Spintronik
= Spin + Elektronik

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Elektronen-Spin und Magnetismus

Zwischenlagenkopplung

Spinabhängiger Widerstand – Magnetwiderstand

Magnetischer RAM

10. Sommerschule 2007

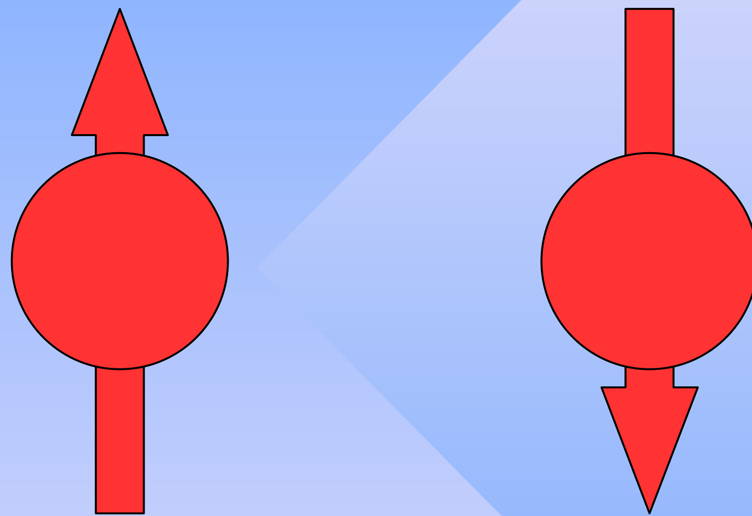
Der Elektronenspin

Spin = ½

Eigendrehimpuls

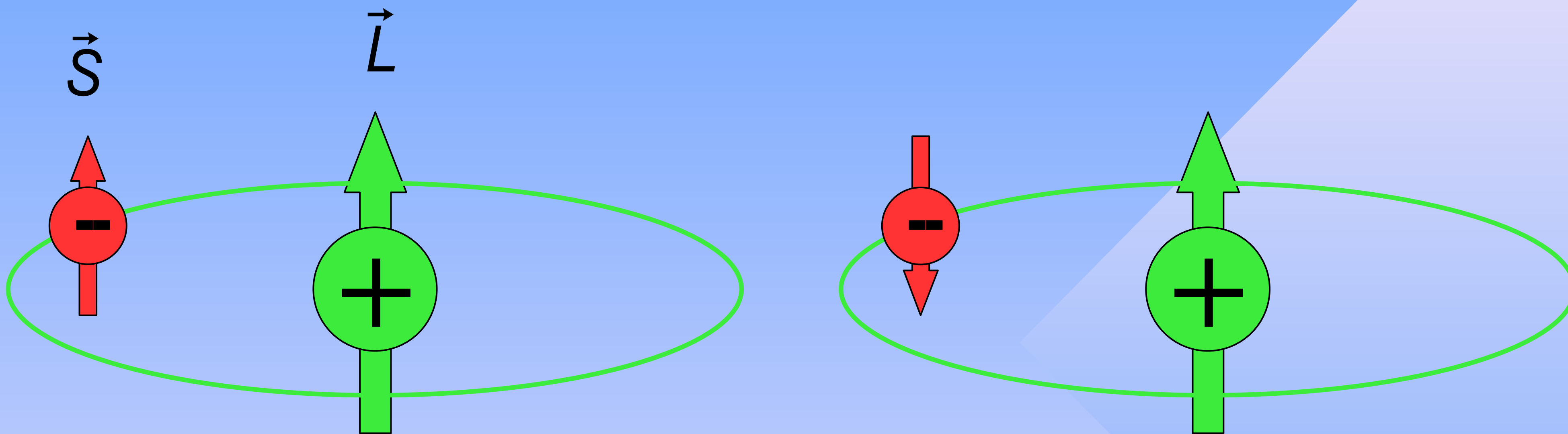
Wolfgang Pauli (1900-1958)

Nobelpreis 1945: „für die Entdeckung des Ausschlussprinzips, auch genannt das Pauli-Prinzip“



$m_s = 1/2$ $m_s = -1/2$

Spin und Bahndrehimpuls

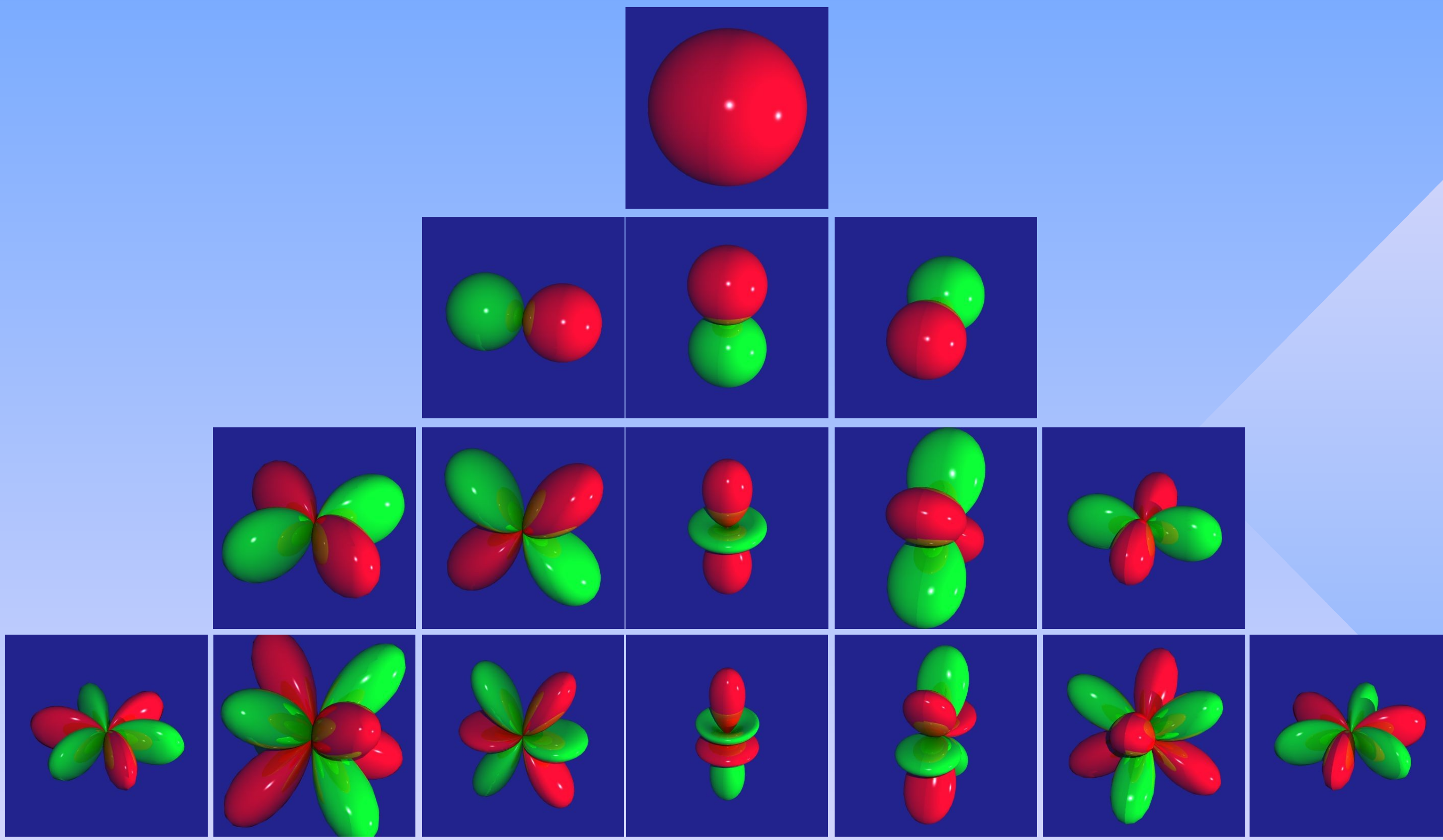


$\vec{S}\vec{L} > 0$ $\vec{S}\vec{L} < 0$

Spin-Bahn-Wechselwirkung

Atomare Orbitale

$m_s = \pm 1/2$



s 2

p 6

d 10

f 14

-3 -2 -1 0 1 2 3

m

http://web.uniovi.es/qcg/harmonics/harmonics.html

Periodensystem der Elemente

s: 2 | d: 10 | p: 6

Group

	I	II											III	IV	V	VI	VII	VIII
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds								

58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

f: 14

Legend

Li Solid · Cs Liquid · H Gas · Tc Synthetic

Alkali metals · Alkali earth metals · Transition metals · Rare earth metals

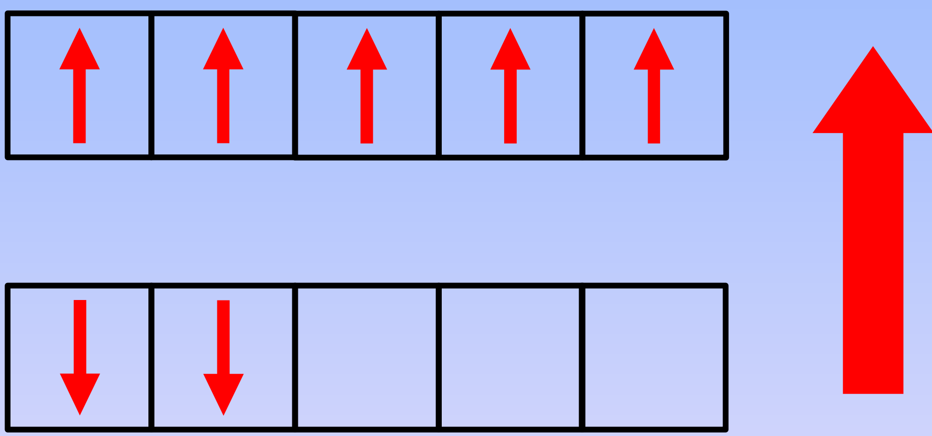
Other metals · Noble gases · Halogens · Other nonmetals

www.chemicool.com

Magnetismus: Hundsche Regel

Gesamtspin S maximal

Co $Z=27$ $1s^2$ $2s^2\ 2p^6$ $3s^2\ 3p^6$ $\mathbf{3d^7}$ $4s^2$ Kobalt

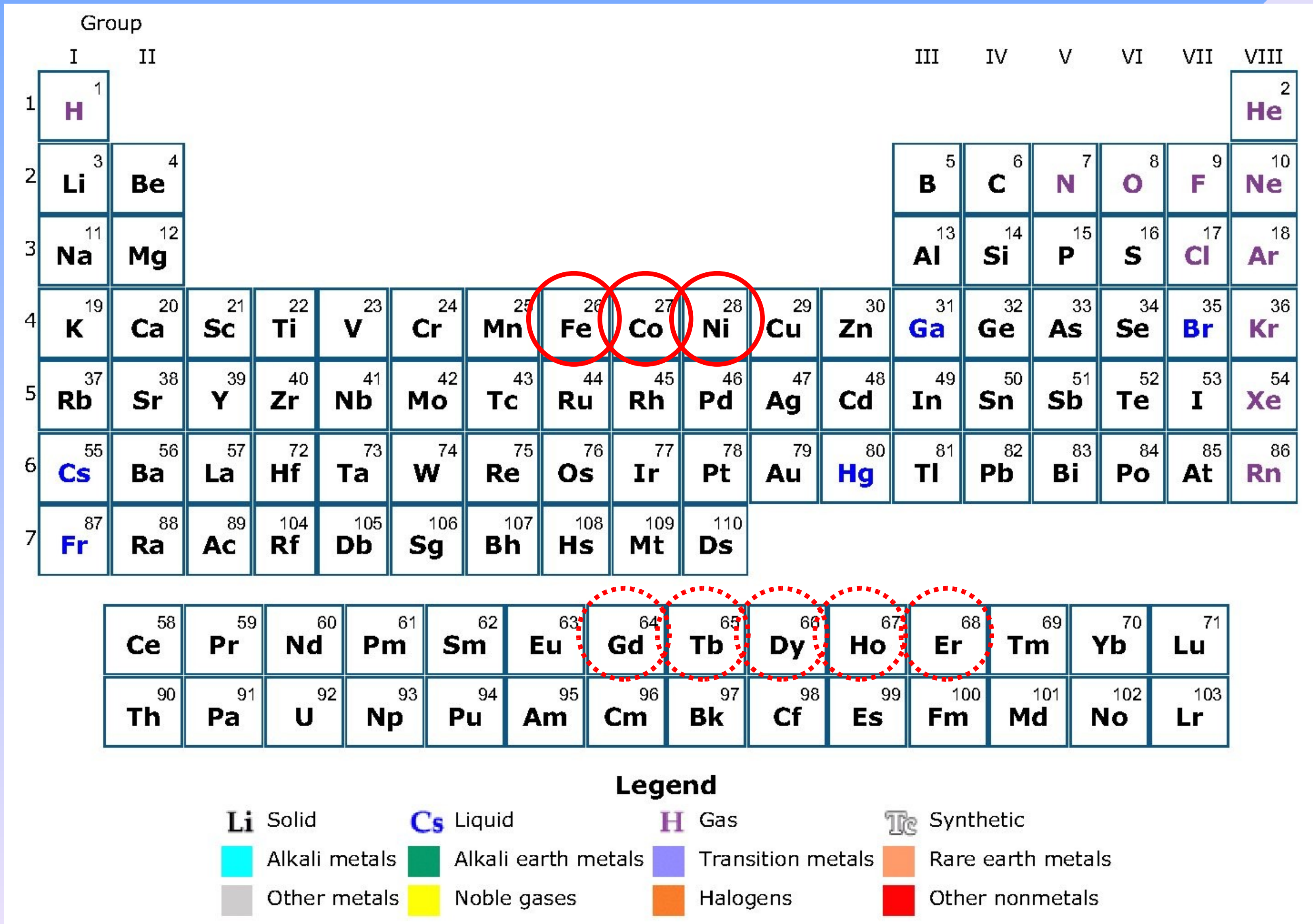


$$\mu_{Atom} = 3$$

Festkörper $\mu = 1.6\mu_B$

Friedrich Hund 1896-1997

Magnetische Elemente



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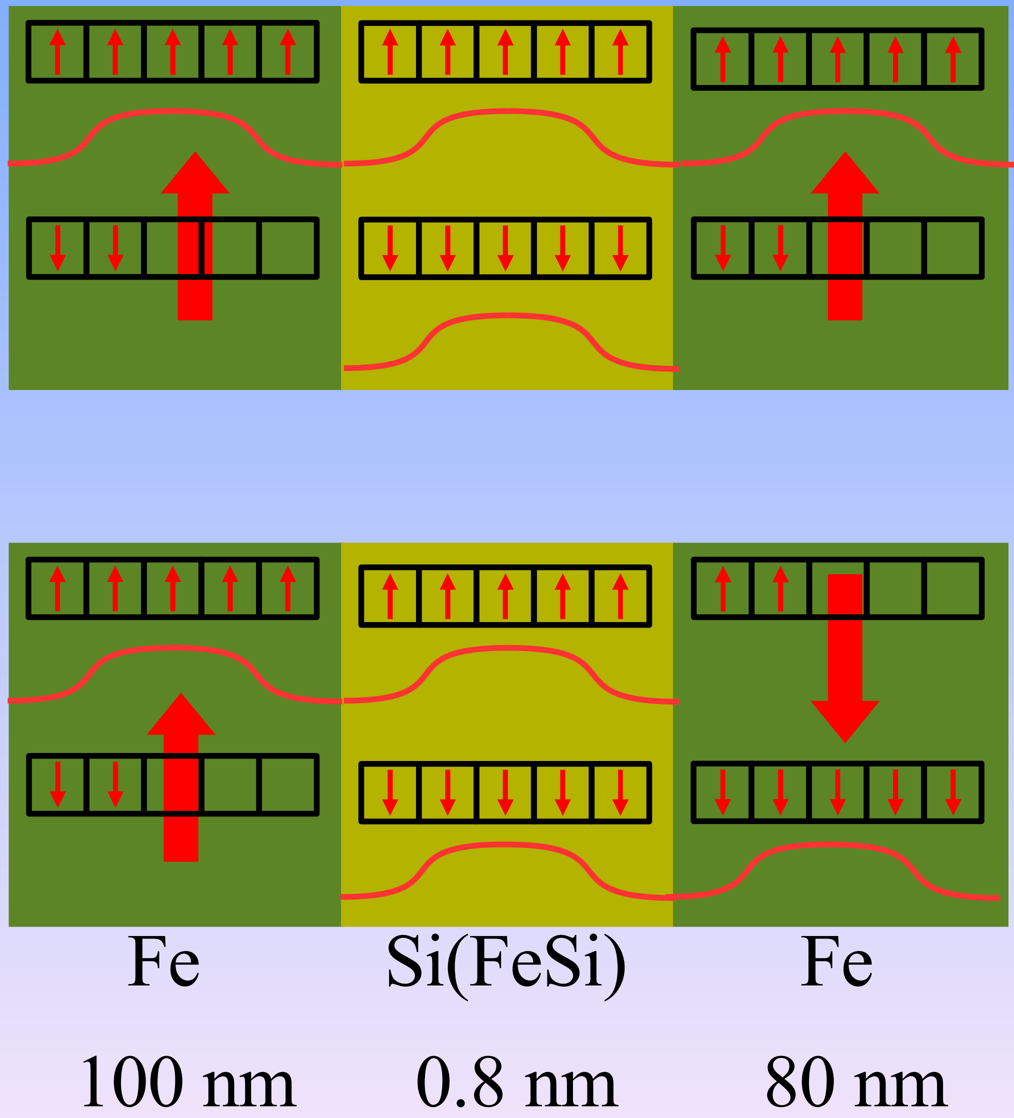
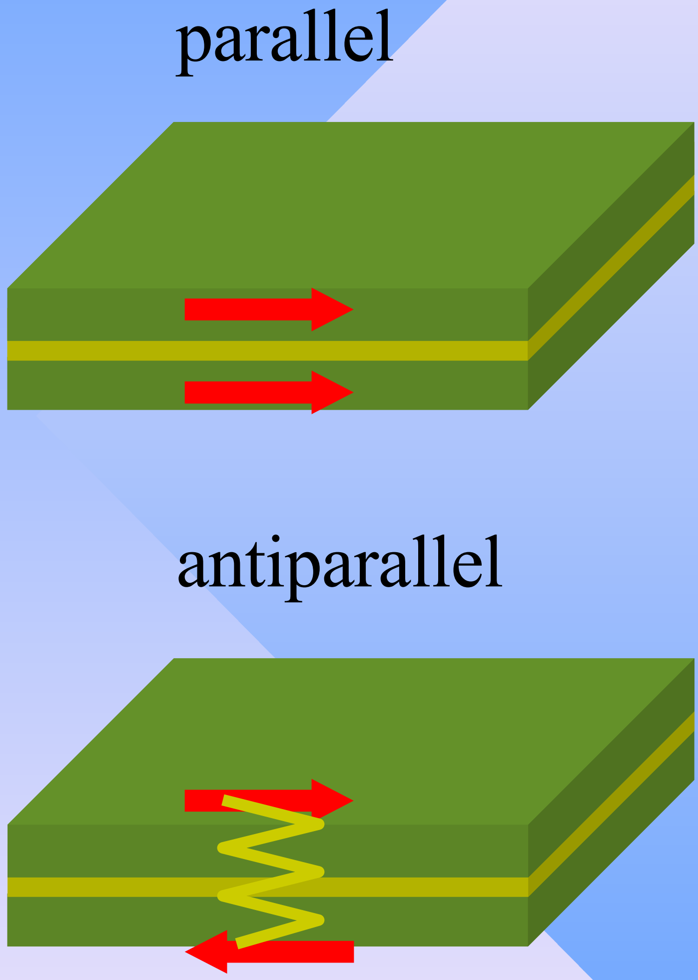
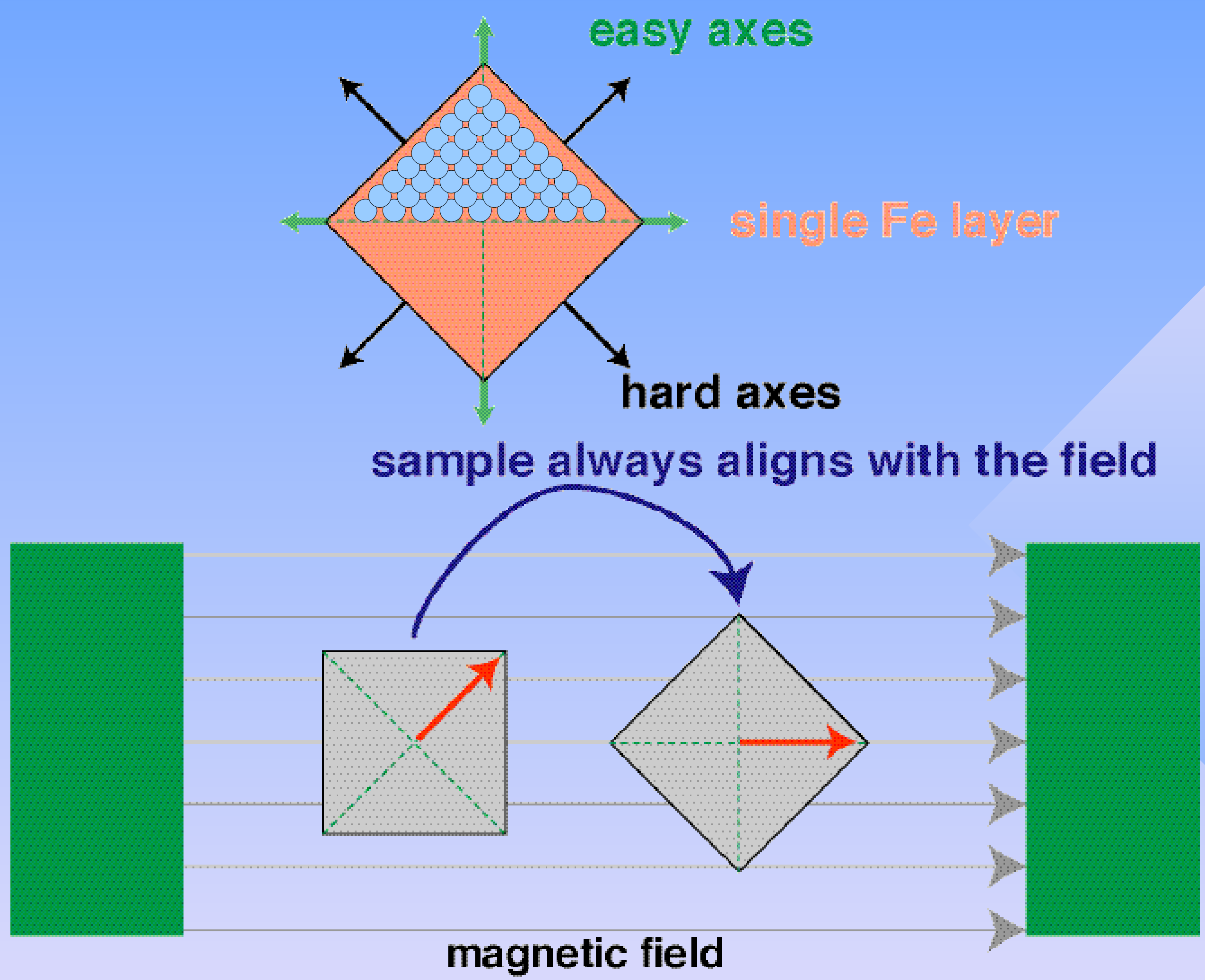
Schichtsysteme: Magnetische Zwischenlagenkopplung 1986

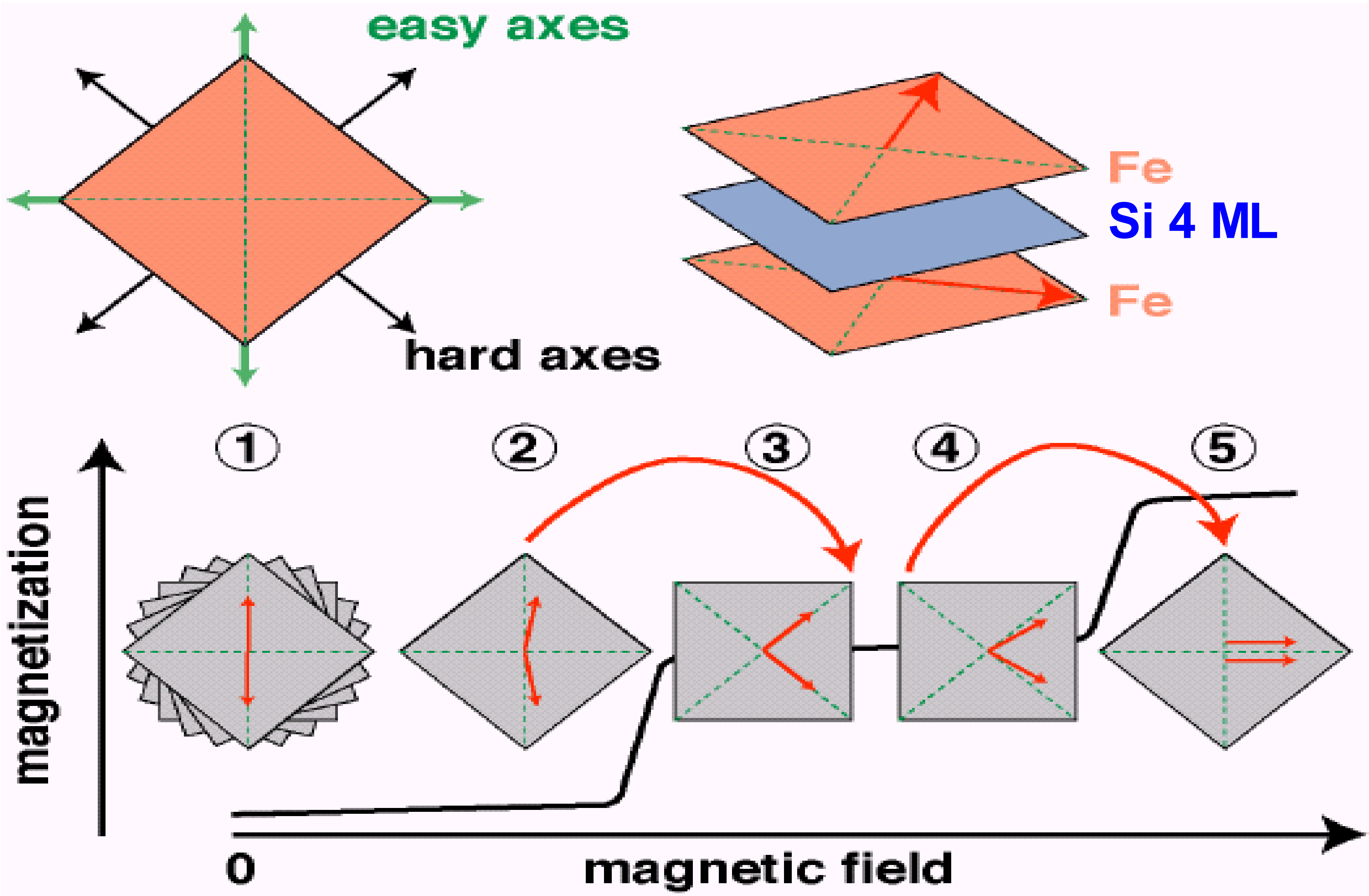




Der normale Kompass (D. Bürgler, FZ Jülich)

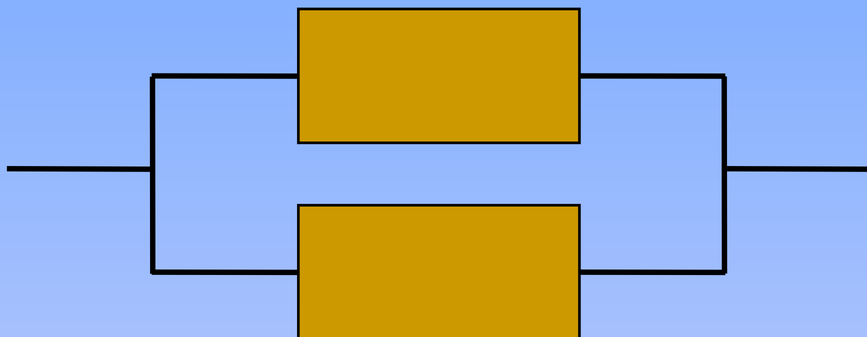


"The crazy compass" (D. Bürgler, FZ Jülich)



Spinabhängiger Widerstand

Nichtmagnetisch Metalle — Al Cr Cu Ru Pt

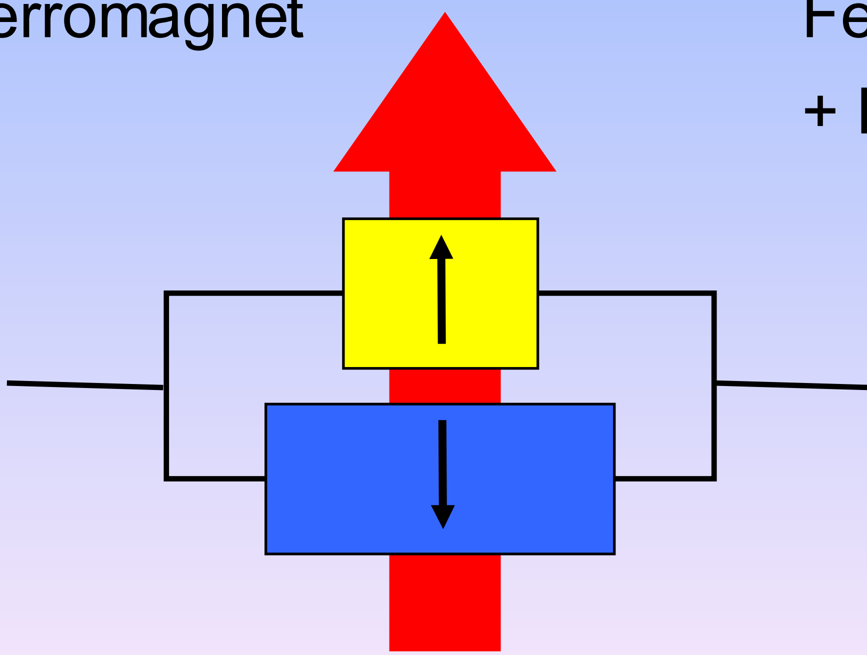


1826

Georg Simon Ohm 1789-1854

Ferromagnet — Fe Co Ni

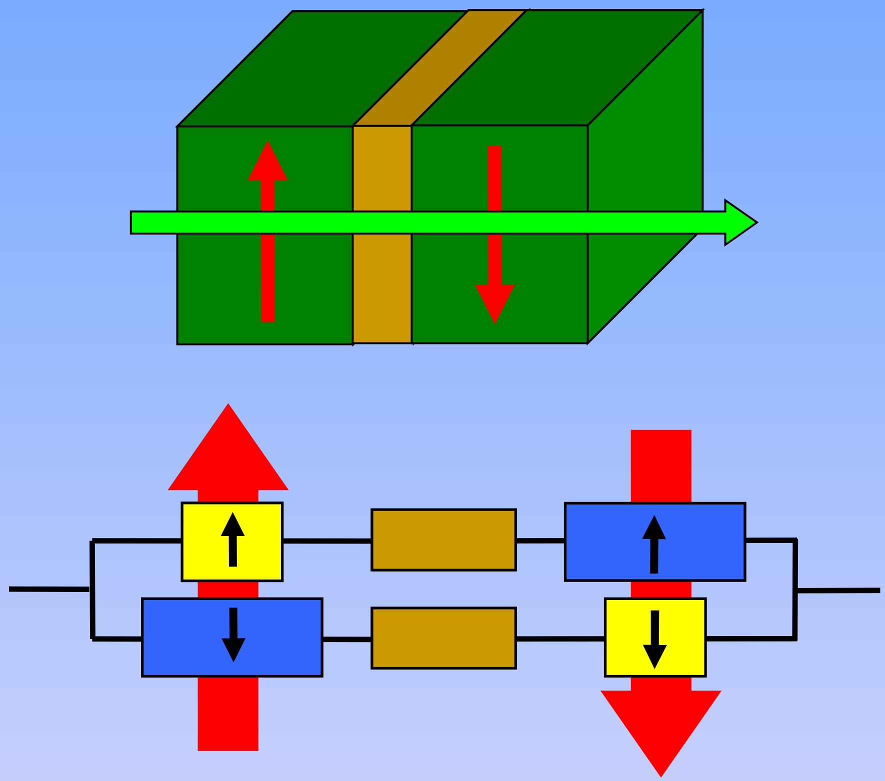
+ Legierungen

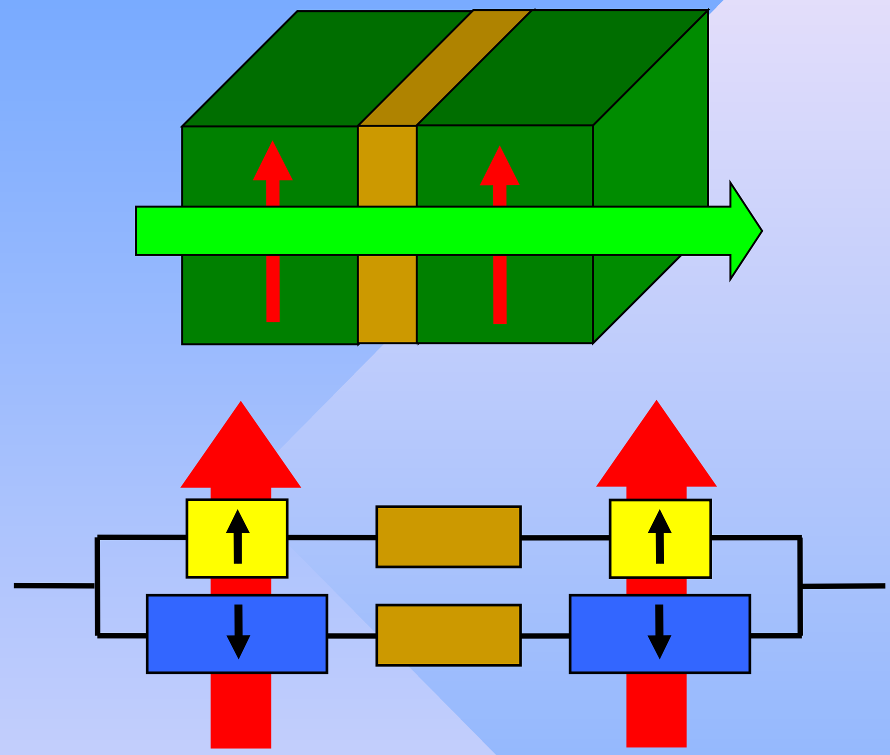


1964

Sir N. F. Mott

Supermagnetwiderstand





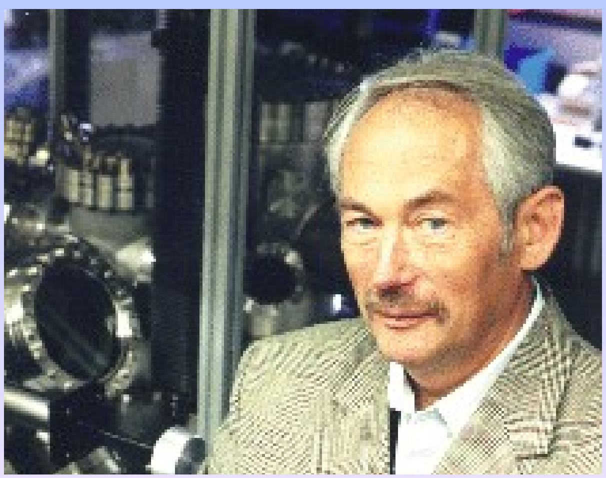
$$R^{AP} \quad > \quad R^{P}$$

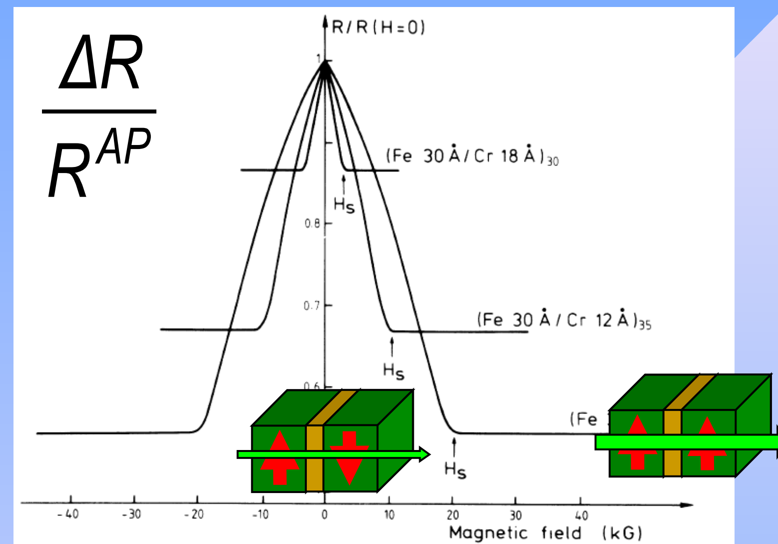
$$\frac{\Delta R}{R^{P}} \quad oder \quad \frac{\Delta R}{R^{AP}}$$

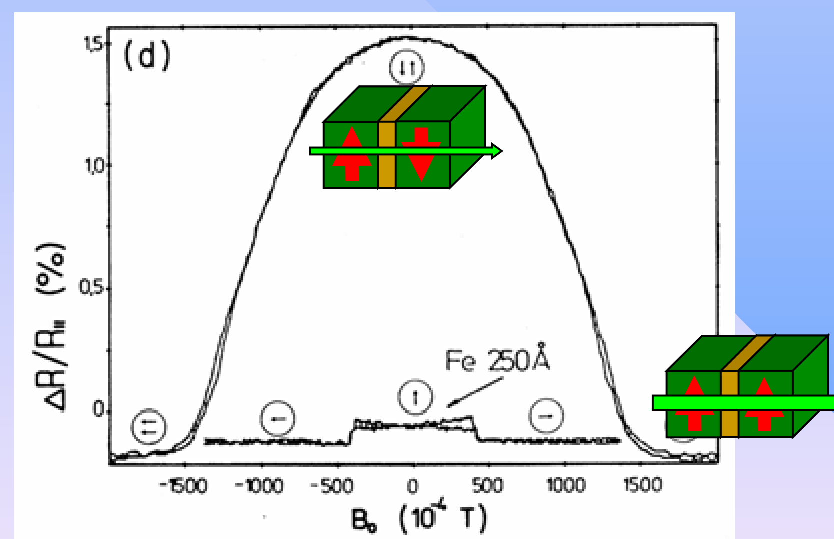
Supermagnetwiderstand
GiantMagnetoResistance (GMR) 1988

Albert Fert, Paris

Peter Grünberg, Jülich

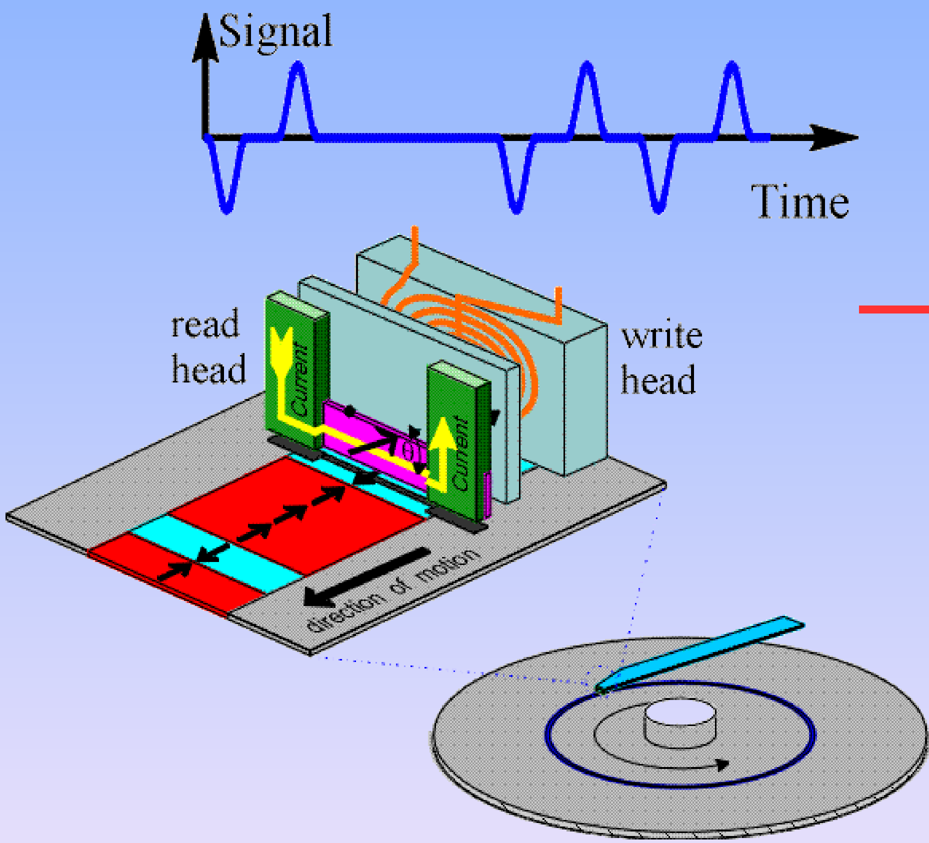


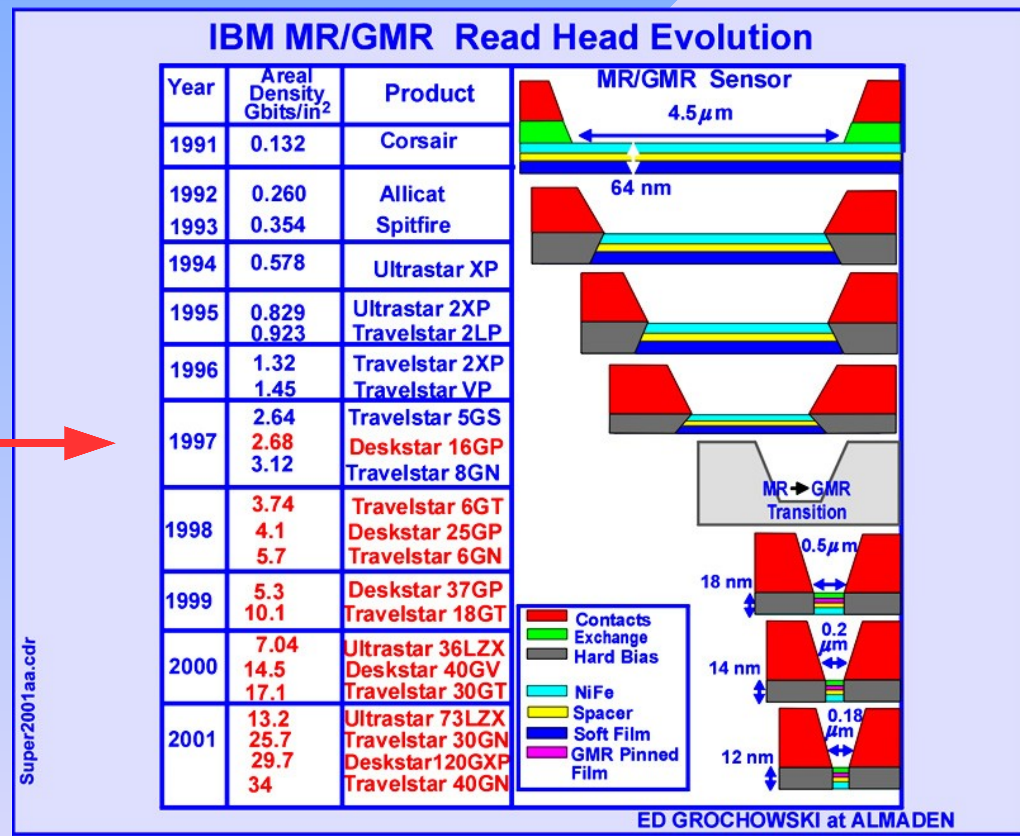




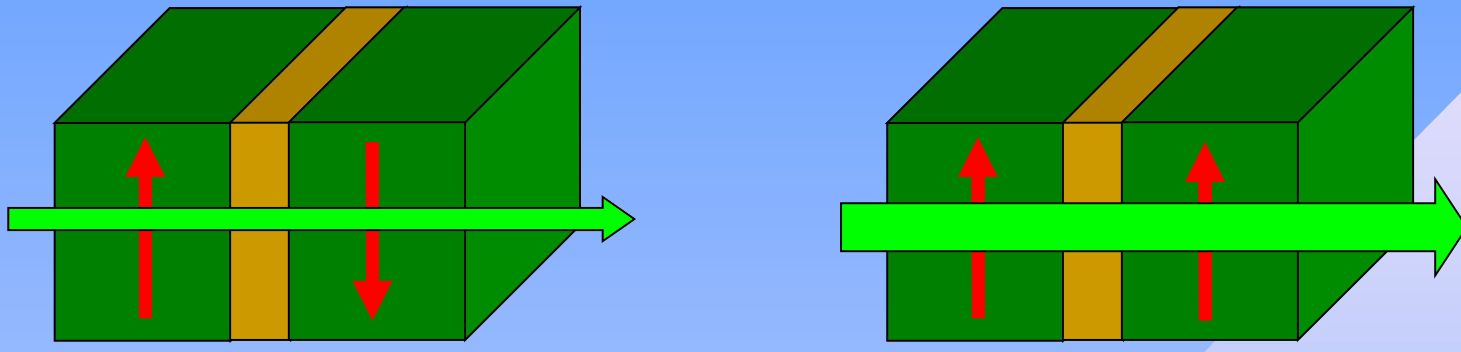
A. Fert et al. Phys. Rev. Lett. **61**, 472 (1988), P. Grünberg et al., Phys. Rev. B **39**, 4828 (1989)

Anwendung von GMR Elementen in Festplatten-Leseköpfen



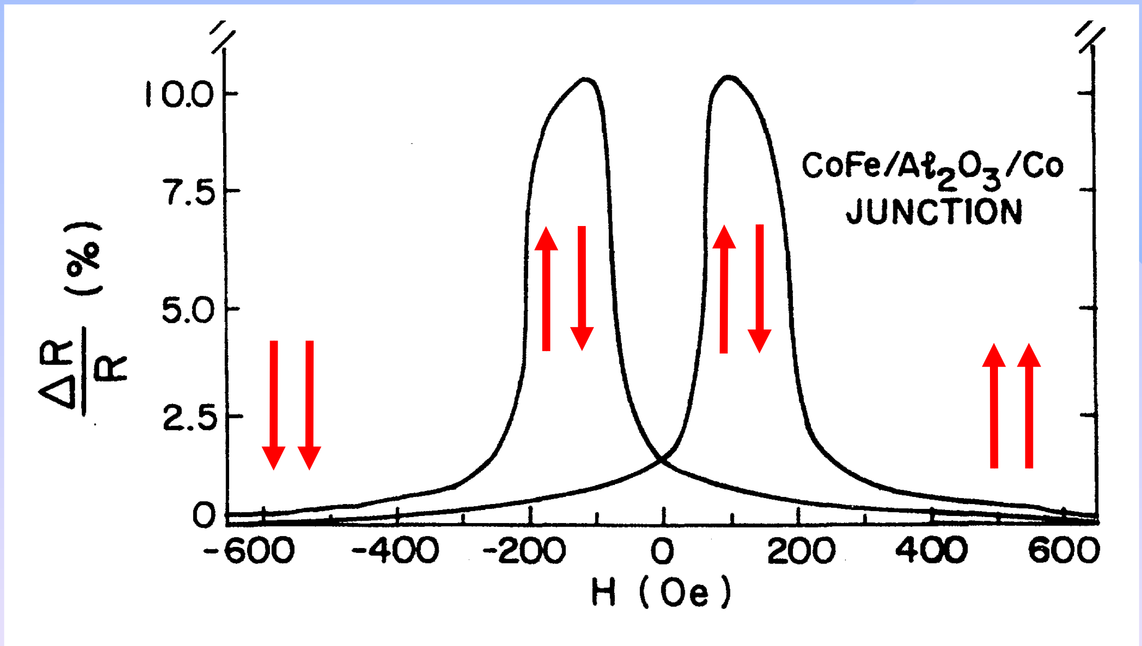


Tunnel-Magnetwiderstand (TMR)



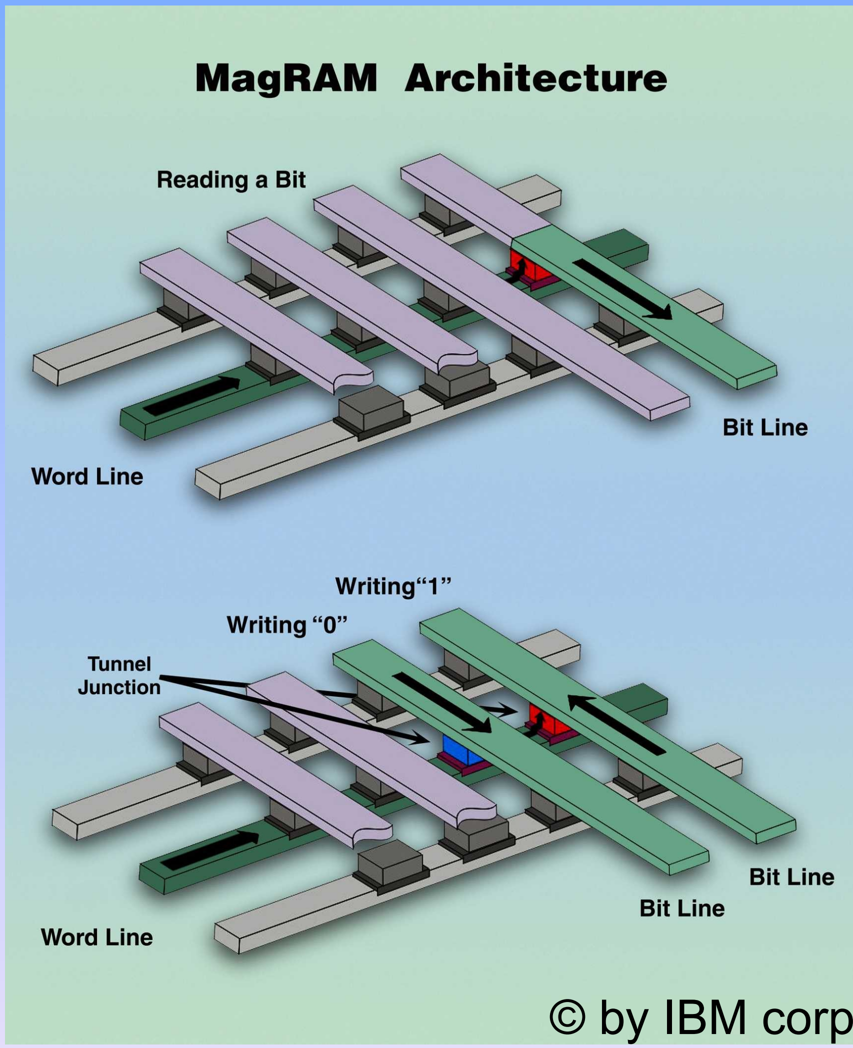
Isolierende Barriere

z.B. MgO, Al_2O_3



J. Moodera et al., PRL **74**, 3275 (1995)

Magnetic Random Access Memory (MRAM)



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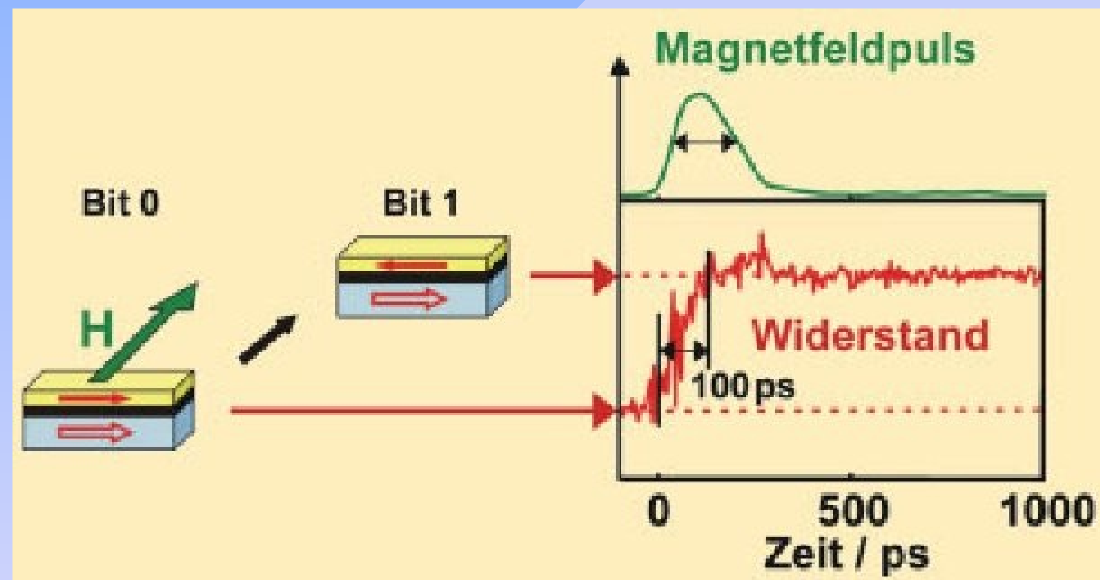
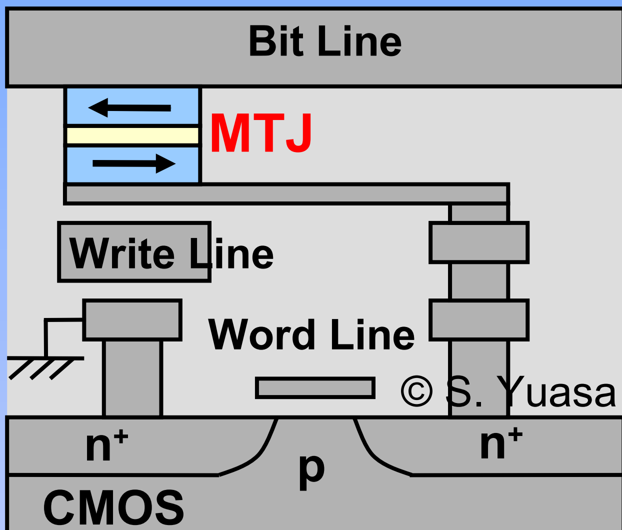


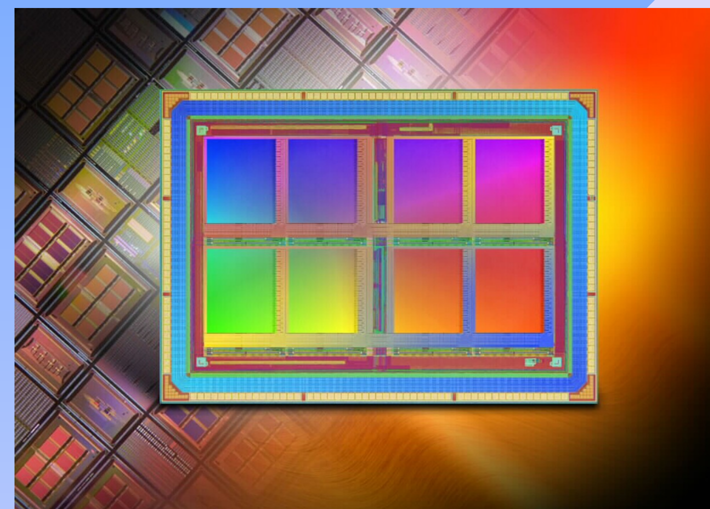
J. Fassbender et al., Physik in unserer Zeit (2003)

MRAM: Aufbau und Eigenschaften



Querschnitt

MTJ = magnetic tunnel junction

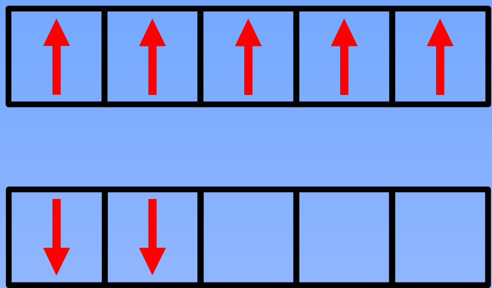


Freescale's 4 Mbit-MRAM

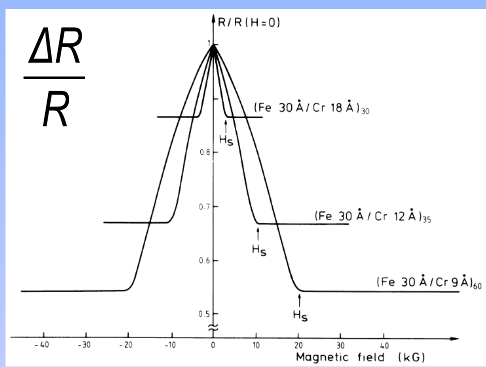
Volume production (2006)

Nichtflüchtigkeit	**10 Jahre**
Zugriffszeit	**< 1 nsec**
Lese-/Schreibzyklen	**10^{16}**
Energieverbrauch	**160mW/256kB (SDRAM 280 mW)**

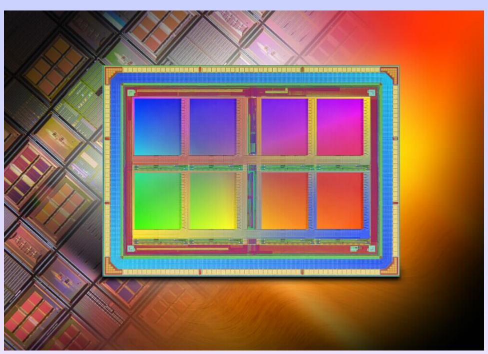
Zusammenfassung



- Magnetismus wird durch die Ausrichtung der Spins der Elektronen verursacht.



- In magnetischen Nanostrukturen treten neue Phänomene auf, z.B. Zwischenlagenkopplung und Supermagnetwiderstand.



- Neue MRAM-Speicherzellen werden
  - leistungsfähiger,
  - kleiner und
  - energiesparender.