Rashba effect: Spin splitting of surface and interface states

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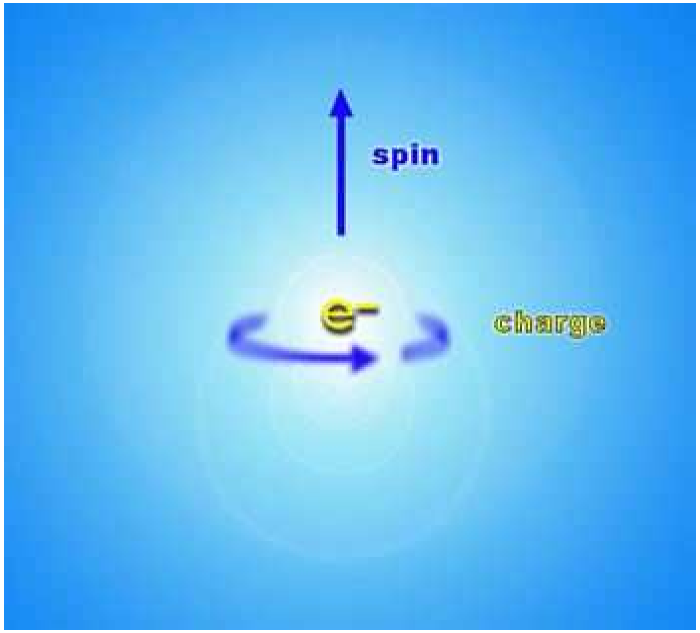
Outline

- Introduction
  - electron spin
  - Zeeman effect
  - spin-orbit coupling
- Rashba effect in semiconductor heterostructures
  - structural inversion asymmetry results in spin splitting
  - basis for spin-dependent transport effects
- Rashba effect at (metal) surfaces
  - basic setup & discovery
  - STM study of effect
- Discussion

Introduction: Spin, Zeeman effect & spin-orbit coupling

Electron spin

- electron = charge + spin



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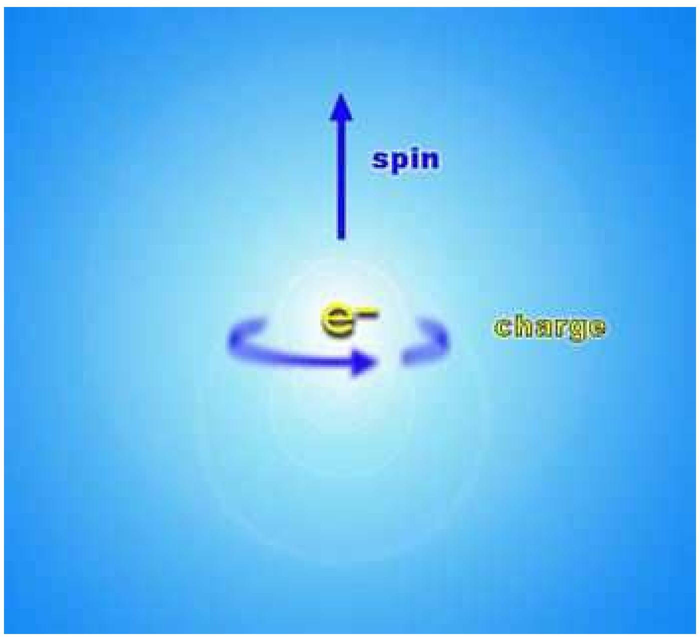

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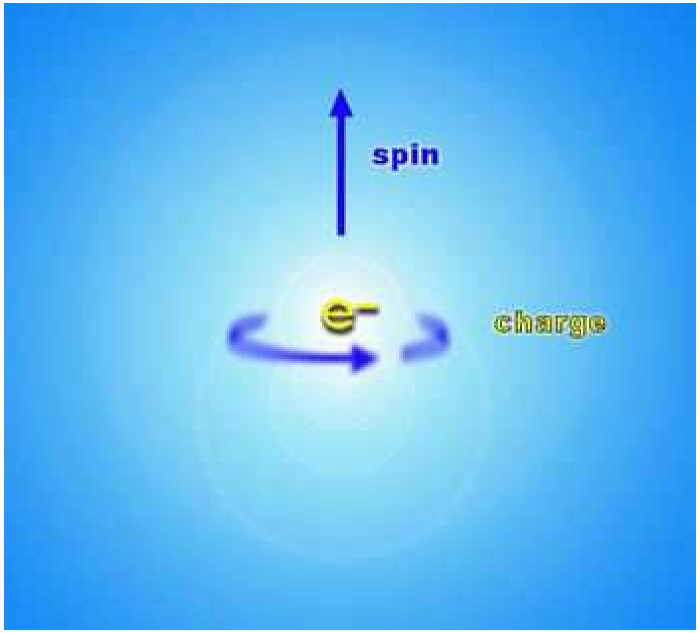
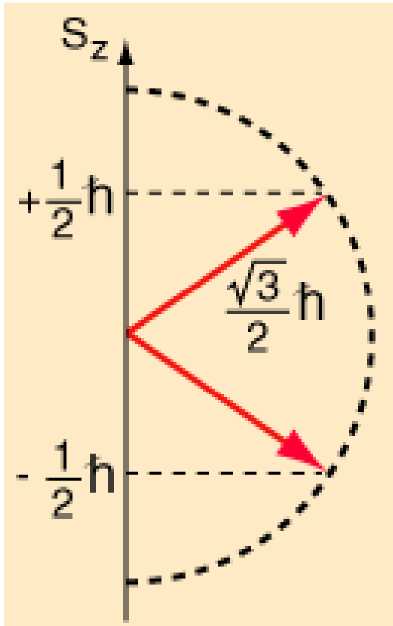
  - quantum discreteness of spin projection: electrons come in two flavours (spin-up ↑ or spin-down ↓)





Magnetic moment due to spin

- microscopic magnetic dipole associated with spin

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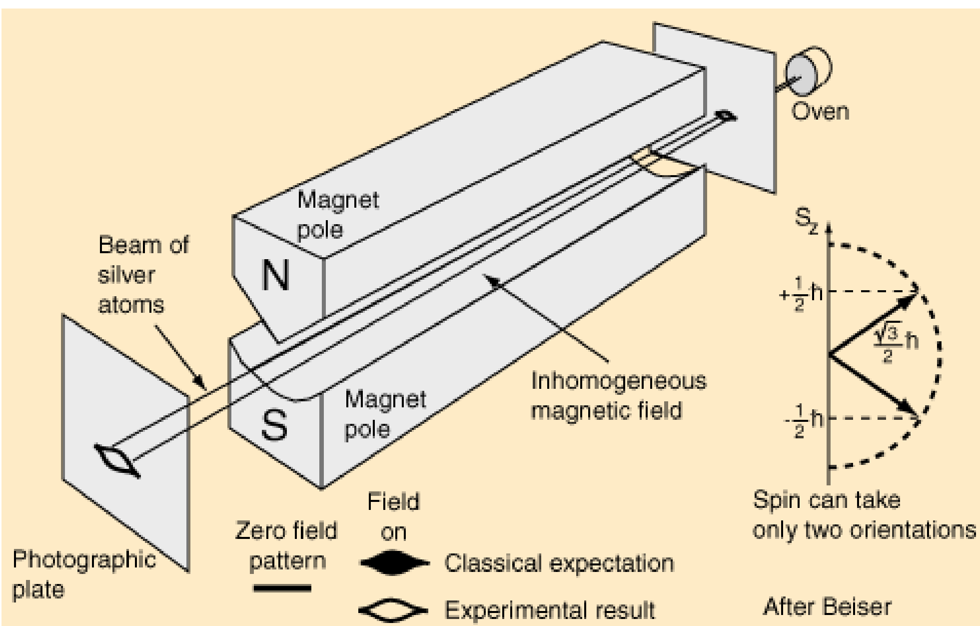

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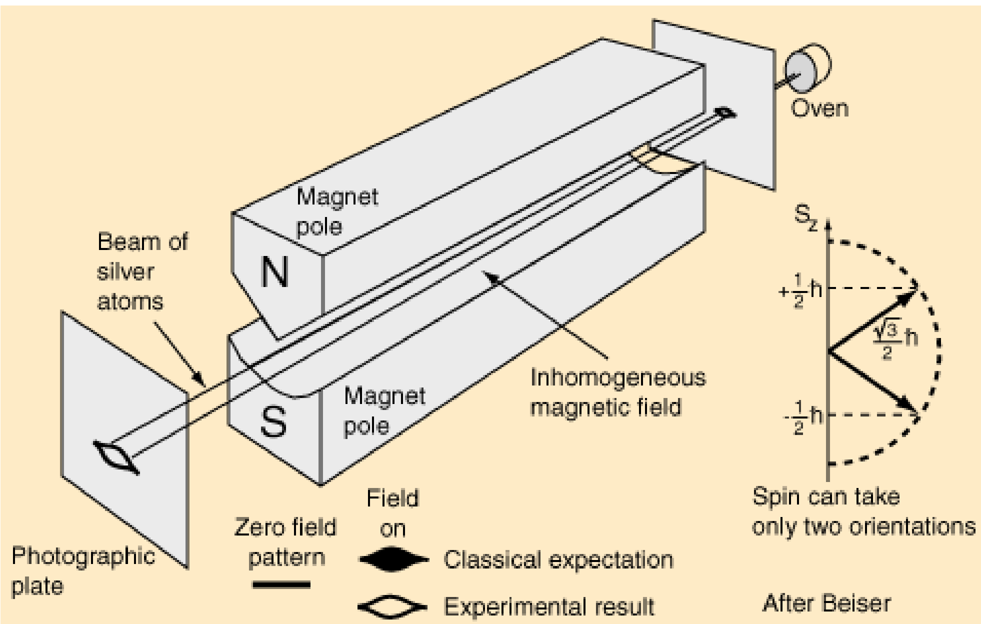

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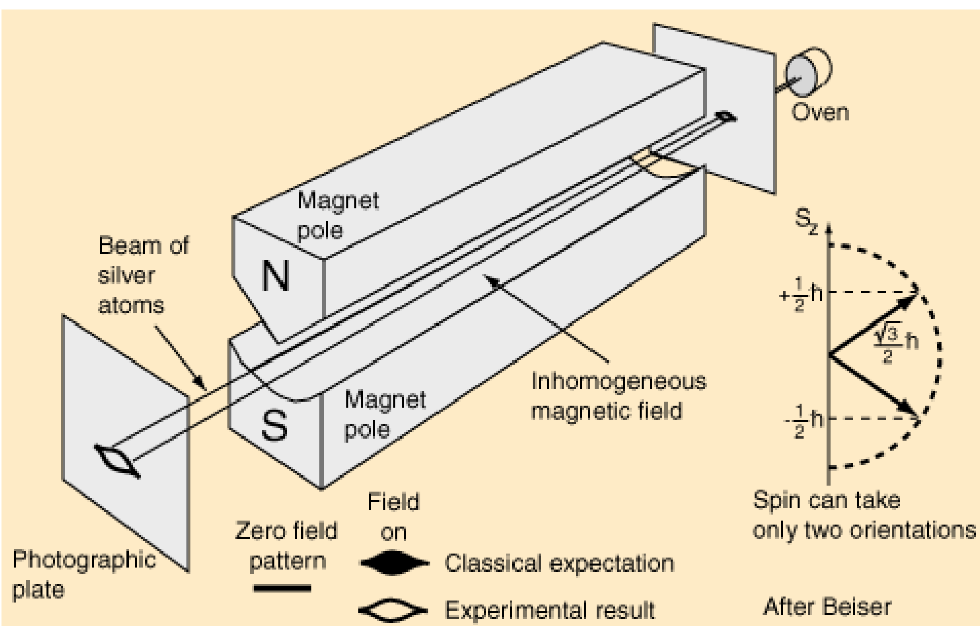
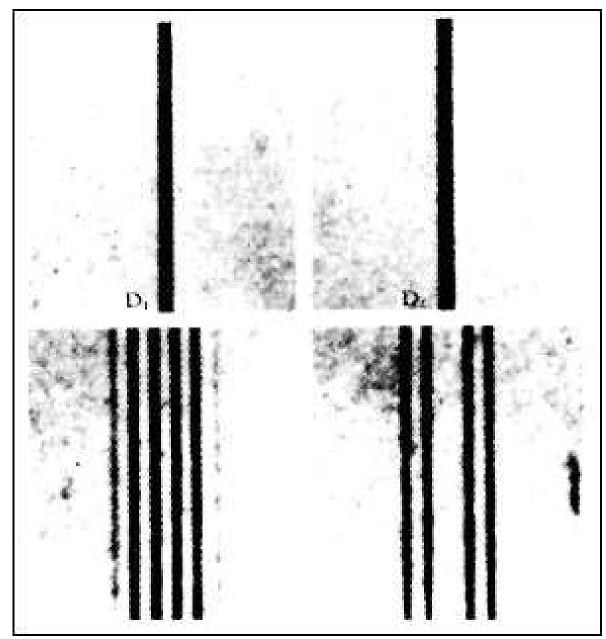
- energy splitting between the two spin states in a magnetic field: Zeeman spin splitting of electron states in atoms





Electric fields interact with spin

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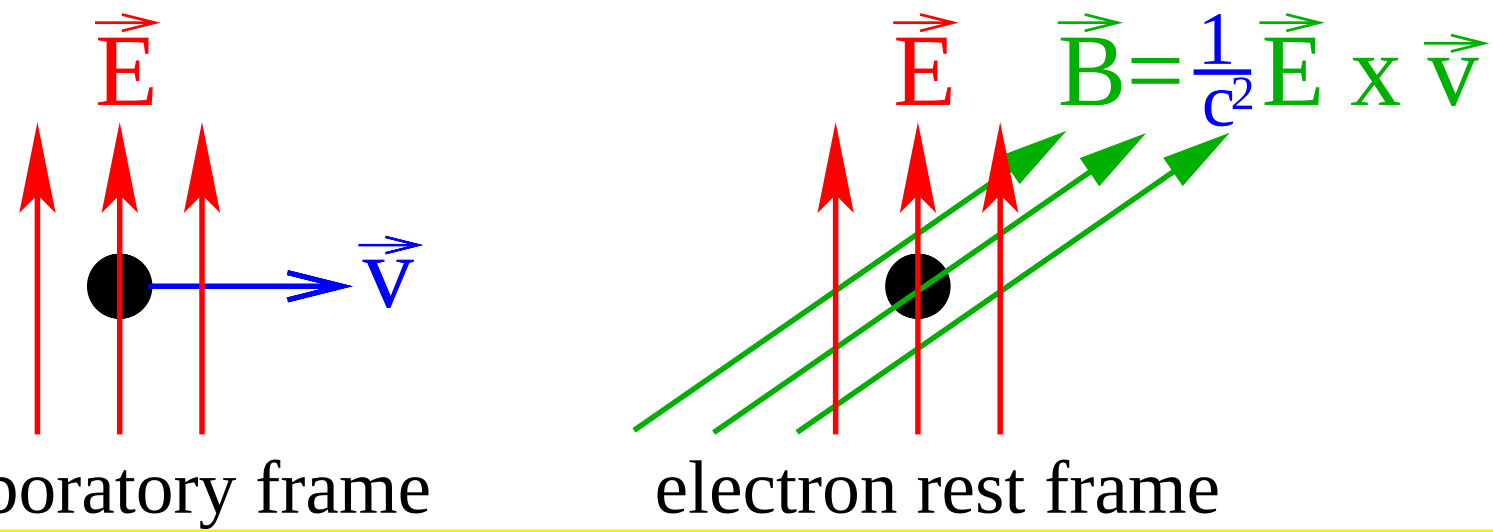

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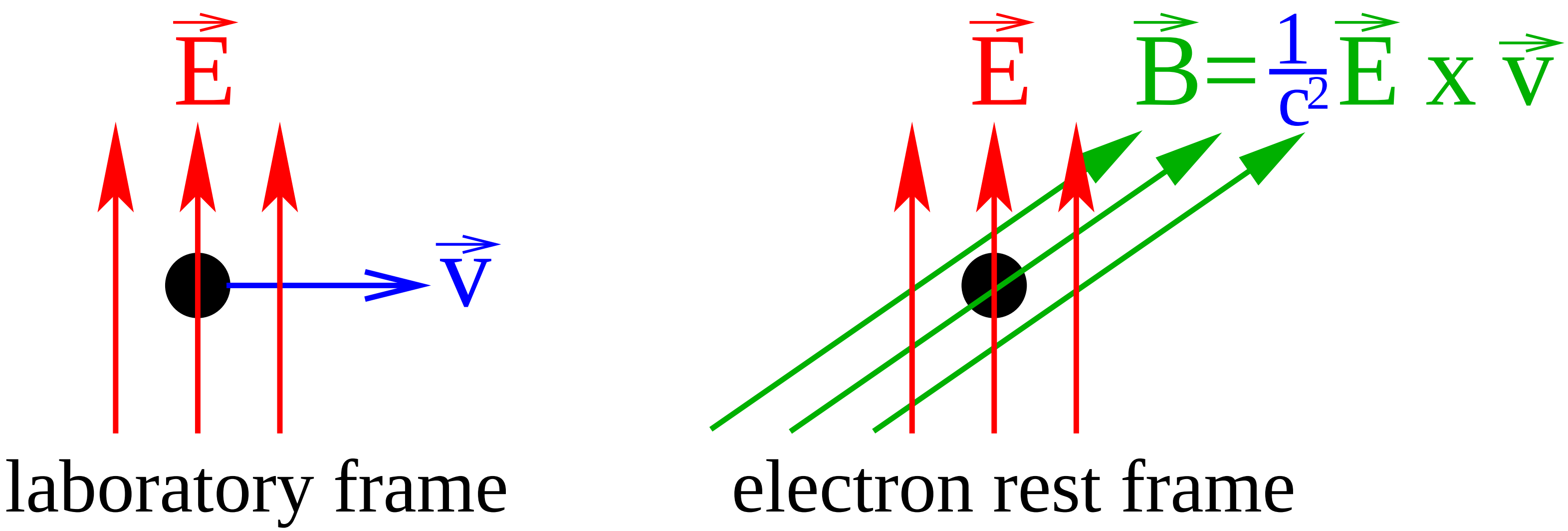

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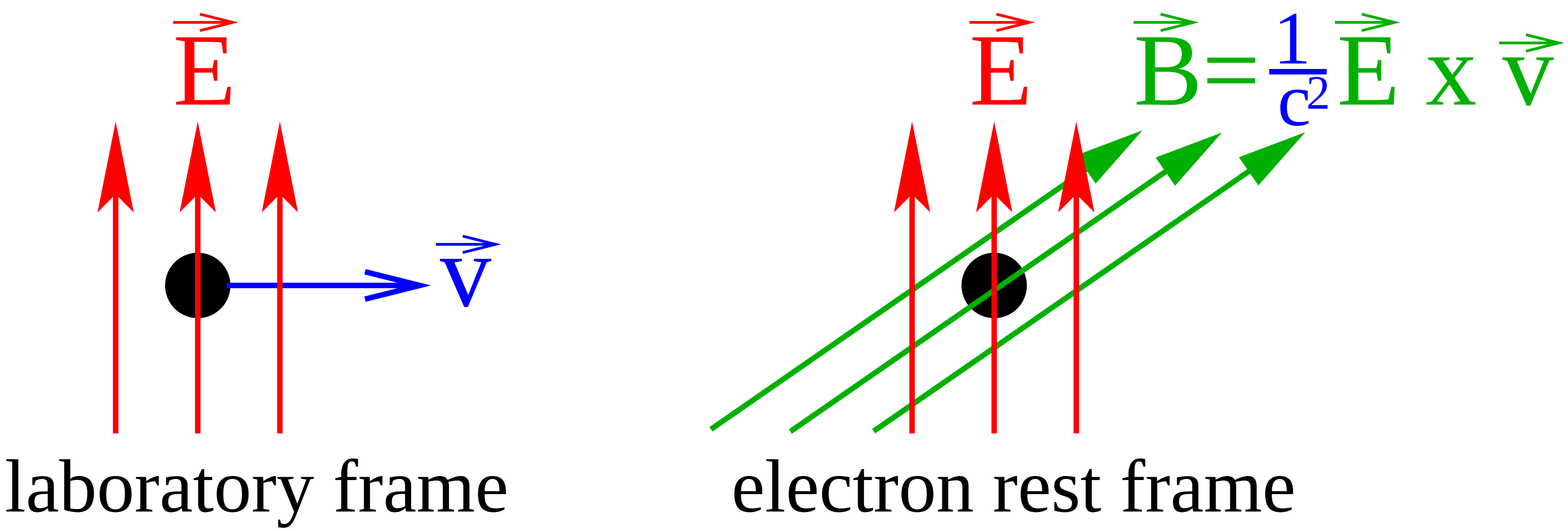
  - orbital motion and spin intertwined: spin-orbit coupling



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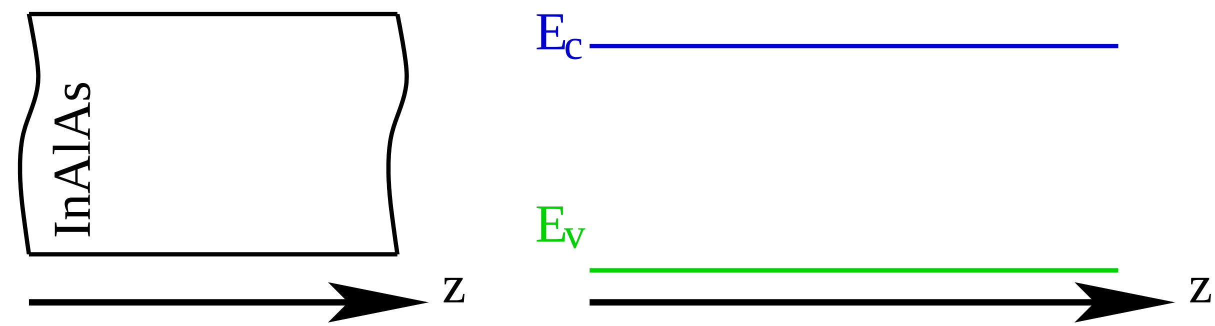
- typically $E_{\mathrm{gap}} \sim 1$ eV, compare with $2m_0c^2 \approx 1$ MeV
  - spin-orbit effects are drastically enhanced in solids!

Rashba effect: Spin splitting & structural inversion asymmetry

Semiconductor heterostructures

- semiconductor: conduction/valence band edges E_c & E_v



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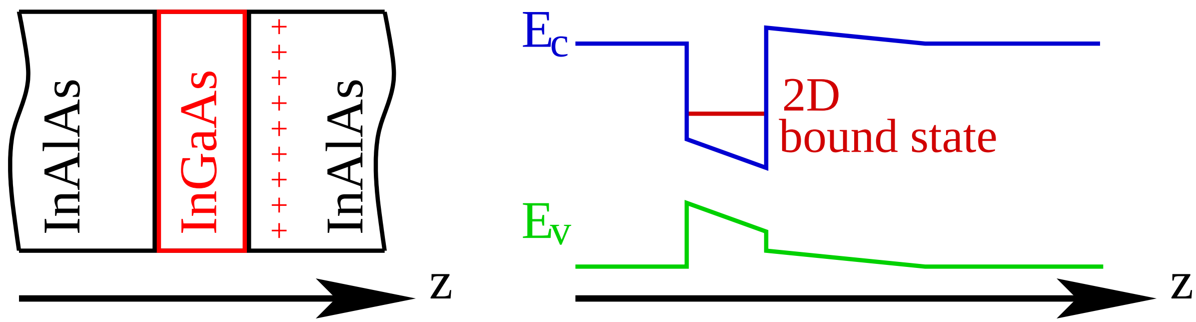

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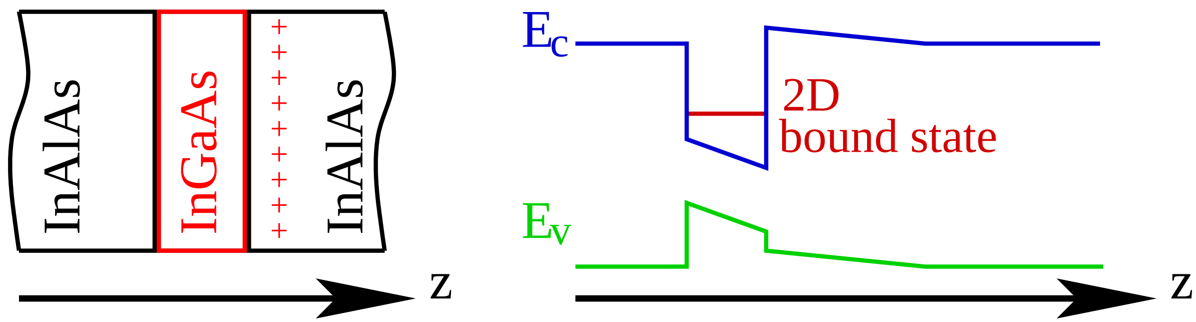

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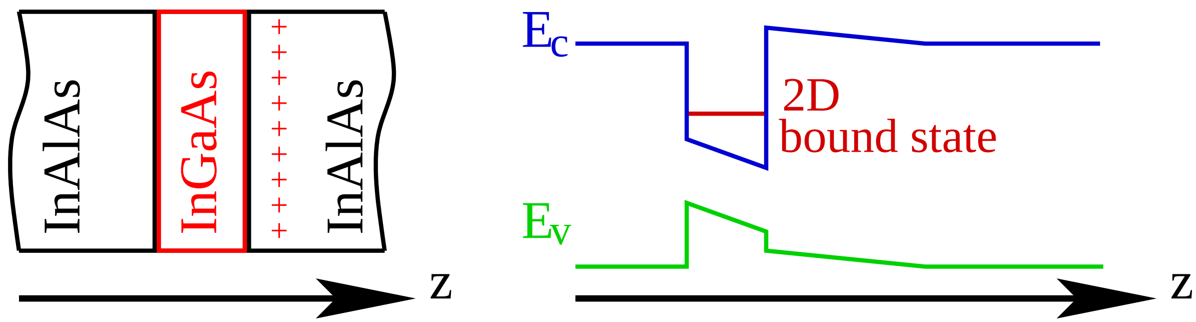

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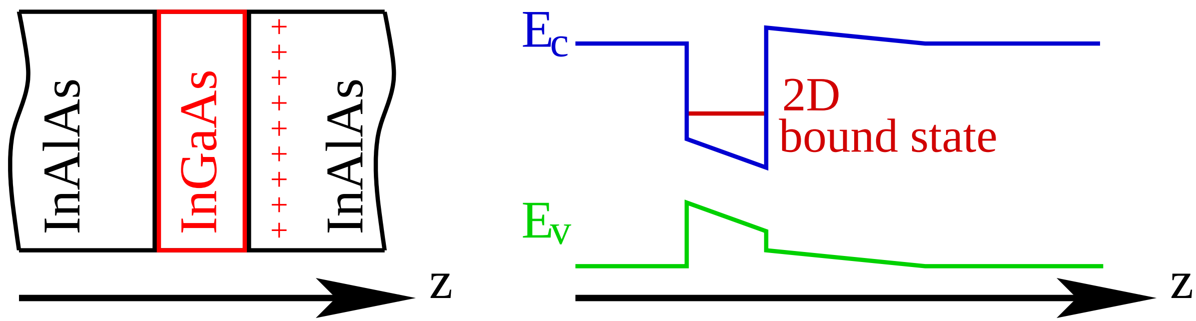

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  - wave-vector scale k_{so} is measure for the structural inversion asymmetry of heterostructure: tuneable!

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Rashba spin splitting

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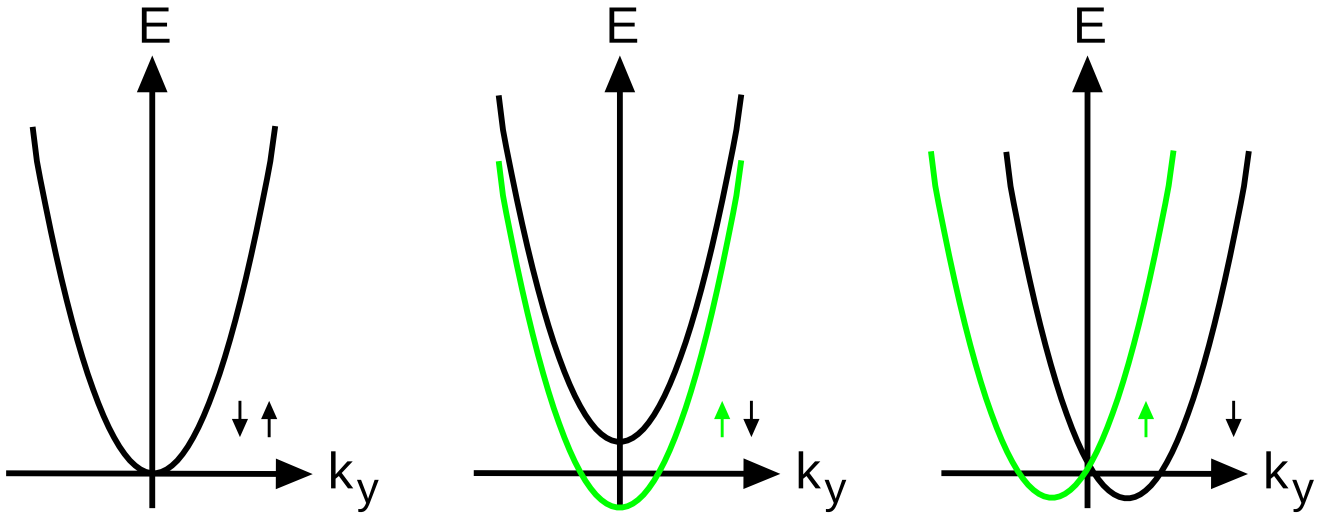
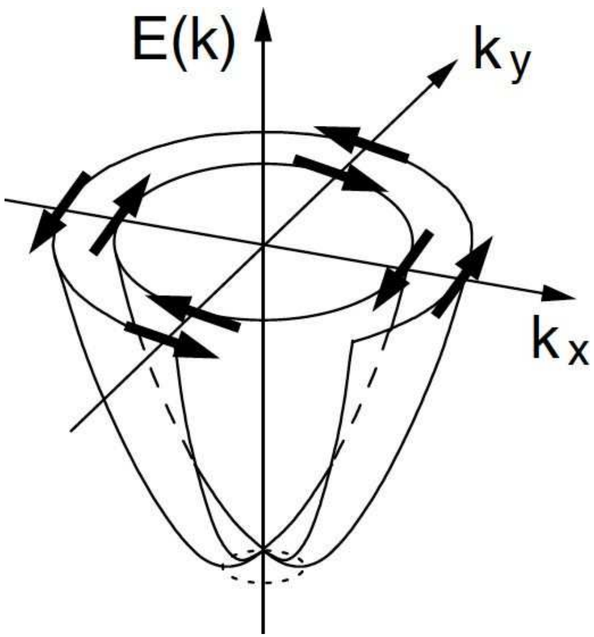
- Rashba term causes momentum-dependent spin splitting, which is different from Zeeman effect!

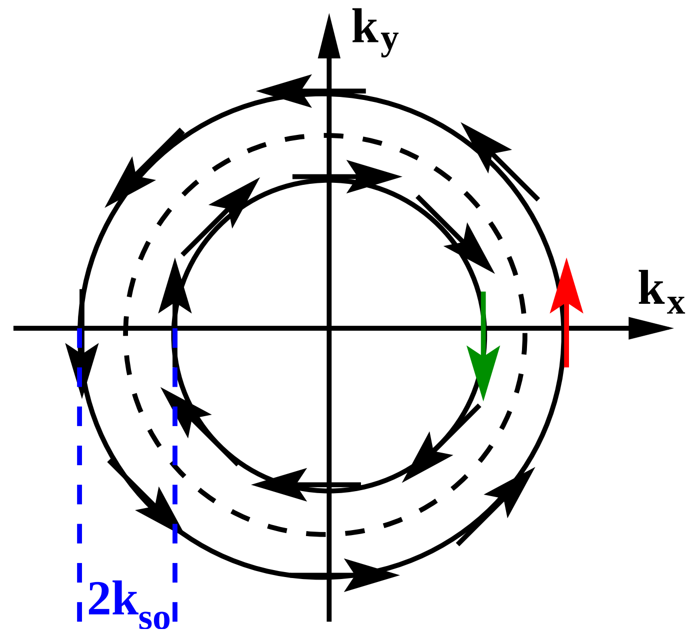


spin−degenerate Zeeman splitting Rashba splitting

Rashba effect & spin electronics

- full picture: 2D electron eigenstates have $\vec{S} \perp \vec{k}$





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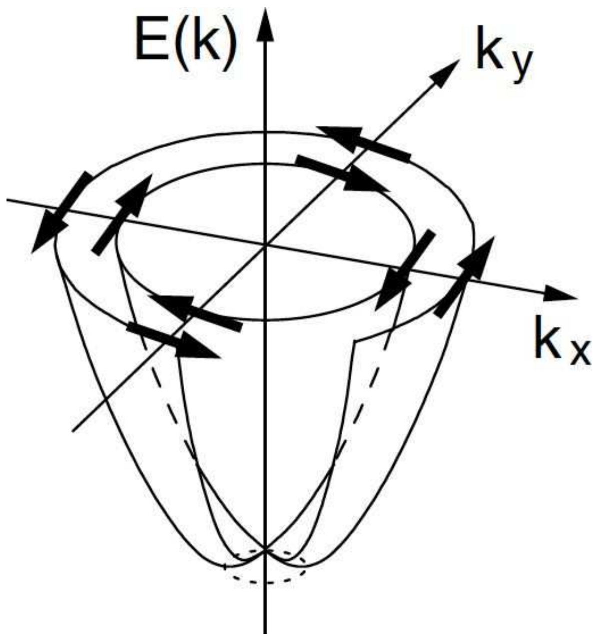

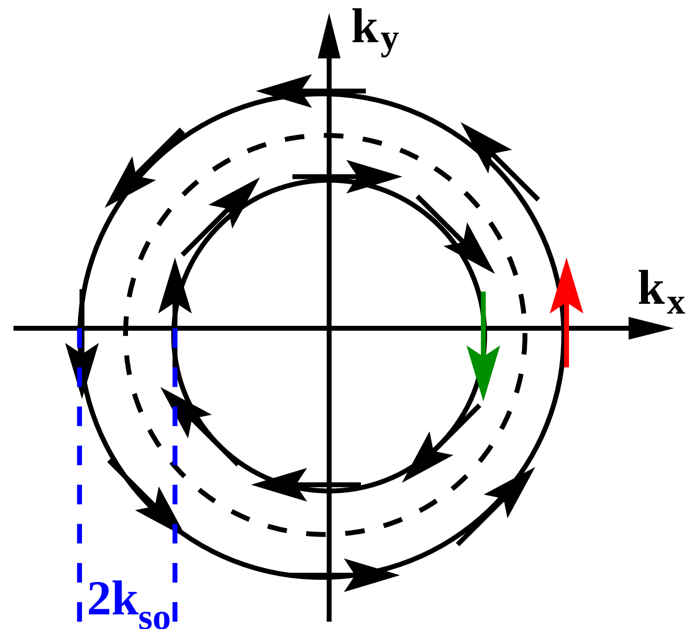

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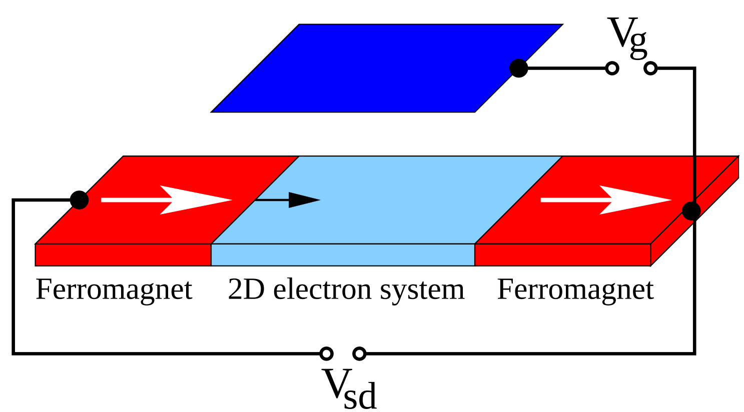

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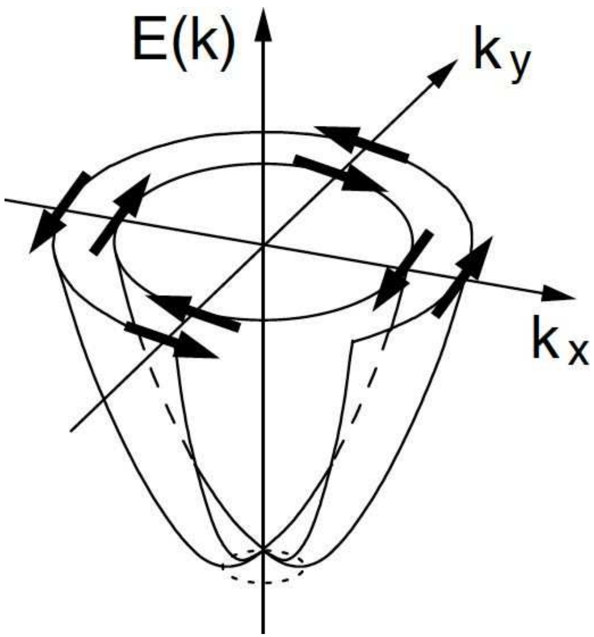

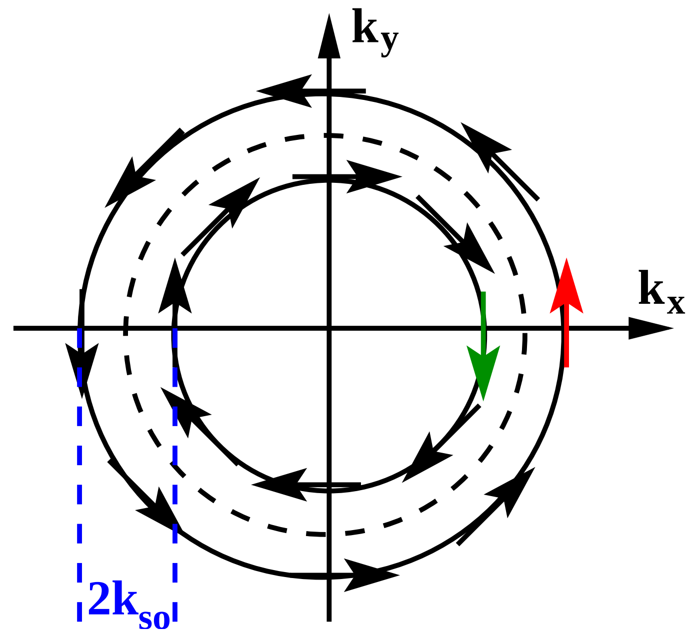

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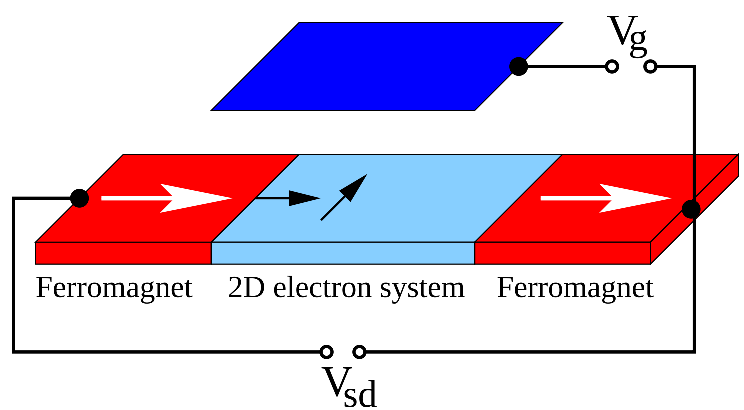

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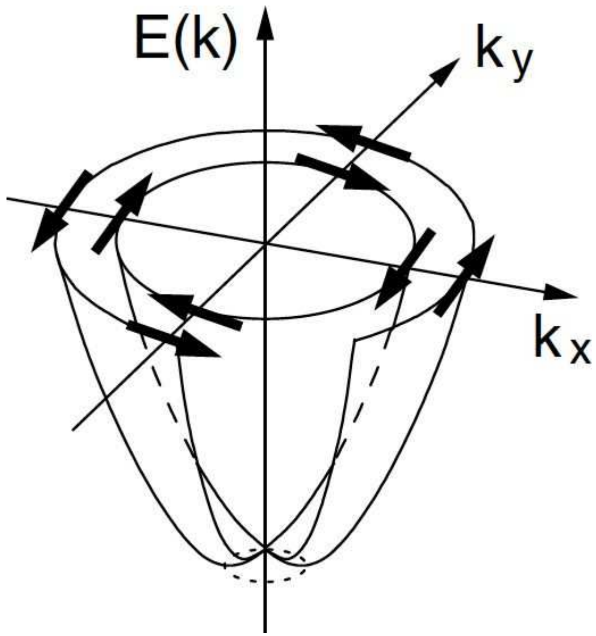

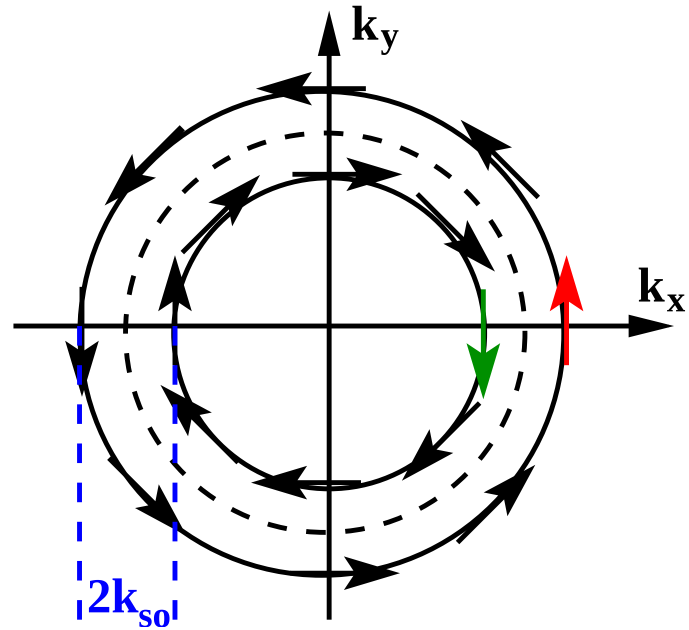

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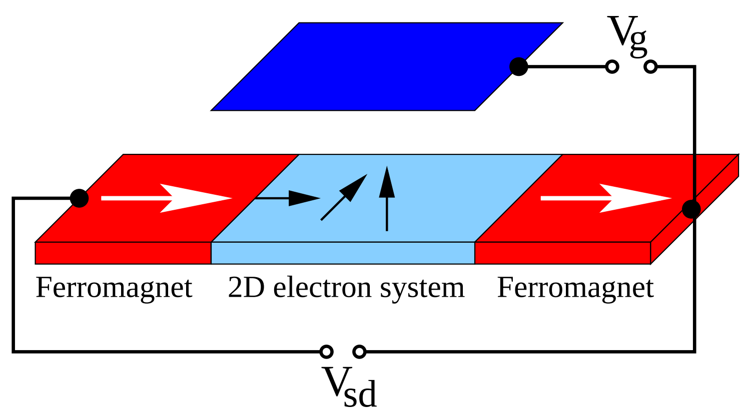

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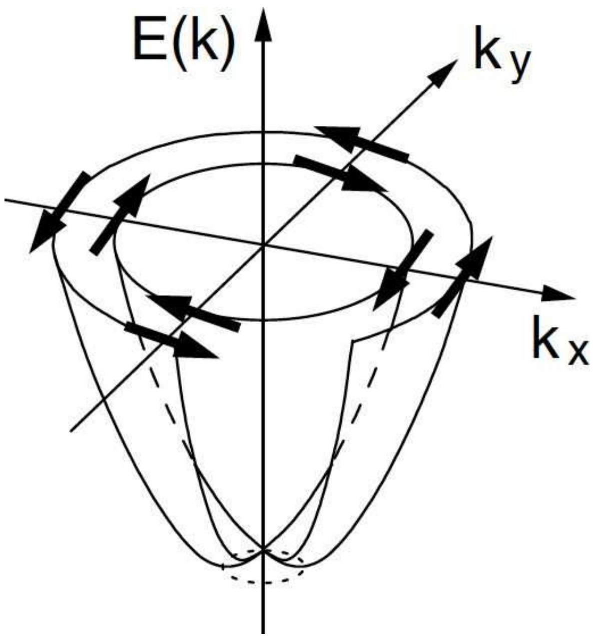

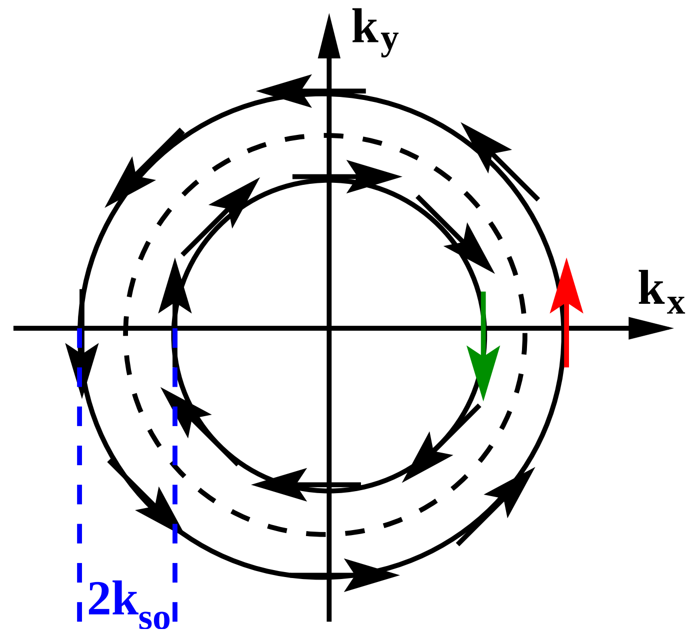

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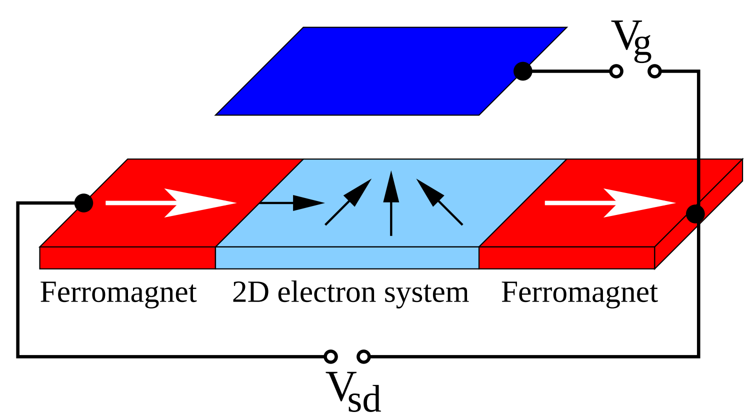

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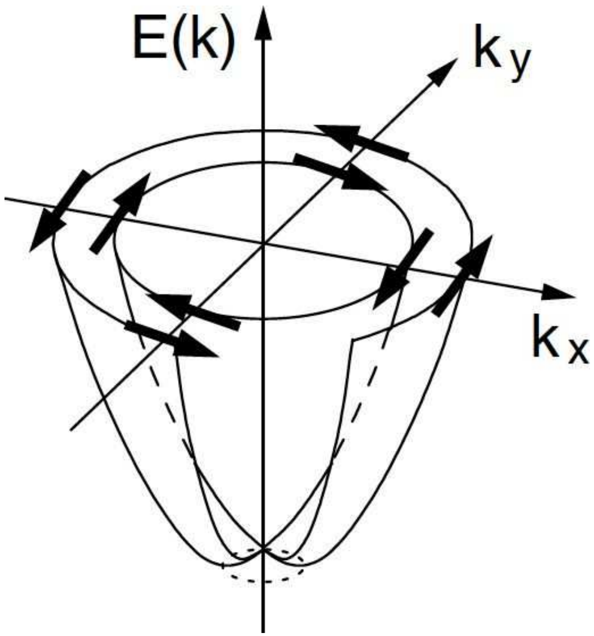

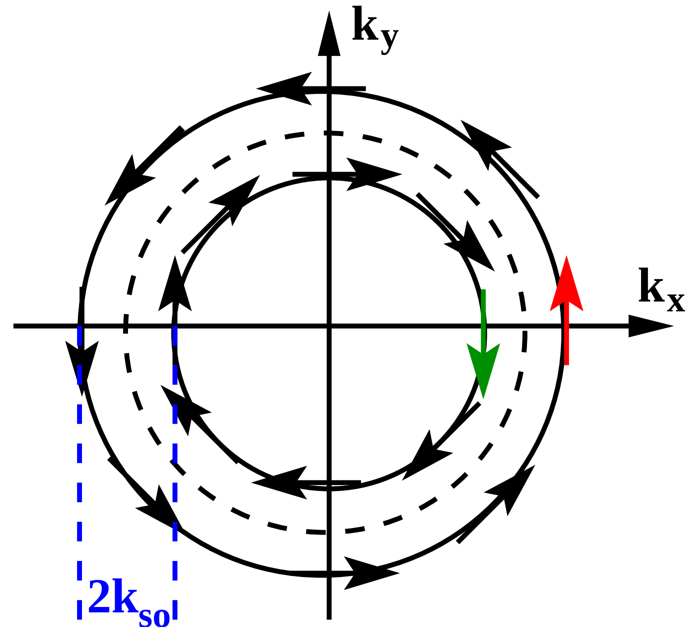

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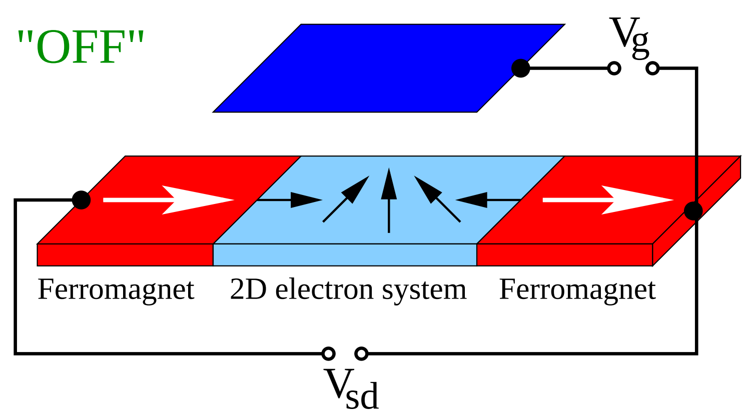

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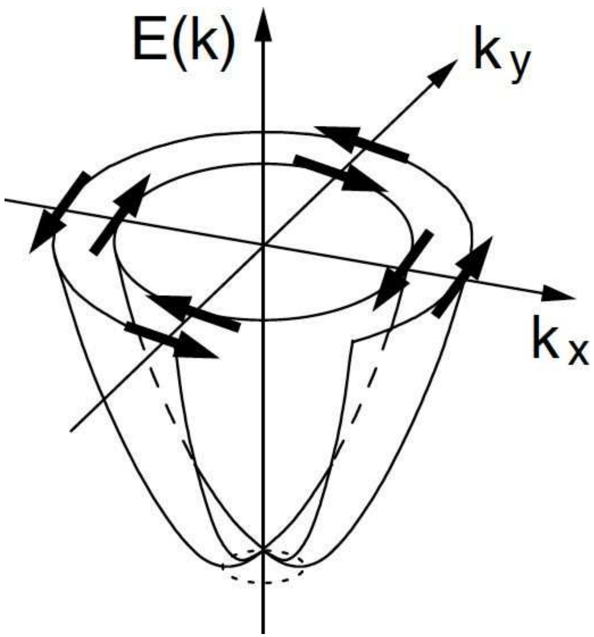

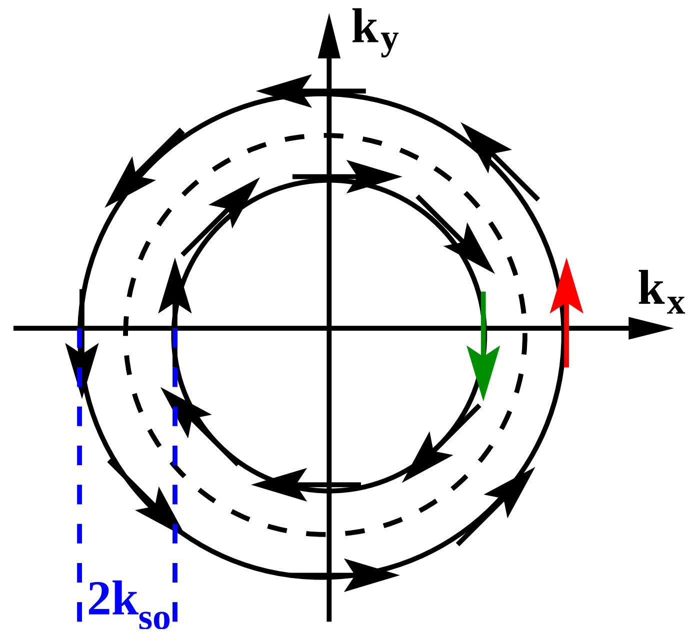

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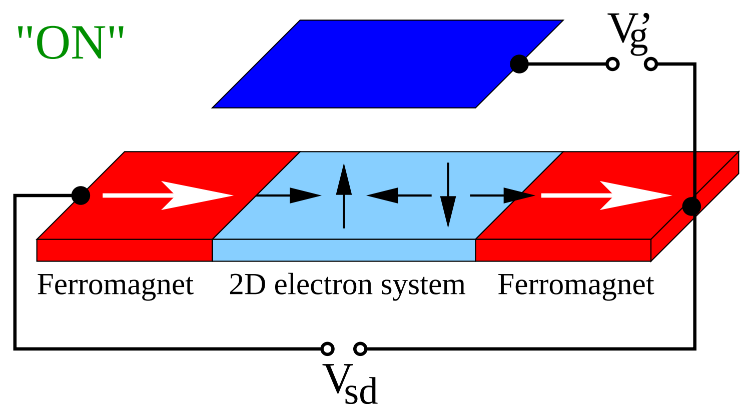

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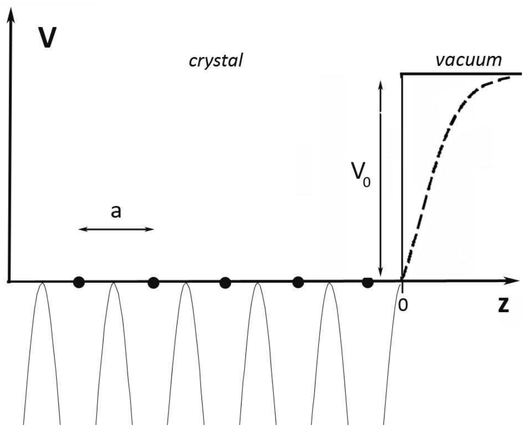
Rashba effect of surface states

Surface states

- potential for electrons in solids terminates at surface



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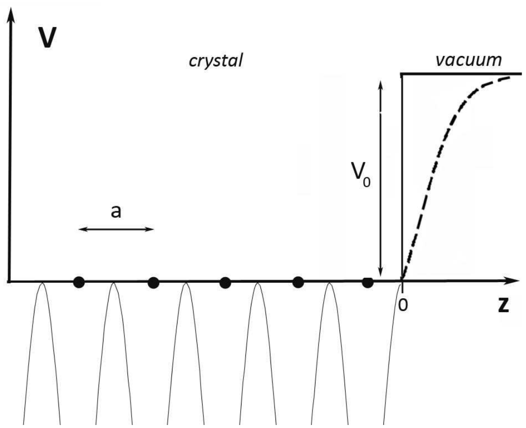

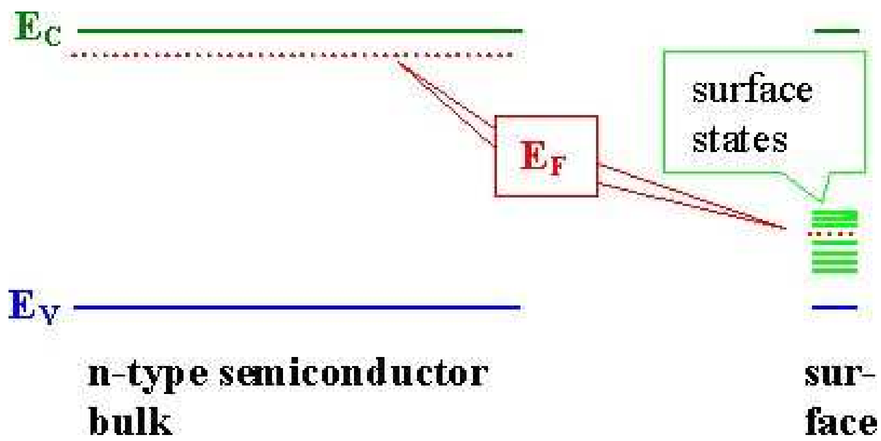

- bulk states (bands) and surfaces states (discrete!) exist

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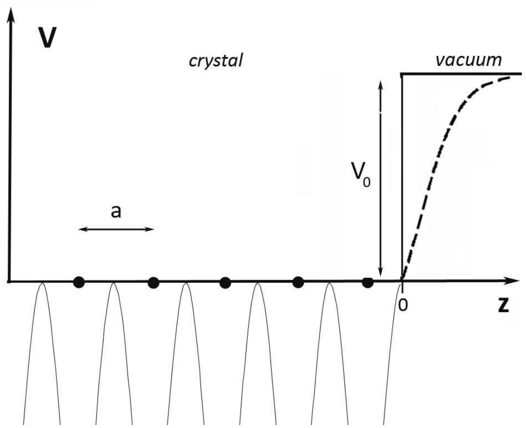
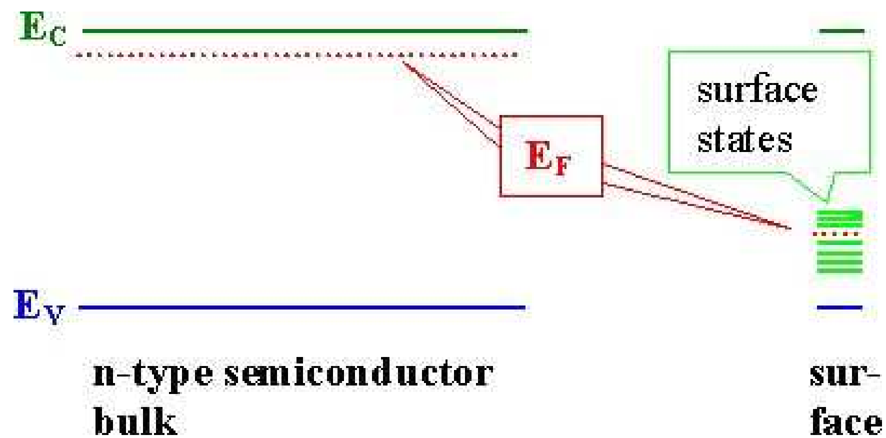
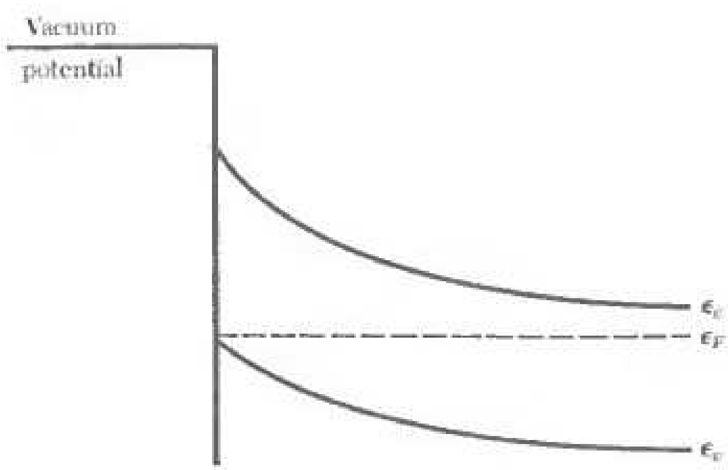
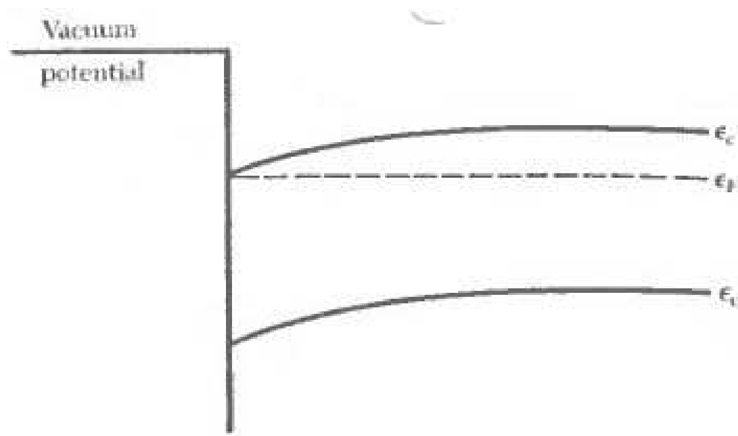




- bulk states (bands) and surfaces states (discrete!) exist
- equilibration between bulk and surface: band bending!





Giant Rashba effect at surfaces

- structural inversion asymmetry due to surface could result in Rashba spin splitting of surface-state dispersions

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LaShell, McDougall & Jensen, PRL (96)
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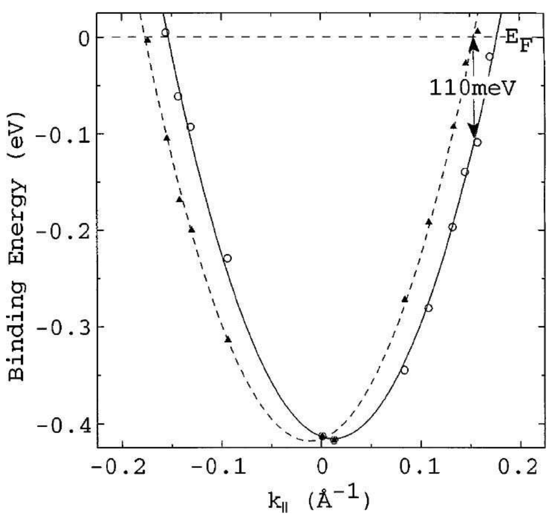

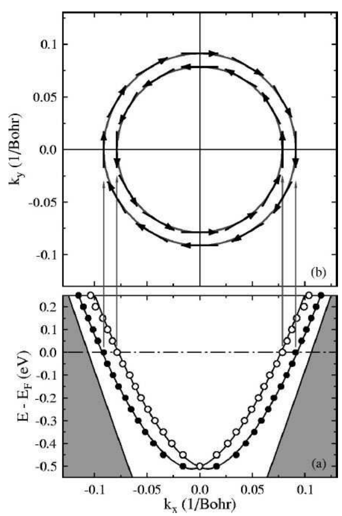

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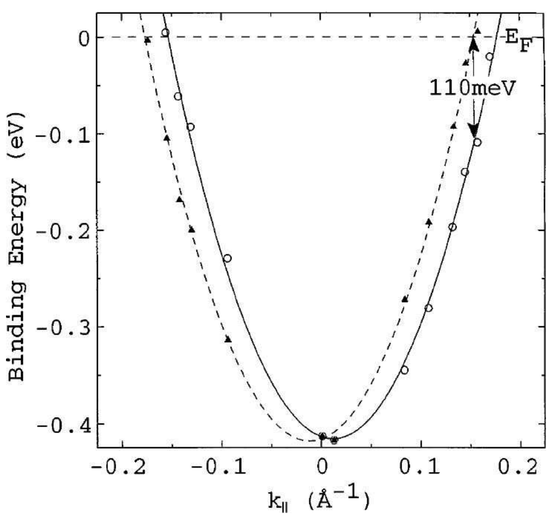

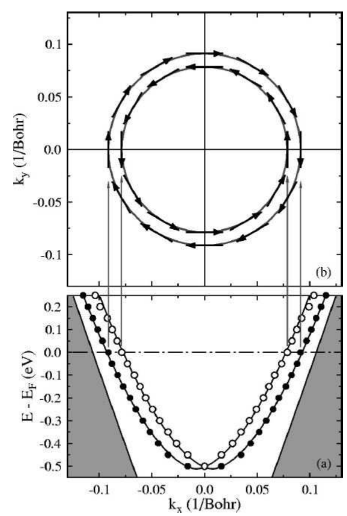

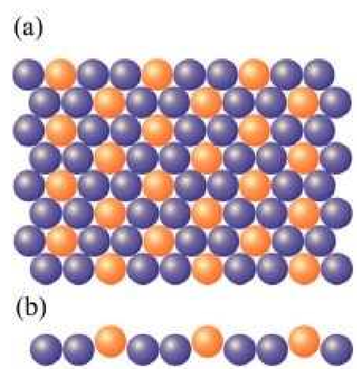

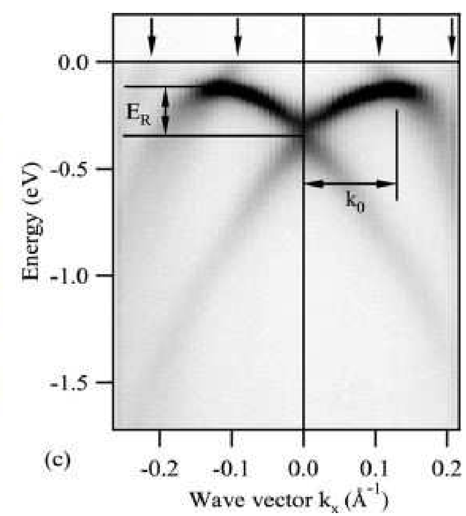

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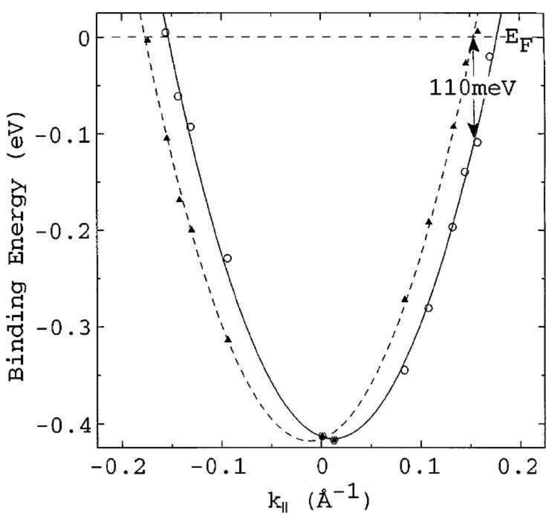
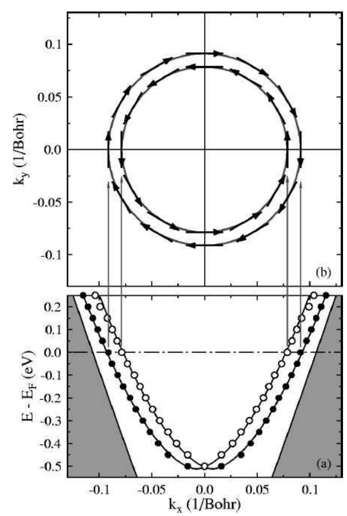
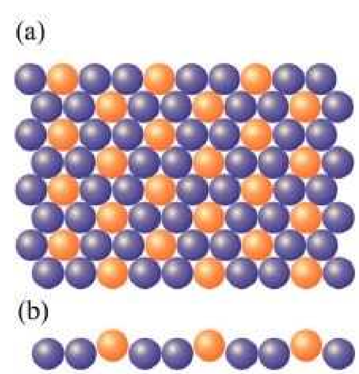
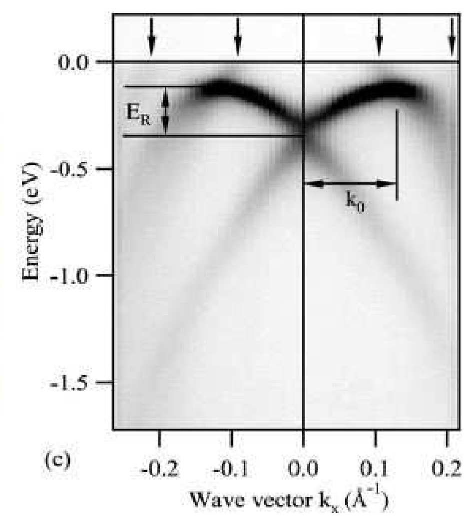
- enhanced surface potential and/or high-Z atom content? Bentmann et al., Europhys. Lett. (09)









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Ast et al., PRB (07)

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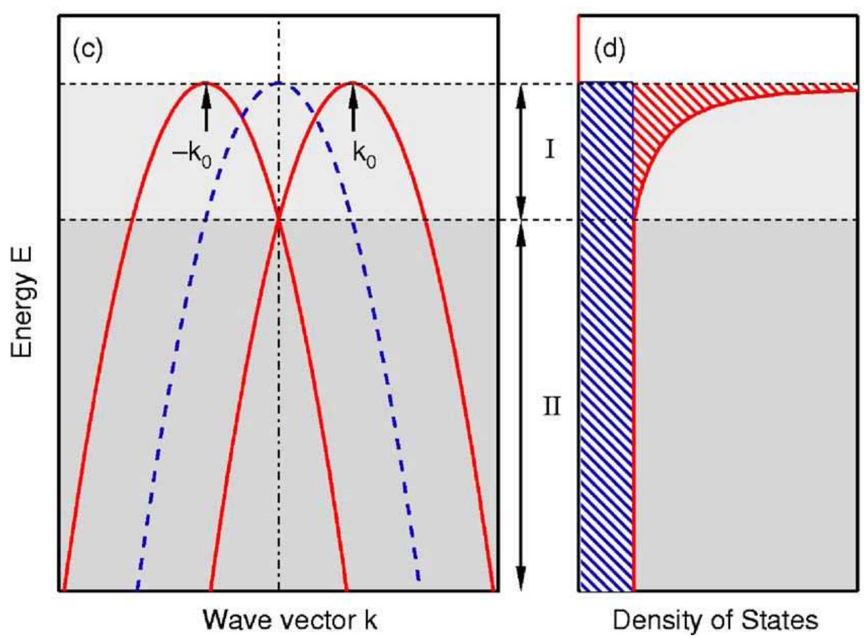

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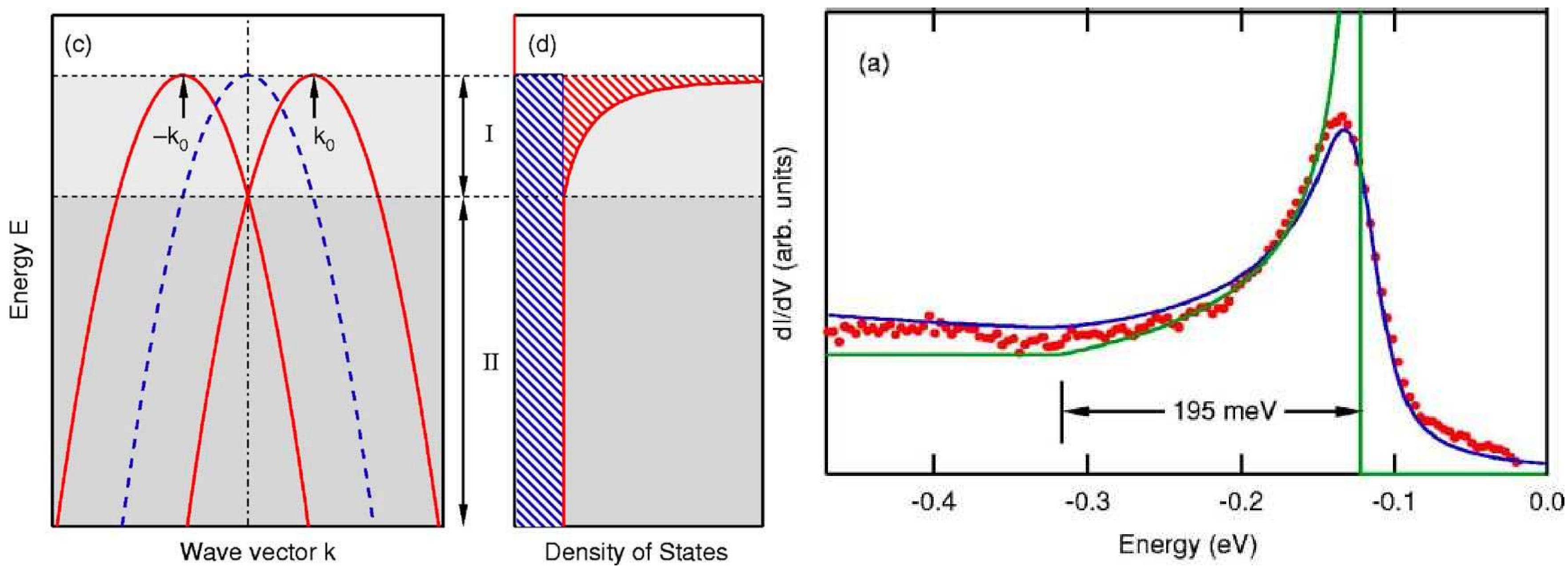
- measuring STM differential conductance dI/dV allows extraction of local spin-splitting energy (unlike ARPES)



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Discussion

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- is graphite surface special (Dirac-electron quasiparticles)