Theoretical physics

Theoretical investigation of a combined influence of anharmonic lattice vibrations, external magnetic field and pressure on magnetic properties of localized spin systems.
supervisor: prof. RNDr. Michal Jaščur, PhD.
study form: full time
Annotation: The theoretical and experimental investigation of magnetic properties of various physical systems under simultaneous influence of different external fields represents an interesting research subject of current condensed matter theory. However, one should emphasize here that the standard statistical-mechanical approach using a suitable statistical ensemble is not straightforwardly applicable to the solving of this problem because of a huge mathematical complexity of relevant calculations. The main aim of the dissertation is therefore to apply simple self-consistent theories developed recently in [1-3] in order to investigate the combined influence of static (elastic) potential energy, anharmonic lattice vibrations, external magnetic field and pressure on magnetic properties of various localized spin systems. It is expected that such a complex theory may predict some new physical phenomena originated by competing effects of all relevant contributions to the total energy of the investigated systems.
1] T. Balcerzak, K. Szalowski and M. Jaščur, J. Phys.: Condens. Matter 22 (2010) 425401.
[2] T. Balcerzak, K. Szalowski and M. Jaščur, J. Appl. Phys. 116 (2014) 043508.
[3] T. Balcerzak, K. Szalowski and M. Jaščur, J. Magn. Magn. Mat. 426 (2017) 310.

A generalized frustrated planar rotator model.
supervisor: doc. RNDr. Milan Žukovič, PhD.
study form: full time
Annotation: It is well known that the 2D XY model exhibits an unusual infinite order phase transition belonging to the Kosterlitz-Thouless (KT) universality class [1]. Introduction of a nematic coupling into the XY Hamiltonian leads to an additional phase transition in the Ising universality class [2]. It has been shown that the higher order harmonics lead to a qualitatively different phase diagram, with additional ordered phases originating from the competition between the ferromagnetic and pseudonematic couplings [3]. The new phase transitions belong to the 2D Potts, Ising, or KT universality classes. The present study will investigate effects of geometrical frustration on the triangular lattice model with antiferromagnetic couplings, which shows an additional chiral phase above the KT line, as well as the presence of quenched nonmagnetic vacancies on the critical properties.
[1] J.M. Kosterlitz and D.J. Thouless, J. Phys. C 6, 1181 (1973).
[2] D.H. Lee and G. Grinstein, Phys. Rev. Lett. 55, 541 (1985).
[3] F.C. Poderoso, J.J. Arenzon, and Y. Levin, Phys. Rev. Lett. 106, 067202 (2011).

Skyrmion excitations in the frustrated Heisenberg antiferromagnet with antisymmetric exchange interactions.
supervisor: doc. RNDr. Milan Žukovič, PhD.
study form: full time
Annotation: An antisymmetric Dzyaloshinskii-Moriya (DM) spin exchange interaction can lead to the formation of twisted magnetic structures [1,2]. These have attracted much interest mainly after the experimental observation of nontrivial magnetic configurations, called magnetic skyrmion lattices, which have important potential technological applications [3]. In ferromagnetic systems, the skyrmion phase arises from the competition of the ferromagnetic and DM interactions and it is stabilized by a magnetic field and thermal fluctuations. Recently, a closely related antiferromagnetic skyrmion (AS) phase was discovered in the frustrated

classical antiferromagnetic Heisenberg model [4]. The objective of the proposed research is exporation of the AS phase stability in a wide parameter space, as well as the study of its response to the effects of magnetic and topological disorder.

[1] I. Dzyaloshinskii, Journal of Physics and Chemistry of Solids 4, 241 (1958)
[2] T. Moriya, Physical Review 120, 91 (1960).
[3] N. Romming, C. Hanneken, M. Menzel, J. E. Bickel, B.Wolter, K. von Bergmann, A. Kubetzka, and R. Wiesendanger, Science 341, 636 (2013).
[4] H. D. Rosales, D. C. Cabra, and Pierre Pujol, Phys. Rev. B. 92, 214439 (2015).

Quantum entanglement in unconventional states of exactly solved models.

supervisor: doc. RNDr. Jozef Strečka, PhD.

study form: full time

Annotation: Quantum entanglement belongs to the most intriguing consequences of the quantum mechanics, which is highly contra-intuitive and remains at a forefront of the current research interest. Among the most challenging issues related to this subject matter is to investigate the thermal entanglement through different measures (e.g. concurrence, negativity, von Neumann entropy, etc.), which quantify how the quantum entanglement evolves with rising temperature. The main focus of this dissertation thesis is to examine different measures of the thermal entanglement in the exactly solved lattice-statistical spin models. In particular, the considerable attention will be devoted to an open questions whether or not the thermal entanglement may coexist with a spontaneous long-range order and how it changes across quantum critical points.

1. M.A. Nielsen, I.L. Chuang, Quantum Computation and Quantum Information, Cambridge University Press, 2000.
2. L. Amico, R. Fazio, A. Osterloh, V. Vedral, Entanglement in many-body systems, Reviews of Modern Physics 80 (2008) 517-575.

Theoretical investigation of phase separation in binary and ternary liquid mixtures.

supervisor: doc. RNDr. Jozef Strečka, PhD.

study form: full time

Annotation: The phase separation of binary and ternary liquid mixtures will be investigated within the framework of the lattice-statistical models such as the generalized Frenkel-Louis and Lin-Taylor models. In particular, the main emphasis will be laid by accounting for the multiparticle (e.g. three-body) interactions, which may play a crucial role in determining possible non-universal critical behavior. Besides, the dissertation thesis will focus on a problem of reentrant miscibility of some binary and ternary liquid mixtures with highly orientation-dependent forces (e.g. hydrogen bonding).

1. T. Narayanan and A. Kumar, Reentrant phase transitions in multicomponent liquid mixtures, Physics Reports 249 (1994) 135-218.
2. J. Strečka, L. Čanová, M. Jaščur, Investigation of phase separation within the generalized Lin–Taylor model for a binary liquid mixture of large hexagonal and small triangular particles, Molecular Physics 104 (2006) 3831-3839.

Theoretical study of frustrated spin models on a bipartite lattices

supervisor: prof. RNDr. Andrej Bobák, DrSc.

consultant: doc. RNDr. Milan Žukovič, PhD.

study form: full time

Annotation: Generally, the frustration is generated by the competition of different kinds of interaction and/or by the lattice geometry. As a result, in the ground state all bonds are not fully satisfied. However, a honeycomb lattice antiferromagnet like the square lattice with only nearest-neighbor exchange interactions are considered as bipartite lattice, the ground state

exhibits long-range ordering. These systems become frustrated, if the next-nearest-neighbor exchange interactions are considered. Hence, it is interesting to study the magnetic properties of such lattices under frustrating interactions, which are still not well understood at present.

Anomalous scaling in anisotropic turbulent environments
supervisor: RNDr. Marián Jurčišin, PhD. – Institute of Experimental Physics Slovak Academy of Sciences Košice
study form: full time
Annotation: Study of the influence of the uniaxial anisotropy of turbulent environments on the anomalous scaling of passive admixtures by using quantum field theory methods in the framework of various turbulent models (Kraichnan model, Kazantsev-Kraichnan model, Navier-Stokes turbulence, kinematic magnetohydrodynamic turbulence, etc.).

Study of cooperative phenomena in coupled electron and spin systems.
supervisor: RNDr. Pavol Farkašovský, DrSc. – Institute of Experimental Physics Slovak Academy of Sciences Košice
study form: full time
Annotation: This PhD thesis will be devoted to the theoretical study of cooperative phenomena in coupled electron and spin systems with an emphasis on understanding the microscopic mechanisms leading to coexistence of quantum states with different order parameters, like the charge/spin ordering and the superconductivity, or the ferromagnetic and ferroelectric state.

Description of the structure of curved graphene and highly stochastic systems using modern approaches of mathematical physics
supervisor: RNDr. Richard Pinčák, PhD. – Institute of Experimental Physics Slovak Academy of Sciences Košice
study form: full time
Annotation: Topic of the dissertation is to develop a theory describing the physical properties of the carbon nanoparticles, where via the spin-orbital, electronic and other interactions induced by the surface curvature one could control the motion of the electrons on the given nanoparticle. We will develop a theory describing the physical properties of the carbon nanoparticles, where the applications of the multi-loop Feynman diagrams as well as the string theory can be utilized. Additionally, we want to develop the phenomenology and the applications of the string theory within the extended and generalized supersymmetric models on the exactly defined time-series as well as graphene. Also, we want to continue in creating theories describing the predictions of the development of courses on financial markets as well as the dynamics of the development of the stock market.