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CONDENSED MATTER PHYSICS

In honour of Professor Ihor Yukhnovskii on the occasion of his 75th birthday

The present and the preceding issues of "Condensed Matter Physics" contain papers written in honour of Professor Ihor Yukhnovskii on the occasion of his 75th birthday. Professor Ihor Yukhnovskii is a well-known Ukrainian physicist, statesman and public figure. He is a founder of the Lviv school of statistical physics. Its main directions are the theory of liquids and electrolyte solutions, the theory of quantum systems of interacting particles, the theory of phase transitions and critical phenomena, theory of disordered systems and the theory of nonequilibrium processes.

The research activity of Ihor Yukhnovskii is closely connected with the name of prominent scientist – Professor N.N.Bogoliubov. Permanent scientific contacts between I.R.Yukhnovskii and N.N.Bogoliubov generated new ideas and solutions of specific physical problems and promoted forming the main scientific directions of Lviv school of statistical physics.

The first papers of Ihor Yukhnovskii were published in collaboration with Professor A.E.Glauberman, who was a supervisor of his Ph.D. work. The main subject of this study was related to applications of Bogoliubov's method of plasma parameter expansion for the study of binary distribution functions in charged particle systems. The results obtained were used in the theory of electrolyte solutions as well as in the theory of the high-temperature plasma.

The method of collective variables developed by I.R.Yukhnovskii permitted to consider one of the central problems in statistical physics: the problem of a correct and simultaneous treatment of the short- and long-range interactions in classical systems of interacting particles. Description of statistical systems in an extended phase space containing coordinates of particles and modes of density fluctuations (collective variables) is the main idea of this approach. Transition to the extended phase space is performed by means of the transition function, its explicit form was found. Two approaches were proposed by I.R.Yukhnovskii to take into consideration the short-range interaction. The first one based on the functional differentiation is reduced to the generalized Mayer group expansions for charged particle systems. The second approach consists in the separation of the short-range interaction contribution and in consideration of the screened long-range interactions. The latter approach appeared to be the particular useful in constructing the theory of condensed matter, namely, the theory of liquids and electrolyte solutions.

In the 60th the method of collective variables first was extended to the ion-dipole systems and then was generalized to the systems with arbitrary electrostatic interactions. The microscopic theory of electrolyte solutions elaborated by I.R.Yukhnovskii and M.F.Holovko was the most important achievement in this field. The use of the high-order group expansions enabled one to study the fundamental role of the molecular subsystem in revealing (on the microscopic level) both the nature of the ion solvation and a peculiarity of the short-range order in electrolyte solutions (I.R.Yukhnovskii, M.F.Holovko, A.O.Nekrot, V.S.Vysochanskii).

In the works of I.R.Yukhnovskii, M.F.Holovko, I.Y.Kuryliak, and Ye.M.Soviak, the theory of electrolyte solutions was extended to the case of spatially bounded systems. Analytical theories for electrolyte mixtures and membranes were suggested. It was found that screening effects for spatially nonuniform systems are qualitatively different from those of bulk systems. The difference is caused by the presence of electrostatic reflection forces in the electrolyte near the interface with the other medium, which rouses adsorption effects. The phenomena of electrolyte ion repulsion from (or attraction to) the surface were proven to depend on dielectric properties of solvents and of the external medium. On the basis of the results obtained a new mechanism of the desalination of water was proposed.

In 1964 I.R.Yukhnovskii initiated studies in the theory of interacting quantum particles. He suggested and developed a new original approach: the method of displacements and collective variables. This method is free of some intrinsic drawbacks of other methods of many-body theory. The essence of the method is extraction from the evolution operator, which is defined on the set of Cartesian particle coordinates, a full multiplication operator that describes the interaction of quantum particle wave packets and is expressed in terms of collective variables. From the mathematical point of view this method maps the partition function of quantum system on the partition function of classical system with many-particle interactions. The method was applied to one of the most important models in the solid state theory – an electron gas in a uniform compensating field (L.F.Blazhyjevskii, G.I.Bigun, M.V.Vavrukh, R.M.Petrashko, P.P.Kostrobij).

Important results in the theory of strongly correlated electronic systems were obtained by a follower of I.R.Yukhnovskii – Professor I.V.Stasyuk. In the mid-60ties the original approach to the consideration of the short-range correlations based on the formalism of site operators (Hubbard operators) was developed in his works. On this basis numerous physical effects in crystals with ferroelectric and structural phase transitions as well as in the systems with high-temperature superconductivity were studied by Prof. I.V. Stasyuk and his collaborators.

The method of a reference system, proposed by Ihor Yukhnovskii, was employed in the studies of various physical systems. For the reference system an accurate solution can be found. This allows one to consider a whole system on the background of a reference one and to reformulate a perturbation theory on this basis. The method of a reference system was successfully applied for the studies of hydrogen-bonded ferroelectrics of the KDP type with taking into account the tunnelling effects (I.R.Yukhnovskii and R.R.Levitskii). For the first time it was shown, that in the reference approach, with the short-range interactions and tunnelling taken into account in cluster approximation, the dynamic properties of the studied systems were to a great extent determined by an effective tunnelling parameter, renormalized by the short-range interactions.

A separate branch in the development of the displacements and collective variables method is connected with the studies of interacting systems of Bose-particles (I.R.Yukhnovskii, I.O.Vakarchuk). These studies resulted in the construction of a quantitative microscopic theory of ^{4}He. An accurate expression for statistical operator of the many-boson system in coherent states representation was found in subsequent works by Professor I.O.Vakarchuk. There, an effective functional of the grand canonical potential was found rigorously. This permitted to define a set of λ-transition characteristics in liquid ^{4}He.

Fundamental results were obtained by Ihor Yukhnovskii in the theory of phase transitions and critical phenomena. His first papers in that direction were published in the mid-70th and contained already the basic ideas of an original method for calculating a partition function of a three dimensional Ising model within the collective variables approach. It was shown (I.R.Yukhnovskii and Yu.K.Rudavskii) that the consistent theory of phase transitions should be based on non-Gaussian measures of critical fluctuations. Two main fluctuational processes with different space-scale were discovered. The first one, called critical regime, has intrinsic renormalization group symmetry and forms universal quantities such as critical exponents and ratios of critical amplitudes. And the second one, which was called the limiting Gaussian regime, provides the thermodynamic stability of a system and is described by the renormalized Gaussian distribution of fluctuations. On this basis explicit expressions for the free energy, the specific heat and other thermodynamic quantities of the Ising model in the vicinity of phase transition were obtained (I.R.Yukhnovskii, M.P.Kozlovskii, V.O.Kolomiets, and I.V.Pylyuk) and the dependence of non-universal characteristics on microscopic parameters was studied.

Taking into account the novelty of the Yukhnovskii's approach, comparison of it with other methods was made. In particular, I.R.Yukhnovskii, M.P.Kozlovskii and Ya.M.Ilnitskii performed a comparative analysis of the collective variables method and the ϵ-expansion approach. They found a series of essential advantages of the collective variables method and the specific conditions at which the recursion relations between the coefficients of effective block structures can be reduced to the well-known K.Wilson's recursion relations.

The detailed study of the Ising model critical behaviour enabled one to generalize I.R.Yukhnovskii's approach to many other condensed systems, in particular, to the study of the phase transition in the n-component model of a ferromagnet. The first papers in that direction were published by I.O.Vakarchuk, Yu.K.Rudavskii and I.R.Yukhnovskii in 1979. They suggested a functional representation of the partition function of the n-component model and wrote down a differential form of the recurrent relations for this model. This became a basis for a further development of this theoretical approach in the papers by Yu.V.Holovatch and I.M.Mryglod. Numerical calculations for both the Ising model and the n-component model were made by V.O.Kolomiets. Critical behaviour of disordered systems was studied in collaboration with Yu.V.Holovatch and M.A.Shpot.

A broad spectrum of studies was performed by Yukhnovskii's disciples, I.O.Vakarchuk and Yu.K.Rudavskii for topologically disordered magnetic systems. The functional approach developed in their papers was applied to the study of amorphous Heisenberg ferromagnets with liquid-like structure, including a vicinity of the phase transition point. These studies resulted in constructing the microscopic theory of liquid magnets, which took into account both liquid structure and Heisenberg exchange interaction responsible for ferromagnetism. Recently, this theory was developed for the study of dynamical properties, and the explicit expressions for hydrodynamic time correlation functions were derived (I.M.Mryglod, M.V.Tokarchuk, and Yu.K.Rudavskii).

In the papers by I.R.Yukhnovskii and Yu.V.Kozitskii, the collective variables method was used in the studies of the critical behaviour of hierarchical models. These studies found their development in works of Yu.V.Kozitskii on rigorous methods in phase transition theory. The functional representation of the partition function for cluster spin models was derived by I.R.Yukhnovskii and M.A.Korynevskii. This allowed, using Yukhnovskii's scheme, to calculate the free energy as well as other thermodynamic functions for a cluster ferroelectric system (M.A.Korynevskii).

In the mid-80ties essential and principally new results were obtained by I.R.Yukhnovskii in his studies of phase transitions in fluids. In cooperation with I.M.Idzyk and V.O.Kolomiets he combined the reference system concept with the approach developed for the critical behaviour of the Ising model and constructed the microscopic theory of the gas-liquid transition. In particular, it was found explicit expressions for the chemical potential isotherm, a jump of density and the phase transition temperature.The thermodynamic properties of a fluid both in one- and two-phase regions were studied. In the papers by I.R.Yukhnovskii and O.V.Patsahan the statistical theory of the fluid in the critical region was extended to the case of the classical many-component mixtures. They used the collective variables method in conjunction with the reference system approach to describe the binary and many-component mixtures near the gas-gas and fluid-fluid transition points.

The I.R.Yukhnovskii's approach to a theoretical description of phase transitions appeared to be very fruitful in its application to real physical objects, in particular, to substitutional binary alloys. In the joint papers by I.R.Yukhnovskii and Z.O.Gurskii the microscopic theory of thermodynamic properties of binary alloys was developed. It was shown that the long-range order in alloys is connected with the atomic density fluctuations that correspond to the absolute minimum of the ordering potential Fourier transform. The equations for chemical potentials of the alloy components were found and analysed. The free energy of the alloy as a function of temperature and concentration and the equation of state were obtained. Thus, the collective variables method yields a solution to the principle problem of the materials theory: to predict physical properties of the alloy at different external parameters, e.g., the temperature and the alloy composition.

In the mid-70th Professor Yukhnovskii initiated studies in the field of nonequilibrium statistical theory. This was done in a close cooperation with Professor D.N.Zubarev. On the basis of collective variables concept a new method in nonequilibrium theory of liquids, known as the generalized collective mode approach, was formulated (I.M.Mryglod, M.V.Tokarchuk, I.P.Omelyan, and T.M.Bryk).

Statistical theory of partially excited systems which takes into consideration the effective resonant interactions was developed in the works of I.R.Yukhnovskii, R.R.Levitskii and O.V.Derzhko. On this basis the virial state equation and the pair spatial distribution functions were obtained. In particular, the suggested theory allowed one to explain the increase of critical temperature and pressure as well as the change of the gas-liquid coexistence curve under the effect of resonance irradiation.

Since 1986 Ihor Yukhnovskii has been paying special attention to problems connected with Chornobyl disaster. That year studies of aqueous solutions of radioactive elements were started. The interest to the problem of interaction of fuel-containing masses and fragments of reactor's active zone with water and constructions' materials in the "Shelter" site was initiated by I.Yukhnovskii and M.Tokarchuk. There were performed the investigations which elucidated the role of radiolysis, hydrolysis and creation of complexes in aqueous solutions of radioactive elements (uranyl, plutonyl ions) that interact with fuel-containing masses. Prof. Yukhnovskii permanently emphasizes the active role of hydrogen in the processes of destruction of fuel-containing masses interacting with aqueous solutions.

Professor Yukhnovskii pays much attention to other problems which are very important to economy of Ukraine. In 1992 he was the first who initiated the development of computer network facilities in Ukraine. At that time the first Ukrainian network for research and educational institutions was created in Lviv (A.Ya.Saban and I.A.Protsykevych). At present the problems of catalysis, optical methods of information protection, new technologies in energetics (fuel cells) are of great interest to Professor Yukhnovskii.

Professor Yukhnovskii is the author of more than 500 papers and books. About 40 researchers under his supervision became Candidates of Sciences and 13 are Doctors of Sciences. Yukhnovskii's scientific and public contributions have been recognized by many awards and honorary degrees. In 1982 he was elected Member of the National Academy of Sciences of Ukraine, in 1986 he was awarded the Krylov Prize of Ukrainian Academy of Sciences.

This overview of the scientific problems, in formulating and solving of which Prof. Yukhnovskii participated, is far from being complete. At present he uses his scientific and life experience in running Interbranch Analytical and Consultative Council of Cabinet of Ministers of Ukraine that analyzes state of the Ukrainian economy, its prospects and trends in its development.

The Editorial Board of "Condensed Matter Physics" congratulates Professor Yukhnovskii on the occasion of his notable anniversary and acknowledges his unique and valuable contribution to science in the world. We also express our grateful thanks to all the authors of these two issues of CMP for their contributions.

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