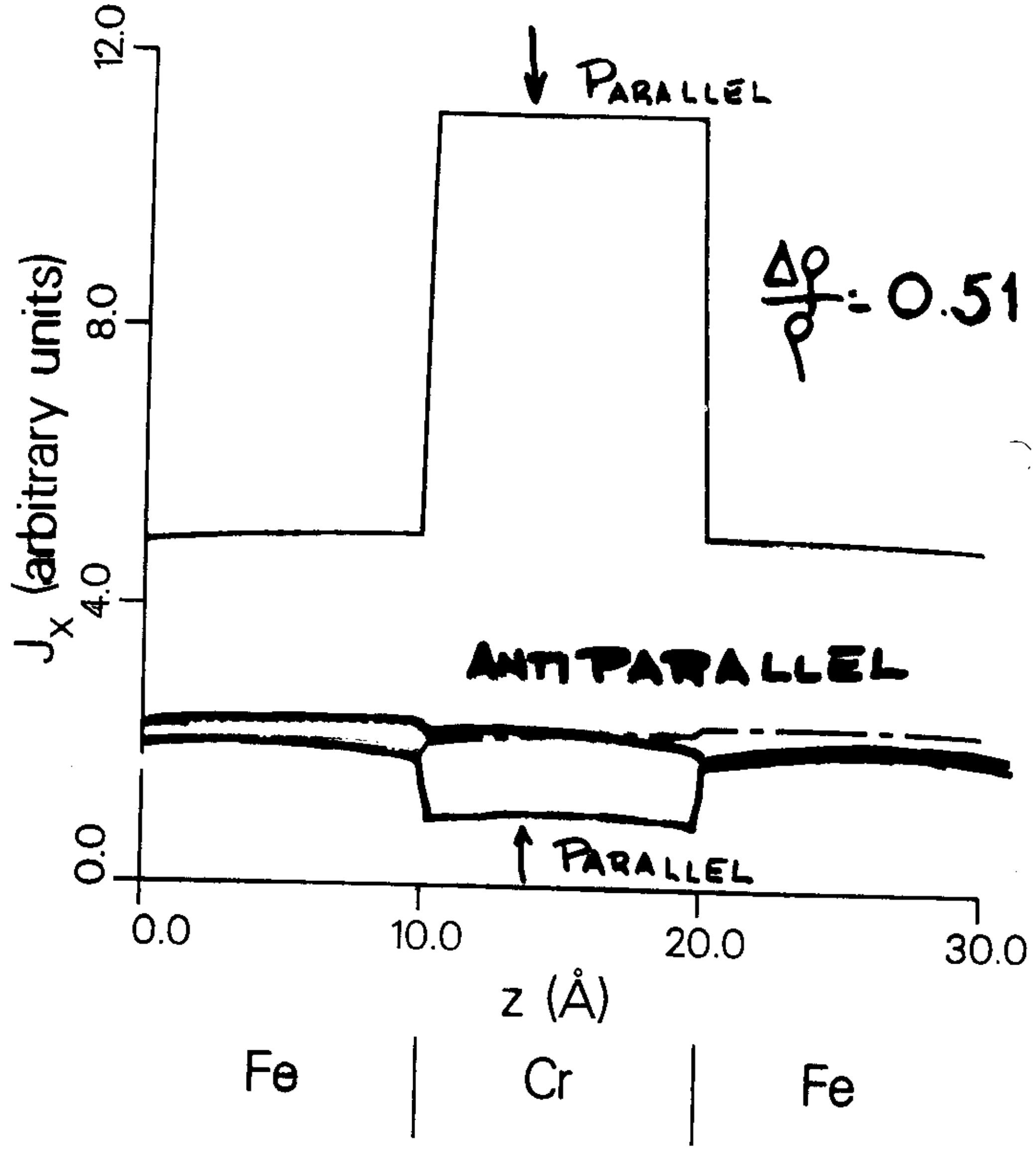


Figure 11

$\tau = 5. \times 10^{-13}\,s$

$d_F = d_s = 10\,\text{Å}$

$S_M = 0$

$S_m = 1$

$P = 0.5$

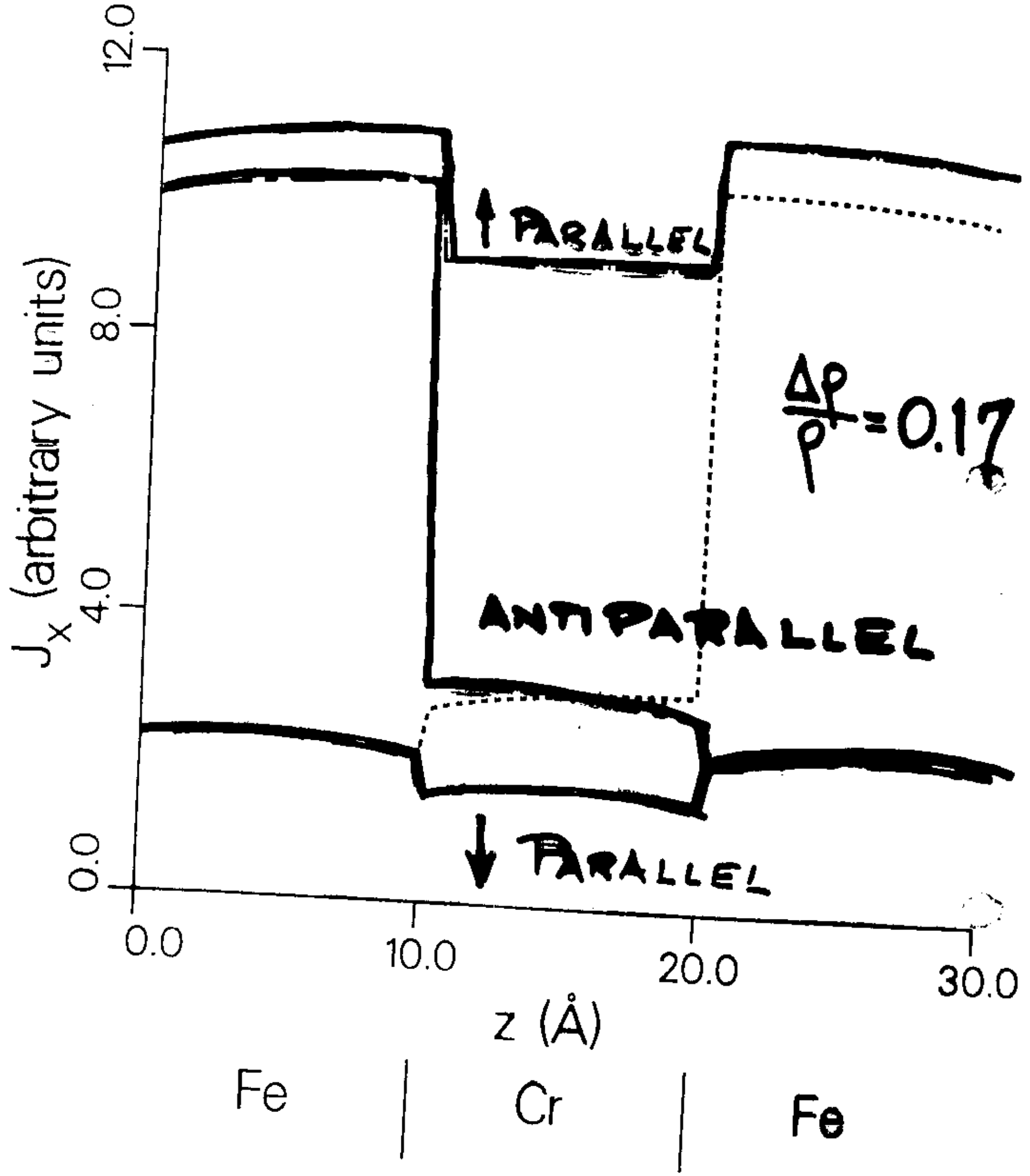


Figure 12

$\tau = 5 \times 10^{-13}\,s$

$d_F = d_s = 10\,Å$

$S_n = 1$

$S_m = 0$

$P = 0.5$