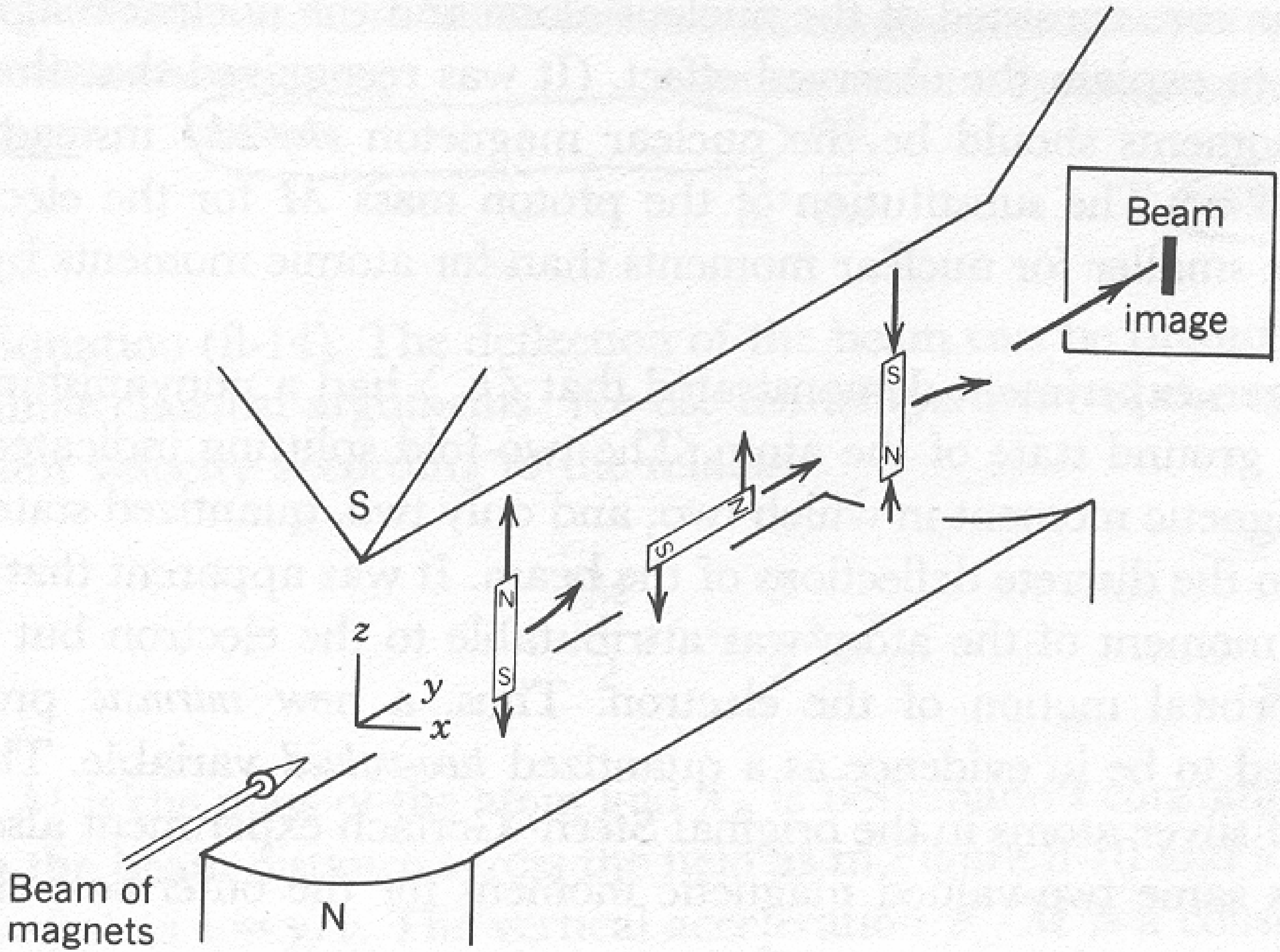
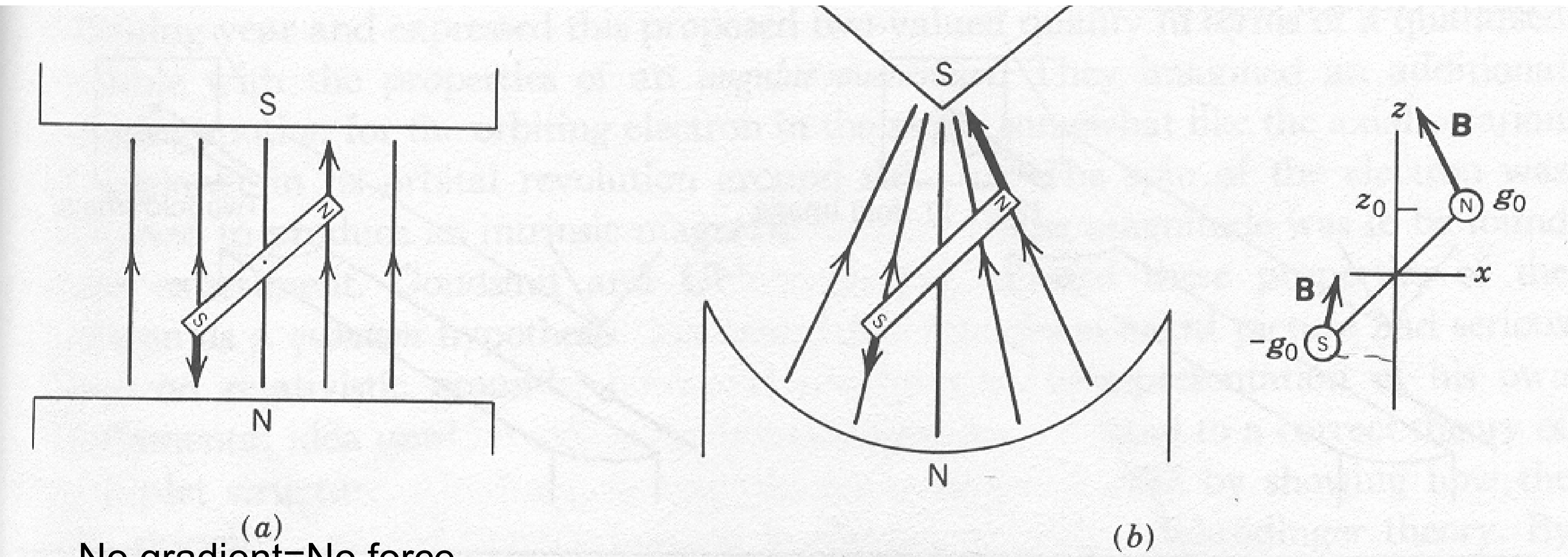
Magneto-Electronics

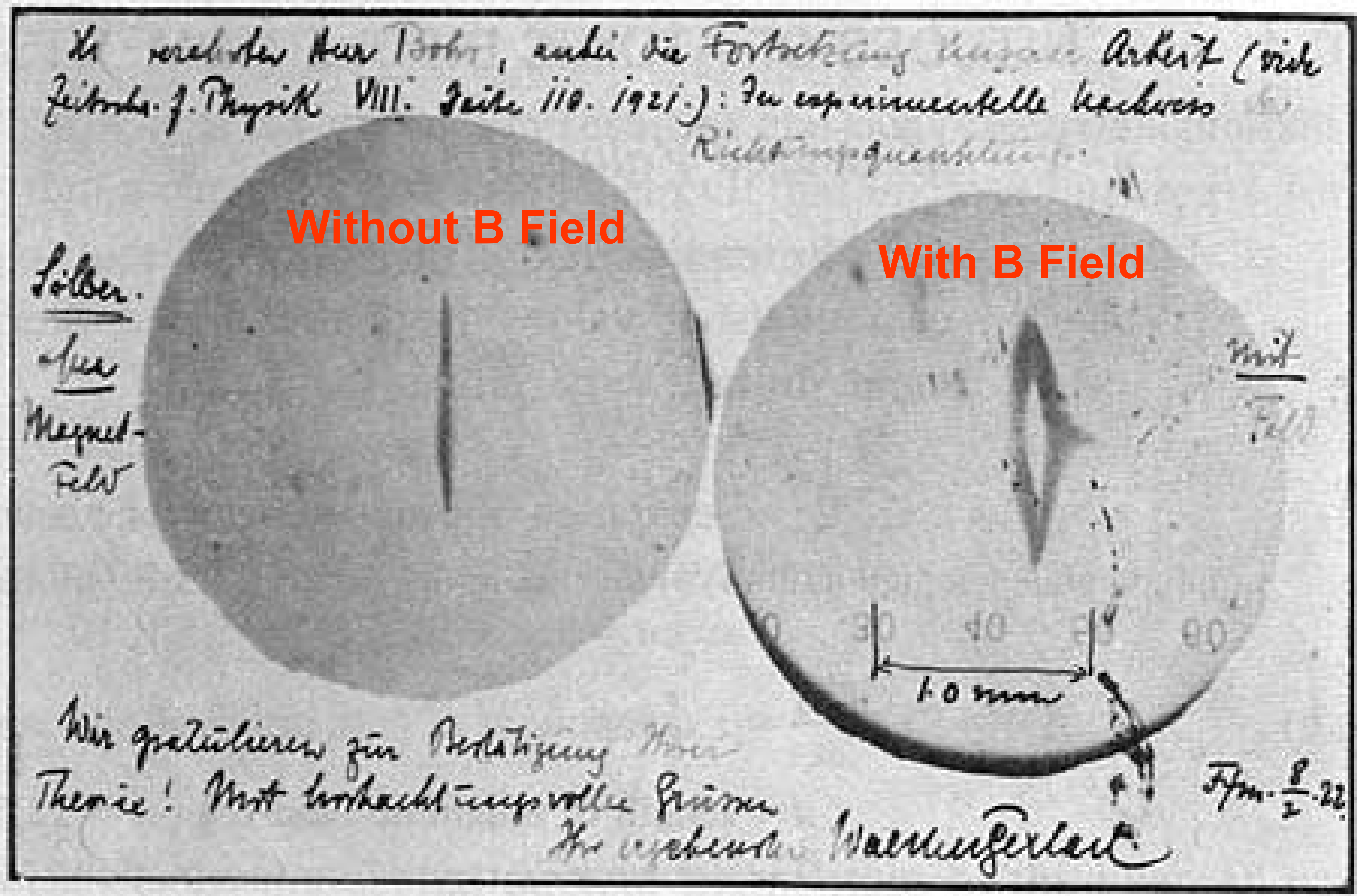
- Electron Spin: Stern-Gerlach Experiment
- Magnetic materials: Spin-dependent DOS
- NM/FM Interface: Johnson-Silsbee Expt.
- NM/FM Multilayers: Giant Magnetoresistance (GMR)
- FM/Insulator/FM: Magnetic Tunnel Junctions

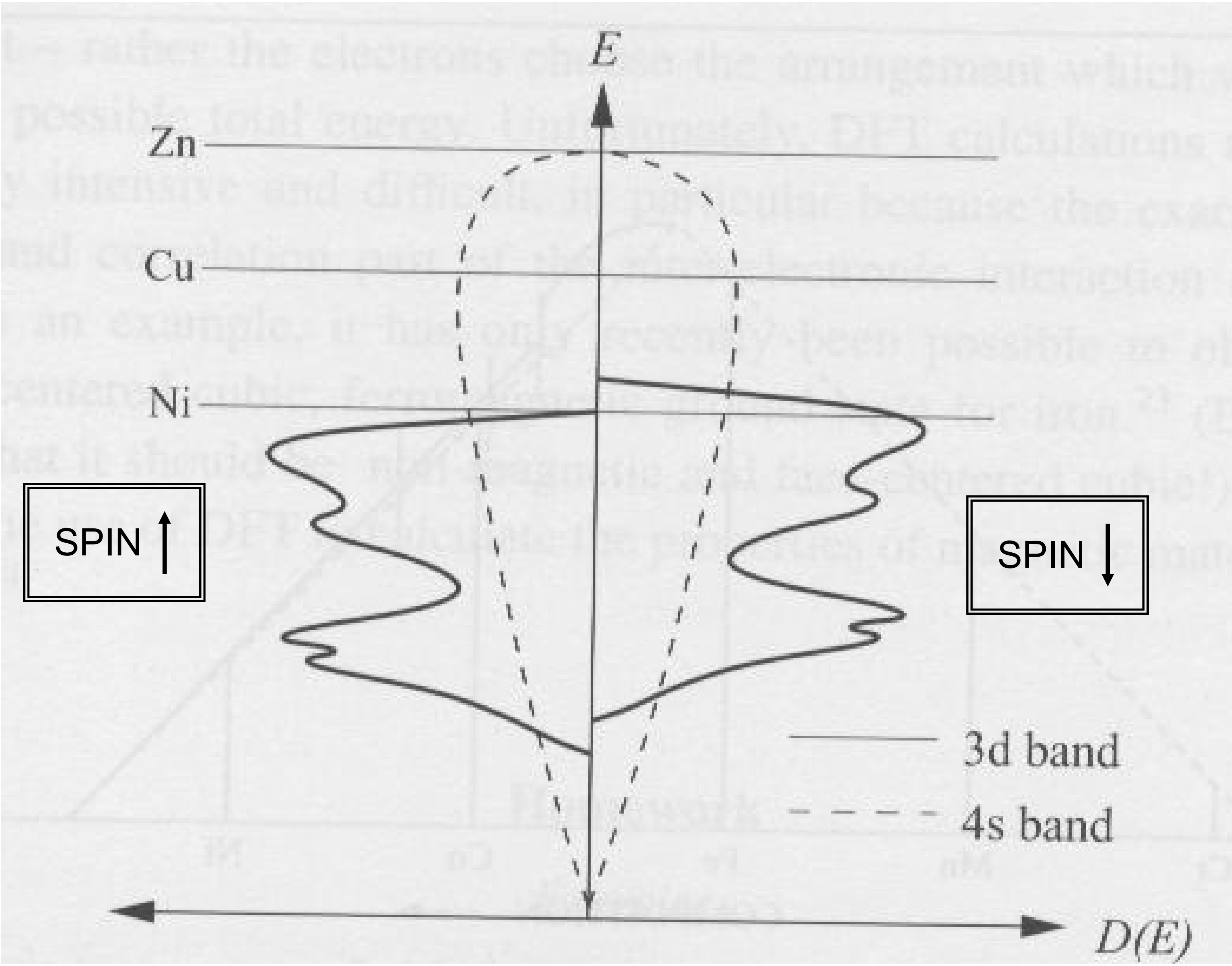

Beam
image
S
N
S
N
S
N
z
y
x
Beam of
magnets
N

Classical “Bar Magnet” in a Magnetic Field



No gradient=No force


Without B Field
With B Field
10 mm


E
Zn
Cu
Ni
SPIN ↑
SPIN ↓
3d band
4s band
D(E)

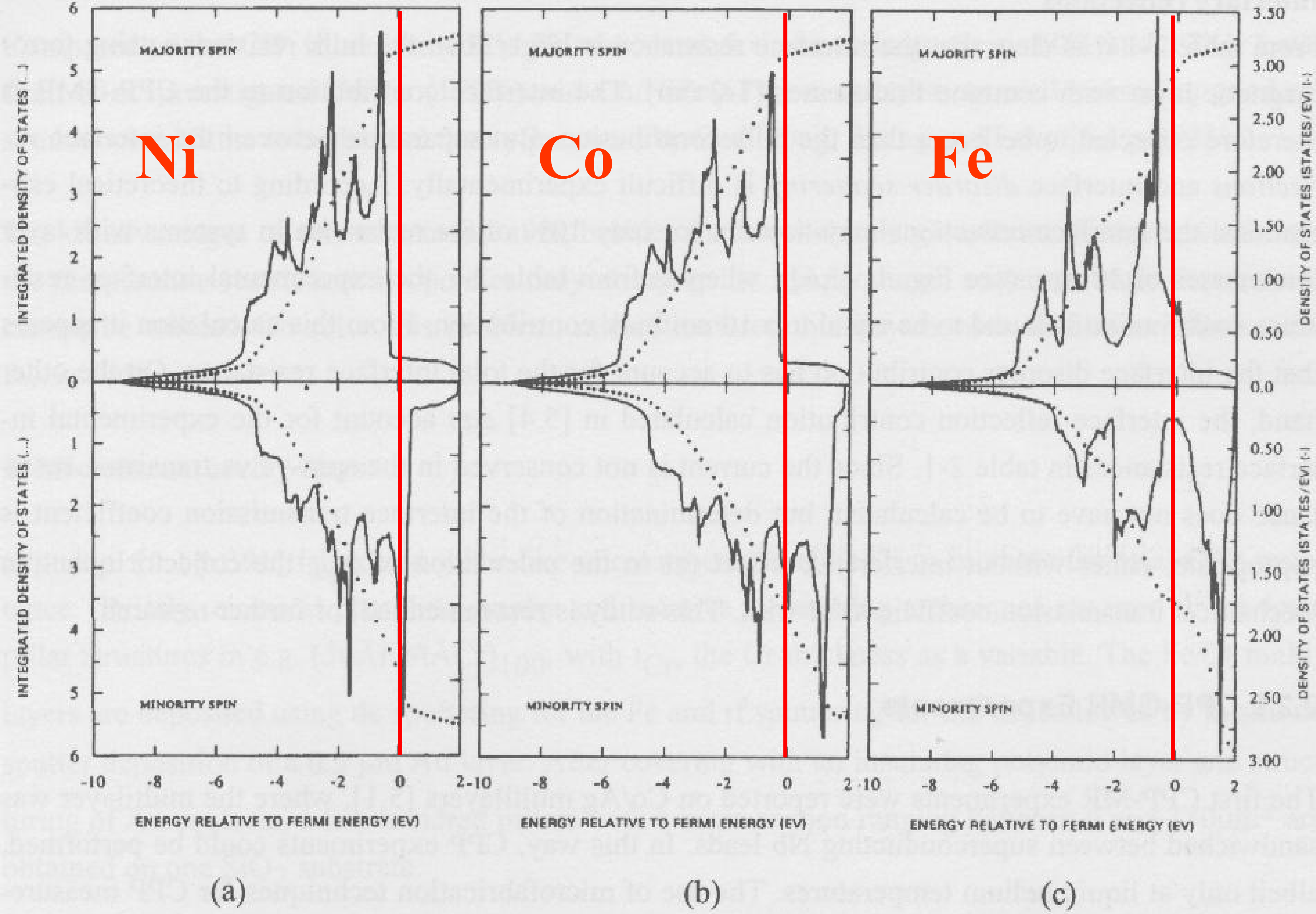
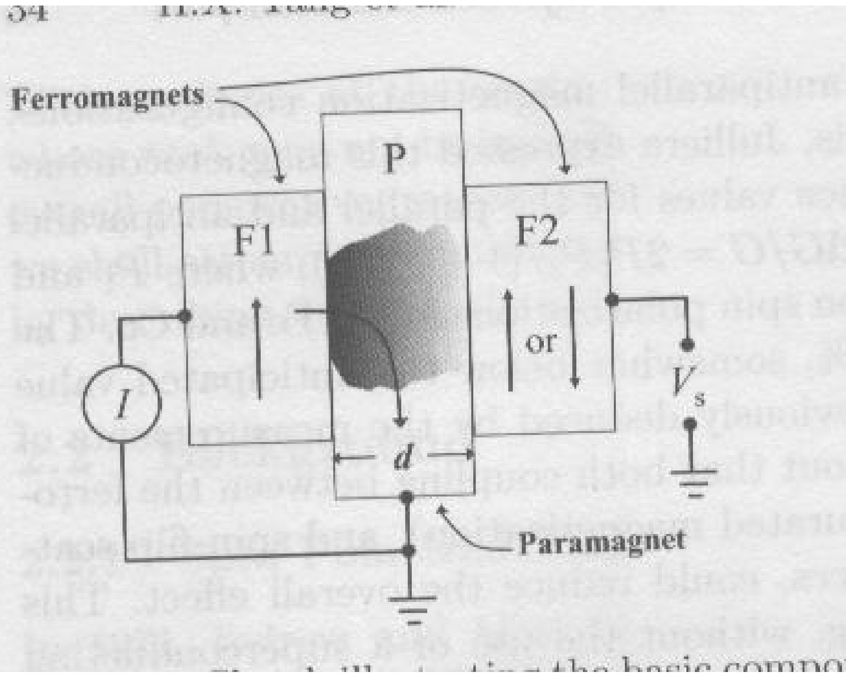
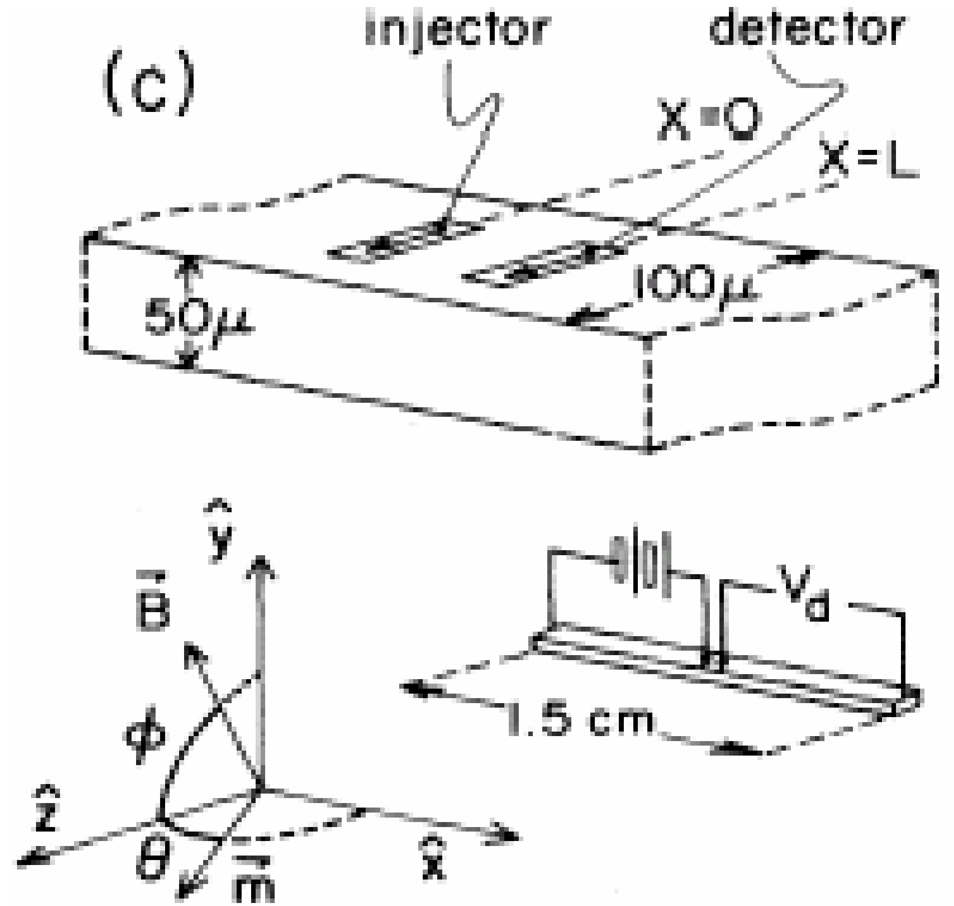


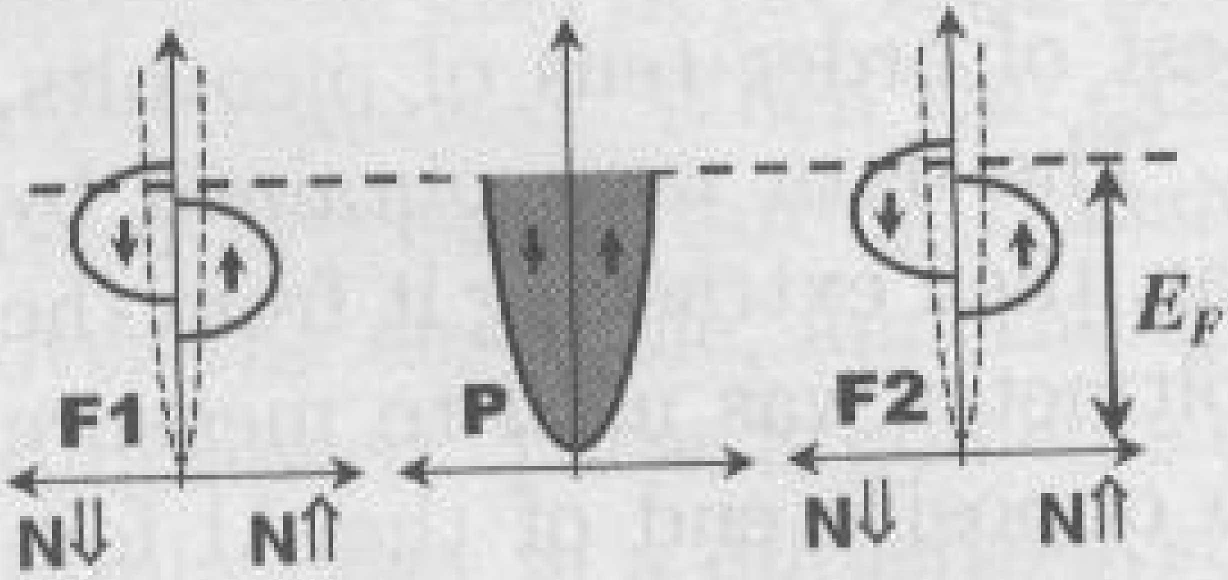
Fig. 2-8 Scheme of density of states (DOS) in transition metals (a) Ni, (b) Co and (c) Fe [10.13].

Johnson and Silsbee, PRL 55 1790 (1985) and PRB 37 5326 (1988)

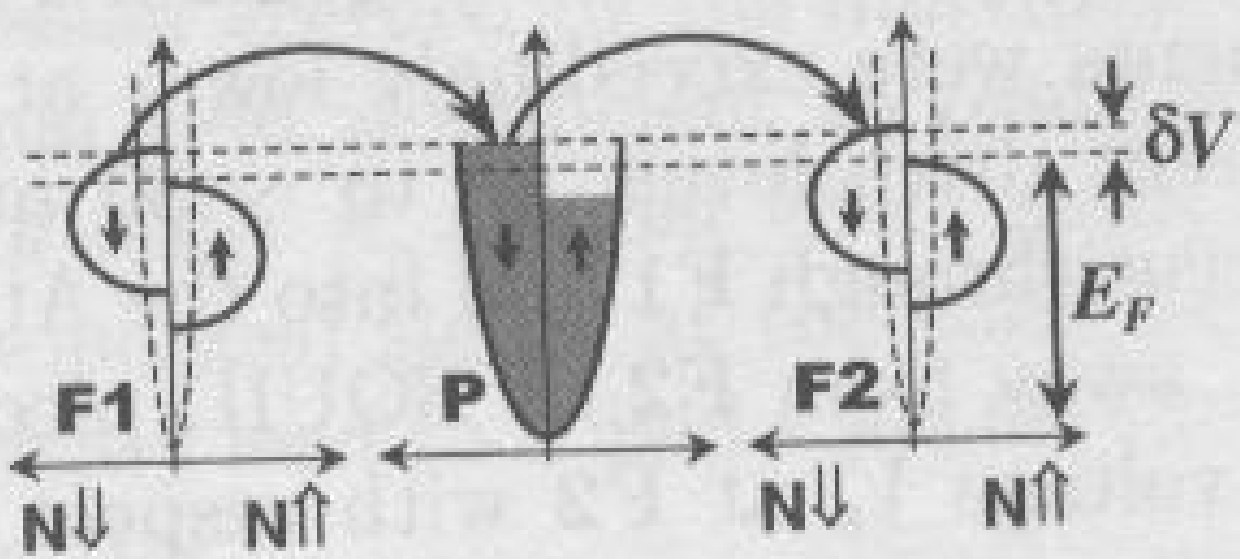




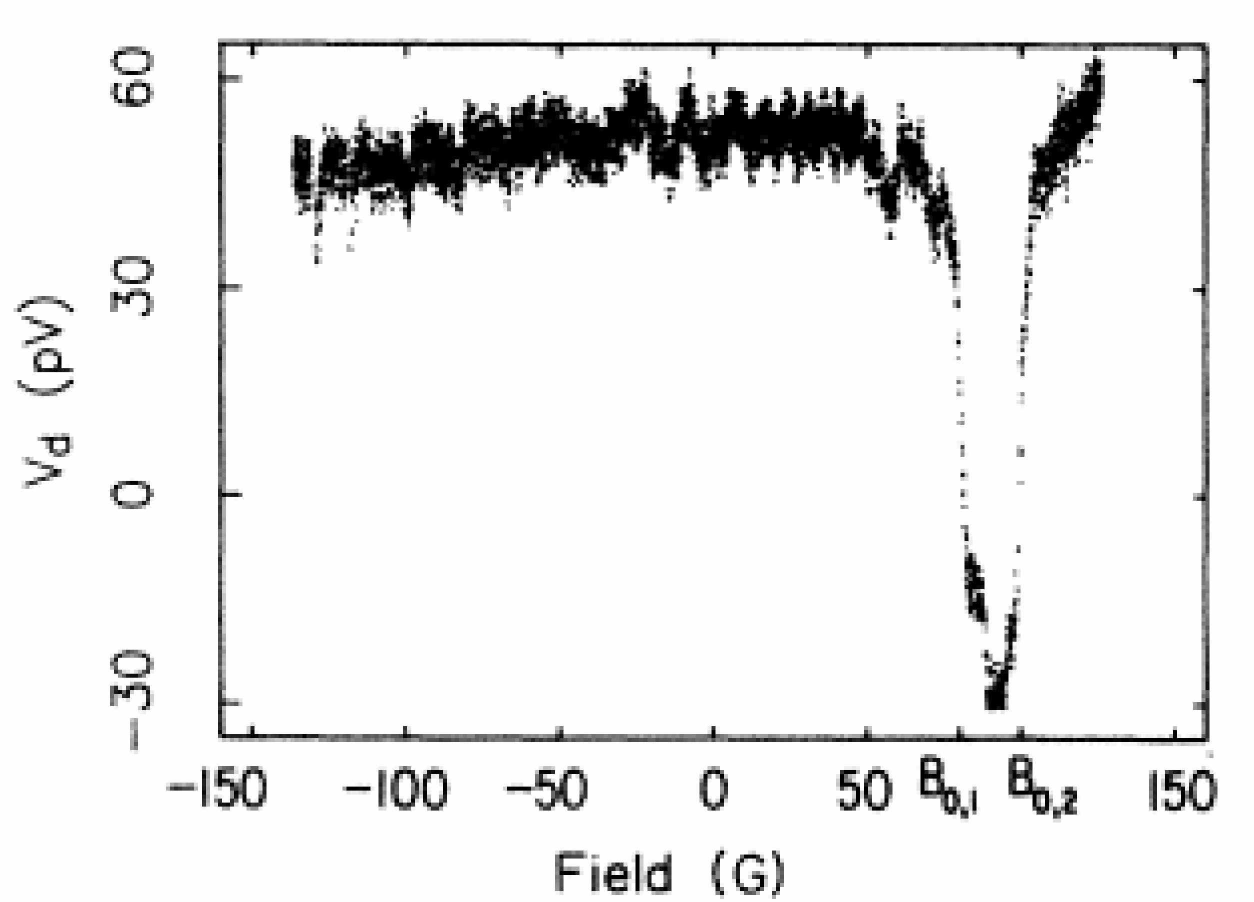
UNBIASED



BIASED



Johnson and Silsbee, PRL 55 1790 (1985) and PRB 37 5326 (1988)



Anisotropic Magneto-Resistance

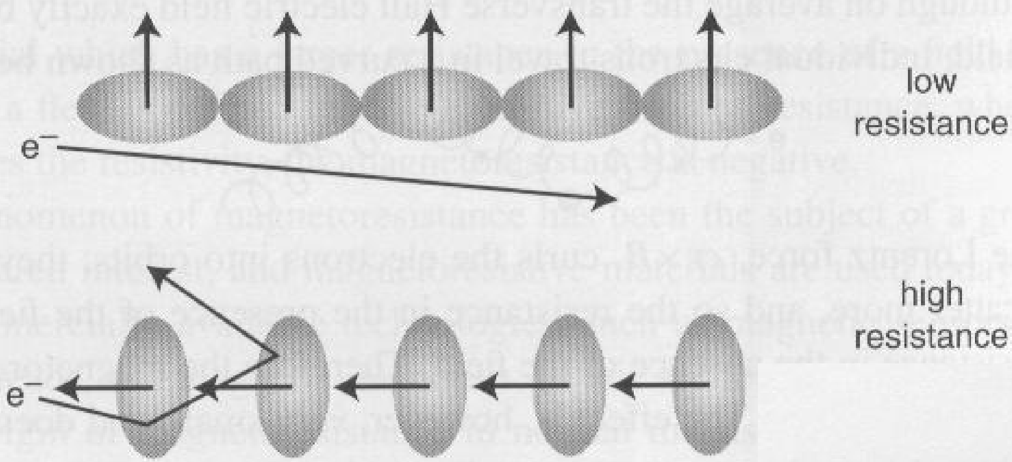
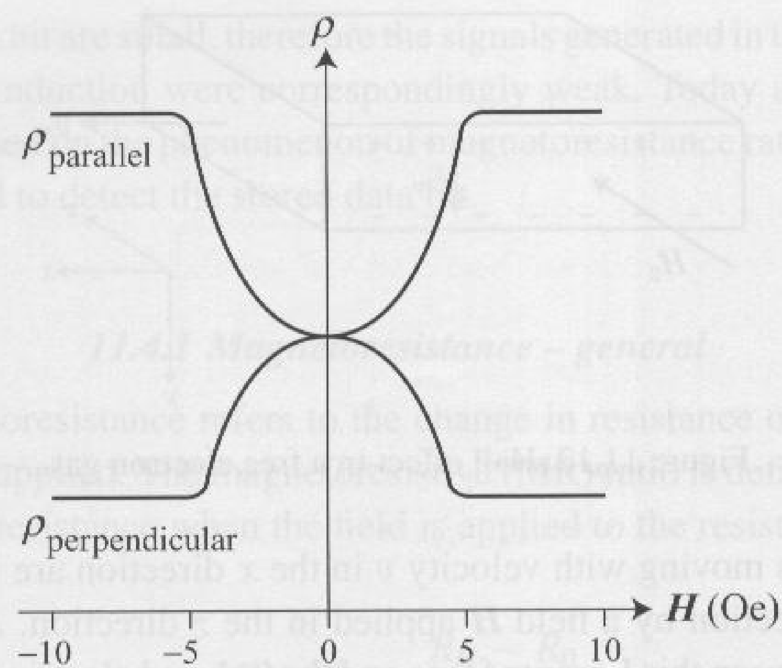


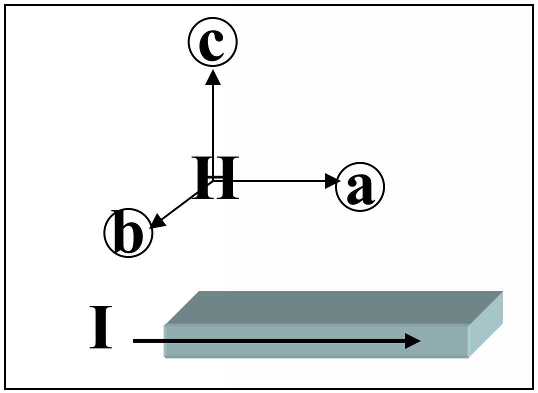
Figure 11.14 The origin of AMR

~2%

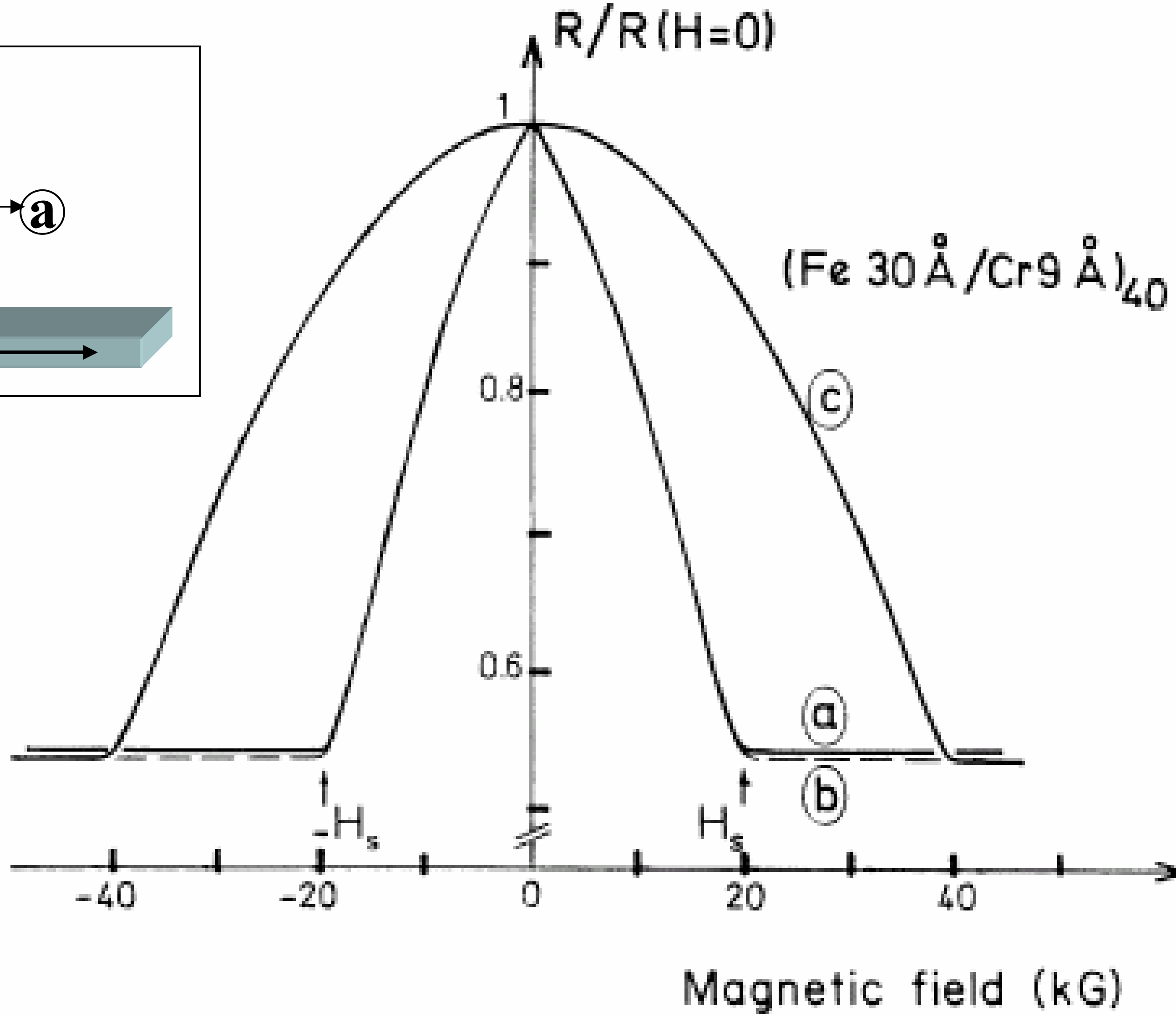


Giant Magneto-Resistance

Baibich et al., PRL 61 2472 (1988)

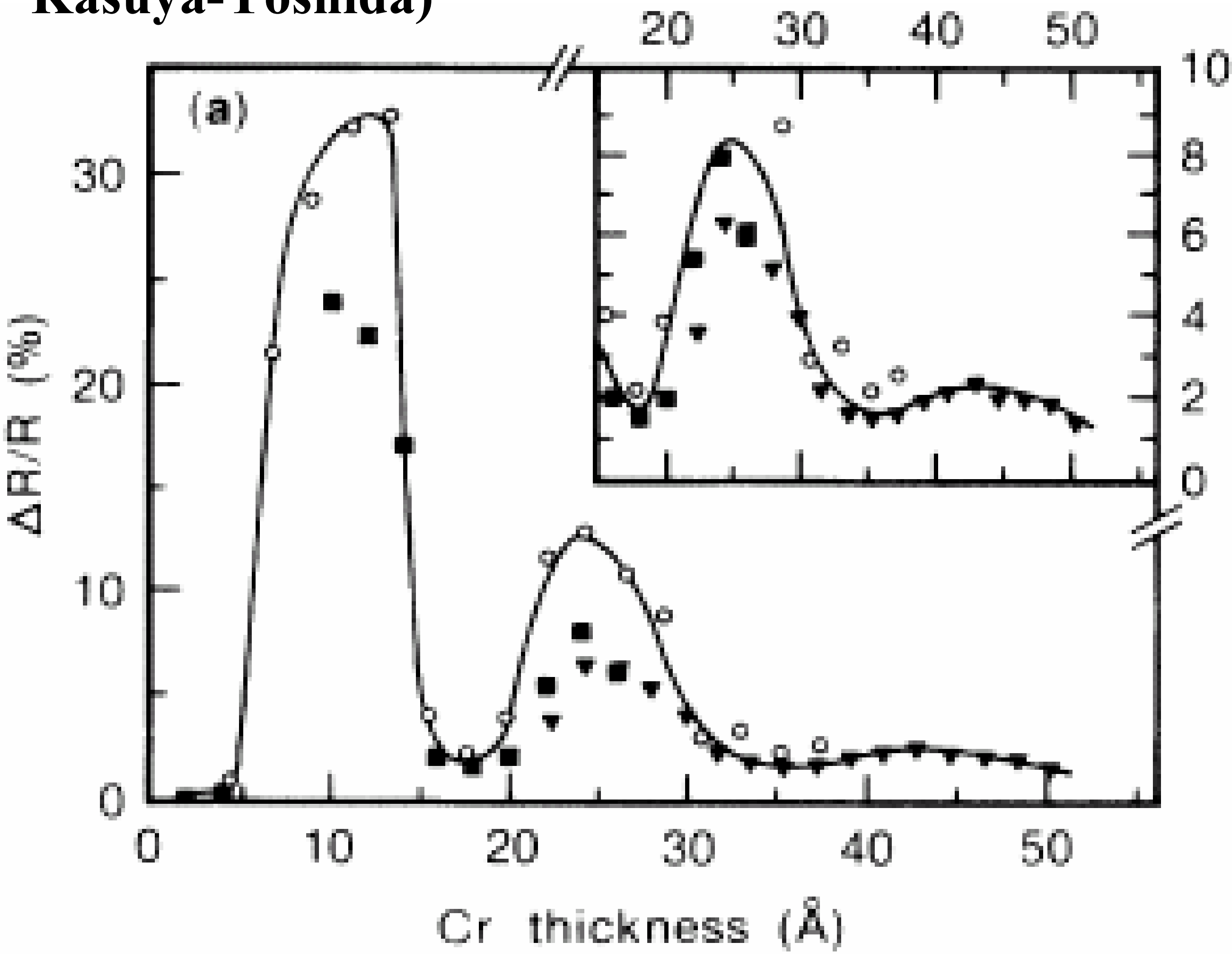


~50%

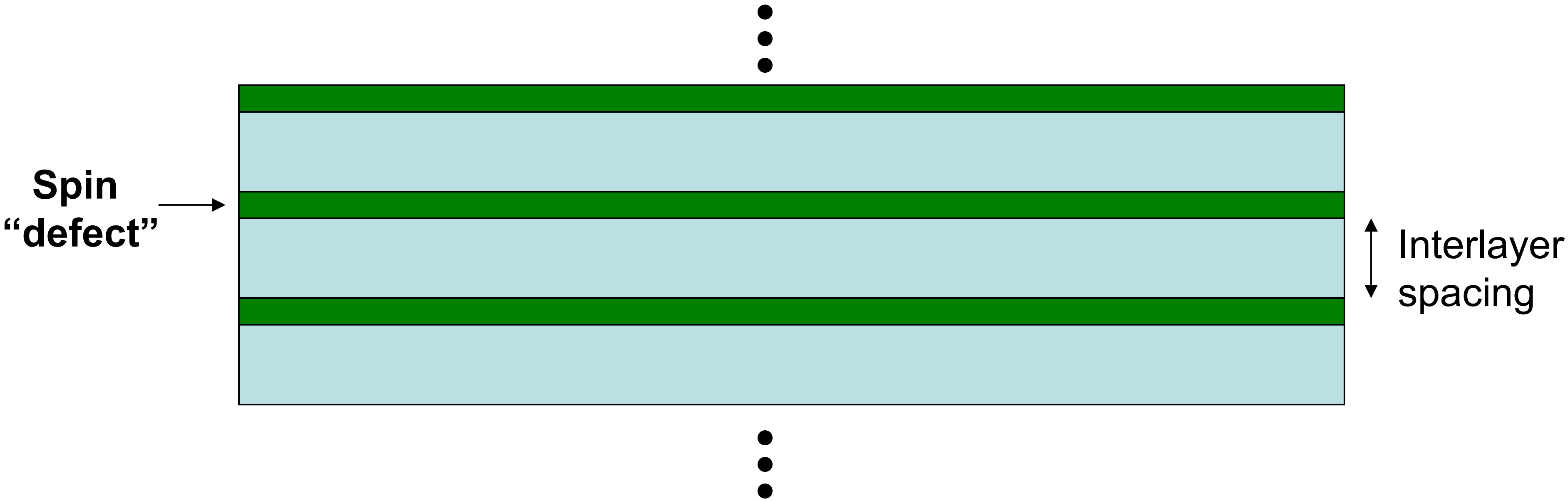


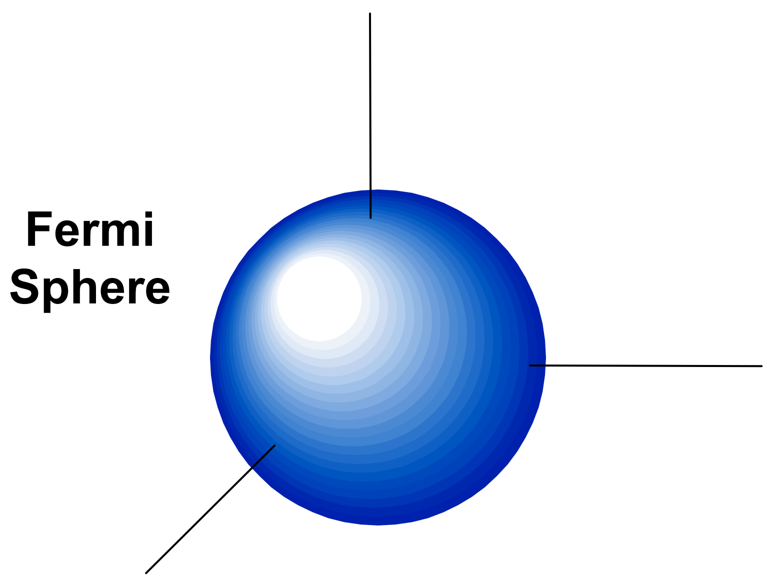
RKKY coupling
(Ruderman-Kittel-Kasuya-Yoshida)

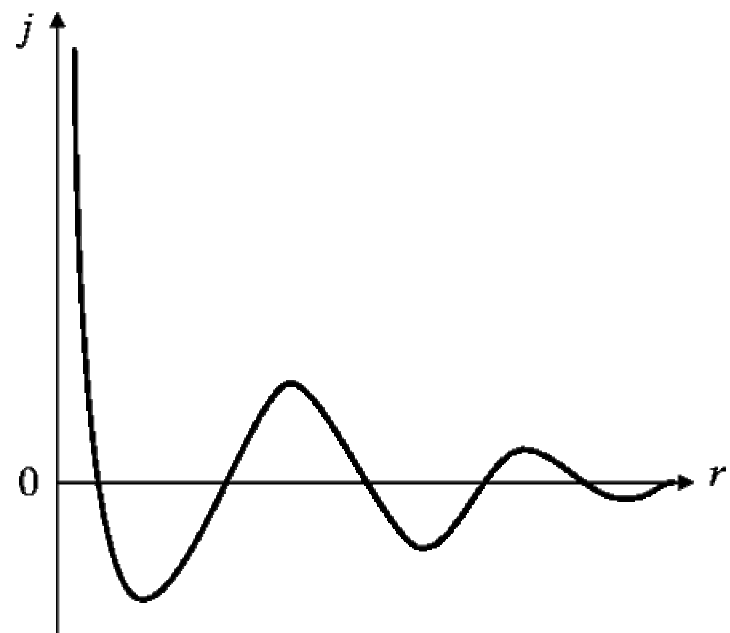
Parkin et al., PRL 64 2304 (1990)



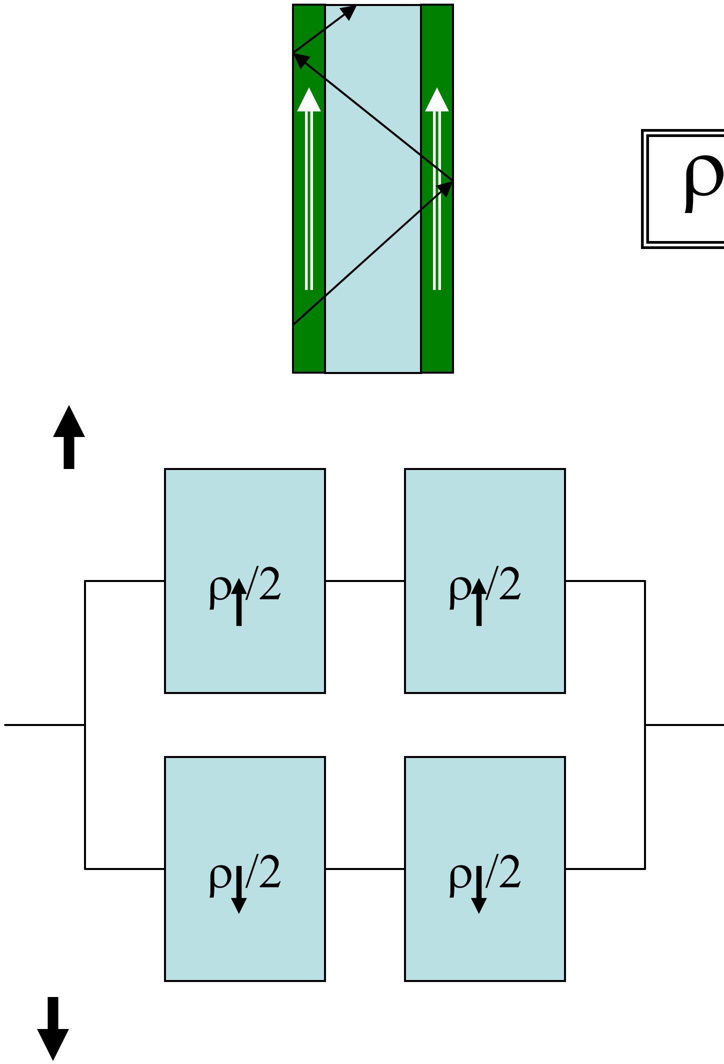
RKKY oscillations of ΔR/R in multilayers





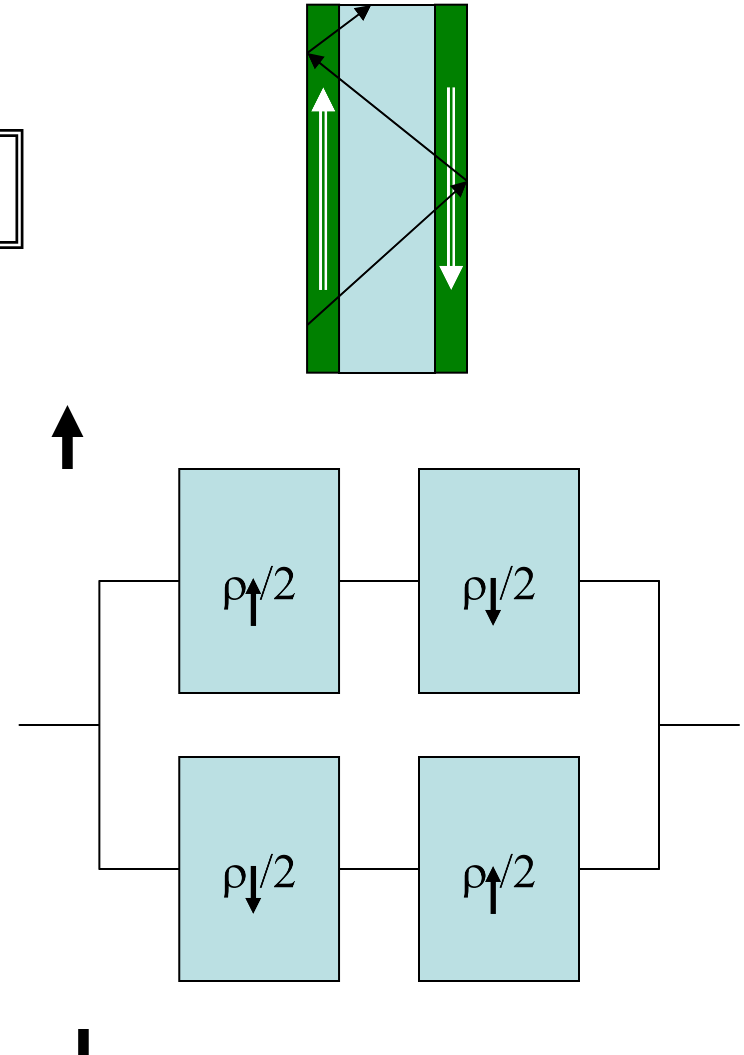


Two-Current Model



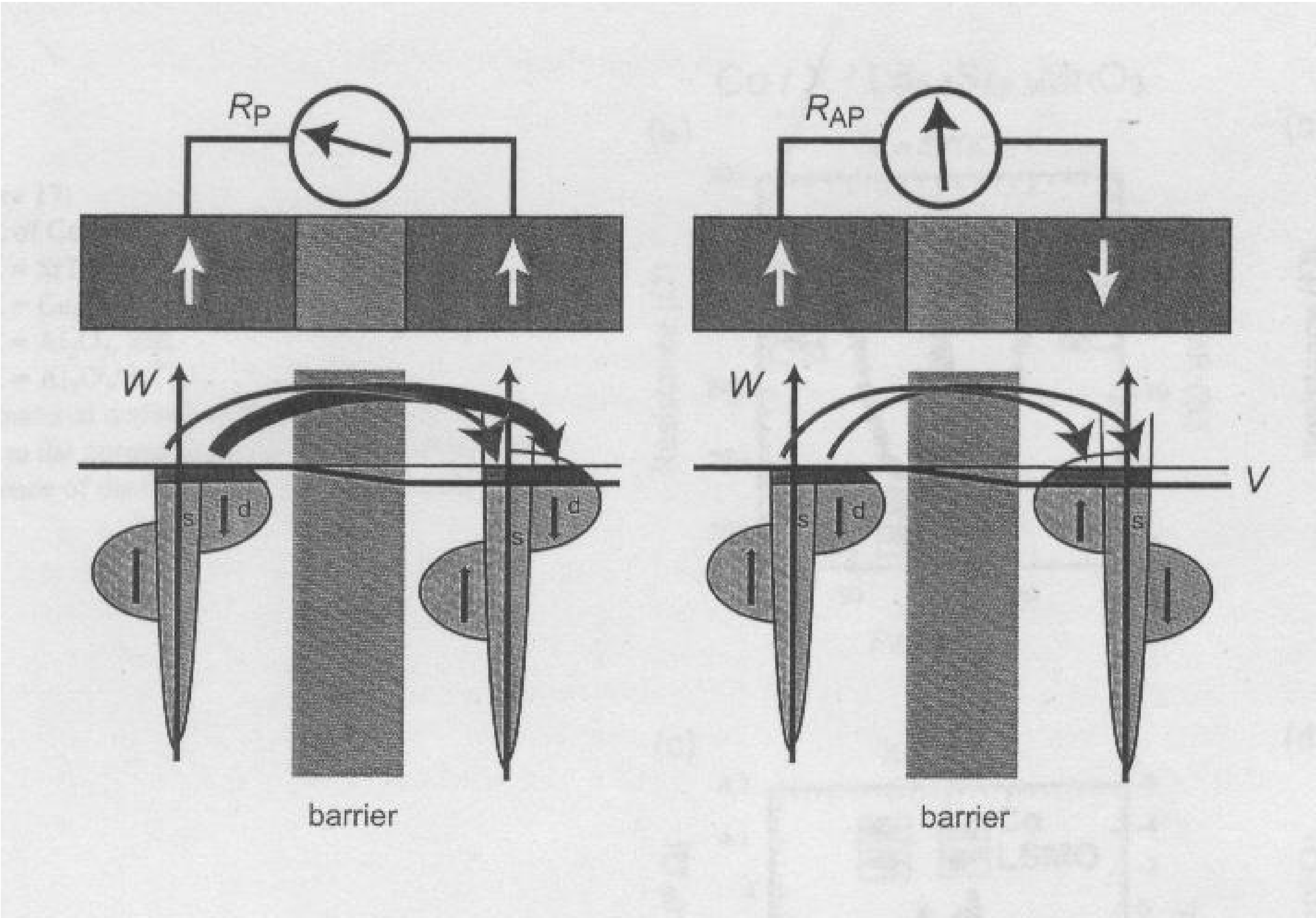
$\rho_{\uparrow} < \rho_{\downarrow}$

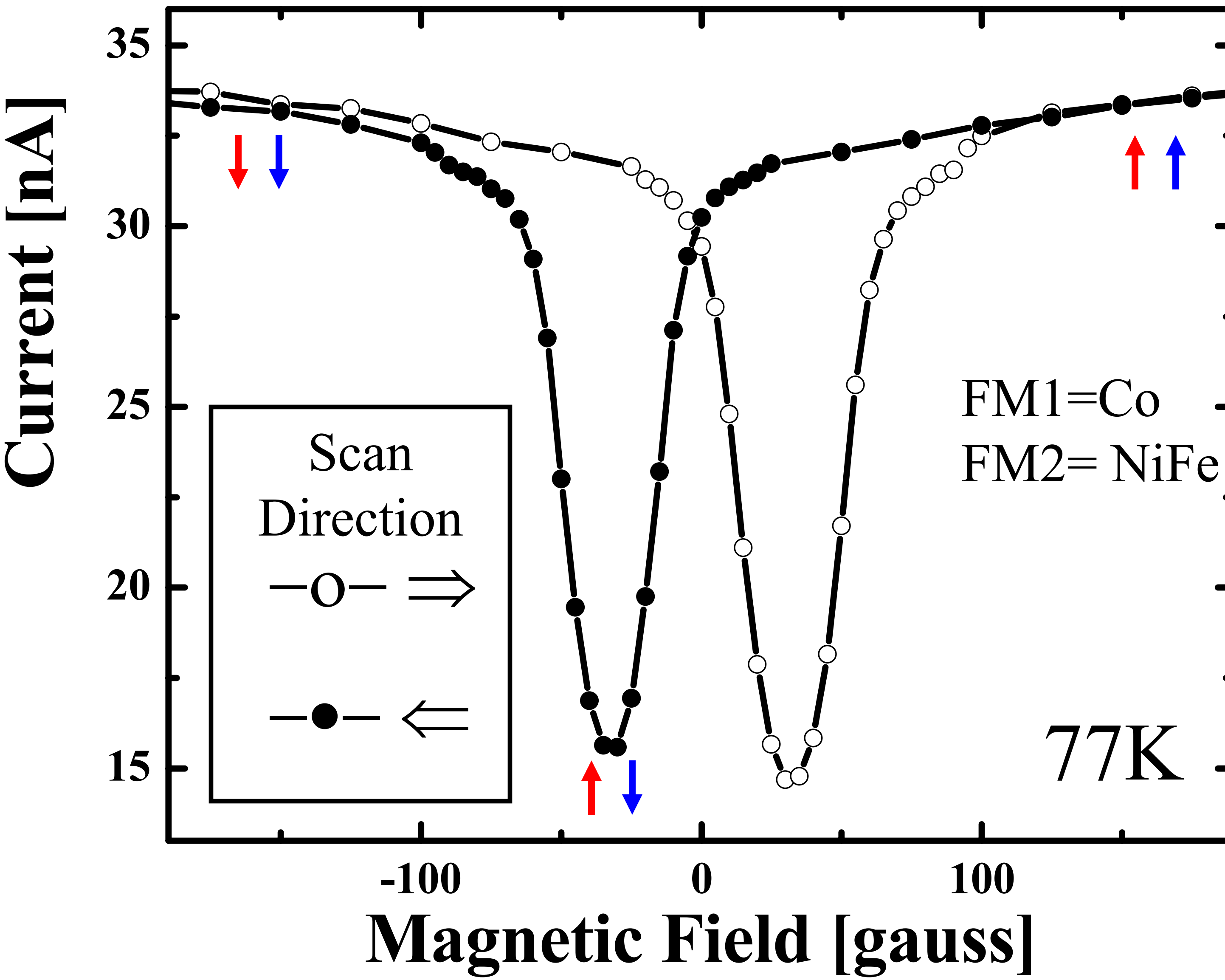
parallel



anti-parallel

Magnetic Tunnel Junctions





Current [nA]
35
30
25
20
15
-100
0
100
Magnetic Field [gauss]
Scan
Direction
FM1=Co
FM2= NiFe
77K

Magnetoresistance = ΔR/R

$$\Delta R/R = \frac{R_{AP} - R_P}{R_P}$$

$$R_P \sim \frac{V}{\uparrow\uparrow + \downarrow\downarrow} \qquad R_{AP} \sim \frac{V}{\downarrow\uparrow + \uparrow\downarrow}$$

$$\Delta R/R = \frac{\dfrac{1}{\downarrow\uparrow + \uparrow\downarrow} - \dfrac{1}{\uparrow\uparrow + \downarrow\downarrow}}{\dfrac{1}{\uparrow\uparrow + \downarrow\downarrow}} = \frac{\uparrow\uparrow + \downarrow\downarrow - \uparrow\downarrow - \downarrow\uparrow}{\downarrow\uparrow + \uparrow\downarrow}$$

$$= \frac{2(\uparrow - \downarrow)^2}{4\downarrow\uparrow} = \frac{2(\uparrow - \downarrow)^2}{(\uparrow + \downarrow)^2 - (\uparrow - \downarrow)^2} = \frac{\dfrac{2(\uparrow - \downarrow)^2}{(\uparrow + \downarrow)^2}}{\dfrac{(\uparrow + \downarrow)^2}{(\uparrow + \downarrow)^2} - \dfrac{(\uparrow - \downarrow)^2}{(\uparrow + \downarrow)^2}}$$

$$\text{Polarization } P = \frac{\uparrow - \downarrow}{\uparrow + \downarrow}$$

$$\Delta R/R = \frac{2P^2}{1-P^2}$$

Julliere's Formula