All electrical spin preparation in a triple dot I-SET

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Interference SET...

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

Coulomb blockade

- Rotational symmetry

Orbitally degenerate states

- Contact geometry

Contact symmetry breaking

$h\Gamma \ll k_B T \ll \Delta E_{ex}$

$E_1 = E_2$

$\frac{\gamma_{1L}}{\gamma_{2L}} \neq \frac{\gamma_{1R}}{\gamma_{2R}}$
... with a magnetic flavour

- Coulomb interaction
- Nanometer scale

Exchange splitting

- Parallel ferromagnetic leads

Spin symmetry breaking

$E_{\text{triplet}} \neq E_{\text{singlet}}$

$\Gamma_{\alpha \uparrow} \neq \Gamma_{\alpha \downarrow}$

The interplay between orbital and spin degree of freedom

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

Young's light-interference experiment (1801)

Double-slit experiment with interference of single electrons (1961)
The “two paths” in the ISET

Particle Number

N

N + 1

Energy
Current blocking

Interference Blockade --ground states--
Interference Blockade --excited state--

Coulomb Blockade
Polarized leads

Parallel polarized leads
No magnetic field on the system

All-electric spin control

S = -1<sub>z</sub>
S = 0<sub>z</sub>
S = 1<sub>z</sub>

\[ eV_b \quad ||b|| \]

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The Hamiltonian

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

\[ H_{\text{sys}} = \xi_0 \sum_{i\sigma} d_{i\sigma}^{\dagger} d_{i\sigma} + b \sum_{i\sigma} \left( d_{i\sigma}^{\dagger} d_{i+1\sigma} + d_{i+1\sigma}^{\dagger} d_{i\sigma} \right) + U \sum_{i} \left( n_{i\uparrow} - \frac{1}{2} \right) \left( n_{i\downarrow} - \frac{1}{2} \right) + V \sum_{i} \left( n_{i\uparrow} + n_{i\downarrow} - 1 \right) \left( n_{i+1\uparrow} + n_{i+1\downarrow} - 1 \right) \]

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

\[ H_{\text{leads}} \quad \text{Ferromagnetic leads with equal parallel polarization} \]

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

Tunnelling restricted to the dot closest to the corresponding lead

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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:

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

  \[\begin{align*}
  \text{Coherent dynamics} & & \text{Effective internal dynamics} & & \text{Tunnelling dynamics}
  \end{align*}\]
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

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

\[ \omega_{\alpha S_z} = \frac{1}{\pi} \sum_{\sigma' \{E\}} \Gamma_{\alpha \sigma'}^{0} \left[ \langle 2_{1} \ell S_{z} | d_{M \sigma'}^{\dagger} | 3\{E\} \rangle \langle 3\{E\} | d_{M \sigma'}^{\dagger} | 2_{1} - \ell S_{z} \rangle p_{\alpha} (E - E_{21}) + \langle 2_{1} \ell S_{z} | d_{M \sigma'}^{\dagger} | 1\{E\} \rangle \langle 1\{E\} | d_{M \sigma'}^{\dagger} | 2_{1} - \ell S_{z} \rangle p_{\alpha} (E_{21} - E) \right] \]

**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 × Spin degeneracy

Orbital degeneracy produces interference blocking
Excited state blocking

Source transition
Drain transition

1x2
1x1

N=1
N=2

Coulomb Blockade

N = 2

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Excited state blocking

Source transition

Drain transition

$V_g$

$N = 1$

$N = 2$

$N = 2$

$2 \times 3$

$1 \times 2$

$1 \times 1$

System

Current

$2 \leftrightarrow 3 \Rightarrow$

$1 \leftrightarrow 2 \Leftarrow$

$1 \leftrightarrow 2 \Leftarrow$

$1 \leftrightarrow 2 \Leftarrow$

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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

$$\omega_L s_z = 0$$
Quasi-degeneracy

The minimal necessary condition is quasi-degeneracy:

\[ \delta E \ll \hbar \Gamma \]

The two N+1 particle states are populated simultaneously and cannot be resolved by the dynamics.
Conclusions

• Symmetric nanojunctions have an orbitally degenerate many-body 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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Thanks

...and you for your attention!