Kraków, August 1st 2013

dr hab. Adam Rycerz

Uniwersytet Jagielloński w Krakowie
Instytut Fizyki im. Mariana Smoluchowskiego
Zakład Teorii Materii Materii Skondensowanej
i Nanofizyki

email: rycerz@th.uj.edu.pl
www: http://th.if.uj.edu.pl/~adamr/

Referee report on the Ph.D. thesis entitled ***"Electronic structure of artificial atoms and molecules: Spin orbit coupling effects"*** by Mr. Michał Nowak

A controllable operation on single-electron spin degree of freedom is widely-regarded as a key step towards the development of future electronics in general, or the solid-state quantum computing in particular. Spin-orbit interaction appearing in semiconducting quantum dots offers a unique possibility to control the electron spin by manipulating external electric fields, as such an interaction couples spin and spacial degrees of freedom. In turn, the device miniaturization is no longer limited by the necessity to control magnetic fields in areas occupied by individual bits (or qubits). Spin orbit coupling, however, may also destroy the quantum coherence, so the efficient solid-state quantum computing also requires the feasible mechanism allowing one to control the effective coupling strength.

The dissertation *"Electronic structure of artificial atoms and molecules: Spin orbit coupling effects"* by Mr. Michał Nowak is devoted to address the above-mentioned issues by discussing the approximate solutions of the Schrödinger equation for one or two interacting electrons confined in selected semiconducting nanostructures with two commonly discussed types of spin-orbit coupling, described by the Rashba and the Dresselhaus effective Hamiltonians. Mr. Nowak has co-authored 10 journal articles, which are cited more than 40 times so far. Two of these articles [Szafran et al., Phys. Rev. B 79, 235303 (2009); and Nowak et el., J. Phys.: Condens. Matter 20, 395225 (2008)] were submitted prior to the graduation, the remaining 8 (all published as regular articles in Physical Review B) are included in the presented dissertation [and further referred as A1-A8]. The dissertation is further supplemented with an unpublished manuscript entitled *"Spontaneous and resonant lifting of the spin blockade in nanowire quantum dots"* [M1]. According to the co-authors' statements provided, Mr. Nowak has leading contribution to each one of the articles [A1-A8,M1], what is expressed by his first position on the list of authors in every case.

The collection of articles constituting the dissertation can be divided in the following four groups, focussing on quite different physical systems:

First, the articles [A1] and [A2] discuss the approximate solutions of the stationary, as well as the time-dependent, Schrödinger equation for electrons in double quantum dot with different types of spin-orbit coupling. In particular, the possibility of realizing the swap operation on two qubits (attributed to spins) by such a physical system is analyzed, and four distinct physical mechanisms leading to the swap operation are identified.

Next, the articles [A3, A6, A7] analyze different ways of tuning the spin-orbit interaction strength by applying external electromagnetic fields to generic quantum dots of rectangular shapes. The material parameters are chosen to reproduce the experimental situation of InAs quantum dots.

Then, papers [A4] and [A5] focus on basic measurable consequences of different types of spin-orbit coupling in quantum rings. The predicted effects include the asymmetry in the charge distribution for closed rings and the particular structure of Fano resonances for open quantum rings, with wide and narrow resonances depending on mutual orientation of injected electron spin and external magnetic field.

Finally, the work [A8] and the unpublished manuscript [M1] describes two different approaches to spin control in narrow nanowire quantum dots, first exploiting relatively strong anisotropy in spin polarizability, and the second utilizing the mechanism for of the spin blockade in such a nanosystem.

Each of the articles present a thorough and innovative study of the problem addressed, with a special attention payed to the numerical precision and stability on one hand, and on the proximity to the physical reality of existing experiments on the other. When possible, the numerical results are compared with those obtained from exactly-solvable simplified models, providing a valuable insight into the physics of the system under consideration. These features show, that the Author posses unique skills including both the ability to build efficient numerical codes employing the up-to date computational tools and infrastructure, and the understanding of current scientific literature in a degree allowing him to address new problems and producing original results leading to publications in world's top journals focussing on condensed matter physics.

In my opinion, the Author's contribution to the thriving field of theoretical research on foundations of solid-state quantum computing is significant, despite of the early stage of his scientific carrier. Also, some theoretical predictions presented in the dissertation, when confirmed experimentally, seem likely to become well-recognized physical phenomena characterizing the nanostructures with spin-orbit coupling. These include: The charge-distribution asymmetry in otherwise symmetric quantum rings [A4], the electrically driven collective spin rotation [A7], and control over the spin blockade in nanowires [M1], just to mention the most remarkable ones.

In conclussion, the dissertation as presented satisfies all the formal requirements for doctoral thesis and I hereby agree for the public defense. Also, I am convinced that the scientific level of the results presented is exceptional and therefore recommend the dissertation to be awarded a distinction.

Adam Rycerz