Summary Implementation of
"Theory of Nuclear Structure and Nuclear Reactions"
(01–3–1114–14/18)

The β decay half-lives of neutron-rich even-even Ni isotopes $^{70-80}$Ni and isotones N = 50 were calculated in the framework of the self-consistent approach based on the Skyrme interaction taking into account the separable version for tensor interaction and the coupling with 2p-2h configurations. These two effects redistribute the Gamow-Teller strength in the nuclear spectrum. Specifically, the lowest 1^+ state strongly shifts down in the open-shell nuclides, the theoretical values of $T_\beta^{1/2}$ decrease by 2-3 orders of magnitude. The theory successfully reproduces the sharp reduction of half-lives for the N = 50 isotones with decreasing proton number, as well as the gradual reduction of the half-lives for the Ni isotopes with increasing neutron number. From the comparison of the effects induced by the surface-peaked effective mass in three doubly-magic nuclei, it was found that ^{132}Sn was largely impacted by the correction, whereas ^{78}Ni and ^{100}Sn are only moderately affected. It was concluded that β-decay rates in these nuclei could be used as a test of different parts of the nuclear energy-density functional.

Thermal effects on the rates and cross-sections of neutrino inelastic scattering off hot nuclei occuring under supernova II conditions were studied with the sample nuclei ^{56}Fe and ^{82}Ge. By applying the thermal QRPA, it was shown that deexcitation of thermally excited nuclear states gives the main contribution to the (νA) inelastic scattering at neutrino energy $E_\nu < 10$ MeV. In contrast to the shell model calculations with strongly reduced single-particle basis, the thermal QRPA does not explore the Axel-Brink hypothesis and automatically satisfies the detailed balance principle. As a result, the present calculations predict the value of cross sections and rates of the νA-process at $E_\nu < 10\ MeV$ by an order of magnitude larger.

The random phase approximation with Skyrme forces was extended to finite temperatures to obtain the strength function of Gamow–Teller transitions in neutral channel for nuclei embedded in a hot supernova medium. It is shown that cross sections and rates for weak-interaction processes involving hot nuclei demonstrate robustness against the variation of the Skyrme force parameters. However, due to a larger strength of thermally unblocked low- and negative-energy GT transitions, the calculated low-energy cross-sections for inelastic neutrino scattering off hot nuclei are larger than those obtained within other approaches.

A two-dimensional collective Hamiltonian on both azimuthal and polar motion in triaxial nuclei is proposed to investigate chiral and wobbling modes. The broken chiral and signature splittings in the mean field approximation are restored by this Hamiltonian. This newly developed model is applied to a triaxial rotor coupled with one proton particle and one neutron hole on $h_{11/2}$ orbital. By diagonalizing the Hamiltonian, the angular momenta and energy spectra are obtained. The results agree with the exact solutions of the particle rotor model at high rotational frequencies.

A microscopic proton-neutron symplectic model of collective motions, based on the non-compact symplectic group Sp(12,R), was introduced by considering the symplectic geometry of the two-component many-particle nuclear system. The dynamical group of the whole many-particle system allows the separation of the nuclear variables into kinematic (internal) and dynamic (collective) ones. Then, the number and type of collective degrees of freedom, related to the dynamical variables, were determined properly by the group-theoretical consideration of the coordinate transformation of the microscopic configuration space, spanned by the $m = A - 1$ translationally invariant Jacobi vectors, to the collective and intrinsic submanifolds.

The ratio of the mass coefficients for the γ-vibrational and rotational motion for the well deformed axially symmetric nuclei is calculated within the cranking model. Analysis of the experimental data showed that the mass coefficient for the gamma-vibrational motion was 3-4 times larger than the mass coefficient for the rotational motion. Experimental data on the beta-vibrational mode also indicate that the beta-vibrational mass coefficients exceed significantly the rotational mass coefficients. The results obtained show that the calculated gamma-vibrational mass coefficients are indeed systematically 2.5-4 times larger than the rotational mass coefficient. This explains qualitatively the experimental data.

Bound states and low-lying resonances of the one-neutron halo nucleus ^{11}Be were calculated within the two-body cluster model with core excitation. The lowest ^{10}Be core excited 2^+ state was considered as quadrupole vibration. Shallow potentials were applied for neutron–core interaction, preventing motion in Pauli forbidden orbits. A good description of available experimental data including dipole excitations of ^{11}Be was obtained. For the bound $1/2^-$ excited state the $[p3/2\otimes 2^+]_{1/2^-}$ wave function component gives the dominant contribution to the structure, which differs from the results obtained in models with deep potentials.

Nuclear scissors modes are considered in the frame of the Wigner-function moments method generalized to consider spin degrees of freedom and pair correlations simultaneously. A new source of nuclear magnetism, connected with counter rotation of spins up and down around the symmetry axis (hidden angular momenta), is discovered. Its inclusion into the theory allows one to improve substantially the agreement with experimental data in the description of energies and transition probabilities of scissors modes in rare-earth nuclei.

The theoretical model was formulated to describe the recently identified collective proton pairing vibrational state in ^{208}Pb. As found, the repulsion between the pair removal phonons is stronger than between the pair addition phonons. Quite generally, we conclude that in heavy nuclei the forces between protons and neutrons responsible for the pairing are quite similar.

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The excitation energies up to 1.2 MeV and the quasiparticle-phonon structure of the low-lying states of the odd-neutron nuclei $^{245\text{-}251}$Cm, $^{249\text{-}255}$Cf, $^{249\text{-}259}$Fm, $^{253\text{-}259}$No and $^{257\text{-}261}$Rf were calculated. As shown, the quasiparticle-phonon interaction is important for description of the experimental data.

The excitation spectra of superheavy nuclei belonging to the alpha-decay chain of ^{288}115 were calculated using two different single-particle potentials, modified two-center and Skyrme-based potentials. Besides *E1* transitions, the strong *M1* and *M2* transitions are expected in ^{276}Mt in the Skyrme-Hartree-Fock and two-center shell model treatments, respectively.

The mass parameters for collective variables of di-nuclear systems formed in cold fusion reactions were microscopically calculated with the linear response theory making use of the width of single-particle states and the fluctuation-dissipation theorem. The microscopical mass parameter in the neck was found to be much larger than one obtained with the hydrodynamical model. Therefore, the di-nuclear system lives a rather long time comparable to the fusion time.

The possibilities of direct production of new isotopes of transfermium nuclei ^{261,263,264}No, ^{263,264}Lr, ^{263,264,266,268}Rf, ^{264,265}Db, and ^{267,268,270,272}Sg were studied in various asymmetric hot fusion-evaporation reactions with radioactive beams. The optimal reaction partners and conditions for the synthesis of new isotopes were suggested. The products of the suggested reactions can fill a gap of unknown isotopes between the isotopes of heaviest nuclei obtained in the *xn* evaporation channels of the cold and hot complete fusion reactions with the stable beams.

The comparative analysis of the hot fusion reactions $^{50}Ti+^{247-249}Bk$ and $^{51}V+^{246-248}Cm$ for synthesis of element 119 was made with the di-nuclear system model and the prediction of nuclear properties in the microscopic–macroscopic approach, where the closed proton shell at $Z \geq 120$ is expected. The quasi-particle structures of nuclei in the α-decay chain of $^{295}119$ and a possible spread of alpha energies were studied. The calculated values of Q_α were compared with available experimental data. The termination of the α-decay chain of $^{295}119$ was revealed.

The possibilities of production of yet-undiscovered neutron-rich isotopes of Ca, Zn, Te, Xe, Gd, Dy, Er, Yb, Hf, W, Os, Pt, Hg, Pb, and Th were explored in various multinucleon transfer reactions with stable and radioactive beams. With these isotopes one can treat the neutron shell evolution beyond N=28, 50, 82, and 126. The probable projectile-target combinations and bombarding energies to produce these neutron-rich isotopes were suggested for future experiments. The production of the isotopes of transfermium nuclides $^{259,260}Md$, $^{260,261}No$, $^{261\text{-}264}Lr$, $^{264,265}Rf$, $^{264\text{-}268}Db$, $^{266\text{-}269}Sg$, $^{266\text{-}271}Bh$, $^{267\text{-}274}Hs$, and $^{270\text{-}274}Mt$ was estimated in various asymmetric hot fusion-evaporation reactions. The excitation functions of the formation of these isotopes in the α*xn* and *pxn* evaporation channels are predicted for the first time.

A new method is suggested to extract pure transfer probabilities P_{tr} and $P_{1n,2n}$ from the transfer and capture (fusion) experimental data. The almost exponential dependence of the extracted pure one- and two-neutron transfer probabilities at backward angle on the minimal distance of approach is shown for the $^{40}Ca + ^{96}Zr$ system. As found, at energy slightly below the Coulomb barrier the ratio P_{1n}/P_{2n} becomes close to unity.

The probability of the formation and decay of a di-nuclear system was investigated for a wide range of relative orbital angular momentum values. The mass and angular distributions of the quasifission fragments were studied for the collision ^{78}Kr (10A·MeV) + ^{40}Ca within di-nuclear system model. The analysis showed the possibility of the 180° rotation of the system so that projectile-like products can be observed in the forward hemisphere with large cross sections, which can explain the phenomenon observed recently in the experiment.

Using the improved scission-point model, the isotopic trends of the charge distribution of fission fragments were studied in induced fission of even-even Th isotopes. The calculated results are in a good agreement with available experimental data. With increasing neutron number, the transition from symmetric to asymmetric fission mode is shown to be related to the change of the potential energy surface. At high excitation energies, there is unexpected large asymmetric modes in the fission of neutron-deficient Th isotopes considered.

The theory of two-dimensional scattering of a slow quantum particle by a central short-range potential was developed. To this end, the variable phase function approach and effective-range approximation were used. For this scattering, the explicit low-energy asymptotics of all partial cross-sections and radial wave functions were derived.

It was established that the channel components of the eigenvector of the truncated scattering matrix belonging to the zero eigenvalue make sense of breakup amplitudes for the corresponding resonance state of a multi-channel system.

The new method for the creation of coherent radiation based on using the quantum molecular-nuclear transitions was suggested. The external radiation act on the two-level system, where the upper level is a molecular state and the lower one is a nuclear resonant state. As a result, unlike the usual laser, there appears a medium with the inverse population and there is no necessity to make preliminary saturation. The process is accompanied by coherent radiation. The method was registered as a patent.

Electron-impact single and double ionization of a helium atom in the presence of laser radiation with low frequency and intensity was studied theoretically. The kinematical regime of high impact energy and large momentum transfer, with two fast electrons in the final channel, was considered. The laser-assisted cross sections were found to be essentially more sensitive to the electron-electron correlations in helium than the field-free ones.

The quantitative theory of resonant processes in confined geometry of atomic traps was developed. In this approach, the widths and shifts of Feshbach resonances were calculated and resonant conditions for «dipolar confinement-induced resonances» were obtained. The quantitative theory of resonant processes in confined geometry of atomic traps was generalized to consider the p-wave Feshbach resonances. Geometric (confinement-induced) resonances were predicted in atom-ion systems, dependence of their positions on the atomic mass and the colliding energy was calculated, analytic and semi-analytic formulae for the position of a geometric resonance were obtained in the "long-wavelength and zero-energy limit". It was found that a slight anisotropy of the confining trap considerably enhances the reactive rate constants in the scattering of cold atoms.

The basic principles of self-organization of a finite number of charged particles interacting via the Coulomb potential in disk geometry were found. As a result, a system of equations was derived, which allows us readily to determine with high accuracy equilibrium configurations of a few hundreds of charged particles.

A three-body system consisting of two identical fermions of mass m and a distinct particle of mass m_1, with zero-range interactions between different particles, was studied in the universal limit of low energies. It was shown that for an unambiguous definition of the (Hermitian) three-body Hamiltonian in the interval $8.619 < m/m_1 \leq 13.607$ one needs to introduce an additional parameter constraining the wave function near the triple-collision point. The dependence of the three-body bound-state energies on m/m_1 and the three-body parameter for the most important case $L^P=1^-$ was calculated.

Assuming the Hamiltonian H reads as a J-self-adjoint 2x2 block-operator matrix, conditions are established ensuring the analytic continuability of one of the Schur complements of the operator 2x2-matrix H-E to the unphysical sheets of the energy E plane. Theorems on factorization of the continued complement in the sense of Markus and Matsaev are prooven. In the Feshbach spectral case, it is established that the operator root of the Schur complement analytically continued to the respective unphysical sheet, generates for H a pair of J-orthogonal invariant subspaces.

The hybrid model of the microscopic optical potential was developed and successfully applied for calculations of cross sections for scattering of π-mesons and the light exotic halo-nuclei on protons and nuclei. Basing on this model and suggesting the two-cluster structure of the ^{11}Be and ^{11}Li nuclei conclusions were made on the far periphery of these nuclei and on a mechanism of their breakup into clusters.

The detailed analysis of the analytical properties of quark propagators from the Dyson-Schwinger equation was performed within the rainbow approximation. It was shown that the propagators are not analytical functions possessing an infinite number of pole-like singularities, which hamper the solution of the Bethe-Salpeter equation for mesons. Rigorous mathematical methods of finding the exact position of poles and corresponding residues were proposed to be used in solving the Bethe-Salpeter equation for mesons in the presence of singularities.

Recent STAR data for the directed flow of protons, antiprotons and charged pions were analyzed within two complementary approaches: transport hadron-string-dynamics models (PHSD/HSD) and 3-fluid hydrodynamics (3FD). Both versions of the kinetic approach, HSD and PHSD, were used to clarify the role of quark degrees of freedom. The PHSD results, simulating a partonic phase and its coexistence with a hadronic one, are consistent with data. Hydrodynamic results were obtained for two equations of states (EoS), pure hadronic and EoS with the crossover type of a phase transition. The latter case is favoured by the experiment under discussion. Special attention is paid to the description of antiprotons based on the balance of the proton-antiproton annihilation channel and inverse process for this pair creation from a multi-meson interaction. Generally, a semi-qualitative agreement between the measured data and the model results supports an idea of realization of a crossover type of quark-hadron phase transition, which softens the nuclear EoS.

The nature of phase transition in hot and dense nuclear matter is discussed in the framework of the effective SU(2) Nambu-Iona-Lasinio model with a Polyakov loop with two quark flavors – one of a few models describing the properties of chiral and confinement-deconfinement phase transitions. The parameters of the models were considered, and the additional interactions were examined that influence the structure of phase diagram and the positions of critical points in it. The effect of meson correlations of the thermodynamic properties of the quark-meson system was examined.

It was proved, that the Tsallis statistics in the grand canonical ensemble satisfies the requirements of the equilibrium thermodynamics in the thermodynamic limit if the thermodynamic potential is a homogeneous function of the first order with respect to the extensive variables of state of the system and the entropic variable $z=1/(q-1)$ is an extensive variable of state. The equivalence of canonical, microcanonical and grand canonical ensembles for the nonrelativistic ideal gas of hadrons was demonstrated.

The results of work are annually published in about 80 papers in journals with high impact factors and in about 30 conference proceedings.

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