BOGOLIUBOV LABORATORY OF THEORETICAL PHYSICS

At the Bogoliubov Laboratory of Theoretical Physics (BLTP), studies are carried out on the following four themes: Theory of Elementary Particles; Modern Mathematical Physics: Gravity, Supersymmetry, Integrability; Nuclear Structure and Dynamics; Theory of Condensed Matter and New Materials. Important components of the BLTP activities are theoretical support of experimental research to be carried out with JINR participation and recruiting of young researchers, students, and postgraduate students to the Laboratory.

THEORY OF ELEMENTARY PARTICLES

Theoretical investigations were continued in the framework of the following projects:

- Standard Model and Its Extensions;
- QCD Parton Distributions for Modern and Future Colliders;
- Physics of Heavy and Exotic Hadrons;
- Mixed Phase in Heavy-Ion Collisions.

Much attention was paid to the study of fundamental problems of quantum field theory as well as to the analysis and theoretical support of current and future experiments.

Prospects for observing a signal from two gluinos were investigated within a certain region of the mSUGRA parameter space. In this region, the lightest stable neutralinos can serve as cold dark matter particles and present a natural explanation of the excess of diffuse galactic gamma rays observed by the EGRET space apparatus. The event selection relies on a very clear signature when decay products of each gluino contain one $b\bar{b}$ pair, one or two $l\bar{l}$ pair(s), and a neutralino. It was found that the clear signatures of the selected processes demonstrate good prospects for discovering gluinos at the LHC [1].

The constraints on the pion distribution amplitude (DA) available from perturbative QCD, nonlocal QCD sum rules and light cone sum rules were analyzed. Good agreement between obtained results and recent high-precision lattice calculations of the second moment of the pion DA was established. It was shown which regions in the space of the first two nontrivial Gegenbauer coefficients a_2 and a_4 of all the constraints overlap, thus tagging the pion structure to the highest degree possible at present [2].

Magnetic fields created in noncentral heavy-ion collision were studied within the microscopic transport model, the Ultrarelativistic Quantum Molecular Dynamics model (UrQMD). Simulations were carried out for different impact parameters in the SPS energy range ($E_{\rm lab} = 10{-}158A$ GeV) and highest energies accessible for RHIC. It is demonstrated that magnetic field emerging in heavy-ion collisions has values of an order of $eB_y \sim 10^{-1}\ m_p^2$ for the SPS energy range and $eB_y \sim m_p^2$ for RHIC energies. The estimated value of the magnetic field strength for the LHC energy amounts to $eB_y \sim 15\ m_p^2$ [3].

Chiral perturbation theory in the two-flavour sector allows one to analyze Green functions in QCD in a limit where the strange quark mass was considered to be large in comparison with the external momenta and the light quark masses. In this framework, the pertinent low-energy constants depend on the value of the heavy quark masses. In the previous article, the dependence on the strange quark mass at two-loop accuracy was worked out for the coupling constants which occur at the order p^4. Analogous relations for some of the couplings which are relevant at the order p^6 were provided [4].

The semileptonic decays of double-heavy baryons were studied using a manifestly Lorentz covariant constituent three-quark model [5]. There were presented

complete results on transition form factors between double-heavy baryons for finite values of the heavy quark/baryon masses and in the heavy quark symmetry limit. Decay rates were calculated and compared to each other in the full theory, keeping masses finite, and also in the heavy quark limit.

In the paper [6] a study of small-x behavior of the structure function F_2 and its slope $\partial \ln(F_2)/\partial \ln(1/x)$ was carried out. Using the leading-twist approximation of the Wilson operator product expansion, it was shown that the Bessel-inspired behavior of the structure function F_2, obtained for a flat initial condition in the DGLAP evolution equations, led to good agreement with experimental data of deep-inelastic scattering at DESY HERA above $Q^2 = 2.5$ GeV^2. The agreement for smaller Q^2 values can be improved essentially by using the «frozen» and analytic modifications of the strong-coupling constant α_s. So the analytic strong-coupling constant can be considered in particular as a useful phenomenological model for physical processes with small values of the transfer momenta squared.

A consistent approach to factorization of scattering amplitudes for exclusive processes beyond the leading-twist approximation was proposed. This method was compared with the covariant method formulated in the coordinate space, based on the operator product expansion. The equivalence of two approaches was proved. The expressions of the impact factor for the transition of virtual photon to transversally polarized rho-meson up to the twist 3 accuracy were computed within these two quite different methods [7].

The renormalization-group properties of transverse-momentum dependent parton distribution functions in the light-cone gauge with the Mandelstam–Leibbrandt prescription for the gluon propagator were addressed. An expression for the transverse component of the gauge field at light-cone infinity, which plays a crucial role in the description of the final-initial-state interactions in the light-cone axial gauge, was obtained. The leading-order anomalous dimension was calculated in this gauge, and the relation to the results obtained in other gauges was worked out. It was shown that using the Mandelstam–Leibbrandt prescription the ensuing anomalous dimension did not receive contributions from extra rapidity divergences related to a cusped junction point of the Wilson lines [8].

An effective Lagrangian for the coupling of the neutral pion with gluons whose strength is determined by a low energy theorem was proposed. The contribution of the gluonic components arising from this interaction to the pion transition form factor was calculated using the instanton liquid model to describe the QCD vacuum. It was found that this contribution was large and might explain the anomalous behavior of the form factor at large virtuality of one of the photons, a feature which was recently discovered by the BaBar Collaboration [9].

The Mellin–Barnes representation was used in order to improve the theoretical estimate of mass corrections to the width of light pseudoscalar meson decays into a lepton pair. The full resummation of the lepton and meson mass corrections to the decay amplitude was performed. The total effect of mass corrections is quite important for η and η' decays. Based on these results, new estimate of the hadronic light-by-light scattering contribution to the muon anomalous magnetic moment in the chiral perturbation theory was found. The influence of the new BaBar data for the pion form factor on the rare decay branchings was considered [10].

Considering quarks as quasiparticles of the model Hamiltonian with four-fermion interaction, we studied response to the process of filling up the Fermi sphere with quarks, calculated the vacuum pressure and demonstrated the existence of filled-in state degenerate with the vacuum one [11].

An adiabatic method for analysis of channeling problem for charged particles with a transversal confining environment induced by an axial homogeneous magnetic field, a crystal lattice or a quantum wire was developed. Effects of resonance transmission and total reflection for the Coulomb scattering with the confining due to an interference of quasi-stationary states imbedded in the continuum were revealed. These effects can increase the rate of recombination processes of ions in a magneto-optical trap, an axis channeling in crystals and quantum wires [12].

MODERN MATHEMATICAL PHYSICS

The topics of main focus in the theme were:

- Supersymmetry and Superstrings;
- Quantum Groups and Integrable Systems;
- Quantum Gravity and Cosmology.

Representative results obtained in 2009 on these subjects are described below.

The background field method for studying classical and quantum aspects of $N = 3$, $d = 3$ Chern–Simons and matter theories in $N = 3$ harmonic superspace was developed. As one of the immediate consequences, a nonrenormalization theorem implying the ultraviolet finiteness of the corresponding supergraph perturbation theory was proved. The general hypermultiplet and gauge superfield propagators in a Chern–Simons background were also derived. The leading supergraphs with two and four external lines were evaluated. In contrast to the nonsupersymmetric theory, the leading quantum correction to the massive charged

hypermultiplet proves to be the super Yang–Mills action rather than the Chern–Simons one. The hypermultiplet mass is induced by a constant triplet of central charges in the $N = 3$, $d = 3$ Poincare superalgebra [13].

New superconformal mechanics with $OSp(4|2)$ symmetry was obtained by gauging the $U(1)$ isometry of a superfield model. It is the one-particle case of the new $N = 4$ super Calogero model. Classical and quantum generators of the $osp(4|2)$ superalgebra were constructed on physical states. As opposed to other realizations of $N = 4$ superconformal algebras, all supertranslation generators are linear in the odd variables, similarly to the $N = 2$ case. The bosonic sector of the component action is standard one-particle (dilatonic) conformal mechanics accompanied by an $SU(2)/U(1)$ Wess–Zumino term, which gives rise to a fuzzy sphere upon quantization. The strength of the conformal potential is quantized [14].

An $su(2)$ Hamiltonian reduction of the general $su(2)$-invariant action for a self-coupled (4,4,0) supermultiplet was performed. As a result, the $N = 4$ supersymmetric mechanics with spin degrees of freedom was elegantly recovered. This observation underscores the exceptional role played by the «root» supermultiplet in $N = 4$ supersymmetric mechanics [15].

A new superfield approach to $N = 4$ supersymmetric mechanics based on the concept of biharmonic superspace (bi-HSS) was developed. It is an extension of the $N = 4$, $d = 1$ superspace by two sets of harmonic variables associated with the two $SU(2)$ factors of the R-symmetry group $SO(4)$ of the $N = 4$, $d = 1$ super Poincare algebra. There are three analytic subspaces in it: two of the Grassmann dimensions 2 and one of the dimensions 3. They are closed under the infinite-dimensional «large» $N = 4$ superconformal group, as well as under the finite-dimensional superconformal group $D(2, 1; \alpha)$. The main advantage of the bi-HSS approach is that it gives an opportunity to treat $N = 4$ supermultiplets with finite numbers of off-shell components on equal footing with their «mirror» counterparts [16].

The general properties of a special class of two-dimensional dilaton gravity (DG) theories with multi-exponential potentials were studied. It was shown, in particular, how the wave-like solutions of the general Toda–Liouville systems can be derived simply. In DG, these solutions describe nonlinear waves coupled to gravity as well as static states and cosmologies. Special attention was paid to making the analytic structure of the solutions of the Toda equations as simple and transparent as possible, with the aim to gain a better understanding of realistic theories reduced to dimensions $1 + 1$ and $1 + 0$ or $0 + 1$ [17].

The integrability of the Lax systems, based on pseudo-Riemannian coset manifolds G/H^*, was completed. It was shown that spherically symmetric black hole solutions in supergravity correspond to geodesics in such manifolds. The proof of Liouville integrability of such differential systems and their integration algorithm were presented. It was also shown that this algorithm could be generalized to generic nondiagonalizable Lax matrices not necessarily associated with symmetric spaces [18].

The Yang–Mills flow equations on a reductive coset space G/H and the Yang–Mills equations on the manifold RxG/H were studied. On nonsymmetric coset spaces G/H, one can introduce geometric fluxes identified with the torsion of the spin connection. Depending on the boundary conditions and torsion, there were derived solutions to the Yang–Mills equations which described instantons, chains of instanton–anti-instanton pairs or modifications of gauge bundles [19].

Viable models of modified gravity which satisfy both local and cosmological tests were investigated. It was demonstrated that some versions of such highly nonlinear models exhibit multiply de Sitter universe solutions, which often appear in pairs, one of them being stable and the other unstable. It was explicitly shown that, for some values of the parameters, it was possible to find several de Sitter spaces (as a rule, numerically); one of them may serve for the inflationary stage, while the other can be used for the description of the dark energy epoch. Based on the de Sitter solutions, multiply SdS universes were constructed which might also appear at the (pre-)inflationary stage. Their thermodynamics were studied and free energies were compared [20].

The methods of heat kernel and spectral zeta functions were applied effectively for calculating vacuum effects in nanophysics problems. The Casimir repulsion between a metal and a dielectric suspended in a liquid were thoroughly studied. The surface modes in three layered systems were modeled by dielectric functions guaranteeing repulsion. It was shown that surface modes play a decisive role in this phenomenon at short separations. For a toy plasma model the contribution of the surface modes was found at all distances [21].

It was proven that the set of Jucys–Murphy elements was maximal commutative for the generic Birman–Wenzl–Murakami algebra. On the basis of this fact the representation theory of the tower of all Birman–Wenzl–Murakami algebras was reconstructed [22].

New nontoric Lagrangian fibrations of smooth quadric were found in terms of pseudotoric structures. A new method of constructing toric and nontoric Lagrangian fibrations of toric Fano manifolds was proposed [23].

The structure of a cotangent bundle was investigated for quantum linear groups $GLq(n)$ and $SLq(n)$. Two explicit formulas for an evolution operator of the model of q-deformed isotropic top introduced by A. Alekseev and L. Faddeev were obtained. Relation between the two forms of the evolution operator was given by a modular functional equation for Riemann theta function [24].

In 2009, investigations within the area «Nuclear Theory» were carried out in accordance with the four projects:

- Nuclear Structure Far from the Valley of Stability;
- Nucleus–Nucleus Interactions and Nuclear Properties at Low Excitation Energies;
- Exotic Few-Body Systems;
- Nuclear Structure and Dynamics at Relativistic Energies.

To study $E0$ transitional density in so-called soft nuclei, an approach was suggested combining the microscopic Generator Coordinate Method with collective eigenfunctions of the phenomenological Bohr Hamiltonian. The expression for the effective density operator was presented by a series expansion in degrees of the operator of the collective momentum where the first term gives the main contribution. The $0^+_{\text{g.s.}} \to 0^+_2$ transitional density was calculated for the nucleus ^{150}Nd using the eigenfunctions of the approximate $X(5)$ solution of the Bohr Hamiltonian. In addition to the maximum and minimum of the $E0$ transitional density located at the nuclear surface, there appeared oscillations in the nuclear interior which can be observed in high-resolution electron scattering experiments [25].

A generalization of the method of Wigner-function moments which includes the effect of pair correlations without violating the continuity equation was proposed. The method was exemplified by the calculation of isovector and isoscalar giant resonances and low-lying excitations in the harmonic oscillator model with quadrupole–quadrupole residual interaction. The analytical formulae, derived in a slightly simplified version of the model, reproduced very well the experimentally observed deformation dependence of the energy and $B(M1)$ factor of the scissors mode. The numerical results are in reasonable quantitative agreement with the experimental data. The pair correlations were shown to be extremely important [26].

The influence of temperature and density of a stellar medium on electron capture rates for nuclei with mass number $A \sim 80$ was studied within a formalism based on the thermofield dynamics. The strength distributions of the allowed and first-forbidden $p \to n$ transitions were calculated for the neutron-rich nucleus ^{80}Ge at different temperatures. The mechanism of thermal unblocking of GT transitions in gf-shell nuclei was exemplified. The total transition strength of the first-forbidden transitions appeared to be scarcely affected by the temperature. Then the electron capture rates were calculated at temperatures and densities corresponding to an advanced stage of stellar evolution [27].

A self-consistent calculation of nuclear matrix elements of the neutrinoless double-beta decays $(0\nu\beta\beta)$ of ^{76}Ge, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{128}Te, ^{130}Te, and ^{136}Xe was performed in the framework of the Renormalized Quasiparticle Random Phase Approximation (RQRPA) and the standard QRPA. The pairing and residual interactions as well as the two-nucleon short-range correlations (SRCs) were derived for the first time from the same modern realistic nucleon–nucleon potentials — the charge-dependent Bonn potential (CD-Bonn) and the Argonne V18 potential. The SRCs were consistently calculated within the coupled-cluster method (CCM). The effect of the finite nucleon size (FNS) was studied. It was found that both the CCM SRCs and the FNS effect reduce the $(0\nu\beta\beta)$-decay nuclear matrix elements by a comparable amount [28].

Reactions induced by collisions of beams of unstable nuclei with nuclear targets were studied. A microscopic four-body model of the breakup of two neutron-halo nuclei was formulated with allowance for special features of their structure. The model relies on the distorted-wave method and describes various cross sections and fragment distributions. The consistent studies of continuum nuclear structure of two-neutron halo nuclei were performed [29].

Possibilities to synthesize new superheavy elements with $Z \geqslant 114$ exploiting the actinide-based reactions with projectiles heavier than ^{48}Ca were investigated. At present, some theoretical models predict an island of stability near the superheavy elements with $Z = 114$ or 126, and $N = 184$. Based on the theoretically predicted mass tables in the superheavy region and the dinuclear system fusion model, the cross sections of the hot fusion reactions with the projectiles ^{48}Ca, ^{50}Ti, ^{54}Cr, ^{58}Fe, ^{64}Ni and targets ^{238}U, ^{244}Pu, ^{248}Cm, ^{249}Cf were calculated. The effects of angular momentum and deformations of colliding nuclei were taken into account. The obtained dependence of the survival probability of superheavy evaporation residues on Z indicates the next doubly magic nucleus beyond ^{208}Pb at $Z \geqslant 120$ [30].

The reasons for the missing of the quasi-fission features in the $^{48}\text{Ca} + ^{144}\text{Sm}$ reaction and the disappearance of the quasi-fission features in the $^{48}\text{Ca} + ^{154}\text{Sm}$ reaction at collision energies $E_{\text{c.m.}} \geqslant 154$ MeV was analyzed in the framework of the combined theoretical method based on the dinuclear system concept and an advanced statistical model. The measured yields of fission fragments were decomposed into contributions coming from fusion–fission, quasi-fission, and fast fission. The decrease in the measured yield of quasi-fission fragments in $^{48}\text{Ca} + ^{154}\text{Sm}$ at the large collision energies and the lack of quasi-fission fragments in the $^{48}\text{Ca} + ^{144}\text{Sm}$ reaction were explained by the overlap in mass angle distributions of the quasi-fission and fusion–fission fragments. Moreover, the comparative analysis of reactions to produce the nuclide $^{A}Z = {}^{302}120$ with three pairs of projectiles (Cr, Fe or Ni) and targets (Cm, Pu or U) showed that the $^{54}\text{Cr} + ^{248}\text{Cm}$ reaction

is preferable because it has a smaller intrinsic fusion barrier and a larger quasi-fission barrier [31].

A possibility of the existence of bound clusters formed by two nucleons and a ϕ meson was studied based on the differential Faddeev equations. For a known ϕN interaction and the Malfliet–Tjon I–III nucleon–nucleon potentials, the ϕnn and ϕnp systems were found to be bound with $E_{\phi nn} = -21.8$ MeV and $E_{\phi np} = -37.9$ MeV, respectively. The results obtained also indicated the possibility of the existence of bigger few-nucleon ϕ-meson clusters [32].

The hyperspheroidal coordinates (suggested by A. V. Matveenko in 1983) were employed to introduce three new adiabatic bases in hyperradial adiabatic approach. Functions that form these bases possess much better asymptotical properties as compared to the ones arising in the standard two-centre Born–Oppenheimer adiabatic method. Advantages of the new approach were demonstrated by the example of the basic reaction in muon-catalyzed fusion physics $d\mu + t \to t\mu + d$ [33].

A series of new bounds on variation of spectral subspaces of a hermitian Hamiltonian under J-self-adjoint perturbations were proved. Also the conditions ensuring the similarity of the total Hamiltonian to a self-joint operator (and, hence, the reality of the spectrum) were found. An a priori sharp norm estimate was established for the rotation of the spectral subspace associated with part of the spectrum whose convex hull does not intersect the remainder of the spectrum. This bound may be viewed as an analog of the celebrated Davis–Kahan $\tan 2\Theta$ theorem for J-self-adjoint perturbations. Furthermore, sharp norm estimates on solutions to the associated Riccati equations were obtained [34].

A novel statistical approach to the analysis of experimental data obtained in nucleus–nucleus collisions at high energies which borrows from methods developed within the context of Random Matrix Theory was proposed. Using the Dyson–Mehta statistical measures for the first time to detect correlations in a system of secondary particles in collisions at high energies, the experimental data from $^{12}\mathrm{C} + {}^{12}\mathrm{C}$ reactions at $4.2A$ GeV/c were studied. The results obtained within the new approach are in a good agreement with those obtained in standard analysis based on the method of effective mass spectra and two-pair correlation function which is often used in high-energy physics. The new method is free from unwanted background contributions [35].

An approach to calculate microscopic optical potential (OP) was applied to study the $^8\mathrm{He} + p$ elastic scattering data. The direct and exchange parts of the real OP were calculated microscopically using the folding procedure and density-dependent M3Y effective interaction based on the Paris NN potential. The imaginary part of the OP was calculated using the high-energy approximation. The spin-orbit contribution to the OP was also included. Three different models of neutron and proton density distributions of ^{8}He were utilized in the calculations. Comparisons were made with the available experimental data at beam energies of 15.7, 26.25, 32, 66 and 73 MeV/nucleon. The ambiguities of the depths of each component of the optical potential were considered by means of the imposed physical criterion related to the volume integral behavior. The surface absorption was found to play rather an important role, in particular for the lowest incident energies [36].

The contribution of the low-lying nucleon resonances $P_{33}(1232)$, $P_{11}(1440)$, $D_{13}(1520)$ and $S_{11}(1535)$ to the invariant mass spectra of di-electrons stemming from the exclusive processes $pp \to ppe^+e^-$ and $pn \to pne^+e^-$ was investigated within a fully covariant and gauge invariant diagrammatical approach. The effective nucleon–meson interactions including the exchange mesons π, η, σ, ω and ρ as well as excitations and radiative decays of the above low-lying nucleon resonances were employed within the one-boson exchange approximation. The total contribution of these resonances is dominant; however, bremsstrahlung processes in pp and, in particular, pn collisions at beam energies of 1–2 GeV are still significant in certain phase space regions [37].

A production of $\mu^+\mu^-$ pairs generated by high-energy electrons emerging from a laser-wakefield accelerator was analyzed. The muon pairs are created in a solid thick high-Z target, following the electron accelerating plasma region. Numerical estimates were presented for 1 to 10 GeV electron beams which are expected to be reliable in the nearest future. Reactions induced by the secondary bremsstrahlung photons dominate the dimuon production. According to present estimates, a 20 pC electron bunch with an energy of 1 (10) GeV may create about 100 (5000) muon pairs. The produced $\mu^\pm$ can be used in studying various aspects of muon-related physics in tabletop installations. This is an important step towards the investigation of more complicated elementary processes induced by laser-driven electrons [38].

THEORY OF CONDENSED MATTER

Theoretical investigations in the Theory of Condensed Matter were continued in the framework of the following projects:

• Physical Properties of Complex Materials and Nanostructures;

• Mathematical Problems of Many-Particle Systems.

The research in the field of complex materials was conducted in the following directions: studies of spin dynamics in new materials within the t–J model, theoretical description of cold atoms trapped in optical lat-

tices, and investigations of transport characteristics in direct bandgap semiconductors.

A relaxation-function theory for the dynamic spin susceptibility in the t–J model was presented. By a sum-rule-conserving generalized mean-field approximation (GMFA), the two-spin correlation functions of arbitrary range, the staggered magnetization, the uniform static susceptibility, and the antiferromagnetic correlation length were calculated in a wide region of hole doping and temperatures. Good agreement with available exact diagonalization (ED) data was found. The correlation length is in reasonable agreement with neutron-scattering experiments on $La_{2-\delta}Sr_{\delta}CuO_4$. Going beyond the GMFA, the self-energy was calculated in the mode-coupling approximation. The spin dynamics at arbitrary frequencies and wave vectors was studied for various temperatures and hole doping. At low doping a spin-wave-type behavior was found as in the Heisenberg model, while at higher doping a strong damping caused by hole hopping occurred, and a relaxation-type spin dynamics was observed in agreement with the ED results. The local spin susceptibility and its (ω/T) scaling behavior were calculated in a reasonable agreement with experimental and ED data [39].

A complete irreversible adiabatic transport of Bose–Einstein condensate (BEC) in a double-well trap was investigated within the mean field approximation. The transfer is driven by time-dependent (Gaussian) coupling between the wells and their relative detuning. The protocol successfully works in a wide range of both repulsive and attractive BEC interaction. The nonlinear effects caused by the interaction can be turned from detrimental into favorable for the transport. The results were compared with familiar Landau–Zener scenarios using the constant coupling. It was shown that the pulsed Gaussian coupling provides a new transport regime where coupling edges are decisive and convenient switch of the transport is possible [40].

The superfluid properties of a 1D Bose gas in a ring trap based on the model of Lieb and Liniger were examined. While the 1D Bose gas has nonclassical rotational inertia and exhibits quantization of velocities, the metastability of currents depends sensitively on the strength of interactions in the gas: the stronger the interactions, the faster the current decays are. It was shown that the Landau critical velocity was zero in the thermodynamic limit due to the first supercurrent state, which had zero energy and finite probability of excitation. The energy dissipation rate of ring currents in the presence of weak defects was calculated, which should be observable on experimental time scales [41].

The effect of edge-type dislocation wall strain field on the Hall mobility in n-type epitaxial GaN was theoretically investigated through the deformation potential within the relaxation time approximation. It was found that this channel of scattering can play a considerable role in the low-temperature transport at a certain set of model parameters. The low-temperature experimental data were fitted by including this mechanism of scattering along with ionized impurity and charge dislocation ones [42].

In the field of nanostructures, the electronic spectra for double-wall zigzag and armchair nanotubes were found. The influence of nanotube curvatures on the electronic spectra was also calculated. The outer shell was found to be hole doped by the inner shell. The difference between Fermi levels of individual shells originates from the different hybridization of pi-orbital. The shift and rotation of the inner nanotube with respect to the outer nanotube were investigated. Stable semimetal characteristics of the armchair DWNTs with regard to the shift and rotation of the inner nanotube were found. The shift of the Fermi vector towards the bigger wave vectors with decreasing of the radius of the armchair nanotube was predicted [43].

The importance of experiments with voltage-dependent field emission energy distribution analysis in carbon nanosheets was emphasized. The analysis shows the crucial influence of the band structure on the energy distribution of field emitted electrons in few-layer graphene. In addition to the main peak, characteristic subpeaks in the energy distribution were found. Their positions strongly depend on the number of layers and the interlayer interaction. The discovery of these peaks in field emission experiments from carbon nanosheets would be a clear manifestation of the quantum size effect in these new materials [44].

Charge formations on superconducting layers and creation of the longitudinal plasma wave in the stack of intrinsic Josephson junctions were found to change crucially the superconducting current through the stack. Investigation of the correlations of superconducting currents in neighboring Josephson junctions and the charge correlations in neighboring superconducting layers allows one to predict the additional features in the current–voltage characteristics. The charge autocorrelation functions clearly demonstrate the difference between harmonic and chaotic behavior in the breakpoint region. It was shown that the use of the correlation functions gives a powerful method for the analysis of the current–voltage characteristics of coupled Josephson junctions [45].

Several mathematical problems of many-particle systems were solved. A model of semi-vicious walkers, which interpolates between the totally asymmetric simple exclusion process and the vicious walkers model, having the both of them as limiting cases was proposed. For this model the asymptotics of the survival probability for m particles were calculated and a scaling function, which describes the transition from one limiting case to another, was obtained. Then, a fluctuation–dissipation relation was used to allow one to reinterpret the result as the particle current generating function in the totally asymmetric simple exclusion process. Thus, the particle current distribution was obtained asymptotically in the large time limit as the number of particles

is fixed. The results were applied to the large deviation scale as well as to the diffusive scale. In the latter a new universal distribution, which has a skew non-Gaussian form, was obtained [46].

Detailed asymptotic analysis of correlation functions for the two-component spanning tree on the two-dimensional lattice was presented when one component contains three paths connecting vicinities of two fixed lattice sites at large distances apart. The known result for correlations on the plane was extended to the case of the upper half-plane with closed and open boundary conditions. Asymptotics of correlations for distance r from the boundary to one of the fixed lattice sites were found for some special cases [47].

The problem of finding integrals of motion for quantum elliptic Calogero–Moser systems with an arbitrary number of particles extended by introducing spin-exchange interaction was considered [48].

DUBNA INTERNATIONAL ADVANCED SCHOOL OF THEORETICAL PHYSICS (DIAS-TH)

In 2009, the research-educational project DIAS-TH was successfully continued. There were the following activities in the framework of DIAS-TH: VII Winter School on Theoretical Physics (January 25 – February 5); XIII Research Workshop «Nucleation Theory and Applications» (April 1–30); Helmholtz International School on Calculations for Modern and Future Colliders (July 10–20); Helmholtz International Summer School on Modern Mathematical Physics (July 20–29).

Regular seminars for students and postgraduates were organized; lecture courses and review lectures on new trends in modern physics were given for students and postgraduates (P. Fre, M. Lashkevich, D. Voskresensky); computer processing of video records of lectures was continued; Web-site of DIAS-TH was supported (http://theor.jinr.ru/∼diastp/diasth/).

COMPUTER FACILITIES

The conference hall of BLTP was equipped with a stationary multimedia projector. The stock of PCs in the Laboratory was replenished with new three PCs. Several dozen memory kits were purchased to upgrade older PCs. A new high-performance laser printer and a color laser multifunction printer were installed. The wireless network coverage was extended with putting in operation of two new access points.

MEETINGS, SCIENTIFIC COLLABORATION

In 2009, besides the schools organized in the framework of DIAS-TH, the Laboratory participated in the organization of 13 international conferences and workshops held in Dubna, Chernogolovka, Prague:

- APCTP–JINR BLTP Joint Workshop «Frontiers in Black Hole Physics at Dubna» (May 25–30, Dubna, Russia);
- APCTP–JINR BLTP Joint Workshop «Frontiers in Nuclear Physics at Dubna» (May 25–30, Dubna, Russia);
- International Workshop «Conformal Field Theory, Integrable Models and Liouville Gravity» (June 27 – July 2, Chernogolovka, Russia);
- XVIII International Colloquium «Integrable Systems and Quantum Symmetries» (June 18–20, Prague, Czech Republic);
- International Conference «Nuclear Structure and Related Topics» (June 30 – July 4, Dubna, Russia);
- XIII International Conference «Symmetry Methods in Physics» (July 6–9, Dubna, Russia);
- Advanced Study Institute «Symmetries and Spin» (July 26 – August 2, Prague, Czech Republic);
- International Workshop «Supersymmetries and Quantum Symmetries» (July 29 – August 3, Dubna, Russia);
- International Bogolyubov Conference «Problems of Theoretical and Mathematical Physics», dedicated to the 100th anniversary of the birth of N. N. Bogoliubov (1909–1992) (August 21–27, Dubna, Russia);
- XIII International Workshop «High Energy Spin Physics» (September 1–5, Dubna, Russia);
- IV Round-Table Discussion «Physics at NICA» (September 8–13, Dubna, Russia);
- Workshop on Precision Physics and Fundamental Physical Constants (December 1–4, Dubna, Russia);
- Round-Table Discussion Italy–Russia@Dubna «Efforts in Fundamental Research and Perspectives for Applied S&T and Business Development» (December 18–19, Dubna, Russia).

In 2009, the international collaboration was supported by grants of the Plenipotentiaries of Bulgaria, the Czech Republic, Poland, the Slovak Republic, Hungary, Romania, and the JINR Directorate; the collaboration with German theorists was based on the Heisenberg–Landau Programme; with Polish theorists, on the Bogoliubov–Infeld Programme; with Czech theorists, on the Blokhintsev–Votruba Programme; and Roumanian theorists on the Titeica–Markov Programme.

Some studies were carried out in collaboration with scientists from Western Europe in the framework of the JINR–INFN, JINR–IN2P3 agreements and on the projects supported by INTAS, RFBR–DFG, RFBR–CNRS. The agreement for collaboration between the Bogoliubov Laboratory and CERN TH is functioning.

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