Interference spin-blockade in symmetric nanojunctions

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Interference SET...

- Weak coupling
- Coulomb interaction
- Nanometer scale
- Low temperature

\[ h\Gamma \ll k_B T \ll \Delta E_{\text{ex}} \]

- Rotational symmetry

\[ E_1 = E_2 \]

- Contact geometry

\[ \gamma_{1L} \neq \gamma_{1R} / \gamma_{2L} \neq \gamma_{2R} \]
... with a magnetic flavour

- **Coulomb** interaction
- **Nanometer scale**

\[ E_{\text{triplet}} \neq E_{\text{singlet}} \]

- Parallel **ferromagnetic** leads

\[ \Gamma_{\alpha\uparrow} \neq \Gamma_{\alpha\downarrow} \]

Exchange splitting

Spin symmetry breaking

The interplay between orbital and spin degree of freedom

excited state blocking and all-electrical spin control on the system.
Current blocking

Interference Blockade --ground states--

Interference Blockade --excited state--

Coulomb Blockade

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Polarized leads

\[ S_z = 0 \]

\[ S_z = -1 \]

\[ S_z = 1 \]

Parallel polarized leads

No magnetic field on the system

All-electric spin control

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The Hamiltonian

\[ H = H_{\text{sys}} + H_{\text{leads}} + H_{\text{tun}} \]

\[ H_{\text{sys}} = \xi_0 \sum_{i\sigma} d_{i\sigma}^\dagger d_{i\sigma} + b \sum_{i\sigma} \left( d_{i\sigma}^\dagger d_{i+1\sigma} + d_{i+1\sigma}^\dagger d_{i\sigma} \right) \]

\[ + U \sum_{i} \left( n_{i\uparrow} - \frac{1}{2} \right) \left( n_{i\downarrow} - \frac{1}{2} \right) \]

\[ + V \sum_{i} \left( n_{i\uparrow} + n_{i\downarrow} - 1 \right) \left( n_{i+1\uparrow} + n_{i+1\downarrow} - 1 \right) \]

\[ H_{\text{tun}} = t \sum_{\alpha k \sigma} \left( c_{\alpha k\sigma}^\dagger d_{\alpha\sigma} + d_{\alpha\sigma}^\dagger c_{\alpha k\sigma} \right) \]

Extended Hubbard Hamiltonian with on-site and nearest neighbors Coulomb interaction

Tunnelling restricted to the dot closest to the corresponding lead

Ferromagnetic leads with equal parallel polarization

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Generalized Master Equation

- We start with the Liouville equation:
  \[ \dot{\rho} = -\frac{i}{\hbar} [\mathcal{H}, \rho] \]

- We consider a reduced density matrix block-diagonal in spin, energy and particle number. We keep coherencies between orbitally degenerate states.

- The Generalized Master Equation is an equation of motion for the reduced density matrix. We calculate it in the lowest non-vanishing order in the coupling to the leads and in the Markov approximation. It reads:

\[ \dot{\sigma} = -\frac{i}{\hbar} [H_{\text{sys}}, \sigma] - \frac{i}{\hbar} [H_{\text{eff}}, \sigma] + \mathcal{L}_{\text{tun}} \sigma \]

- Coherent dynamics
- Effective internal dynamics
- Tunnelling dynamics
The effective Hamiltonian

The effective Hamiltonian is expressed in terms of angular momentum operators and renormalization frequencies:

\[ H_{\text{eff}} = \sum_{\alpha S_z} \omega_{\alpha S_z} L_\alpha, \]

In particular in the Hilbert space of the 2 particle first excited states:

\[ L_\alpha = \frac{\hbar}{2} \begin{pmatrix} 1 & e^{i2|\ell|\phi_\alpha} \\ e^{-i2|\ell|\phi_\alpha} & 1 \end{pmatrix} \]

\[ \omega_{\alpha S_z} = \frac{1}{\pi} \sum_{\sigma'} \Gamma^0_{\alpha\sigma'} \left[ \langle 2_1 \ell S_z | d_{M\sigma'}^\dagger | 3\{E\} \rangle \langle 3\{E\} | d_{M\sigma'} | 2_1 - \ell S_z \rangle p_\alpha (E - E_{2_1}) + \langle 2_1 \ell S_z | d_{M\sigma'}^\dagger | 1\{E\} \rangle \langle 1\{E\} | d_{M\sigma'} | 2_1 - \ell S_z \rangle p_\alpha (E_{2_1} - E) \right] \]

Bias and gate dependent
Blocking conditions

The interference blocking state:

- is a **linear combination of degenerate** system eigenstates
- is **achievable from the global minimum** via a finite number of allowed transitions
- has **vanishing tunnelling amplitudes** for all energetically allowed outgoing transitions
  \[ \mathcal{L}_{\text{tun}} \sigma_B = 0 \]
- is an eigenstate of the **effective Hamiltonian**
  \[ [H_{\text{eff}}, \sigma_B] = 0 \]
Many-body spectrum

Orbital degeneracy produces interference blocking
Excited state blocking

Source transition
Drain transition

2x3 System

1x2
1x1

N=1
N=2

Coulomb Blockade

N = 2

V_{g}

V_{o}
Excited state blocking

- Source transition
- Drain transition

2x3

1x2

1x1

System

N=1

N=2

Current

N = 2

V_0

V_g

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Excited state blocking

Three linear combinations of 2-particle excited states are coupled ONLY to the source.
Triplet splitting

The states decoupled from the right lead are eigenstates of $L_R$. They are eigenstates of $H_{\text{eff}}$ only if $\omega L S_z = 0$.
Conclusions

- Symmetric nanojunctions have an orbitally degenerate manybody spectrum

- Destructive interference between orbitally degenerate states leads to the formation of ground- as well as excited- interference blocking states

- Exploiting the interplay of interference blocking and Coulomb interaction we could achieve all-electrical spin control of a triple dot junction

References:

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