Quantum cooperative phenomena and highly correlated electronic systems

In many cases, the key to understanding the fundamental properties of matter lies in the study of matter at low temperatures. Under conditions when thermal oscillations do not hide subtle interactions, a field of quantum cooperative phenomena opens up that has no analogues in classical physics. This range of phenomena includes magnetism, superconductivity, spin density waves, charge density waves, Bose–Einstein condensation, superfluidity. It should be noted that current trends in world science are based on the priority of the study of physical effects in materials that are promising for the latest technological applications. At the same time, the general trend is manipulation at the level of individual electronic degrees of freedom such as spin or orbital states using the interaction between them and the crystal lattice. It is this ability — to manipulate certain degrees of freedom — has led to the emergence of breakthrough areas of electronics — spintronics and magnonics. The growth in the number of publications in the last two areas is explosive in the world scientific literature. The use of quantum cooperative phenomena, topologically protected electronic and magnetic states, the involvement of orbital degrees of freedom is the next level of development that is just unfolding. In accordance with the above trends, this issue of the journal is devoted to research on new features of quantum cooperative phenomena, as well as the basics of optimizing physical properties and managing the functionality of new materials to implement them in the element base of modern micro- and nanoelectronics devices. These are low-dimensional magnetic systems, topological insulators, non-traditional superconductors, etc.

In the opening paper of V. Krivoruchko, the possible realization of a topological spin triplet superconducting state is discussed. The author considers hybrid nanostructures which consist of singlet superconductors — half-metallic manganites. The basic idea is that the half-metal spin-polarized charge carriers may provide local high-temperature spin-triplet superconductivity due to proximity effect. From this point of view, the author discuss a few experiments which demonstrate the appearance of a local superconductor state has been observed by the point-contact Andreev-reflections spectroscopy in the superconductor–semi-metallic manganite hybrid systems.

The microwave stimulation of a superconductive state has been investigated experimentally by A. P. Shapovalov, V. E. Shaternik, O. Boliasova, and O. Y. Suvorov. Authors use self-fabricated MoRe–Si(W)–MoRe heterostructures with hybrid barriers formed by a Si semiconductor layer with W metal nanoclusters. The stimulation effect has observed at frequencies above a threshold value that can be explained by a non-equilibrium redistribution of filled energy levels in tungsten clusters.

In the paper of A. M. Kutsyk, A. L. Kasatkin, and A. A. Kordyuk, the input of fractional vortices and their subsequent dynamics inside a two-band superconductor are studied on the basis of numerical solutions of the time-dependent Ginzburg–Landau equations. The case is considered when superfluid electronic condensates from two zones are characterized by different parameters, such as coherence lengths and London depth penetration, which, in turn, leads to different critical magnetic fields H_c and fractions of fractional flux.

The self-doped manganites $SmMnO_{3+\delta}$ ($\delta \sim 0.1$) demonstrate strongly correlated spin and charge behavior that is seen in the magnetization dependence on temperature (4.2–250 K) and magnetic fields presented in the article of F. N. Bukhanko and A. F. Bukhanko. In the low-temperature range (4.2–12 K), the magnetization shows a drastic difference depending on the magnitude of the magnetic field when using relatively weak fields (0.1, 1, and 3.5 kOe). The general unusual temperature behavior of magnetization, characteristic for spin liquids, allows the authors to use well known theoretical models of quantum liquids to explain the obtained results at a qualitative level.

The coupling between the lattice, magnetic, and electronic subsystems can lead to very interesting physical properties and effects, interesting from both a fundamental and an applied point of view. In the theoretical work of A. A. Zvyagin, the effect of the external electric field and/or the external strain on the low-temperature behavior of the quantum spin chain was studied. It has been shown that the external electric field or the strain can cause the quantum magnetic structural phase transition between two magnetically ordered phases with different order parameters. The observation of such a quantum critical point in the temperature behavior of the magnetic susceptibility and specific heat is predicted.

In the paper of O. V. Usatenko, S. S. Melnyk, and V. A. Yampolskii, the transverse Anderson localization of the p-polarized wave, which propagates along the layers in the randomly stratified dielectric and evanesces exponentially in the direction across the layers, has been studied. It was shown that the Anderson mechanism does not reduce the transparency of the optical tunnel barrier but, on the contrary, can significantly enhance it. In contrast, the Anderson mechanism changes the dispersion law for the surface plasmon-polariton waves so that the localization depth increases for given wave vector, but it decreases for given frequency.

The effect of the local exchange anisotropy on the spectral properties of a binuclear molecular magnet with $S = 1/2$ magnetic ions and with the C_2 internal permutation symmetry was investigated by A. V. Zhuravlev. An anomalous variation of the magnetic system average spin depending on the misalignment of the local anisotropy axes has been found. Particularly, a fully nonmagnetic state of an $S = 1/2$ spin dimer and "silent" EPR mode has been predicted.

In the four experimental papers in this issue, Raman scattering is the main research method. In recent decades and especially after the discovery of high-temperature superconductivity in the cuprates and by new developments in instrumentation, the role of Raman spectroscopy in search for conventional as well as exotic excitations in strongly correlated matter and manifestations of quantum effects has been greatly enhanced. Raman spectroscopy has provided new and valuable insights into the rich variety of intriguing physical properties for both fundamental research and potential applications.

In the paper by the group of authors A. Glamazda, A. Sharafeev, R. Bohle, P. Lemmens, K.-Y. Choi, R. Sankar, and F.S. Shou presents Raman scattering study of the Pb-doped dichalcogenide Pb_xTaSe_2 (x = 0, 0.25, 0.33, 0.5, 0.75, and 1). Title compound consists of alternating stacking of hexagonal $TaSe_2$ and Pb layers. It was found that with an increase in the concentration of lead, with the crossover of CDW to topological superconductivity, a pronounced hardening of the in-plane E_{2g} mode is observed. This effect was discussed in the framework of nontrivial coupling between the Pb and $TaSe_2$ layers, which is responsible for structural and electronic changes.

The great challenges in modern condensed-matter physics are quantum spin systems that have a ground state with no long-range magnetic order and an energy gap in the magnetic excitation spectrum. The details of their magnetic behavior depend on the specific type of spin correlations, largely determined by the lattice topology. In the article by V. Gnezdilov, P. Lemmens, D. Wulferding, A. Kitada, and H. Kageyama, first Raman scattering data on the quasi-2D quantum spin compound $(CuCl)LaNb_2O_7$ measured in the wide temperature range of 1.5–295 K are presented. The main goal of the work was to derive a better understanding of the spin and lattice dynamics of this compound. Phonon data were used to derive an effective structural model that may serve as a basis for its unconventional magnetic properties. The pronounced temperature behavior of the quasielastic scattering indicates the presence of sizable quantum fluctuations in the system. Finally, it was shown that the low-energy excitation spectrum of the $(CuCl)LaNb_2O_7$ has a rich and complex structure. It contains a one-triplet mode, several singlet modes, which are interpreted as collective two-particle singlet bound states of strongly localized triplets, a well pronounced wide band which may be interpreted within the framework of correlated three triplets, and two-magnon excitations.

The paper of F. Buscher *et al.*, which should be given special attention, devoted to experimental study of the quasielastic Raman scattering of plane-wave light and light that carries an orbital angular momentum (OAM), or the twisted light, by liquid crystals. The discovery that photons might additionally convey integer amounts of OAM quickly opened new areas of research in twisted and structured light, optical vortices, and singular optics. Naturally, the question arose about potential connections between OAM itself, and chiroptical forms of light–matter interaction. Despite a controversial discussion, several recent studies have suggested that certain conditions for such an OAM coupling can be anticipated. Experimental observations given in the paper suggest that the observation of iridescence in the chiral phase of a liquid crystal may help to investigate these regimes, favorable for the OAM transfer between light and matter.

Authors S. A. Klimin and A. V. Peschanskii performed comprehensive studies of $KDy(WO_4)_2$ crystal using Raman scattering and IR transmission spectroscopy. The energy scheme for the crystal-field (CF) levels of Dy^{3+} ions was created. The Jahn–Teller phase transition at $T_c = 6.3$ K was recorded by both experimental techniques and appeared as an abrupt shift of CF excitations to the higher energy. This observation was interpreted as a lowering of the ground CF state of the Dy^{3+} ion arising due to cooperative interionic interactions in the Dy subsystem. Splitting of the low-lying first excited CF level of Dy^{3+} ion indicates the simultaneous structural transitions. The role of Davydov interaction is discussed.

The second part of our special topic consists of five papers which will be published in the next No. 12 issue of the journal. Here we give its short overview:

In the paper of E. Zubov "Reentrant induced superconductivity in hybrid structure with high barrier transparency", the influence of electron tunneling on spontaneous and induced order parameters in the hybrid structure normal metal–superconductor is considered.

Authors M. Belogolovskii, E. Zhitlukhina, and P. Seidel of the paper "Probing long-range current-carrying edge modes by two quantum point contacts" propose an experiment to study anomalous boundary conduction states in quantum samples.

The effect of magnetic and structural phase transitions on the spin, lattice and electronic excitations has been studied in the paper of A. Yu. Glamazda, V. P. Gnezdilov, P. Lemmens, G. A. Zvyagina, and I. A. Gudim "Raman scattering study of the rare-earth binary ferroborate $Nd_{0.75}Dy_{0.25}Fe_3(BO_3)_4$ single crystal".

The static topological spin structures in the quasi-one-dimensional anisotropic Heisenberg ferromagnets have been studied analytically and numerically in the paper of O. V. Charkina, V. I. Belan, and M. M. Bogdan "Structural transformation of spin nanoclusters in low-dimensional anisotropic ferromagnets under applied magnetic field".

In the paper S. A. Klimin, P. S. Berdonosov, and E. S. Kuznetsova "Quasi-doublets of non-Kramers Ho^{3+} and magnetic ordering of holmium francisite-analog $Cu_3Ho(SeO_3)_2O_2Cl$", the holmium optic spectra has been studied in the wide temperature range. The onset of the magnetic order has been detected by the spectra splitting.

V. P. Gnezdilov and Yu. G. Pashkevich