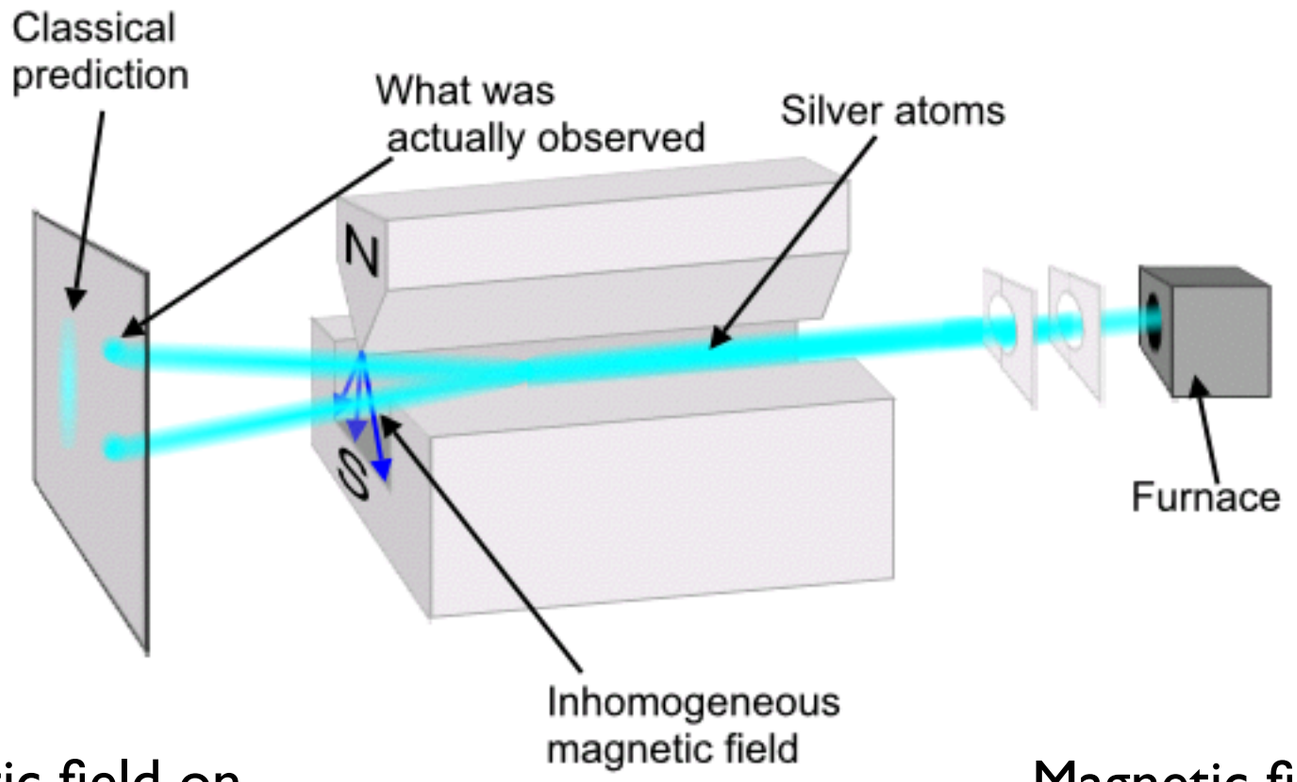
Spin in Stern-Gerlach experiment

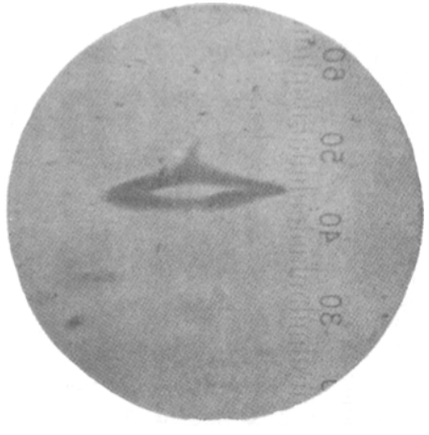
Der experimentelle Nachweis der Richtungsquantelung im Magnetfeld.

Von **Walther Gerlach** in Frankfurt a. M. und **Otto Stern** in Rostock.

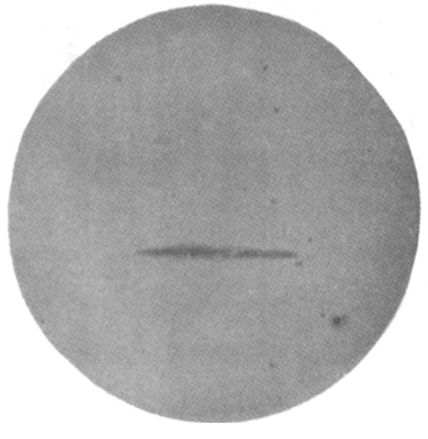
Mit sieben Abbildungen. (Eingegangen am 1. März 1922.)



Magnetic field on

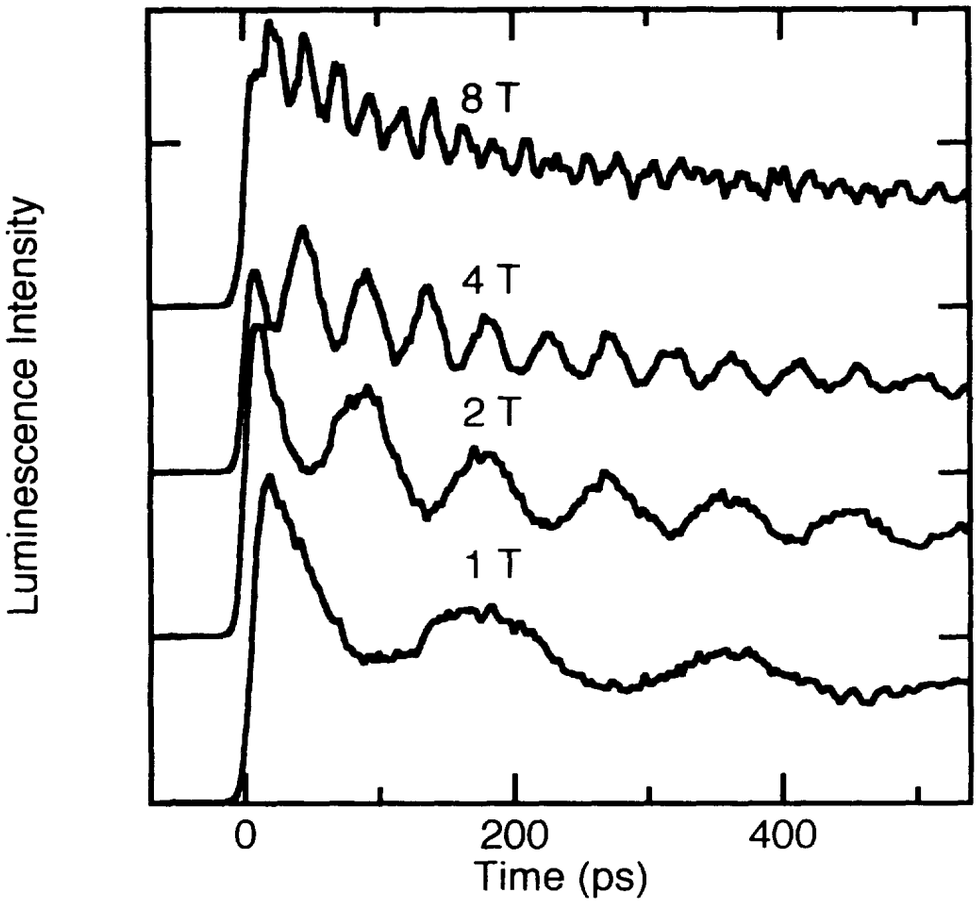


Magnetic field off



Spin precession in solid state devices: recombination of photo-excited spin-polarised electrons

$$\Omega_L = g\mu_B B/\hbar = eB/m \cdot g/2$$



- long spin coherence times (500 ps)
- determination of Lande *g*-factor (here, on a quantum well)

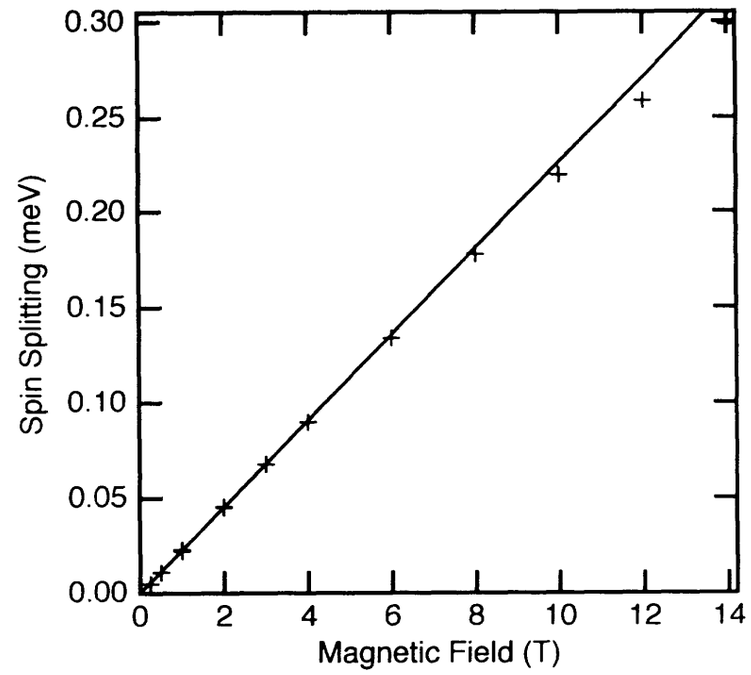
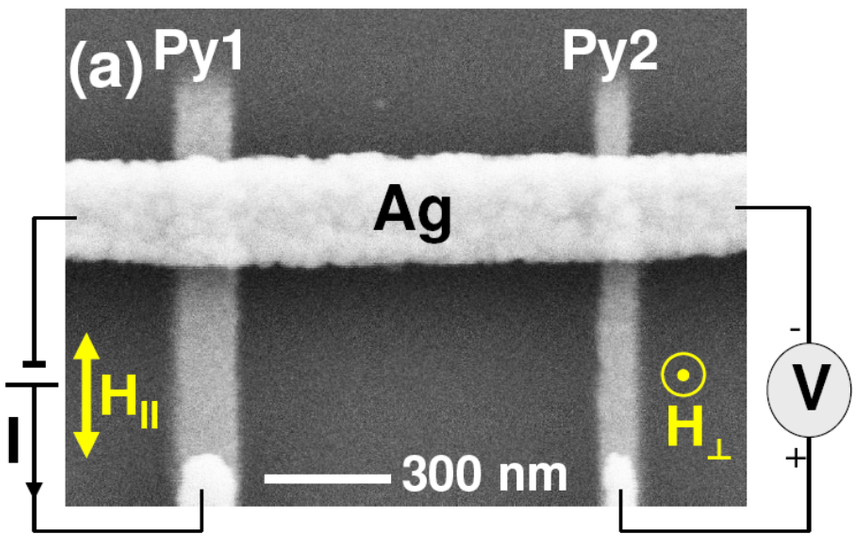
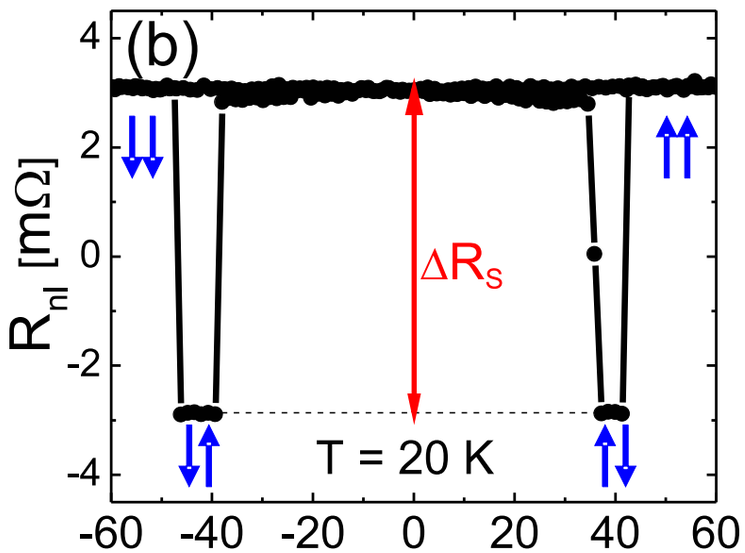


FIG. 4. Dependence of the electron spin splitting on the applied magnetic field (crosses), and spin splitting expected for a constant g factor of -0.390 (line).

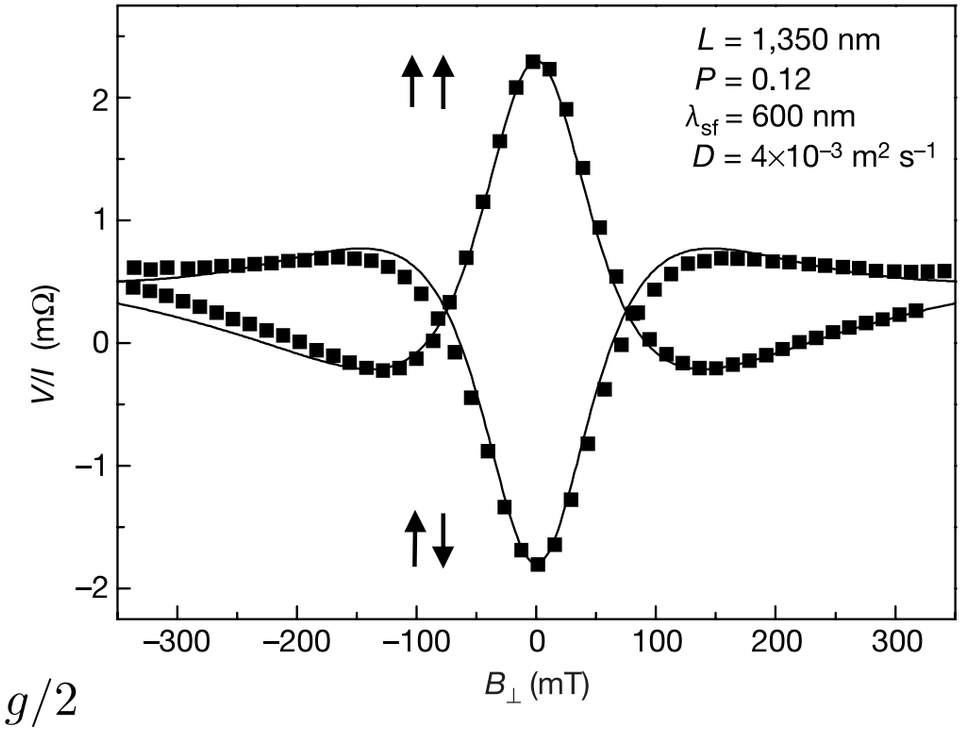
Spin precession in solid state devices: Hanle effect





Original idea probably by Johnson & Silsbee, PRL 55, 1790 (1985)

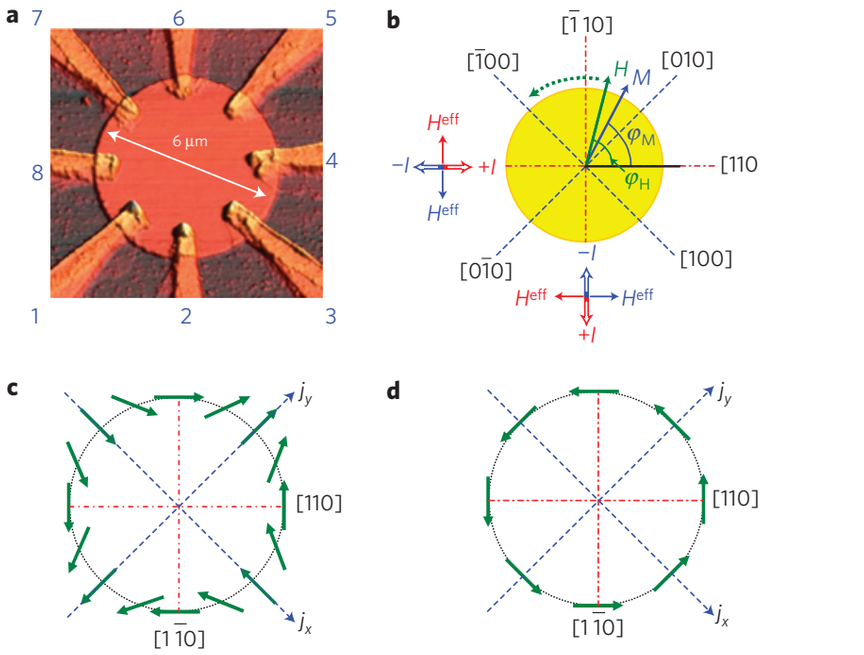
- spin injection - left FM contact
- non-local detection on the right

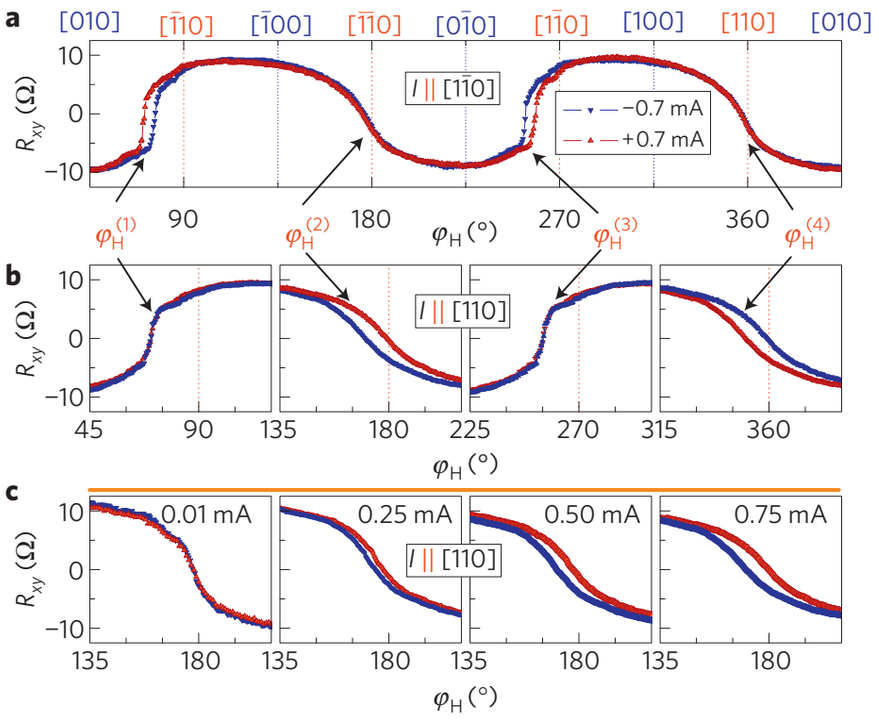


$$V(B_\perp) = \pm I \frac{P^2}{e^2 N_{\mathrm{Al}} A} \int_0^\infty P(t) \cos(\omega_{\mathrm{L}} t) \exp(-t/\tau_{\mathrm{sf}}) \mathrm{d}t$$

$$P(t) = \frac{1}{\sqrt{4\pi D t}} \exp[-L^2/4Dt] \qquad \Omega_L = g\mu_B B/\hbar = eB/m \cdot g/2$$

Spin polarisation in response to el. field: Edelstein effect



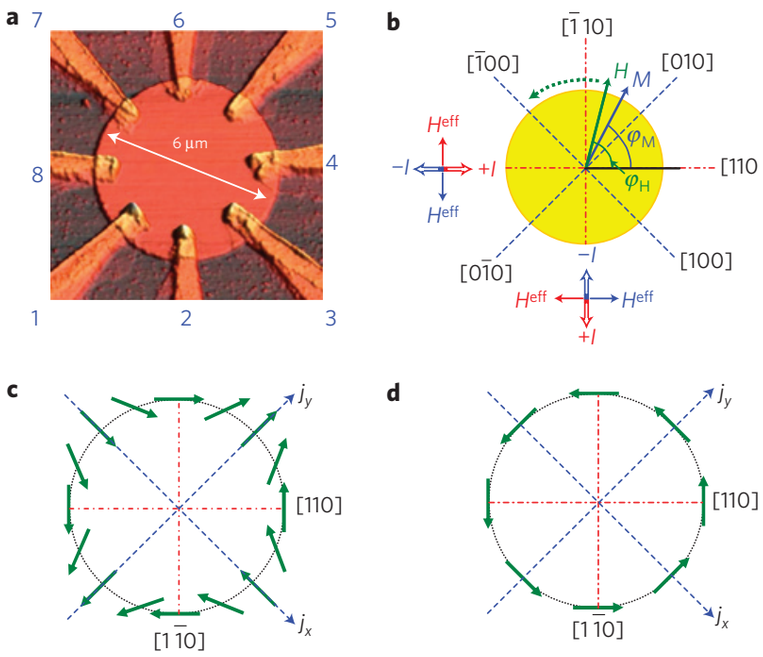


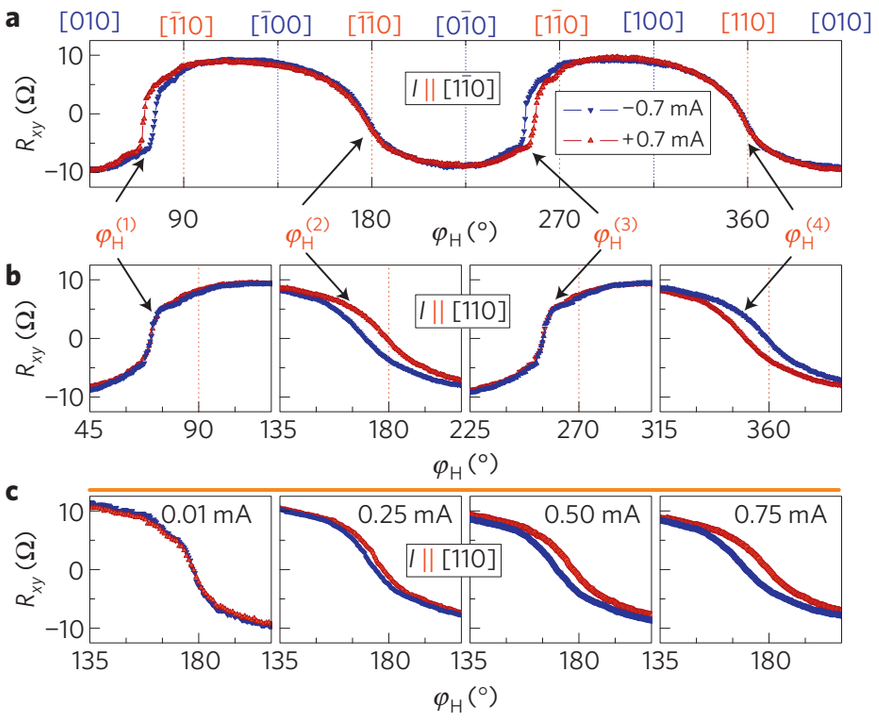
- ferromagnetic film
- magnetic field rotated in-plane
- “usual” response (t-AMR):

$$R_{xy} = R_0 C_I \sin 2\phi_H$$

- deviations due to magnetic anisotropy
- moreover, hysteresis…

Spin polarisation in response to el. field: Edelstein effect





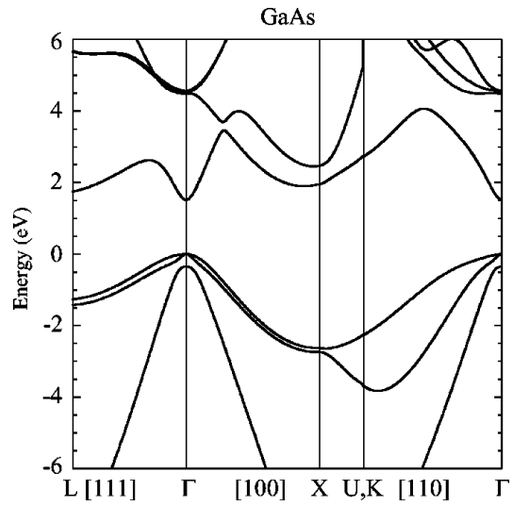
… action on magnetic moments

$$\vec{T} = \frac{J_{ex}}{\hbar}\vec{m} \times \vec{M}$$

in the context of s-d type Hamiltonian

$$H = H_{KL} + h\hat{e}_M \cdot \mathbf{s}$$

… as applicable to (Ga,Mn)As



- ferromagnetism ind. by carriers
- Mn d-states coupled to hole p-states (carrier)

$$H = H_{KL} + J_{pd}\sum_{i,I}\vec{S}_I \cdot \vec{s}_i\delta(\vec{r}_i - \vec{R}_I)$$

Topics for the bonus lecture (role of spin in transport):

- multilayers (GMR, TMR…)
- SOI-related effects:
  - ✦ Edelstein effect, SOT
  - ✦ AMR (and AHE)
  - ✦ SHE, QSHE (topological insulators)

Abbreviations explained: giant/tunneling magnetoresistance (GMR/TMR), spin-orbit interaction (SOI), anomalous Hall effect (AHE), anisotropic magnetoresistance (AMR) and (quantum) spin-Hall effect (Q)SHE.