THEORETICAL PHYSICS

Microscopic substantiation of stochastic hydrodynamic equations for Fermi – systems.

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consultant: RNDr. Tomáš Lučivjanský, PhD.
study form: full time
Annotation: In modern statistical mechanics, the Green's function method is actively used. However, within the framework of the microscopic approach, this method is used to study mainly thermodynamic characteristics (critical exponents, equations of state, etc.). For purely dynamic problems, the standard approach is to construct phenomenological stochastic equations of the Langevin type with a random Gaussian force. The microscopic substantiation of this type of equations is an actual problem of statistical physics. There is a powerful Keldysh-Schwinger technique, which makes it possible to uniformly take into account the statistical and dynamic characteristics of the system within the framework of a microscopic description. The dissertation will be devoted to the study of many-particle quantum systems using the methods of quantum field theory. Special attention will be given to analysis of microscopic analogs of hydrodynamic equations in many-particle Fermi systems using the technique of real-time Green's functions at finite temperature (the Keldysh-Schwinger technique).
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Theoretical study of skyrmion states in geometrically frustrated antiferromagnetics.

supervisor: prof. RNDr. Milan Žukovič, PhD. (milan.zukovic@upjs.sk)
study form: full time
Annotation: An antisymmetric Dzyaloshinskii-Moriya spin exchange interaction (DMI) can lead to the formation of twisted magnetic structures. These have attracted much interest mainly after the experimental observation of nontrivial magnetic configurations, called magnetic skyrmion lattices, which have potential technological applications [1]. In ferromagnetic (FM) systems, the skyrmion phase arises from the competition between FM interactions and DMI and it is stabilized by a magnetic field and thermal fluctuations. A similar antiferromagnetic (AFM) skyrmion phase has been discovered in the frustrated classical AFM triangular-lattice Heisenberg model in the field not only with DMI [2] but also without DMI due to further neighbor exchange interactions [3]. It has been shown that magnetic frustration can improve stability of the skyrmion phase [4] and that the usage of AFMs in skyrmion-based devices has certain advantages over the implementation of FM magnets [5]. The goal of the proposed research is theoretical search for suitable candidates among geometrically frustrated AFMs that would display skyrmion phases with physically and technologically interesting properties.
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Generalized XY models and their application in spatial data prediction.
supervisor: prof. RNDr. Milan Žukovič, PhD. (milan.zukovic@upjs.sk)
study form: full time
Annotation: It turns out that the XY model, generalized by adding higher-order terms to Hamiltonian, can exhibit rich critical behavior with a number of interesting phases [1]. The complexity and unpredictability of the observed phases is increased by the presence of other effects, such as geometric frustration and competition of different types of interactions [2]. The aim of the first part of the research is to study the influence of frustration due to the competition of the higher-order terms on the critical behavior of the generalized XY model. The second part of the research will be devoted to the use of appropriately defined generalized XY models for the prediction of missing values in massive spatial data, e.g. from remote sensing of the Earth. Traditional prediction methods are not suitable for such data, mainly due to high computational complexity as well as other limitations [3]. The proposed research aims to develop strategies for the development of efficient prediction methods that would be flexible and suitable for automatic processing using massively parallel algorithms implemented on graphics processors (GPUs) [4].
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M. Žukovič, M. Borovský, M. Lach and D.T. Hristopulos, GPU-Accelerated Simulation of Massive Spatial Data Based on the Modified Planar Rotator Model, Mathematical Geosciences 52 123 (2020).

Bound magnons as a consequence of destructive quantum intereference of frustrated Heisenberg and Hubbard models.
supervisor: doc. RNDr. Jozef Strečka, PhD. (jozef.strecka@upjs.sk)
study form: full time
Annotation: Geometric spin frustration of quantum Heisenberg and Hubbard models may under certain circumstances lead to existence of unusual bound quantum states known as localized magnons. The dissertation thesis will be devoted to a theoretical study of selected frustrated quantum Heisenberg and Hubbard models, whose low-temperature behavior can be described within the classical lattice-gas models on account of bound states with character of localized magnons.
References:
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Quantum and thermal phase transitions of low-dimensional spin systems.
supervisor: doc. RNDr. Jozef Strečka, PhD. (jozef.strecka@upjs.sk)
study form: full time
Annotation: Classical and quantum spin systems may exhibit anomalous magnetic behavior in a close vicinity of thermal and quantum phase transitions. The main goal of the dissertation thesis is to investigate behavior of basic magnetic quantities (magnetization, magnetic susceptibility and specific heat) of selected low-dimensional Ising-Heisenberg and Heisenberg spin models in a close neighborhood of thermal and quantum phase transitions. The emphasis will be laid upon magnetic-field-driven and pressure-driven quantum phase transitions as well as thermal phase transitions, which may emerge in two-dimensional Ising-Heisenberg and Heisenberg spin models in a presence of the external magnetic field.
References:
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Spin-orbit torque in two-dimensional material van der Waals heterostructures.
supervisor: RNDr. Martin Gmitra, PhD.
study form: full time
Annotation: Spin-orbit coupling is a microscopic interaction between charge and spin. In a variety of materials it opens novel strategies for nanoelectronics design. Spin-orbit torque provides a potential to propose new technology for low-power, non-volatile memory and logic devices utilizing current induced magnetization manipulation. Recent discovery of two-dimensional materials offers a unique opportunity to build van der Waals heterostructures and study proximity effects between spin-orbit coupling and magnetism, and utilize them to create novel heterostructures with a variety of properties. There are established two microscopic mechanisms for spin-orbit torque origin, the spin Hall effect and inverse spin galvanic effect leading to damping-like torque and field-like torque, respectively. The research will be focused on first-principles calculations of electronic structure and development of theory for the corresponding spin-orbit torques in technologically relevant heterostructures.
References:
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The study of the electronic properties of graphene fullerene onions with a reactive atom inside.

supervisor: RNDr. Richard Pinčák, PhD. (pincak@saske.sk)
study form: full time
Annotation: Different types of graphene onions will be studied by methods of quantum theory and statistical physics. In particular, the C20 @ C80, C60 @ C240 and C240 @ C540 onions will be selected as subjects of the basic study because they are among the most stable ions. But even these fullerenes have different diameters, charges and also electron properties, so we can draw more conclusions for them with examples of similar inner and outer shells. Individual reactive atoms such as Ni, Fe and Co are incorporated inside each of these fullerenes (Figure 1). The aim of this study is to find new stable onion structures with suitable electronic properties required by the nano-industry. Basic theories and approaches to solving a given topic without a reactive atom inside are published in the works [1-3].

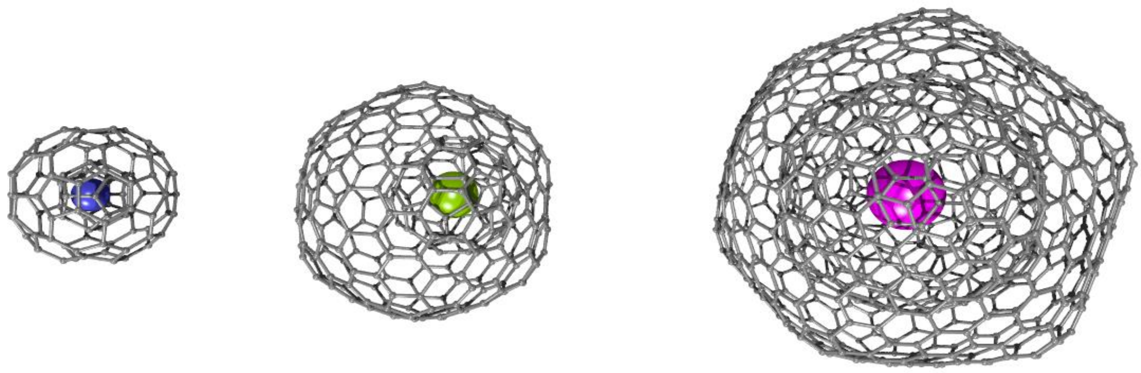

Fig. 1. Atomic structures of a) C20@C80+Ni; b) C60@C240+Fe; c) C240@C540+Co

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