INTERNATIONAL WORKSHOP ON

FEW-BODY SYSTEMS

(FBS-Dubna-2016)

Bogoliubov Laboratory of Theoretical Physics
JOINT INSTITUTE FOR NUCLEAR RESEARCH
Dubna, Russia, July 4 – 7, 2016

PROGRAM AND ABSTRACTS

Dubna
2016

INTERNATIONAL WORKSHOP ON
FEW-BODY SYSTEMS
(FBS-Dubna-2016)
BLTP, JINR, Dubna, Russia, July 4 – 7, 2016

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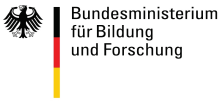

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INTERNATIONAL WORKSHOP ON
FEW-BODY SYSTEMS
(FBS-Dubna-2016)
BLTP, JINR, Dubna, Russia, July 4 – 7, 2016

Overview

The International Workshop on Few-Body Systems, FBS-Dubna-2016, will be held on July 4 – 7, 2016, at the Bogoliubov Laboratory of Theoretical Physics, JINR, Dubna, Russia. The Workshop is dedicated to the memory of Vladimir Belyaev (22.06.1933–02.03.2015), a prominent theoretician who was one of the pioneers of few-body physics.

The program of Workshop will cover various topics in physics of few-body systems including scattering theory, Coulombic few-body problems, few-body resonances, Efimov effect, Borromean binding, etc. Few-body systems theory is dedicated to various quantum systems that might be considered consisting of several (say two, three, or four) elementary constituents. Depending on a particular situation and the energy range under consideration, the role of such constituents may be played by quarks, mesons, individual nucleons, nuclei or even by atoms and molecules. Smallness of the number of constituents in a system allows one to develop mathematically rigorous, exact and faithful approaches to its treatment, that do not require further simplifying physical assumptions or approximations. Due to their universality, the approaches based on the theory of few-body systems pave the way to successful solving various problems in nuclear physics, in physics of atoms and molecules, in quantum chemistry etc.

The purpose of the workshop is to bring together experts and young researchers working on few-body problems of nuclear physics, astrophysics, and physics of atomic and molecular collisions, for presenting their new results, identifying hot topics, and reporting on progress in methods and approaches.

Program of the workshop includes the following topics:

- Scattering theory for quantum systems of several particles;
- Recent progress in theory of Coulombic few-body systems;
- Universal properties of few-body systems at ultra-low energies;
- Efimov and Thomas effects, Borromean binding, halo systems;
- Numerical approaches to solving few-body bound-state, resonance and scattering problems.

Sessions of the workshop will take place at the **Conference Hall** of the Bogoliubov Laboratory of Theoretical Physics. The workshop schedule is as follows.

Workshop Schedule[1]

	05.07 Tu	06.07 We	07.07 Th
9.00-9.40	**Registration**		
9.45	**Opening**		
Chair	***Motovilov***	***Revai***	***Popov***
10.00	Richard	Frederico	Kukulin
10.30	Revai	Grimm	Janek
11.00	Yakovlev	Fey	Shebeko
11.30 - 11.50	***Coffee break***	***Coffee break***	***Coffee break***
Chair	***Frederico***	***Grimm***	***Richard***
11.50	Pupyshev	Motovilov	Penkov
12.20	Kartavtsev	Rakityansky	Gusev
12.50	Melezhik	Roudnev	Vinitsky
13.20	Kolganova	Yarevsky	Malykh
13.50 15.00	***Lunch***	***Lunch***	***Lunch***
Chair	***Yakovlev***	***Kukulin***	***Rakityansky***
15.00	Lakaev	Irgaziev	Lekala
15.30	Geynts	Orlov	Meoto
16.00	Yurovsky	Ishmukhamedov	Popov
16.30 16.50	***Coffee break***	***Coffee break***	***Coffee break***
Chair	***Lakaev***	***Vinitsky***	***Gevorkyan***
16.50	Rubtsova	Soloviev	Samarin
17.20	Shevchenko	Zarubin	Musulmanbekov
17.50	Tashpulatov	Gevorkyan	Makhaldiani
19.00		***Banquet***	

[1] Status of June 28, 2016

PROGRAMME

July 5, Tuesday

09:00 - 09:40 REGISTRATION

09:45 - 10:00 WQRKSHOP OPENING

10:00 - 10:30 JEAN-MARC R. RICHARD (Villeurbanne, France)
Stability domain of few-charge systems

10:30 - 11:00 JANOS RÉVAI (Budapest, Hungary)
Three-body calculation of the 1*s level shift in kaonic deuterium with realistic multichannel* $K\overline{N}$ *interactions*

11:00 - 11:30 SERGEY L. YAKOVLEV (St. Petersburg, Russia)
Asymptotic solution to multichannel scattering problem with nontrivial asymptotic nonadiabatic coupling

11:30 - 11:50 COFFEE BREAK

11:50 - 12:20 VASILY V. PUPYSHEV (JINR)
Two-dimensional Coulomb scattering of a quantum particle: Low-energy approximations of the wave-functions

12:20 - 12:50 OLEG I. KARTAVTSEV (JINR)
Exact and qualitative results in the two-species few-body problem

12:50 - 13:20 VLADIMIR S. MELEZHIK (JINR)
Confinement-induced resonances in ultracold atom-ion systems

13:20 - 13:50 ELENA A. KOLGANOVA (JINR)
Weakly bound He_2Li *molecules*

13:50 - 15:00 LUNCH BREAK

15:00 - 15:30 SAIDAKHMAT N. LAKAEV (Samarkand, Uzbekistan)
The existence of bound states in a system of three particles in an optical lattice

15:30 - 16:00 VALERY L. GEYNTS (Moscow, Russia)
Stability of the inverse resonance problem

16:00 - 16:30 VLADIMIR YUROVSKY (Tel Aviv, Israel)
Consequences of non-Abelian permutation symmetry in systems of spinor particles

16:30 - 16:50 COFFEE BREAK

16:50 - 17:20 OLGA A. RUBTSOVA (Moscow, Russia)
Continuum discretization for quantum scattering in medium

17:20 - 17:50 NINA SHEVCHENKO (Řež, Czech Republic)
Three-body systems with strangeness

17:50 - 18:10 SADULLA M. TASHPULATOV (Tashkent, Uzbekistan)
Structura of essential spectrum and discrete spectrum of four-electron systems in the Hubbard Model

July 6, Wednesday

10:00 - 10:30 TOBIAS FREDERICO (São José dos Campos, Brazil)
Scale symmetry breaking and limit cycle in four boson systems

10:30 - 11:00 RUDOLF GRIMM (Innsbruck, Austria)
Few-body physics with ultracold atoms: Efimov and beyond

11:00 - 11:30 CHRISTIAN FEY (Hamburg, Germany)
Towards field control of polyatomic ultralong-range Rydberg molecules

11:30 - 11:50 COFFEE BREAK

11:50 - 12:20 ALEXANDER K. MOTOVILOV (JINR)
Eigenvectors of multichannel scattering matrices at resonance energy values

12:20 - 12:50 SERGEI A. RAKITIANSKI (Pretoria, South Africa)
Residues of a multi-channel S-matrix at the spectral points

12:50 - 13:20 VLADIMIR A. ROUDNEV (St. Petersburg, Russia)
Multichannel Coulomb scattering calculations with Merkuriev-Faddeev equations

13:20 - 13:50 EVGENY A. YAREVSKY (St. Petersburg, Russia)
Potential splitting approach to $e-H$ and $e-He^+$ scattering

13:50 - 15:00 LUNCH BREAK

15:00 - 15:30 BAKHADIR F. IRGAZIEV (Tashkent, Uzbekistan)
Determination of resonance-state properties from a phase shift analysis with the S-matrix pole

15:30 - 16:00 IURII V. ORLOV (Moscow, Russia)
On the effective-range expansion used to calculate the asymptotic normalization coefficients for bound states wave functions

16:00 - 16:30 ILYAS ISHMUKHAMEDOV (JINR)
Two atomic tunneling dynamics in a waveguide-like trap

16:30 - 16:50 COFFEE BREAK

16:50 - 17:20 EVGENI A. SOLOV'EV (JINR)
Dynamical adiabatic theory of atomic and nuclear collisions

17:20 - 17:50 PAVEL ZARUBIN (JINR)
Unstable nuclei in dissociation of light stable and radioactive nuclei

17:50 - 18:10 ASHOT S. GEVORKYAN (Erevan, Armenia)
Classical nonintegrability, quantum irreversibility and chaos on the example of three-body problem

July 7, Thursday

10:00 - 10:30 VLADIMIR I. KUKULIN (Moscow, Russia)
Nuclear physics with dibaryon degrees of freedom

10:30 - 11:00 MARIAN JANEK (Žilina, Slovakia)
Experimental studies of the few-body systems at Nuclotron

11:00 - 11:30 OLEKSANDR V. SHEBEKO (Kharkov, Ukraine)
Gauge-independent treatment of radiative capture in nuclear reactions: Application to the theory of nucleus-nucleus Bremsstrahlung

11:30 - 11:50 COFFEE BREAK

11:50 - 12:20 FEDOR M. PEN'KOV (Almaty, Kazakhstan)
Contribution of resonant tunneling to quantum diffusion of molecules in crystals

12:20 - 12:50 ALEXANDER GUSEV (JINR)
On tunneling problem of the two-atomic molecule on whole axis

12:50 - 13:20 SERGUE I. VINITSKY (JINR)
Quantum transmission of clusters with several identical particles through barriers and wells

13:20 - 13:50 ANASTASIA V. MALYKH (JINR)
One-dimensional three-body problem with inverse-square two-body interaction

13:50 - 15:00 LUNCH BREAK

15:00 - 15:30 M. LESLIE LEKALA (Pretoria, South Africa)
Calculation of thermodynamic properties of BEC condensates using few-body methods

15:30 - 16:00 EMILE F. MEOTO (Pretoria, South Africa)
On the construction of reliable Y-Y interactions via inverse scattering method

16:00 - 16:30 YURI POPOV (Moscow, Russia)
Dynamics of atomic hydrogen in strong low frequency laser field

16:30 - 16:50 COFFEE BREAK

16:50 - 17:20 VIACHESLAV V. SAMARIN (JINR)
Study of ground states of few-body nuclei by Feynman's continual integrals method

17:20 - 17:50 GENIS MUSULMANBEKOV (JINR)
The role of quarks in nuclear structure. Borromean nuclei

17:50 - 18:10 NUGZAR MAKHALDIANI (JINR)
Renormdynamics and solvable models of strong interactions

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Abstracts

of contributed presentations

Towards field control of polyatomic ultralong-range Rydberg molecules

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Ultralong-range Rydberg molecules (ULRM) are ”giant molecules” consisting of a Rydberg atom and one or more polarizable ground state atoms. The underlying binding differs from conventional covalent binding as it originates from frequent s- and p-wave scattering of the Rydberg electron by t he ground state atoms [1,2]. The most striking features of ULRM are huge bond lengths 1000 Bohr radii, oscillatory potential energy surfaces supporting several equilibrium configurations and large permanent dipole moments 1000 Debye. In the talk we will, firstly, discuss the binding mechanism and, secondly, illustrate how weak external electric or magnetic fields can be employed to modify the nuclear and electronic properties of diatomic ULRM, such as the bond length, the orientation or the electric dipole moment [3,4]. Especially parallel as well as crossed field configurations provide unique ways to control the topology of the potential energy surfaces [5]. Our aim is to extend these results to triatomic ULRM. Lastly, we will therefore report on our recent advances towards this direction [6].

1. C. H. Greene, A. S. Dickinson, H. R. Sadeghpour, Phys. Rev. Lett. 85, 2458 (2000).
2. V. Bendkowsky, B. Butscher, J. Nipper, J. P. Shaffer, R. Lцw, T. Pfau, Nature 458, 1005 (2009).
3. M. Kurz, P.Schmelcher, Phys. Rev A 88, 022501 (2013).
4. A. T. Krupp, A. Gaj, J. B. Balewski, P. Ilzhцfer, S. Hofferberth, R. Lцw, T. Pfau, M. Kurz, P. Schmelcher, Phys. Rev. Lett. 112, 143008 (2014).
5. M. Kurz, P. Schmelcher, J. Phys. B: At. Mol. Opt. Phys. 47, 165101 (2014).
6. C. Fey, M. Kurz, P. Schmelcher, arXiv: 1605.03856 (2016).

Scale symmetry breaking and limit cycle in four boson systems

Tobias Frederico

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We present an approximate solution of the four-boson Faddeev-Yakubovski (FY) equations with contact interaction in the the large momentum limit. For that purpose, the Danilov

technique [1] used to treat the three-boson Skorniakov-Ter-Martirosian equation in the ultraviolet region, which leads to the well-known log-periodic solution carrying the three-body scale, is generalized and applied to the four-boson FY equations. We explore the breaking of the scale symmetry of such equations to expose the four-boson log-periodic solutions. Within this approach, we show that the geometrical ratio between two consecutive tetramer energies (obtained in the zero energy limit for the triton binding) is given by $exp(2\pi/s_4)$, with $s_4 \sim 1.25$. This new limit cycle, which is independent of the trimer one, was verified numerically by solving the FY equations at the unitary limit [2].

1. Danilov G.S., JETP 40, 698 (1961); Sov. Phys. JETP 13, 349 (1961).
2. Hadizadeh M.R., Yamashita M.T., Tomio L., Delfino A., Frederico T., Phys. Rev. Lett. 107, 135304 (2011).

Classical nonintegrability, quantum irreversibility and chaos on the example of three-body problem

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As follows from the quantum analog of Arnold's theorem, in the limit of $\hbar \to 0$, the quantum Hamiltonian system transits to the regime of a regular classical motion, that generally speaking is not always true. Moreover, in the case when the classical analog of the quantum system is nonintegrable, it would be logical to expect a chaotic behavior in the motion of bodies system that is impossible because of the linearity of the Schrödinger operator. Thus, the description of transition from the quantum region of motion to the chaotic classical motion is one of an important open problem of the modern theoretical and mathematical physics. In present work we consider the classical three-body system and have shown that the problem can be reduced to the 6th order system on the 3D Riemannian manifold. Using the reduced three-body Hamiltonian we have obtained the equation describing classical multichannel scattering of the three-body taking into account quantum fluctuations. It is shown that in the framework of this representation the equation for the probability current of multichannel scattering is irreversible which can generate the quantum chaos.

Stability of the inverse resonance problem

Valeriy L. Geynts

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We consider stability problems for recovering of the potential of the Schroedinger operator from the set of its eigenvalues and resonances.

Few-body physics with ultracold atoms: Efimov and beyond

Rudolf Grimm

Institute of Experimental Physics, Universität Innsbruck, Innsbruck, Austria
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It will be an experimental talk, presenting an overview what has happened in the last 10 years and discussing the present status.

On tunneling problem of the two-atomic molecule on whole axis

Alexander Gusev

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A tunneling problem of the two atomic molecule through repulsive barrier on whole axis in Jacobi and polar coordinates is considered. Quantum diffusion of the molecule below dissociation threshold is studied.

Determination of resonance-state properties from a phase shift analysis with the S-matrix pole

B.F. Irgaziev[1], Y.V. Orlov[2]

[1]National University of Uzbekistan, Tashkent, Uzbekistan
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[2]Skobeltsyn Institute of Nuclear Physics, MSU, Moscow, Russia

Asymptotic normalization coefficient (ANC) is fundamental nuclear constant playing an important role in nuclear physics and astrophysics. We derive a new useful relationship between ANC of the Gamow radial wave function and the renormalized Coulomb-nuclear partial scattering amplitude. We use an analytical approximation in the form of a series for the nonresonant part of the phase shift which can be analytically continued to the point of an isolated resonance pole in the complex plane of the momentum. By applying the suggested method we calculate the ANC values for the nuclei ^{5}He, ^{5}Li, and ^{16}O resonances which lie slightly above the threshold for the α^{12}C channel.

Two atomic tunneling dynamics in a waveguide-like trap

Ilyas Ishmukhamedov[1,2], Vladimir S. Melezhik[2,3]

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[2]BLTP, JINR, Dubna, Russia
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We calculate tunneling rates of two one-dimensional interacting atoms confined in an anharmonic optical potential. The interaction is modeled by a finite-range Gaussian potential. We consider the ground state and an excited state of a relative and center-of-mass motions.

Experimental studies of the few-body systems at Nuclotron

Marián Janek

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The purpose of the DSS (Deuteron Spin Structure) experimental program is to obtain the information about two- and three nucleon short-range correlations (including their spin-dependent parts) from deuteron induced reactions at Nuclotron JINR. The experimental data on the energy dependence of the cross section and analyzing powers of dp-elastic scattering obtained using internal target and polarized and unpolarized deuteron beam at Nuclotron will be reported. Preliminary results on the dp- nonmesonic breakup in different kinematic configurations at the intermediate energies will be also presented. Future perspectives due to the measurements of the tensor analyzing power and spin correlation parameter in the (d,p) reactions on different targets using extracted deuteron beam at Nuclotron will be discussed.

Exact and qualitative results in the two-species few-body problem

Oleg I. Kartavtsev

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Bound-state and scattering problem for few two-species particles with contact interaction are considered. In particular, the exact solution is found in one dimension for odd-parity states of N identical particles interacting both with each other and with a fixed center. These findings are used to discuss a "phase diagram" representing the dependence of a number of bound states on the mass ratio and the interaction strength ratio.

Weakly bound He_2Li molecules

Elena A. Kolganova[1,2]

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We carry out calculations on the van der Waals trimers $^7Li^4He_2$ and $^6Li^4He_2$ using the differential Faddeev equations, which allows us to give accurate binding energies for both the ground and the exited state of the system. The results obtained indicate on the Efimov character of the excited state in both systems.

Zeeman effect at magnetorotational explosive nucleosynthesis in dynamo active supernovae

Vladimir Kondratyev

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Zeeman effect is shown to enhance nuclear binding energy for open shell nuclei. Resulting noticeable increase of respective explosive nucleosynthesis products is found to correspond to magnetization strength of teratesla.

Nuclear physics with dibaryon degrees of freedom

Vladimir I. Kukulin

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Numerous implications of incorporation of the dibaryon degrees of freedom (D.D.F) into nuclear and hadronic physics are discussed.It is demonstrated that the incorporation of DDF changes essentially our traditional images about nuclear structure,short-range nuclear forces

and also about nuclear-physical processes associated with high transferred momenta,in particular about meson production reactions.Account of the DDF in nuclear matter at higher density leads to its phase transition to the phase of cold Bose-Einstein condensate of very high density which must have far going astrophysical applications.

The existence of bound states in a system of three particles in an optical lattice

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We report the existence of bound states of the three-particle Schroedinger operator H(K), K being the three-particle quasi-momentum, associated to a system of three particles in an optical lattice interacting via pairwise attractive or repulsive potentials.

Calculation of thermodynamic properties of BEC condensates using few-body methods

Mantile L. Lekala

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Recently we developed the method for calculating the bound state properties of a finite number of interacting bosons [1, 2, 3]. The method is based on the technique of the correlated potential harmonics expansion [4]. It was shown that for large A the Jacobi polynomial $P_K^{\alpha,\beta}(z)$ transforms into the associated Laguerre polynomial $L_K^{\beta}(\zeta^2)$, where $\zeta = \alpha(1+z)/2$, and that this transformation alone improves convergence dramatically and permits the use of few-body techniques in calculating ground state properties. The results obtained agree very well with other methods in regions where the other methods are valid. In this work we extend the method to investigate the thermodynamic properties of the BEC condensates, of uniform and mixed atoms. Preliminary results on uniform condensates show that the method is reliable for use none S-wave calculations, and thus able to investigate thermodynamic properties of the systems. The mixed BEC calculations are underway. In this paper we discuss the convergence properties of the method, the implications of the methods and comparative study with other competing methods.

1. Sofianos SA, Das TK, Chakrabarti B, Lekala ML, Adama RM, Rampho GJ. *A few-body approach to Bose-Einstein condensation*. Few-Body Systems, Vol 54, 1529 – 1532 (2013).
2. Sofianos SA, Das TK, Chakrabarti B, Lekala ML, Adam RM, Rampho GJ. *Beyond mean-field ground state energies and correlated properties of a trapped Bose-Eistein condensate*. Physical Review A 87, 013608 (2013).
3. Lekala ML, Chakrabarti B, Rampho GJ, Das TK, Sofianos SA, Adam RM. *Behaviour of trapped ultracold dilute Bose gases at large scattering length near a Feshbach resonance*. Physical Review A 89, 023624 (2014).
4. Das TK, Chakrabarti B. *Potential harmonics expansion method for trapped interacting bosons: Inclusion of two-body correlation*. Physical Review A 70, 063601 (2004).

Renormdynamics and solvable models of strong interactions

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After a short introduction in renormdynamics, solvable models for coupling constants and masses considered.

One-dimensional three-body problem with inverse-square two-body interaction

Oleg I. Kartavtsev[1] and Anastasiya V. Malykh[2]

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The properties of three identical particles interacting via (attractive) inverse-square two-body potential $V(r) = -g/r^2$ are investigated. It has been known for a long time that the N-body problem is completely integrable if the attraction is small ($g < 1/4$ in dimensionless units) and a natural zero boundary condition is imposed for $r \to 0$ [1].

For the potential strength exceeding the critical value $g = 1/4$, the singular inverse-square potential should be regularized, e. g., by imposing a proper boundary condition. In this case one obtains an infinite spectrum of the two-body bound states, whose energies are scaled

as $E_n/E_{n-1} = const$. The three-body problem is no more integrable and requires a careful investigation. In this report, the solution of the (2 + 1)-scattering problem for $g > 1/4$ is given to elucidate the essential three-body properties, in particular, to study the three-body resonances.

One should notice the connection of the present investigation with the four-boson problem, e. g., the resonance scattering of one particle off the bound trimer in the Efimov state [2].

1. F. Calogero, J. Math. Phys. 10, 2191 (1969); J. Math. Phys. 10, 2197 (1969).
2. J. von Stecher, J. P. D'Incao, C. H. Greene, Nat. Phys. 5, 417 (2009).

Confinement-induced resonances in ultracold atom-ion systems

Vladimir S. Melezhik[1,2]

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We have investigated confinement-induced resonances in a system composed by a tightly trapped ion and a moving atom in a waveguide. We have determined the conditions for the appearance of such resonances in a broad region – from the "long-wavelength" limit to the opposite case when the typical length scale of the atom-ion polarisation potential essentially exceeds the transverse waveguide width. Our results, which can be investigated experimentally in the near future, could be used to determine the atom-ion scattering length, the temperature of the atomic ensemble in the presence of an ion impurity, and to control the atom-phonon coupling in a linear ion crystal in interaction with a quasi one dimensional atomic quantum gas.

On the construction of reliable Y-Y interactions via inverse scattering method

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Currently only limited data sets exist for systems with strangeness $S = -2$. Only about 52 $Y-N$ scattering and almost none $Y-Y$ scattering data exist, as compared to over 4300 $N-N$ scattering data. On the theory side various different phenomenological potentials are used to analyse and study the dynamics of these $S = -2$ hypernuclear systems. In this work we use the limited existing data to construct via inverse scattering method of Marchenko reliable $Y-Y$ interactions. The constructed potentials are used to calculate bound state properties of few selected $S = -2$ hypernuclear systems. The convergence properties of the method are discussed as well as the new parametrization used to construct the potentials. It is shown that this parametrization is very stable and reliable.

Eigenvectors of multichannel scattering matrices at resonance energy values

Alexander K. Motovilov[1,2]

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Our exposition concerns a class of three-body Hamiltonians and some multi-channel Hamiltonians involving only two-body channels. First, we recall the formulas that express the multi-channel T- and S-matrices on unphysical energy sheets through those same matrices but only taken in the physical sheet. The explicit representations for the unphysical-sheet T- and S-matrices imply that a resonance on an unphysical energy sheet is the (complex) energy value where the appropriately truncated scattering matrix on the physical sheet has eigenvalue zero. We show that the channel components of the eigenvector of the truncated scattering matrix belonging to its zero eigenvalue make sense of breakup amplitudes for the corresponding resonance state. In the case of a multi-channel problem with purely binary channels this statement has been already proven. Now we extend this result to the truncated three-body scattering matrices responsible for resonances on the two-cluster three-body unphysical sheets.

The role of quarks in nuclear structure. Borromean nuclei

Genis Musulmanbekov

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Starting with the quark model of nucleon structure in which the valence quarks are strongly correlated within the nucleon, the light nuclei are constructed by assuming similar correlations of quarks of neighboring nucleons. It is shown that quark loops are responsible for formation of the nuclear configurations that correspond to the 'halo' (borromean) nuclei.

On the effective-range expansion used to calculate the asymptotic normalization coefficients for bound states wave functions

Iurii V. Orlov

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Applications of the effective-range expansion method using ph ase shift energy behaviour are considered to calculate the nuclear vertex constants and asymptotic normalization coefficients for the bound states wave functions. Some limitations of this method which are connected with the nearest amplitude singularity are studied, especially the relative input of the nuclear and Coulomb interactions into the effective-range function.

Contribution of resonant tunneling to quantum diffusion of molecules in crystals

P. M. Krassovitskiy, Fedor M. Pen'kov

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Probabilities of resonant tunneling through a potential barrier are compared for a rigid molecule and an excited molecule of Berillium. It is shown that the resonance spectrum is mainly governed by the transmission resonance spectrum of the rigid molecule. Analytical expressions for the probability for the tunneling of the rigid molecule through a barrier allow resonance-spectrum-averaged observables, including quantum diffusion, to be estimated.

Dynamics of atomic hydrogen in strong low frequency laser field

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We consider in comparison Strong Field Approximation (SFA) and numerical calculation of the time dependent Schroedinger equation (TDSE). Convergence of the Born series is also considered.

Two-dimensional Coulomb scattering of a quantum particle: Low-energy approximations of the wave-functions

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By assumption, a charged quantum particle moves in the two-dimensional plane and is scattered by a fixed Coulomb center lying in the same plane. The expansions of the wave-function and all radial wave-functions of this particle over integer powers of the wave number and the Bessel function s of real order are derived. It is proven that the finite sums of these expansions are the approximations of the wave-functions at low-energies.

Residues of a multi-channel S-matrix at the spectral points

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The S-matrix of a multi-channel scattering process is written in terms of the corresponding Jost matrix. This matrix is presented in a semianalytic form where all the factors responsible for branching of the Riemann surface of the energy are given explicitly. The remaining (unknown) factors in the Jost matrix are single-valued analytic functions of the energy, defined on a simple complex plane. This functions can be expanded in Taylor series around practically any point on this plane. The expansion coefficients can be either calculated (if the interaction potential is given), or used as the adjustable parameters to fit any available experimental data. When the expansion coefficients are found, the residues of the *S*-matrix

as well as the asymptotic normalization constants (ANC) and vertex constants for the two-body decays of the bound and resonant states can be obtained. In a sense, the suggested method is a generalization of the effective-range theory. The difference is that the center of expansion is not the threshold energy, but any appropriate energy on the complex plane.

Three-body calculation of the 1s level shift in kaonic deuterium with realistic, multichannel $K\overline{N}$ interactions

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In a previous test calculation [1] we demonstrated the applicability of the Coulomb Sturmian expansion method for the exact calculation of the 1*s* level shift in three-body hadronic atoms. For the hadron-nucleon interaction simple one-channel complex interactions were used. In the present work we calculate the 1*s* level shift of kaonic deuterium using realistic, multichannel $K\overline{N}$ interactions, both of phenomenological and "chiral" (energy dependent) type. The main issue in this case is the correct evaluation of the occuring convolution integral over the multilevel Riemann energy surface.

1. P. Doleschall, J. Révai, N. V. Shevchenko, *Three-body calculation of the 1s level shift in kaonic deuterium*, Phys. Lett. B 744 (2015) 105.

Stability domain of few-charge systems

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A review is presented of the stability domain of few-charge systems when the masses are changed. Some quark-model analogues will also be presented.

Multichannel Coulomb scattering calculations with Merkuriev-Faddeev equations

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We present the results of positron-Hydrogen scattering calculations above the positronium formation threshold. The multichannel boundary conditions as well as the principles of choosing Merkuriev splitting functional parameters are discussed.

Continuum discretization for quantum scattering in medium

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The Bethe-Goldstone-type formalism to determine a reaction matrix for two particles in medium (e.g. nucleons in nuclear matter) are reformulated in terms of a resolvent of the effective total Hamiltonian defined in the Pauli-allowed subspace. As a result, the reaction matrix at many relative momenta and energies can be found by using the respective Hamiltonian matrix diagonalization in the stationary wave packet basis which simplifies strongly the self-energy iterations. The proposed discrete approach is expected to be useful for an accurate treatment of three-nucleon correlations in nuclear matter on the basis of the reduced Bethe-Faddeev equations.

Study of ground states of few-body nuclei by Feynman's continual integrals method

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The energy and the square modulus of the wave function for the ground states of ^{3}H, ^{3,4,6}He nuclei have been calculated by Feynman's continual integrals method. Nucleon-nucleon interaction with strong repulsive core was used. Calculations were performed using parallel computing on graphics processing units (NVIDIA CUDA technology). The efficiency of the approach for few-nucleon systems was shown. The method may be useful as the addition to the well-known Faddeev equations and hyperspherical functions method.

Gauge-independent treatment of radiative capture in nuclear reactions: Application to the theory of nucleus-nucleus Bremsstrahlung

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Our departure point in describing electromagnetic (EM) interactions with nuclei (in general, bound systems of charged particles) is to use the Fock-Weyl criterion and a generalization of the Siegert theorem (see [1] where this approach is compared with that by Friar and Fallieros [2]). It has been shown how one can meet the gauge invariance principle (GIP) in all orders in the charge and construct the corresponding EM interaction operators in case of nuclear forces arbitrarily dependent on velocity (see paper [1] and refs. therein). Along the guideline we have derived the conserved current density operator for a dicluster system (more precisely, the system of two finite-size clusters with many-body interaction effects included). Being expressed through electric and magnetic field strengths and matrix elements of the generalized electric and magnetic dipole moments of a system the single-photon transition amplitudes attain a manifestly gauge-independent (GI) form. Special attention is paid to the cluster structure of the T-matrix for radiative process $A+B \to \gamma+C$, in which a target-nucleus A captures a projectile-nucleus B that is followed by the single-photon emission and formation of a system C=A+B in a bound or continuum state , e.g., as in case of $\alpha+\alpha \to \gamma+\alpha+\alpha$ bremsstrahlung. We show how the decomposition of T into

separate contributions responsible for the photon emission stems from the time-space current components and depends on the interactions between colliding nuclei (clusters) . The latter may be nonlocal. Evidently, if we switch off the $\alpha - \alpha$ interaction in entrance and exit channels, such a process will be impossible. Keeping this in mind, it is easily to see (at least, within potential models of the $\alpha - \alpha$ scattering) that the relevant Coulomb-like integrals with distorted waves can be calculated in terms of the half-off-energy-shell $\alpha - \alpha$ scattering amplitudes (cf.,e.g., [4]). When calculating these quantities we show a constructive way for taking into account the interplay between the Coulomb repulsion and strong interaction of colliding nuclei. At the same time, one should note that the bremsstrahlung amplitudes in question are expressed through the cluster form factors.

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Three-body systems with strangeness

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Three-body systems consisting of nucleons and antikaons are interesting exotic objects of different type with different properties. For example, a quasi-bound state caused by strong antikaon-nucleon attraction exists in $K^- pp$ and $K^- K^- p$ systems. Unfortunately, it is hard to measure binding energy and width of such a state: several experiments devoted to the $K^- pp$ system reported very different results. One more example is (anti)kaonic deuterium. The lowest level of this exotic atom is shifted due to presence of the strong interactions. The shift and the width of $1s$ level can be measured directly, but accurate theoretical evaluation of this observables is hard. The talk summarizes results of theoretical works [1-3] devoted to the $\bar{K}NN$ and $\bar{K}\bar{K}N$ systems. The calculations were performed using Faddeev-type AGS equations with coupled channels.

1. Shevchenko N.V. and Révai J., Phys. Rev. C 90, 034003 (2014).
2. Révai J. and Shevchenko N.V., Phys. Rev. C 90, 034004 (2014).
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Dynamical adiabatic theory of atomic and nuclear collisions

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In the dynamical adiabatic approximation, the three principal conceptual problems are resolved: Firstly, it is compatible with the boundary conditions whereas in standard adiabatic two-Coulomb center basis there are non-vanishing inelastic transitions when the internuclear distance tends to infinity. Secondly, the rotational transitions are transformed into the radial transitions via a new type of L3-crossings, in contrast with the standard adiabatic basis where these transitions could only be included by the numerical close-coupling calculations. And thirdly, the ionization process can be described using a basis of the complete discrete orthogonal wave packets which is much more satisfactory than the standard adiabatic approach where the continuum states used have no direct physical meaning. General formulas were applied to a model problem of electron detachment in the process $A^- + A \to A + A + e$ in which the electron-atom interactions are described by the short-range potentials. New approach to description of rotational transitions as transitions via the radial L3-crossings is analyzed for the $(HeH)^{2+}$ quasimolecular system. For this system, the dynamical adiabatic results for the charge transfer process in collisions of He^+ with $H(1s)$ are discussed.

Structura of essential spectrum and discrete spectrum of four-electron systems in the Hubbard Model

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We investigate spectral properties of a four-electron system in the Hubbard model framework. We prove that the essential spectrum of the system in a quintet state consists of a single segment and the four-electron bound states or four-electron anti bound states is absent. We show that the essential spectrum of the system in singlet and triplet states is the union of at most three segments. We also prove that at most one four-electron bound states or four-electron anti bound states exist in singlet and triplet states.

Quantum transmission of clusters with several identical particles through barriers and wells

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We consider a close-channel method for solving the problem of quantum transmission through potential barriers and wells for a composite system consisting of several identical particles coupled via pair oscillator-type potentials in the symmetrized-coordinate representation. We confirm the efficiency of the proposed approach by calculating complex energy values and analyzing the metastable states of composite systems of several identical particles on a line.

Asymptotic solution to multichannel scattering problem with nontrivial asymptotic nonadiabatic coupling

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The multichannel scattering problem in adiabatic representation is considered. The nonadiabatic coupling matrix is assumed to have the nontrivial constant asymptotic behavior at large internuclear separations. The asymptotic solutions at large internuclear distances are constructed. It is shown that in the first order of perturbation theory these solutions are identical to the asymptotic solutions of the reprojection approach, which was proposed earlier as a remedy for the electron translation problem in the context of the Born-Oppenheimer approach.

Potential splitting approach to e-H and e-He^+ scattering

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Approach based on splitting the reaction potential into a finite range part and a long range tail part is proposed. The solution to the Schrödinger equation with the long range tail of the reaction potential is used as an incoming wave. This reformulation of the scattering problem into inhomogeneous Schrödinger equation with asymptotic outgoing waves makes it suitable for solving with the exterior complex scaling. The validity of the approach is studied and demonstrated numerically. The approach is illustrated with calculations of the electron resonant scattering on the hydrogen atom and the positive helium ion.

Consequences of non-Abelian permutation symmetry in systems of spinor particle

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The first applications of the group-theoretical methods in quantum mechanics in works by Wigner, Heitler, and Dirac in 1926–1929 were devoted to the permutation symmetry. A general interest to this topic was lost after the discovery of the Pauli exclusion principle, which allows only permutation-symmetric or antisymmetric wavefunctions for bosons or fermions, respectively, and forbids non-Abelian irreducible representations of the symmetric group, where a wavefunction is transformed into a linear combination of several wavefunctions in the representation. Such representations can appear in physical systems with spinor and spatial degrees of freedom. In the talk I would like to present some consequences of the non-Abelian permutation symmetry. They are the selection rules [1] for high-spin particles, the suppression of the decay of states with well-defined spins in Bose gases [2], and second-order phase transitions in Fermi gases that do not have analogs in gases with undefined total spin. These phase transitions are manifested as discontinuities in the specific heat.

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Unstable nuclei in dissociation of light stable and radioactive nuclei

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A role of the unstable nuclei ^{6}Be, ^{8}Be and ^{9}B in the dissociation of relativistic nuclei ^{7,9}Be, ^{10}B and ^{10,11}C is under study on the basis of nuclear track emulsion exposed to secondary beams of the JINR Nuclotron. Contribution of the configuration ^{6}Be + n to the ^{7}Be nucleus structure is $8 \pm 1\%$ which is near the value for the configuration ^{6}Li + p. Distributions over the opening angle of α-particle pairs indicate to a simultaneous presence of virtual ^{8}Be g.s. and ^{8}Be 2+ states in the ground states of the ^{9}Be and ^{10}C nuclei. The core ^{9}B is manifested in the ^{10}C nucleus with a probability of $30 \pm 4\%$. ^{8}Be g.s. decays are presented in $24 \pm 7\%$ of ^{2}He + ^{2}H events of the ^{11}C coherent dissociation and $27 \pm 11\%$ of the ^{3}He ones. The channel ^{9}B + H amounts $14 \pm 3\%$. The ^{8}B g.s. nucleus is manifested in the coherent dissociation $^{10}\text{B} \rightarrow {}^{2}\text{He} + \text{H}$ with a probability of $34 \pm 7\%$ including $14 \pm 4\%$ of ^{9}B decays.

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