Transport through quantum dots coupled to ferromagnetic leads in the cotunneling regime

I. Weymann[1,2], J. Martinek[2,3], J. Koenig[2],
J. Barnaś[1,3], and G. Schoen[2]

[1]*Department of Physics, A. Mickiewicz University, Umultowska 85, 61-614 Poznań, Poland*
[2]*Institut für Theoretische Festkörperphysik, Universität Karlsruhe, Germany*
[3]*Institute of Molecular Physics, Polish Academy of Sciences, M. Smoluchowskiego 17, 60-179 Poznań, Poland*

We have analyzed theoretically the first and second order spin-dependent transport through quantum dots with arbitrary value of the Coulomb interaction. In order to determine the electric current, occupation (spin accumulation) and tunnel magnetoresistance (TMR) in the sequential and cotunneling regimes, we have employed the real-time diagrammatic technique. Our considerations apply to both the linear and nonlinear response regimes. However, we take into account only collinear alignments of the leads' magnetic moments. Consequently, the system considered can be either in parallel or anti-parallel configurations.

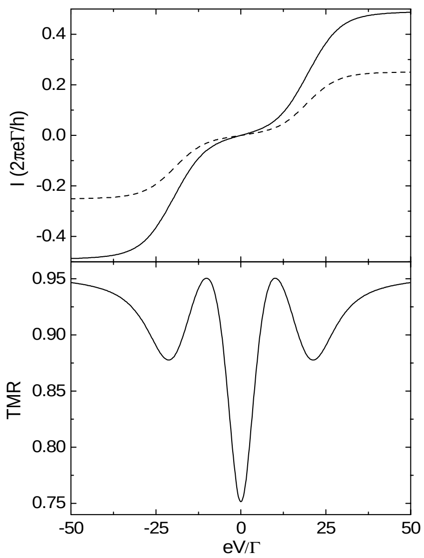

Fig. 1. The currents flowing through the system in the parallel (solid line) and anti-parallel (dashed line) magnetic configurations (upper part) and the resulting TMR effect (bottom part). The parameters are: $\varepsilon = -10\Gamma$, $U = 20\Gamma$, $T = 1.8\Gamma$, $P=0.7$, and $\Gamma = \Gamma^{\uparrow} + \Gamma^{\downarrow}$.

When the leads' magnetic moments are parallel, the higher-order tunneling processes give rise to finite spin polarization of the dot, even for zero transport voltage, which also strongly depends on the position of the dot level. This polarization leads to an effective spin-splitting of the dot level. For anti-parallel configuration of the leads' magnetizations, and for symmetric coupling, there is no spin polarization at zero-bias, although for a finite bias voltage and an odd number of electrons on the dot a significant nonequilibrium spin accumulation is induced in the Coulomb blockade regime due to the second-order spin-current. Furthermore, we have found a strong parity effect for the linear-response TMR in the cotunneling regime. It is shown that for an even number of electrons on the dot, the tunnel magnetoresistance corresponds to the value predicted by Julliere, while for an odd number of electrons the value of TMR is significantly reduced below the Julliere's value.

In addition, we predict a zero-bias anomaly in the differential conductance for anti-parallel configuration. The zero-bias anomaly manifests itself as a maximum in differential conductance. This anomalous behavior results from spin asymmetry between cotunneling events. In the parallel configuration the contribution to current coming from the elastic processes is generally larger than the contribution due to inelastic cotunneling events, whereas in the anti-parallel configuration the situation is reversed. Another effect giving rise to the zero-bias anomaly is the competition between the two-barrier and one-barrier second-order tunneling processes. The latter ones flip the spin on the dot and thus open the system for the fastest two-barrier inelastic processes. This effectively leads to a maximum in the differential conductance at zero bias. The rates at which those two kinds of processes take place are comparable at low bias voltages. However, once the voltage is raised the maximum in the differential conductance disappears due to spin accumulation.

Figure 1 presents the currents flowing through the system in the parallel and anti-parallel magnetic configurations and the resulting TMR effect. It is demonstrated that the difference in currents in these both configurations leads straightforwardly to a minimum in the tunnel magnetoresistance effect at the zero-bias.

Name of the presenting author: Ireneusz Weymann
e-mail address: weymann@main.amu.edu.pl
url's: http://spin.amu.edu.pl/~mezo/