JOINT INSTITUTE FOR NUCLEAR RESEARCH

LXIX INTERNATIONAL CONFERENCE
“NUCLEUS-2019”
ON NUCLEAR SPECTROSCOPY AND NUCLEAR STRUCTURE

“Fundamental Problems of Nuclear Physics, Nuclei at Borders of Nucleon Stability, High Technologies”

Dedicated to the International Year of the Periodic Table of Chemical Elements

Dubna, Russia, 1–5 July 2019

BOOK OF ABSTRACTS

Edited by *V. V. Samarin* and *M. A. Naumenko*

Dubna 2019

Organizers

Russian Academy of Sciences
Joint Institute for Nuclear Research
St. Petersburg State University
Moscow State University

Organizing Committee

V. A. Matveev (Chairman, JINR, Dubna)
V. B. Brudanin (Co-Chairman, JINR, Dubna)
Yu. E. Penionzhkevich (Co-Chairman, JINR, Dubna)
M. A. Naumenko (Scientific Secretary, JINR, Dubna)
V. V. Voronov (JINR, Dubna)
V. V. Samarin (JINR, Dubna)
V. N. Shvetsov (JINR, Dubna)
N. S. Zelenskaya (MSU, Moscow)
A. K. Vlasnikov (SPbSU, St. Petersburg)
O. M. Korotchik (JINR, Dubna)

The contributions are reproduced directly from the originals presented by the Organizing Committee.

I69 **International** Conference "NUCLEUS-2019" on Nuclear Spectroscopy and Nuclear Structure (LXIX; 2019; Dubna).

LXIX International Conference on Nuclear Spectroscopy and Nuclear Structure "Fundamental Problems of Nuclear Physics, Nuclei at Borders of Nucleon Stability, High Technologies" Dedicated to the International Year of the Periodic Table of Chemical Elements (Dubna, Russia, 1–5 July 2019): Book of Abstracts / Ed. by V. V. Samarin and M. A. Naumenko. — Dubna: JINR, 2019. — 388 p.

ISBN 978-5-9530-0518-0

Международная конференция «ЯДРО-2019» по ядерной спектроскопии и структуре атомного ядра (LXIX; 2019; Дубна).

LXIX Международная конференция по ядерной спектроскопии и структуре атомного ядра «Фундаментальные проблемы ядерной физики, ядра у границ нуклонной стабильности, высокие технологии», посвященная Международному году Периодической таблицы Д. И. Менделеева (Дубна, Россия, 1–5 июля 2019 г.): Аннот. докл. / Под ред. В. В. Самарина, М. А. Науменко. — Дубна: ОИЯИ, 2019. — 388 с.

ISBN 978-5-9530-0518-0

ISBN 978-5-9530-0518-0

Contents

Experimental study of properties of atomic nuclei

- **Neutron-rich nuclei of lightest elements;**
- **Nuclei far from stability valley;**
- **Synthesis of superheavy elements;**
- **Giant resonances;**
- **Multiphonon and multi-quasiparticle states of nuclei;**
- **High-spin and superdeformed states of nuclei;**
- **Beta decays of nuclei.**

RADIOACTIVE ION BEAMS (RIBs) FOR THE STUDY OF HEAVY NEUTRON-RICH NUCLEI

Ter-Akopian G.M., Oganessian Yu.Ts., Bezbakh A.A., Fomichev A.S., Golovkov M.S., Gorshkov A.V., Krupko S.A., Nikolskii E.Yu., Sidorchuk S.I., Stepantsov S.V., Wolski R.
Flerov Laboratory of Nuclear Reactions, JINR, Dubna, 191980 RF
E-mail: gurgen@jinr.ru

Quasi-elastic, multi-nucleon transfer (MNT) reactions induced by the RIBs with energy 4–6 MeV/u allow one to produce moderately excited nuclei with atomic numbers $95 < Z < 110$ and neutron numbers approaching $N = 172$ (see in Fig. 1). This offers a new approach to the study of so far unknown nuclei in neighborhood of the recently discovered island if super-heavy nuclei [1, 2]. Informative for the study of r-process in the neutron star mergers [3, 4] will be data specifying significant fission characteristics obtained for the nuclei along the ^{254}Cf-feeding path by means of the RIB MNT reactions. The choice of suitable RIBs available from the newly built ACCULINNA-2 fragment separator [5] and possible results of appropriate experiments will be discussed.

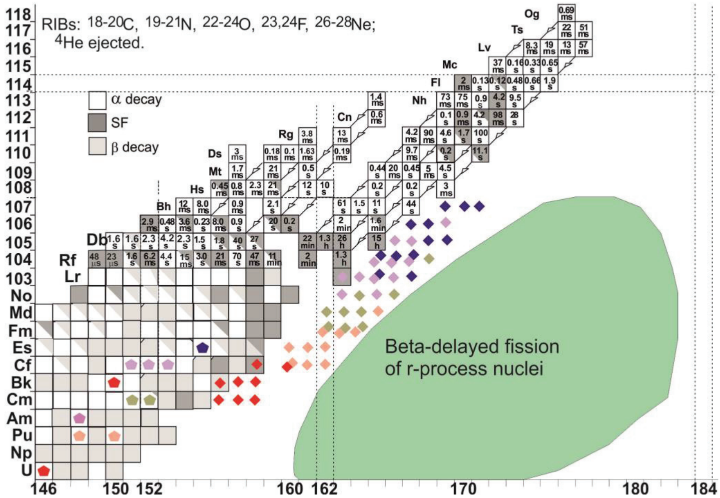


Fig. 1. Plot showing nuclei in the vicinity of the stability island. Targets suitable for the MNT implementation and the so far unknown neutron-rich nuclei lying on the β-decay path of r-process products are shown with pentagons and diamonds, respectively.

1. Yu.Oganessian and V.K.Utyonkov // Rep. Prog. Phys. 2015. V.78. 036301.
2. Yu.Ts.Oganessian *et al.* // Phys. Scr. 2017. V.92. 023003.
3. Meng-Ru Wu *et al.* // arXiv:1808.10459v2 [astro-ph.HE] 6 Jan 2019.
4. Y.Zhu *et al.* // arXiv:1806.09724v1 [astro-ph.HE] 25 Jun 2018.
5. A.S.Fomichev *et al.* // Eur. Phys. J. A. 2018. V.54. P.97.

SPECTROSCOPY OF THE ISOTOPES OF TRANSFERMIUM ELEMENTS IN DUBNA: PRESENT STATUS AND PERSPECTIVES

Yeremin A.V.[1], Lopez-Martens A.[2], Hauschild K.[2], Popeko A.G.[1], Malyshev O.N.[1], Chepigin V.I.[1], Svirikhin A.I.[1], Isaev A.V.[1], Popov Yu.A.[1], Chelnokov M.L.[1], Kuznetsova A.A.[1], Tezekbayeva M.S.[1], Dorvaux O.[3], Gall B.[3], Piot J.[4], Antalic S.[5], Mosat P.[5], Tonev D.[6], Stefanova E.[6]

[1] FLNR JINR, 141980 Dubna, Russia; [2] CSNSM, IN_2P_3-CNRS, UMR 8609, F-91405 Orsay, France; [3] IPHC-DRS/ULP, IN_2P_3-CNRS, F-67037 Strasbourg, France; [4] GANIL, CEA-DSM, IN_2P_3-CNRS, F-14076 Caen, France; [5] Comenius University, 84248 Bratislava, Slovakia; [6] INRNE, BAS, 1784 Sofia, Bulgaria

E-mail: eremin@jinr.ru

Important information on the structure of Super Heavy Elements (SHE) can come from the study of lighter deformed transfermium ($Z \sim 100$–106) elements. The cross-section for the formation of these nuclei is many orders of magnitude higher than for $Z \geq 110$ so that detailed spectroscopy becomes possible.

The opportunity to have high intensity (> 1 pμA) accelerated beams with $A \leq 50$ together with the use of exotic targets provide the possibility to study many aspects of heavy ion induced reactions exploiting new generation of high efficiency, high resolution experimental setups.

In recent years α-, β- and γ- spectroscopy of heavy nuclei at the focal plane of recoil separators ("decay spectroscopy") has been very intensively developed. The mixing of α decay with γ and β decay spectroscopy allows to investigate single particle states behavior as well as the structure of little known elements in the $Z = 100$–104 and $N = 152$–162 region.

In the years 2004–2019 using the GABRIELA (Gamma Alpha Beta Recoil Investigations with the ELectromagnetic Analyser) set-up the experiments aimed to the gamma and electron spectroscopy of the Fm–Db isotopes, formed at the complete fusion reactions with heavy ions ^{22}Ne, ^{48}Ca, ^{50}Ti and ^{54}Cr were performed at FLNR JINR.

At the years 2017–2019 we performed model experiments using method of high resolution alpha spectroscopy and gamma quanta detection to study decay properties of ^{254,255,256,257}Rf in the reactions ^{50}Ti + ^{206,207,208}Pb → ^{256,357,258}Rf*, ^{250,252,254,2565}No in the reactions ^{48}Ca + ^{204,206,208}Pb → ^{252,354,256}No* and ^{256}No in the reaction ^{22}Ne + ^{238}U → ^{260}No*.

A COINCIDENT ^{9}Be(*d,d'n*)X EXPERIMENT AT DEUTRON ENERGY OF 15 MeV

Konobeevski E.S.[1], Afonin A.A.[1], Kasparov A.A.[1], Lebedev V.M.[2], Mitcuk V.V.[1,3], Mordovskoy M.V.[1,3], Spassky A.V.[2], Zuyev S.V.[1]

[1] *Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia;*
[2] *Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow, Russia;*
[3] *Moscow Institute of Physics and Technology (State University), Moscow, Russia*
E-mail: konobeev@inr.ru

The results of the simulation of the ^{9}Be(d,d'n)X and ^{9}Be(d,d'α)X reactions show that recording an inelastic scattered deuteron excited a specific ^{9}Be state in coincidence with a particle from the decay of this state allows one to determine the contributions of various cluster configurations to the structure of this state.

A study of the ^{9}Be cluster structure in the coincident experiment was started on the deuteron beam of the Skobeltsyn Institute of Nuclear Physics. Scattered deuterons are detected by a telescope of three silicon detectors in one arm of the setup. In the second arm of the setup, either a neutron detector is installed.

As a neutron detector liquid hydrogen-containing scintillator EJ301 with ability of neutron-gamma separation was used. Neutron energy was determined by time-of-flight technique using a fast output of the E-detector as a start and that of the n-detector as a stop signal. The calibration of the spectrometer was obtained measuring timing spectrum of α-n coincidence in two-body $d + {}^{2}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + n$ reaction.

Preliminary data are obtained for timing (energy) spectra of neutrons from the breakup of various excited levels of ^{9}Be.

The reported study was funded by RFBR according to the research project N 18-32-00944.

A NEW APPROACH TO DESCRIBE ALPHA-DECAY HALF-LIVES OF SUPERHEAVY NUCLEI

Ansari A.
Lamerd higher education center, Lamerd, Iran
E-mail: ansariahmad@shirazu.ac.ir

Synthesis and decay of superheavy nuclei have been investigated in the many works [1]. However, elements with atomic number $Z > 118$ have not been synthesized yet due to absence of proper projectiles and targets nuclei and inability of the current laboratories in the synthesis of new elements. In this research work, "Synthesis Box" as a new approach is used to investigate new elements decay [2]. In this new approach considering all different combinations of available target and projectile nuclei to produce element 120 the following reaction is suggested: $^{50}\text{Ti} + {}^{251}\text{Cf} \rightarrow {}^{298}120 + 3n$. The compound nucleus formation and survival probability and the probability of the residue nuclei formation have been calculated. The results of this new approach were in good agreement with the experimental data for the synthesized nuclei with atomic numbers $Z = 114$–118. Then the results of the synthesis box for new element 120 have been compared with another research works which was found that the half-life of element with $Z = 120$ is in order of microsecond.

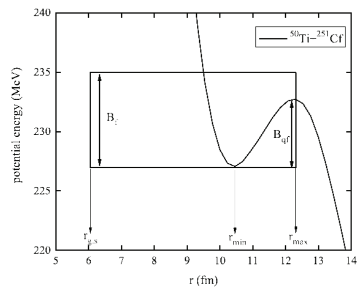


Figure 1. Synthesis box as a new approach to describe superheavy element decay.

Table 1. Calculated α-decay half-lives compared with the experimental ones for superheavy nuclei belonging to $^{298}120$ α-decay chain.

	$^{286}114$	$^{290}116$	$^{294}118$	$^{298}120$
This work	$0.14^{+0.17}_{-0.11}\ s$	$12.2^{+10.3}_{-2.80}\ ms$	$0.95^{+1.30}_{-1.50}\ ms$	$1\ \mu s$
Experimental data [1]	$0.16^{+0.19}_{-0.06}\ s$	$10.0^{+11.9}_{-3.90}\ ms$	$0.89^{+1.07}_{-0.31}\ ms$	-
[3]	$0.16^{+0.07}_{-0.05}\ s$	$13.4^{+7.7}_{-5.2}\ ms$	$0.66^{+0.23}_{-0.18}\ ms$	$2\ \mu s$
[4]	$0.11^{+0.05}_{-0.03}\ s$	$8.9^{+5.4}_{-3.3}\ ms$	$0.39^{+0.15}_{-0.11}\ ms$	$0.2\ \mu s$

1. Y.T.Oganessian *et al.* // Phys. Rev. C. 2006. V.74. P.044602. See references therein.
2. A.Ansari and N.Ghahramany // Int. J. Mod. Phys. E. 2017. V.26. No.7. P.1750050.
3. C.Samanta, P.Roy Chowdhury, D.N.Basu // Nucl. Phys. A. 2007. V.789. P.142.
4. G.Royer and H.F.Zhang // Phys. Rev. C. 2008. V.77. P.037602.

EVOLUTION OF THE NEUTRON SINGLE-PARTICLE STRUCTURE OF $N = 50$ ISOTONES WITHIN THE DISPERSIVE OPTICAL MODEL

Bespalova O.V., Klimochkina A.A.
Federal State Budget Educational Institution of Higher Education M.V.Lomonosov Moscow State University, Skobeltsyn Institute of Nuclear Physics (SINP MSU), 1(2), Leninskie gory, GSP-1, Moscow 119991, Russian Federation
E-mail: besp@sinp.msu

The evolution of the neutron single-particle energies of isotones with $N = 50$ approaching to the neutron drip-line (see Fig. 1) is calculated within the dispersive optical model (DOM) [1]. The calculated energies of $1g_{9/2}$ and $2d_{5/2}$ states are close to the neutron separation energy $-S_n(N,Z)$ and $-S_n(N+1,Z)$ respectively and the particle-hole gap between them substantially decreases with decreasing Z number. Near the neutron drip line, the $2d_{5/2}$ and $2s_{1/2}$ level sequence changes, and the $2s_{1/2}$ state with $l = 0$ becomes the first predominantly unoccupied state. The absence of the centrifugal barrier for this state facilitates the halo structure of ^{70}Ca to be formed. The result is consistent with the predictions of the halo structure of the Ca isotopes near the neutron drip line by the relativistic continuum Hartree-Bogoliubov and non-relativistic Skyrme Hartree-Fock-Bogoliubov calculations [2, 3].

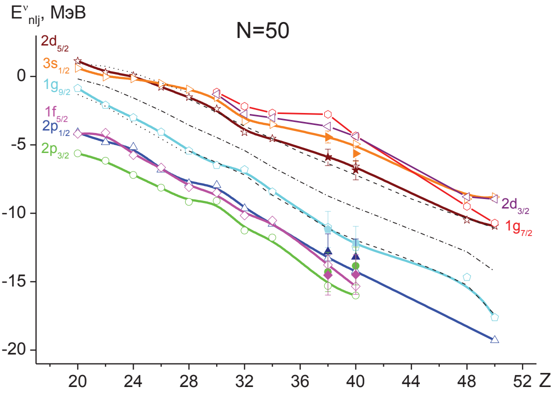


Fig. 1. Neutron single-particle energies of $N = 50$ isotones. Solid symbols – the experimental data, open symbols connected by the solid lines – calculation by DOM, dashed-dotted line – the Fermi energy, dashed lines – neutron separation energies $-S_n(N,Z)$ and $-S_n(N+1,Z)$ for even-even nuclei from AME data.

1. C.Mahaux, R.Sartor // Adv. Nucl. Phys. 1991. V.20. P.1.
2. J.Meng, H.Toki, J.Y.Zeng, *et al.* // Phys. Rev. C. 2002. V.65. 041302.
3. J.Terasaki, S.Q.Zhang, S.G.Zhou, *et al.* // Phys. Rev. C. 2006. V.74. 054318.

PRODUCTION OF HEAVY HELIUM ISOTOPE ^{6}He IN STOPPED PION ABSORPTION

Chernyshev B.A., Gurov Yu.B., Lapushkin S.V., Tel'kushev M.V., Sandukovsky V.G.
National Research Nuclear University "MEPhI", Moscow, Russia
E-mail: chernyshev@mephi.ru

An overview of experimental results on the level structure of heavy helium isotope ^{6}He, obtained in the reactions of the stopped pion absorption by light nuclei, is presented. The measurements were performed at low energy pion channel of LANL with two-arm multilayer semiconductor spectrometer. The method of investigation relies on precise measurements of energy of charged particles emitted after pion absorption by nuclei. Two (three)-particle channels of neutron-rich nuclei production reveal themselves via peaks in the missing mass spectra for one (two) registered particles. Important advantage of this method is the possibility to study with high statistics a wide range of excitation energies up to E_x = 40 MeV.

Excited states of the ^{6}He were observed in several reaction channels on the ^{9}Be, ^{10,11}B and ^{12}C nuclei: ^{9}Be(π^-,*t*)^{6}He, ^{10}B(π^-,*pt*)^{6}He, ^{10}B(π^-,*dd*)^{6}He, ^{11}B(π^-,*pd*)^{6}He, ^{10}B(π^-,^{4}He)^{6}He, ^{12}C(π^-,*d*^{4}He)^{6}He and ^{12}C(π^-,*t*^{3}He)^{6}He. Several excited levels were found only in our measurements. Among the helium states there are few candidates on isobar-analogs of hydrogen isotopes. In reaction ^{9}Be(π^-,*t*)*tt* four cluster resonances ^{6}He(*tt*) were observed. A comparison with experimental and theoretical data other works is performed.

ISOBAR ANALOG STATES IN ^{12}B AND ^{12}N: SEARCH FOR STATES WITH ENHANCED RADII

Demyanova A.S.[1], Danilov A.N.[1], Ogloblin A.A.[1], Starastsin V.I.[1], Dmitriev S.V.[1], Sergeev V.M.[1,2], Goncharov S.A.[2], Belyaeva T.L.[3], Maslov V.A.[4], Sobolev Yu.G.[4], Penionzhkevich Yu.E.[4], Trzaska W.H.[5], Khlebnikov S.V.[6], Tyurin G.P.[6], Burtebayev N.[7], Janseitov D.M.[4,7], Gurov Yu.B.[8]

[1] NRC Kurchatov Institute, Moscow 123182, Russia; [2] Lomonosov Moscow State University, GSP-1, Leninskie Gory, Moscow 119991, Russia; [3] Universidad Autónoma del Estado de México, C.P. 50000, Toluca, México; [4] Flerov Laboratory for Nuclear Research, JINR, Dubna, Moscow Region 141980, Russia; [5] Department of Physics, University of Jyväskylä, P.O. Box 35, FI-40014 Jyväskylä, Finland; [6] V.G. Khlopin Radium Institute, St. Petersburg 194021, Russia; [7] Institute of Nuclear Physics, National Nuclear Center of Republic of Kazakhstan, Almaty 050032, Republic of Kazakhstan; [8] National Research Nuclear University MEPhI, Moscow 115409, Russia

E-mail: danilov1987@mail.ru

On base of Asymptotic normalization coefficients (ANC) analysis halo was observed for 2 states of ^{12}B: 2^-, 1.67 MeV and 1^-, 2.62 MeV [1]. Independently on base of ANC analysis of our experimental data [2, 3] on reaction ^{11}B(d,p)^{12}B at $E(d)$ = 21.5 MeV [3] neutron halo existence was confirmed for these states. Some new results were obtained for higher excited states: halo-like states were observed for 0^+, 2.72 MeV and 3^-, 3.39 MeV states [3]. It should be mentioned that the last one is unbound state, which is 19 keV above the neutron emission threshold and in both states last neutron has a non-zero orbital momentum.

Natural question arises – what can we expect in isobar-analogues 2^- and 1^- states in ^{12}N. To study them we propose to use MDM [4, 5]: this method can be applied to the reaction (^{3}He,t). Its first application made it possible to determine the proton halo in unbound state of ^{13}N [6]. We have studied existing literature data on ^{12}C(^{3}He,t)^{12}N reaction. This data is incomplete and there is no possibility to make definite answer on question about halo in 2^- and 1^- states of ^{12}N. By this reason experiment was done by our group on ^{12}C(^{3}He,t)^{12}N reaction at the end of 2018. The measurements were conducted at the University of Jyväskylä (Finland) using the K130 cyclotron at $E(^3\mathrm{He})$ = 40 MeV. The 150 cm diameter Large Scattering Chamber was equipped with three ΔE–E detector telescopes, each containing two independent ΔE detectors and one common E detector. The differential cross sections of the (^{3}He,t) reaction on ^{12}C were measured in the angular range 8°–70° c.m. Preliminary results for angular distributions are obtained. MDM analysis of preliminary (^{3}He,t) experimental data will be done soon.

1. Z.H.Liu *et al*. // Phys. Rev. C. 2001. V.64. 034312.
2. T.L.Belyaeva *et al*. // EPJ Web Conf. 2017. V.165. 01004.
3. T.L.Belyaeva *et al*. // Phys. Rev. C. 2018. V.98. 034602.
4. A.N.Danilov *et al*. // Phys. Rev. C. 2009. V.80. 054603.
5. A.S.Demyanova *et al*. // Phys. Atom. Nucl. 2017. V.80. P.831.
6. A.S.Demyanova *et al*. // JETP Letters. 2016. V.104 (8). P.526.

SPECTROSCOPY OF ^{128}I USING ICF REACTION

Bhujang B.[1], Das P.[1], Pasi V.[1], Palit R.[2]
[1] *Department of Physics, Indian Institute of Technology Bombay, Powai, Mumbai, India;*
[2] *Department of Nuclear and Atomic Physics, TIFR, Mumbai, India*
E-mail: pragya@phy.iitb.ac.in

Incomplete fusion reaction (ICF) provides an attractive opportunity to produce nuclei close to the beta-stability line. Despite its advantages laid by Dracoulis *et al.* [1] – by comparing ICF process in ^{176}Yb(^{11}B, α3*n*)^{180}Ta with complete fusion (CF) reaction ^{176}Yb(^{7}Li, 3*n*)^{180}Ta – research is very sparse.

We performed two different studies. In the first study, we measured the absolute cross sections of ICF and CF products by off-line gamma-ray spectrometry using ^{10,11}B beams on $^{122,\ 124}$Sn targets [2, 3]. The enhanced ICF cross sections observed in our experiments could not be reproduced satisfactorily by the existing sum rule model (SRM). To obtain a much improved theoretical estimate, we proposed a model [3] – a refined version of SRM – by visualizing the process classically.

In our second study, we chose one ICF reaction ^{124}Sn(^{11}B, α3*n*)^{128}I for the on-line spectroscopy. The experiment was performed with 21 clover HP Ge detectors using 70 MeV beam from the Pelletron-Linac facility at the Tata Institute of Fundamental Research (TIFR), Mumbai, India. Fig. 1 (a) presents a double-gated spectrum obtained by gating on the energy cube made from the list mode data. We placed a new 133 keV γ-ray (Fig. 1 (b)) – absent in the earlier work using a CF reaction [4] but observed in the (*n*, γ) process [5] – with confirmed spin by measuring the transition multipolarity for the first time.

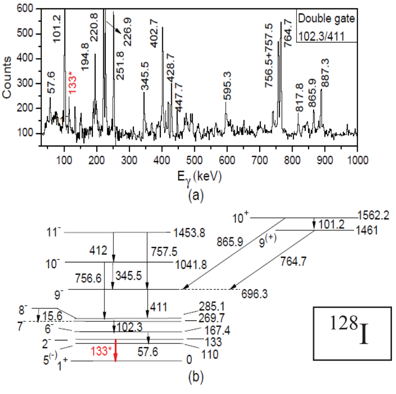


Fig.1. (a) Gated projected spectrum indicating a new 133 keV transition; (b) bottom part of the decay scheme.

We have established the spin-parity of many states using DCO, polarization and PDCO techniques. Further, we have tried to understand theoretically – using particle rotor model and total Routhian surface calculations – the phenomena of signature splitting and inversion in the yrast negative-parity band. Triaxial nuclear shapes seem to play an important role.

1. G.D.Dracoulis *et al.* // J. Phys. G: Nucl. Part. Phys. 1997. V.23. P.1191.
2. Bhushan Bhujang *et al.* // Journ. Phys.: Conf. Series 2013. V.420 (1). 012128.
3. Bhushan Bhujang, Pragya Das // Submitted to EPJA.
4. B.Ding *et al*. // Phys. Rev. C. 2012 V.86. 034302.
5. S.L.Sakharov *et al*. // Nucl. Phys. A. 1991. V.528. P.317.

NEW DIRECTIONS IN THE STUDY OF NUCLEON HALOS

Demyanova A.S.
National Research Center "Kurchatov Institute", Moscow, Russia
E-mail: a.s.demyanova@bk.ru

The discovery of the halo is one of the most important achievements of nuclear physics at the end of the last century. The halo was discovered in the ground states of the nuclei lying on the border of stability with the help of a new "tool" – beams of radioactive nuclei. The main property of the halo is an increased radius of valence neutrons, 2 to 3 times the size of the core. However, there were no direct methods for measuring the short-lived radii at that time.

Our group has developed the following methods for measuring nuclear radii in short-lived states:

1) a modified diffraction model (MDM), using the features of the diffraction component of the differential cross section.
2) the rainbow scattering method based on the features of the rainbow component of the differential cross section.
3) The method of asymptotic normalization coefficients (ANC).
4) Spreading of MDM on charge exchange reactions (^{3}He, *t*) and, possibly, (*d*, ^{2}He).

The use of these methods allowed us to obtain the following results:

- halo found in "non-exotic" stable nuclei (^{9}Be, ^{13}C)
- halo detected not only in the ground, but also excited states of the nuclei (^{9}Be, ^{13}C)
- a halo is detected not only in the states of the discrete spectrum, but also in the continuum states (^{9}Be rotational bands)
- a proton halo was first detected in ^{13}N. In the mirror states of ^{13}N – ^{13}C, halos are observed (proton and neutron, respectively), having the same radii
- considered the issue of borromian and tango structures in three-body halos
- halo in isobar-analog states: ^{6}He ($2n$) – ^{6}Li (np) – ^{6}Be ($2p$); ^{12}B – ^{12}C – ^{12}N.

IMPROVED CHARACTERISTICS OF THE 15.1 keV M1+E2 NUCLEAR TRANSITION IN ^{227}Th

Kovalík A.[1,2], Inoyatov A.Kh.[1], Perevoshchikov L.L.[1], Ryšavý M.[2], Filosofov D.V.[1], Dadakhanov J.A.[1], Muminov T.M.[3]

[1] *Dzhelepov Laboratory of Nuclear Problems, JINR;* [2] *Nuclear Physics Institute of the ASCR CZ, Řež near Prague, Czech Republic,* [3] *National University of Uzbekistan, Tashkent, Republic of Uzbekistan*

E-mail: inoyatov@jinr.ru

According to the latest nuclear data compilation [1], the second excited state 24.3 keV ($3/2^+$) of ^{227}Th is depopulated to the ($1/2^+$) ground state also by a cascade of the 15.1(2) keV (M1) and 9.3(1) keV (E2) gamma-ray transitions through the first excited state 9.3 keV ($5/2^+$). Characteristics of the both nuclear transitions play important role in the spin-parity assignment of the higher excited levels of ^{227}Th. Nevertheless, their adopted energies [1] exhibit (as can be seen above) very great uncertainties and their multipolarities (derived only in the pioneer work [2]) are not yet reliably determined.

Employing the advanced low energy nuclear electron spectroscopy technique developed in our laboratory, we measured the spectrum of the conversion electrons of the 15.1 keV nuclear transition emitted in the β^-decay of ^{227}Ac in which only the ground state and the lowest three excited levels of ^{227}Th are populated. From the measured spectra, the preliminary value of 15099.5(15) eV was determined for the transition energy which is more accurate than the present adopted one by a factor of 130. Moreover, we removed the present uncertainty in the transition multipolarity. It was found to be M1 + E2 with the preliminary value of the E2 admixture parameter $\Delta = 0.0015(5)$. The obtained results demonstrate that the internal conversion electron spectroscopy remains a powerful tool for determination of nuclear transition energies particularly in the low energy region which is comparable even with the crystal diffraction method.

1. Filip Kondev *et al*. // Nucl. Data Sheets for *A*=227. 2016. V.132. P.331.
2. G.I.Novikova, E.A.Volkova, L.L.Gol'din, D.M.Ziv, and E.F.Tret'yakov // Zh. Eksp. Teor. Fiz. 1959. V.37. P.928; Sov. Phys. JETP. 1960. V.10. P.663.

INVESTIGATION OF THE 24.3 keV M1 + E2 NUCLEAR TRANSITION IN ^{227}Th BY THE CONVERSION ELECTRON SPECTROSCOPY

Kovalík A.[1,2], Inoyatov A.Kh.[1], Perevoshchikov L.L.[1], Ryšavý M.[2], Filosofov D.V.[1], Dadakhanov J.A.[1], Muminov T.M.[3]

[1] *Dzhelepov Laboratory of Nuclear Problems, JINR;* [2] *Nuclear Physics Institute of the ASCR CZ, Řež near Prague, Czech Republic,* [3] *National University of Uzbekistan, Tashkent, Republic of Uzbekistan*

E-mail: inoyatov@jinr.ru

Characteristics of the 24.33(5) keV M1 + E2 [1] gamma-ray transition depopulating the 24.38(3) keV ($3/2^+$) [1] level of ^{227}Th to the ($1/2^+$) [1] ground state play important role (together with the 15.1(2) keV (M1) [1] and 9.3(1) keV (E2) [1] gamma-ray transitions) not only in the spin-parity assignment of the lowest excited levels of ^{227}Th and its ground state but consequently also the spin sequence and band structures of higher levels. Though this nuclear transition is not essential one, we decided to re-investigated its characteristics by means of the internal conversion electron spectroscopy applying the methods and apparatus developed in our laboratory for the low energy nuclear electron spectroscopy. For the investigation, a source of ^{227}Ac (prepared by a sorption on a carbon polycrystalline foil) was used as in its β^-decay only the ground state and the three lowest excited states of ^{227}Th are generated. Altogether, 10 spectrum lines of the measured $L_{1,2,3}$ and $M_{1,2,3}$ conversion electron spectra were evaluated. A preliminary value of 24344.2(19) eV was determined from the obtained data for the transition energy. This value agrees with the adopted one of 24330(50) eV [1] but it is by a factor of 26 more precise. The multipolarity of the investigated nuclear transition was confirmed to be M1 + E2 with the preliminary admixture parameter δ^2(E2/M1) = 0.012(2). The obtained value matches within one standard deviation the adopted one of 0.009(1) [1] as well as that of 0.010(1) [2] determined from the $M_{1,2,3}$ subshell ratios measured with the iron-free orange spectrometer. Moreover, our value agrees also with that of 0.01 deduced in the pioneer work [3] also from the ratios of the measured $M_{1,2,3}$ subshell conversion lines.

[1] Nucl. Data Sheets. 2016. V.132. P.331.
[2] U.Müller *et al.* // Phys. Rev. C. 1997. V.55. P.2267.
[3] G.I.Novikova *et al*. // Zh. Eksp. Teor. Fiz. 1959. V.37. P.928.

ENHANCED MONOPOLE AND DIPOLE TRANSITIONS IN MEDIUM-HEAVY NUCLEI INDUCED BY α CLUSTER STRUCTURES

Ito M.[1], Nakao M.[1], Umehara H.[2], Ebata S.[3]
[1] *Department of Pure and Applied Physics, Kansai University, Japan;* [2] *Department of Physics, Osaka University, Japan;* [3] *Laboratory for Advanced Nuclear Energy, Institute of Innovative Research, Tokyo Institute of Technology, Japan*
E-mail: itomk@kansai-u.ac.jp

Alpha cluster structures are well known to appear in excited states of lighter mass nuclei. According to recent studies, the isoscalar monopole (IS0) [1, 2] and dipole excitations (IS1) [3, 4] are considered to be important probes to identify the α cluster structure. We have calculated the continuum IS0 and IS1 transitions in the ^{44}Ti = α + ^{40}Ca system [5].

In Fig.1, the IS1 strength for ^{44}Ti → α + ^{40}Ca is plotted. There is a sharp peak around $E_x = 5$ MeV, while a broad peak is generated around E_x = 15 MeV. These peaks correspond to the dipole resonance, in which the relative motion of α + ^{40}Ca is excited with $L = 1$. The integrated values of these peaks are comparable to the single particle strength (Weisskopf unit), and their fraction of the energy-weighted-sum-rule is about 5 % in the range of E_x < 15 MeV. The peak energy of E_x = 5 MeV is much lower than the single particle excitation energy, corresponding to $1hw$ = 12 MeV. Thus, the enhancement of the low-lying IS1 is a characteristic feature in the clustering phenomena.

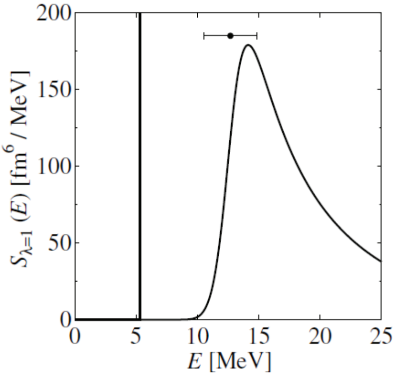


Fig. 1. IS1 continuum strength. The ordinate and abscissa represent the strength and excitation energy, respectively. The dot with the error bar shows the resonant energy with the decay width.

We have also extended the similar calculation to Te isotopes with the Te = α + Sn structure in the mass range from A = 104 to A = 110. From a series of our calculations, the systematic enhancement in the IS0 and IS1 strengths has been confirmed in the lower excitation energy of $E_x \leq 15$ MeV. We will also discuss the enhanced B(E1) strength observed in low-lying states in rare-earth region [6].

1. T.Yamada *et al*. // Prog. Theor. Phys. 2008. V.120. P.1139.
2. T.Yamada *et al*. // Phys. Rev. C. 2012. V.85. 034315.
3. Y.Chiba, M.Kimura and Y.Taniguchi // Phys. Rev. C. 2016. V.93. 034319.
4. Y.Chiba, Y.Taniguchi and M.Kimura // Phys. Rev. C. 2017. V.95. 044328.
5. M.Nakao, H.Umehara, S.Ebata, and M.Ito // Submitted to Phys. Rev. C (2018).
6. M.Spieker *et al*. // Phys. Rev. Lett. 2015. V.114. 192504.

CLUSTER THOMAS-EHRMAN EFFECT IN MIRROR NUCLEI

Nakao M.[1], Umehara H.[2], Ebata S.[3], Ito M.[1]
[1] Department of Pure and Applied Physics, Kansai University, Japan; [2] Department of Physics, Osaka University, Japan; [3] Laboratory for Advanced Nuclear Energy, Institute of Innovative Research, Tokyo Institute of Technology, Japan
E-mail: itomk@kansai-u.ac.jp

An interesting phenomenon arising from the *S*-orbit, can be seen in the Coulomb shift for the mirror systems. The famous example is known as "Thomas-Ehrman Shift", which was discussed in $^{17}O = {}^{16}O + n$ and $^{17}F = {}^{16}O + p$ [1]. As a result of the spatial extension of the *S*-wave orbit, the excitation energy of the $1s_{1/2}$ state in ^{17}F seems to be compressed in comparison to ^{17}O [1].

On the contrary, the α cluster structures are well known to appear in the excited states of light mass systems [2]. In the α cluster structure, the α particle and a residual nucleus are weakly coupled with a large mixture of the *S*-wave component. Therefore, we can expect that an anomalous feature similar to Thomas-Ehrman shift (TES) occurs in the α cluster structure.

	ΔE_{Coul}		ΔE_{ex}	
	Exp.	Th.	Exp.	Th.
0_1^+ (B. S.)	1.12	1.12	0	0
0_2^+ (B. S.)	1.06	1.14	0.06	0.03
0_4^+ (Res.)	–	0.53	–	0.58
0_5^+ (Res.)	–	0.65	–	0.46

Table 1. Energy shifts in $^{18}O - {}^{18}Ne$ systems. The left-most column shows the energy levels. In the middle and right-most ones, the energy shift (ΔE_{Coul}) with respect to the α threshold and the shift of excitation energy (ΔE_{ex}) are shown, respectively. Exp. and Th. mean the experimental data and theoretical calculation, respectively.

Coulomb shift is analyzed for the mirror cluster systems of $^{18}O = \alpha + {}^{14}C$ and $^{18}Ne = \alpha + {}^{14}O$ by applying the orthogonality condition model (OCM) [3]. The results are summarized in Table 1. ΔE_{Coul} means the energy difference of $^{18}O - {}^{18}Ne$ with respect to the α threshold, while ΔE_{ex} denotes the difference in the excitation energy measured from the individual ground states. ΔE_{Coul} is about 1.1 MeV for the bound 0_1^+ and 0_2^+ having the spatially compact shell model structure but it is reduced to be about $\Delta E_{\mathrm{Coul}} = 0.5$ MeV for the resonant 0_4^+ and 0_5^+ states with the developed α cluster structure. The decrease in ΔE_{Coul} corresponds to the lower shift in the excitation energy (ΔE_{ex}) for the higher $0_{4,5}^+$ states in the proton-rich system of ^{18}Ne. This results can be interpreted in terms of the extension of the TES effect to α cluster degrees of freedom.

We have also checked the monopole transition from the ground 0_1^+ state to the excited 0^+ states [4]. A combination of the cluster TES and the monopole transition is proposed as new probe to identify α cluster structures.

1. A.Bohr and B.R.Mottelson. Nuclear Structure. 1969. V.I. P.320.
2. H.Horiuchi *et al*. // Suppl. Prog. Theor. Phys. 2012. V.192. P.1 and references therein.
3. M.Nakao, H.Umehara, S.Ebata, and M.Ito // Submitted to Phys. Rev. C (2018).
4. T.Yamada *et al*. // Prog. Theor. Phys. 2008. V.120. P.1139.

DOUBLE K-SHELL IONIZATION OF KRYPTON AND XENON BY A 88-keV PHOTON

Gavrilyuk Yu.M.[1], Gangapshev A.M.[1], Kazalov V.V.[1], Kuzminov V.V.[1], Panasenko S.I.[2], Petrenko O.D.[2], Ratkevich S.S.[2], Tekueva D.A.[1]
[1] *Baksan Neutrino Observatory INR RAS, Moscow, Russia;* [2] *V.N.Karazin Kharkiv National University, Kharkiv, Ukraine*
E-mail: v.kazalov@gmail.com

A search of double K-capture of ^{78}Kr and ^{124}Xe using a large copper low-background proportional counters are carried out for many years at the Baksan Neutrino Observatory of the INR RAS [1, 2]. The signal detection from two neutrino mode of double K-capture is based on comparing the spectra of energy releases in the region of relaxation of the excited electron shell of the daughter atom. To detect a signal from such a process, it is desirable to have calibration procedures that determine the efficiency of their registration. It is known that, besides the 2K-capture, other rare physical phenomena that can create a double-K vacancy in atoms are exist. For example, double-K-shell photoionization of the atom can create the "hollow atom" by absorbing a single photon with the release of two correlated electrons. Such processes can contribute to the background of required three-point events when searching for 2K-capture.

To determine the probability of the double K-vacancy production by a single external photon in krypton and xenon, a low background proportional copper counter was used. The same low-background setting was used as in the search experiment for 2K-capture of ^{78}Kr [1]. The detector was filled with samples of natural krypton and xenon to a pressure of 4.7 and 5.0 atm, respectively.

The counter was irradiated through the wall of its casing by photons with an energy of 88 keV from a ^{109}Cd source, passing through a collimating orifice with a diameter of 12 mm and a length of 60 mm in the layer of copper shield located in the middle of the detector length. The counting rate was ~ 3.3 s^{-1}, the counting rate of the background in the range of 10–150 keV was ~ 20 h^{-1}. The total number of registered events was 2.5×10^7 in krypton and 4.2×10^7 in xenon. The statistics collection time was 2000 and 3600 hours respectively.

As a result of the data obtained it was determined the shake-off process inner-shell ionization. The double- to single-K-shell ionization ratios of atoms by single photon with energy 88 keV were determined to be $3.7(3)\times10^{-4}$ for krypton and $1.1(3)\times10^{-4}$ for xenon.

1. S.S.Ratkevich *et al*. // Phys. Rev. C. 2017. V.96. P.065502.
2. Yu.M.Gavrilyuk *et al.* // Physics of Particles and Nuclei. 2018. V.49. No.1. P.36.

SEARCH FOR ^{9}He IN STOPPED PION ABSORPTION BY ^{14}C

Chernyshev B.A., Gurov Yu.B., Lapushkin S.V., Leonova T.I., Sandukovsky V.G.
Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow, Russia
E-mail: tileonova@yandex.ru

The experimental search for the production of heavy helium isotope ^{9}He was carried out in the stopped π^--meson absorption reactions [1] on the radioactive target ^{14}C. The study of ^{9}He was performed in the missing mass spectra in the ^{14}C(π^-, *p* ^{4}He)X and ^{14}C(π^-, *d* ^{3}He)X reactions. The experiment was carried out at the LANL with a two-arm semiconductor spectrometer [2]. ^{9}He states search was carried out to excitation energies of ~ 30 MeV. Energy resolution in measurements was 3.0 MeV, the error of absolute energy calibration did not exceed 0.2 MeV. Three excited states have been observed.

1. Yu.B.Gurov *et al*. // Phys. Part. Nucl. 2009. V.40. No 4. P.558.
2. Yu.B.Gurov *et al*. // Phys. Part. Nucl. 2018. V.49. No 2. P.249.

SEARCH FOR ^{7}H AT ACCULINNA-2

Belogurov S.G.[1], Bezbakh A.A.[1,2], Biare D.[1], Chudoba V.[1,3], Fomichev A.S.[1,4], Gazeeva E.M.[1], Golovkov M.S.[1,4], Gorshkov A.V.[1,2], Grigorenko L.V.[1,5,6], Kaminski G.[1,7], Kostyleva D.A.[1], Krupko S.A.[1,2], Muzalevskii I.A.[1,3], Nikolskii E.Yu.[1,5], Parfenova Yu.L.[1], Pluciński P.[1,8], Quynh A.M.[1,9], Serikov A.[1], Sharov P.G.[1,2], Sidorchuk S.I.[1], Slepnev R.S.[1], Stepantsov S.V.[1], Swiercz A.[1,8], Szymkiewicz P.[1,8], Ter-Akopian G.M.[1,4], Wolski R.[1,10], Zalewski B.[1,7]

[1] Joint Institute for Nuclear Research, 141980 Dubna, Russia; [2] SSC RF ITEP of NRC "Kurchatov Institute", 117218 Moscow, Russia; [3] Institute of Physics, Silesian University in Opava, 746 01 Opava, Czech Republic; [4] Dubna State University, 141982 Dubna, Russia; [5] National Research Center "Kurchatov Institute", 123182 Moscow, Russia; [6] National Research Nuclear University "MEPhI", 115409 Moscow, Russia; [7] Heavy Ion Laboratory, University of Warsaw, 02-093 Warsaw, Poland; [8] AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, 30-059 Krakow, Poland; [9] Nuclear Research Institute, 670000 Dalat, Vietnam; [10] Institute of Nuclear Physics PAN, 31342 Krakow, Poland

E-mail: muzalevsky@jinr.ru

The ^{7}H isotope is the Golden Fleece to be searched by the RIB holders. Until the present moment only upper limits of its lifetime and ground state energy were estimated. Such unbound complicated five-body nuclear system, which has extremely large mass-to-charge ratio, lies far beyond the drip-line and has not been detected yet.

An experimental search for the ^{7}H resonance was performed with the ^{2}H(^{8}He,^{3}He)^{7}H reaction. Beam of the ^{8}He with energy of ~26 *A* MeV provided by ACCULINNA-2 fragment separator interacted with the gaseous cryogenic deuterium target (6 mm thick at 27K and at 1 atm). The detector system was consisted of Si and CsI telescope detectors intended for detection of the recoil ^{3}He and ^{3}H emitted from ^{7}H decay. Compared to the previous works dedicated to ^{7}H the main advantage and novelty of the used setup was the possibility to measure the angle and energy of the emitted tritium.

Events with a coincidence of detected ^{3}He and ^{3}H was considered as candidates for ^{7}H event. The number of coincidences of the decay products allowed us to estimate the reaction cross-section. Measuring the spectra of ^{3}He under the small angles allows to reconstruct the ^{7}H missing-mass spectrum. The obtained angles and energies of ^{3}He and ^{3}H in coincidence gave a lot of informative angular correlations.

In the report we will present preliminary ^{7}H missing-mass spectrum together with estimation of detection efficiency of the ^{7}H and various angular correlations of reaction products (e.g. missing-mass spectrum with the angle of the emitted tritons). Simulations needed for data analysis has been performed within the ExpertRoot framework [1].

1. http://er.jinr.ru/

β DECAY OF ^{133}In AND ^{134}In: γ EMISSION FROM NEUTRON-UNBOUND STATES

Piersa M.[1], Korgul A.[1], Fraile L.M.[2,3], Benito J.[2], IDS Collaboration
[1] *University of Warsaw, Poland;* [2] *Universidad Complutense de Madrid, Spain;*
[3] *CERN, Switzerland*
E-mail: monika.piersa@fuw.edu.pl

The study of ^{133}Sn provides excellent conditions to investigate single-particle transitions relevant in the neutron-rich ^{132}Sn region due to the simplicity of its nuclear structure. After many experimental activities employing one-neutron transfer reactions [1–4], traditional β-decay studies are an attractive technique to refine our knowledge on ^{133}Sn. Since the positions of neutron single-particle states in ^{133}Sn were established and confirmed in many measurements [1–5], our focus moves to single-hole states expected at higher excitation energies. Because of the low neutron-separation energy of ^{133}Sn, S_n=2.4 MeV [6], all of them are supposed to be neutron-unbound. β-decay studies are therefore a natural choice to investigate their nature, since there is a large energy window for their population in the β decay of ^{133}In ($Q_β$ = 13.4(2) MeV [6]).

Our experiment was performed at the ISOLDE Decay Station, where excited states in ^{133}Sn were investigated via the β decay of ^{133}In and complemented by studies of the βn decay branch of ^{134}In. Isomer-selective ionization using the ISOLDE RILIS enabled the β decays of ^{133g}In ($I^π = 9/2^+$) and ^{133m}In ($I^π = 1/2^-$) to be studied independently for the first time. Thanks to the large spin difference of those two β-decaying states, it is possible to investigate separately the lower- and higher-spin states in the daughter ^{133}Sn and thus to probe independently different single-particle and single-hole levels. We identified new γ transitions following the ^{133}In → ^{133}Sn and ^{134}In → ^{133}Sn decays. Single-hole states in ^{133}Sn were found at energies exceeding S_n up to 3.7 MeV [7]. Due to centrifugal barrier hindering the neutron from leaving the nucleus, the contribution of electromagnetic decay of those unbound states was found to be significant.

1. K.L.Jones *et al.* // Nature (London). 2010. V.465. P.454.
2. K.L.Jones *et al.* // Phys. Rev. C. 2011. V.84. 034601.
3. J.M.Allmond *et al.* // Phys. Rev. Lett. 2014. V.112. 172701.
4. V.Vaquero *et al.* // Phys. Rev. Lett. 2017. V.118. 202502.
5. P.Hoff *et al.* // Phys. Rev. Lett. 1996. V.77. P.1020.
6. M.Wang *et al.* // Chin. Phys. C. 2017. V.41. 030003.
7. M.Piersa *et al.* // Phys. Rev. C. 2019. V.99. 024304.

GLOBAL ANALYSIS OF NUCLEAR DATA COLLECTED IN PNPI

Soroko Z.N., Sukhoruchkin S.I.
B.P. Konstantinov Petersburg Nuclear Physics Institute NRC "Kurchatov Institute" 188300
E-mail: soroko_zn@pnpi.nrcki.ru

In this work, we perform the global analysis of nuclear data collected in PNPI and published in the Landolt-Boernstein Library New Series, Springer. In the analysis of data on energies of all known nuclei, both parameters of the CODATA fine structure ($m_e/3$=170 keV=$\varepsilon_o/6$ and $m_N/8$=161 keV), which were found earlier [1] in a separate analysis were confirmed.

We use a new method of data analysis based on the selection of data for all isotopes of each element. We study the location of the grouping effect in the values of the excitation energies collected among all the isotopes of given element. In the combined E^*-distribution for Z = 40–72, the maximum at 3.072 MeV close to $3\varepsilon_o$=3.066 MeV was found. The random probability of such a grouping is less than 10^{-5}.

Another method consisted in the analysis of the combined data for isotopes of neighboring near-magic elements (nuclei with Z = 8–9–10, Z = 20, 22 etc.). The grouping effect in the values of the excitation energies of different isotopes of a certain element, which was considered earlier, was the first step. The second step was based on the observation of the similarity in the excitations in several near-magic nuclei. For example, it was noticed long ago, that the first excitations of ^{18}O and ^{24}Ne, namely, $E_1^*(2^+)$=1982.1(1) keV and $E_1^*(2^+)$=1981.6(4) keV are unexpectedly close to each other.

Now we have found that the grouping effect in the sum of ordinary D-distributions in neighboring elements Z = 8, 9, 10 at the first excitations of ^{18}O and ^{24}Ne at D = 1982 keV (161 intervals with a deviation of 2.4σ over the mean value) can be compared with a maximum at the same value in a similar analysis of the combined spectrum of the same three elements (n = 546 + 804 + 701 = 2051, for Z = 8, 9, 10). The mean value $n \approx 1200$ in the combined spectrum of all 55 isotopes of these three elements is much larger than the mean value n = 126 (the sum of the results of a separate analysis), but the effect of about 160 values (over the mean level, in the combined analysis) is much greater than the effect of 35 values, obtained during the routine analysis of individual data. To explain this effect, we use the Adjacent Interval Method of data analysis [2].

1. S.I.Sukhoruchkin // Nucl. Part. Phys. Proc. 2018. V.300-302. P.75.
2. S.I.Sukhoruchkin // Discreteness in particle masses and parameters of the Standard Model. Lambert Ac. Publ., 2017.

THE PROPERTIES OF ^{12}C STATES AT HIGH EXCITATION ENERGIES

Starastsin V.I.[1], Demyanova A.S.[1], Danilov A.N.[1], Ogloblin A.A.[1], Dmitriev S.V.[1], Sergeev V.M.[1], Maslov V.A.[2], Sobolev Yu.G.[2], Goncharov S.A.[3], Trzaska W.H.[4], Heikkinen P.[4], Gurov Yu.B.[5], Belyaeva T.L.[6], Burtebayev N.[7]

[1] National Research Centre Kurchatov Institute, Moscow, 123182, Russia; [2] JINR, Dubna, Moscow Region, 141700, Russia; [3] Moscow State University, Moscow, 119992 Russia; [4] JYFL, Department of Physics, University of Jyvskyl, FI-40014 Jyvskyl, Finland; [5] MEPHI, Moscow, 115409, Russia; [6] Universidad Autonoma del Estado de Mexico, 50000, Mexico; [7] Nuclear Physics Institute, Almaty, 050032, Kazakhstan

E-mail: starastsinvi@ya.ru

The experiment was done on K-130 cyclotron in Jyväskylä (Finland) to study ^{11}B(^{3}He,d)^{12}C reaction with energy $E(^{3}\mathrm{He}) = 25$ MeV. The aim of the experiment was to determine the properties of high-lying excited state of ^{12}C: 1) to verify the spin-parity value of the 13.35 MeV state (2^- [1–3] or 4^- [4–5]); 2) to search for states with large spin (5^- or 6^+) around the excitation energy 20 MeV and check if they belong to rotational bands.

From our experimental data spin-parity of the 13.35 state was confirmed to be 4^-.

In [6] new 22.4 (5^-, $T = 1$) MeV state was observed and an assumption was made that it is a member of proposed negative parity branch (9.64 (3^-) – 13.35 (4^-)) of g.s. rotational band (g.s. (0^+) – 4.44 MeV (2^+) – 14.08 MeV (4^+)). However, there are facts which contradict this prediction: 1) all states except 22.4 MeV have isospin $T = 0$; 2) in [7] was shown that 9.64 MeV state has an increased radius while all other members have normal radii.

In our experiment we observed the state at 22.4 MeV. Coupled-channel analysis of angular distribution for this state showed the following variants of spin-parity: 5^- with probability of 30% and 6^+ with probability of 70%. The question remains whether we can assume that the state of 22.4 MeV is the next member of the Hoyle band: 7.65 (0^+) – 9.9 (2^+) – 13.75 (4^+).

1. F.Ajzenberg-Selove // Nucl. Phys. A. 1990. V.506. P.1.
2. G.M.Reynolds *et al*. // Phys. Rev. C. 1971. V.3. P.442.
3. P.K.Bindal *et al*. // Phys. Rev. C. 1974. V.9. P.2154.
4. M.Freer *et al*. // Phys. Rev. Lett. 2014. V.113. 012502.
5. O.S.Kirsebom *et al*. // Phys. Rev. C. 2010. V.81. 064313.
6. M.Freer *et al*. // Phys. Rev. Lett. 2014. V.113. 012502.
7. A.S.Demyanova *et al.* // Int. J. Mod. Phys. E. 2008. V.17. P.2118.

THE ^{157}Yb DECAY

Vaganov Yu.A., Kalinnikov V.G., Stegailov V.I., Sushkov A.V., Shirikova N.Yu.
Joint Institute for Nuclear Research, Joliot-Curie 6, Dubna, Moscow region, Russia, 141980
E-mail: stegajlov2013@yandex.ru

The investigations of the nuclei characteristics in the transition area ($N = 88$; $Z = 67$, 68) in the odd-odd nuclei ^{156}Ho, ^{158}Ho, ^{160}Ho have been accomplished and the detailed research of the transition area: ^{158}Tm, ^{160}Tm, ^{162}Tm has been begun in the program of studies.

The comprehension of odd-odd nuclei's characteristics and structures may be of great importance about the characteristics and structures lying near odd/even and odd/odd nuclei. The characteristics of odd/even nucleus ^{157}Tm (a decay of ^{157}Yb, ^{157}Tm) together with ^{157}Er could be perceived as a basis to ^{158}Tm and it is suggested to be discussed at this moment.

The decay scheme ^{157}Yb $\rightarrow$ ^{157}Tm has been justified by the results of γ-γ-coincidence measurements. Based on the measurements of the spectra of electron conversion, at the decay of ^{157}Yb, we have determined internal conversion rate for number of transitions and the characteristics of I^{π} for some of the excited states (105.7 keV, $I^{\pi} = 3/2^{+}$; 164.7 keV, $I^{\pi} = 3/2^{-}$; 231.1 keV, $I^{\pi} = 3/2^{+}$; 347.8 keV, $I^{\pi} = 5/2^{+}$; 353.9 keV, $I^{\pi} = 5/2^{-}$), and also the characteristics I^{π} of the isomeric state 35.3 keV. This state is popular with γ-transition 129.3 keV of the type E2 from the level of 164.5 keV, from this level also follows the E1-transition in the ground state of ^{157}Tm ($1/2^{-}$). Therefore, probably, the isomer has the characteristics as it follows: $I^{\pi} = 7/2^{-}$.

1. V.I.Stegailov *et al*. // Abstr. of conf. on Nuclear Physics "Nucleus 1994" St.-Pb., 1994. P.66.

THE BREAKING THRESHOLDS OF THE COOPER PAIRS OF NUCLEONS IN THE ^{162,164}Dy NUCLEI

Sukhovoj A.M., Mitsyna L.V., Vu D.C.
Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Research, Dubna, Russia
E-mail: suchovoj@nf.jinr.ru

The intensity spectra of the two-step γ-quanta cascades in the ^{162,164}Dy nuclei measured [1] using the high-segmented 4π-calorimeter of γ-rays [2], in the energy interval below the neutron binding energy, were analyzed by our method proposed in [3]. In the framework of generally accepted statistical model of the nucleus, the authors of [1] cannot satisfactorily describe their measured spectra of intensities. Our method with the use of maximum-likelihood procedure allowed us to do this with a percent accuracy. At that, a strongest anti-correlation between the nuclear level density and the partial radiative widths was taken into account in our analysis, necessity of which follows from the developed models of the process of fragmentation of the excited nuclear levels [4].

For ^{162,164}Dy nuclei, in the range of the neutron binding energy, as for more than 40 nuclei investigated by us earlier [5], in the dependences of the level density on their excitation energy there are several (3–4) breaks. As a logarithm of the level density is proportional to the nuclear entropy, these breaks have simple explanation that they are just points of breaking of the Cooper pairs of nucleons in the excited nucleus.

The breaking thresholds of the second and the third Cooper pairs obtained analyzing the experimental data from [1] in comparison with the results for ^{164}Dy nucleus, which was investigated by us earlier, with a capture of neutrons in the heat spot, are shown in the Table. For the data from [1] the breaking thresholds of the second and the third Cooper pairs are presented both for neutron resonances with a spin $J = 2$ and for $J = 3$.

Table. The obtained breaking thresholds of Cooper pairs of nucleons.

Nucleus	The breaking thresholds, MeV			
	of the second Cooper pair		of the third Cooper pairs	
	for $J = 2$	for $J = 3$	for $J = 2$	for $J = 3$
^{162}Dy from [1]	4.33(14)	4.56(7)	6.54(33)	6.35(20)
^{164}Dy from [1]	2.77(4)	2.83(6)	6.47(23)	6.78(3)
^{164}Dy from [5]	2.57(1)		5.48(5)	

1. S.Valenta *et al*. // Phys. Rev. C. 2008. V.96. 064307.
2. R.Reifarth *et al*. // Nucl. Instrum. Methods A. 2004. V.531. P.530.
3. A.M.Sukhovoj *et al*. // Phys.Atom. Nucl. 2016. V.79. №3. P.313.
4. L.A.Malov, V.G.Solov'ev // Sov. J. Nucl. Phys. 1977. V.26. P.384.
5. .D.C.Vu *et al*. // Phys.Atom. Nucl. 2017. V.80. №2. P.237.

SPONTANEOUS FISSION OF ^{254,256}Rf AND ^{250}No – NEW EXPERIMENTAL DATA

Svirikhin A.I.[1], Andreev A.V.[1], Yeremin A.V.[1], Izosimov I.N.[1], Isaev A.V.[1], Kuznetsov A.N.[1], Kuznetsova A.A.[1], Malyshev O.N.[1], Popeko A.G.[1], Popov Yu.A.[1], Sokol E.A.[1], Chelnokov M.L.[1], Chepigin V.I.[1], Schneidman T.M.[1], Andel B.[2], Mosat P.[2], Kalaninova Z.[2], Asfari M.Z.[3], Gall B.[3], Dorvaux O.[3], Brione P.[3], Yoshihiro N.[4], Mullins S.[5], Jones P.[5], Piot J.[6], Stefanova E.[7], Tonev D.[7], Hauschild K.[8], Lopez-Martens A.[8], Rezynkina K.[8]

[1] Joint Institute for Nuclear Research, Dubna, Russia; [2] Comenius University, Bratislava, Slovakia; [3] IPHC, IN2P3-CNRS, Strasbourg, France; [4] Kyushu University, Fukuoka, Japan; [5] iThemba LABS, Cape Town, South Africa; [6] GANIL, Caen, France; [7] INRNE, Sofia, Bulgaria; [8] CSNSM, IN2P3-CNRS, Orsay, France

E-mail: asvirikhin@jinr.ru

In the last years we carried out several experiments aimed to investigate properties of short-lived SF isotopes.

The neutron-deficient isotopes ^{254,256}Rf were produced in fusion-evaporation reactions using an enriched lead targets and an intense ^{50}Ti beam. Fusion-evaporation residues were separated by the SHELS separator (FLNR, Dubna) and implanted into a large-area double-sided silicon 48x48 strip detector surrounded by ^{3}He-based neutron counters. The half-life, decay branching ratio and average number of neutrons per spontaneous fission ^{254,256}Rf is measured.

Next we carried out an experiment aimed at investigating the properties of spontaneous fission of neutron deficient isotope ^{250}No produced in the reaction with ^{48}Ca-beam and ^{204}Pb-target. Earlier two spontaneous fission half-lives ($t_{1/2} \approx 4$ and $t_{1/2} \approx 40$ μs) originate from ^{250}No were registered. The obtained excitation functions after the evaporation of 2 neutrons from the compound ^{252}No nuclei have been compared with similar data obtained earlier. From the experimental data for the first time the average number of neutrons per spontaneous fission and TKE-spectra of fission fragments of both ^{250}No activities was determined.

EXAMINATION OF BETA-DELAYED NEUTRON EMISSION PHENOMENA IN VERY NEUTRON RICH ISOTOPES

Testov D.[1], Verney D.[2], Penionzhkevich Yu.E.[1], Boso A.[3], Delafosse C.[4], Didierjean F.[5], Ibrahim F.[6], Lukyanov S.M.[1], Maslov V.A.[1], Matea I.[2], Roussière B.[3], Severyukhin A.P.[1], Sobolev Yu.G.[1], Smirnov V.[1].
[1] Joint Institute for Nuclear Research, Dubna, Moscow region, Russia; [2] Institut de Physique Nuclèaire, IN2P3/CNRS and University Paris Sud, Orsay, France; [3] National Physical Laboratory, Teddington, Middlesex; [4] UK; University of Jyväskylä, Jyväskylä, Finland; [5] Universitè de Strasbourg, CNRS, Strasbourg, France
E-mail: dumon@jinr.com

Nowadays availability of neutron-rich beams has arisen interest to the phenomena of beta-delayed (multi-neutron) neutron emission. The interest is triggered by importance of nuclear data for astrophysical r-process calculations [1]. Beta-delayed neutron emission represents an additional source of neutrons which favours neutron captures shifting thus abundance peaks towards heavier masses. In many cases when the experimental data is not available these parameters are obtained using different theoretical approaches. This model looks simple only from the first sight. In practice the information on neutron emitter states and their configuration is very scarce. Thus, for a long time a competition between neutron and gamma emission from such states was neglected – the assumption which is known not to be correct. The most recent experimental confirmation of gamma/neutron competition in beta-decay of neutron-rich nuclei was proposed in *A.Gottardo PRL 116, 182501 (2016)* by observation of high-energy gamma-rays. From another side, contribution of forbidden decays is expected to be stronger crossing the major neutron shells which influences beta-decay properties. In contrast, it was shown that in nuclei located at $N+1$, $N+2$, $N+3$ probability of beta delayed neutron emission oscillates as a function of the neutron number. Finally, the multi-neutron emission process after beta decay is even less understood. In the region of medium and heavy nuclei it was observed only for a few nuclei. As the energy available in beta-decay increases together with a drop in neutron separation energy, it may lead to an enhancement of multi-neutron emission – the fact which has not (yet) confirmed. Therefore, to answer the questions above, neutron-rich nuclei in the vicinity of $N=50$ and 82 were produced and studied at ALTO ISOL facility. The beta-decay station equipped with a powerful long neutron-counter TETRA [3] allowed to detect beta, gamma and neutron activity following beta decay of In. It will be presented the experimental details and the preliminary results.

1. Yu.E.Penionzhkevich // JINR NEWS. 2017. V.4. P.17.
2. D.Verney *et al*. // Phys. Rev. C. 2017. V.95. 054320.
3. D.Testov *et al*. // Nucl. Inst. Meth. A. 2016. V.815. P.96.

RECOIL FORCE FROM NEUTRINO RADIATION IN ELECTRON-CAPTURE DECAY AS A PROBE OF LORENTZ INVARIANCE, NUCLEAR AND ATOMIC STRUCTURE

Barabanov A.L., Titov O.A.
National Research Center "Kurchatov Institute", Moscow, Russia
E-mail: titov_oa@nrcki.ru

We consider the possibility to measure the recoil force from neutrino radiation acting on a sample of radioactive atoms with electron-capturing nuclei. This force is determined by angular distribution of emitted neutrinos. Since the weak interaction violates parity, the angular distribution is asymmetric if the decaying nuclei are polarized [1], and one can observe non-zero recoil force.

An estimate for this force was made in Ref. [2]. The force turned out to be comparable with small forces measured by modern atomic force microscopes. The possibility to measure the neutrino mass was considered in Ref. [3]. The authors of Refs. [2, 3] considered only the case of pure Gamow–Teller nuclear transition with nuclear spin decreasing by one; the asymmetry of neutrino emission was not considered properly.

We derive an expression for the neutrino recoil force for the general case of allowed nuclear transitions taking into account the angular distribution of neutrinos, emitted in electron capture by polarized nuclei. Numerical estimates for recoil forces are given for electron-capturing isotopes.

The possibility to observe the neutrino recoil force by means of modern micromechanical devices (cantilevers) is considered. In the approach considered in Refs. [2, 3], the displacement of the cantilever is measured, and the force is determined from Hooke's law. We propose to modify this approach and measure the force resonantly using methods of magnetic resonance force. This allows to reduce the required mass of the radioactive source significantly (by 5 orders of magnitude for Sb-119, for instance).

We show that neutrino recoil force measurement can be applied to test fundamental symmetries. For example, Lorentz invariance violation may lead to additional contributions in neutrino angular distribution [4] and modify the recoil force. Another application is probing nuclear matrix elements ratio for mixed Fermi and Gamow-Teller nuclear transitions. One can also determine the probabilities of electron capture from different atomic shells.

1. S.B.Treiman // Phys. Rev. 1958. V.110. P.448.
2. C.DeAngelis, L.M.Folan, V.I.Tsifrinovich // Phys. Rev. C. 2012. V.86. 034615.
3. L.M.Folan, V.I.Tsifrinovich // Mod. Phys. Lett. A. 2014. V.29. P.1430042.
4. K.K.Vos, H.W.Wilschut, R.G.E.Timmermans // Phys. Rev. C. 2015. V.91. 038501.

ANALYSIS OF EXPERIMENTAL DATA ^{158,160}Gd WITHIN THE FRAMEWORK PHENOMENOLOGICAL MODEL

Usmanov P.N.[1], Vdovin A.I.[2], Yusupov E.K.[1]
[1] *Namangan Engineering- Technology Institute, Namangan, Uzbekistan;* [2] *Joint Institute for Nuclear Research, Dubna, Russia*
E-mail: usmanov1956.56@mail.ru

A theoretical analysis of the states of positive parity of $^{158.160}$Gd isotopes has been carried out. The calculation was performed in the framework of the phenomenological model [1, 2], which takes into account the mixing of the states of low-lying rotational bands. The energy spectrum is described and the wave functions are determined. The quadrupole and monopole electric and dipole magnetic transitions between the states of rotational bands are calculated. The values of the multipole mixing coefficients are estimated δ. The nonadiabaticities exhibited in electromagnetic transitions and the behavior of transitions are $X_I = B(\mathrm{E0}; I_K^+ \to I_{gr}^+)/B(\mathrm{E2}; I_K^+ \to I_{gr}^+)$ between levels of nonzero spin discussed. The table shows the calculated values of the magnetic moments of the states of the ground rotational band for $^{158.160}$Gd, which are compared with experimental data.

Magnetic moments $\mu_{gr}(I)$ states of the ground rotational band.

I	^{158}Gd		^{160}Gd	
	exp.[3,5]	theor.	exp.[4,5]	theor.
2	0.84(20)	0.84	0.72(4)	0.72
4	1.55(13)	1.66	1.52(20)	1.44
6	2.28(30)	2.50	2.30(30)	2.16
8	-	3.33	-	2.88
10	-	4.16	3.40(50)	3.60
12	-	4.99	-	4.31

1. P.N.Usmanov and I.N.Mikhailov // Fiz. Elem. Chastits At. Yadra. 1997. V.28. P.887.
2. P.N.Usmanov, A.A.Okhunov, U.S.Salikhbaev, A.I.Vdovin // Phys. of Part. Nucl. Letters. 2010. V.7. No.3. P.185.
3. G.Helmer // Nucl.Data Sheets. 1996. V.77. P.481.
4. W.Reich // Nucl.Data Sheets. 2005. V.105. P.555.
5. E.Stuchbery, A.G.White, G.D.Dracoulis, *et al*. // Z. Phys. A – Hadrons and Nuclei. 1991. V.338. P.135.

THE HEAVIEST NUCLEI ^{294}Ts AND ^{294}Og: EXPERIMENTAL STUDY AND PERSPECTIVES

Voinov A.A.[1], Utyonkov V.K.[1], Oganessian Yu.Ts.[1], Rykaczewski K.P.[2], Brewer N.T.[2,3,4], Abdullin F.Sh.[1], Boll R.A.[2], Dean D.J.[2], Dmitriev S.N.[1], Ezold J.G.[2], Felker L.K.[2], Grzywacz R.K.[2,4], Itkis M.G.[1], Kovrizhnykh N.D.[1], McInturff D.C.[2], Miernik K.[3,5], Owen G.D.[2], Polyakov A.N.[1], Popeko A.G.[1], Roberto J.B.[3], Sabelnikov A.V.[1], Sagaidak R.N.[1], Shirokovsky I.V.[1], Shumeiko M.V.[1], Sims N.J.[2], Smith E.H.[2], Subbotin V.G.[1], Sukhov A.M.[1], Svirikhin A.I.[1], Tsyganov Yu.S.[1], Van Cleve S.M.[3], Vostokin G.K.[1], White C.S.[2], Hamilton J.H.[6], Stoyer M.A.[7]

[1] FLNR, JINR, Dubna 141980, Russian Federation; [2] ORNL, Oak Ridge, TN 37831, USA; [3] JINPA, ORNL, Oak Ridge, TN 37831, USA; [4] Dep. of Phys. and Astron., UT, Knoxville, TN 37996, USA; [5] Faculty of Physics, UW, Warsaw, Poland; [6] Dep. of Phys. and Astron., VU, Nashville, TN 37235, USA; [7] Nucl. and Chem. Sci. Division, LLNL, Livermore, CA 94551, USA

E-mail: voinov@jinr.ru

More than 50 new inhabitants of the predicted "Island of stability" of the superheavy elements have been observed in the experiments using accelerated ^{48}Ca ions and targets ranging from ^{235}U to ^{251}Cf. The determined decay properties of all the observed isotopes indicate increase of their life-times with approach to the hypothetic closed neutron shell $N = 184$ [1]. However, the heaviest nuclei synthesized by now, ^{294}Ts ($Z = 117$) and ^{294}Og ($Z = 118$), have 177 and 176 neutrons [2, 3] and are still 7 and 8 neutrons apart from $N = 184$.

This work reviews experimental studies that have been performed employing the DGFRS (JINR, Dubna) and resulted in production of the heaviest ^{294}Ts and ^{294}Og in the most recent experiments. Future possibilities of synthesizing new nuclides in the region of SHEs with higher Z (119 and 120), as well as of more neutron-rich isotopes of Lv, Ts, and Og nuclei are discussed.

1. Yu.Ts.Oganessian and V.K.Utyonkov // Nucl. Phys. A. 2015. V.944. P.62.
2. Yu.Ts.Oganessian *et al.* // Phys. Rev. Lett. 2012. V.109. P.162501.
3. N.T.Brewer *et al*. // Phys. Rev. C. 2018. V.98. P.024317.

STUDY OF ^{6}He – *d* REACTIONS AT THE ACCULINNA-2 SEPARATOR

Zalewski B.[1,2], Belogurov S.G.[1,3], Bezbakh A.A.[1,4,] Chudoba V.[1,5], Fomichev A.S.[1,6], Gazeeva E.M.[1,6], Golovkov M.S.[1,6], Gorshkov A.V.[1,4], Kaminski G.[1,2], Krupko S.A.[1,4], Mauyey B.[1,7,8], Muzalevskii I.A.[1,5,6], Napiorkowski P.[2], Nikolskii E.Yu.[1,9], Piątek W.[2], Pluciński P.[2], Rusek K.[2], Serikov A.[1,6], Sidorchuk S.I.[1], Slepnev R.S.[1], Sharov P.G.[1,4], Sokołowska N.[10], Ter-Akopian G.M.[1,6], Trzcińska A.[2], Wolski R.[1,11]

[1] Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia; [2] Heavy Ion Laboratory, University of Warsaw, Warsaw, Poland; [3] National Research Nuclear University, MEPhI, Russia; [4] SSC RF ITEP of NRC "Kurchatov Institute", Russia; [5] Institute of Physics, Silesian University in Opava, Czech Republic; [6] Dubna State University, Russia; [7] Institute of Nuclear Physics, Kazakhstan; [8] L.N. Gumilyov Eurasian National University, Kazakhstan; [9] National Research Center "Kurchatov Institute", Russia; [10] Faculty of Physics, University of Warsaw, Poland; [11] Institute of Nuclear Physics PAN, Poland

E-mail: zalewski@slcj.uw.edu.pl

Measurement of reactions of ^{6}He with deuterium target was performed in inverse kinematics at the beam energy of 160 MeV. The measurement was performed at the ACCULINNA-2 fragment separator, Joint Institute for Nuclear Research, Russia using ^{6}He beam delivered by U400M cyclotron. Both energies and angles of the ejectiles were detected in a range from 30 to 80 degrees in the laboratory frame. Preliminary data analysis of elastic scattering in terms of optical model will be presented.

THE EFFECT OF PAIRING CORRELATIONS AND DEFORMATION IN FLAT SUPERDEFORMED BANDS

Dadwal A., Mittal H.M.
Dr. B. R. Ambedkar National Institute of Technology, Jalandhar 144011, India
E-mail: dadwal.anshul@gmail.com

A systematic study of flat superdeformed bands (SD) in the Tl and Pb isotopes is done using the shape fluctuation (SF) model [1]. The intraband gamma-transition energies of the SD bands are split into the rotational and shape fluctuation energy. Two trends are observed in the SD bands of the Tl and Pb isotopes: **I:** SD bands, which follow the shape fluctuation (SF), curve of the yrast SD band ^{196}Pb; **II:** The SD bands, which do not follow the SF curve of the yrast SD band ^{196}Pb and have nearly constant dynamic MoI (known as flat SD bands). The variation of the SF energy reveal that they have maximum contribution from the rotational energy term. These results are further supported by the calculation of negligible value of the vibrational distortion factor $\mathfrak{J}^{(2)}_{vib}$ [2]. The vibrational distortion parameter describe the magnitude of deviation from the perfect rigid rotor behavior, implying that smaller the magnitude of $\mathfrak{J}^{(2)}_{vib}$ the SD band, more closer it is to the *perfect rigid rotor*.

The similar systematics of the flat SD bands have been obtained for pairing correlations. A negligible value effective pairing parameter Δ_0 and pairing energy (E_{pair}) is obtained using the exponential model of pairing attenuation [3] and calculation using Woods-Saxon potential (see Fig. 1), respectively.

Considering these evidences, it seems that the flat SD bands have minimal shape fluctuation energy and effective pairing parameter, and higher deformation. These observations provide support to the "super rigid" structure of the flat SD bands.

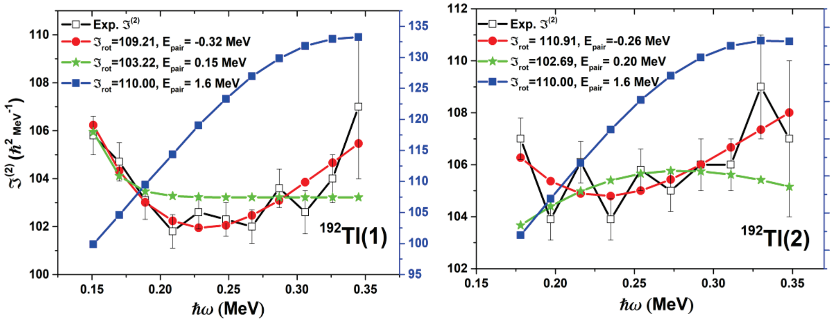


Fig. 1. The comparison of the calculated and experimental dynamic MoI using different values of pairing energy in flat SD bands ^{192}Tl(1, 2).

1. M.Sathpathy and L.Sathpathy // Phys. Lett. B. 1971. V.34. P.377.
2. S.Roy // Phys. Rev. C. 2016. V.94. P.064329.
3. A.Dadwal and H.M.Mittal // J. Phys. G: Nucl. Part. Phys. 2018. V.45. P.065103.

MECHANISMS OF FORMATION OF MODULATION EFFECTS IN ELASTIC DIFFRACTION SCATTERING OF CHARGED PARTICLES

Dyachkov V.V.[1], Dusebayeva K.S.[2], Zaripova Yu.A.[1], Yushkov A.V.[1]
[1] National Nanotechnology Laboratory of Open Type, Almaty, Kazakhstan; [2] Kazakh National University named al-Farabi, Almaty, Kazakhstan
E-mail: slava_kpss@mail.ru

One of the methods of experimental detection of a multi-cluster structure is the decomposition of experimental angular distributions of differential cross sections for elastic diffraction scattering into multi-cluster components. Within the framework of the diffraction theory and under the assumption of total absorption inside the sphere of interaction, the authors obtained a decomposition of the total amplitude into several multi-cluster modes [1], and for the first time measurements of nuclear clustering by two direct methods on medium-energy alpha particle beams [2] were performed.

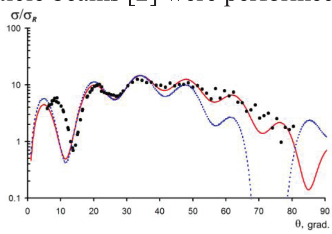


Fig. 1. The angular distribution of elastic scattering $^9Be(\alpha,\alpha)^9Be$ E_α=104 MeV.

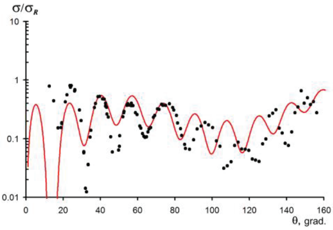


Fig. 2. The angular distribution of elastic scattering $^{20}Ne(\alpha,\alpha)^{20}Ne$ E_α=33 MeV.

This paper describes experimental data in the framework of the theory of diffraction scattering as a superposition of wave functions on an absolutely black core and on absolutely black substructures. Figure 1 shows the fit of the full wave function consisting of two modes (dashed curve) and three modes (solid curve). The first mode is responsible for scattering on the nucleus as a whole, the second on nuclear alpha-clusters, the third on nucleons. It can be seen that for the ^{9}Be in the forward hemisphere there is a sufficient divergence, since an unpaired neutron makes a significant contribution to the cross section. Figure 2 shows the characteristic lift at the rear angles. The phenomenon of uneven lifting in the angular distributions of differential cross sections and a rise under the rear angles during elastic diffraction scattering of charged particles, obviously, occurs due to the scattering mechanism on cluster configurations without recoil.

1. V.V.Dyachkov, K.S.Dyussebayeva, M.M.Akhmetzhanova Modulation of angular distributions of scattered alpha particles by multicluster nuclei // 68 International Conference "NUCLEUS-2018", Voronezh, 2018. Book of abstracts. P.60.
2. Yu.A.Zaripova, V.V.Dyachkov, A.V.Yushkov, T.K.Zholdybayev, D.K.Gridnev. Direct experimental detection of spatially localized clusters in nuclei on alpha-particle beams // International Journal of Modern Physics E. 2018. V.27 (2). 18500171.

TEST FOR VALIDITY OF ROTATIONAL ENERGY FORMULAE FOR SD BANDS IN *A* ~ 190 MASS REGION

Karday M., Dadwal A., Mittal H.M.
Dr. B. R. Ambedkar National Institute of Technology, Jalandhar, Punjab-144011, India
E-mail: mittalhm@nit.ac.in

The rotational energy formulae/model viz. *ab*-formula, variable moment of inertia (VMI) model, Harris ω^2 expansion, nuclear softness (NS) formula, exponential model with pairing attenuation and modified exponential model with pairing attenuation are employed to the superdeformed bands (SD) in $A \sim 190$ mass region. These formulae/models are used to calculate the band head spins of the superdeformed bands ^{194}Hg(1,3), ^{193}Tl(1,2), ^{192}Pb(1), ^{194}Pb(1), ^{196}Pb(1,2,3) and a comparison with their experimentally observed values of spins is made. The least squares fitting [1,2] of γ-ray transition energies is performed to calculate the model parameters viz. the band head moment of inertia, the effective pairing gap parameter and the softness parameter. The dynamic moment of inertia is also calculated and its variation with rotational frequency is investigated. A comparison of these formulae/models suggests that VMI model fails to make an accurate determination of the spins of the superdeformed bands in $A \sim 190$ mass region. However, NS formula and exponential model with pairing attenuation proved to be powerful approaches in the spin determination of the superdeformed bands in $A \sim 190$ mass region.

[1] C.S.Wu *et al.* // Phys. Rev. C. 1992. V.45. P.1.
[2] A.Dadwal and H.M.Mittal // Eur. Phys. J. A. 2017. V.53. P.132.

STRUCTURE AND TOTAL STRENGTH OF THE MAGNETIC DIPOLE RESONANCE ON EXCITED STATES IN ^{22}Na NUCLEI

Kachan A.S., Kurhuz I.V., Utenkov S.N.
Institute of High Energy Physics and Nuclear Physics, NSC KIPT NAS of Ukraine, Kharkov, Ukraine
E-mail: kachan@kipt.kharkov.ua

The γ decay of the resonance-like structure (RLS) observed in the reaction of radiation capture of protons by ^{21}Ne nuclei in the energy range of accelerated protons of 0.8–3.0 MeV was studied. The measurements were performed on the ESU-5 accelerator at the NSC KIPT. The distribution of magnetic dipole γ transitions on the ground and excited states of the ^{22}Na nucleus is obtained. The obtained discrete distributions of the M1 transitions have a resonant character. The magnetic dipole resonance (MDR) on the ground and excited states of the ^{22}Na nucleus was identified. The RLS observed by us has a complex structure, i.e. consists of the states belonging to both the M1 resonance on the ground state and the M1 resonance built on the excited states. The position of the center of gravity (CG) and the value of the total MDR strength on the ground and excited states in the ^{22}Na nucleus are determined. E_{cg} on the state 0.657 MeV is obtained equal to 7.96 MeV; E_{cg}. on the state of 0.89 MeV obtained equal to 7.61 MeV; E_{cg} at the state 1.528 MeV obtained equal to 7.84 MeV; E_{cg} on the state of 1.936 MeV obtained equal to 7.51 MeV; E_{cg} on the state of 1.951 MeV obtained equal to 7.91 MeV.

From the data obtained it follows that the position of the MDR CG on the first excited state practically coincides with that predicted by the Brink-Axel hypothesis. With an increase in the energy of the excited state, on which the M1 resonance is built, the deviation of the position of the MDR CG begins to differ from that predicted by the Brink – Axel hypothesis. The value of the total MDR strength on the ground state for the ^{22}Na nucleus corresponds to the behavior of that for the *sd*-shell nuclei, derived from the Kurat sum rule in the framework of the single-particle shell model [1]. The total MDR strength on the excited states is close to the value of the total strength on the ground state for the ^{22}Na nucleus, and significantly less than that of the ^{23}Na nucleus [2], which may indicate the influence of the valence np pair on the formation of the MDR in the excited states as well as for the ground state [1].

1. A.S.Kachan *et al*. // Yad. Fiz. 1989. V.49. P.367.
2. A.S.Kachan *et al.* // Bull. Russ. Acad. Sci. Phys. 2011. V.75. P.217.

LIFETIMES OF QUASI-PARTICLE BANDS IN ^{129}Cs

Lamani U.[1], Das P.[1], Bhujang B.[1], Pasi V.[1], Palit R.[2]
[1] Department of Physics, Indian Institute of Technology Bombay, Powai, Mumbai, India;
[2] Department of Nuclear and Atomic Physics, TIFR, Mumbai, India
E-mail: pragya@phy.iitb.ac.in

Measurement of lifetimes of nuclear states constitutes an indispensable probe into the microscopic structure of nuclei. Sihotra *et al.* [1] developed many quasi-particle bands in ^{129}Cs, and Wang *et al.* [2] measured the lifetimes of states in picoseconds using Doppler shift attenuation method (DSAM). With the same technique but using a single target – instead of two different materials (target and backing [2]) – we obtained many new results on lifetime.

We produced ^{129}Cs through the reaction ^{124}Sn(^{11}B, 6*n*)^{129}Cs using ^{11}B beam at energy 70 MeV from the Pelletron-Linac accelerator at Tata Institute of Fundamental Research (TIFR), Mumbai, India. The experimental set-up consisted of 21 Compton suppressed HPGe clover detectors. The triple coincidence data were collected in list mode. Fig. 1 presents the right- and left-side Doppler shifts of a γ-transition in the forward (23°) and backward (157°) detectors, respectively, in comparison to the Gaussian peak at 90° detectors.

The lifetimes were found by observing the lineshape profile of the decaying γ-transition and fitting using the software by J. C. Wells [3]. We needed various parameters – side-feeding lifetime and its intensity, dynamic moment of inertia and branching ratio – to obtain an accurate value of the lifetime. A rotational cascade side-feeding model of five transitions was assumed. The software COMPA [4] gave an estimate of the side-feeding lifetime, while its intensity and branching ratios were obtained from the experimental decay scheme. Table 1 lists the newly found lifetimes. Calculations using particle-rotor model and total Routhian surface are being carried out.

Table 1.

Energy (keV)	Spin	Mean lifetime (ps)	Band (in ref [1])
1014.1	$43/2^-$	1.28	B6
957.7	$39/2^-$	1.03	B6
917.7	$35/2^-$	0.83	B6
707.1	$31/2^+$	2.07	B4
459.4	$11/2^+$	1.12#	B4

Error in lifetime value is within 20%. #Tentative value.

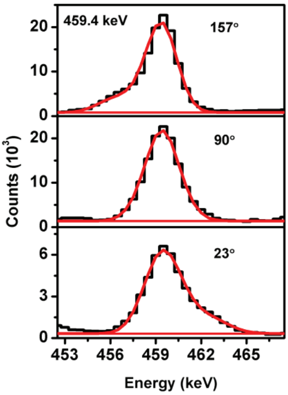


Fig. 1. Typical lineshape profiles with forward and backward Doppler shifts in 23° and 157° detectors, respectively.

1. S.Sihotra *et al.* // Phys. Rev. C. 2009. V.79. 044317.
2. WANG Lie-Lin *et al.* // Chin. Phys. Lett. 2010. V.27. No.2. 022101.
3. J.C.Wells and N.R.Johnson // ORNL report 1991. 6689. P.44.
4. J.Srebny *et al.* // Nucl. Phys. A. 2001. V.683. P.21.

NUCLEAR_REFS_MANAGER PROGRAM PACKAGE

Shuliak G.I., Rodionov A.A.
Petersburg Nuclear Physics Institute named by B.P.Konstantinov of NRC "Kurchatov Institute"
E-mail: rodionov_aa@_pnpi.nrcki.ru; 0z@rambler.ru

The program package Nuclear_refs_manager is proposed [1]. This is the manager of references to publications in nuclear physics. It may be used as a librarian program for the systematization of large collections of nuclear and other scientific publications. The package is proposed for specialists in nuclear physics and other scientists for the maintaining the collections of publications which contain articles, abstracts, private communications, etc. The manager uses keywords (keynums) system which satisfies to the format of the bibliographic database of Brookhaven National Laboratory [2]. Keynums may be put into the correspondence to files with articles, abstracts, URLs and other information. Publications which haven't keynums may be included into the user's library also. The manager allows to find an article in the user's collection, to read information about a given publication and to read the publication itself, using external plugins (readers) installed in the operational system. Nuclear_refs_manager supports a grouping which may be organised for journals, years of publication, authors, user's themes, etc. The search is realised for journals, year of publication, authors, keywords and keynums, words in abstracts, etc.

The Nuclear_refs_manager program package is written in C language and works under operational systems Linux (X Window), and MS Windows. The program package is developed under the GNU 2.0 license and maybe downloaded from the site http://georg.pnpi.spb.ru/russian/progs/ or https://www-nds.iaea.org/public/ensdf_pgm/. Package is distributed both in executable codes and source texts. All remarks and proposals will be accepted gratefully.

Authors are grateful to the IAEA NDS staff for the organization of the Technical Meeting on "Improvement of Codes for Nuclear Structure and Decay Data Evaluations". Personal thanks to Paraskevi (Vivian) Dimitriou and Viktor Zerkin.

1. G.I.Shuliak, A.A.Rodionov; Certificate RF №2016612088 of State registration of program Nuclear_refs_manager.
2. http://www.nndc.bnl.gov/nndcscr/documents/ensdf/nsr.pdf

PREDICTIONS OF α-DECAY ENERGIES AND HALF-LIVES FOR SUPERHEAVY NUCLIDES

Simonov M.V.[1], Ishkhanov B.S.[1,2], Tretyakova T.Yu.[2], Vladimirova E.V.[1]
[1] *Faculty of Physics, Lomonosov Moscow State University, Moscow, Russia;* [2] *Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia*
E-mail: tretyakova@sinp.msu.ru

Significant advances in synthesis of new isotopes made superheavy elements (SHE) one of the most intriguing topics in modern nuclear physics [1]. The main decay mode in the SHE region is α-emission, so it becomes the main tool of new nuclei identification. Thus, accurate theoretical predictions of the α-decay energy and half-lives are crucial for experimental study of new elements.

To determine the decay energy, it is necessary to estimate the masses of the initial and final nuclei. The method of local mass relations based on the residual neutron-proton interaction was used to evaluate the unknown binding energies. As a source of experimental data AME2016 was used. The dependence of the *np*-correlations magnitude on A has a smooth behaviour and is successfully used to estimate unknown masses of isotopes [2-4].

The obtained values of the α-decay energy for isotopes with $Z = 102 – 106$ are compared with the evaluated data from AME2016, as well as with the results of theoretical calculations in FRDM [5]. Evaluation of α-decay half-lives was carried out using the Viola-Seaborg formula [6]. In the most studied area with $N \sim 150$, our estimates are in good agreement with the predictions obtained in other approaches.

1. Yu.Ts.Oganessian *et al.* // Phys. Scr. 2017. V.92. 023003.
2. B.S.Ishkhanov, T.Yu.Tretyakova // Moscow Univ. Phys. Bull. 2017. V.72. P.203.
3. B.S.Ishkhanov *et al*. // Chinese Phys. C. 2019. V.43. 014104.
4. J.Janecke *et al.* // At. Data and Nucl. Data Tabl. 1988. V.39. P.265.
5. P.Moller *et al.* // At. Data and Nucl. Data Tabl. 2016. V.109–110. P.1.
6. A.Parkhomenko, A.Sobiczewski // Acta Phys. Pol. B. 2005. V.10. P.36.

DETAILED STUDY OF Rf AND No ISOTOPES RADIOACTIVE DECAY PROPERTIES

Tezekbayeva M.S.[1,2], Yeremin A.V.[1,3], Lopez-Martens A.[4], Hauschild K.[4], Svirikhin A.I.[1,3], Malyshev O.N.[1,3], Isaev A.V.[1], Chepigin V.I.[1], Popeko A.G.[1,3], Kuznetsova A.A.[1], Popov Yu.A.[1,3], Chelnokov M.L.[1], Sokol E.A.[1], Gall B.[5], Dorvaux O.[5]

[1] *JINR Flerov Laboratory of Nuclear Reactions, Dubna, Russia;* [2] *Institute of Nuclear Physics, Almaty, Kazakhstan;* [3] *Dubna State University, Dubna, Russia;* [4] *CSNSM Institut National de Physique Nucléaire et de Physique des Particules du CNRS, Orsay, France;* [5] *IPHC Institut National de Physique Nucléaire et de Physique des Particules du CNRS, Strasbourg, France*

E-mail: tezekbaeva@jinr.ru

The results of detailed study of No and Rf isotopes radioactive decay properties in complete fusion reactions ^{50}Ti + ^{208}Pb and ^{48}Ca + ^{208,206,204}Pb with subsequent neutron evaporation from the excited compound nucleus at the kinematic separator SHELS were performed. The decay properties for ^{256}Rf based on 9 registered recoil–alpha–alpha correlations and 6270 spontaneous fission events were refined. The half-life times were obtained for spontaneous fission events $T_{1/2}$ = (6.9 ± 0.23) ms and alpha decay $T_{1/2}$ = (5.7 ± 1.2) ms, with brunches b_{SF} = 99.71% and b_{α} = 0.29% respectively. ^{254}No, ^{252}No and ^{250}No isotopes were investigated in the reactions with ^{48}Ca projectile. For the ^{254}No events which can be attributed to decay from the 2 isomer states were observed. For the first time decays from the ground and isomer state were measured for spontaneous fission isomers of ^{250}No. The total kinetic energy of fission fragments is obtained for the isotope ^{252}No.

DEPENDENCE OF DEFORMATION OF EXOTIC NUCLEI FROM THE HALF-LIFE

Zaripova Yu.A.[1], Dyachkov V.V.[1], Sereda Yu.M.[2], Yushkov A.V.[1]
[1] *Scientific Research Institute of Experimental and Theoretical Physics, Almaty, Republic of Kazakhstan;* [2] *Joint Institute for Nuclear Research, Dubna, Russia*
E-mail: ZJ_KazNU@mail.ru

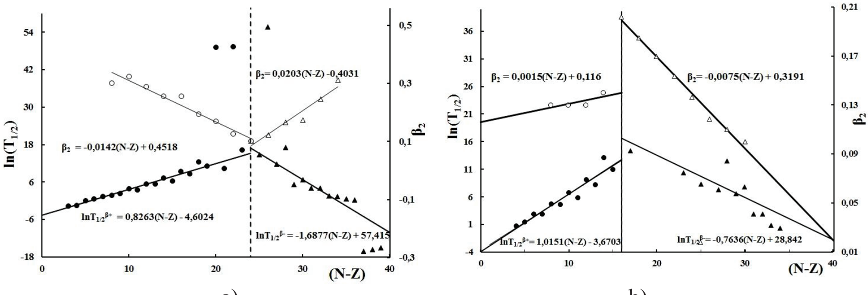
The deformation of nuclei is usually measured by their excitation into lower collective rotational states 2^+ with the subsequent extraction of nuclear matrix elements. The nuclear quadrupole deformation parameter is uniquely related to these elements β_2 [1]. However, this method is unsuitable for exotic short-lived nuclei, the inelastic scattering on which is difficult to measure, and for odd nuclei is impossible at all.

The authors of this work managed to find a correlation between the parameter β_2 and half-life $T_{1/2}$ for oblate nuclei with sign$\beta_2 < 0$ and anti-correlation for elongated nuclei sign$\beta_2 > 0$. As a result analytical expressions for the function $\beta_2(T_{1/2})$ have been obtained. For example, for elongated spheroids

$$\beta_2\left(T_{1/2}^{\beta^+}\right) = -0{,}0109 \cdot lnT_{\frac{1}{2}}^{\beta^+} + 0{,}3444, \qquad \textit{at } \mathrm{sign}\beta_2 > 0,$$

$$\beta_2\left(T_{1/2}^{\beta^-}\right) = -0{,}008 \cdot lnT_{\frac{1}{2}}^{\beta^-} + 0{,}2823, \qquad \textit{at } \mathrm{sign}\beta_2 > 0.$$

These relations make it possible to calculate with a high accuracy (from 5 to 10%) the parameters of the shape of the nuclei β_2, knowing the half-lives $T_{1/2}$ for the exotic nuclei for which this quantity is most accurately measured. Figure 1 shows such calculations for isotopic cerium (Fig. 1a) and tellurium (Fig. 1b) series in comparison with experimental half-life values [2, 3].



a) b)

Fig. 1. The phenomenon of β_2 anti-correlation with $T_{1/2}$ for oblate nuclei (a) and β_2 correlation with $T_{1/2}$ elongated nuclei (b).

1. A.V.Yushkov // Physics of Elementary particles and Atomic Nuclei. 1993. V.24(2). P.348.
2. N.N.Pavlova *et al.* // IZVESTIYA AKADEMII NAUK SSSR SERIYA FIZICHESKAYA. 1979. V.43. P.2317.
3. Nuclear Structure and decay Data: https://www.nndc.bnl.gov/nudat2/

NEW METHOD OF EXPERIMENTAL DETECTION AND STUDY OF MULTI-NEUTRONS

Yushkov A.V., Dyachkov V.V., Zaripova Yu.A.
Scientific Research Institute of Experimental and Theoretical Physics, Almaty, Republic of Kazakhstan
E-mail: zjkaznu2016@gmail.com

Multi-neutron systems (quasi-nuclei) in a bound state still cannot be found (despite numerous targeted searches) [1]. Meanwhile, by analogy with a biological cell, searches for multi-neutrons packed in original nucleon "membranes" are possible. This idea is also promoted by the well-known EMC effect and, recently discovered by us, the phenomenon of a reduction in the size of clusters relative to their size in the free state (in the light nuclei) [2]. Such a compression is expected to bring the neutron matter into a different phase state, similar to the fact that the neutron in the free state is radioactive, and stable in the volume of the nucleus.

The kinematic effects in the ^4n, ^{4}H, ^{4}He, ^{4}Li nuclei are experimentally quite detectable (Fig. 1) due to the significant difference in their binding energies ε and masses m. Experiments at the U-150m accelerator (Almaty) made it possible to detect clusters with masses $m \leq 4$, but to distinguish, for example, α-clusters from $4n$-nuclei and heavier multiclusters, heavy ion beams are needed. The kinematics of ^{16}O + ^4n, ^{16}O + ^{4}H, ^{16}O + ^{4}Li nuclear reactions (Fig. 1) differs from the usual kinematics by its "loop" character – each reaction in the spectrum is represented not by one, but by two peaks, which is an unequivocal identification feature. Requirements for the angular resolution of a heavy ion spectrometer δθ = ±0.1°; angle step requirements for measuring the angular distributions of differential cross sections Δθ=0.1°.

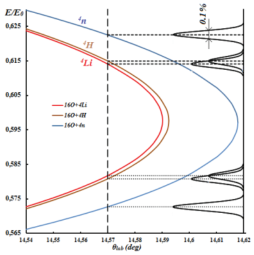


Fig. 1. Kinematics for the detection of multi-neutron membrane clusters on a beam of heavy ^{16}O ions.

From Fig. 1 it is clear that multiclusters with a mass greater than 4 will be experimentally distinguishable from charged clusters.

Such measurements are unique, but quite feasible [3]. Similar to Fig. 1, the calculations performed for isobaric chains ^2n, ^{2}H and ^3n, ^{3}H, ^{3}He, ^{3}Li also show the feasibility of these experiments in a loop technique [2] on beams of heavy ions.

1. Yu.E.Penionzhkevich, R.G.Kalpakchieva. *Light nuclei at the neutron stability boundary*. – Dubna: JINR, 2016. – 383 p.
2. V.V.Dyachkov *et al.* // International Journal of Modern Physics E. 2018. V.27(2). P.1850017.
3. A.V.Yushkov, N.N.Pavlova // IZVESTIYA AKADEMII NAUK SSSR SERIYA FIZICHESKAYA. 1976. V.40. P.826.

Experimental study of mechanisms of nuclear reactions

- Reactions with beams of radioactive nuclei;
- Reactions with polarized particles;
- Reactions with heavy ions;
- Fusion and fission of nuclei;
- Multifragmentation of nuclei;
- Reactions with neutrons and ultracold neutrons;
- Reactions induced by elementary particles.

NEW ERA OF RESONANCE REACTION STUDIES

Goldberg V.Z.[1], Rogachev G.V.[2]
[1] *Cyclotron Institute, Texas A & M University, College Station, Texas 77843, USA;*
[2] *Department of Physics and Astronomy and Cyclotron Institute, Texas A & M University, College Station, Texas 77843, USA*
E-mail: goldberg@comp.tamu.edu

Experimental methods and scientific problems of current interest are naturally evolving. However, radical changes to the aims and the techniques of the resonance reactions studies instigated by development of rare isotope beams and by the introduction of the Thick Target Inverse Kinematics approach (TTIK) [1, 2] are probably unparalleled. This field had initially benefitted from remarkable achievements of the electrostatic accelerators in the production of precisely focused and energy controlled ion beams with exquisite energy resolution. The aim was to study nuclear states of a complicated structure at rather high excitation energy and the isobaric analog states. Now relatively simple structure of the lowest states of exotic nuclei populated in the resonance reactions induced by rare isotope beams is the main field of these studies. It is not surprising that due to these changes the most of the new discoveries of new light nuclei was made in resonance reactions studies [3–7].

Resonance reactions are actively used to support the understanding of processes of the astrophysical interest and to study cluster states in atomic nuclei [8]. We plan to present a comprehensive review of the new applications of the resonance reactions using a contemporary technique including detection n and γ [8–10].

1. K.P.Artemov *et al*. // Yad.Fiz. 1990. V.52. P.634; Sov.J.Nucl.Phys. 1990. V.52. P.408.
2. V.Z.Goldberg, A.E.Pakhomov // Yad.Fiz. 1993. V.56. No 9. P.31; Phys. Atomic Nuclei. 1993. V.56. P.1167.
3. L.Axelsson *et al*. // Phys.Rev.C. 1996. V.54. R1511.
4. W.A.Peters *et al*. // Phys.Rev. C. 2003. V.68. 034607.
5. V.Z.Goldberg *et al*. // Phys.Lett. B. 2010. V.692. P.307.
6. E.Uberseder *et al*. // Phys.Lett. B. 2016. V.754. P.323.
7. J.Hooker *et al*. // Phys.Lett. B. 2017. V.769. P.62.
8. A.K.Nurmukhanbetova *et al*. // Nucl. Inst. and Meth. Phys. Res. A. 2017. V.847. P.125.
9. M.Barbui *et al*. // Phys.Rev. C. 2018. V.98. 044601.
10. A.K.Nurmukhanbetova *et al*. // Submitted to Phys. Lett. B.
11. V.Z.Goldberg *et al*. // To be submitted to Phys. Lett. B.

NEW DATA ON PHOTODISINTEGRATION OF ^{127}I: REALIBILITY OF EXPERIMENTAL REACTION CROSS SECTIONS

Varlamov V.V.[1], Davydov A.I.[2], Ishkhanov B.S.[2], Orlin V.N.[1]
[1] *Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia;* [2] *Physics Faculty, Lomonosov Moscow State University, Moscow, Russia*
E-mail: Varlamov@depni.sinp.msu.ru

There is the old and well-known problem of significant disagreements between data on partial photoneutron reaction cross sections obtained using beams of annihilation quasimonoenergetic photons the method of neutron multiplicity-sorting at Livermore (USA) and Saclay (France). It was obtained that for 19 nuclei ^{51}V, ^{75}As, ^{89}Y, ^{90}Zr, ^{115}In, ^{116,117,118,120,124}Sn, ^{127}I, ^{133}Cs, ^{159}Tb, ^{165}Ho, ^{181}Ta, ^{197}Au, ^{208}Pb, ^{232}Th, ^{238}U as a rule (γ,1*n*) reaction cross sections are larger at Saclay, but (γ,2*n*) cross sections vice versa larger at Livermore [1]. The averaged ratio $\sigma_S^{int}/\sigma_L^{int}$ of integrated cross sections for Saclay data to those for Livermore data is equal to 1.08 in the case of (γ,1*n*) reaction but 0.83 in the case of (γ,2*n*) reaction. Using the objective physical criteria for data reliability and the experimental-theoretical method for evaluation of partial photoneutron reaction cross sections [2] it was shown that many experimental data are nor reliable because do not satisfy the mentioned criteria and that the main reason is unreliable (erroneous) sorting of many neutrons between 1*n* and 2*n* channels. For ^{75}As and ^{181}Ta, the positions of which in the systematics for $\sigma_S^{int}/\sigma_L^{int}$ ratios are specifically large, 1.21 and 1.25, correspondingly, it was found [3] that many neutrons in various channels were lost.

The evaluation of partial reaction cross sections for ^{127}I using physical criteria of data reliability is of large interest because $\sigma_S^{int}/\sigma_L^{int} = 1.34$ [4, 5] is the largest value in the systematics mentioned above. New reliable partial and total photoneutron reaction cross sections for ^{127}I were obtained as $\sigma^{eval}(\gamma,in) = F^{theor}_i\ \sigma^{exp}(\gamma,xn)$ using Saclay [5] $\sigma^{exp}(\gamma,xn)$ and F^{theor}_i calculated in the combined model of photonucleon reactions (CMPNR) [6]. The significant disagreements between evaluated and experimental data were obtained and discussed in detail.

The research was carried out in the Department of Electromagnetic Processes and Atomic Nuclei Interactions of the MSU SINP. It is supported by the Coordinated Research Project (F41032, the Research Contract 20501) of the International Atomic Energy Agency.

1. V.V.Varlamov *et al.* // Eur. Phys. Jour. A. 2014. V.50. P.114.
2. V.V.Varlamov *et al.* // Izv. RAN, Ser. Fiz. 2010. V.74. P.875.
3. V.V.Varlamov *et al.* // Phys. Atom. Nucl. 2012. V.75. P.1339.
4. R.L.Bramblett *et al.* // Phys. Rev. 1966. V.148. P.1198.
5. R.Bergere *et al.* // Nucl. Phys. A. 1969. V.133. P.417.
6. B.S.Ishkhanov *et al.* // Phys. Atom. Nucl. 2008. V.71. P.493.

PRODUCTION CROSS SECTIONS FOR SUPERHEAVY NUCLEI

Zhang F.S.[1,2,3]

[1] *Key Laboratory of Beam Technology of Ministry of Education, College of Nuclear Science and Technology, Beijing Normal University, Beijing 100875, China;* [2] *Beijing Radiation Center, Beijing 100875, China;* [3] *Center of Theoretical Nuclear Physics, National Laboratory of Heavy Ion Accelerator of Lanzhou, Lanzhou 730000, China*

E-mail: fszhang@bnu.edu.cn

The main progresses to produce superheavy nuclei in the fusion and multinucleon transfer reactions at low energies by using different models are reviewed [1–9]. One finds the production cross sections of these nuclei in multinucleon transfer reactions are much larger than those in fusion-evaporation [1, 2] and fragmentation [9] reactions.

1. L.Zhu, W.J.Xie and F.S.Zhang, Production cross sections of superheavy elements $Z = 119$ and 120 in hot fusion reactions // Physical Review C. 2014. V.89. P.014619.
2. L.Zhu, Z.Q.Feng, C.Li, and F.S.Zhang, Orientation effects on evaporation residue cross section in ^{48}Ca-induced hot fusion reactions // Physical Review C. 2014. V.90. P.014612.
3. L.Zhu, Z.Q.Feng and F.S.Zhang, Production of heavy neutron-rich nuclei in transfer reactions within the dinuclear system model // J. Phys. G: Nucl. Part. Phys. 2015. V.42. P.085102.
4. C.Li, F.Zhang, J.Li, L.Zhu, and F.S.Zhang, Multinucleon transfer in the ^{136}Xe + ^{208}Pb reaction // Physical Review C. 2016. V.93. P.014618.
5. L.Zhu, J.Su, W.J.Xie, and F.S.Zhang, Theoretical study on production of heavy neutron-rich isotopes around the $N = 126$ shell closure in radioactive beam induced transfer reactions // Physics Letters B. 2017. V.767. P.437.
6. C.Li, P.W.Wen, J.Li, G.Zhang, B.Li, X.Xu, Z.Liu, S.Zhu, F.S.Zhang, Production mechanism of new neutron-rich heavy nuclei in the ^{136}Xe + ^{198}Pt reaction // Physics Letter B. 2018. V.776. P.278.
7. F.S.Zhang, C.Li, L.Zhu, P.W.Wen, Production cross sections for exotic nuclei with multinucleon transfer reactions // Front. Phys. 2018. V.13. P.132113.
8. C.Li, X.Xu, J.Li, G.Zhang, B.Li, C.A.T.Sokhna, Z.S.Ge, F.Zhang, P.W.Wen, and F.S.Zhang, Production of new neutron-rich heavy nuclei with Z = 56–80 in the multinucleon transfer reactions of ^{136}Xe + ^{198}Pt // Physical Review C. 2019. V.99. P.024602.
9. F.S.Zhang and L.X.Ge // Nuclear Multifragmentation. 1998. Science Press, Beijing.

NUCLEAR TEMPERATURE AND ITS DEPENDENCE ON TARGET-MASS IN LOW-ENERGY FISSION

Andronenko M.N.[1], Andronenko L.N.[1], Neubert W.[2]
[1] *National Research Center "Kurchatov Institute", Petersburg Nuclear Physics Institute, Gatchina, Russia;* [2] *Forschungszentrum Rossendorf Inc., 01314 Dresden, Germany*
E-mail: andronenko_ln@pnpi.nrcki.ru

Earlier nuclear temperatures characterizing low-energy fission reactions were obtained by the so-called isotope thermometry. In this approach yield ratios of light charged particles (with $1 \leq Z \leq 14$), accompanying fission, were exploited resulting in the mean temperature of about $T = 1.2$ MeV [1]. This method was also utilized for appropriate yields of fission fragments. We used for this evaluated data from the ENDF/B-VII.1 library [2]. In an advanced procedure we generated temperature distributions to improve the reliability of the obtained values. The temperatures for low-energy binary fission are of about $T = 0.6$ MeV.

The fragment yields available in fission product yield data base were simultaneously analysed to prove isoscaling as previously it was done for spallation products in p(1 GeV) + A reactions [3] and e.g. in a recent study [4] for photofission reactions. The extracted isoscaling parameters α (β) are related to the adjacent common temperature via the equation

$$\alpha = 4C_{sym}\left(\left(Z_1/A_1\right)^2 - \left(Z_2/A_2\right)^2\right)/T,$$

where C_{sym} is the symmetry energy coefficient and the A_i and Z_i are the mass and the atomic numbers of the nuclei undergoing fission.

The results for fission processes, taken from different sets of the ENDF/B data base (both for n-induced low-energy fission and spontaneous one), are in good agreement with those found by the isotope thermometry. The dependence of the temperature on the mass of the fissioning nuclei, established by the above mentioned different methods, shows a striking difference in comparison with other processes.

1. M.N.Andronenko *et al*. // Eur. Phys. J. A. 2001. V.12. P.185.
2. https://www-ndc.iaea.org
3. M.N.Andronenko, L.N.Andronenko, W.Neubert // Eur. Phys. J. A. 2007. V.31. P.125.
4. J.Drnoyan *et al*. // Phys.Part.Nucl.Lett. 2016. V.13. P.342.

DISSOCIATION FEATURES OF RELATIVISTIC ^{10}C NUCLEI IN NUCLEAR TRACK EMULSIONS

Artemenkov D.A., Kornegrutsa N.K.
Joint Institute for Nuclear Research, Dubna, Russia
E-mail: artemenkov@lhe.jinr.ru

The phenomenon of multiple fragmentation of relativistic nuclei can serve as a source of coherent ensembles of the lightest nuclei and nucleons. In this respect only nuclear track emulsion providing 0.5 μm spatial resolution allow one to follow tracks of all relativistic fragments in forward cone defined by a nucleon Fermi motion [1]. Nuclear track emulsion is exposed to a mixed beam of ^{12}N, ^{10}C and ^{7}Be nuclei formed by means of primary 1.2 *A* GeV ^{12}C nucleus beam at Nuclotron, JINR. The scanning along the total length of primary tracks in emulsion layers that was equal to 924.7 m revealed 6144 inelastic interactions. Dissociation of 1.2 *A* GeV ^{10}C nuclei in nuclear track emulsions is studied [2, 3]. It is shown that most precise angular measurements provided by this technique play a crucial role in the restoration of the excitation spectrum of the $2\alpha + 2p$ system. Strong contribution of the cascade process $^{10}\text{C} \rightarrow {}^{9}\text{B} \rightarrow {}^{8}\text{Be}$ identified. Our experimental data compared with Geant4 + QMD modeling results.

1. Web site of the BECQUEREL Project // http://becquerel.jinr.ru (2019).
2. D.A.Artemenkov *et al*. // Phys. At. Nucl. 2010. V.73. P.2103.
3. D.A.Artemenkov *et al*. // Few-Body Syst. 2011. V.50. 259-261.

THE PRECISION OF THE CALCULATION OF THE NEUTRON AND GAMMA YIELDS AS A RESULT OF (α,*n*) REACTIONS FOR LOW-BACKGROUND EXPERIMENTS

Barbarian V.A.
Lomonosov Moscow State University, Faculty of Physics, Moscow, Russia
E-mail: va.barbaryan@physics.msu.ru

Nuclear recoil backgrounds are one of the most dangerous backgrounds for many dark matter experiments. A primary source of nuclear recoils is radiogenic neutrons produced in the detector material itself. These neutrons result from fission and (α,*n*) reactions originating from uranium and thorium contamination. Therefore, precision calculation of backgrounds is very important.

The evaluation includes both explicit measurements through ICPMC and HPGe, as well as numerical-theoretical calculation based on programs. NeuCBOT [1] is a tool for calculating (α,*n*) yields and neutron energy spectra for arbitrary materials. The core of the calculations performed with this tool is the nuclear reaction database generated by TALYS [2]. But instead of the library from TALYS (TENDL), the code can be run using libraries from JENDL (experimental). It gives the best agreement with the experimental data.

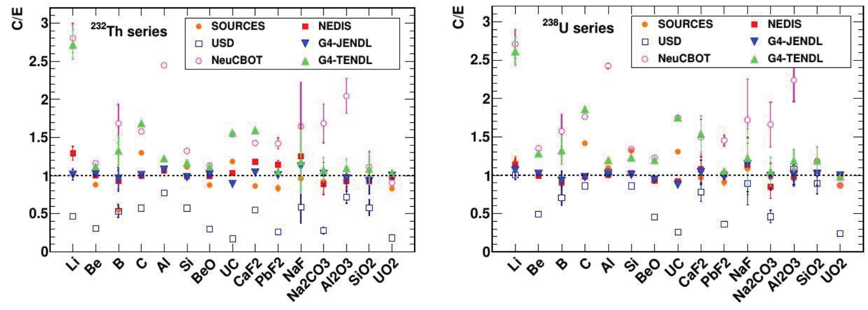


Fig. 1. Code validated versus SOURCES, NEDIS, USD, NeuCBOT, and G4.

The report provides a brief overview of software tool and a comparison of results using their calculations with experimental data. The causes of discrepancies, methods of eliminating them, and the influence of the precision of calculations on the results of low-background experiments are discussed.

1. https://github.com/shawest/neucbot
2. http://www.talys.eu/fileadmin/talys/user/docs/talys1.8.pdf

MEASUREMENT OF THE ROT-EFFECT IN FISSION OF ^{235}U INDUCED BY MONOCHROMATIC COLD POLARIZED NEUTRONS WITH AN ENERGY OF 60 MeV

Kopatch Yu.N.[1], Novitsky V.V.[1,2], Ahmadov G.S.[1,3], Gagarski A.M.[4], Berikov D.B.[1,5], Danilyan G.V.[1,2], Hutanu V.[6], Klenke J.[7], Masalovich S.[7], Deng H.[6]

[1] Joint Institute for Nuclear Research, 141980 Dubna, Russia; [2] Institute for Theoretical and Experimental Physics of National Research Centre "Kurchatov Institute", 117218 Moscow, Russia; [3] National Nuclear Research Centre, Baku, Azerbaijan; [4] Petersburg Nuclear Physics Institute of National Research Centre "Kurchatov Institute", 188300 Gatchina, Russia; [5] L.N.Gumilyov Eurasian National University, 010000 Nur-Sultan, Kazakhstan; [6] RWTH Aachen University and JCNS at Maier-Leibnitz Zentrum, 85748 Garching, Germany; [7] Forschungs-Neutronenquelle Heinz Maier-Leibnitz, D-85747 Garching, Germany

E-mail: daniyar.berikov@gmail.com

An experiment studying *T*-odd effects in binary fission of ^{235}U induced by monochromatic cold polarized neutrons was performed at the POLI instrument of the FRM2 reactor in Garching. In particular, triple correlations between the spin of the incoming neutrons and the emission directions of fission fragments and prompt γ-rays/neutrons were investigated. The neutrons were polarized using ultra compact SEOP (Spin Exchange Optical Pumpning) based ^{3}He polarized. The anisotropy parameter *A* determined from the experimental data for prompt gamma-rays and neutrons was established at the level of 10^{-4}. In spite of the smallness of the effects, the results are in agreement with the most modern theoretical model prediction.

The details of the experimental setup on beamline POLI, as well as the results of the experiment and the future plans will be presented.

STUDY OF ^{10}Li LOW ENERGY SPECTRUM IN THE ^{2}H(^{9}Li,*p*) REACTION AT THE ACCULINNA-2 FRAGMENT SEPARATOR

Bezbakh A.A., Acculinna collaboration
Joint Institute for Nuclear Research, Dubna, Russia
E-mail: bezbakh@jinr.ru

A significant part of experiments dedicated to the investigation of the structure of light neutron rich exotic nuclei is based on the detection of charged particles – nuclear interaction products. The experimental difficulty of detection of neutrons from reactions is caused by relatively low (in comparison with charged particles) detection efficiency of neutron detectors. However neutron measurements can considerably enrich nuclear physics with information on nuclear structure especially near the neutron drip line, where neutron decay is the dominant process. The ACCULINNA-2 fragment separator was commissioned at FLNR, JINR in 2017. One of the first experiments was measurement of ^{2}H(^{9}Li,*p*)^{10}Li reaction. Radioactive ion beam of ^{9}Li with an average energy of 27 MeV/*A* was used to bombard gaseous deuterium target. Coincidences of protons with neutrons and ^{9}Li from ^{10}Li decay were measured. This allows to reconstruct ^{10}Li excitation energy spectrum together with angular correlations of the decay.

K*(892) MESON MEASUREMENTS IN Cu + Au COLLISIONS AT 200 GEV

Borisov V.S., Berdnikov Ya.A., Berdnikov A.Ya., Kotov D.O., Mitrankov Iu.M.
Peter the Great St.Petersburg Polytechnic University (SPbPU), Saint Petersburg, Russia
E-mail: v1v1v2013vlad@gmail.com

The measurement of hadron production is a unique tool to study the strongly coupled quark-gluon plasma (QGP) produced in heavy ion collisions and its evolution to hadronic matter. Highly energetic partons traversing the QGP medium suffer significant energy loss, leading to modification of the fragmentation functions and softening of the measured transverse momentum (p_T) distribution [1].

Due to short lifetime and strange valence quark content, the K^* meson is sensitive to the properties of the hot dense matter and strangeness production from an early partonic phase (i.e. QGP) [2]. K^* meson was measured in symmetric Cu + Cu collisions of heavy ions. To continue the study of the QGP, K^*-meson production in asymmetric Cu + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV was analyzed.

In this report, we present transverse momentum spectra and nuclear modification factors for K^* (892) → Kπ in Cu + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV using the PHENIX detector at RHIC [3]. The results are compared to the ones obtained in symmetric Cu + Cu systems. The K^*-meson nuclear modification factors in Cu + Cu and Cu + Au collisions for similar N_{part} (number of participants) values exhibit similar shape. Thereby, production and suppression of the K^*-meson seem to depend on nuclear overlap size, but not on its geometry. The comparison of our results to the φ, π^0, η, K_S and ω mesons nuclear modification factors in Cu + Au collisions are also provided. For all centralities up to 40–60%, the K^* and φ mesons are less suppressed than π^0, η, K_S and ω in the intermediate p_T range, whereas at higher p_T, K^*, φ, π^0, η, K_S and ω show similar suppression values. In peripheral collision all light mesons R_{AA} seem to be equal to unity within uncertainties. The observation of these patterns in many collision systems can provide a contribution to better understand the interplay between canonical suppression and strangeness enhancement.

We acknowledge support from Russian Ministry of Education and Science, state assignment 3.1498.2017/4.6.

1. X.Wang and M.Gyulassy // Phys. Rev. Lett. 1992. V.68. P.1480.
2. C.Adler *et al*., STAR Collaboration // Phys. Rev. C. 2002. V.66. 061901(R).
3. K.Adcox *et al*. // Nucl. Phys. A. 2005 V.757. P.30.

PRODUCTION MECHANISMS FOR EXOTIC- AND HYPER-NUCLEAR CLUSTERS IN RELATIVISTIC ION COLLISIONS

Botvina A.S.
FIAS and ITP J.W. Goethe University, D-60438 Frankfurt am Main, Germany; Institute for Nuclear Research, Russian Academy of Sciences, 117312 Moscow, Russia
E-mail: a.botvina@gsi.de

In relativistic ion collisions one can obtain many new nuclear clusters including ones with strange and other heavy quarks. This opens novel opportunities for nuclear/particle physics and astrophysics. In particular, hypernuclei allow to explore the many-body aspects of the strong three-flavor interaction at low energies, which is important both for structure of finite nuclei and for neutron stars. Also the production mechanisms of such clusters can clarify the equation of state of normal and strange matter, as well as the particle correlations in dense nuclear surroundings. We show that the transport, coalescence and statistical models [1–4] can describe the whole process, and demonstrate the important regularities of the cluster formation. In the midrapidity region the coalescent mechanism including the following de-excitation of hot light clusters is very promising for description of produced nuclei. Such normal and hyper-nuclei can be measured in many experiments at Dubna (MPD, BM@N) and Darmstadt (HADES, CBM), and provide exclusive information about baryon interaction in matter at subnuclear densities. The special attention is also paid to the formation of large hyper-residues and their following decay in peripheral ion collisions. A broad distribution of predicted hypernuclei in masses and isospin allows for investigating binding energies of exotic hypernuclei [4], and the hypermatter at low temperatures. We point at the abundant production of multi-strange nuclei that can give an access to multi-hyperon systems and strange nuclear matter. The realistic estimates of hypernuclei yields in various collisions are presented and compared with available experiments. There is a saturation of the hypernuclei yield at high energies [1], therefore, the optimal way to pursue this experimental study is to use the accelerator facilities of intermediate energies, like Nuclotron and NICA (Dubna) and FAIR (Darmstadt).

1. A.S.Botvina *et al*. // Phys. Rev. C. 2017. V.95. P.014902.
2. A.S.Botvina *et al*. // Phys. Lett. B. 2015. V.742. P.7.
3. A.S.Botvina *et al*. // Phys. Rev. C. 2016. V.94. P.054615.
4. N.Buyukcizmeci *et al.* // Phys. Rev. C. 2018. V.98. P.064603.

CODES DESCRIPTIVE OF NUCLEAR REACTIONS AND ISOMERIC CROSS SECTION RATIOS DATA

Chuvilskaya T.V.
Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow 119991, Russia
E-mail: tatchuv@anna19.sinp.msu.ru

Investigations of isomeric cross-section ratios (ICSR) of the reactions ^{187}Re(α,n)^{190mg}Ir and ^{194}Pt(α,n)^{197mg}Hg in the energy range 18–32 MeV were carried out using off-beam measurements of induced activity of members of the isomeric pair. Analysis of the obtained ICSR data is performed using the codes EMPIRE-3 and TALYS. These codes are based mainly on widely used Hauser-Feshbach model (HFM), grounded on the statistical theory of nuclear reactions. Other mechanisms play a more limited role. The area of application of the HFM lies in the range of 10–50 MeV compound nucleus excitation energy, where the widths of resonances are greater than the distances between them.

For the reaction ^{187}Re(α,n)^{190mg}Ir experimental values of ICSR up to energy E_{pr} = 23 MeV are in agreement with calculated by EMPIRE-3 ones with an accuracy of 20–30 %. At higher energy of α-particles calculated isomeric ratios exceed experimental ones, this behavior is an evidence indicating that mechanisms of α-reactions other than statistical ones (pre-equilibrium, direct) become dominant. As for the data calculated by TALYS a good agreement with experimental results takes place. For the reaction ^{194}Pt(α,n)^{197mg}Hg a good agreement of the experimental and calculated values of ICSR is seen in the α-particle energy range E_{pr} = 14–18 MeV for both EMPIRE-3 and TALYS codes. At higher energies of α-particles calculated isomeric ratios exceed experimental ones and this difference turns out to be more significant for EMPIRE-3 code than for TALYS. The discrepancies of the measured and the calculated results revealed in the framework of the analysis are of the same order as the ones revealed in the framework of the analysis of ICSR of well-studied earlier ^{41}K(α,n)^{44mg}Sc. These results confirm that the ICSR measurements are a good test of the mentioned above reaction mechanisms.

DELAYED NEUTRONS FROM PHOTOFISSION OF ^{238}U AT $E_{\gamma\ max} \approx 10$ MeV IN DIFFERENT TIME INTERVALS AFTER IRRADIATION

Dzhilavyan L.Z., Lapik A.M., Nedorezov V.G., Ponomarev V.N., Rusakov A.V., Solodukhov G.V.
Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia
E-mail: dzhil@inr.ru

In fission of actinide nuclei, neutron-rich nuclei are formed, and in small part of their β^--decays highly excited nuclei can be populated, which in some cases can be de-excited by emission of so delayed neutrons (see, e.g., [1–5]).

Emission of delayed neutrons is connected with the physics of the nuclear fission process, leading to definite characteristics of this process – distributions of fragment-nuclei in their mass and charge numbers A and Z. And in these cases it is possible to obtain almost unique data about neutron-rich isotopes required for nuclear spectroscopy (see [1]). On the other hand, delayed neutrons are of great applied interest for controlling operation of nuclear reactors and detecting unauthorized transportation of fissionable materials (see, e.g., [4]).

Measurements were made at the pulsed linear electron accelerator LUE-8-5 of the INR RAS [6] at the energy of incident electrons $E_e \approx 10$ MeV. Fast neutrons were registered by scintillation spectrometers with discrimination of background γ-quanta using differences in shapes of scintillation pulses. More details of the used technique are in [5] and in the references therein. To separate delayed neutrons from the different temporal groups (see, e.g., [2]), measurements were made for several time intervals after irradiation (especially for the short-lived groups). To avoid negative influence on the used scintillation detectors from background of γ-quanta and neutrons, produced by beam pulses, the controlled dividers of power supplies for the photomultiplier tubes of the scintillation detectors [7] were used (also especially for short-lived groups).

There were obtained the first data on delayed neutrons connected with β^--decays of short-lived radioisotopes with half-life $T_{1/2}$ down to ≈ 20 ms.

1. S.Y.F.Chu, L.P.Ekström, R.B.Firestone. The Lund/LBNL Nuclear. Data Search. 1999. http://nucleardata.nuclear.lu.se/toi/
2. V.M.Piksaikin, L.E.Kazakov, S.G.Isaev, *et al.* // Voprosy Atomnoy Nauki i Tekhniki. Seriya: Yadernye konstanty. 2001. Vypusk 7. P.67.
3. V.M.Piksaikin, L.E.Kazakov, S.G.Isaev, *et al.* // Voprosy Atomnoy Nauki i Tekhniki. Seriya: Yadernye konstanty. 2001. Vypusk 7. P.73.
4. S.S.Verbitskii, V.N.Emokhonov, A.M.Lapik, *et al.* // Bull. Russ. Acad. Sci.: Phys. 2011. V.75. P.1544.
5. L.Z.Dzhilavyan, A.M.Lapik, V.G.Nedorezov, *et al.* // Phys. Part. Nuclei (submitted).
6. V.G.Nedorezov, V.N.Ponomarev, G.V.Solodukhov // Int. Conf. "Nucleus-2018". Book of Abstracts. Saint-Petersburg. 2018. P.214.
7. L.Z.Dzhilavyan, A.M.Lapik, A.V.Rusakov // Ibid. P.224.

ANISOTROPY OF ANGULAR DISTRIBUTIONS OF FISSION FRAGMENTS FROM NEUTRON-INDUCED FISSION OF ^{232}Th, ^{233}U, ^{235}U, ^{238}U, ^{239}Pu, ^{237}Np, ^{nat}Pb, AND ^{209}Bi IN INTERMEDIATE ENERGY RANGE 1-200 MeV

Gagarski A.M.[1], Vorobyev A.S.[1], Shcherbakov O.A.[1], Vaishnene L.A.[1], Barabanov A.L.[2], Kuz'mina T.E.[3]

[1] B.P. Konstantinov Petersburg Nuclear Physics Institute of National Research Centre "Kurchatov Institute", Gatchina, Russia; [2] National Research Centre "Kurchatov Institute", Moscow, Russia; [3] V.G. Khlopin Radium Institute, St.-Petersburg, Russia

E-mail: gagarskiy_am@pnpi.nrcki.ru

Angular distributions of fission fragments from the neutron-induced fission have been measured for a number of heavy target-nuclei in the energy range 1–200 MeV at the neutron time-of-flight spectrometer GNEIS [1] based on the 1-GeV proton synchrocyclotron of the NRC KI–PNPI (Gatchina). The anisotropy of fission fragments $W(0^o)/W(90^o)$ deduced from the experimental data on angular distributions for ^{232}Th, ^{233}U, ^{235}U, ^{238}U, ^{239}Pu, ^{237}Np, ^{nat}Pb and ^{209}Bi [2–5] are presented and discussed in comparison with the results of other authors. A special attention is devoted to the neutron energy range above 20 MeV where the existing data are still scarce in spite of the ever-growing interest to this field stimulated by the development of new nuclear technologies.

1. O.A.Shcherbakov *et al.* // Phys. Part. Nucl. 2018. V.49. P.81.
2. A.S.Vorobyev *et al.* // JETP Lett. 2015. V.102. P.203.
3. A.S.Vorobyev *et al.* // JETP Lett. 2016. V.104. P.365.
4. A.S.Vorobyev *et al.* // JETP Lett. 2018. V.107. P.521.
5. A.S.Vorobyev *et al.* // Bull. Russ. Acad. Sci. Phys. 2018. V.82. P.1240.

CORRELATION STUDY OF ^{7}He SPECTRUM FROM ^{2}H(^{6}He,*p*) REACTION

Gazeeva E.M., ACCULINNA collaboration
Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia
E-mail: gazeeva1993@gmail.com

Low energy excitation spectrum of ^{7}He populated in one neutron transfer ^{2}H(^{6}He,*p*) reaction was measured with the ^{6}He beam at the new ACCULINNA-2 facility (FLNR JINR). Coincidences of proton, ^{6}He and neutron were analyzed. Due to complete kinematics conditions there are at least two ways to reconstruct low energy spectrum of ^{7}He from experimental observables. The missing mass spectrum is calculated from the momenta of incoming beam and outgoing proton, whereas the invariant mass spectrum takes the neutron and outgoing ^{6}He momenta only. Both methods have been used for low energy excitation spectrum of ^{7}He. The results are presented and discussed.

NEW DATA ON THE NUCLEON STRUCTURE FROM THE REACTION OF ELECTRON SCATTERING OFF PROTONS

Golubenko A.A.[1,2], Isupov E.L.[1], Golovach E.N.[1], Ishkhanov B.S.[1,2], Chesnokov V.V.[1]
[1] *Skobeltsyn Nuclear Physics Institute at Moscow State University;* [2] *Lomonosov Moscow State University, Physical Faculty*
Email: aa.golubenko@physics.msu.ru

The studies of inclusive electron scattering data off nucleons provided detailed information on the distributions for all quark flavors and gluons in ground state of nucleon [1]. The Jefferson Lab inclusive electron scattering data in the resonance region allow us to obtain the data on the electrocouplings of the most nucleon resonances with masses <1.8 GeV [2]. The report presents the method for evaluation of inclusive electron scattering observables in the resonance region from the experimental data and a method to estimate the resonance contributions to the observations for inclusive electron scattering off protons.

The developed approach allowed us to estimate the resonance contributions at the observed inclusive electron scattering off protons from the experimental data of the electrocouplings N* at the first time. This opens up new possibilities of access to the parton distributions of the ground state of the nucleon in the resonance region of the Bjorken variable x_B. Preliminary results of studies of exclusive meson electrogenation channels at the CLAS12 detector in the resonance region and their analysis also be presented.

1. A.Accardi, L.T.Brady, W.Melnitchouk, J.F.Owens, N.Sato // Phys. Rev. D. 2016. V.93. P.114017.
2. V.I.Mokeev // Few Body Syst. 2018. V.59. P.46.

COMPARATIVE ANALYSIS OF SCATTERING OF PROTONS AND MESONS ON A ^{15}C NUCLEUS

Imambekov O., Ibraeva E.T.
Institute of Experimental and Theoretical Physics of Al-Farabi KazNU, Almaty, Kazakhstan
E-mail: onlas@mail.ru

Carbon isotopes have been intensively studied in recent decades, both experimentally and theoretically [1]. This is due both to the high prevalence of stable ^{12}C, and to the fact that beams of unstable isotopes were obtained at medium and high energies. This allowed in the inverse kinematics to investigate various reactions involving these unstable isotopes. Among unstable isotopes, ^{15}C is of particular interest. At present, it has been established that ^{15}C is a single-neutron halo nucleus with a low binding energy of the last neutron $\varepsilon = 1.218$ MeV. The ground state has a full spin $J^{\pi} = 1/2^{+}$ and a lifetime $\tau = 2.45$ s.

Here we investigate its halo structure by scattering various particles: protons, $\pi^{\pm}$ -, and K^{+} -mesons, based on the Glauber theory of diffraction scattering. The scattering of a proton on this nucleus was previously investigated by us in [2]. The study of the scattering of different particles on the same nucleus, in a single theoretical approach, can provide interesting, mutually complementary information about the structure of the nucleus. For example, $\pi^{\pm}$ -mesons are more strongly absorbed when interacting with the nucleus and, therefore, their interaction with the nucleus is to a large extent peripheral. Whereas, K^{+} -mesons are absorbed weakly and have a large free path in a nuclear medium, which makes it possible to use them as a probe to study the inner region of the nucleus.

The state of the ^{15}C core is described by the wave function in the many-particle shell model. The ground state is 98% determined by the *s*-component: $\left|(1s)^4(1p)^{10}(2s)^1\right\rangle$, a few more percent comes from the *d*-component $\left|(1s)^4(1p)^{10}(1d)^1\right\rangle$, the remaining waves are only fractions of percent.

In this paper, we calculated the differential cross section of single and double collisions of protons, $\pi^{\pm}$ -, and K^{+} -mesons per ^{15}C at different energies of the incident particles. Here we also analyzed the contributions to the scattering cross sections for various shells.

1. R.Kalpakchieva, Yu.E.Penionzhkevich // PEPAN. 2002. V.33. P.1247.
2. E.T.Ibraeva, O.Imambekov, *et al*. // Bull. Russ. Acad. Sci. Phys. 2009. V.73. P.845.

BREAK-UP REACTIONS OF ^{6}Li, ^{7}Be, AND ^{8}B

Issatayev T.[1,2,3], Lukyanov S.M.[1], Hue B.M.[1,4], Mendibayev K.[1,2,3], Artukh A.G.[1], Aznabayev D.[1,5], Borcea C.[6], Calinescu S.[6], Erdemchimeg B.[1], Kabyshev A.[2], Klygin S.A.[1], Kononenko G.A.[1], Kuterbekov K.A.[2], Maslov V.A.[1], Ostashko V.V.[5], Rotaru F.[6], Sailiant F.[7], Sereda Yu.M.[1], Sobolev Yu.G.[1], Vorontsov A.N.[1], Thiep T.D.[1,4]

[1] FLNR, Dubna, Russia; [2] Gumilyov L.N. Eurasian National University, Nur-Sultan, Kazakhstan; [3] Institute of Nuclear Physics, Almaty, Kazakhstan; [4] Institute of Physics, VAST, Hanoi, Vietnam; [5] Nuclear Physics Institute, Kyev, Ukraine; [6] National Inst. for Physics and Nuclear Engineering, IFIN-HH, Bucharest Magurele, Romania;
[7] Ganil, Bp 5027, 14076 Caen cedex 5, France;
E-mail: issatayev@jinr.ru

Secondary beams (^{6}Li, ^{7}Be, ^{8}B) obtained by separation of fragmentation products of ^{15}N beam (50 MeV/A) impinging on a Be target using COMBAS spectrometer. The secondary products were detected by a telescope consisting of five Si-detectors (ΔE) and CsI(Tl) detector (E_r). By the ΔE–E method, the telescope allowed us to achieve unambiguous particle identification originating from incident secondary beams as well as theirs reaction products resulting from reactions with one of Si detectors chosen as the target. Accordingly, break-up reactions of ^{6}Li, ^{7}Be, ^{8}B (Fig.1) were studied in this experiment. The parallel momentum distribution of ^{3,4}He, ^{6}Li, ^{7}Be produced from the break-up of ^{6}Li, ^{7}Be and ^{8}B was also determined. Theoretical analysis of presented experimental data was carried out using a numerical solving of the time-dependent Schrödinger equation for the outer weakly bound nucleons of the projectile nuclei.

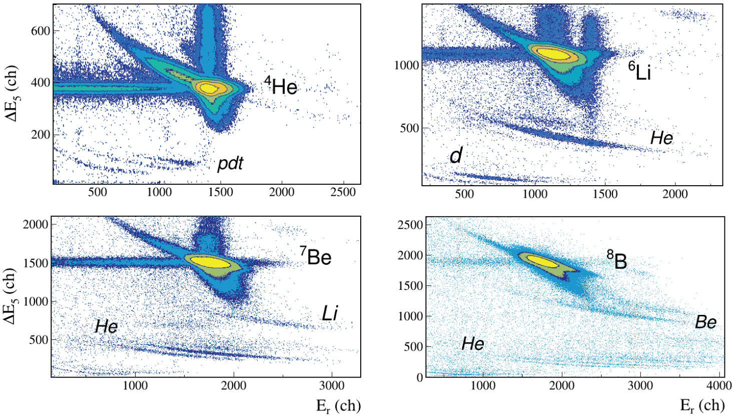


Fig. 1. Two-dimensional energy spectrum of ^{4}He, ^{6}Li, ^{7}Be, and ^{8}B after the secondary reaction.

FISSION AND QUASIFISSION IN THE REACTIONS WITH WELL-DEFORMED NUCLEI

Itkis I.M.[1], Knyazheva G.N.[1], Kozulin E.M.[1], Kozulina N.I.[1], Novikov K.V.[1], Gikal K.B.[1], Diatlov I.N.[1], Pchelintsev I.V.[1], Vorobiev I.V.[1], Pan A.N.[1,2], Singh P.P.[3]

[1] Joint Institute for Nuclear Research, Dubna, Russia; [2] Institute of Nuclear Physics, Almaty, Kazakhstan; [3] Indian Institute of Technology Ropar, Ruipnagar, Punjab, India

E-mail: jitkis@jinr.ru

It is known that in the reactions with well-deformed nuclei their mutual orientation affects considerably the reaction dynamics. The analysis of mass-energy and angular distributions of fragments obtained in the reactions of ^{40,48}Ca with well-deformed ^{152,154}Sm isotopes at energies near and below the Coulomb barrier has shown that the quasifission process contributes significantly in the capture cross section, whereas in the case of the spherical ^{144}Sm target no evidence of quasifission has been found.

The evidence of quasifission caused by the orientation effects was observed in the reactions of light ions like F, O, Ne, with actinide targets (well-deformed nuclei) at energies near and below the Coulomb barrier. The conclusion about the presence of quasifission for these systems was derived from the anomalous large anisotropies and increase of the dispersion of mass distributions. However, the quasifission process is rather unexpected for the reactions with such light projectiles. Moreover, the measurement of the evaporation residues cross sections for the ^{16}O + ^{238}U reaction at near- and sub-barrier energies have shown that the complete fusion is the main process for this system. The large angular anisotropies obtained for these reactions are well described in the framework of the dynamic model of fission-fragment angular distributions which takes into account thermal fluctuations of the orientation degree of freedom and stochastic aspects of nuclear fission. The width of mass distributions can be explained within the multimodal concept of the compound nucleus fission.

To study the role of the multimodal fission the mass and energy distributions of fission fragments formed in the reactions ^{16,18}O + ^{232}Th, ^{238}U, and ^{22}Ne + ^{232}Th, ^{238}U at energies around the Coulomb barrier have been measured. It was found that at these energies the mass and energy distributions of fragments exhibit the multimodal structure, which results in the larger variance of the mass distributions.

The experiments have been carried out at the U400 cyclotron of the Flerov Laboratory of Nuclear Reactions (JINR, Dubna, Russia) using the double-arm time-of-flight spectrometer CORSET.

This work was supported by the Indian Department of Science and Technology (DST) and the Russian Science Foundation (RSF) (Project No. 19-42-02014).

STUDY ELASTIC SCATTERING OF DEUTERONS FROM ^{13}C NUCLEI WITH OPTICAL AND FOLDING MODELS

Burtebayev N.[1,2], Janseitov D.M.[1,2,3], Kerimkulov Zh.K.[1,4], Burtebayeva J.[1], Nassurlla Maulen[2], Demyanova A.S.[5], Danilov A.N.[5], Starastsin V.I.[5], Aimaganbetov A.[4]

[1] Institute of Nuclear Physics, Almaty, Kazakhstan; [2] al-FarabiKazakh National University, Almaty, Kazakhstan; [3] Joint Institute for Nuclear Research, Dubna, Russia; [4] Eurasian National University, Nur-Sultan, Kazakhstan; [5] NRC Kurcatov Institute, Moscow, Russia

E-mail: janseit.daniar@gmail.com

The scattering of nucleons and complex nuclear particles (deuterons, alpha particles, heavy ions) on the nuclei is an important source of information about nuclear structure [1]. But the parameters of optical potential of interaction of particles with light nuclei at low and medium energies, derived from the analysis of differential cross sections of elastic scattering in the optical model, are subject to ambiguities and require reliable estimates.

In order to obtain reliable information about the potential of nuclear interaction, obtained in a cyclotron U150M of Institute of Nuclear Physics(Almaty, Kazakhstan), the experimental data on the scattering of deuterons in ^{13}C nuclei at $E_{(d)}$= 14.5 and 18 MeV analyzed both in terms of the standard optical model with the set of potentials in the parameterized form and finding its parameters by comparing the theoretical and experimental cross sections, and within a microscopic model in which the potentials are based on the effective nucleus-nucleus forces [2].

In this paper we carried out a comparative analysis of the elastic scattering of deuterons from ^{13}C nuclei in the optical and folding models.

1. G.R.Satchler // Direct Nuclear Reactions. N.Y.-Oxford: Oxford Univ. Press, 1983.
2. G.R.Satchler, W.G.Love. Folding model potentials from realistic interactions for heavy-ion scattering // Phys. Rep. 1979. V.55.

STUDY OF ELASTIC AND INELASTIC SCATTERING OF ALPHA PARTICLES BY ^{9}Be NUCLEI AT ENERGY E_α=29 MeV

Burtebayev N.[1], Kerimkulov Zh.K.[1,2], Galanina L.I.[3], Saduyev N.O.[1,4], Mukhamejanov Y.S.[1,4], Janseitov D.M.[1,4,5], Nassurlla Maulen[1,4], Alimov D.K.[1,2], Talpakova K.A.[1,2]

[1] Institute of Nuclear Physics, Almaty Kazakhstan; [2] L.N. Gumilev Eurasian National University, Nur-Sultan, Kazakhstan; [3] SINP MSU, Moscow, Russia; [4] al-Farabi.Kazakh National University, Almaty, Kazakhstan; [5] Joint Institute for Nuclear Research, Dubna, Russia

E-mail: zhambul-k@yandex.ru, janseit.daniar@gmail.com

The angular distributions of elastic and inelastic scattering of alpha particles by ^{9}Be nuclei have been measured at the U-150M cyclotron of the Institute of Nuclear Physics (Almaty, Kazakhstan) at energy $E_{\alpha,\mathrm{lab}}$ = 29 MeV. The following measured excited states of the ^{9}Be nucleus have been measured: $1/2^{+}$ (E_x = 1.68 MeV), $5/2^{-}$ (E_x = 2.43 MeV) and $5/2^{+}$ (E_x = 3.05 MeV). The error of the obtained data does not exceed 10%.

The levels of the main band $3/2^{-}$ (ground state) and $5/2^{-}$ (E_x = 2.43 MeV) were analyzed within the framework of the coupled channels method using the FRESCO computer code [1]. The global values of the optical potential from [2] were taken as starting parameters. In the process of fitting, only the depths of the real and imaginary parts of the potential were varied, and only a small correction was made for radii and diffusions. The levels of positive parity $3/2^{+}$ (neutron halo) and $5/2^{+}$ were analyzed using the single-particle model and the modified diffraction model (MDM). The obtained optical potentials, deformation parameters, spectroscopic amplitudes and radii (MDM) [3] are in good agreement with the literature data.

1. I.J.Thompson // Comput.Phys.Rep. 1988. V.7. P.167.
2. Ashok Kumar, S.Kailas, Sarla Rathi, K.Mahata // Nucl. Phys. A. 2006. V.776. P.105.
3. A.A.Ogloblin *et al*. // Nucl. Phys. A. 2010. V.834. P.143.

TRUE QUATERNARY FISSION – CONFIRMATION FROM ^{235}U(n_{th}, f) REACTION

Kamanin D.V.[1], Pyatkov Yu.V.[1,2], Alexandrov A.A.[1], Alexandrova I.A.[1], Goryainova Z.I.[1], Malaza V.[3], Kuznetsova E.A.[1], Strekalovsky A.O.[1], Strekalovsky O.V.[1], Tomas A.V.[2], Zhuchko V.E.[1]

[1] Joint Institute for Nuclear Research, Dubna, Russia; [2] National Nuclear Research University MEPhI (Moscow Engineering Physics Institute), Moscow, Russia; [3] University of Stellenbosch, Faculty of Military Science, Military Academy, Saldanha 7395, South Africa

E-mail: kamanin@jinr.ru

In our previous publications [1, 2] we discussed possible physical scenario standing behind rectangular-like structures in the fission fragments mass-correlation distributions from ^{252}Cf(sf). The rectangle is bounded by the known magic nuclei such as ^{68}Ni, ^{84}Se and others. The fission events aggregated in the rectangle show extremely low total kinetic energies. Special cinematic analysis of the experimental observables allowed us to come to conclusion that the mother nucleus undergoes true quaternary fission. Such decay channel is observed for the first time. Similar fission events were observed as well in ^{235}U(n_{th}, f) reaction. Their properties are discussed in this report.

1. D.V.Kamanin *et al*. // Int. Symposium on Exotic Nuclei "EXON-2016", Kazan, Russia, 04–10 September 2016. Conference proceedings, Editors: Yu.E.Penionzhkevich, and Yu.G.Sobolev. Published by World Scientific Publishing Co. Pte. Ltd., 2017. P.243.
2. Yu.V.Pyatkov *et al*. // Journal of Physics: Conference Series. 2017. V.863. 012046.

PROSPECTS FOR THE STUDY HYPERONS AND HYPERNUCLEI AT THE NICA COLLIDER

Kolesnikov V.I., Vasendina V.A., Zinchenko A.I. for the MPD Collaboration
Joint Institute for Nuclear Research, Dubna, Russia
Email: vadim.kolesnikov@cern.ch

A new project named NICA (Nuclotron-based Ion Collider facility) is under realization at JINR [1]. The main NICA scientific goal is the experimental exploration of yet poorly known region of the QCD phase diagram of high baryon density. Of particular interest is the strange sector of the phase diagram, which can be probed with multiple hadron specie (from kaons to multistrange hyperons) and hypernuclei. The MultiPurpose Detector (MPD) at NICA is a high-resolution device providing precise reconstruction of heavy-ion collisions and measure of the production of charged and neutral kaons, hyperons, nuclear clusters, and hypernuclei [2].

In my report physics motivation for the study of strangeness and hypernuclei production at NICA will be given together with the model predictions for the estimated particle production yields. The latter will be supported with the first results of feasibility study for hyperon and hypernuclear reconstruction with the MPD detector.

1. V.Golovatyuk, V.Kekelidze, V.Kolesnikov, O.Rogachevsky, A.Sorin // Eur.Phys.J. A. 2016. V.52. no.8. P.212.
2. Kh.U.Abraamyan *et al*. // Nucl. Instrum. Meth. A. 2011. V.628. P.99.

PRELIMINARY DATA ON *nn*-SCATTERING LENGTH IN *nd→pnn* REACTION AT NEUTRON ENERGY OF 50-80 MeV

Konobeevski E.S., Mordovskoy M.V., Zuyev S.V.
Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia
E-mail: konobeev@inr.ru

For an experimental study of the parameters of *nn* interaction, nuclear reactions leading to the formation of two interacting neutrons in the final state are used. In these reactions, information on low-energy parameter of the *nn* interaction – $^1S_0$ singlet scattering length a_{nn} – can be obtained. The difference between the neutron-neutron and proton-proton scattering lengths determines the measure of the violation of charge symmetry breaking (CSB) of nuclear forces.

In [1], an attempt was made to explain the discrepancies between the experimental data on a_{nn} obtained in different studies by the effect of 3*N* forces depending on the velocity of flying apart the *nn* pair and the charged fragment (different in the experiments under consideration). It is shown that the higher the flying apart velocity of the fragments, the faster these fragments leave the area of action of 3*N*-forces, and the less should be their effect on the parameters of *nn*-interaction extracted from the experiment.

As shown in [1], the smallest effect on the extracted a_{nn} value was in the $nd \rightarrow pnn$ reaction at neutron energy of 25 MeV [2] and 40 MeV [3]. To test the hypothesis about the effect of 3*N*-forces, the experiments are needed at minimum and maximum flying apart velocities.

We present the results of a preliminary study of the $nd \rightarrow pnn$ reaction at neutron energy of 50–80 MeV. The source of neutrons is the beamstop of the INR linear accelerator protons with energy of 200 MeV. An active scintillation C_6D_{12} target was used as a deuterium target. Two neutrons and a proton in each event of the *nd* breakup reaction are detected by a neutron hodoscope and the C_6D_{12} scintillator, respectively. In this case, the kinematics of the reaction allows to reconstruct the energy of the primary neutron.

To determine the a_{nn} value, the experimental dependences of the $n + d \rightarrow p + n + n$ reaction yield on the relative energy of two neutrons are compared with simulation results depending on the scattering length.

1. E.S.Konobeevski *et al*. // Physics of Atomic Nuclei. 2018. V.81. N.5. P.595.
2. V.Huhn, L.Wätzold, Ch.Weber *et al.* // Phys. Rev. C. 2000. V.63. P.014003.
3. E.S.Konobeevski *et al*. // Physics of Atomic Nuclei. 2010. V.73, N.8. P.1343.

MEASUREMENTS OF GAMMA-RAY YIELDS AND ANGULAR CORRELATIONS FROM REACTIONS INDUCED BY 14.1 MEV NEUTRONS USING TAGGED NEUTRON METHOD

Kopatch Yu.N.[1], Bystritsky V.M.[1], Fedorov N.A.[1,2], Grozdanov D.N.[1,3], Ruskov I.N.[1,3], Skoy V.R.[1], Tretyakova T.Yu.[1,4], Aliyev F.A.[1,5], Gundorin N.A.[1], Hramco C.[1,6], Kumar A.[7], Gandhi A.[7], Wang D.[8], Bogolyubov E.P.[9], Barmakov Yu.N.[9], TANGRA collaboration

[1] Joint Institute for Nuclear Research (JINR), Dubna, Russia; [2] Faculty of Physics, Lomonosov Moscow State University (MSU), Moscow, Russia; [3] Institute for Nuclear Research and Nuclear Energy of Bulgarian Academy of Sciences (INRNE-BAS), Sofia, Bulgaria; [4] Skobeltsyn Institute of Nuclear Physics Lomonosov Moscow State University (SINP MSU), Moscow, Russia; [5] Institute of Geology and Geophysics, Baku, Azerbaijan; [6] Institute of Chemistry, Academy of Science of Moldova, Chisinau, Republic of Moldova; [7] Banaras Hindu University, Varanasi, India; [8] Xi'an Jiao Tong University, Xi'an, China; [9] All-Russia Research Institute of Automatics (VNIIA), Moscow, Russia

E-mail: kopatch@nf.jinr.ru

Fast neutrons with the energy of ~ 14 MeV can be produced by the D(T,α)*n* nuclear reaction where deuterons are accelerated up to ~ 100 keV toward tritium target. In this process, both neutrons and α-particles are emitted into 4π. It has been shown long time ago (e.g., [1]) that the neutrons can be "tagged" by detecting the associated 3.5 MeV alpha-particle, which is emitted at opposite direction to the neutron (in c.m. system). These "tagged" neutrons interact with the investigated target and can produce γ quanta in (*n*, *n*'γ) or other reactions. The use of the tagged neutron method (TNM) gives the information about the time of emission and the direction of the corresponding neutron and leads to a significant reduction of the background in the experimental data.

We used the TNM technique to measure angular distributions and yields of the γ-rays emitted from the reactions of 14.1 MeV neutrons with various nuclei. As a source of tagged neutrons we used the portable neutron generator ING-27 produced by VNIIA (Moscow). The 3.5 MeV α-particles were registered by a built-in 64-pixel Si charged particle detector. The gamma-rays from the interaction of neutrons with the sample we registered by an array of 18 BGO scintillator detectors placed at different angles to measure the angular correlations. A dedicated series of measurements with the same targets was performed using an HPGe detector giving the information about the relative yields of gamma-lines for each investigated sample.

We report the results of measurements in comparison with the available data from other authors.

1. V.Valkovic *et al.* // Nucl. Instr. Meth. 1969. V.76. P.29.

ON POSSIBILITY OF OBSERVING QUARK OSCILLATOR EXCITATIONS IN DEUTERON NUCLEUS

Kostenko B.F.
Joint Institute for Nuclear Research, Dubna, Russia
E-mail: bkostenko@jinr.ru

There are at least three independent experimental evidences for existence of oscillator excitation levels in deuteron. The first one is contained in paper [1] where deuteron-deuteron scatterings at 8.9 GeV/c momentum of primary deuterons and big transfer momenta were studied. Usually it is taken for granted that two distinct peaks observed there correspond to elastic *d–d* and *d–N* scatterings. Our calculations [2] revealed that it is not the case (see Fig.1).

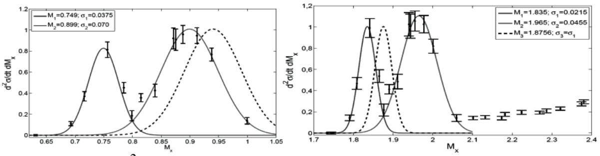


Fig.1.Effective mass (GeV/c²) distribution of particle X for $d+d \to X+d$ reaction. Theoretical peaks for $X=p$ and $X=d$ are shown by dashed lines in the left and right pictures. Experimental data are taken from [1]. Parameters of their normal distribution interpolation shown by solid lines are also given.

Additional study shows that the experimental peaks may be described perfectly well if one assumes that they correspond to transitions between different oscillator levels described by the following formula $M_n = M_d + 10.08\, n,\ n = 1,2,...$, where masses are taken in MeV/c². The second experimental evidence for existence of oscillator excitation levels in two-nucleon system came from [3], where dibaryon resonances were observed in *p–p* system obtained by "deeply cooling" highly excited *n–p* system. It can be checked that all these dibaryons are located on the straight line $M_n = M_d + \Delta M + 10.08\, n,\ n = 1,2,...$, where $\Delta M = 2M_p - M_d$. The third type of possible oscillator excitations in *n–p* system was found in EVA experiment data [4]. These data bear a strong likeness between highly excited states of *n–p* system and coherent superposition of dibaryons with masses described by the afore-cited formula. They also help to explain the surprising peak positions shown above in the pictures. Furthermore, it can be shown that these data give an encouraging evidence for observing nucleons-to-quarks phase transitions in the EVA experiment (see [5]).

1. A.M.Baldin *et al*. // JINR Communication. 1979. 1-12397.
2. B.Kostenko, J.Pribish // PoS (Baldin ISHEP XXII) P.122.
3. Yu.A.Troian // Phys. Part. Nucl. 1993. V.24. P.294.
4. A.Tang *et al*. // Phys. Rev. Lett., 2003. V.90. 042301.
5. B.Kostenko // arXiv:1902.052052 v3 [nucl-th].

PIONS AND LIGHT FRAGMENTS IN ^{12}C FRAGMENTATION AT 2 GEV/NUCLEON

Abramov B.M.[1], Baznat M.[2], Borodin Yu.A.[1], Bulychjov S.A.[1], Dukhovskoy I.A.[1], Krutenkova A.P.[1], Kulikov V.V.[1], Martemianov M.A.[1], Matsyuk M.A.[1], Turdakina E.N.[1]
[1] SRC "Kurchatov institute" – ITEP, Moscow, Russia; [2] Institute of Applied Physics, Academy of Sciences of Moldova, Republic of Moldova
E-mail: kulikov@itep.ru

Momentum distributions of charged pions and light nuclear fragments from ^{12}C fragmentation at 3.5^{o} were measured in FRAGM experiment on Be target at ITEP TWA heavy ion facility. Carbon beam energy was 2.0 GeV/nucleon. Yields of positive and negative pions have been measured up to 4 GeV/c momentum, which is approximately two times larger than maximal pion momentum from interaction of free nucleons. Light fragment momentum spectra cover more than 4 orders of cross section magnitude in cumulative region. These data are used for testing four ion-ion interaction models: Binary Cascade, Quantum Molecular Dynamics, Los-Alamos Quark Gluon String model and Liege Intranuclear Cascade Model. Successes and drawbacks of the models are discussed. Together with our data at lower energies from 0.3 to 0.95 GeV/nucleon [1, 2], the energy dependence of the cumulative spectra parameters has been traced and compared with the above mention model predictions and nucleon – nucleus data.

1. B.M.Abrsmov *et al.* // Phys.Atom.Nucl. 2018. V.81. P.330.
2. B.M.Abrsmov *et al.* // Phys.Atom.Nucl. 2016. V.79. P.700.

PROBING THE ASYMMETRIC FISSION OF SUB-LEAD NUCLEI AT ENERGIES ABOVE COULOMB BARRIER

Kumar D.[1], Kozulin E.M.[1], Cheralu M.[1], Knyazheva G.N.[1], Itkis I.M.[1], Itkis M.G.[1], Novikov K.V.[1], Diatlov I.N.[1], Pchelintsev I.V.[1], Saveleva E.O.[1], Vorobiev I.V.[1], Singh P.P.[2]

[1] *Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia;* [2] *Department of Physics, Indian Institute of Technology Ropar, Rupnagar, Punjab, India*

E-mail: dm978dph@gmail.com

Nuclear reactions induced by heavy-ions have allowed us to probe fission dynamics of exotic nuclei situated far from the line of stability which provides new and striking features of complex nuclear reaction processes [1]. The pre-actinide nuclei lying near lead region within a narrow band of isospin ($1.48 \le N/Z \le 1.58$) mainly exhibit symmetric fission mode [1–3]. In an excellent work of G.N. Knyazheva *et al.* performed at FLNR, JINR, the symmetrical mass distributions were obtained in $^{16}O + ^{186}W \to ^{202}Pb$, $^{40,48}Ca + ^{144,154}Sm \to ^{192,194,202}Pb$ up to high excitation energies in addition to quasifission process in deformed nuclei ^{154}Sm which was influence by shell closer structure of fission fragments [2]. Similarly, symmetric mass distributions were observed in ^{213}At, ^{210}Po, ^{200}Pb within studied excitation energies indicating the absence of shell effects at the saddle except a small contribution of asymmetry in ^{201}Po at 30.8 MeV [3, 4].

In recent years, the influence of shell structure on the asymmetric mass distributions of extremely neutron-deficient sub-lead nuclei has been under intense scrutiny because of the scarcity of experimental data which presents only a fragmentary picture. A number of theoretical and experimental efforts have been made to unravel the mystery of asymmetric mass splits since the discovery of asymmetry in ^{180}Hg, however, major investigations are limited to even-even neutron-deficient nuclei ($^{178,180,182,190}Hg$, ^{178}Pt etc.) only [1]. It was interpreted as driven by the shell structure of the fissioning nuclei instead of the shell effects of nascent fission fragments. In a recent article, it is revealed that a single neutron can make a sudden and unprecedented shape staggering in odd-mass mercury isotopes $^{181,183,185}Hg$ [5]. Therefore, exploring the fission fragment mass-energy distributions of odd-mass mercury nuclei became interesting and thereby aimed at the U400 cyclotron of the FLNR, JINR, Dubna, using the double-arm time-of-flight spectrometer CORSET which may play a crucial role to understand the effect of deformation on asymmetric mass splits. These findings could possibly clear the picture of asymmetric mass distributions witnessed in sub-lead nuclei.

This work was supported by the Indian Department of Science and Technology (DST) and the Russian Science Foundation (RSF) (Project No. 19-42-02014).

1. A.N.Andreyev *et al.* // Rep. Prog. Phys. 2018. V.81. P.016301 and reference therein.
2. G.N.Knyazheva *et al.* // Phys. Rev. C. 2007. V.75. P.064602.
3. A.Sen *et al.* // Phys. Rev. C. 2017. V.96. P.064609.
4. A.Chaudhuri *et al.* // Phys. Rev. C. 2016. V.94. P.024617.
5. B.A.Marsh *et al.* // Nature Phys. 2018. V.14. P.1163.

EXPERIMENTS WITH GABRIELA DETECTOR SYSTEM ON SHELS

Kuznetsova A.A.[1], Yeremin A.V.[1], Lopez-Martens A.[2], Hauschild K.[2], Popeko A.G.[1], Malyshev O.N.[1], Chepigin V.I.[1], Svirikhin A.I.[1], Isaev A.V.[1], Popov Yu.A.[1], Chelnokov M.L.[1], Dorvaux O.[3], Gall B.[3]
[1] *FLNR, JINR, 141980 Dubna, Russia;* [2] *CSNSM, IN2P3-CNRS, UMR 8609, F-91405 Orsay, France;* [3] *IPHC-DRS/ULP,* IN_2P_3*-CNRS, F-67037 Strasbourg, France*
E-mail: kuznetsova.jinr@gmail.com

For several years, on SHELS (**S**eparator for **H**eavy **EL**ements **S**pectroscopy) was carried out more dozen experiments, aimed to investigation of characteristics of heavy elements and discover new isotopes. Projectiles from ^{22}Ne to ^{54}Cr, and targets of $^{204–208}$Pb, ^{209}Bi, ^{236,238}U were used. Perfect data acquisition system GABRIELA lets fix 70% alpha particles and 90% gamma-quanta by spontaneous fission, and also accurately to separate events by time (1μs). The mixing of α- decay with γ- and β-decay spectroscopy allows to investigate single particle states behavior, as well as the structure of little known elements in the $Z = 100–104$ and $N = 152–162$ region.

PHI MESON MEASUREMENTS IN *p* + Au AND He + Au COLLISIONS AT 200 GeV

Berdnikov Ya.A., Berdnikov A.Ya., Kotov D.O., Larionova D.M., Larionova M.M., Mitrankov Iu.M.
Peter the Great St.Petersburg Polytechnic University, Saint-Petersburg, Russia
E-mail: dashalario@gmail.com

The PHENIX experiment aims to study the hot and dense state of the strongly interacting matter produced in high energy heavy ion collisions, the quark-gluon plasma (QGP) [1]. Collisions of small systems (such as *p* + Au, He + Au) are very interesting for the interpretation of the results obtained in PHENIX, as they allow physicists to understand whether the suppression of hadron yields at high transverse momentum in heavy ion collisions is caused by QGP effects or by the effects of cold nuclear matter (CNM) [2]. In addition, non-zero elliptic flow and a hint of suppression of high transverse momentum hadrons suggests that mini-QGP can be formed in collisions of light and heavy nuclei. Due to relatively small hadronic interaction cross section, φ meson production can provide new information about QGP and CNM effects [3, 4].

We present invariant transverse momentum spectra and nuclear modification factors (R_{AA}) for φ-meson as a function of p_T and rapidity measured in He + Au and *p* + Au collisions at 200 GeV. Comparisons of φ-meson results in *p* + Au, *d* + Au and He + Au collisions at 200 GeV and comparison of φ R_{AA} to π^0 R_{AA} results in He + Au and *p* + Au collision have been carried out.

In the intermediate p_T range φ-meson production in *p* + Au shows a hint of enhancement in most central and Minimum Bias collisions. In He + Au collisions in all centralities φ R_{AA} seems to be equal to unity. In the intermediate p_T range in most central collisions φ-meson nuclear modification factors seem to depend on the collision system size.

Nuclear modification factors for φ-meson and π^0-meson are in agreement within uncertainties in all centrality bins in the whole p_T range. This might indicate that cold nuclear effects are not responsible for the differences between φ and π^0 seen in Au + Au, Cu + Cu, Cu + Au and U + U collisions.

In both *p* + Au and He + Au collision systems φ R_{AA} in Au-going direction shows a hint of enhancement, in He/*p*-going direction – a hint of suppression. At mid-rapidity φ R_{AA} is equal to unity within uncertainties. These results may provide a constraint on various cold nuclear matter effects included in models like AMPT and EPOS [5].

We acknowledge support from Russian Ministry of Education and Science, state assignment 3.1498.2017/4.6.

1. I.Arsene *et al.* // Nucl. Phys. A. 2005. V.757. P.1.
2. A.Adare *et al.* // Phys. Rev. Lett. 2018. V.121. I.22. 222301.
3. A.Adare *et al*. // Phys. Rev. D. 2018. V.98. I.9. 092006.
4. A.Berdnikov *et al*. // J. Phys.: Conf. Ser. 2018. V.1135. 012044.
5. M.Sarsour *et al.* // EPJ Web of Conf. 2017. V.164. 07057.

MEASUREMENT OF TENSOR ANALYZING POWERS IN INCOHERENT π^0-MESON PHOTOPRODUCTION ON THE DEUTERON

Lukonin S.E.[1], Gauzshtein V.V.[1], Karpenko E.S.[1], Kuzin M.Ya.[1], Loginov A.Yu.[1], Nikolenko D.M.[2], Rachek I.A.[2], Sadikov R.Sh.[2], Toporkov D.K.[2], Shestakov Yu.V.[2], Zevakov S.A.[2]

[1] *Tomsk Polytechnic University, Tomsk, Russia;* [2] *Budker Institute of Nuclear Physics, Novosibirsk, Russia*

E-mail: gauzshtein@tpu.ru

The results of measurement of three tensor analyzing powers in incoherent π^0-meson photoproduction on the deuteron in the proton energy range of 15–200 MeV and neutron energy range of 15–150 MeV are presented. Experimental statistics of the reaction under study was isolated from the experiment that was designed to investigate deuteron photodisintegration [1]. In this experiment, neutrons and protons were recorded by the upper and lower arms of the detecting system, respectively. The measured asymmetries of the yields with regard to the change in the sign of tensor polarization of P_{zz} deuterons were used to calculate the tensor analyzing powers in the $\gamma d \to pn\pi^0$ reaction. With allowance for systematic and statistical errors, the average tensor polarization of the target during the experiment was $P_{zz}^{+} = 0.341 \pm 0.025 \pm 0.009$ and $P_{zz}^{-} / P_{zz}^{+} = -1.70 \pm 0.15$. A detailed description of the experimental setup and detection equipment is provided in [1, 2].

The obtained experimental data are compared with the results of statistical simulation of the $\gamma d \to pn\pi^0$ reaction. The event generation was followed by verification that it belongs to the permissible region of the kinematic phase space. After the generation of independent kinematic variables, the reaction amplitude was calculated. The model described in [3] was used to calculate the amplitude of the $\gamma d \to pn\pi^0$ reaction. In the framework of the model, the quasi-free pion photoproduction on nucleons that form the deuteron and the contribution of nucleon-nucleon and pion-nucleon rescattering were considered. The measurements cover the photon energy range of 250–500 MeV. In general, there is a qualitative agreement between experimental and available theoretical predictions. It is planned to give further attention to extraction of the experimental data on the $\gamma d \to pn\pi^0$ reaction from the experimental statistics accumulated using the DEUTERON setup in 2018 using the photon tagging system.

1. I.A.Rachek *et al*. // Physical Review Letters. 2007. V.98. P.182303.
2. V.V.Gauzshtein *et al.* // Physics of Atomic Nuclei. 2015. V.78. N.1. P.1.
3. A.Fix, H.Arenhövel // Phys. Rev. C. 2005. V.72. P.064005.

MULTINUCLEON TRANSFER IN REACTION ^{18}O(10MeV/A) + Ta

Lukyanov S.M.[1], Zernyshkin V.A.[1], Issatayev T.[1], Kolesov I.V.[1], Maslov V.A.[1], Mendibayev K.[1], Penionzhkevich Yu.E.[1,2]

[1] *Flerov laboratory of Nuclear Reactions, JINR, Dubna, Russian Federation;* [2] *MEPhI, National Research NuclearUniversity, Moscow, Russia*

E-mail: lukyan@jinr.ru

The availability of new radioactive ion beams has broadened the study of nuclear structure and nuclear reactions. The main mechanism to produce the secondary beams is the fragmentation of the projectile. Alternative method for the production of the exotic nuclei is the multinucleon transfer. This type of transfer reactions occurring in low-energy collisions of heavy ions is currently considered to comprise the most promising method for the production of new heavy neutron-rich nuclei, which could be not obtainable by other reaction mechanisms. For instance in the case of the neutron–rich isotopes, that could lead to the higher survival probability. We measured production cross section for the B, C, N and O isotopes in the reaction ^{18}O + Ta and the beam energy at 10 MeV/*A* (Fig.1). The cross-sections were obtained by integrating the momentum distributions of the isotopes. We compare the extracted cross-sections to the fragmentation cross-sections. It was shown that in deep inelastic processes the production yields of different isotopes could be well described using statistical models, and could also be explained by the reaction Q-value taking into account pairing corrections (Q_{gg}-systematics) [1, 2].

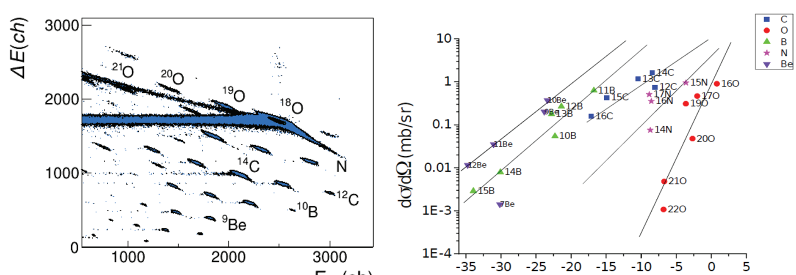


Fig.1 Left panel: Identification matrix ΔE–E_r of the products of the ^{18}O(10MeV/A) + Ta reaction. Right panel: Q_{gg} systematic for the ^{18}O(10 MeV/A) + Ta reaction products.

1. V.V.Volkov // Phys. Rep. 1978. V.44. P.93, and references therein.
2. V.V.Volkov // Treatise on Heavy-lon Science. V.8, ed. D. Allan Bromley (Plenum, 1989). P.101 and references therein.

NEUTRINO INTERACTION WITH THE Ga-Ge SYSTEM AND NUCLEAR RESONANCES

Lutostansky Yu.S.[1], Koroteev G.A.[2], Osipenko A.P.[1], Tikhonov V.N.[1]
[1] *National Research Center "Kurchatov Institute", Moscow, Russia;* [2] *Moscow Institute of Physics and Technology (State University), Moscow, Russia*
E-mail: lutostansky@yandex.ru

Investigation of the resonance structure of strength functions is an important task for calculating the cross sections of the neutrino capturing reactions that can be used in neutrino detectors.

In the resonance structure of the strength function, analog resonance, the giant Gamow-Teller resonance (GTR) [1] and three pigmy resonances (PRi) [2] are selected. Even when the two resonances of GTP and PR1 are not taken into account in the ^{71}Ga(ν_e,e^-)^{71}Ge reaction, the neutrino capture cross section σ(E) decreases from ~ 20% to ~ 60% with the neutrino energy in the interval 2–12 MeV [3]. Only not accounting the GTR gives a decrease in the σ(E) value in this reaction by 25% even at E_ν = 4 MeV [4].

The number of events in the interaction of solar neutrinos with these nuclei is given in the table for ^{71}Ga(ν_e,e^-)^{71}Ge reaction. All values are given in SNU. The spectrum of solar neutrinos is taken from model B16-AGSS09met [5].

Neutrino energy (MeV)	Calc. with out GTR	Calc. with out GTR and PR1	Calc. with out GTR and PR1, PR2	Calc. with out GTR, PR1, PR2, PR3
2	9.7	18	22	24
4	25	38	43	47
6	29	44	56	66
8	30	53	66	74
10	32	59	70	76
12	36	62	71	77
14	42	64	72	77

It can be seen from the table that boron neutrinos with energies up to 16.36 MeV (E_{max} = 6.44 MeV) make the main contribution and it is important to take into account all the resonances.

This work was supported in part by the Russian Foundation for Basic Research (project 18-02-00670).

1. Yu.V.Gaponov, Yu.S.Lyutostanskii // JETP Lett. 1972. V.15. P.120.
2. Yu.S.Lutostansky // JETP Lett. 2017. V.106. P.7.
3. Yu.S.Lutostansky, V.N.Tikhonov // Phys. Atomic Nuclei. 2018. V.81. P.540.
4. Yu.S.Lutostansky, A.P.Osipenko, V.N.Tikhonov // Bull. Russ. Acad. Sci.: Phys. 2019. V.83. P.488.
5. N.Vinyoles // Astrophys. J. 2017. V.835. P.202.

INVESTIGATION OF FORMATION OF RESIDUAL NUCLEI FROM ^{209}Bi BY REACTIONS WITH 660 MeV PROTONS AND COMPARISON WITH MCNP SIMULATION RESULTS

Melyan E.[1,2], Katovský K.[1], Balabekyan A.[2]

[1] *Brno University of Technology, Brno, Czech Republic;* [2] *Yerevan State University, Yerevan, Armenia*

E-mail: melyan@feec.vutbr.cz

Bismuth targets were irradiated by 660 MeV proton beam on Phasotron accelerator at the Joint Institute for Nuclear Research (JINR) in Dubna, Russia. Cross-sections of the formation of about 70 residual nuclei are determined by the method of induced activity [1]. The experimental cross sections of residual nuclei are compared with the data obtained by Titarenko *et al*. [2] as well as with the results of MCNP (Monte Carlo N-Particle Transport Code) [3] simulation. Comparison theoretical calculations and experimental results show good agreement between experiment and simulation data.

1. R.Balabekyan *et al*. // Journal of Contemporary Physics (Armenian Academy of Sciences), 2016. V.51. P.211.
2. Yu.E.Titarenko *et al*. // IAEA, Nuclear Data Section 2002. INDC(CCP)-434 http://www-nds.iaea.org/reports/indc-ccp-434.pdf
3. C.J.Werner // "MCNP Users Manual - Code Version 6.2", 2017. Los Alamos National Laboratory.

EXPERIMENTAL STUDY OF CLUSTER STRUCTURE OF ^{9}Be NUCLEI IN THE MECHANISM OF THEIR INTERACTION

Mendibayev K.[1,2,3], Denikin A.S.[1,4], Issatayev T.[1,2,3], Janseitov D.M.[1,2], Kuterbekov K.A.[3], Lukyanov S.M.[1], Mrazek J.[5], Naumenko M.A.[1], Penionzhkevich Yu.E.[1,6], Trzaska W.H.[7], Urazbekov B.A.[1,8]

[1] Joint Institute for Nuclear Research, Dubna, Russian Federation; [2] Institute of Nuclear Physics, Almaty, Kazakhstan; [3] L.N. Gumilev Eurasian National University, Nur-Sultan, Kazakhstan; [4] University "Dubna", Dubna, Moscow Region, Russia; [5] Nuclear Physics Institute, Řež, Czech Republic; [6] National Research Nuclear University MEPhI, Moscow, Russia; [7] Department of Physics, University of Jyväskylä, Jyvaskylä, Finland; [8]University of Campania "Luigi Vanvitelli", Caserta, Italy

E-mail: kayrat1988@bk.ru

The inelastic scattering and multi-nucleon transfer reactions was studied by bombarding a ^{9}Be target with a ^{3}He beam at the incident energy of 30, 40 and 47 MeV. The experimental angular distributions for ^{9}Be(^{3}He, ^{3}He)^{9}Be, ^{9}Be(^{3}He, ^{4}He)^{8}Be, ^{9}Be(^{3}He, ^{7}Be)^{5}He, ^{9}Be(^{3}He, ^{6}Li)^{6}Li and ^{9}Be(^{3}He, ^{7}Li)^{5}Li reaction channels were measured on the extracted beams of the cyclotrons K-120 of the University of Jyväskylä (Jyväskylä, Finland) and U-120 of the Institute of Nuclear Physics (Řež, Czech Republic). Registration and identification of the scattered reaction products was carried out by the ΔE–E telescope of silicon semiconductor detectors [1].

Experimental angular distributions for the corresponding ground states (g.s.) were analyzed within the framework of the optical model, the coupled-channel approach and the distorted-wave Born approximation. The contributions of different exit channels have been determined confirming that the ($\alpha + {}^{5}$He) configuration plays an important role [2]. ^{9}Be consisting of two bound helium clusters (^{3}He + ^{6}He) is significantly suppressed, whereas the two-body configurations ($n + {}^{8}$Be) and ($\alpha + {}^{5}$He) including unbound ^{8}Be and ^{5}He are found more probable. From the analysis of these data, the probabilities of cluster configurations $n + {}^{8}$Be and $\alpha + {}^{5}$He were determined, which were 69% and 25%, respectively.

1. S.M.Lukyanov, K.Mendibayev, Yu.E.Penionzhkevich, *et al.* // Preprint of JINR E-7-2017-65.
2. S.M.Lukyanov, Yu.E.Penionzhkevich, *et al.* // Journ. Phys.: Conf. Ser. 2017. V.863. 012027.

PRODUCTION OF RADON ISOTOPES IN THE REACTION $^{40}Ar + ^{232}Th$ AT MASS SEPARATOR MASHA

Novoselov A.S.[1], Krupa L.[1,2], Rodin A.M.[1], Chernysheva E.V.[1],·Dmitriev S.N.[1], Gulyaev A.V.[1],· Štekl I.[2], Holik M.[2], Broulim J.[2], Kamas D.[1,3], Kliman J.[3], Komarov A.B.[1], Salamatin V.S.[1],·Stepantsov S.V.[1],·Vedeneev V.Yu.[1], Opíchal A.[4], Pechousek J.[4], Yukhimchuk S.A.[1]

[1] Flerov Laboratory of Nuclear Reactions, JINR, Dubna, 141980, Russia; [2] Institute of Experimental and Applied Physics, Czech Technical University in Prague, Czech Republic, Horska 3a/22, 128 00 Praha 2; [3] Institute of Physics SASc, Dubravska cesta 9, 84228 Bratislava, Slovakia; [4] Faculty of Science of Palacký University in Olomouc, 17. listopadu 1192/12, 779 00 Olomouc, Czech Republic

E-mail: noval@jinr.ru

Nuclei near the neutron $N = 126$ and $N = 152$ shell closures are of great interest, since this region of nuclei is not enough investigated so far and in addition its research has direct relation to the synthesis of superheavy elements. As it is known the island of stability close to superheavy elements ($Z = 112–118$) exists due to shell effects in the nucleus. The more detailed investigation of these shell effects can greatly help in the synthesis of the next superheavy elements.

The experiment was carried out on upgraded mass separator “MASHA” including the modernization of rotating target node, hot catcher, ECR-ion source, beam diagnostics and DAQ system at the Flerov Laboratory of Nuclear Reactions (JINR, Dubna). The beam of ^{40}Ar ions from U400-M cyclotron were used with energy E = 282 MeV. The composite target ^{232}Th was used in the experiment: An alcohol solution of thorium nitrate was deposited into flexible graphite (thickness = 0.3 mm) and annealed at the temperature 1900°C.

Production yields of radon isotopes were measured in the multinucleon transfer reaction $^{40}Ar + ^{232}Th$. The isotopes with given masses were detected using two detectors: a multi-strip detector of the well-type (made in CANBERRA) and a position-sensitive quantum counting hybrid pixel detector of the TIMEPIX type. The isotopes implanted into the detectors then emit alpha- and beta-particles until reaching the long lived isotopes. The position of the isotopes, the tracks, the time and energy of beta- particles were measured and analyzed. A new software for the particle recognition and data analysis of experimental results was developed and used. The software uses the neural network approach. It was shown that MASHA + TIMEPIX setup is a powerful instrument for investigation of neutron-rich isotopes far from stability limits.

FIRST OBSERVATION OF ^{21}Ne STRUCTURE IN THE ^{17}O(α,α) RESONANCE REACTION

Nauruzbayev D.K.[1,2], Goldberg V.Z.[3], Nurmukhanbetova A.K.[4], Golovkov M.S.[5], Volya A.[6], Rogachev G.V.[3]

[1] *National Laboratory Nur-Sultan, Nazarbayev University, Nur-Sultan, 010000,Kazakhstan;* [2] *Saint Petersburg State University, Saint Petersburg, Russia;* [3] *Cyclotron Institute, Texas A&M University, College Station, Texas, USA;* [4] *Nazarbayev University, Nur-Sultan, Nazarbayev University, Nur-Sultan, 010000,Kazakhstan;* [5] *Joint Institute of Nuclear Research, Dubna, Russian;* [6] *Department of Physics, Florida State University, Tallahassee, Florida 32306, USA*

E-mail: anurmukhanbetova@nu.edu.kz

^{20}Ne nucleus is a famous textbook example of α-clustering. On the other hand, practically nothing is known on α-cluster structure in ^{21}Ne. The low neutron binding energy in ^{21}Ne makes this case much more special than, for instance, nearby ^{19}Ne. The properties (in particular, widths) of α-cluster states in ^{21}Ne should be sensitive to single particle admixtures. A combination of ^{20}Ne collective deformation with the extra neutron, and with the α-cluster degree of freedom can be also an interesting issue. There were no data on ^{21}Ne because of the experimental difficulties (in particular, of the classic approach to resonance scattering) and because of the difficulties of the interpretation of resonance scattering of α particle on ^{17}O with spin $5/2^+$.

We will present the first measurements of ^{17}O + α elastic scattering done at DC-60 cyclotron using the Thick Target Inverse Kinematic (TTIK) [1–3] method.

The *R*-matrix analysis of this experimental data has been performed for the first time [4]. The α and neutron decay channels of ^{21}Ne were included for this fit. A total of 35 states were used to fit of the total energy spectrum, from excitation energy of 8 MeV to 13 MeV. We identified that the α-cluster states in ^{21}Ne have many surprising properties, the foremost of which is the discovery of a broad, $l = 0$ state which is evidence of a developed α-cluster structure. Similar states may be present in many other nuclei in this mass range and have impact on our understanding of the cluster structure as well as on calculations of the various nuclear processes in stars. We also found that the properties of the positive parity levels support a weak coupling of the ^{17}O α-cluster.

The present data can also be used to revise results of the measurements of ^{17}O(α,*n*) reactions [4].

1. K.Artemov *et al*. // Sov. J. Nucl. Phys. 1990. V.52. P.408.
2. D.K.Nauruzbayev *et al*. // PhysRevC. 2017. V.96. 014322.
3. A.K.Nurmukhanbetova *et al*. // NIM in Phys. Res.S. A. 2017. V.847. P.1.
4. A.Nurmukhabetova *et al*. // Submitted to Phys. Lett. 2019.

FISSION OF ^{258}Md USING ^{4}He + ^{254}Es REACTION

Okubayashi M.[1], Nishio K.[2], Hirose K.[2], Kean K.R.[2,3], Makii H.[2], Orlandi R.[2], Tsukada K.[2], Asai M.[2], Toyoshima A.[2,4], Chiera N.M.[2], Ito Y.[2], Matsuda M.[2], Nagame Y.[2], Sato T.K.[2], Suzuki H.[2,5], Tokoi K.[2,5], Tomitsuka T.[2,6], Yanagihara R.[2,4], Tanaka T.[7,8], Morimoto K.[8], Andreyv A.N.[2,9], Tsekhanovich I.[10], Chiba S.[3], Ishizaki S.[1], Aritomo Y.[1], Rykaczewski K.P.[11], Boll R.A.[11], Kubono S.[8]

[1] Kindai University; [2] Japan Atomic Energy Agency; [3] Tokyo Tech.; [4] Osaka University; [5] Ibaraki University; [6] Niigata University; [7] Kyushu University; [8] RIKEN Nishina Center; [9] University of York; [10] University of Bordeaux; [11] ORNL

E-mail: tetsubomb69@gmail.com

The experiment to study fission of ^{258}Md was performed for the first time at JAEA tandem facility using the reaction of ^{4}He + ^{254}Es. The double-velocity measurement of both fission fragments was applied to determine the fission-fragment mass and total kinetic energy. Here, data from two excited states of the compound nucleus, 15 and 18 MeV, were taken. In the presentation, the results of data analysis will be given. The preliminary spectra reveal the presence of two fission modes leading to symmetric and asymmetric fissions.

ISOSPIN DYNAMICS AND NUCLEAR DIPOLAR DEGREE OF FREEDOM

Papa M.[1], Acosta L.[2], Cardella G.[1], Favela F.[3], De Filippo E.[1], Gnoffo B.[4], Lanzalone G.[4,5], Maiolino C.[4], Martorana N.[4,6] Pagano A.[1], Pagano E.V.[1,6], Pirrone S.[1], Politi G.[1,6], Quattrocchi L.[7], Rizzo F.[4,6] Russotto P.[4], Trifiró A.[7], Trimarchi M.[7]

[1] INFN Istituto Nazionale di Fisica Nucleare Catania Italy; [2] Instituto de Fisica, Universidad Nacional Autonoma de Mexico, Mexico City; [3] Instituto de Fisica, Universidad Nacional Autonoma de Mexico, Mexico City; [4] INFN Laboratori Nazionali del Sud Catania Italy; [5] Facolta' di Ingegneria e Archetettura Univ.' Kore Enna Italy; [6] Dipartimento di Fisica e Astronomia Univ. di Catania; [7] INFN Messina Italy, Dip. Di Scienze Fisice e della Terra, Univ. Messina

E-mail: massimo.papa@ct.infn.it

One of the most important and intriguing problems in studying Heavy Ion collisions at the Fermi energies is to recover information directly linked to the dynamical stage of the reaction without the blurring effects of later stages associated to the statistical decay of the hot sources which can be prominent for central collision. When the dynamical stage is well characterized, the obtained results can give clear information on the effective interactions governing the dynamics. In the last decades [1–3] it has been shown that the time derivative of the total average dipole obtained by measuring the charges Z and velocities of all the charged particles produced in a heavy ion collision does not depend on the statistical decay processes. It rather depends on the dynamics of the isospin equilibration processes between ions having large differences in the charge/mass ratios.

In this contribution we illustrate the results of a first investigation on this subject by studying the system $^{48}Ca + ^{27}Al$ at 40 MeV/A using the multi-detector CHIMERA [4] at the LNS and by selecting mid-peripheral collisions. These investigations continue with a new campaign of measurements carried out in June 2018 with the aim of studying more central collisions which are able to select higher density. Preliminary results of this second phase of investigation will be shown.

1. M.Papa *et al*. // Phys. Rev. C. 2005. V.72. 064608, and references therein.
2. M.Papa and G.Giuliani // J. Phys.: Conf. Ser. 2011. V.312. 082034.
3. M.Papa *et al.* // Phys. Rev. C. 2015. V.91. 041601R.
4. A.Pagano // Nucl. Phys. News 2012. V.22. P.25; G.Cardella *et al*. // Phys. Rev. C. 2012. V.85. 064609 and references therein.

NEUTRON RADIATION CALCULATION FOR STATIONARY CAMPAIGNS OF WWER-1200 REACTORS

Petrovski A.M., Rudak Ed.A., Korbut T.N., Kravchenko M.O.
Joint Institute for Power and Nuclear Research - Sosny, National Academy of Sciences of Belarus, 220109, Minsk, Belarus
E-mail: apetrovski@sosny.bas-net.by

Spent fuel from a nuclear power reactor has a high neutron radioactivity due to spontaneous fission of heavy actinides contained in the fuel. Actinides generation is nonlinear with respect to burnout, as a result of which the fuel with a relatively small increase in burnout, neutron activity may increase several times. In the presented work the neutron radiation of spent fuel from WWER-1200 reactors is investigated. Comparison of neutron radiation of spent fuel from a WWER-1000 reactor with a burnup of 40 MW day/kg and a WWER-1200 reactor with a burnout of 70 MW day/kg was made.

THE BM@N EXPERIMENT FOR STUDIES OF BARYONIC MATTER AT THE NUCLOTRON

Plotnikov V.A.[1] for the BM@N Collaboration
[1] *Joint Institute for Nuclear Research, Dubna, Russia*
E-mail: vplotnikov@jinr.ru

BM@N (Baryonic Matter at Nuclotron) is the first experiment realized at the accelerator complex of NICA-Nuclotron. The aim of the BM@N experiment is to study interactions of relativistic heavy ion beams with fixed targets. The scientific program of the BM@N experiment comprises studies of nuclear matter in the intermediate energy range between experiments at SIS and NICA/FAIR facilities. The BM@N experiment is in the starting phase of its operation and has recorded first experimental data. The experimental runs were performed in the carbon, argon and krypton beams with the kinetic energy ranging from 2.3 to 4 GeV per nucleon. The extended configuration of the BM@N set-up is being developed for the heavy ion beam program. The future experimental program of the experiment and first experimental results on the production of charged kaons and Lambda-hyperons are presented.

IDENTIFICATION AND ENERGY MEASURING OF CHARGED PARTICLES USING IONIZATION LOSS IN MULTIPLE LAYER GASEOUS DETECTOR

Potashev S.I., Burmistrov Yu.M., Zuyev S.V., Karaevsky S.Kh., Kasparov A.A., Konobeevski E.S., Razin V.I., Afonin A.A.
Institute for Nuclear Research of Russian Academy of Sciences, Moscow, Russia
E-mail: potashev@inr.ru

In experiments for interaction electron with nuclei at LUE-8 electron accelerator is required identification and determination the charged particle energy. The identification of charged particles in a novel multilayer gaseous detector is based on the detection of their ionization losses in several sensitive gaps separated by absorbing cathodes. The proportionality of the amplitude of the signal to the magnitude of the ionization loss and the correlation of the amplitudes measured in several sensitive gaps provides the charged particle identification. The contribution of conversion electrons is also estimated. The detector of the same kind is used as the air ion chamber for monitoring the accelerator electron beam. In this case, the magnitude of the loss averaged over the accelerator electron bunch is measured several times. The registration of the waveform from the detector is carried out using the DT5720 CAEN signal processor. Coincidence event for charged particle is selected by taking signals in a given time gate for each electronic channel. Background events are out of time gates. Amplitude spectrum of electrons for the decay of ^{90}Sr with the limiting energy of 0.5459 MeV and ^{90}Y with the limiting energy of 2.27 MeV is shown in Fig.1. Ionization losses from electrons from both sources are observed in the spectrum for the first sensitive gap of detector. The spectra for the second and subsequent sensitive gaps contain only the contribution from the losses of electrons of the source ^{90}Y. The spectrum of ionization losses becomes wider with the passage of each of the next sensitive gap.

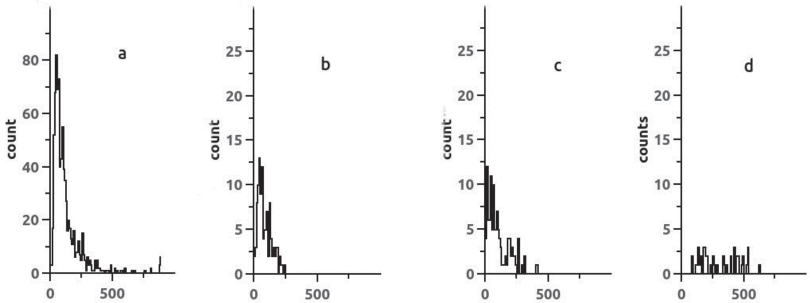


Fig. 1. Amplitude spectra a), b), c) and d) of electrons from the ^{90}Sr(^{90}Y) source in four consecutive sensitive gaps. Last three cathodes of detector are simultaneously absorbers.

UPDATED VERSION OF THE COLLINEAR CLUSTER TRI-PARTITION SCENARIO

Pyatkov Yu.V.[1,2], Kamanin D.V.[2], Alexandrov A.A.[2], Alexandrova I.A.[2], Goryainova Z.I.[2], Malaza V.[3], Strekalovsky A.O.[2], Strekalovsky O.V.[2,4], Zhuchko V.E.[2]

[1] *National Nuclear Research University MEPhi (Moscow Engineering Physics Institute), Moscow, Russia;* [2] *Joint Institute for Nuclear Research, Dubna, Russia;* [3] *University of Stellenbosch, Faculty of Military Science, Military Academy, Saldanha 7395, South Africa;* [4] *Dubna State University, Dubna, Russia*

E-mail: yvp_nov@mail.ru

In our recent publication [1] we have proposed possible scenario of the collinear cluster tri-partition (CCT) in ^{252}Cf(sf). Under our model, one of the most populated CCT modes giving rise to the so called "Ni-bump" occurs as a two-stage breakup of the initial three body chain like the nuclear configuration with an elongated central cluster. The model gave answers to many critical questions on the CCT scenario. Nevertheless, it's needed in further clarification. The updated version is discussed in this report.

1. Yu.V.Pyatkov *et al.* // Phys. Rev. C. 2017. V.96. 064606.

STUDY OF THE SHORT-LIVED RESONANCE PRODUCTION AND RECONSTRUCTION WITH THE MPD EXPERIMENT AT NICA

Ivanishchev D.A., Kotov D.O., Malaev M.V., Riabov V.G., Ryabov Yu.G.
NRC «Kurchatov Institute» - Petersburg Nuclear Physics Institute, Gatchina, Russia
E-mail: riabov_vg@pnpi.nrcki.ru

Measurements of short-lived hadronic resonances ($K^{*}(892)^{0,\pm}$, $\rho(770)^{0}$, $\phi(1020)$, $\Sigma(1385)^{\pm}$, $\Lambda(1520)$ and $\Xi(1530)^{0}$) are used to probe properties of the late hadronic phase in relativistic heavy ion collisions. Due to their lifetimes comparable to that of the fireball, the hadronic resonances are sensitive to the competing effects of particle re-scattering and regeneration in the hadronic gas, which modify particle momentum distributions and yields. A proper understanding of the properties of the hadronic phase is mandatory for interpretation of the experimental results related to the formation of the quark-gluon matter.

We present results of UrQMD based studies of the influence of the hadronic phase on the measured properties of resonances in heavy ion collisions at NICA energies. Moreover, we discuss prospects for resonance measurements in the MPD experimental setup and results of the feasibility studies obtained using Monte Carlo simulation of the detector performance.

STUDY OF NEUTRAL MESON PRODUCTION WITH PHOTON CONVERSIONS IN THE MPD EXPERIMENT AT NICA

Ivanishchev D.A., Kotov D.O., Kryshen E.L., Malaev M.V., Riabov V.G., Ryabov Yu.G.
NRC «Kurchatov Institute» - Petersburg Nuclear Physics Institute, Gatchina, Russia
E-mail: ryabov_yg@pnpi.nrcki.ru

The MPD experiment is aimed to study strongly interacting matter in nucleus-nucleus collisions at the future NICA collider in the energy range 4–11 GeV per nucleon pair. Neutral pion an eta measurements via two-photon decays will allow the MPD experiment to extend the variety of registered particle species and will provide important information on dynamics and properties of the medium created in heavy ion collisions at NICA energies. The measurement of neutral pion and eta meson spectra is also important as a first step towards the analysis of thermal photons sensitive to the temperature of the produced medium. In this contribution, the feasibility of neutral meson production measurements in the two-photon channel via photon conversions will be presented, and implications for the study of thermal photons will be discussed.

INVESTIGATION OF α AND ^{3}He SCATTERING ON ^{14}N AT ENERGIES 50 AND 60 MeV

Burtebayev N.[1], Duisebayev B.A.[1], Sadykov B.M.[1], Sakuta S.B.[2], Zholdybayev T.K.[1], Nassurlla Maulen[1,3]
[1] Institute of Nuclear Physics, Almaty, Kazakhstan; [2] National Research Center "Kurchatov Institute", Moscow, Russia; [3] Al Farabi Kazakh National University, Almaty, Kazakhstan
E-mail: sadykovbm@inp.kz

The experimental data on the cross sections of the nuclear reactions and their analysis in the framework of the various theoretical models are the main source of the information on the structure of the nucleus. In this connection, the new experimental data on the cross sections of the nuclear reactions opens a new level of the information support for the fundamental (nuclear physics, nuclear astrophysics, new energy sources) and applied (the medical use of the artificial radioactive isotopes) researches.

In the present work, a new analysis was made of the experimental data obtained earlier for the elastic and inelastic scatterings of ^{3}He and α-particles on ^{14}N nuclei at a beam energy of 50 and 60 MeV, supplemented by the measurements of the differential cross-sections for the 5.69 MeV (1^-) and 7.03 MeV (2^+) states. The main objectives of the study were to obtain new data on the deformation parameters.

The differential cross-sections of elastic and inelastic scattering of ^{3}He and α-particles with E = 50–60 MeV on ^{14}N nucleus were measured on the U-150M Kazakh isochronous cyclotron. A gas target was used in the experiment. The statistical uncertainties of the measured differential cross sections were less than 10%. The uncertainty in the estimation of the thickness was not more than 3%. The total energy resolution ranged from 400 to 500 keV, depending on the scattering angle. It was resulting mostly from the spread of the beam energy and the target thickness.

Differential cross sections on elastic scattering were analyzed within the framework of the optical model (code SPI-GENOA [1]) using the potentials of Woods–Saxon parameterization. The parameters of the potentials were defined phenomenologically from fitting the calculated cross sections to the experimental data. Analysis of cross sections of inelastic scattered ions of ^{3}He and α-particles were carried out using the distorted wave Born approximation (with code DWUCK4 [2]) with form-factor of a macroscopic collective excitation using optimal optical potential parameters obtained from elastic scattering. The character of the angular distributions of elastic and inelastic scattering is described quite well.

1. F.G.Perey // NBI version. 1976.
2. P.D.Kunz // University of Colorado, Boulder, Colorado, USA (unpublished).

SCATTERING OF α-PARTICLES BY ^{11}B NUCLEI AT AN ENERGY OF 40 MeV AND ROLE OF THE EXCHANGE MECHANISM WITH TRANSFER OF ^{7}Li

Burtebayev N.[1], Nassurlla Maulen[1,2], Nassurlla Marzhan[1], Saduyev N.O.[2], Sabidolda A.[1], Zazulin D.[1,2], Sakuta S.B.[3], Trzcińska A.[4], Wolińska-Cichocka M.[4]

[1] Institute of Nuclear Physics, Almaty, Kazakhstan; [2] Al Farabi Kazakh National University, Almaty, Kazakhstan; [3] National Research Center "Kurchatov Institute", Moscow, Russia; [4] Heavy Ion Laboratory, Warsaw University, Warsaw, Poland

E-mail: sbsakuta@mail.ru

The elastic and inelastic scattering of α-particles with the excitation of low-lying states of the ^{11}B nucleus (0.0 ($3/2^-$), 4.445 ($5/2^-$), 6.74 ($7/2^-$), 2.125 MeV ($1/2^-$) and 5.02 MeV ($3/2^-$)) was investigated at an energy of 40 MeV. A typical spectrum of the α-particles scattered at 40 MeV is shown in Fig. 1. The analysis of the experimental angular distributions was carried out via the coupled channels method within the framework of the collective model using code FRESCO [1]. The calculations reproduce quite well the experimental cross sections in the full angular range with the optical potential found for the system ^{11}B + α and with the parameter of quadrupole deformation $\beta_2 = 0.545$. The calculations indicate the advantage of negative sign of the deformation that agrees with the results of the analysis of the scattering of protons, α particles and ^{3}He [2].

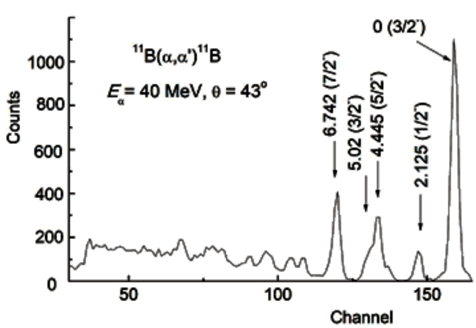


Fig. 1. Energy spectrum of α-particles scattered on ^{11}B nuclei at the beam energy of 40 MeV measured at the angle of 43°.

It is shown that the exchange mechanism with the transfer of the heavy ^{7}Li cluster does not play an important role in the scattering of α-particles on ^{11}B nuclei at energy of 40 MeV.

1. I.J.Thompson // Comput. Phys. Rep. 1988. V.**7**. P.167, available at: http://www.fresco.org.uk/.
2. N.Burtebaev, M.K.Baktybaev, B.A.Duisebaev, R.J.Peterson, S.B.Sakuta // Phys. Atomic Nuclei. 2005. V.68. P.1303.

CROSS SECTION OF NEUTRINO ABSORPTION BY GALLIUM-71 NUCLEI

Semenov S.V.
National Research Centre "Kurchatov Institute", Moscow, Russia
E-mail: Semenov_SV@nrcki.ru

Interaction of neutrino from artificial sources with gallium-71, which is the question of interest for oscillation experiments, aimed at sterile neutrino searches, is examined. The cross section of neutrino absorption is calculated [1]. The calculations are based on the new measurement of reaction threshold. The corresponding contributions of the excited states of germanium-71, observed by the means of charge exchange reactions, are estimated. The influence of cross section values on calibration experiments data analysis is considered.

1. S.V.Semenov // Proceedings of the International Conference "The multi-messenger astronomy: gamma-ray bursts, search for electromagnetic counterparts to neutrino events and gravitational waves", 7-14 October 2018. Nizhnij Arkhyz (SAO) and Terskol (BNO).

AN EFFECTIVE METHOD OF EXCITATION FUNCTION MEASUREMENTS FOR (α,*n*) REACTIONS AT LOW ENERGIES

Serikov A.[1,2], Bezbakh A.A.[1], Gazeeva E.M.[1,2], Goldberg V.Z.[3], Golovkov M.S.[1,2], Kurmanaliyev Zh.K.[1,4], Nauruzbayev D.K.[5,6], Nurmukhanbetova A.K.[5]

[1] Joint Institute for Nuclear Research, Dubna, Russia; [2] Dubna State University, Dubna, Russia; [3] Cyclotron Institute, Texas A&M University, College station, Texas, USA; [4] L.N. Gumilyov Eurasian National University, Nur-Sultan,010000, Kazakhstan; [5] National Laboratory Nur-Sultan, Nazarbayev University, Nur-Sultan, 010000, Kazakhstan; [6] Saint Petersburg State University, Saint Petersburg, Russia

E-mail: adilzhan_serikov@bk.ru

This work is dedicated to the development of the thick target at inverse kinematics method (TTIK) [1, 2] with an aim to examining the possibility of measuring excitation functions for (α,*n*) reactions. The usage of pulse beams in the frame of TTIK approach in combination with time of flight measurements enables to measure excitation function in a wide energy range with an experimental resolution of a few dozen keV even at cyclotrons. Test experiment was performed on the basis of the heavy ion accelerator DC-60 at The Institute of Nuclear Physics' Nur-Sultan branch (Nur-Sultan, Kazakhstan). The excitation function of resonance reaction $^{13}C(\alpha,n)^{16}O$ in excitation energy range of ~ 8.2–8.9 MeV was measured. The obtained results are compared with the data of other recognized works [3–5] and the future of new approach is discussed.

1. K.P.Artemov *et al.* // Yad.Fiz. 1990. V.52. P.634; Sov.J.Nucl.Phys. 1990. V.52. P.408.
2. V.Z.Goldberg, A.E.Pakhomov // Yad.Fiz. 1993. V.56. No 9. P.31; Phys.Atomic Nuclei 1993. V.56. P.1167.
3. R.B.Walton *et al.* // Phys. Rev. 1957. V.107. P.1065.
4. B.K.Barnes *et al.* // Phys. Rev. 1965. V.140. P.616.
5. M.Heil *et al.* // Phys. Rev. C. 2008. V.78. 025803.

A SYSTEMATIC STUDY OF PRE-COMPOUND EMISSION IN LIGHT AND HEAVY ION INDUCED REACTIONS AT LOW ENERGIES

Sharma Manoj Kumar[1], Kumar Mahesh[1], Shuaib Mohd.[2], Sharma Vijay R.[3], Yadav Abhishek[4], Singh Pushpendra P.[5], Singh Devendra P.[6], Singh B.P.[2,3], Prasad R.[2]

[1] Department of Physics, Sri Varshney College, Aligarh-202001, India; [2] Department of Physics, Aligarh Muslim University, Aligarh-202 002, India; [3] Departamento de Aceleradores, Instituto Nacional Investigaciones Nucleares, Apartado Postal 18-1027, C.P. 11801 Ciudad de Mexico, Mexico; [4] NP-Group Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi-110 067, India; [4] Physics Department, S. V. College, Aligarh-202001, India; [5] Department of Physics, Indian Institute of Technology Ropar, Rupnagar, Punjab-140 001, India; [6] Department of Physics, University of Petroleum and Energy Studies, Dehradun-248 007, India

E-mail: manojamu76@gmail.com

During the last few decades, the mechanism of pre-compound (PCN) emission has been a topic of considerable attention for testing nuclear models in light and heavy ion fusion reactions at relatively high energies above 10 MeV/*A*. Recent studies showing the observations of PCN emission even at low incident energies below 10 MeV/*A*, where evaporation process dominates, have renewed interest to carry out further research in the aforesaid reaction mechanism [1–3]. In order to carry out such study at energies below 10 MeV/nucleon and to develop a systematics in PCN process, the excitation functions of the reaction residues produced in the $\alpha + {}^{51}V$, $\alpha + {}^{55}Mn$, $\alpha + {}^{93}Nb$, $\alpha + {}^{121}Sb$, $\alpha + {}^{123}Sb$, ${}^{12}C + {}^{128}Te$, ${}^{12}C + {}^{169}Tm$, ${}^{16}O + {}^{159}Tb$, ${}^{16}O + {}^{169}Tm$ and ${}^{16}O + {}^{181}Ta$ systems have been measured. These experiments have been carried out using accelerator facilities of the Variable Energy Cyclotron Centre (VECC), Kolkata, India and Inter University Accelerator (IUAC), New Delhi, India. The measured excitation functions have been analyzed within the framework of both the semi-classical as well as some quantum mechanical models.

In the present work, the significant contribution of the PCN emission has been obtained in the above mentioned systems. A new systematics has been developed in terms of target mass number and excitation energy of the nucleon at the surface of an excited compound system. Further details will be presented.

1. Manoj Kumar Sharma *et al.* // Eur. Phys. J. A. 2018. V.54. P.205.
2. Manoj Kumar Sharma *et al.* // Phys. Rev. C. 2018. V.98. 054607.
3. Manoj Kumar Sharma *et al.* // Phys. Rev. C. 2015. V.91 014603.

UPGRADE OF THE GERDA PHASE II EXPERIMENT

Shevchik E.A. on behalf of GERDA collaboration
Joint Institute for Nuclear Research, Dubna, Russia
E-mail: egor.shevchik@gmail.com

The GERDA collaboration is performing a sensitive search for neutrinoless double beta decay of ^{76}Ge at the INFN Laboratori Nazionali del Gran Sasso, Italy. After the latest data release performed in the middle of 2018, the total (Phase I + II) exposure of 82.4 kg·yr was achieved, the largest exposure obtained so far by a single experiment searching for 0νββ decay of ^{76}Ge. No signal was observed and a lower limit of $0.9 \cdot 10^{26}$ yr (90 % C.L.) was derived. GERDA collaboration reached important milestones in the 0νββ search with ^{76}Ge in the Phase II by achieving the $6 \cdot 10^{-4}$ cts/(keV·kg·yr) background index and the half-life sensitivity of 10^{26} years.

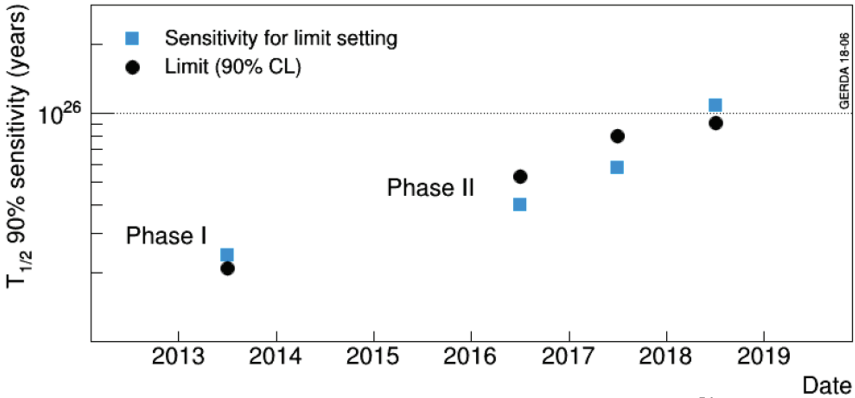


Fig. 2. The improvement of the lower limit of the half-life for 0νββ decay of ^{76}Ge by the Gerda experiment with time.

The upgrade of the GERDA Phase II setup was undertaken in April and May 2018 by improving the liquid argon (LAr) veto instrumentation and by deploying a new type of germanium detectors. The goal of the upgrade was to reduce background and provide tests of the inverted coaxial Ge detectors, which are intended to use in the next large scale experiment.

GERDA will collect data until the end of 2019. The next generation Ge experiment LEGEND-200 aimed to sensitivity of 10^{27} years will take place with modified GERDA infrastructure.

THE FINAL RESULTS OF THE NEMO-3 EXPERIMENT AND STATUS OF THE SUPERNEMO PROJECT

Shitov Yu.A. on behalf of the NEMO-3/SuperNEMO collaborations
Joint Institute for Nuclear Research, Dubna, Russia
E-mail: shitov@jinr.ru

The SuperNEMO project is aimed to search neutrinoless double beta decay ($0\nu\beta\beta$), which would be an indication of new fundamental physics beyond the Standard Model, such as the nature of neutrino (either Dirac or Majorana), the absolute neutrino mass scale, and neutrino hierarchy. Observation of $0\nu\beta\beta$ would also help to resolve the topical puzzles of fundamental physics: CP violation, Leptogenesys, GUTs.

SuperNEMO is a next generation $0\nu\beta\beta$-experiment based on the improved successful NEMO-3 tracking and calorimetric technology. The goal of SuperNEMO is to reach sensitivity on the Majorana effective neutrino mass of 50–100 meV with an exposure of 500 kg*y by using ~ 100 kg of enriched ^{82}Se.

Final results on ^{82}Se [1] and ^{100}Mo [2] for the NEMO-3 will be presented and discussed, as well as the progress in the construction of the Demonstrator (first module) of the SuperNEMO project (shown in Fig.1), the data taking of which will start at the end of this year.

Fig. 1. The Demonstrator of the SuperNEMO under antiradon tent built in the underground laboratory (Modane, France).

1. R.Arnold *et al.* // Eur. Phys. J. C. 2018. V.78. P.821.
2. R.Arnold *et al.* // arXiv:1903.08084, submitted to the EPJC.

A STUDY OF INCOMPLETE FUSION IN HEAVY ION REACTIONS AT LOW ENERGIES

Singh B.P.[1], Shuaib Mohd.[1], Majeed Ishfaq[1], Yadav Abhishek[2], Sharma Manoj Kumar[3], Sharma Vijay R.[4], Singh Pushpendra P.[5], Kumar Mahesh[3], Sood Arshiya[5], Kaushik Malika[5], Sahoo Rudra N.[5], Singh D.P.[6], Gupta Unnati[7], Kumar R.[8], Muralithar S.[8], Singh R.P.[8], Prasad R.[1]

[1] Department of Physics, Aligarh Muslim University, Aligarh-202002, India; [2] Department of Physics, Jamia Millia Islamia, Jamia Nagar, New Delhi-10025, India; [3] Physics Department, S.V. College, Aligarh-202001, India; [4] Departamento de Aceleradores, Instituto Nacional de Investigaciones Nucleares, Apartado Postal 18-1027, C.P. 11801, Ciudad de Mexico, Mexico; [5] Department of Physics, Indian Institute of Technology, Ropar, Punjab-140 001, India; [6] Department of Physics, UPES, Dehradun-248 007, India; [7] Department of Physics & Astrophysics, University of Delhi, Delhi-110 007, India; [8] NP-Group, Inter University Accelerator Centre, New Delhi-110057, India

E-mail: bpsinghamu@gmail.com

The reaction mechanism of heavy-ion interactions at low projectile energies is still not well understood. Both the complete fusion (CF) as well as incomplete fusion (ICF) of projectile has been observed at these energies. In the ICF reactions, a part of the incident ion fuses with the target nucleus while the remnant moves forward with the same velocity as that of projectile. Several models have been proposed, however, none of them is able to explain the ICF data at energies ≈ 4–7 MeV/n. In order study the ICF reactions and to study its influence on various entrance channel parameters, we have undertaken a programme for the measurement and analysis of excitation functions and recoil range distributions in heavy ion interactions at low energies. Complementary measurements for the ^{19}F + ^{169}Tm system have been carried out. The experiments have been carried out using pelletron accelerator facility at the Inter University Accelerator Centre, New Delhi, India. Excitation functions (EF) for the reaction channels ^{184}Pt(4n),^{183}Pt(5n), ^{184}Ir(p3n), ^{183}Ir(p4n), ^{183}Os(αn), ^{181}Os(α3n), ^{179}Os(α5n), ^{177}W(2α3n) and ^{175}Ta(2αp4n) have been measured using stacked foil activation technique. The measured EFs were analysed within the framework of statistical model code PACE4. Analysis of data has indicated significant contribution of ICF processes in the alpha emitting channels. The forward recoil range distributions (FRRD) of the residues have also been measured in a separate experiment using recoil catcher technique, which is the most direct and irrefutable method for deciphering the two competing processes. It may be pointed out that, it is the first measurement of FRRD using a non-alpha cluster beam. The results of the present work have been used to develop systematics for incomplete fusion processes that may be useful for the development of a theoretical model for ICF reactions at low energies. The details will be presented.

CHARGE-EXCHANGE REACTIONS ON LOW-ENERGY BEAMS OF HEAVY IONS

Skobelev N.K.
Joint Institute for Nuclear Research, Dubna, Russia
E-mail: skobelev@jinr.ru

Quasi-elastic charge-exchange nuclear reactions are of great interest, when the ejected particle in mass and other characteristics (including energy) differs little from the incident one, but has a different ratio of protons and neutrons.

Reactions of quasi-elastic scattering of neutrons and protons on nuclei often lead to charge exchange as well as to the excitation of isobar-analog states. In addition to the (p, n) reaction, these states can be excited in other charge-exchange reactions, for example, in the $(^3He, t)$ reaction. This reaction has a certain advantage over the (p, n) reaction. First, it is easier to identify charged particles (t) than neutrons in the (p, n) reaction. Second, in the $(^3He, t)$ reaction and in other charge-exchange reactions with heavy ions, multistage processes play a much smaller role; therefore, the extracted information on the properties of nuclear interaction is more reliable. The cross sections for such reaction channels reach significant values even when the energy of bombarding particles is close to the Coulomb barrier for the reactions on ^{45}Sc and ^{197}Au [1, 2]. Charge-exchange reactions on beams of heavy ions are also observed at higher energies of bombarding particles. For example, in the reactions on beams of the ^{18}O heavy ions with ^9Be [3] and ^{181}Ta, charge-exchange channels $(^{18}O, ^{18}F)$, $(^{18}O, ^{18}N)$, as well as $(^{18}O, ^{18}C)$ were registered at ^{18}O energy from 10 to 35 MeV/A.

Charge-exchange reactions on heavy-ion beams are interesting for the study of particle-hole states in a wide range of nuclei; from them, reliable information on the properties of excited isobar-analog states is extracted, and therefore – the model representations of the isobar-spin potential and isovector nucleon-nucleus interaction.

1. N.K.Skobelev, A.A.Kulko, Yu.E.Penionzhkevich *et al.* // Phys. Part. Nucl. Lett. 2013. V.10. P.410.
2. N.K.Skobelev, Yu.E.Penionzhkevich *et al.* // Phys. Part. Nucl. Lett. 2014. V.11. P.114.
3. A.G.Artukh *et al.* // Nucl. Phys. A. 2002. V.701. P.96c.

TWO-PHONON COUPLED-CHANNEL ANALYSIS OF THE SPIN DEPENDENCE OF *p*-WAVE NEUTRON SCATTERING BY SPHERICAL NUCLEI

Skorkin V.M.
Institute for Nuclear Research, Moscow, Russia
E-mail: skorkin@inr.ru

The spin-orbit splitting of neutron strength function 3*p*-maximum show spin dependence of *p*-wave neutron-nuclear scattering by nuclei [1].

The number dependence of the $p_{1/2}$- and $p_{3/2}$-neutron strength functions for spherical nuclei in the region $A = 70–130$ is described within the many-phonon coupled-channel approach [2].

In the present work, we analyzed the mass and spin dependences of the *p*-strength function, scattering radii, inelastic scattering cross section for even-even nuclei using the two-phonon coupled-channel optical model [3]. The experimental data has been descripted for the five-channel approximation generalized optical model with $0^+–2^+–0^+–2^+–4^+$ coupled circuit of vibration states.

The nuclear potential had the valid part in the form of Woods-Saxon with $V_0 = 53$ MeV and $r_0 = 1.22$ fm, the symmetry potential $V_0 = 22$ MeV and the spin-orbit term $V_{SO} = 8$ MeV. The deformation parameters of the nuclear field corresponded to the experimental values of the quadrupole deformation β_2.

The calculated values of the $p_{1/2}$- and $p_{3/2}$-neutron strength functions в 3*p* maxima $\sim 8\cdot10^{-4}$ and $\sim 6\cdot10^{-4}$ correspond to the experimental values of $S_{1/2} \approx 8\cdot10^{-4}$ and $S_{3/2} \approx 6\cdot10^{-4}$. At the same time, the calculated interval between $3p_{1/2}$ and $3p_{3/2}$ peaks at $A \approx 110$ and $A \approx 95$ close to experimental value $\Delta A_{max} \approx 15$.

In the region $A \approx 70–130$, the main contribution to 2^+-collective state excitation is made by the $p_{1/2}$- and $p_{3/2}$-cannels. The direct reaction cross section at a neutron energy of ~1 MeV comparable with the fluctuation cross section and correlates with the *A*-dependence of the strength functions.

1. G.S.Samosvat // Phys. Particl. and Nucl. 1995. V.26. No.1. P.1567.
2. V.V.Samoilov, M.G.Urin // Nucl. Phys. 1990. V.52. No.5. P.1325.
3. R.M.Musaelyan *et al*. // Bull. Rus. Acad. Sci: Phys. 1992. V.56. No.11. P.122.

ENERGY DEPENDENCE OF TOTAL REACTION CROSS SECTIONS FOR ^{6,8}He, ^{8,9}Li BEAM PARTICLES ON ^{28}Si, ^{59}Co, ^{181}Ta TARGETS

Sobolev Yu.G.[1,2], Penionzhkevich Yu.E.[1,3], Samarin V.V.[1,4], Kugler A.[5], Louko J.[6], Naumenko M.A.[1], Siváček I.[1,5], Stukalov S.S.[1]

[1] JINR, Joint Institute for Nuclear Research, 141980, Dubna, Russia; [2] National Research Center "Kurchatov Institute" Moscow, 123182, Russia; [3] MEPhI, National Research NuclearUniversity,115409, Moscow, Russia; [4] Dubna State University, Dubna, Russia; [5] NPI ASCR, Nuclear Physics Institute, CZ 250 68, Řež, Czech Republic; [6] Department of Physics, P.O. Box 35 (YFL) FI-40014 University of Jyvaskyla, Finland

E-mail: sobolev@jinr.ru

New experimental data of direct measurement of total reaction cross section values for interaction ^{6,8}He, ^{8,9}Li cocktail beam particles with ^{28}Si, ^{59}Co, ^{181}Ta target nuclei in the energy range 15–40 A MeV are presented. Modified transmission method based on prompt *n*, γ radiation detection by multi-module γ-spectrometer [1] was used. In this work 12 module CsI(Tl) high efficiency γ-spectrometer has been applied. Presented data for ^{6,8}He + ^{28}Si and ^{9}Li + ^{28}Si reactions, in the frame of the experimental uncertainties, are overlapping with previously published results obtained by other transmission methods [2]. It confirms the observation of the peculiarity of cross section "bump" in $\sigma_R(E)$ for ^{6,8}He + ^{28}Si and ^{9}Li + ^{28}Si reactions at $E \sim$ 10–30 A MeV [3,4]. Theoretical analysis of presented experimental data was carried out in the microscopic model based on a numerical solving of the time-dependent Schrödinger equation for the outer weakly bound neutrons of the projectile nucleus [5].

1. Yu.E.Penionzhkevich, Yu.G.Sobolev, V.V.Samarin, M.A.Naumenko // Phys. Rev. C. 2019. V.99. 014609.
2. Yu.E.Penionzhkevich, Yu.G.Sobolev, V.V.Samarin, M.A.Naumenko // Phys. At. Nucl. 2017. V.80. P.928.
3. Yu.G.Sobolev, E.V.Zemlyanaya, R.Kalpakchieva, *et al.* // Bull. Russ. Acad. Sci. Phys. 2005. V.69. № 11. P.1790.
4. Yu.G.Sobolev, Yu.E.Penionzhkevich, *et al.* // Phys. Part. Nucl. 2017. V.48. N.6. P.922.
5. V.V.Samarin // Phys. At. Nucl. 2015. V.78. P.128.

ON THE TOTAL PHOTOABSORPTION CROSS SECTIONS. MEASUREMENT NEAR PARTICLE THRESHOLD

Solodukhov G.V., Lapik A.M., Nedorezov V.G., Ponomarev V.N., Rusakov A.V., Turinge A.A.
INR RAS, Moscow, Russia
E-mail: solod@inr.ru

The review of experimental data on total nuclear photoabsorption cross sections near the threshold is given. The program of possible experiments on this subject at the linear electron accelerator LUE-8-5 RV of INR RAS is discussed. The results of the simulation performed by the GEANT-4 program are presented. It is shown that the total photoabsorption method, which was previously has been used in the giant dipole resonance region [1], can be applied to energies near the threshold (from 5 to 10 MeV). This area contains new information about nuclear excitations of different nature (pygmy resonances). The problem of subtraction of the atomic cross sections of photoabsorption from the total ones to determine the absolute values of nuclear cross sections is discussed. The preliminary results of the first measurements at the LUE-8-5RV and gamma spectrometer are presented. The possibilities of practical application of the obtained results are discussed.

1. G.M.Gurevich, L.E.Lazareva, V.M.Mazur, G.V.Solodukhov // Proc. of 3rd Seminar “Electromagnetic interaction of nuclei” Moscow. 1975. P.61.
2. V.N.Ponomarev, G.V.Solodukhov, V.G.Nedorezov // Int. Sem. on Electromagnetic Interactions of Nuclei (EMIN-2018). Proc. of RAS ser. phys., in print.

FISSION FRAGMENTS BINARY BRAKE-UP AT CROSSING OF METAL FOILS

Strekalovsky A.O.[1], Kamanin D.V.[1], Pyatkov Yu.V.[1,2], Alexandrov A.A.[1], Alexandrova I.A.[1], Goryainova Z.I.[1], Malaza V.[3], Kuznetsova E.A.[1], Strekalovsky O.V.[1,4], Zhuchko V.E.[1]

[1] Joint Institute for Nuclear Research, 141980 Dubna, Russia; [2] National Nuclear Research University "MEPHI", 115409 Moscow, Russia; [3] University of Stellenbosch, Faculty of Military Science, Military Academy, Saldanha 7395, South Africa; [4] Dubna State University, 141980 Dubna, Russia

E-mail: alex.strek@bk.ru

In our previous publications [1–3] we discussed the new original effect appeared at crossing of the metal foils by fission fragments (FFs). In the series of recent experiments we have compared the mass of the FF before (Mtt) and after (Mte) it passes the foil event by event. In the light of the obtained results, an FF from conventional binary fission is supposed to be born in the shape isomer state which looks like a di-nuclear system consisting of the magic core and lighter cluster. Comparison of the correlation mass distributions Mtt-Mte for different metal foils is presented in order to test possible models of the effect.

1. Yu.V.Pyatkov *et al*. // Proceedings of the 22th International Seminar on Interaction of Neutrons with Nuclei. P.83.
2. Yu.V.Pyatkov *et al*. // International Symposium on Exotic Nuclei "EXON-2014", Conference proceedings, Editors: Yu.E.Penionzhkevich and Yu.G.Sobolev. Published by World Scientific Publishing Co. Pte. Ltd., 2015. P.383.
3. Yu.V.Pyatkov *et al*. // Int. Symposium on Exotic Nuclei "EXON-2016", Conference proceedings, Editors: Yu.E.Penionzhkevich and Yu.G.Sobolev. Published by World Scientific Publishing Co. Pte. Ltd., 2017. P.284.

PERFORMANCE OF ANISOTROPIC FLOW MEASUREMENTS WITH THE MPD EXPERIMENT AT NICA

Anikeev A.A., Parfenov P.E., Taranenko A.V., Truttse A.A.
National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow, Russia
E-mail: AVTaranenko@mephi.ru

Multi-Purpose Detector (MPD) experiment at NICA collider has a potential of discoveries in the area of QCD phase diagram with high net baryon densities and moderate temperatures. Anisotropic transverse flow is one of the key observables to study the properties of matter created in heavy-ion collisions. MPD performance for anisotropic flow measurements is studied with Monte-Carlo simulations of gold ions at NICA energies 4–11 GeV using different heavy-ion event generators. Different combinations of the MPD detector subsystems are used to investigate the possible systematic biases in flow measurement and to study effects of detector azimuthal non-uniformity. Resulting performance of the MPD for flow measurements will be demonstrated for directed and elliptic flow of identified charged hadrons as a function of rapidity and transverse momentum in different centrality classes.

STUDY OF THE DIFFERENTIAL CROSS SECTION OF THE DEUTERON – PROTON ELASTIC SCATTERING AT 1 – 2 GeV

Terekhin A.A.[1], Ladygin V.P.[1], Ladygina N.B.[1], Piyadin S.M.[1], Khrenov A.N.[1], Kurilkin A.K.[1], Isupov A.Y.[1], Reznikov S.G.[1], Gurchin Y.V.[1], Janek M.[2]
[1] *Joint Institute for Nuclear Research, Dubna, Russia;* [2] *Physics Department, University of Zilina, Zilina, Slovakia*
E-mail: aterekhin@jinr.ru

The study of the different observables in the reactions with deuteron at intermediate and high energies is necessary to understand of the nucleon-nucleon and three-nucleon interaction structure, relativistic effects role and the mechanism of manifestation of the fundamental degree of freedom.

The results of studies of the deuteron-proton elastic scattering differential cross section at energies of 500–1000 MeV/nucleon at the Internal Targets Station at Nuclotron are presented. The obtained results are compared with world data at the similar energies, as well as with the theoretical calculations performed in the framework of the relativistic multiple scattering theory. The best agreement is observed at 500 MeV/nucleon, however, the discrepancy between theory and experiment is increased with the energy increasing. The energy dependences of the differential cross section at six fixed scattering angles in cm. for energy range $\sqrt{s}$ = 3.1–3.42 GeV are in reasonable agreement with the behavior of the world data, as well as with the predictions of the quark counting rules.

EXPERIMENTAL STUDY OF ECR ION SOURCE PARAMETERS USING SHORT PULSE INJECTIONS OF HG AND NOBLE GASES LEAKAGES AT MASHA SETUP

Vedeneev V.Yu.[1], Rodin A.M.[1], Krupa L.[1,2], Chernysheva E.V.[1], Dmitriev S.N.[1], Gulyaev A.V.[1], Gulyaeva A.V.[1], Kamas D.[3], Komarov A.B.[1], Novoselov A.S.[1], Opíchal A.[4], Salamatin V.S.[1], Stepantsov S.V.[1], Podshibyakin A.V.[1], Yukhimchuk S.A.[1]

[1] Joint Institute for Nuclear Research, Flerov Laboratory of Nuclear Reactions, Joliot Curie 6, Dubna, Moscow region, 141980 Russia; [2] Institute of Experimental and Applied Physics, Czech Technical University in Prague, Horska 3a/22, Prague 2, 12800, Czech Republic; [3] Institute of Physics, Slovak Academy of Sciences, Dubravska cesta, 9, Bratislava, 84228 Slovakia; [4] Palacký University Olomouc, Křížkovského 511/8, CZ-771 47 Olomouc, Czech Republic

E-mail: vvedeneyev@gmail.com

A short pulse injection of mercury as a homologue of Copernicium and Flerovium and noble gases such as leakages of Xenon and Krypton inside the ECRIS represents more real picture on a processes inside the system during an experiment than continuous one. A large extraction time of mercury makes detection and research of mercury-like SHEs almost impossible. An extraction time could be decreased using different ion source chamber and transportation line wall coverings. For that reasons an extraction time and efficiency of ECR ion source were measured at MASHA installation, FLNR, using short-time gas valve “Parker”, which could make injections with a duration up to 2 ms and compared to results gathered with continuous calibrated leakages. In a present speech a question and a solving of these problems would be risen.

THE HOYLE STATE IN ^{12}C AND ^{16}O DISSOCIATION

Zaitsev A.A.
Joint Institute for Nuclear Research (JINR), Dubna, Russia
E-mail: zaicev@lhe.jinr.ru

Events of dissociation of relativistic light nuclei observable in detail in the nuclear track emulsion (NTE) contain holistic information on ensembles of lightest nuclei which is of interest to the nuclear cluster physics [1]. The best spatial resolution provided by the NTE technique turns out to be a decisive factor for recognition relativistic ^{8}Be and ^{9}B decays among the projectile fragments [2]. The decays are identified by the invariant mass M^* defined by the sum of all products of 4-momenta P_i of relativistic fragments He and H. Subtracting the sum of the residual masses M is a matter of convenience $Q = M^* - M$. The components P_i are determined by the fragment emission angles under the assumption of conservation a projectile momentum per nucleon.

Production of α-particle triples in the Hoyle state (HS) in dissociation of ^{12}C nuclei at 3.65 and 0.42 A GeV in nuclear track emulsion is revealed by the invariant mass approach [3]. Contribution of the HS to the dissociation $^{12}\mathrm{C} \rightarrow 3\alpha$ is (11 ± 3) %. Reanalysis of data on coherent dissociation $^{16}\mathrm{O} \rightarrow 4\alpha$ at 3.65 A GeV is revealed the HS contribution of (22 ± 2) %. These observations indicate that it is not reduced to the unusual ^{12}C excitation and, like ^{8}Be, is a more universal object of nuclear molecular nature. The analysis of the NTE layers exposed to relativistic ^{14}N nuclei is resumed in the HS context. Video records of events of dissociation of relativistic nuclei in NTE obtained using a microscope and a digital camera can be found [4].

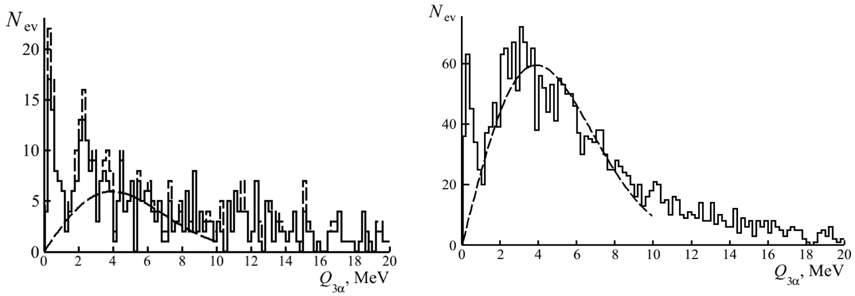


Fig. Distribution over invariant mass $Q_{3\alpha}$ of α-triples in dissociation of $^{12}\mathrm{C} \rightarrow 3\alpha$ GeV (left) and 3α combinations in "white" stars $^{16}\mathrm{O} \rightarrow 4\alpha$ at 3.65 A GeV (right).

1. P.I.Zarubin // Lect. Notes in Physics, Clusters in Nuclei, 2014. V.875(3) P.51; arXiv: 1309.4881.
2. D.A.Artemenkov, A.A.Zaitsev, P.I. Zarubin // Phys. Part. Nucl. 2017. V.48 P.147; arXiv:1607.08020.
3. D.A.Artemenkov *et al.* // Rad. Meas. 2018. V.119. P.119; arXiv:1812.09096.
4. The BECQUEREL Project. http://becquerel.jinr.ru/movies/movies.html.

PHOTONUCLEAR REACTIONS ON BORON AND BERYLLIUM TARGETS

Zheltonozhskaya M.V.[1], Zheltonozhsky V.A.[2], Savrasov A.M.[2], Chernyaev A.P.[1]
[1] *Lomonosov Moscow State University, Moscow, Russia;* [2] *Institute for Nuclear Research, Kyiv, Ukraine*
E-mail: zhelton@yandex.ru

Photonuclear reactions in light nuclei with the escape of charged particles remain rather unplumbed to date. At the same time, the study of these reactions is of considerable interest because of their significant difference from (γ,*n*)-reactions. These differences are associated with the excitation of other states, often inaccessible for the (γ,*n*) channel. In addition, a significant contribution of direct and semi-direct processes is expected for photonuclear reactions with the emission of charged particles, especially at energy values of bremsstrahlung gamma quanta exceeding the energy range of giant dipole resonance.

The measurement of integral cross sections was carried out by the activation method on the bremsstrahlung of the Skobeltsyn Institute of Nuclear Physics of Lomonosov Moscow State University microtron with a 55 MeV maximum electron energy on targets from the natural isotopic composition of boron and beryllium. Measurements of irradiated targets were carried out by semiconductor spectrometers with HPGe detectors with an energy resolution of 1.8–2 keV on ^{60}Co γ-lines. In the spectra, γ-transitions from the ^{7}Be decay are reliably identified.

The integral cross sections were first studied for the filling of ^{7}Be both in the (γ,2*n*)-reaction in beryllium and in boron reactions at the 55 MeV boundary energy of the bremsstrahlung gamma rays. The simulation of the braking spectrum was carried out with the Geant4 program code. The following integral cross sections were obtained: ^{9}Be(γ,2*n*)^{7}Be – 44(4) mb×MeV, ^{10}B(γ,*t*)^{7}Be – 52(5) mb×MeV, ^{11}B(γ,*tn*)^{7}Be – 35(4) mb×MeV, ^{10}B(γ,*dn*)^{7}Be – 84(8) mb×MeV, ^{11}B(γ,*d*2*n*)^{7}Be – 61(6) mb×MeV, ^{10}B(γ,*p*2*n*)^{7}Be – 101(10) mb×MeV, ^{11}Be(γ,*p*3*n*)^{7}Be – 82(8) mb×MeV. According to the results of modeling with software codes TALYS-1.9 and EMPIRE-3.2 we fixed domination of non-statistical processes. A comparison the theoretical and experimental results indicates the dominance of the (γ,*t*) reaction on ^{10}B.

The obtained data are discussed.

EXCITATION OF ^{179}Hf^{m2} AND ^{180}Hf^{m} IN (γ, γ')-REACTIONS

Zheltonozhsky V.A.[1], Zheltonozhskaya M.V.[2], Savrasov A.M.[1]
[1] *Institute for Nuclear Research, Kyiv, Ukraine;* [2] *Lomonosov Moscow State University, Moscow, Russia*
E-mail: zhelton@yandex.ru

The study of cross sections in photonuclear reactions for hafnium was most fully carried out for (γ,*n*)- and (γ,γ')-reactions. Moreover, previously it was asserted the cross section of the (γ,γ')-reaction with the isomeric state filling intense decreases when the (γ,*n*)-channel is opened. However, in [1], an increase in the ^{180}Hf(γ,γ')^{180}Hf^{m} reaction cross section was observed at E_{bd} = 20 MeV. Therefore, there is considerable scientific interest in studying the excitation function of both the ^{180}Hf(γ,γ')^{180}Hf^{m} and ^{179}Hf(γ,γ')^{179}Hf^{m2} reactions with bremsstrahlung gamma quanta with energy values exceeding the energy range of giant dipole resonance.

The study of integral cross sections was carried out by the activation method on the bremsstrahlung of the Skobeltsyn Institute of Nuclear Physics of Lomonosov Moscow State University microtron with a 55 MeV maximum electron energy on hafnium targets with natural isotopic composition and enriched on ^{179}Hf, ^{180}Hf. Measurements of irradiated targets were carried out by semiconductor spectrometers with HPGe detectors with an energy resolution of 1.8–2 keV on ^{60}Co γ-lines. In the spectra, γ-transitions from the ^{179}Hf^{m2} and ^{180}Hf^{m} decays are reliably distinguished.

For the first time the integral cross sections of ^{179}Hf^{m2} and ^{180}Hf^{m} filling in (γ,γ')-reactions with a 55 MeV boundary energy brake γ-quanta were measured. The simulation of the braking spectrum was carried out in the program code Geant4. The following values were obtained: σ^{int} = 2.8(10) μb×MeV for the reaction ^{179}Hf(γ,γ')^{179}Hf^{m2} and σ^{int} = 7.8(23) μb×MeV for the reaction ^{180}Hf(γ,γ')^{180}Hf^{m}. It was fixed non-statistical processes domination according to the simulation results in the TALYS-1.9 and EMPIRE-3.2 software codes. But TALYS-1.9 was better described the experimental results. The obtained data are discussed.

1. N.A.Demekhina, A.S.Danagulyan, and G.S.Karapetyan // Phys. Atom. Nucl. 2001. V.64. P.1879.

STUDIES OF PHOTONUCLEAR REACTIONS IN Hf NUCLEI AND IN REACTIONS WITH CHARGED PARTICLES ESCAPE

Zheltonozhsky V.A.[1], Savrasov A.N.[1], Zheltonozhskaya M.V.[2], Chernyaev A.P.[2]
[1] Institute for Nuclear Research, Kyiv, Ukraine; [2] Lomonosov Moscow State University, Moscow, Russia
E-mail: zhelton@yandex.ru

The study of the cross sections and yields of high-spin isomeric states filling allows to obtain various information about the structure of the excited levels in the continuous and discrete excitation regions, and about the mechanisms of nuclear reactions. Some of these isomers are ^{178m}Lu and ^{179m2}Hf. Therefore, the aim of the work is to study the cross sections of ^{178m}Lu and ^{179m2}Hf in reactions with bremsstrahlung gamma quanta for energy values exceeding the energy range of giant dipole resonance.

The study of integral cross sections was carried out by the activation method on the bremsstrahlung of the Skobeltsyn Institute of Nuclear Physics of Lomonosov Moscow State University microtron with a 55 MeV maximum electron energy on tantalum targets with natural isotopic composition and hafnium targets enriched on ^{179}Hf, ^{180}Hf. Measurements of irradiated targets were carried out by semiconductor spectrometers with HPGe detectors with an energy resolution of 1.8–2 keV on ^{60}Co γ-lines. In the spectra, γ-transitions from ^{178m}Lu and ^{179m2}Hf decays were reliably distinguished.

The integrated cross sections of the ^{178m}Lu filling levels in (γ,*d*(*pn*))-reactions on ^{180}Hf and in the (γ,*p*) reaction on ^{179}Hf, as well as the integrated cross sections of ^{179m2}Hf in (γ,*d*(*pn*)) reactions on tantalum were first measured for the 55 MeV boundary energy of the bremsstrahlung gamma rays.

The isomeric ratios of the yields for the 20 and 55 MeV boundary energies were first measured for the ^{180}Hf (γ,*d*(*pn*))^{178m,g}Lu reaction. Its value was 0.122(5) and 0.23(3), correspondingly. For the *K*-forbidden transition to ^{179m2}Hf this value was $2.9(3)\times10^{-3}$.

The simulation of the braking spectrum was carried out with program code Geant4. The following integral cross sections were obtained: σ^{int} = 396(30) μb×MeV for the reaction ^{180}Hf(γ,*d*(*pn*))^{178m}Lu, σ^{int} = 3.1(7) mb ×MeV for the reaction ^{79}Hf(γ,*p*)^{178m}Lu and σ^{int} = 37(4) μb×MeV for the reaction ^{181}Ta(γ,*d*(*pn*))^{179m2}Hf.

It was obtained the non-statistical processes domination according to the simulation results with the TALYS-1.9 and EMPIRE-3.2 software codes. The theoretical integral cross sections are significantly lower than the experimental values. The obtained results are discussed.

INVESTIGATION OF ENERGY DEPENDENCE OF THE FORMATION OF PROTONS FROM (*p,xp*) REACTION WITH ^{103}Rh NUCLEUS

Zholdybayev T.K.[1,2], Alieva G.[3], Sadykov B.M.[1], Nassurlla Maulen [1,2], Duisebayev B.A.[1], Kabdrakhimova G.D.[3], Ismailov K.M.[4]
[1] *Institute of Nuclear Physics, Almaty, Kazakhstan;* [2] *al Farabi Kazakh State University, Almaty, Kazakhstan;* [3] *Gumilev Eurasian State University, Nur-Sultan, Kazakhstan;* [4] *Nazarbayev University, Nur-Sultan, Kazakhstan*
E-mail: timjol@yandex.ru

Experimental information on the double-differential and integral cross sections of the reactions induced by nucleons in the wide energy range is key in the physical scenario of the realization of all nuclear technologies associated with the creation of a subcritical nuclear-energy system (ADS). The information currently available on the cross sections of nuclear reactions that occur during the interaction of neutrons and charged particles [1, 2] does not correspond to the existing needs. New data on the cross sections of nuclear reactions occurring in the target and fuel assemblies, structural materials that lead to the formation of a cascade of subsequent secondary products of reactions, allow the correct modeling of the emerging neutron fluxes.

Inclusive spectra of protons emitted from proton induced reactions on ^{103}Rh nucleus at $E_p = 7$, 22 and 30 MeV was received on isochronous cyclotron U-150M of Institute of Nuclear Physics. A self-supporting foil with an enrichment of ^{103}Rh of the order of 98% was used as target. The thickness was determined from the change in energy loss by α-particles from the radioactive source ^{226}Ra passing through the target and amounted to 3 μm (accuracy 3–5%). The total systematic error was less than 10 % and the statistical uncertainty was less than 15 %.

The obtained experimental data on integral cross sections of the investigated reaction were analyzed in the framework of modern versions of nuclear reaction models using the TALYS calculation code. To describe the complete inclusive spectra of scattered particles, it is necessary to take into account all possible mechanisms of nuclear reactions. A distinction between direct nuclear reactions, pre-equilibrium decay and equilibrium emission at different incident protons energy for ^{103}Rh(*p,xp*) reaction was established.

1. Y.Ikeda // Journal of Nuclear Science and Technology. 2002. Suppl.2. P.13.
2. A.V.Ignatyuk, M.N.Nikolaev, V.I.Fursov // Atomic Energy. 2014. V.116. P.209.

TOTAL NEUTRON CROSS SECTION MEASUREMENTS AT THE ENERGY E_n=14.1 MeV FOR ^{12}C, ^{19}F, ^{32}S, ^{115}In ^{128}Te, ^{208}Pb

Artemov S., Ergashev F., Kajumov M., Karakhodzhaev A., Tojiboev O., Abdullaeva G.A., Kulabdullaev G.A., Ruziev E., Tatarchuk V., Yuldashev B.
Institute of Nuclear Physics, Academy of Sciences Uzbekistan, Tashkent
E-mail: artemov@inp.uz, abdullaeva@inp.uz

Experimental neutron total cross sections as a function of neutron energy are a fundamental data set for the evaluation of nuclear data libraries. In the energy range of fast neutrons, this is especially important for innovative nuclear applications, like accelerator driven systems and transmutation of nuclear waste. Moreover neutron cross section data must be provided for all nuclides constituting the materials to be used in fusion devices, including the breeders, neutron multipliers, coolants, shielding, structure, magnets and insulators, with special emphasis on high-quality data around 14 MeV.

To measure the total neutron cross sections, the authors developed a convenient technique using silicon semiconductor detectors with the simple and compact detecting system [1]. The created technique was used to measure A + *n* total cross sections at the energy E_n = 14.1 MeV for several nuclei in different mass region. The neutron generator NG-150 of the INP AS in D + T regime of neutrons generation is used as fast neutrons source. The results of measurements and their comparison with available experimental data are presented in the Table 1. The measured neutron total cross sections are analyzed in the frameworks of the up-to-date global optical model potentials [5, 6].

Table 1. Comparison of the measured and literature total cross sections.

element	thickness, mm	density g/cm^3	σ^{tot} (our) barn	σ^{tot} (lit) barn
^{12}C	148	2.25	1.43 ± 0.10	1.30 ± 0.06 [2]
^{19}F	148	1.7	2.08 ± 0.15	1.74 ± 0.04 [3]
^{32}S	112	1.91	1.77 ± 0.13	1.95 ± 0.03 [3]
^{128}Te	37	5.86	4.42 ± 0.26	4.76 ± 0.03 [4]
^{115}In	20	7.15	4.50 ± 0.17	4.54 ± 0.02 [4]
^{208}Pb	50	11.34	5.38 ± 0.11	5.45 ± 0.02 [3]

1. S.V.Artemov *et al*. // Abstr. 68 Int. Conf. «NUCLEUS-2018» 2 – 6 July 2018, Voronezh, Russia. P.245.
2. M.J.Rapp *et al*. // Nucl. Sci. and Engin. 2012. V.172. P.268.
3. W.P.Abfalterer *et al*. // Phys. Rev. C. 2001. V.63. 044608.
4. Yu.V.Dukarevich *et al*. // Nucl. Phys. A. 1967. V.92. Issue 2. P.433.
5. Xiao-Hua Li *et al.* // Nucl. Phys. A. 2012. V.874. P.62.
6. A.J.Koning *et al*. // Nucl. Phys. A. 2003. V.713. P.231.

SYSTEM OF SAFE DATA TRANSMISSION FROM THE SHE-FACTORY DC-280

Baginyan A.S., Pashenko S.V., Sorokoumov V.V.
Joint Institute for Nuclear Research, Dubna, Russia
E-mail: bag@jinr.ru

The article presents a scheme of the data transmission network providing the commissioning of the DC-280 accelerator complex. The main indicators of communication channel characteristics are given. Discusses the calculations settings of network devices that provide secure access to network resources. Shown settings for transmission of unicast and multicast packets, IPv4 and IPv6 protocols [1]. An authorization scheme and storage system for the entire switch configuration sequence is presented. The monitoring system of the network is considered and the payload of links based on SNMP [2] is shown.

Given the forecast for future utilization of communication unblocked channels [3]. Detail description of the necessity to use DHCP snooping [4] functionality is given. A system of wireless access to a local computer network has been developed. In conclusion, a summary is given and a forecast is given on the future development of the LAN of the accelerator complex, as well as the backbone of the communication links.

1. A.S.Baginyan, A.G.Dolbilov // TCAM - from Ipv4 to Ipv6 / T-Comm. 2013. No.4. P.24.
2. J.Case, K.McCloghrie, M.Rose, S.Waldbusser // RFC 1448 – Protocol Operations for version 2 of the Simple Network Management Protocol / April 1993.
3. M.Christensen, K.Kimball, F.Solensky // Considerations for Internet Group Management Protocol (IGMP) and Multicast Listener Discovery (MLD) Snooping Switches, rfc4541, May 2006.
4. J.Touch and R.Perlman // "Transparent Interconnection of Lots of Links (TRILL): Problem and Applicability Statement", RFC 5556, May 2009.

TOTAL REACTION CROSS SECTIONS OF LIGHT NUCLEI MEASURED BY THE COMBAS FRAGMENT-SEPARATOR

Erdemchimeg B.[1,2], Artukh A.G.[1], Davaa S.[2], Issatayev T.[1], Klygin S.A.[1], Kononenko G.A.[1], Khuukhenkhuu G.[2], Ostashko V.V.[3], Lukyanov S.M.[1], Mikhailova T.I.[1], Maslov V.A.[1], Mendibayev K.[1,4], Sereda Yu.M.[1], Penionzhkevich Yu.E.[1], Vorontsov A.N.[1]

[1] *Joint Institute for Nuclear Research, 141980, Dubna, Russia;* [2] *National University of Mongolia, NRC, Ulaanbaatar, Mongolia;* [3] *Institute for Nuclear Research, National Academy of Sciences of Ukraine, Ukraine;* [4] *Eurasian Gumilev University, Nur-Sultan*

E-mail: erdem@jinr.ru

Preliminary results of measurements of the total reaction cross sections σ_R for ^{3}He, ^{4}He, ^{6}Li, ^{7}Be, ^{8}B, ^{10}B, $^{9-11}$C, and ^{12}N nuclei at energy range (10–45) *A* MeV with ^{28}Si target is presented. The secondary beams of light nuclei were produced by bombardment of the ^{15}N (50 *A* MeV) primary beam on Be target and separated by COMBAS fragment-separator. In dispersive focal plane a horizontal slit defined the momentum acceptance as 1% and a wedge degrader of 600 μm Al was installed. The B_ρ of the second section of the fragment-separator was adjusted for measurements in energy about 25 *A* MeV. The strong absorption model reproduces the *A*-dependence of σ_R, but not the detailed structure. We are comparing our experimental data's with results of Glauber model and preliminary results are obtained.

IMPROVEMENT OF THE DATA PROCESSING TECHNIQUE IN TANGRA SETUP

Fedorov N.A.[1,2], Tretyakova T.Yu.[3], Kopatch Yu.N.[1], Bystritsky V.M.[1], Grozdanov D.N.[1,4], Aliyev F.A.[1,5], Ruskov I.N.[1,4], Skoy V.R.[1], Hramco C.[1,6], Kumar A.[7], Gandhi A.[7], Wang D.[8], Bogolyubov E.P.[9], Barmakov Yu.N.[9], TANGRA collaboration

[1] Joint Institute for Nuclear Research (JINR), Dubna, Russia; [2] Faculty of Physics, Lomonosov Moscow State University (MSU), Moscow, Russia; [3] Skobeltsyn Institute of Nuclear Physics Lomonosov Moscow State University (SINP MSU), Moscow, Russia; [4] Institute for Nuclear Research and Nuclear Energy of Bulgarian Academy of Sciences (INRNE-BAS), Sofia, Bulgaria; [5] Institute of Geology and Geophysics, Baku, Azerbaijan; [6] Institute of Chemistry, Academy of Science of Moldova, Chisinau, Republic of Moldova; [7] Banaras Hindu University, Varanasi, India; [8] Xi'an Jiao Tong University, Xi'an, China; [9] All-Russia Research Institute of Automatics (VNIIA), Moscow, Russia

E-mail: na.fedorov@physics.msu.ru

The correct determination of the full-energy absorption peak area in a gamma-spectrum obtained by a scintillation detector is quite complex task in case if there are a lot of peaks in it. There are several processes of gamma-quantum interaction with the scintillator crystal, as a result there are several components in the measured gamma-spectrum appear. The correct description of the gamma-detector response can significantly improve our data analysis procedure results.

Moreover, the influence of the neutron and gamma-quanta absorption and scattering in the experimental setup construction elements and in the surrounding items has to be taken into account. There are several sources distorting the measured data: the absorption of neutrons and gamma-quanta in the irradiated sample, interaction of direct and scattered neutrons with BGO detectors, random (α–γ) coincidences, neutron scattering from the setup construction and environment materials.

To take into account the impact of these effects and improve our results for gamma-quanta angular distributions, we used Monte-Carlo simulation-based methods for estimation of the neutrons and gamma-rays absorption inside the irradiated sample and the cases of the detectors. A similar method was used for estimation of the data uncertainties.

In this work a prototype of the gamma-ray detector response function Geant4 simulation-based is presented.

MEASUREMENT OF ^{6,7}Li + *d* AND ^{9}Be + *d* REACTIONS CROSS-SECTIONS

Generalov L.N., Vikhlyantsev O.P., Karpov I.A., Kuryakin A.V., Tumkin A.D., Fil'chagin S.V., Velichko K.S.
Russian Federal Nuclear Center – All-Russian Research Institute of Experimental Physics, Sarov, Russia
E-mail: otd4@expd.vniief.ru

At deuteron energies E_d=3.5–10 MeV measured are differential cross-section of reactions ^{6}Li(d,$d_{0,1}$), ^{6}Li(d,α_0), ^{6}Li(d,xt), ^{7}Li(d,$d_{0,1,2}$), ^{7}Li(d,$t_{0,1}$), and ^{9}Be(d,xt) reaction differential cross-section in the interval E_d = 1.4–9 MeV. The measurement procedure is given in [1]. Integral cross-sections are determined by differential cross-sections and are given in Fig. 1, 2 for ^{6}Li(d,d_1), ^{6}Li(d,xt), ^{7}Li(d,t_0), and ^{9}Be(d,xt) reactions.

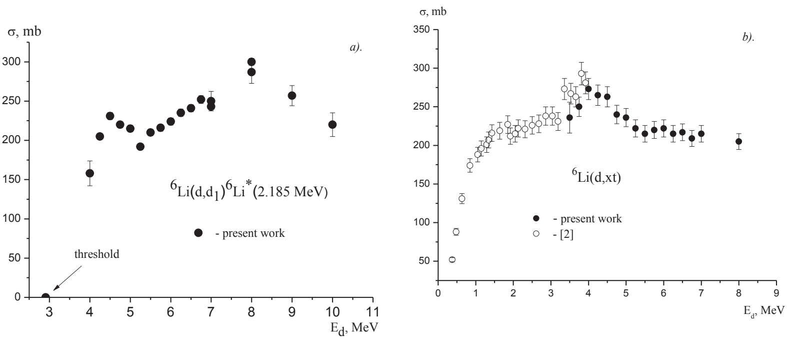


Fig.1. a) ^{6}Li(d,d$_1$) reaction integral cross-sections; b) ^{6}Li(d,xt) reaction integral cross-sections.

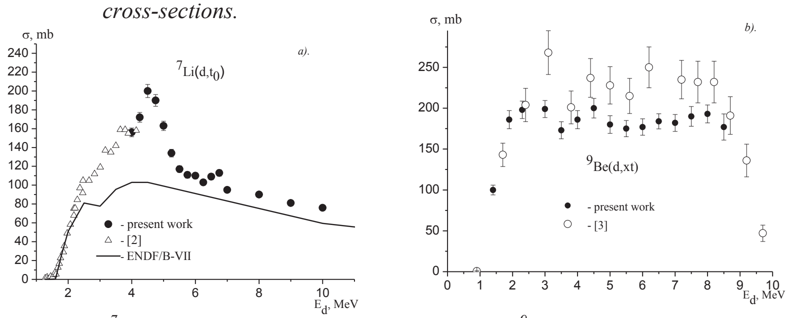


Fig.2. a) ^{7}Li(d,t$_0$) reaction integral cross-sections; b) ^{9}Be(d,xt) reaction integral cross-sections.

1. O.P.Vikhlyantsev, L.N.Generalov, A.V.Kuryakin, *et al*. // Nucl. Phys. and Engineering. 2016. V.7. №4. P.326.
2. R.L.Macklin, H.E.Benta // Phys. Rev. 1955. V.97. No3. P.753.
3. S.N.Abramovich, L.N.Generalov, B.Ya.Guzhovskii, *et al*. // Izv. RAN. Ser. Phys. 1994. V.58. №1. P.87.

TOTAL CROSS-SECTIONS OF ^{12}C(*d,n*)^{13}N, ^{14}N(*d,n*)^{15}O, ^{14}N[(*d,t*) + (*d,d + n*)]^{13}N, ^{14}N(*d,n* + α)^{11}C, ^{16}O(*d,n*)^{17}F REACTIONS

Generalov L.N., Karpov I.A.
Russian Federal Nuclear Center – All-Russian Research Institute of Experimental Physics, Sarov, Russia
E-mail: otd4@expd.vniief.ru

At deuteron energies 1–12 MeV ^{12}C(*d,n*)^{13}N (β^+, $T_{1/2}$=9.965 min), ^{14}N(*d,n*)^{15}O (β^+, $T_{1/2}$=122 s), ^{14}N[(*d,t*) + (*d,d + n*)]^{13}N (β^+, $T_{1/2}$=9.965 min), ^{14}N(*d*,α+*n*)^{11}C (β^+, $T_{1/2}$=20.39 min), ^{16}O(*d,n*)^{17}F (β^+, $T_{1/2}$=64.5 s) reactions cross-sections are measured by activation method. As targets the mylar films ($C_5H_4O_2$) of 5 μm thickness and layers of atmospheric air of thickness 2.1, 5.1, and 7.1 mm are used. The measurement procedure is given in [1]. The paper reports a procedure of measurement results processing, and also discusses reaction σ cross-sections at average energies $\overline{E}_d$ of deuteron interaction in targets. A part of our data together with some literature data is given in Fig. 1, 2.

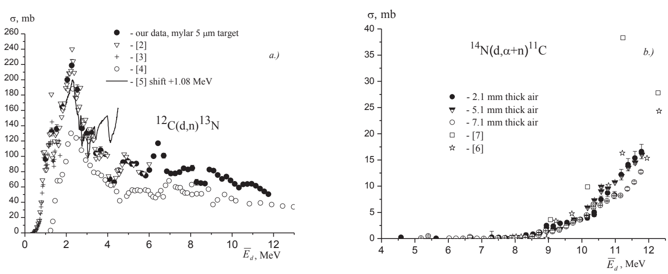


Fig.1. Cross-sections of ^{12}C(d,n)^{13}N (a) and ^{14}N(d,α + n)^{11}C reactions (b).

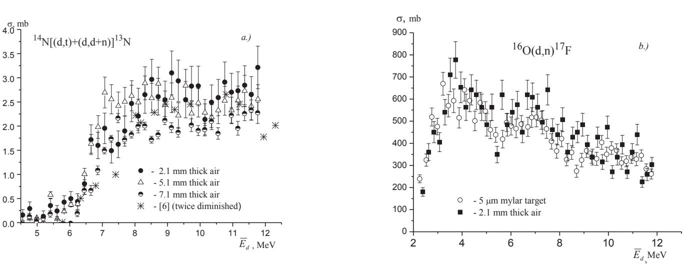


Fig.2. Cross-sections of ^{14}N[(d,t) + (d,d + n)]^{13}N (a) and ^{16}O(d,n)^{17}F reactions (b).

1. L.N.Generalov, S.N.Abramovich // Int.Conf. «Nucleus-2017». Sep.12-15, 2017. Almaty. P.63.
2. R.W.Miclemann *et al.* // Nucl.Instr.Meth. B. 1990. V.51. P.1.
3. I.Ya.Barit *et al.* // Jour. Radioanalit.Nucl.Chemistry. 1986. V.97. P.97.
4. M.L.Firouzbakht, D.J.Schlyer, A.P.Wolf // Rad. Acta. 1991. V.55. P.1.
5. R.J.Jaszczak // Phys.Rev. 1969. V.181. P.1428.
6. Z.Szucs // Jour. Radiochem.Acta. 1998. V.80. P.59.
7. M.Sajjad, R.M.Lambeght // Jour. Radiochem.Acta. 1985. V.38. P.57.

A POSSIBILITY OF DETERMINING CLUSTER STRUCTURE OF EXCITED STATES OF ^{9}Be IN ^{9}Be(d,$d'n$)X AND ^{9}Be(d,$d'\alpha$)X REACTIONS

Kasparov A.A.[1], Afonin A.A.[1], Zuyev S.V.[1], Konobeevski E.S.[1], Mitcuk V.V.[1,2], Mordovskoy M.V.[1,2]

[1] *Institute for Nuclear Research of the Russian Academy of Science, Moscow, Russia;*
[2] *Moscow Institute of Physics and Technology (State University), Dolgoprudnyi, Russia*
E-mail: kasparov2001911@gmail.com

Recently, Beryllium nuclei attract attention of experimenters and theorists because of their cluster structure [1–3]. Together with the three-particle structure ($\alpha + \alpha + n$), two-particle configurations (^{8}Be + n and ^{5}He + α) are also possible in this nucleus. To determine the cluster structure of the excited states of ^{9}Be, we propose to detect the inelastic scattered deuteron in coincidence with particle from the breakup of particular excited state of ^{9}Be.

A kinematic simulation of ^{9}Be(d,$d'\alpha$)X and ^{9}Be(d,$d'n$)X reactions with excitation of a certain low-lying level E_x was carried out. The results of the simulation show that detecting an inelastic scattered deuteron in coincidence with a particle from the decay of specific excited ^{9}Be states allow us to determine the cluster configuration of these states.

For example, Figure 1a and 1b show the spectra of neutrons and alpha particles from the breakup of 6.76 MeV and 3.05 MeV levels for various breakup channels, respectively. It is seen that the energy behavior of the simulated neutron spectrum for the $\alpha + {}^{5}$He configuration differs significantly from those for the $n + {}^{8}$Be and $\alpha + \alpha + n$ configurations, while registering alpha particles it is possible to distinguish the $n + {}^{8}$Be and $\alpha + \alpha + n$ decay channels.

The reported study was funded by RFBR according to the research project № 18-32-00944.

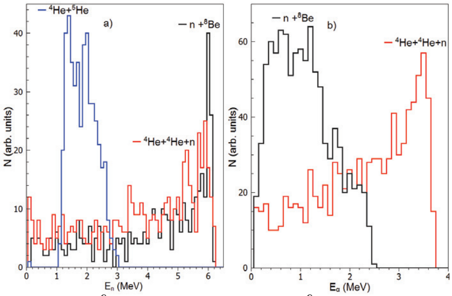


Fig. 1. Simulation of reactions ^{9}Be(d,d′n)X (a) and ^{9}Be(d,d′α)X (b) for various breakup channels at deuteron beam energy of 15 MeV. (a) – Neutron spectrum from the breakup of E^{*}=6.76 MeV level, $\Theta_{d'}$=30°, Θ_n=20°; (b) – Alpha spectrum from the breakup of E^{*}=3.05 MeV level, $\Theta_{d'}$=50°, Θ_α=55°.

1. S.M.Lukyanov *et al.* // WJNST. 2015. V.5. P.265.
2. T.A.D.Brown *et al*. // Phys. Rev C. 2007. V.76. P.054605.
3. Y.Hirayama *et al.* // Phys. Rev C. 2015. V.91. P.024328.

NEUTRON-PHYSICAL CHARACTERISTICS EVALUATION OF THE SUBCRITICAL ASSEMBLY "YALINA-THERMAL" WITH LOW ENRICHMENT URANIUM FUEL

Korbut T.N., Yedchik I.A., Kuzmin A.V., Kravchenko M.O.
State Scientific Institution "Joint Institute for Power and Nuclear Research – Sosny" of the National Academy of Sciences of Belarus, Minsk, Belarus
E-mail: tamara.korbut@gmail.com

The paper presents the results of studies of the Subcritical Assembly "Yalina-Thermal" [1, 2] of the State Scientific Institution "Joint Institute for Energy and Nuclear Research – Sosny" of the National Academy of Sciences of Belarus. Subcritical systems controlled by external sources (Accelerator driven system – ADS) are considered promising for energy production and transmutation of long-lived fission products and minor actinides. The study of the processes taking place in the "Yalina-Thermal" assembly with low enrichment uranium fuel (UO_2 fuel of 10% enrichment at ^{235}U) is of great interest in the innovative plant designs development and is consistent with IAEA recommendations for reducing enrichment for research and test reactors.

The spatial-energy neutron distributions are calculated by the MCU Monte-Carlo code with ENDF/B-VIII.0 [3], JENDL-4.0 [4] and JEFF-3.3 Evaluated Neutron Data libraries. The experimental and calculated values of the multiplication factor k_{eff} of the "Yalina-thermal" assembly are compared with various configurations of the core load using a ^{252}Cf source.

1. International Atomic Energy Agency, Use of Low Enriched Uranium Fuel in Accelerator Driven Subcritical Systems, IAEA-TECDOC-1821, IAEA, Vienna (2017).
2. V.A.Beresneva, T.N.Korbut and S.V.Korneyev // Phys. Atom. Nuclei. 2018. V.81. P.1441.
3. D.A.Brown *et al*. // Nuclear Data Sheets. 2018. V.148. P.1.
4. K.Shibata *et al*. JENDL-4.0: A New Library for Nuclear Science and Engineering // J. Nucl. Sci. Technol. 2011. V.48(1). P.1.

RECENT TECHNICAL DEVELOPMENTS AT THE ISOLTRAP MASS SPECTROMETER TO REACH MORE EXOTIC NUCLIDES

Kulikov I. for the ISOLTRAP collaboration
GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany
E-mail: ivan.kulikov@cern.ch

High-precision mass spectrometry of radioactive isotopes is of high interest for scientific communities. Atomic masses provide direct insights on key nuclear structure phenomena, such as shell effects or onsets of deformation, and the way they evolve far from stability. In the field of astrophysics, the masses of exotic species constitute the most critical nuclear physics inputs in nucleosynthesis calculation.

The mass spectrometer ISOLTRAP, located at the radioactive ion-beam facility ISOLDE/CERN [1], pioneered the technique of on-line Penning-trap mass spectrometry of short-lived isotopes. During its thirty years of operation, over 400 short-lived nuclides have been measured. With the well-established Time-of-Flight Ion-Cyclotron-Resonance (ToF-ICR) mass measurement technique the achievable mass precision is on the level of 10^{-8}. To improve the ISOLTRAP's ability to deliver purified beams to the measurement Penning trap, a Multi-Reflection Time-of-Flight Mass Separator (MR-ToF MS) has been constructed [2]. This device is routinely used as mass spectrometer as well. This contribution will present the specifics of both mass measurement techniques through recent investigations of ^{70}As, ^{49,50}Sc and ^{73}Br isotopes.

To push such investigations towards more exotic and rare radioisotopes the efficient transportation, collection, accumulation and cooling of the beam is required. To this end, radio-frequency cooler and buncher (RFQ-CB) device have become the tool of choice [3]. This poster will highlight recent technical developments laying the groundwork for the overall improvement of RFQ-CB and the alignment of ISOLTRAP's horizontal beam line.

1. S.Kreim *et al*. // Nucl. Instrum. Meth. B. 2013. V.317. P.492.
2. F.Wienholtz *et al*. // Int. J. Mass Spectr. 2017. V.421. P.285.
3. F.Herfurth *et al*. // Nucl. Instrum. Meth. A. 2001. V.469. P.254.

PARTICLE PASSAGE SIMULATION THROUGH ZERO DEGREE CALORIMETER OF BM@N EXPERIMENT USING THE BMNROOT PACKAGE

Makarov A.A., Naumov P.Yu., Salakhutdinov G.Kh.
National Research Nuclear University MEPhI, Moscow, Russia
E-mail: gurrman@outlook.com

Simulation with beam of ^{12}C was made at E_{kin}= 4 GeV/nucleon for the zero degree calorimeter (ZDC) module of BM@N experiment.

The data were analysed by the special software BmnRoot [1], which has been made by team from JINR and based on FairRoot [2] package. It provides vast variety of abilities for simulation and analysis as it is based on CERN ROOT and uses GEANT4 libraries for particle interactions and tracing. The BmnRoot has LAQGSM inherited from the FairRoot, which is capable of simulating hadron-nucleus and nucleus-nucleus reactions at energies from ~ 20 MeV up to 200 GeV per nucleon.

The ZDC module was simulated and calibrated so that the beam of ^{12}C hits exactly at its centre. The detectors response was analyzed and the procedure for obtaining centrality parameter is being developed.

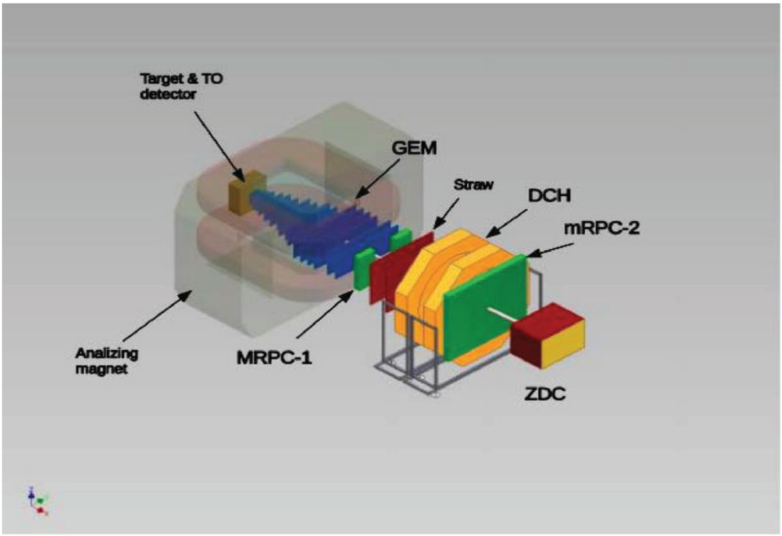


Fig. 1. The schematic view of the BM@N experiment.

1. http://bmnshift.jinr.ru/wiki/doku.php#bmnroot
2. https://fairroot.gsi.de/?q=about

STUDY OF NEUTRON SPATIAL DISTRIBUTION FROM SOURCE ON BASE OF LUE-8 ELECTRON ACCELERATOR WITH ^{3}HE- AND ^{10}B-DETECTORS

Meshkov I.V.[1], Afonin A.A.[2], Potashev S.I.[2], Burmistrov Yu.M.[2], Drachev A.I.[3], Zuyev S.V.[2], Karaevsky S.Kh.[2], Kasparov A.A.[2], Konobeevski E.S.[2], Kuznetsov S.P.[1], Marin V.N.[2], Ponomarev V.N.[2], Solodukhov G.V.[2]

[1] P.N. Lebedev Physical Institute of the Russian Academy of Sciences Moscow; [2] Institute for Nuclear Research of Russian Academy of Sciences, Moscow; [3] State Research Institute for Chemistry and Technology of Organoelement Compounds, Moscow, Russia

E-mail: meshkoviv@lebedev.ru

Spatial distribution of neutrons from channel of the neutron source based on LUE-8 electron accelerator was investigated. This work is performed in frame of preparing of experiments on the nuclear and solid state physics and the applied research in the field of the condensed matter and biology with using a small-angle scattering, diffraction and radiography. A possibility of control by parameters of the neutron flux and the spectrum shape was determined for various experimental configurations and wide range of tasks.

Slow neutrons are detected with the positionable or fixed ^{3}He-detector and the positional sensitive neutron detector (PSND) based on the ^{10}B layer and proportional chamber [1, 2]. They are installed on the axis of the output collimated neutron channel at distances of 108, 193 or 353 cm from the moderator center. To reduce the neutron counting rate in detectors the mask with uniform series of holes was mounted in front of them at a distance of 108 cm. The ^{3}He-counter was moved by motor mechanically in a horizontal plane perpendicularly to the channel axis. It together with PSND recorded the neutron flux profile in real time. The neutron pulse waveform and the ^{3}He-detector position were recorded simultaneously using the L-783 LCard signal processor. Pulse heights from the PSND were used for a determination of X and Y coordinates of neutron.

It was found that the flux profile at a distance of less than 200 cm has asymmetry. At the same time, a small uniform background of neutrons at the distance of 353 cm is observed.

1. S.P.Kuznetsov *et al.* // Bull. Russ. Acad. Sci. Phys. 2018. V.82(6). P.725.
2. I.V.Meshkov *et al.* // Bull. Russ. Acad. Sci. Phys. 2018. V.82(6). P.728.

PHI MESON MEASUREMENTS IN HEAVY ION COLLISIONS AT PHENIX EXPERIMENT

Berdnikov A.Ya., Berdnikov Ya.A., Kotov D.O., Larionova M.M., Mitrankov Iu.M.
Peter the Great St.Petersburg Polytechnic University, Saint Petersburg, Russia
E-mail: mitrankovy@gmail.com

The PHENIX detector [1] at RHIC [2] provides the capabilities to measure light meson production in a broad set of collision systems. Measurements of light meson production in Au + Au and Cu + Cu collisions allowed PHENIX collaboration to study the properties of quark-gluon plasma (QGP). Now we continue to investigate QGP in collisions of symmetric nuclei (U + U) and in asymmetric Cu + Au collisions. The φ meson has hidden strangeness and does not suffer considerable rescattering in the hadronization stage, since it interacts scarcely with hadrons. These features help to study jet quenching effect and strangeness enhancement, which both provide a look inside QGP [3].

This report is devoted to the φ-meson production in Cu + Au collisions at 200 GeV and in U + U collisions at 192 GeV. We present comparisons of φ-meson nuclear modification factors R_{AA} obtained in U + U and Cu + Au results to results obtained in Au + Au and Cu + Cu and comparisons of φ meson R_{AA} to π^0 and η meson R_{AA} in Cu + Au and U + U collisions.

New φ-meson results obtained in Cu + Au and U + U collisions are in agreement with previous Au + Au and Cu + Cu results at same N_{part} (number of participants) value in the whole p_T range in all centrality bins. Consequently, production and suppression of the light mesons seem to scale with the average size of the nuclear overlap region, regardless of the details of its shape.

In the intermediate p_T range φ meson R_{AA} shows flattening around unity in contrary to π^0 and η mesons R_{AA} in U + U and in Cu + Au central collisions. While at high-p_T in the most central collisions and in whole p_T range in the peripheral collisions all light mesons R_{AA} seem to be in agreement within uncertainties. It provides a contribution to the understanding of the strangeness enhancement competing with energy loss. Recombination and radial flow are two alternative explanations of these experimental results [4].

We acknowledge support from Russian Ministry of Education and Science, state assignment 3.1498.2017/4.6.

1. I.Arsene *et al*. // Nucl. Phys. A. 2005. V.757. P.1.
2. K.Adcox *et al*. // Nucl. Phys. A 2005. V.757. P.30.
3. A.Adare *et al*. // Phys. Rev. D. 2018. V.98. I.9. 092006.
4. A.Adare *et al*. // Phys. Rev. C. 2011. V.83(2). 024909.

INVESTIGATION OF (*p,xp*) AND (*p,xα*) REACTION ON ^{58}Ni NUCLEUS AT 30 MeV PROTON ENERGY

Zholdybayev T.K.[1,2], Sadykov B.M.[1], Nassurlla Maulen[1,2], Mukan Zh.[1,3], Duisebayev B.A.[1], Duysenbayeva A.Zh.[2], Zhumadilov I.[2], Baybekova N.[3]
[1] *Institute of Nuclear Physics, Almaty, Kazakhstan;* [2] *al Farabi Kazakh State University, Almaty, Kazakhstan;* [3] *Gumilev Eurasian State University, Nur-Sultan, Kazakhstan*
E-mail: zhuldiz_mukan@mail.ru

In the middle of the last century, the idea of creating a nuclear power system was put forward, implemented to date as the Accelerator Driven System (ADS), consisting of a proton accelerator (deuterons), a neutron-producing targets and a subcritical reactor (blanket) [1]. In addition to receiving energy, the system allows the transmutation of long-lived radioactive waste from the nuclear industry [1]. According to the physical scenario of the ADS operation, high-energy protons during the passage of the target assembly generate not only a neutron flux, but also a spectrum of more complex nuclides of hydrogen and helium that act as initiating reaction agents with the emission of secondary neutrons. The range of nucleon composition and excitation energies in the ADS system is much wider than in traditional reactors. New additional data are needed on nuclear reactions with hydrogen and helium nuclides occurring in target, fuel assemblies, and structural materials [2].

The double-differential cross-section of (*p,xp*) and (*p,xα*) reaction on ^{58}Ni nucleus at E_p=30 MeV have been measured on isochronous cyclotron U-150M of Institute of Nuclear Physics. Cross sections for ^{58}Ni(*p,xp*) nuclear reactions were obtained in the range of angles from 30° to 135° using the telescope of a time-of-flight silicon detector 100 μm thick and a total absorption detector (CsI(Tl) scintillator) 2.5 cm thick. Cross sections for ^{58}Ni(*p,xα*) nuclear reactions were measured in the range of angles from 30° to 120° using a spectrometric telescope of silicon detectors 50μm and 1 mm thick.

The experimental data have been analyzed within the framework of the two-component exciton model of preequilibrium decay [3, 4] and microscopic theory of the multi-step direct and multi-step compound processes [5]. The satisfactory theoretical description of the double-differential and integral cross sections for investigated reaction on ^{58}Ni nucleus has been reached. The contribution of the equilibrium, preequilibrium and direct mechanisms to the formation of outgoing particles spectra was established.

1. A.S.Gerasimov, G.V.Kiselev // PEPAN. 2001. V.32. is.1. P.143.
2. A.V.Ignatyuk, M.N.Nikolaev, V.I.Fursov // Atomic Energy. 2014. V.116. P.209.
3. J.J.Griffin // Phys. Rev. Lett. 1966. №9. P.478.
4. C.Kalbach PRECO-2006: Exiton model preequilibrium nuclear reaction code with direct reaction. Durham NC 27708-0308. 2007.
5. M.Herman, G.Reffo, H.A.Weidenmüller // EMPIRE – statistical model code for nuclear reaction calculations (version 2.13 Trieste). IAEA, 2000.

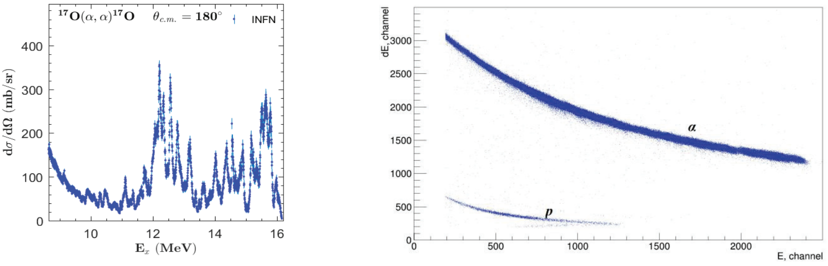
STRONG RESONANCES AT HIGH EXCITATION ENERGY IN ^{17}O + ALPHA RESONANCE SCATTERING

Nauruzbayev D.K.[1,2], Goldberg V.Z.[3], Nurmukhanbetova A.K.[4], La Cognata M.[5], Di Pietro A.[5], Figuera P.[5], Golovkov M.S.[6,7], Cherubini S.[5], Gulino M.[5], Lamia L.[5], Pizzone R.G.[5], Spartà R.[5], Tumino A.[5], Serikov A.[6,7], Gazeeva E.M.[6,7]

[1] National Laboratory Nur-Sultan, Nazarbayev University, Nur-Sultan, Kazakhstan; [2] Saint Petersburg State University, Saint Petersburg, Russia; [3] Cyclotron Institute, Texas A&M University, College station, Texas, USA; [4] Nazarbayev University, Nur-Sultan, Kazakhstan; [5] Istituto Nazionale di Fisica Nucleare,Catania, Italy; [6] Joint Institute for Nuclear Research, Dubna, Russia; [7] Dubna State University, Dubna, Russia

E-mail: dosbol.nauruzbayev@nu.edu.kz

Recently, first measurements of ^{17}O + alpha resonance scattering were performed in Nur-Sultan [1]. These measurements revealed a very strong group of the states in the vicinity of a high energy limit of data [1]. These resonances could not be analyzed because they were too close to the edge of the spectrum. Therefore we performed new measurements at higher energy of ^{17}O beam at 54.4 MeV using the TTIK method at the INFN-LNS tandem. An array of four single Si detectors of 500 μm thickness and one ΔE–E telescope of Si detectors (75 and 1080 μm) were placed at the back of two meter diameter chamber to detect light recoils at different angles including 0º (laboratory system) in steps of 5º. The ΔE–E telescope was needed to evaluate the contribution of protons to charge particle spectra. At present, the most interesting result of this work is an observation of very strong resonances at high excitation energies of 16 MeV. At this excitation energy the density of states in ^{21}Ne is well over 100 levels per 1 MeV. These resonances are also over 10 MeV above the neutron decay threshold. It is not evident, how to obtain additional information about these remarkable resonances. For instance, their observation is practically impossible in a simple ^{20}Ne(*n*,*p*) reaction. The data are analyzed in the framework of *R*-matrix approach.



a) *b)*

Fig. 1. a) Excitation function for the ^{17}O(α,α) ^{17}O elastic scattering at 180° degree from INFN-LNS Tandem. b) dE-E spectrum of ^{17}O + ^{4}He interaction.

1. A.Nurmukhabetova *et al*. // Submitted to Phys. Lett. 2019.

FORMATION AND DECAY OF THE COMPOSITE SYSTEM *Z* = 120 IN REACTIONS WITH HEAVY IONS AT ENERGIES NEAR THE COULOMB BARRIER

Novikov K.V.[1], Kozulin E.M.[1], Knyazheva G.N.[1], Itkis I.M.[1], Itkis M.G.[1], Diatlov I.N.[1], Cheralu M.[1], Kozulina N.I.[1], Kumar D.[1], Pan A.N.[1,2], Pchelintsev I.V.[1], Saveleva E.O.[1], Sahoo R.N.[2]., Singh P.P.[2], Thakur S.[2], Vorobiev I.V.[1]

[1] *Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, 141980 Dubna, Russia;* [2] *Department of Physics, Indian Institute of Technology Ropar, Rupnagar, Punjab - 140001, India*

E-mail: kiryuha-ya@mail.ru

One of the actual problems of modern nuclear physics is the study of the interaction mechanism of nuclei and the study of competing processes in their interaction. Study of competition between compound nucleus fission and quasifission in heavy-ion-induced reactions and its dependence on the reaction entrance channel are important for picking up the right target-projectile combination for the synthesis of superheavy elements.

The reactions ^{64}Ni + ^{238}U, ^{58}Fe + ^{244}Pu, ^{52}Cr + ^{248}Cm, ^{54}Cr + ^{248}Cm with energies near the Coulomb barrier were chosen to investigate the competition of compound nucleus fission and quasifission. All reactions lead to the formation of composite systems with $Z = 120$. Mass-energy distributions of binary fragments formed in the reactions have been measured using the double-arm time-of-flight spectrometer CORSET.

The process of compound nucleus fission and the process of quasifission were separated based on the analysis of the energy distributions of the reaction fragments. The evaluation of the cross section for fissionlike events was carried out as a result of the research. The analysis of the dependence of the reaction entrance channel on the probability of quasifission and compound nucleus fission was also carried out.

This work was supported by the Indian Department of Science and Technology (DST) and the Russian Science Foundation (RSF) (Project No.19-42-02014).

COMPUTATIONAL STUDY OF HIGH NUCLEAR FUEL BURNUP RADIOTOXICITY FOR WWER-1200 REACTOR

Korcheva J.A., Harbachova N.V., Kuzmina N.D., Petrovski A.M.
Joint Institute for Power and Nuclear Research - Sosny, National Academy of Sciences of Belarus, 220109, Minsk, Belarus
E-mail: apetrovski@sosny.bas-net.by

Radiotoxicity behavior of WWER-1200 reactor high burnup spent nuclear fuels discussed by the authors. Radionuclides concentrations as function of nuclear fuel burn up to 70 MWt day/kg for 4.95 % initial enrichment have been calculated on the base of approximation relations of Regulation RB-093-14 (Moscow, 2014). Time dependences of fission products and actinides activities and radiotoxicity behavior were derived at different stages: in case of spent nuclear fuel is disposed in intermediate storage facility and when it will transmit in geological repository.

PROCESSING OF REACTIONS NUMERIC INFORMATION ON NUCLEAR REACTIONS FOR EXFOR INTERNATIONAL LIBRARY OF EXPERIMENTAL NUCLEAR DATA

Pikulina G.N., Taova S.M.
Russian Federal Nuclear Center – All-Russia Research Institute of Experimental Physics, Sarov, Russian Federation
E-mail: otd4@expd.vniief.ru

The main task of the compilation of nuclear data for the EXFOR international library is to ensure entering the reliable physical values obtained during experimental researches of nuclear reactions.

There is described the method of getting physical numeric values in the table mode from raster image of curves. The program unit for graphic data digitizing is included in the EXFOR-Editor software package developed by the VNIIEF Center of Nuclear Physical Data [1]. There are considered the concrete examples of the EXFOR-Editor tools to process the numeric table data and control their reliability [2].

1. G.N.Pikulina, S.M.Taova // Physics of Atomic Nuclei. 2018. V.81. No.10. P.1450.
2. G.N.Pikulina *et al.* // Vestn. MIFI. 2013. V.2. No.1. P.125.

SIMULATION STUDY OF THE EXTERNAL MAGNETIC FIELD INFLUENCE ON FUSION PLASMA

Kuzenov V.V.[1,2,3], Ryzhkov S.V.[1]

[1] Bauman Moscow State Technical University, Moscow, Russia; [2] Institute for Problems in Mechanics of RAS, Moscow, Russia; [3] N.L. Dukhov VNIAA of SC "ROSATOM", Moscow, Russia

E-mail: svryzhkov@bmstu.ru

We investigate the influence of magnetic field on the thermal conductivity and plasma jet parameters in the concept of magneto-inertial fusion (MIF) [1–12]. Thermophysical and hydrodynamic calculations of the interaction of high-power radiation with a plasma target in a magnetic field are presented.

Issues of numerical simulation of the experiment on compression and heating of the target in a magnetic field are discussed. It has been found that the applied magnetic field predominantly increases the plasma lifetime and plasma jet characteristics (velocity, Mach number, density, etc.).

An analysis of the effects of the application of an external magnetic field on the behavior of plasma-driven guns (plasma jets) and laser-driven systems (laser beams) is carried out. Thermodynamic questions in simulation of experiments on magnetic inertial synthesis are touched upon.

This work was supported by the Ministry of Science and Higher Education of the Russian Federation (Russian Minobrnauki Project No. 13.5240.2017/8.9).

1. V.V.Kuzenov, S.V.Ryzhkov // Bull. Russ. Acad. Sci.: Phys. 2016. V.80. P.598.
2. V.V.Kuzenov, S.V.Ryzhkov, V.V.Shumaev // Problems of Atomic Science and Technology. 2015. No.1 (95). P.97.
3. S.V.Ryzhkov, V.I.Khvesyuk, A.A.Ivanov // Fusion Science and Technology. 2003. V.43. № 1. P.304.
4. V.V.Kuzenov // Physics of Atomic Nuclei. 2017. V.80. P.1683.
5. V.V.Kuzenov, S.V.Ryzhkov // Probl. Atom. Sci. Tech. 2013. № 4 (86). P.103.
6. V.V.Kuzenov, S.V.Ryzhkov // Mathematical Models and Computer Simulations. 2018. V.10. P.255.
7. A.Yu.Chirkov, S.V.Ryzhkov, P.A.Bagryansky, A.V.Anikeev // Fusion Science and Technology. 2011. V.59. № 1. P.39.
8. V.V.Kuzenov, S.V.Ryzhkov // Journal of Physics: Conference Series. 2017. V.830. 012124.
9. V.V.Kuzenov, S.V.Ryzhkov // Applied Physics. 2014. No.3. P.26.
10. V.V.Kuzenov, S.V.Ryzhkov, V.V.Shumaev // Problems of Atomic Science and Technology. 2015. No.4 (98). P.53.
11. V.V.Kuzenov, S.V.Ryzhkov // Applied Physics. 2015. No.2. P.37.
12. S.V.Ryzhkov, A.Yu.Chirkov, A.A.Ivanov // Fusion Science and Technology. 2013. V.63. № 1. P.135.

INVESTIGATIONS OF THE (*n*,γf) - REACTION AS A METHOD TO STUDY PROPERTIES OF TRANSITIONS BETWEEN HIGHLY EXCITED STATES IN HEAVY NUCLEI

Shcherbakov O.A., Vorobyev A.S., Gagarski A.M., Vaishnene L.A.
B.P. Konstantinov Petersburg Nuclear Physics Institute of National Research Centre "Kurchatov Institute", Gatchina, Russia
E-mail: shcherbakov_oa@pnpi.nrcki.ru

The neutron-induced fission after preliminary emission of one or more gamma-quanta, also called as (*n*,γf)-reaction, was first proposed theoretically. The evaluations of the probability of this reaction used the single-particle (SP) and giant dipole resonance (GDR) models for the gamma-ray strength function. Only the dipole electric (E1) and magnetic (M1) γ-transitions were taken into account. The parameters used for calculations of prefission widths and gamma-ray spectra were taken from the evaluated data on the neutron capture reaction. From the experimental point of view, the prefission gamma-rays related to the transitions between highly excited states in compound fissioning nucleus are masked by the much more intensive gamma-rays from fission fragments. Due to this principal difficulty, up to now only few attempts have been done by the experimentalists to measure the prefission width and gamma-ray spectra, namely for ^{235}U and ^{239}Pu [1]. In both cases it was found that the GDR model predicts prefission widths comparable with the experimental ones under assumption that M1-radiation dominates in prefission γ-transitions in compound nucleus ^{236}U, while in ^{240}Pu the E1-transitions dominate. As far as the prefission gamma-ray spectrum is concerned, only two measurements have been done for a few low-energy resonances of ^{239}Pu. A prefission gamma-ray spectrum deduced from the experimental data demonstrated a presence of transitions associated with excited states in the 2-nd well of the double-humped fission barrier of ^{239}Pu.

Recently, the (*n*,γf)-reaction was re-evaluated using modern nuclear reaction calculations for slow and fast neutron-induced fission of ^{235}U and ^{239}Pu [2]. The impact of an additional low-lying M1 "scissors mode" in the gamma-ray strength function was analyzed. This and other intriguing properties of the prefission gamma-ray spectra could shed a light on the structure of the highly excited states in compound fissioning nuclei and transitions between them. A new theoretical approach to "old" problem of the (n,γf)-reaction, as well as the international research efforts to improve experimental and evaluated databases for main fissile nuclei ^{235}U and ^{239}Pu, have inspired new experimental studies of the (n,γf)-reaction at the neutron TOF-facility GNEIS of the PNPI.

1. O.A.Shcherbakov // Sov. J. Part. Nucl. 1990. V.21. P.177.
2. J.E.Lynn *et al.* // Phys. Rev. C. 2018. V.97. 064601.

INTERMEDIATE STRUCTURE OF FAST NEUTRON SCATTERING BY Se ISOTOPES

Skorkin V.M.
Institute for Nuclear Research, Moscow, Russia
E-mail: skorkin@inr.ru

In the studies of elastic and inelastic fast neutron scattering by even-even nuclei in the region $A \approx 70$–80, the energy and isotopic intermediate structure of the cross sections was revealed [1, 2]. The intermediate structure of the cross sections measured with a resolution of 15 keV is more pronounced for heavy selenium isotopes in the energy range from 300 keV to 1 MeV.

The structure of the elastic and inelastic cross sections can be due to the coupling of the input channel with the phonon or quasiparticle configurations of the particle-core system.

The analyzes of the averaged over 100 keV energy cross sections for elastic and inelastic scattering neutron scattering up to 1 MeV based on the *R*-matrix formalism is performed. The intermediate structure may be due to the three-quasiparticle input state in the $p_{3/2}$ channel.

The contribution of intermediate resonances to the *p*-neutron strength function is 70%. The total strength function $S_{3/2} \approx 3 \cdot 10^{-4}$ is consistent with the experimental one and calculated with the generalized optical model.

1. V.P.Efrosinin *et al.* // Sov. Journ. Nucl. Phys. 1979. V.29. No.3. P.631.
2. R.M.Musaelyan *et al*. // Bull. Acad. Sci. USSR. Phys. Ser. 1989. V.53. No.5. P.1012.

MEASUREMENTS OF DIRECT PHOTON IN He + Au COLLISIONS AT 200 GeV

Berdnikov Ya.A., Berdnikov A.Ya., Kotov D.O., Solovev V.N.
Peter the Great St.Petersburg Polytechnic University, Saint-Petersburg, Russia
E-mail: hydraca39@gmail.com

Collisions of heavy nuclei at relativistic energies, such as the ones at RHIC, provide a unique opportunity for the study of nuclear matter at very high temperatures and energy densities, like those that existed in the earliest moments of the universe. Under these conditions matter is expected to enter a state where quarks and gluons are no longer confined into hadrons. The motivation for the experimental program at RHIC is to explore this transition and study the QCD medium that evolves from it [1]. Collisions of different systems are very interesting for the interpretation of the results obtained in PHENIX, as they allow physicists to get the details of the evolution of the medium created in heavy-ion collisions.

Direct photons are produced at all stages of the collision, not originating from hadron decays and escaped from the hot nuclear matter unaffected [2]. Photons emitted in different stages of collision are dominating in different p_T regions. Such behavior helps to investigate the direct photon yield in order to study the properties of deconfined partonic state at different stages.

Direct photon yields in low-p_T region were already been investigated at the Relativistic Heavy Ion Collider (RHIC) [3] for $p+p$, $p+\mathrm{Au}$ and $d+\mathrm{Au}$ collisions. Recent analysis at RHIC has shown very intriguing results for low p_T with high thermal photon yield and strong elliptic flow of direct photons.

The aim of analysis of other small system collisions is to check that all measurements are consistent with the transition phase from 2 to 20 multiplicity and with theoretical models as $p+p$ and similar measurements are in good agreement with QCD expectations.

In this report we present an excess of low-p_T direct photons above the decay photon spectrum obtained in He + Au collisions at the energy 200 GeV measured at PHENIX. We also present the comparison with results of measurements in other collisions.

We acknowledge support from Russian Ministry of Education and Science, state assignment 3.1498.2017/4.6.

1. Carla M.Vale *et al.* // Nucl. Phys. A. 2009. V.830. P.66.
2. M.Thoma *et al.* // Phys. Rev. D. 1995. V.51. P.862.
3. K.Adcox *et al*. // Nucl. Phys. A. V.757. P.184.

NEUTRAL PI- AND ETA-MESONS PRODUCTION IN SMALL COLLISION SYSTEM OF HELIUM-3 AND GOLD AT 200 GeV

Berdnikov A.Ya., Berdnikov Ya.A., Kotov D.O., Sultanov M.A., Zharko S.V.
Peter the Great St.Petersburg Polytechnic University, Saint-Petersburg, Russia
E-mail: malik-211212@list.ru

A variety of evidences of quark-gluon plasma (QGP), deconfined matter state at extreme conditions of temperature [1], was systematically observed in collisions of ultra-relativistic heavy nuclei, such as copper, gold, or uranium [2–5]. Traditionally, small collision systems, such as *p* + Au, *d* + Au or ^{3}He + Au, are considered as ones without QGP production. Although, recent analyses on elliptical flows suggest that small droplets of QGP are created in these systems [6]. This fact makes small collision systems interesting for research of other QGP evidences and jet-quenching [7], in particular. Jet-quenching is related to energy loss of hard-scattered partons in quark-gluon medium and manifests itself in suppressed production of hadron yields at high transverse momenta (p_T) region in comparison with ones measured in elementary proton-proton collisions. Neutral pi- (π^0) and eta-meson (η) production research provide an efficient tool for jet-quenching probes as long as their yields can be measured in a large transverse momentum range with relatively small uncertainties.

In this report, results of π^0- and η-mesons nuclear modification factor (R_{AA}) measurements in ^{3}He + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV/*c* are presented. The yields are measured via $\pi^0 \rightarrow \gamma\gamma$ and $\eta \rightarrow \gamma\gamma$ decay channels using electromagnetic calorimeter of PHENIX spectrometer at RHIC. In central ^{3}He + Au collisions, an approximately 30% suppression of meson yields is observed at p_T > 10 GeV/*c*, while in semi-peripheral and peripheral collisions R_{AA} are equal to unity in the same transverse momentum region. The meson yields suppression and R_{AA} centrality dependence can be considered as a signature of jet-quenching in ^{3}He + Au collisions. Obtained results can be useful for additional parameter discrimination and further development of different jet-quenching effective models.

We acknowledge support from Russian Ministry of Education and Science, state assignment 3.1498.2017/4.6.

1. E.V.Shuryak // Phys. Rept. 1980. V.61. P.71.
2. I.Arsene *et al*. // Nucl. Phys. A. 2005. V.757. P.1.
3. B.B.Back *et al*. // Nucl. Phys. A. 2005. V.757. P.28.
4. J.Adams *et al*. // Nucl. Phys. A. 2005. V.757. P.102.
5. K.Adcox *et al*. // Nucl. Phys. A. 2005. V.757. P.184.
6. C.Aidala *et al.* // Nature Physics. 2019. V.15. P.214.
7. M.Gyulassy *et al*. // Phys. Rev. Lett. 1992. V.68. P.1480.

EVALUATED INTEGRAL CROSS SECTION OF THE ^{3}He(^{3}He,2p)^{4}He REACTION OBTAINED WITH REGARD TO ELECTRON SCREENING

Taova S.M., Generalov L.N., Zherebtsov V.A.
Russian Federal Nuclear Center – All-Russian Research Institute of Experimental Physics, Sarov, Russia
E-mail: otd4@expd.vniief.ru

Results of experimental data analysis on the ^{3}He(^{3}He,2p)^{4}He reaction with regard to electron screening are presented. Published data [1–6] on the reaction running in gas environment are analyzed. An algorithm of experimental data approximation in the low energy region described in [7] is improved. The potential of electron screening 388 eV is obtained. Using the obtained potential the enhancement factors are defined and the ^{3}He(^{3}He,2p)^{4}He reaction cross sections are calculated at low interaction energy of particles.

1. M.Junker *et al.* // Phys. Rev. C. 1998. V.57. P.2700.
2. R.Bonetti *et al.* // Phys.Rev. Lett. 1999. V.82. P.5205.
3. M.R.Dwarakanath *et al.* // Phys. Rev. C. 1971. V.4. P.1532.
4. M.R.Dwarakanath // Phys. Rev. C. 1974. V.9. P.805.
5. V.Nuen-Min *et al*. // Sov. Nucl. Phys. 1966. V.3. № 6. P.1064.
6. T.Itahashia *et al.* // Nucl. Phys. A. 2003. V.718. P.466c.
7. S.M.Taova *et al.* // Izv. RAS. 2018. V.82. №6. P.705.

INVESTIGATION OF THE CLUSTER STRUCTURE OF ^{9}Be BY REACTIONS WITH A DEUTERON BEAM

Urazbekov B.A.[1,2,3], Denikin A.S.[2,3], Itaco N.[1], Janseitov D.M.[3,4], Lukyanov S.M.[3], Mrazek J.[5], Mendibayev K.[3,6], Penionzhkevich Yu.E.[3], Sakhiyev S.K.[6,7], Trzaska W.H.[8], Issatayev T.[3,6]

[1] Università Degli Studi della Campania Luigi Vanvitelli, Naples, Italy; [2] Dubna state university, Dubna, Russia; [3] Joint institute for nuclear research, Dubna, Russia; [4] Al-Farabi kazakh national university, Almaty, Kazakhstan; [5] Nuclear Physics Institute CAS, Řež, Czech Republic; [6] Gumilev Eurasian national university, Nur-Sultan, Kazakhstan; [7] Abai national pedagogical university, Almaty, Kazakhstan; [8] Department of Physics, University of Jyväskylä, Jyväskylä, Finland

E-mail: bakytzhan.urazbekov@gmail.com

The cluster structure of nuclei arises from a correlated motion of nucleons inside a nucleus. In this regime a simple subgroup can be seen as a single particle. This kind of behaviour can give insights into numerous characteristics of the nucleus, as well as affect the processes of nuclear reactions. Investigation of the cluster structure in nuclei is still one of the priority problems of modern nuclear physics in connection with the intensive developments of experimental devices.

Angular distributions of protons, deuterons, tritons and alpha particles emitted in the d + ^{9}Be reaction at E_{lab} = 19.5 and 35.0 MeV are measured. The elastic channel is analyzed in the framework of both the Optical Model and the Coupled Channel approach.

Two kind of optical potentials are analyzed: the semi-microscopic Double Folding potential and the phenomenological Woods–Saxon potential. The deformation parameter β_2 is obtained for the transition $5/2^- \rightarrow 3/2^-$ ^{9}Be. The (d,p) and (d,t) one nucleon exchange reactions are analyzed within the coupled reaction channel approach. The spectroscopic amplitudes for the different nuclear cluster configurations are calculated.

Differential cross sections for the reaction channel ^{9}Be (d,α)^{7}Li are calculated within the coupled reaction channel method including all possible reaction mechanisms. Corresponding contributions to the cross sections are analyzed.

MID-RAPIDITY LIGHT NEUTRAL MESONS PRODUCTION IN ULTRA-RELATIVISTIC Cu + Au AND U + U COLLISIONS

Berdnikov A.Ya., Berdnikov Ya.A., Kotov D.O., Radzevich P.V., Zharko S.V.
Peter the Great St.Petersburg Polytechnic University, Saint-Petersburg, Russia
E-mail: zharkosergey94@gmail.com

Collisions of ultra-relativistic heavy nuclei are used for production of quark-gluon plasma (QGP) [1], a state of deconfined matter at temperatures larger than 10^{12} K. Today, systematic study of QGP evidences is carried out in the experiments at RHIC [2–5] and LHC [6–8]. Production of light neutral mesons (such as π^0, η, K_S, ω) with large transverse momenta (p_T) is suffered from jet-quenching effect [9]: meson yields are suppressed when compared to yields in elementary $p+p$ collisions. This effect is related to hard-scattered partons energy loss in a quark-gluon medium, thus different meson production measurements at high transverse momenta provide a systematic probe of jet-quenching versus properties of these particles (mass, spin, flavor etc.). Measurements in different heavy nuclei collision systems provide a variation of initial-state conditions for plasma production and is useful to study a jet-quenching effect dependence from energy density and geometry of the collisions.

In this report we present results on π^0, η, K_S, ω nuclear modification factor (R_{AA}) measurements at mid-rapidity in Cu + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV/*c* and U + U collisions at $\sqrt{s_{NN}}$ = 192 GeV/*c*. Analysis is carried out with PHENIX spectrometer at RHIC, meson yields are measured using PHENIX electromagnetic calorimeter. In both collision systems we found that measured R_{AA} are independent from meson species at different p_T and centrality intervals. In central Cu + Au collisions meson invariant yields are suppressed twice when compared to elementary $p+p$ collisions. Meson production in central U + U collisions shows a fivefold suppression.

Comparison of different meson production shows that meson suppression is the same in different heavy-ion collision systems (Au + Au, Cu + Cu, Cu + Au, U + U) at similar collision energy and similar numbers of participant nucleons, which suggests jet-quenching independence from initial collision geometry.

We acknowledge support from Russian Ministry of Education and Science, state assignment 3.1498.2017/4.6.

1. E.V.Shuryak // Phys. Rept. 1980. V.61. P.71.
2. I.Arsene *et al*. // Nucl. Phys. A. 2005. V.757. P.1.
3. B.B.Back *et al*. // Nucl. Phys. A. 2005. V.757. P.28.
4. J.Adams *et al*. // Nucl. Phys. A. 2005. V.757. P.102.
5. K.Adcox *et al*. // Nucl. Phys. A. 2005. V.757. P.184.
6. S.Chatrchyan *et al.* // Eur. Phys. J. C. 2012. V.72. P.1945.
7. G.Aad *et al.* // Phys. Lett. B 2013. V.719. P.220.
8. T.Gunji // Nucl. Phys. A. 2016. V.956. P.11.
9. M.Gyulassy *et al*. // Phys. Rev. Lett. 1992. V.68. P.1480.

Theory of atomic nucleus and fundamental interactions

- **Nuclear many-body problem;**
- **Microscopic description of collective degrees of freedom and their interaction with single-particle degrees of freedom;**
- **Theory of systems with small number of particles;**
- **Nonlinear nuclear dynamics;**
- **Meson and quark degrees of freedom in nuclei, mesoatoms;**
- **Hypernuclei and other exotic systems;**
- **Double beta decay and neutrino mass problem;**
- **Interaction of nucleus with atomic shell electrons;**
- **Verification of theories of elementary particle interaction and conservation laws;**
- **Nuclear and particle physics applied to astrophysical objects.**

FULLY SELF-CONSISTENT STUDY OF ISOBARIC ANALOG RESONANCES

Borzov I.N.[1,2], Tolokonnikov S.V.[1,3]

[1] National Research Centre "Kurchatov Institute", 123182, Moscow, Russia; [2] Bogolubov Laboratory of Theoretical Physics, Joint Institute of Nuclear Research, 141980, Dubna, Russia; [3] Moscow Institute of Physics and Technology, 141701, Dolgoprudny, Russia

E-mail: Borzov_IN@nrcki.ru, ibor48@mail.ru

The fully self-consistent framework for isobaric-analog resonances is presented. The nuclei around the neutron shells at $N = 20, 50, 82, 126$ including non-magic nuclei with pairing in both neutron and proton sectors are treated in. the Density Functional plus Continuum Quasiparticle Random Phase Approximation (DF + CQRPA). The recently established new Fayans functional DF3-f is applied for calculations of the IAR energies in long isotopic chains. A comparison with the relativistic QRPA [1, 2] and SAMi + RPA [3] shows better performance and flexibility of the DF + CQRPA. In particular, constraining the strength of exchange Coulomb contribution from the binding energy splitting of the doublets and triplets of the mirror nuclei allows for better description of the IAR energies [4]. In Fig.1 a comparison with the available experimental IAR energies for Ca, Sn and Pb isotopic chains is given.

Supported by the grant of Russian Scientific Foundation (RSF 16-12-10161).

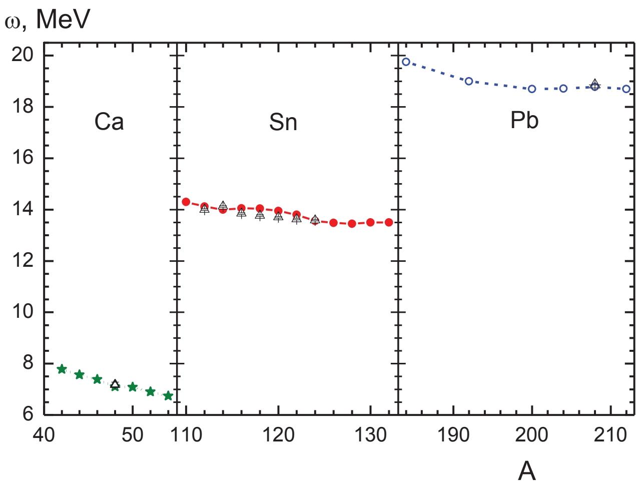


Fig. 1.The IAR energies (relative to the parent nucleus ground state) in the Ca, Sn and Pb isotopic chains in comparison with the data.

1. N.Paar, T.Niksic, D.Vretenar, P.Ring // Phys.Rev. C. 2004. V.69. 054303.
2. Z.M.Niu, Y.F.Niu, H.Z.Liang, W.H.Long, J.Meng // Phys.Rev. C. 2017. V.95. 044301.
3. X.Roca-Maza, G.Col`o, H.Sagawa // Phys.Rev. C. 2016. V.94. 044313.
4. I.N.Borzov, S.V.Tolokonnikov // Physics of Atomic Nuclei (in print, 2019).

COLLINEAR TRI-PARTITION AND THE COLLECTIVE NUCLEAR MODEL

Karpeshin F.F.
D.I.Mendeleyev Institute for Metrology, Saint-Petersburg, Russia
E-mail: fkarpeshin@gmail.com

Careful attention in the literature raises the question of the possibility of collinear true ternary fission (TTF) into comparable fragments. The performed trajectory calculations [1-3] show that the very minimum deviation of the middle fragment from the fission axis at the time of rupture by ~ 0.5 fm leads to the irrevocable destruction of the collinearity. However, it was noted only in [2, 3] that this configuration with a displaced middle fragment contradicts the collective Bohr model. This is especially clearly manifested in the case of spontaneous fission of ^{252}Cf. No configuration with displaced middle fragment can be realized in the case of fission of this spinless nucleus. Such a configuration is strictly forbidden by the symmetry principles, which are in the basis of the collective Bohr's model. Indeed, such a triangular shape, being not axially symmetric, only can reply to the projection of the angular momentum I on the nuclear axis $K > 0$. As $I \geq K$, non-zero K values are only possible if fissile nucleus has a non-zero spin. This is not the case if spontaneous fission of ^{252}Cf is considered. Therefore, it is only the symmetric configuration “three in line” which survives fission. Such fission was figuratively called “co-axial” in Ref. [3].

Furthermore, even such a “co-axial” initial configuration is not enough yet for the final collinearity. It can be destroyed during spreading of the fragments under action of the accelerating Coulomb force between them in combination with perpendicular to the fission axis component of the initial velocity of the fragments. This component arises at the moment of scission due to big spins and large relative angular momentum of the fragments, similar to the ROT effect. Big spins of the fragments are confirmed by experiment. Such spins can be formed due to the wriggling vibrations of the fissile nucleus. The orbital momentum arises for compensation of the total spin of the fragments. The final value of the divergence between heavy and light fragments, however, does not exceed 2°, which value is not resolved by the experimental setup of Ref. [4]. Basing on the above consideration, one can conclude that the collinear trajectory in the case of true ternary spontaneous fission of ^{252}Cf is really most probable.

1. R.B.Tashkhodjaev *et al*. // Phys. Rev. C. 2016. V.94. P.054614.
2. F.F.Karpeshin // Izv. RAN, Ser. Fiz. 2017. V.81. P.1350; Bull. Russ. Acad. Sci.: Physics. 2017. V.81. P.1207.
3. F.F.Karpeshin // Yad. Fiz. 2018. V.81. P.155; Phys. At. Nucl. 2018. V.81. P.157.
4. Yu.V.Pyatkov *et al*. // Phys. Rev. C. 2017. V.96. 064606.

ISOBARIC CHARGE-EXCHANGE RESONANCES AND THE SOLAR NEUTRINOS CAPTURE BY NUCLEI

Lutostansky Yu.S., Osipenko A.P., Tikhonov V.N.
National Research Center "Kurchatov Institute", Moscow, Russia
E-mail: lutostansky@yandex.ru

Isobaric charge-exchange states are manifested in the corresponding charge-exchange reactions, for example (ν,*e*), (*p,n*), (*n,p*), (^{3}He,*t*), (*t*,^{3}He), (^{6}Li,^{6}He) etc., or in β-transitions of nuclei and the processes accompanying the β-decay of nuclei. Among these states, collective resonance excitations are of the most interest. The theoretical investigation of these collective states began with the first calculations of the giant Gamow-Teller resonance (GTR) [1] and other collective states [2] long time before their experimental studies in the charge-exchange reactions [3, 4]. Below the GTR is lying the isobaric analog resonance (AR), and lower, the so-called, pigmy resonances (PR) [5].

The energies and matrix elements of the excited states that determine the structure of the charge-exchange strength function $S(E)$, were calculated both in the self-consistent theory of finite Fermi systems (TFFS), and in its approximate model version. Calculations of the neutrino capture cross-sections $\sigma(E)$ for the isotopes ^{71}Ga, ^{98}Mo and ^{127}I [6] were made with allowance for the resonance structure of the strength function $S(E)$ and the effect of each resonance on the energy dependence $\sigma(E)$ was analyzed. It is found that in calculations of the neutrino capture cross-section $\sigma(E)$ on the isotopes ^{71}Ga, ^{98}Mo, and ^{127}I, all charge-exchange resonances in the strength function $S(E)$ must be taken into account. The exclusion of just high-lying giant Gamow-Teller resonance considerably reduces the rate of solar neutrino capture (by 17% for ^{71}Ga up to 65% for ^{127}I) [7]. So it is shown that the resonance stricture has a considerable effect on the cross section $\sigma(E)$ (especially at high energies) and it could also affect the interpretation of the experimental data.

This work was supported in part by the Russian Foundation for Basic Research (projects no. 18-02-00670).

1. Yu.V.Gaponov, Yu.S.Lyutostanskii // JETP Lett. 1972. V.15. P.120.
2. Yu.V.Gaponov, Yu.S.Lyutostanskii // Sov. J. Nucl. Phys. 1974. V.19. P.33.
3. R.R.Doering, A.Galonsky, D.Patterson *et al.* // Phys. Rev. Lett. 1975. V.35. P.1691.
4. A.Galonsky, R.R.Doering, D.M.Patterson *et al.* // Phys. Rev. 1976. V.14. P.748.
5. Yu.S.Lutostansky // JETP Lett. 2017. V.106. P.7.
6. Yu.S.Lutostansky. V.N.Tikhonov // Phys. Atomic Nuclei. 2018. V.81. P.540.
7. Yu.S.Lutostansky, A.P.Osipenko, V.N.Tikhonov // Bull. Russ. Acad. Sci.: Phys. 2019. V.83. P.488.

SELF-ORGANIZATION IN NUCLEAR STRUCTURE AND ITS IMPACT TO HEAVY NUCLEI

Otsuka T.[1,2,3]
[1] *University of Tokyo, Hongo, Bunkyo-ku, Tokyo, 113-0033, Japan;* [2] *Nishina Center,RIKEN, Hirosawa, Wako-shi, Saitama, 351-0198, Japan;* [3] *Instituut voor Kern- en Stralingsfysica, KU Leuven, B-3001 Leuven, Belgium*
E-mail: otsuka@phys.s.u-tokyo.ac.jp

The interplay between the single-particle states and the collective modes has been one of the central subjects of nuclear physics since the very beginning. If the single-particle aspect is too strong, for instance, with a large gap between relevant orbits, it certainly suppresses the collective mode. Thus, the single-particle states and the collective modes have been considered to counteract against each other, and the former behaves as the resistance power against the latter. However, an opposing idea has arisen. The nuclear force is characterized by the component driving a given collective mode, like the quadrupole interaction for the quadrupole deformation. Recently, the monopole component of nuclear forces has been shown to reduce the resistance power: the energies of single-particle orbits can be optimized for a given mode by choosing favorable configurations. In fact, the monopole components of the central and tensor forces exhibit strong orbital dependences, and can move single particle energies depending on configurations of other nucleons. This mechanism is called the quantum self-organization, and is consistent with the general self-organization concept. While its effect has been seen in the quantum phase transition of Zr isotopes [1], the same underlying mechanism is shown to promote the shape evolution in ^{148}Sm to ^{154}Sm in a different way. These phenomena have been described quantitatively by state-of-the-art Monte Carlo Shell Model calculations with reasonable interactions, showing good agreements with experiment. Thus, single-particle states are not necessarily an enemy of the collectivity, but can be a good friend. One of the striking results is that contrary to the conventional idea by Bohr and Mottelson, rotational nuclei may not show low-lying β or γ vibrations, but may be consequences of equilibrium shapes with triaxiality. This picture may go beyond the liquid drop model, including its quantized versions. The disappearance of β or γ vibration may produce interesting impacts on the fission process, and the self-organization may enhance the stability of certain heavy nuclei, including super heavy nuclei. These exciting challenges will be touched upon.

1. T.Togashi, Y.Tsunoda, T.Otsuka *et al*. // Phys. Rev. Lett. 2016. V.117. 172502.

AB INITIO CALCULATIONS OF LIGHT NUCLEI WITHIN THE NO-CORE SHELL MODEL

Shirokov A.M.[1,2,3]

[1] *D. V. Skobeltsyn Institute of Nuclear Physics, M. V. Lomonosov Moscow State University, Moscow, Russia;* [2] *Pacific National University, Khabarovsk, Russia;* [3] *Department of Physics and Astronomy, Iowa State University, Ames, USA*

E-mail: shirokov@nucl-th.sinp.msu.ru

I shall overview some our recent results of theoretical *an initio* studies of light nuclei within the no-core shell model (NCSM) as well as various recent developments of the NCSM approach.

In particular, I shall discuss a new *NN* interaction based on the chiral effective field theory and adapted to reproduce not only *NN* scattering data but also properties of light nuclei without three-nucleon forces.

To improve the accuracy of the NCSM predictions, various techniques are used to extrapolate the NCSM results to the case of the infinite basis space. One of the most promising such techniques is based on the deep learning with artificial neural networks.

We have also developed the SS-HORSE extension of the NCSM which makes it possible to calculate energies and widths of unbound nuclear resonant states.

The NCSM can be used to justify the standard shell model with an inert core. For the standard shell model applications within the valence *sd* shell, we calculate in NCSM with realistic *NN* interactions the ground state energy of ^{16}O and spectra of ^{17}O and ^{17}F nuclei to obtain the core energy and energies of the neutron and proton single-particle states in the *sd* shell. Next, we calculate in NCSM the ^{18}F nucleus and reduce the obtained Hamiltonian matrix to the $0\hbar\omega$ model space to derive the effective interaction of valence nucleons.

GIANT RESONANCES IN ^{40,48}Ca, ^{68}Ni, ^{90}Zr, ^{116}Sn, ^{144}Sm AND ^{208}Pb AND PROPERTIES OF NUCLEAR MATTER

Shlomo S., Bonasera G., Anders M.R.
Cyclotron Institute, Texas A&M University, College Station, Texas 77843, USA
E-mail: s-shlomo@tamu.edu

We have carried out calculations of centroid energies, E_{CEN}, of the isoscalar ($T = 0$) and isovector ($T = 1$) giant resonances of multipolarities $L = 0 - 3$ in ^{40,48}Ca, ^{68}Ni, ^{90}Zr, ^{116}Sn, ^{144}Sm and ^{208}Pb, within the fully self-consistent spherical Hartree-Fock (HF)-based random phase approximation (RPA) theory, using 33 different Skyrme-type effective nucleon-nucleon interactions of the standard form commonly adopted in the literature. We also study the sensitivity of E_{CEN} to physical properties of nuclear matter (NM), such as the effective mass m^*/m, nuclear matter incompressibility coefficient K_{NM}, enhancement coefficient κ of the energy weighted sum rule for the isovector giant dipole resonance and the symmetry energy and its first and second derivatives at saturation density, associated with the Skyrme interactions used in the calculations. Constraining the values of the NM properties, by comparing the calculated values of E_{CEN} to the experimental data, we find that interactions associated with the values of $m^*/m = 0.70$ to 0.90, $K_{NM} = 210$ to 240 MeV and κ = 0.25 to 0.70 best reproduce the experimental data. These constraints can be used to construct the next generation energy density functional (EDF) with improved prediction of properties of nuclei and nuclear matter.

A BIG STEP TOWARDS THE STUDY OF SUPER-HEAVY CALCIUM ISOTOPES

Tarasov O.B.[1], Ahn D.S.[2], Bazin D.[1], Fukuda N.[2], Gade A.[1,3], Hausmann M.[4], Inabe N.[2], Ishikawa S.[5], Iwasa N.[5], Kawata K.[6], Komatsubara T.[2], Kubo T.[4], Kusaka K.[2], Morrissey D.J.[1,7], Ohtake M.[2], Otsu H.[2], Portillo M.[4], Sakakibara T.[5], Sakurai H.[2], Sato H.[2], Sherrill B.M.[1,3], Shimizu Y.[2], Stolz A.[1], Sumikama T.[2], Suzuki H.[2], Takeda H.[2], Thoennessen M.[1,3], Ueno H.[2], Yanagisawa Y.[2], Yoshida K.[2]

[1] National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, USA; [2] RIKEN Nishina Center, RIKEN, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan; [3] Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA; [4] Facility for Rare Isotope Beams, Michigan State University, East Lansing, MI 48824, USA; [5] Department of Physics, Tohoku University, 6-3 Aramaki-aza-aoba, Aoba, Sendai 980-8578, Japan; [6] Center for Nuclear Study, University of Tokyo, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan; [7] Department of Chemistry, Michigan State University, East Lansing, MI 48824, USA

E-mail: tarasov@nscl.msu.edu

Measurements at NSCL [1,2] have demonstrated that the fragmentation of ^{76}Ge and ^{82}Se beams using a two-stage separator can be used to produce new neutron-rich isotopes in the calcium region. This work was continued at the RIKEN RIBF facility, using a higher beam energy and intensity, and so accessing the one-order-of-magnitude lower production cross sections needed to explore the stability of $^{59;60}$Ca.

The discovery of $^{60}_{20}\mathrm{Ca}_{40}$ and seven other neutron-rich nuclei near the limits of stability is reported [3] from the projectile fragmentation of a 345 MeV/u primary ^{70}Zn beam on Be targets at the RI Beam Factory. During a 99.5 hour measurement, ^{47}P, ^{49}S, ^{52}Cl, ^{54}Ar, ^{57}K, ^{59,60}Ca, and ^{62}Sc, the most neutron-rich isotopes of the respective elements, were observed for the first time. In addition, one event consistent with ^{59}K was observed. The results are compared with the drip-line predictions of a wide variety of mass models. The two isotopes ^{49}S and ^{52}Cl, discovered in this work, emerge as key discriminators between different models. The energy density functionals in best agreement with the limits of existence in the explored region, HFB-22 and UNEDF0, predict the even-mass Ca isotopes to be bound out to at least ^{70}Ca, at odds with ab-initio models that predict the neutron drip line in Ca to be closer to ^{60}Ca with ^{59}Ca unbound.

The potential for the synthesis of such super neutron-rich calcium isotopes at Facility for Rare Isotope Beams (FRIB) / MSU will be discussed.

1. O.B.Tarasov *et al.* // Phys.Rev.Lett. 2009. V.102. P.142501.
2. O.B.Tarasov *et al.* // Phys.Rev.C 2013. V.87. P.054612.
3. O.B.Tarasov *et al.* // Phys.Rev.Lett. 2018. V.121. P.022501.

PARTICLE-HOLE DISPERSIVE OPTICAL MODEL: UNIQUE FEATURES AND NEW IMPLEMENTATIONS

Urin M.H.
National Research Nuclear University "MEPhI" (Moscow Engineering Physics Institute), Moscow, Russia
E-mail: urin@theor.mephi.ru

The physical content, unique features and new implementations of the recently developed particle-hole dispersive optical model (PHDOM) [1] are briefly presented. Within the model, the main modes of damping a great variety of high-energy (*p*-*h*)-type excitations associated with giant resonances are described together. Being formulated in terms of the energy-averaged *p*-*h* Green function, the model is a microscopically-based extension of the standard and non-standard continuum-RPA versions to phenomenological consideration of the spreading effect. The latter is described in terms of the strength of the energy-averaged specific *p*-*h* interaction (*p*-*h* self-energy term). The imaginary part of this strength determines the real one via a dispersive relationship, which follows from the spectral expansion of the 2*p*-2*h* Green function. Supposing that different *p*-*h* states are "decaying" into chaotic states independently of one another, one gets the model equations in a closed form. Weak violations of the model unitarity, which are due to the methods used for describing the spreading effect, were examined and ways for unitarity restoration were proposed [2]. The unique features of the PHDOM are concerned with its ability to describe: (i) the energy-averaged double transition density and, as a result, various strength functions at arbitrary (but high-enough) excitation energies, including giant resonances; (ii) direct one-nucleon decay of (*p*-*h*)-type excitations; (iii) the shift of resonance-like structures related to mentioned excitations due to the spreading effect. In first implementations of the PHDOM, the following input quantities are used: the Landau-Migdal p-h interaction, a partially self-consistent phenomenological mean field, properly parameterized the imaginary part of the strength of the *p*-*h* self-energy term. The intensity of this part is, actually, only one specific model parameter taken from the description of the observable total width of a given giant resonance. New implementations of the PHDOM current version to the description of direct one-neutron decay of the giant dipole resonance [3], and main damping parameters of the isobaric analog and charge-exchange giant monopole resonances [4] are briefly presented.

This work was partially supported by the Russian Foundation of Basic Research (grant No. 19-02-0060).

1. M.H.Urin // Phys. Rev. C. 2013. V.87. P.044330; M.H.Urin // EPJ Web Conf. 2018. V.182. P.02125.
2. M.L.Gorelik, S.Shlomo, B.A.Tulupov and M.H.Urin // Nucl. Phys. A. 2018. V.970. P.353.
3. B.A.Tulupov, M.H.Urin // EPJ Web Conf. 2018. V.194. P.04003.
4. G.V.Kolomiytsev, M.L.Gorelik, M.H.Urin // Eur. Phys. J. A. 2018. V.54. P.228.

STUDY OF OCTUPOLE DEFORMATION IN NEUTRON-RICH XENON ISOTOPES

Abolghasem M., Alexa P.
VSB-Technical University of Ostrava, Czech Republic
E-mail: mojgan.abolghasem.st@vsb.cz

The neutron-rich nuclei above the doubly closed ^{132}Sn towards the neutron drip-line is an accessible area for spectroscopic studies [1, 2]. The theoretical study of shape and structural changes of this mass region is of particular interest. There are two different theoretical approaches for study of evolution of nuclear shapes and structural changes: algebraic models (IBM, algebraic collective model [3]) or a more fundamental microscopic approach (mean field [4] or shell model [5]).

In this contribution we study octupole ground-state deformation in neutron-rich xenon isotopes. We perform microscopic calculations based on the axial Skyrme-Hartree-Fock model [6] using 18 different Skyrme functional parameterizations [7].

In previous work [8] we presented ground-state deformations (β_2, β_3, β_4) for neutron-rich Te, Xe, Ce and Nd isotopes for the parameterization, which best fits the experimental binding energies. In this contribution we compare the potential energy curves as a function β_3 deformation parameter obtained for different Skyrme functional parameterizations along the chain of xeon isotopes.

1. J.M.Allmond *et al*. // Phys. Rev. Lett. 2017. V.118. 092503.
2. B.Moon *et al.* // Phys. Rev. C. 2017. V.95. 044322.
3. D.J.Rowe *et al*. // Phys. Rev. C. 2009. V.79. 054304.
4. M.Bender *et al*. // Rev. Mod. Phys. 2003. V.75. P.121.
5. H.Naidja *et al*. // Phys. Rev. C. 2017. V.96. 034312.
6. M.Bender *et al*. // Rev. Mod. Phys. 2003. V.75. P.121.
7. P.Klüpfel *et al.* // Phys. Rev. C. 2009. V.79. 034310.
8. M.Abolghasem *et al*. // Acta Phys. Polon. B. 2019. V.50. P.555.

MICROSCOPIC DESCRIPTION OF PYGMY AND GIANT DIPOLE RESONANCES IN ^{48,50}Ca AND ^{68,70}Ni

Arsenyev N.N.[1], Severyukhin A.P.[1,2], Voronov V.V.[1], Giai N.V.[3]

[1] Bogoliubov Laboratory of Theoretical Physics, JINR, Dubna, Russia; [2] Dubna State University, Dubna, Russia; [3] Institut de Physique Nucléaire, CNRS-IN2P3, Université Paris-Sud, Orsay Cedex, France

E-mail: arsenev@theor.jinr.ru

The structure of exotic neutron-rich nuclei is one of the main science drivers in contemporary nuclear physics research. An attention has been devoted to effects of varying the ratio between the proton Z and neutron N numbers on different nuclear structure characteristics of nuclei deviated from their valley of beta-stability. One of the phenomena associated with the change in N/Z ratios is the pygmy dipole resonance (PDR) [1]. One of the successful tools for describing the PDR is the quasiparticle random phase approximation (QRPA) with the self-consistent mean-field derived from Skyrme energy density functionals (EDF) [2]. Such an approach can describe the properties of the low-lying states reasonably well by using existing Skyrme interactions. Due to the unharmonicity of the vibrations there is a coupling between one-phonon and more complex states [3]. The main difficulty is that the complexity of calculations beyond standard QRPA increases rapidly with the size of the configuration space, and one has to work within limited spaces. Using a finite rank separable approximation for the residual particle-hole interaction derived from the Skyrme forces one can overcome this numerical problem [4–6].

In the present report, we analyze the effects of phonon-phonon coupling (PPC) on the E1 strength distributions of neutron-rich calcium and nickel isotopes. Using the same set of the EDF parameters we describe available experimental data for ^{48}Ca, ^{68}Ni and give prediction for ^{50}Ca, ^{70}Ni. The inclusion of the PPC results in the formation of low-energy 1^- states of ^{48}Ca. There is an impact of the PPC effect on low-energy E1 strength of ^{48}Ca [7]. The effect of the low-energy E1 strength on the electric dipole polarizability is discussed. We predict a strong increase of the summed E1 strength below 10 MeV (12 MeV), with increasing neutron number from ^{48}Ca (^{68}Ni) till ^{50}Ca (^{70}Ni) [8].

This work is partly supported by CNRS-RFBR agreement No. 16-52-150003.

1. D.Savran, T.Aumann, A.Zilges // Prog. Part. Nucl. Phys. 2013. V.70. P.210.
2. N.Paar, D.Vretenar, E.Khan, G.Colò // Rep. Prog. Phys. 2007. V.70. P.691.
3. V.G.Soloviev // Theory of Atomic Nuclei: Quasiparticles and Phonons. 1992. Bristol/Philadelphia.
4. N.V.Giai, Ch.Stoyanov, V.V.Voronov // Phys. Rev. C. 1998. V.57. P.1204.
5. A.P.Severyukhin, V.V.Voronov, N.V.Giai // Phys. Rev. C. 2008. V.77. P.024322.
6. A.P.Severyukhin, V.V.Voronov, N.V.Giai // Eur. Phys. J. A. 2004. V.22. P.397.
7. N.N.Arsenyev, A.P.Severyukhin, V.V.Voronov, N.V.Giai // Phys. Rev. C. 2017. V.95. P.054312.
8. N.N.Arsenyev, A.P.Severyukhin, V.V.Voronov, N.V.Giai // in preparation.

GENERALIZED QUASISPIN FORMALISM AND FERMION STRUCTURE OF THE COLLECTIVE STATES OF NUCLEI

Baktybayev K.[1], Baktybayev M.K.[1,2], Koilyk N.O.[1], Dalelkhankyzy A.[1]
[1] *Al-Farabi Kazakh national University, Almaty Kazakhstan;* [2] *Satbayev University, Almaty Kazakhstan*
E-mail: murat.baktybayev@gmail.com

The explanation of the structure of these collective states of multi-nucleon systems based on fermion degrees of freedom is an important problem of nuclear theory. For this purpose, attempts were made to use semi-microscopic approaches in which a large shell space was cut to the SD-pair subspace of nucleons. The operators of such a fermion subspace were mapped into ideal bosonic operators.

This paper proposes a microscopic-fermion calculation of the properties of collective states of nuclei and parameters of the boson theory based on the generalized quasi-spin formalism. It introduces new generalized quasi-spin interaction operators

$$S_+=\sum\alpha_j S^+_j,\ S_-=\sum(1/\alpha_j)S_j,\ S_0=N-\Omega,\ \Omega=\Sigma\alpha_j(j+1/2),$$

which include α_j values reflecting the nonuniform distribution of nucleons over nondegenerate j-shells. This eliminates the well-known drawbacks of the usual quasi-spin formalism. The proposed calculation method also introduces double tensors of operators, which act in the spaces of both angular moments and generalized quasispin ones, with the help of these tensors many-particle matrix elements of operators are easily expressed through two-particle ones. The total Hamiltonian of the system is diagonalized in the representation of a generalized quasispin.

The proposed method is applied in this work to the study of the properties and structure of the states of even ruthenium isotopes $^{100\text{–}108}$Ru. The calculated values of the spectra and probabilities of electromagnetic transitions between states of different bands are found. In particular, the values of quadrupole B(E2), their relative values between different transitions are determined: $B_1(E_i-E_j/B_2(E_i-E_j)$, as well as the ratio of the probability B(E2) transitions to the probabilities of magnetic dipole transitions: δ(E2/M1). The calculated values are compared with their experimental data in the literature.

1. A.Arima, F.Iackello // Ann. Phys. 1976. V.99. P.253.
2. T.Mizusaki, T.Otsuka // Progr. Theor. Phys. Suppl. 1996. №125. P.65.
3. Yan-An Luo, Feng Pan, *et al*. // Phys. Rev. C. 2005. V.71. 044304.
3. K.Baktybayev *et al.* // Adv. Stud. Theor. Phys. 2012. V.6. P.1389.
4. N.Yoshinaga *et al.* // Progr. Theor. Phys. Suppl. 1996. №125. P.65.

MICROSCOPIC STRUCTURE OF COLLECTIVE STATES OF NUCLEI AND GENERALIZED QUASISPIN FORMALISM

Baktybayev K.[1], Baktybayev M.K.[1,2], Koilyk N.O.[1], Dalelkhankyzy A.[1]
[1] Al-Farabi Kazakh national University, Almaty Kazakhstan; [2] Satbayev University, Almaty Kazakhstan
E-mail: murat.baktybayev@gmail.com

Collective states lying in the low energy regions of heavy and medium atomic nuclei are successfully described by the phenomenological model of interacting bosons (IBM) [1, 2]. Attempts were also made to calculate the IBM parameters by pre-cutting the shell-model space to the SD pair nucleon subspace, and then the SD-fermion space operators were mapped to the ideal boson space.

In the present paper, a direct fermion-microscopic calculation of the parameters of the phenomenological theory based on the generalized quasi-spin formalism is assumed, in which the pair shell space is described by the quantum number of the generalized quasispin with given internuclonal forces. Calculations are facilitated by the inclusion in the theory of double tensors acting in spaces, both angular moments and generalized quasispins [3]. In the method used, the disadvantages of the usual quasi-spin formalism are eliminated by introducing generalized quasi-spin interaction operators. The new operators include quantities reflecting the nonuniform distribution of nucleons over nondegenerate j-shells. Using this method made it possible to more accurately solve many-particle problems for fermion systems with certain quantum numbers and with given paired internucleon forces. The method was applied to the calculation of the structure of multi-nucleon states of real nuclear systems. The implementation of the method in systems of interacting bosons makes it much easier to solve problems with certain symmetric Hamiltonians, and to calculate the parameters of the boson theory through the matrix elements of fermion interaction operators. The use of double tensors makes it possible to express many-particle matrix elements in terms of two-particle.

In this paper, the method is applied to the study of the properties and structure of even isotopes of neodymium $^{132\text{-}138}$Nd. Apart from the spectrum in the low-energy region of these nuclei and the probabilities of the quadrupole transitions B(E2), their relative values between different E2 transitions are calculated. The ratios of the probabilities of E2 transitions to the values of magnetic dipole transitions: δ(E2/M1). All these calculated values are compared with the available experimental data.

1. A.Arima, F.Iackello // Ann. Phys. (N.Y.). 1979. V.123. P.468.
2. Yan-An Luo, Feng Pan, *et al*. // Phys. Rev. C. 2005. V.71. 044304.
3. K.Baktybayev *et al*. // Adv. Stud. Theor. Phys. 2012. V.6. P.1399.
4. N.Yoshinaga *et al*. // Progr. Theor. Phys. Suppl. 1996. №.125. P.65.

LEVEL DENSITIES OF NUCLEI WITH *Z* = 112–120

Bezbakh A.N.[1], Shneidman T.M.[1], Rahmatinejad A.[1,2], Antonenko N.V.[1]
[1] *Joint Institute for Nuclear Research, Dubna, Russia;* [2] *Department of Physics, Faculty of Science, University of Zanjan, Zanjan, Iran*
E-mail: bezbakh@theor.jinr.ru

The intrinsic level densities of superheavy nuclei with $Z = 112–120$ are calculated using the single-particle spectra obtained with the modified two-center shell model. The role of the shell and pairing effects on the level density are studied. The extracted level density parameter is represented as a function of mass number and ground-state shell correction.

1. J.Maruhn, W.Greiner // Z. Phys. A. 1972. V.251. P.431.
2. G.D.Adeev, P.A.Cherdantsev // Yad. Fiz. 1975. V.21. P.491.
3. V.G.Soloviev, Theory of Complex Nuclei. Pergamon Press. Oxford. 1976.

A NEW KIND OF ATOMIC NUCLEI: LOCAL MAGIC NUCLEI

Boboshin I.
Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
E-mail: Boboshin@depni.sinp.msu.ru

In this study, a new kind of atomic nuclei has been discovered, local magic nuclei [1]. A theory of these nuclei has been developed in our study as well.

These nuclei have been discovered by the data analysis. They have same observed peculiarities as traditional magic nuclei but, unlike the latter ones, have no magic isotopes or isotones and, besides, manifest themselves at new magic numbers. They place inside as well as outside the valley of stability. To describe the new phenomena, we introduce 'miraculous pairs' (N, Z) etc., where the underline denotes a number losing its magicity in another pair.

In theory, it is shown directly that these nuclei arise due to the one-time appearance of gaps within shells. The shell evolution is driven by two-particle nucleon-nucleon interactions. The proton-neutron tensor force makes a decisive contribution in all cases. Diagrams of the nucleon orbit energies have been constructed. New magic numbers $N = 32, 34$ in nuclei $Z \approx 40$ are predicted. A new evolving shell scheme which develops the traditional Goeppert–Mayer–Jensen scheme has been constructed.

1. Igor Boboshin // Preprint of Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University № 2018-1/892.

FISSION BARRIERS IN ACTINIDE REGION WITHIN THE FAYANS ENERGY-DENSITY FUNCTIONAL

Borzov I.N.[1,2], Tolokonnikov S.V.[1,3]
[1] National Research Centre "Kurchatov Institute", 123182, Moscow, Russia; [2] Bogolubov Laboratory of Theoretical Physics, Joint Institute of Nuclear Research, 141980, Dubna, Russia; [3] Moscow Institute of Physics and Technology, Dolgoprudny, Russia
E-mail: Borzov_IN@nrcki.ru, ibor48@mail.ru

The modified Fayans Density Functional FANDF0_a with a strong effective tensor interaction is applied to the fission barriers in the actinide region. The influence of the octupole degree of freedom was studied in [1]. It is shown that with these new provisions in effect, the second barrier mostly turns to be lower than the first one. This generic feature has an impact on the competition between the fission and neutron capture which has an impact on the astrophysical r-process nucleosynthesis.

Supported by the Russian Scientific Foundation under the Grant 16-12-10161.

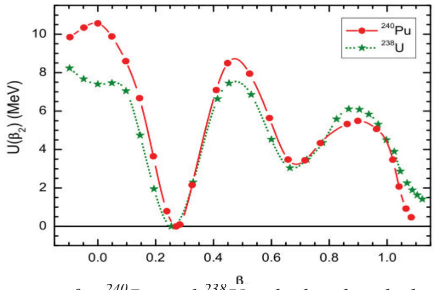


Fig. 1. The fission barriers for ^{240}Pu and ^{238}U calculated with the Fayans density functional FANDF0_a.

1. S.V.Tolokonnikov, I.N.Borzov, Yu.S.Lutostansky, E.E.Saperstein // JETP. Lett. 2018. V.107. P.94.

THE FAYANS ENERGY-DENSITY FUNCTIONAL AND CHARGE RADII OF VERY NEUTRON-RICH K ISOTOPES

Borzov I.N.[1,2], Tolokonnikov S.V.[1,3]
[1] *National Research Centre "Kurchatov Institute", 123182, Moscow, Russia;* [2] *Bogolubov Laboratory of Theoretical Physics, Joint Institute of Nuclear Research, 141980, Dubna, Russia;* [3] *Moscow Institute of Physics and Technology, Dolgoprudny, Russia*
E-mail: Borzov_IN@nrcki.ru, ibor48@mail.ru

The charge radii for K isotopes around the neutron shell closures at $N = 32, 34$ are treated in the fully self-consistent framework with the modified Fayans Density Functional FANDF0_a. The influence of the form of nuclear pairing (volume, surface, gradient) on the radii is studied. A comparison with the experimental charge radii [1] is made for a long isotopic chain. The staggering of the experimental radii can be explained only assuming the complicated volume + surface + gradient form of the paring part of the EDF. The correlation between the anomalous two-neutron emission and neutron-skin ($R_n - R_p$) formation found in [2] is discussed. As for the anomalous radii increase at $A > 47$, it can be explained only if the quasiparticle-phonon coupling is included in the model (see [3]).

Supported by the grant of Russian Scientific Foundation (RSF 16-12-10161).

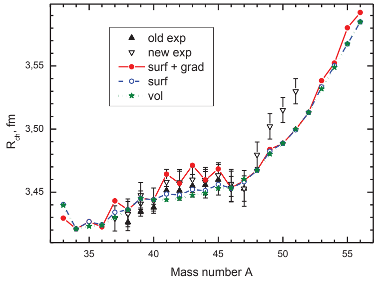


Fig.1 The impact of the different forms of paring correlations (volume, surface, surface+gradient) on the charge radii. The experimental data are from [1].

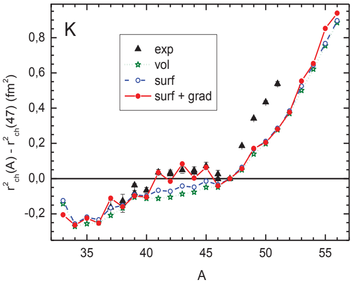


Fig.2 The difference of the rms charge radii of the K isotopes with the reference rms radius of the A = 47 vs the experimental data [1] calculated with the different forms of paring correlations.

1. K.Kreim *et al.* // Phys. Lett. B. 2014. V.731. P.97.
2. I.N.Borzov // Phys.At. Nucl. 2018. V.81(6). P.680.
3. E.E.Saperstein, I.N.Borzov, S.V.Tolokonnikov // JETP Letters. 2016. V.104. P.218.

SHELL-MODEL STUDY OF THE NUCLEAR STRUCTURE OF ^{27}Si NUCLEUS

Mebrek H.[1], Bouhelal M.[2], Bahloul D.[1]
[1] PRIMALAB Laboratory; Departement of Physics, University of Batna 1, Avenue Boukhloufa M El Hadi, 05000 Batna, Algeria; [2] Laboratoire de Physique Appliquée et Théorique, Larbi Tebessi University, Tébessa 12022, Algeria
E-mail: m_bouhelal@yahoo.fr

Nuclear structure study of *sd* shell nuclei around $N \approx Z$ is very important. Indeed, in this region, the excitation energies and electromagnetic properties are well known, particularly for stable nuclei [1]. Atomic nuclei at or around the $N = Z$ line exhibit various phenomena. These nuclei lie along the explosive rp-process nuclear synthesis pathway and, hence, their low-lying structure may be of interest in determining reaction rates.

Our work focuses on the study of the spectroscopic properties, complete energy spectrum, and electromagnetic transitions, of the ^{27}Si in the framework of the shell model using the PSDPF interaction [2]. This nucleus is directly implicated in the radiative proton-capture, (p,γ) reaction, ^{26}Al$(p,\gamma)^{27}$Si [3]; ^{27}Si level structure is important to the determination of its reaction rate.

The energy spectrum of this nucleus, up to excitation energies of astrophysical interest, as well the electromagnetic transitions will be compared with the most recent experimental data.

1. https://www.nndc.bnl.gov/nudat2/.
2. M.Bouhelal, *et al.* // Nucl. Phys. A. 2011. V.864. P.113.
3. A.Kankainen *et al.* // Eur. Phys. J. A. 2016. V.52. P.1.

IS THE NUCLEAR LEVELS DISTRIBUTION A SIGNATURE OF QUANTUM CHAOS?

Bunakov V.E.
Petersburg Nuclear Physics Institute, National Research Center Kurchatov Institute, Gatchina, Russia
E-mail: bunakov@VB13190.spb.edu

It is shown that Wigner distribution with its characteristic level repulsion might be a signature of quantum chaos only if one considers nuclear levels with the same fixed spin and parity. If one mixes the levels whose quantum numbers are different then the level repulsion disappears and the resulting level distribution of the chaotic system would not be described by the Wigner law. Thus, Wigner's repulsion of levels disappears even for a chaotic system if we pay no attention to intact integrals of motion (spins in this case) and sum several independent sequences of levels.

It is also shown that the popular belief about the Poisson level distribution for the regular system is wrong and misleading. In order to prove this belief one usually considers a special class of regular systems without the level degeneracy, for instance a two-dimensional rectangular billiard whose ratio of the side lengths a_x/a_y is an irrational number. The eigen-energies of this system are defined by the two independent quantum numbers n_x and n_y:

$$E_{n_x n_y} = \frac{\hbar^2 \pi^2}{4m}\left(\frac{n_x^2}{a_x^2} + \frac{n_y^2}{a_y^2}\right)$$

If we fix the value of one quantum number, say n_y, then we obtain a sequence of non-degenerate levels whose distribution has nothing to do with the Poisson one. However, if we shall not distinguish between n_x and n_y (not fixing n_y), then we shall obtain a superposition of the infinite number of level sequences shifted with respect to one another by the unceasingly changing quantities

$$\frac{\hbar^2 \pi^2}{4m}\frac{(2n_y + 1)}{a_y^2}$$

This superposition of a large number of independent level sequences would produce the Poisson distribution law. For the majority of other regular systems their level distribution is far from being Poissonian.

Thus system's level distribution is a poor signature of quantum chaoticity, not to mention its measure. A better criterion of chaos and of its quantitative measure was suggested in our previous papers (see e.g. [1, 2]).

1. V.E.Bunakov // Phys. At. Nucl. 2016. V.79. P.394.
2. V.E.Bunakov // Phys. At. Nucl. 2016. V.79. P.995.

PLASMA SCREENING ENHANCEMENT OF NUCLEAR FUSION REACTIONS AND DETAILED BALANCE PRINCIPLE

Chugunov A.I.
Ioffe Institute, St. Petersburg, Russia
E-mail: andr.astro@mail.ioffe.ru

In compact stars (white dwarfs and envelopes of neutron stars) nuclear fusion reaction rates are enhanced for many orders of magnitude by plasma screening [1]. The screening enhancement factors F was extensively studied for the first stage of the reaction – formation of the compound nucleus ($\mathrm{A+B \to C^*}$). However, naive usage of these results as enhancement factors for reaction rate at certain exit channel (e.g. $\mathrm{A+B \to C^* \to D+E}$) can lead to violation of the detailed balance principle [2, 3]. To solve this problem in reaction network codes, Ref. [2] suggests to select a 'preferred' direction of the reaction and calculate the rate of reverse reaction according to the detailed balance.

Here I suggest a more accurate approach based on accurate treatment of the mechanism of the plasma screening enhancement of reaction rate. Namely, the screening enhancement factor for compound nucleus formation F is known to be factorized as $F=F_{\mathrm{cl}}F_{\mathrm{q}}$ [4]. Here F_{cl} is classical enhancement factor, it is associated with increase of the number density of closely separated nuclei in classically allowed region and can be calculated on the base of thermodynamics [5]. F_{q} is quantum part of the screening factor, it is associated with screening effect on the internuclear potential in classically forbidden zone, i.e. on course of the tunneling [4]. If $F_{\mathrm{q}} \approx 1$, which holds true if the tunneling length for Gamow peak ions is much smaller than typical separation of nuclei in plasma, $F \approx F_{\mathrm{cl}}$. As far as F_{cl} is essentially thermodynamic quantity and does not deal with details of nuclear reaction as it is; the branching ratios for decay of the compound nucleus are unaffected by screening and F_{cl} can be directly applied as enhancement factor for arbitrary exit channel. This prescription agrees with the detailed balance principle [3]. If, in opposite, $\mathrm{F_q}$ significantly differs from 1, the plasma screening affects the tunneling probability, which is crucial part of nuclear reaction as it is. As a result, the partial width for decay of compound nucleus to initial nuclei ($\mathrm{C^* \to A+B}$) is affected by screening, thus the branching ratios for decay of compound nucleus are reweighted. This effect should be included to get accurate enhancement factor for nuclear reaction rate (e.g. $\mathrm{A+B \to C^* \to D+E}$) and correspondent procedure is described in presentation.

1. E.E.Salpeter // Australian Journal of Physics. 1954. V.7. P.373.
2. A.C.Calder *et al.* // Astrophysical Journal. 2007. V.656. P.313.
3. D.Kushnir, E.Waxman, A.I.Chugunov // Monthly Notices of the Royal Astronomical Society, accepted.
4. D.G.Yakovlev *et al.* // Phys. Rev. C. 2006. V 74. 035803.
5. H.E.Dewitt, H.C.Graboske, M.S.Cooper // Astrophysical Journal. 1973. V.181. P.439.

SRC BASED MODEL FOR THE NUCLEAR STRUCTURE

Dalal Ranjeet
Department of physics, Guru Jambheshwar University of Science and Technology, India
E-mail:ranjeetdalal@gmail.com

A new approach for the nuclear structure is proposed which is based upon the experimental observations of Short-Ranged Correlation (SRC) of nucleons. The existence of SRCs inside nuclei has been verified by many experiments [1–3] and is considered to be underlying reason behind the EMC effect [4]. Using few assumptions, a SRC based nuclear structure model is proposed. The model is shown to be equivalent to the liquid drop model for the consideration of the nuclear binding energy. Equivalence of the present approach to the cluster model for the specific applications is also highlighted. Further, this model provides new insights for the symmetric/asymmetric nature of spontaneous fission mass distributions of various nuclei and it provides an alternative explanation to the phenomena of Giant Resonances.

1. E.Piasetzky *et al.* // PRL. 2006. V.97. 162504.
2. R.Subedi *et al.* // Science. 2008. V.320. 1476.
3. C.C.d.Atti // Physics Report. 2015. V.590. 1.
4. European Muon Collab. (J.Aubert *et al*.) // Phys. Lett. B. 1983. V.123. P.275.

SYMMETRIES OF THE NUCLEAR SHELLS IN THE NUCLEAR SHELL-MODEL APPROACH

Drumev K.P.
Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria
E-mail: kdrumev2000@gmail.com

The symmetry of the well-known three dimensional isotropic harmonic oscillator, used as a good first order approximation to any attractive potential, is SU(3). This symmetry lies at the base of the Elliott approach for the quite successful description of a number of characteristics in many *sd*-shell atomic nuclei. A possible existence of higher-rank symmetries of the nuclear shells as well as common symmetries of some important parts of the nuclear force have been looked for during the years. This search is related to the realization of an effective and unified description of several competing modes in nuclei.

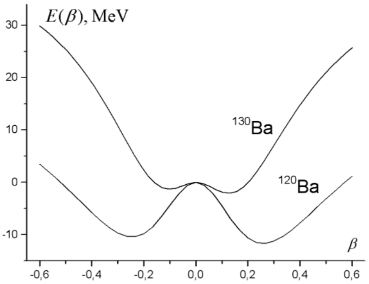
Some of our new findings on these topics will be pointed out as we will demonstrate the advantages they imply by addressing the highly-dimensional many-body nuclear problem in the traditional shell-model unrestricted full space calculations.

DEFORMATION ENERGY IN Ba-EVEN ISOTOPES CALCULATED WITH THE MICROSCOPICAL IBM1

Efimov A.D.[1,2], Mikhajlov V.M.[3]
[1] Admiral Makarov State University of Maritime and Inland Shipping; [2] Ioffe Institute, St.-Petersburg; [3] Physical Institute of St.-Petersburg State University, Russia
E-mail: efimov98@mail.ru

A microscopical version of the Interaction Boson Model 1 (IBM1) has been developed in [1]. It deals, as phenomenological IBM1, with s- and d-bosons, later are the mapping pair neutron and proton excitations (D-phonons) the structure of which defined by the Modified Random Phase Approximation (MRPA). This approach gives both parameters of IBM1, $\varepsilon_{\rm d}, k_1, k_2, C_{L=0,2,4}$ and Ω, the maximum number of d-bosons

$$H_{\rm IBM} = \varepsilon_{\rm d} d^+ \cdot d + [k_1 d^+ \cdot d^+ ss + k_2 (d^+ d^+)^{(2)} \cdot ds + \text{H.c.}] + 1/2 \sum_L C_L (d^+ d^+)^{(\rm L)} \cdot (dd)^{(\rm L)}.$$



The parameters of IBM1 are calculated with taking into account the impact of pair quasiparticle phonons, energy of which are much higher than the D-phonons. As MRPA uses rather wide single-particle spectrum in comparison with valence shells, microscopic Ω is, as a rule, greater than a phenomenological value (half the number of particles or holes in valence shells). It is known in IBM1 that increase of Ω results in decrease of $\varepsilon_{\rm d}$. Indeed, in $^{120\text{-}124}$Ba $\Omega = 20$ and $\varepsilon_{\rm d}$ fluctuates about -0.85 MeV, for ^{128,130}Ba Ω reduces ($\Omega \simeq 17$) that leads to rise of $\varepsilon_{\rm d}$, i.e. -0.12 for ^{128}Ba and 0.08 for ^{130}Ba. Parameters and Ω calculated microscopically [2] give quite satisfactory description of energies and $B(\text{E2})$. For comparison with others approaches, in particular, with the Hartree-Fock-Bogolubov method with the Gogny forces [3], the potential deformation energies $E(\beta)$ are determined for Ba even isotopes

$$E(\beta) = <\Phi | H | \Phi>; \; \Phi \sim \left\{ s^+ + \frac{A}{2\Omega} \beta d_0^+ \right\}^{\Omega}.$$

The dependence on β of $E(\beta)$ is shown in Figure for $A = 120$ and 130. The curves are obtained with microscopic parameters and Ω [2]. Results agree reasonably with those in [3]: for ^{120}Ba $E(\beta) \simeq -11.6$ MeV at $\beta \simeq 0.27$, for ^{130}Ba $E(\beta) \simeq -2$ MeV at $\beta \simeq 0.13$ while in [3] for ^{120}Ba $E(\beta) \simeq -8$ MeV at $\beta \simeq 0.38$ and for ^{130}Ba $E(\beta) \simeq -1.8$ MeV at $\beta \simeq 0.20$.

1. A.D.Efimov, V.M.Mikhajlov // Bull.Russ. Acad. Sci. 2012. V.76. P.857; // EPJ Web of Conferences. 2016. V.107. 03013.
2. A.D.Efimov, V.M.Mikhajlov // Bull. RAS. Ser. Phys. 2019. V.84, in press.
3. S.Goriely, S.Hilaire, *et al.* // Phys. Rev. C. 2016. V.94. 044306.

NEUTRON-NUCLEUS AND MESON-NUCLEUS REACTIONS ON LITHIUM IN THE THEE-BODY APPROACH

Egorov M.V.
Russian Federal Nuclear Center – Academician E.I. Zababakhin All-Russian Research Institute of Technical Physics, Snezhinsk, Russia
E-mail: egorovphys@mail.ru

Neutron-induced nuclear reactions taken place on ^{6}Li and ^{7}Li in the range of kinetic neutron energies E_n=0.1–20 MeV is described with the help of nucleus cluster model and three-body Faddeev integral equations [1]. Total and differential cross sections of inelastic neutron scattering on ^{6}Li and ^{7}Li with the formation of three and four particles in the final state are calculated. Three-body interaction of clusters which form the target nucleus ground state in ^{6}Li(n,n')$d\alpha$ and ^{7}Li(n,n'α)t reactions is shown to be of great importance. The chosen parameterization of two-body separable potentials gives n–Li scattering lengths practically coinciding with experimental ones. Within the chosen sequential microscopic approach total cross sections of ^{6}Li(n,n'd)α, ^{6}Li(n,2n')^{5}Li, ^{6}Li(n,2n')αp, ^{7}Li(n,n't)α, ^{7}Li(n,2n')^{6}Li, ^{7}Li(n,2n')αd, ^{6}Li(n,n'γ)^{6}Li, ^{7}Li(n,n'γ)^{7}Li reactions were calculated for the first time [2].

In the same manner it is calculated the meson-nucleus interaction that takes place in the final state of reaction ^{7}Li(γ,$\pi^0\eta$)^{7}Li in the photon energy region E_γ up to 2 GeV. Despite a relatively large length $a_{\eta\,^7\mathrm{Li}}$ in comparison with η–He scattering length [3] the η–^{7}Li final state interaction was determined to be negligible. The π^0–^{7}Li interaction calculated using the Faddeev equation within the given parameterization of the separable πt and $\pi\alpha$ potentials turned out to be also small. Our calculation has demonstrated that the effect of pion absorption by ^{7}Li which is calculated within the pion optics and contribution of the excited target-nucleus J^π=1/2$^-$ configuration can have a dominant role in the total cross section.

1. L.D.Faddeev // Soviet Physics (JETP). 1960. V.12. P.1014.
2. M.V.Egorov // Nucl. Phys. A. 2019. [https://doi.org/10.1016/j.nuclphysa.2019.03.016].
3. A.Fix, O.Kolesnikov // Phys. Rev. C. 2018. V.97. 044001.

SKYRME ENERGY DENSITY FUNCTIONAL FOR NUCLEAR MATTER: RELATION BETWEEN INCOMPRESSIBILITY AND EFFECTIVE MASS

Erdoğan M.[1], Manisa K.[2], Bircan H.[2]
[1] *Selçuk University Sciences Faculty Physics Department, Konya, Turkey;* [2] *Kütahya Dumlupınar University Arts and Sciences Faculty Physics Department, Kütahya, Turkey*
E-mail: merdogan@selcuk.edu.tr

The Variational Monte Carlo (VMC) method [1, 2] is employed to determine equation of state of symmetric nuclear matter. The Urbana V_{14} potential [3] is used for the nucleon-nucleon interactions in the calculations. New Skyrme parameter sets are found to consistently reproduce the characteristics of symmetric nuclear matter, such as the binding energy, saturation density, incompressibility and effective mass, obtained from VMC calculations. Also, the relation between incompressibility, effective mass and the density dependence of the new Skyrme parameter sets is investigated for symmetric nuclear matter.

1. K.Manisa *et al*. // Int. J. Mod. Phys. E 2005. V.14. P.255.
2. K.Manisa *et al*. // Cent. Eur. J. Phys. 2003. V.8. P.587.
3. I.E.Lagaris and V.R.Pandharipande // Nucl. Phys. A. 1981. V.359. P.331.

HIGH-ORDER BOGOLIUBOV MANY-BODY PERTURBATION THEORY FOR OPEN-SHELL NUCLEI

Frosini M.[1], Demol P.[2], Ripoche J.[3], Tichai A.[4], Somà V.[1], Duguet T.[1,2]
[1] IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France; [2] KU Leuven, Instituut voor Kern- en Stralingsfysica, 3001 Leuven, Belgium; [3] CEA, DAM, DIF, F-91297 Arpajon, France; [4] ESNT, CEA-Saclay, DRF, IRFU, Département de Physique Nucléaire, Université de Paris Saclay, F-91191 Gif-sur-Yvette, France
E-mail: mikael.frosini@cea.fr

Ab initio methods aim at providing a unified description of nuclei from realistic two- and three-nucleon interactions. In the last ten years, such calculations have become possible for medium-mass nuclei. In particular, genuine singly open-shell nuclei have become accessible thanks to the formulation of appropriate single-reference expansion many-body methods. Among these methods, a perturbative variant coined as Bogoliubov many-body perturbation theory (BMBPT) has been formulated [1], implemented and shown to provide accurate results up to Ni isotopes at a low computational cost [2].

A key objective is to implement BMBPT up to a highly non-trivial order in realistic *ab initio* nuclear structure calculations. A software has been designed to both generate and evaluate BMBPT diagrams to arbitrary order [3]. Since BMBPT takes the form of a perturbative sequence, it is of interest to investigate its behavior to much higher orders. While it is not doable in realistic calculations, it can indeed be done by working in a small, i.e. schematic, configuration space and still give insights about the behavior of this novel perturbation theory. Systematically investigating the characteristics of BMBPT is particularly interesting because particle-number symmetry is broken in this formalism. The expansion involves two coupled sequences associated with the energy and the average particle number given that the latter needs to be constrained to the targeted physical value at each working order. This makes the approach intrinsically iterative and at variance with previously studied MBPT.

In order to investigate these peculiar features, a parallelized numerical code was developed to recursively compute BMBPT corrections up to arbitrary high orders, the configuration space being limited to four and six quasi-particle excitations of the Bogoliubov vacuum built from a restricted initial single-particle basis. In this talk results regarding the (non-)convergent character of the BMBPT sequence will be presented, the possible use of resummation techniques originating from applied mathematics, e.g. Padé theory, will be discussed along with the elaboration of the optimal strategies to adopt in realistic BMBPT calculations.

1. T.Duguet, A.Signoracci // J. Phys. G: Nucl. Part. Phys. 2016. V.44. 015103.
2. A.Tichai, P.Arthuis, T.Duguet, H.Hergert, V.Somà // Phys. Lett. B. 2018. V.786. P.195.
3. P.Arthuis, T.Duguet, A.Tichai, R.D.Lasseri, J.-P.Ebran // arXiv:1809.01187.

MICROSCOPIC DESCRIPTION OF NEGATIVE PARITY STATES IN ^{154}Sm

Ganev H.G.
Joint Institute for Nuclear Research, Dubna, Russia
E-mail: huben@theor.jinr.ru

The structure of the negative-parity states in ^{154}Sm is studied within the framework of the fully microscopic proton-neutron symplectic model (PNSM) with Sp(12,R) dynamical algebra without involving additional degrees of freedom, inherent to other approaches to odd-parity states. A good description of the energy levels (Fig.1) of the $K = 0_1^-$ and $K = 1_1^-$ bands, as well as the reproduction of some energy splitting quantities which are usually introduced in the literature as a measure of the octupole correlations, is obtained. The microscopic structure of low-lying collective states with negative-parity in ^{154}Sm shows that practically there are no admixtures from the higher shells and hence the presence of a very good U(6) dynamical symmetry. Additionally, the structure of the collective states under consideration shows also the presence of a good SU(3) quasi-dynamical symmetry (Fig.2). The intraband ground state *B*(E2) and interband *B*(E1) transition strengths between the states of ground and $K=0_1^-$ bands are reproduced without the use of an effective charge.

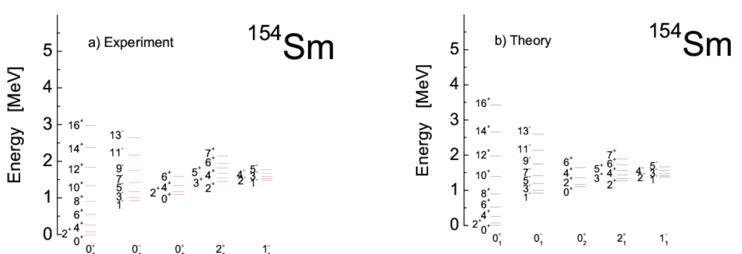


Fig. 1. Comparison of theoretical excitation energies ^{154}Sm with experiment.

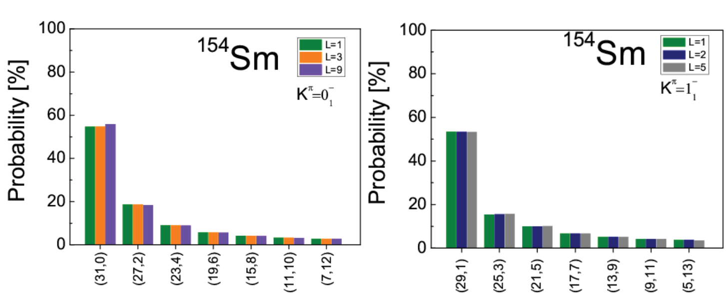


Fig. 2. Calculated SU(3) probability distributions for the wave functions of the $K = 0_1^-$ and $K = 1_1^-$ bands for three different angular momentum values.

DYNAMICAL SYMMETRIES IN SHELL AND COLLECTIVE MODELS OF THE NUCLEAR STRUCTURE

Georgieva A.I.[1], Drumev K.P.[2], Garistov V.P.[2]
[1] *Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria;* [2] *Institute of Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria*
E-mail: anageorg48@gmail.com

The dynamical symmetries in the algebraic shell model [1] and the collective Interacting Vector Boson Model /IVBM/ [2] realized in terms of fermion and boson creation and annihilation operators are investigated. The obtained analytic eigen-energies in both models are compared with the experimental ones and the strengths of the corresponding terms of the model Hamiltonians are evaluated in both cases.

In the algebraic SU(3) Shell Model the correlations and transition between the quadrupole and pairing phases – dynamical symmetries are investigated in application to nuclear systems in the first few light shells.

In the symplectic extension of the IVBM the spectra of heavy even-even nuclei with transitional between rotational and vibrational character is well reproduced. The algebraic connections between dynamical symmetries of the nuclear collective spectra and the ordering of the low lying states with fixed angular momentum permits a reasonable and experimentally proved prediction of the position of the 0^+ band heads of the collective bands. The introduction of fermion degrees of freedom [3] allows for the description of the spectra of odd-odd and odd-even nuclei.

The models based on dynamical symmetries give an elegant and simple way to describe the complex spectra of nuclei with different shapes.

1. A.I.Georgieva, K.P.Drumev // Nuclear Physics Review. 2017. V.34. P.61; K.P.Drumev, A.I.Georgieva // Bulg. J. Phys. 2015. V.42. P.534.
2. A.I.Georgieva and V.P.Garistov // Journal of Physics: Conference Series. 2015. V.590. 012033.
3. V.P.Garistov and A.I.Georgieva // AIP Conference Proceedings. 2019. V.2075. 070001. https://doi.org/10.1063/1.5091192.

DESCRIPTION OF ISOSCALAR MULTIPOLE GIANT RESONANCES WITHIN THE PARTICLE-HOLE DISPERSIVE OPTICAL MODEL

Gorelik M.L.[1], Shlomo S.[2], Tulupov B.A.[3], Urin M.H.[4]
[1] Moscow Economic School, Moscow, Russia; [2] Cyclotron Institute, Texas A&M University, College Station, USA; [3] Institute for Nuclear Research, RAS, Moscow, Russia; [4] National Research Nuclear University "MEPhI" (Moscow Engineering Physics Institute), Moscow, Russia
E-mail: gorelik@theor.mephi.ru

A continuing interest in experimental and theoretical studies of the isoscalar multipole giant resonances (ISMPGRs), in particular, the compression modes of nuclear excitations, is explained by the possibility of determining the nuclear-matter incompressibility coefficient. In this work, we present a description of the mentioned giant resonances in closed shell medium-heavy nuclei. Calculations performed within the particle-hole dispersive optical model (PHDOM) [1], provide the description of properties of each GR, including the energy-averaged strength function, double and one-body projected transition densities and partial probabilities of direct one-nucleon decay. All the model parameters (related to a mean field and Landau-Migdal particle-hole interaction) are taken from independent data. Only the parameters related to the imaginary part of the energy-averaged particle-hole self-energy term, responsible for the spreading effect, are adjusted to describe within the model the total width of the considered giant resonance. An example of the application of the above-described approach for the isoscalar giant monopole resonance in ^{208}Pb is given in Ref. [2]. In the present work, we extend such a description for ISMPGRs with multipolarity $L \leq 3$. Overtones of the isoscalar monopole and quadrupole giant resonances are also considered. Calculation results obtained for Zr, Sn, and Pb are compared with the available experimental data. In particular, the unique data concerned with direct one-nucleon decay of the isoscalar dipole giant resonance [3] are considered. Possibilities to use the one-body projected transition density for describing inelastic α-scattering accompanied by excitation of isoscalar giant multipole resonances are also discussed.

This work was partially supported by the Russian Foundation for Basic Research (grant No. 19-02-0060).

1. M.H.Urin // Phys. Rev. C. 2013. V.87. P.0044330.
2. M.L.Gorelik, S.Shlomo, B.A.Tulupov, M.H.Urin // Nucl. Phys. A. 2016. V.955. P.116; Nucl. Phys. A. 2018. V.970. P.353.
3. M.Hunyadi *et al*. // Phys. Rev. C. 2007. V.75. P.014606.

CLUSTERING AND HALOES IN LIGHT NUCLEI ^{8}B AND ^{9}Be IN FERMIONIC MOLECULAR DYNAMICS (FMD)

Henninger K.R.
iThemba Laboratory for Accelerator-based Sciences, Western Cape, South Africa
E-mail: katharinehenninger@gmail.com

Structure of light weakly-bound nuclei impacts astrophysical reaction rates such as those in the proton-proton (PP) chain. Calculations of these reaction rates often rely on theoretical input pertaining to structure, because experiments at energies relevant to astrophysics are low-yield and thus high-uncertainty. Modelling the structure of light weakly-bound nuclei is challenging, since these nuclei feature clusters or other exotic structures that are difficult to access using a basis of spatially-isotropic single-particle states (such as the shell-model supplies). The Fermionic Molecular Dynamics (FMD) model offers a basis general enough to describe both shell model like states and clustering. We discuss FMD calculations for ^{8}B and ^{9}Be, and for their mirrors ^{8}Li and ^{9}B. We also discuss and propose ways of using this theoretical structural input in calculation of reaction rates. It is shown that the FMD calculations reproduce energy levels and radii fairly, and that subtraction of the Coulomb energy calculated from the FMD states restores degeneracy of the mirror levels within at most ~ 100 keV. Our calculations give a one-proton halo of 2.389 fm, in good agreement with the experimental determination of 2.38(4) fm [1].

1. M.H.Smedberg *et al*. // Phys. Lett. B. 1999. V.452. P.1.

STRUCTURE OF β-DECAY STRENGTH FUNCTION $S_\beta(E)$, SU(4) REGION AND QUENCHING OF AXIAL-VECTOR WEAK INTERACTION CONSTANT IN HALO NUCLEI

Izosimov I.N.
Joint Institute for Nuclear Research, Dubna, Russia
E-mail: izosimov@jinr.ru

In heavy and middle nuclei, because of repulsive character of the spin-isospin residual interaction, the energy of Gamow-Teller (GT) resonance (GTR) is larger than the energy of isobar-analogue resonance (IAR), $E_{\rm GTR} > E_{\rm IAR}$ [1, 2]. One of the consequences [3, 4] of Wigner's spin-isospin SU(4) symmetry is $E_{\rm GTR} = E_{\rm IAR}$. SU(4) symmetry-restoration effect induced by the residual interaction, which displaces the GTR towards the IAR with increasing $(N-Z)/A$.

In ^{6}Li nucleus [5] for low energy super-GT phonon [6] or GTR (experimental reduced GT strength $B(\rm GT) = 7.630 g_V^2/4\pi$, Σ(Ikeda sum rule) = $6(g_A^{eff})^2/4\pi$) we have $E_{\rm GTR} < E_{\rm IAR}$, $E_{\rm GTR} - E_{\rm IAR} = -3562.88$ keV, where g_V and g_A^{eff} are the vector and effective axial-vector weak interaction constants. In ^{11}Be nucleus for low energy ($E = 18.19$ MeV) super-GT phonon or GTR (experimental reduced GT strength $B(\rm GT) = 23 g_V^2/4\pi$, Σ(Ikeda sum rule) = $15(g_A^{eff})^2/4\pi$) we have $E_{\rm GTR} < E_{\rm IAR}$, $E_{\rm GTR} - E_{\rm IAR} = -2.97$ MeV. Using these data and data about $E_{\rm GTR} - E_{\rm IAR}$ from [1, 2], we estimated that the value $Z/N = 0.5 - 0.6$ corresponds to the region, where $E_{\rm GTR} \approx E_{\rm IAR}$, i.e. SU(4) region [5].

Resonance structure of the $S_\beta(E)$ for GT β-decay in halo ^{6}He and ^{11}Li nuclei is analyzed. The free-nucleon value of axial-vector weak constant g_A is well known from neutron β-decay data: $g_A/g_V = -1.2723(23)$, $(g_A/g_V)^2 = 1.618$. Inside nuclear matter value of g_A is effected by many nucleon correlations [7] and quenched or enhanced value of g_A^{eff} might be needed to reproduce experimental data. Compare experimental total strength for β-transitions in $g_V^2/4\pi$ units with the Ikeda sum rule in $(g_A^{eff})^2/4\pi$ units, one can determine [1, 2] the ratio of squared axial-vector and vector weak interaction constants value $(g_A^{eff}/g_V)^2$. We obtained that $(g_A^{eff}/g_V)^2 = 1.272 \pm 0.010$ for ^{6}He, and $(g_A^{eff}/g_V)^2 = 1.5 \pm 0.2$ for ^{11}Li β-decays.

Quenching of the weak axial-vector constant g_A^{eff} in halo nuclei is discussed.

1. Yu.V.Naumov, A.A.Bykov, I.N.Izosimov // Sov. J. Part. Nucl. 1983. V.14(2). P.175.
2. I.N.Izosimov, V.G.Kalinnikov, A.A.Solnyshkin // Phys. of Part. and Nucl. 2011. V.42. P.963.
3. Yu.V.Gaponov, D.M.Vladimirov, J.Bang // Heavy Ion Physics. 1996. V.3. P.189.
4. Yu.S.Lutostansky, V.N.Tikhonov // Physics of Atomic Nuclei. 2016. V.79. P.929.
5. I.N.Izosimov // Physics of Particles and Nuclei Letters. 2018. V.15. P.621.
6. Y.Fujita *et al.* // Phys. Rev. C. 2015. V.91. P.064316.
7. J.Suhonen // Frontiers in Physics. 2017. V.5. P.55.

A VMI APPROACH TO THE IDENTICAL BANDS IN SUPERDEFORMED NUCLEI

Jain P.[1], Mandal S.K.[2]
[1] *Amity Institute of Nuclear Science and Technology, Amity University AUUP;* [2] *Department of Physics and Astrophysics, University of Delhi, India*
E-mail: poonam.jn1@gmail.com

The Variable Moment of Inertia (VMI) model, is used for the reliable phenomenological analysis of identical Superdeformed bands (SD) in $A \sim 190$ mass region. It was proposed that for the truly identical bands, the band head moment of inertia, which depends intimately on the intrinsic structure of the rotational bands, should be similar. In the current work we studied the gamma ray transition energies in the identical bands and observed the difference of (1–3) keV. Also, the study indicates that each pair of conjugate nuclei has dynamic and kinematic identical moment of inertia. The comparison between kinematic, dynamic moment of inertia and gamma ray transition energies are in good agreement. Therefore, the current work is significant in the recent study of Superdeformed Identical bands using VMI approach.

1. Y.X.Liu *et al*. // Phys. Rev. C. 2001. V.63. P.054314.
2. V.S.Uma *et al*. // Pram. J. Phys. 2016. V.86. P.185.
3. A.Dadwal and H.M.Mittal // Euro. Phys. J. A. 2017. V.53. P.132.

SHAPE AND PAIRING PHASE TRANSITIONS IN ATOMIC NUCLEI

Jolos R.V.
Joint Institute for Nuclear Research, Dubna, Russia
E-mail: jolos@theor.jinr.ru

There are three well known limiting models describing collective motion in even-even nuclei: vibrator, axially symmetric rotor, and gamma-soft or axially asymmetric rotor. The physical pictures presented by these models are used as a basis for description of the observed properties of nuclei belonging to different parts of the nuclide chart. It is known also that with variation of the number of nucleons the nuclear shape and pairing correlation strength are changed. Sometimes a smooth evolution of these characteristics are observed. However, there are examples of the abrupt changing of the shape and pairing. In the last years examples of the shape phase transitions with the excitation energy increase have been found.

In this review a microscopical mechanism of the origin of the shape phase transitions using interaction between nucleons with the key role played by the monopole proton-neutron interaction will be discussed. Some examples of the so called shape coexistence and creation of deformation with angular momentum increase will be described. The heaviest superheavy nuclei discovered in Dubna's hot fusion experiments are predicted to have small quadrupole deformation of the order of a typical value of the amplitude of the zero point oscillations of the shape of spherical nuclei. At the same time they can be prolate or oblate, or even triaxial as it follows from the calculations.

1. R.F.Casten // Nature Physics. 2006. V.21. P.811.
2. R.V.Jolos, P. von Brentano, and J.Jolie. // Phys. Rev. C. 2012. V.86. P.024319.

BOHR—WEISSKOPF EFFECT AND HYPERFINE MAGNETIC ANOMALIES IN THE ATOMIC SPECTRA

Karpeshin F.F.[1], Trzhaskovskaya M.B.[2]
[1] *D.I.Mendeleyev Institute for Metrology, Saint-Petersburg, Russia;* [2] *Petersburg Nuclear Physics Institute of the National Research Center Kurchatov Institute, Gatchina, Russia*
E-mail: fkarpeshin@gmail.com

The constants A of the hyperfine structure determine, in the first approximation, the shifts of the atomic level due to the interaction with the magnetic moment of the nucleus, depending on the total momentum of the atom F: $W(F) = AK / 2$, where $K = F(F + 1) - J(J + 1) - I(I + 1)$, I, J – the nuclear spin and total electronic momentum, respectively. The ratio $AI / \mu = A / g$, μ being the magnetic moment of the nucleus, g – the gyromagnetic ratio, approximately holds throughout the isotopic chains. The ratio of the AI / μ values for any two isotopes defines hyperfine anomaly for these nuclei ${}^1\Delta^2$: $A_1 g_2 / A_2 g_1 = 1 + {}^1\Delta^2$, for the nuclei 1 and 2. A common misconception is that the anomalies are due to the finite nuclear size, but it is not. The anomalies are related to the Bohr—Weisskopf (BW) effect, which arises as a consequence of the finite distribution of the magnetization over the nuclear volume. We show, that, again in spite of the commonly spread opinion, the BW effect can be perfectly described by any of the reasonable nuclear models, well known in internal conversion theory: surface or volume current model, yielding the rms radius of the magnetization distribution. Although the retrieved values of the radius turn out to be slightly different, depending on the model. For the H-like and Li-like ^{209}Bi ions, the difference is within 1%. It is due to the contribution of the higher multipole moments of the magnetization distribution [1]. Comparison to experimental data for these ions allows us to retrieve the rms value of $R_2 = 6.83$ fm or 5.96 fm, depending on the supposed nuclear magnetic moment $\mu = 4.1106$ or 4.092 nuclear magnetons, respectively. For the magnetic anomalies, an analytical expression is obtained: ${}^1\Delta^2 = 2\delta R_2 / R_2$, where δR_2 – change of the R_2 radius. Absence or very small anomaly show that the R_2 radii are very close in the both nuclei.

1. F.F.Karpeshin, M.B.Trzhaskovskaya // Nucl. Phys. A. 2015. V.941. P.66.
2. F.F.Karpeshin, M.B.Trzhaskovskaya // Yad. Fiz. 2018. V.81. P.155; Phys. At. Nucl. 2018. V.81. P.157.
3. F.F.Karpeshin, M.B.Trzhaskovskaya // 2019. arXiv:1901.07826; Comput. Phys. Rep. 1988. V.7. P.167.

NEEC AND NEECxe NUCLEAR EXCITATION AS AN EXTENTION OF THE DI-ELECTRONIC RECOMBINATION

Karpeshin F.F.[1], Trzhaskovskaya M.B.[2], Vitushkin L.F.[1]
[1] D.I.Mendeleyev Institute for Metrology, Saint-Petersburg, Russia; [2] Petersburg Nuclear Physics Institute of the National Research Center Kurchatov Institute, Gatchina, Russia
E-mail: fkarpeshin@gmail.com

Very often, understanding of the atomic processes needs insight into physics of the nuclei. And *vice versa*. Successful experiments were performed at GSI on di-electron recombination. During this process, in the lithium-like ions the recombining electron transfers energy to the 2*s* electron and excites it to the $2p_{1/2}$ and $2p_{3/2}$ states. Next step is search for the nuclear excitation: NEEC, and NEECxe in particular [1], *via* the reverse conversion (RC) process. Nuclear excitation occurs due to absorbtion of the kinetic energy of the incoming electron and its binding energy in the final state by the nucleus. NEECxe assumes that the excitation energy will be high enough, for emission of 1-, 2- or more conversion electrons, which will form a signature of the process.

NEEC also can be used for the purpose of test triggering isomeric nuclei. Such experiments occupy a central position in many research programs concerning nuclear physics in plasma. Consider a 1851-keV $19/2^-$ isomer of ^{129m}Sb, with a half-life of 17.7 m. The isomer can be excited through NEEC to this state by means of the E2 conversion transition. This level has a lifetime of $T_{1/2} > 2$ μs. It gets deexcited by the M2 transition to the lower-lying 1128.45-keV $11/2^+$ level. Also it makes a radiative transition back to the 1852-keV level. For an H-like atoms, the binding energies are presented in the Table, together with the ICC values and calculated cross-sections. The predominant contribution comes from the L2 and L3 electronic orbits. Triggering excitation to the 1861-keV level can be registered by emission of the 732-keV radiative line.

Table. Results of calculation of NEEC on the ^{129m}Sb isomeric nuclei, for the 9.9-keV E2 transition. The Weisskopf estimate is used for the nuclear transition width. ε_b - the binding energy

Shell	ε_b, keV	E, keV	σ, b
L2	9.260	0.640	1.32×10^{-4}
L3	8.925	0.975	1.07×10^{-4}

1. F.F.Karpeshin *et al.* // Bull. Russ. Acad. Sci. Phys. 2014. V.78. P.672.

INTERPRETATION OF THE REACTOR ANOMALY OF NEUTRINO DATA IN MODELS WITH STERILE NEUTRINOS

Khruschov V.V.[1,2], Fomichev S.V.[1,3]
[1] National Research Centre Kurchatov Institute, Moscow, Russia; [2] Center for Gravitation and Fundamental Metrology, VNIIMS, Moscow, Russia; [3] Moscow Institute of Physics and Technology (State University), Moscow Region, Russia
E-mail: Khruschov_VV@nrcki.ru

The observed deficit of electron antineutrinos in reactor fluxes at short distances from the source is called the Reactor antineutrino anomaly [1].

In this report the possibility of explaining the anomalous behavior of experimental data obtained at short distances from the source for reactor antineutrino fluxes as an effect of one or three sterile neutrinos is considered. The corrections due to the introduction of additional sterile neutrinos are found for the values of the survival probability of electron antineutrinos calculated in the model with three active neutrinos and one sterile neutrino in the approximation of mixing the active and sterile neutrino [2]. The results obtained can be used to interpret the results of experiments on the verification of the Reactor anomaly data measured at short distances from antineutrino sources.

1. G.Mention *et al.* // Phys. Rev. D. 2011. V.83. P.073006.
2. K.N.Abazajian *et al.* // arXiv [hep-ph]. 2012. 1204.5379. P.1.

REFINEMENT OF THE NEUTRINO-GALLIUM CAPTURE CROSS SECTION AND THE CONTRIBUTIONS OF STERILE NEUTRINOS FOR THE INTERPRETATION OF NEUTRINO DATA ON THE GALLIUM ANOMALY

Khruschov V.V.[1,2], Fomichev S.V.[1,3], Semenov S.V.[1]
[1] National Research Centre Kurchatov Institute, Moscow, Russia; [2] Center for Gravitation and Fundamental Metrology, VNIIMS, Moscow, Russia; [3] Moscow Institute of Physics and Technology (State University), Moscow Region, Russia
E-mail: Khruschov_VV@nrcki.ru

The Gallium neutrino anomaly consists in the deficit of electron neutrinos measured at short distances in the experiments performed by the SAGE and GALLEX collaborations [1].

In the present report oscillation curves for the survival probability of electron neutrinos in the model with three active and three sterile neutrinos are presented. The results obtained adjust the results of calculations in the model with three active neutrinos and one sterile neutrino in the approximation of two-neutrino mixing [2]. Together with the refinement of the reaction cross section for neutrino capture by gallium nuclei [3, 4], these results can be used to interpret and predict the results of experiments for verification of the Gallium anomaly of neutrino data obtained at short distances from the neutrino sources.

1. C.Giunti and M.Laveder // Phys. Rev. C. 2011. V.83. P.065504.
2. S.M.Bilenky, C.Giunti and W.Grimus // Eur. Phys. J. C. 1998. V.1. P.247.
3. V.Barinov *et al.* // Phys. Rev. D. 2018. V.97. P.0733001.
4. S.V.Semenov // Proc. Intern. Conf. The multi-messenger astronomy. 2018. N. Arkhyz (SAO) and Terskol (BNO).

DAMPING PARAMETERS OF HIGH-ENERGY CHARGE-EXCHANGE SPIN-MONOPOLE EXCITATIONS: A SEMI-MICROSCOPIC DESCRIPTION

Kolomiytsev G.V., Urin M.H.
National Research Nuclear University "MEPhI" (Moscow Engineering Physics Institute), Moscow, Russia
E-mail: kolomiytsev@theor.mephi.ru

The recently developed semi-microscopic particle-hole dispersive optical model (PHDOM) [1] is implemented to describe the main damping parameters of high-energy charge-exchange spin-monopole excitations in medium-heavy closed-shell nuclei. These excitations include Gamow-Teller Resonance (GTR), its overtone (Isovector Giant Spin-Monopole Resonance in the $\beta^{(-)}$-channel (IVGSMR$^{(-)}$)), the isobaric partner of IVGSMR$^{(-)}$ – IVGSMR$^{(+)}$. Within the PHDOM the particle-hole (*p–h*) structure and main relaxation modes of high-energy (*p–h*)-type excitations are together taken into account. These modes include Landau damping, coupling to the single-particle continuum and to many-quasiparticle configurations (the spreading effect). Within the model, first two modes are described microscopically (in terms of a mean field and *p–h* interaction), whereas the spreading effect is described phenomenologically (in terms of the energy-averaged *p–h* self-energy term).

In the present work, which is an extension of previous studies of Ref. [2], we describe within the PHDOM the energy-averaged strength function and partial direct one-nucleon decay probabilities of the above-mentioned giant resonances. To some extent, the calculation scheme is similar to that used recently in the description of main damping parameters of high-energy charge-exchange (non-spin-flip) monopole excitations [3, 4]. The new element is calculating the "projected" (one-body) transition density for the considered GRs. The calculation results obtained for the ^{132}Sn and ^{208}Pb parent nuclei are compared with available experimental data.

This work was partially supported by the Russian Foundation of Basic Research (grant No. 19-02-0060).

1. M.H.Urin // Phys. Rev. C. 2013. V.87. P.044330.
2. I.V.Safonov, M.H.Urin // Phys. At. Nucl. 2012. V.75. P.1481.
3. G.V.Kolomiytsev, M.L.Gorelik, M.H.Urin // Eur. Phys. J. A. 2018. V.54. P.228.
4. G.V.Kolomiytsev, M.L.Gorelik, M.H.Urin // EPJ Web Conf. 2018. V.194. P.02010.

ON RESONANT INFLUENCE OF MATRIX WITH ISOMERIC NUCLEI ON ISOMERIC TRANSITION PROBABILITY

Koltsov V.V.
JSC Khlopin Radium Institute, Saint-Petersburg, Russia
E-mail: vladimir-koltsov@yandex.ru

The probability P_{conv} of conversion transitions of energy ΔE_N in nuclei inside matrix varies due to atomic electron shells deformation or due to changing by the matrix boundary conditions on electro-magnetic (EM) field the intensity of EM zero-point fluctuations (ZPF) at frequency of $\Delta E_N / \hbar$ which are inducing the transition [1]. In the present work it is carried out the study of the P_{conv} variation due to changing of interaction between atomic electrons and ZPF when matrix phase transitions are occurring. In free atom the electrons of binding energy E_b interact with ZPF of frequency $\omega > E_b / \hbar$ only [2], the formula (1) gives spectral contribution $\mathrm{d}W_e$ of this interaction into total energy of the electrons. Inside matrix there are the allowed energy bands and the binding energy E_b is decreased by ΔE_b value of several eV. Hence the energy of electrons is increased due to their interaction with ZPF, and the energy density of ZPF themselves is decreased by $\mathrm{d}W_e$ value over the frequency range of $(E_b - \Delta E_b)/\hbar < \omega < E_b/\hbar$. The formula (2) gives the ratio of energy $\mathrm{d}W_e$ to ZPF spectral energy density in free space

$$\mathrm{d}W_e \sim \frac{\hbar\,\omega\,\mathrm{e}^2 n\,\mathrm{d}\omega}{\pi\, m\, c^3} \qquad (1), \qquad \frac{\mathrm{d}W_e}{\mathrm{d}W} \sim \left(\frac{\hbar\omega\,\mathrm{e}^2 n\,\mathrm{d}\omega}{\pi\, m c^3}\right) : \left(\frac{\hbar\omega^3\,\mathrm{d}\omega}{4\,\pi^2 c^3}\right) = \frac{\mathrm{e}^2 n}{m\omega^2} \qquad (2),$$

where n is atomic concentration, e and m are electron charge and mass, c is the light velocity.

If the binding energy E_b of some electron in free atom is over transition energy ΔE_N by several eV, than in formatting of matrix the ZPF energy density at transition frequency is decreasing according to formula (2) and the probability P_{conv} is decreasing correspondingly. As an example, for isomeric transition of ^{99m}Tc (ΔE_N = 2172 eV) the resonant matrix is ytterbium, for which the binding energy of M_2 shell electrons is 2178 eV. In formatting of Yb-matrix the probability of ^{99m}Tc isomeric transition is decreasing by ~ 0,001%. To the contrary, in dissociating of matrix with isomeric nuclei the probability of isomeric transitions is increasing.

1. V.V.Koltsov // On resonant properties of nuclear conversion transition and on possibility of its resonant stimulation. Abstracts of LXVIII meeting on nuclear spectroscopy and nuclear structure. July 2 – 6, 2018. Voronezh. Russia. P.126.
2. Th.Welton // Phys. Rev. 1948. V.74. P.1157.

ON EXCITATION OF NUCLEAR TRANSITIONS IN PLASMA UNDER ITS IRRADIATION WITH RESONANT PHOTONS

Koltsov V.V.
JSC Khlopin Radium Institute, Saint-Petersburg, Russia
E-mail: vladimir-koltsov@yandex.ru

The most effective de-excitation mechanism for nuclear transitions in plasma – it is the suggested in Ref. [1] the process of electronic inverse internal conversion (IIC), when plasma electron of energy E_e is captured on the vacant atomic level of ionization potential J and excess electron energy $\Delta E_e = E_e + J$ transfers to nuclear excitation of energy ΔE_N. In this process the necessary condition is $|\Delta E_N - \Delta E_e| < \Gamma$, where Γ is the width of direct conversion transition. The value of Γ is very small and only small part of plasma electrons satisfies this resonant condition, because of that the IIC probability is small.

That is why interesting to study the influence of irradiation of plasma with photons of frequency nearby the transition frequency $\Delta E_N / \hbar$. Previously such irradiation was studied in view of IIC stimulation which is similar to the stimulation of transitions with photon emission [2]. In the present work it is carried out the study of another mechanism of the IIC probability increase under the resonant photon irradiation due to which concentration of the resonant electrons increases. In resonant irradiating an electron from the atomic level J by photo effect comes into continuous spectrum just with the resonant energy which is necessary for IIC. And it is not necessary to have the atoms only of that isotope for which the nuclear transition is considered, because the resonant electrons are generated in resonant photon irradiating of other isotope atoms of the same element.

The suitable object for experimental study of the process, which was suggested in Ref. [3], is the de-excitation of ^{110m}Ag isomer, which is occurred by excitation of the triggering level above the isomeric one by $\Delta E_N = 1128$ eV. The resonant photon irradiation can be provided by adding platinum into plasma, because one of the Pt characteristic roentgen lines of 1127.3 eV is almost in resonance with triggering transition.

1. V.I.Goldanskii, V.A.Namiot // JEPT Letters, 1976. V.23. №9. P.451.
2. V.V.Koltsov // On resonant properties of nuclear conversion transition and on possibility of its resonant stimulation. Abstracts of LXVIII meeting on nuclear spectroscopy and nuclear structure. July 2 – 6, 2018. Voronezh. Russia. P.126.
3. V.V.Koltsov // Bull. Russ. Acad. Sci.: Phys. 2018. V.82. No.10. P.1320.

SEARCH FOR DE-EXCITATION OF NUCLEAR ISOMERS ^{186m}Re AND ^{110m}Ag IN PLASMA OF HIGH-POWER PICOSECONDS LASER PULSE

Borodin V.G.[1], Vatulin V.V.[2], Jidkov N.V.[2], Elin I.P.[2], Komarov V.M.[1], Karasev V.V.[3], Koltsov V.V.[3], Malinov V.A.[1], Rimsky-Korsakov A.A.[3], Suslov N.A.[2], Charuhchev A.V.[1]

[1] JSC Scientific Research Institute of Optical-Electronic Instruments (OEI Institute), Sosnovy Bor, Leningrad region, Russia; [2] National Reseach Institute of Experimental Physics, Russian Federal Nuclear Center, Sarov, Russia: [3] JSC Khlopin Radium Institute, Saint-Petersburg, Russia

E-mail: vladimir-koltsov@yandex.ru

Stimulation of de-excitation of nuclear isomers (SDENI) in laser plasma due to triggering transitions of energy ΔE_N by inverse internal electronic conversion is the most effective for the plasma electronic temperature $\theta \geq \Delta E_N$. The de-excitation probability P_{SDENI} is proportional to electronic concentration n_e and plasma lifetime, which is about the duration of laser pulse τ. In Ref. [1] for laser pulses of energy 300 J, power density $D \sim 10^{15}$ W/cm^2 and $\tau = 0.3$ ns in plasma of $\theta \sim 1$ keV there was found out the de-excitation of ^{186m}Re isomer ($T_{1/2} = 2\cdot10^5$ years, $\Delta E_N \approx 3$ keV) placed on W-backing.

It was interesting to study the plasma of more power laser pulses even of smaller τ but of grater θ and $n_{e.}$ We had used the Progress-M facility of OEI Institute which provides laser pulses of $\tau \sim 1$ ps, $Q \approx 20$ J, $D \sim 10^{18}$ W/cm^2 [2]. We formed plasma by irradiation of salts of ^{186m}Re and ^{110m}Ag ($T_{1/2} = 249$ days, $\Delta E_N = 1128$ eV). ^{186m}Re was deposited on W-backing and ^{110m}Ag was deposited on W-backing too and also on Ga and Pt-backings in which characteristic roentgen radiation there are lines of 1124.8 and 1127.3 eV respectively. These lines are close to the energy of the triggering transition of ^{110m}Ag and are radiated in laser shooting. According to Ref. [3] the P_{SDENI} increases when isomeric nuclei are irradiating with photons which are in resonance with triggering transition.

We looked for isomer de-excitation by measuring the disturbed balance between isomeric and ground nuclear states. With this purpose we measured the time dependence of intensity of γ-emission after ground nuclear states β-decay. Probably, we observed the SDENI effect only with ^{110m}Ag on Pt-backing, when after laser pulse the intense of γ-quanta of β-decay of ^{110}Ag ground state was above the intense of γ-quanta of β-decay of ^{110m}Ag isomeric state by 1.6 ± 0.3 times. If this excess was the result of SDENI then $P_{\mathrm{SDENI}} \sim 10^{-5}$.

1. V.V.Vatulin, N.V.Jidkov, A.A.Rimsky-Korsakov *et al*. // Bull. Russ. Acad. Sci: Phys. 2017. V.81. № 10. P.1159.
2. V.G.Borodin *et al.* // Quantum Electronics. 1998. V.25. P.115.
3. V.V.Koltsov // On resonant properties of nuclear conversion transition and on possibility of its resonant stimulation. Abstracts of LXVIII meeting on nuclear spectroscopy and nuclear structure. July 2 – 6, 2018. Voronezh. Russia. P.126.

SYNTHESIS OF MAGNETIZED NUCLEI AT THE ZEEMAN REGIME

Kondratyev V.N.[1,2]
[1] Bogolubov Laboratory of Theoretical Physics, JINR, 141980-RU Dubna, Russia, [2] Physics Department, Taras Shevchenko National University of Kyiv, 03022-UA Kyiv, Ukraine
E-mail: vkondrat@gmail.com

Synthesis of ultramagnetized atomic nuclei relevant for supernovae, neutron star mergers, magnetar crusts and heavy-ion collisions is analyzed. Nuclear magnetic reactivity of Zeeman type is shown to dominate for field intensities below ten teratesla. Respective linear magnetic response is given as a combined reactivity of valent nucleons, can be described in terms of nuclear magnetic susceptibility, see Fig. 1, and enhances binding energy for open shell nuclei [1]. For magic nuclei with closed shells the binding energy effectively decreases because of additional pressure induced by an interaction of free nucleon gas with a field. As a result, composition of atomic nuclei created in ultramagnetized matter depends on a field strength. Magnetic field effects in nuclear structure result in an enhancement of nucleosynthesis products of smaller mass numbers for iron group nuclides. In particular, growing of titanium portion at field strength of _1 teratesla is favorably compared to direct observational data of supernova remnants, see Fig. 2, and implies an excess of major titanium isotope in galactic chemical composition.

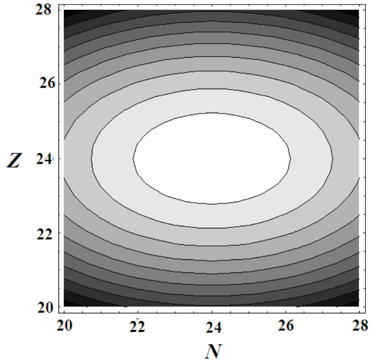


Fig. 1. Contour plot for nuclear magnetic susceptibility versus number of protons Z and neutrons N in a case of $1f_{7/2}$ shell, i.e., the iron shell closure.

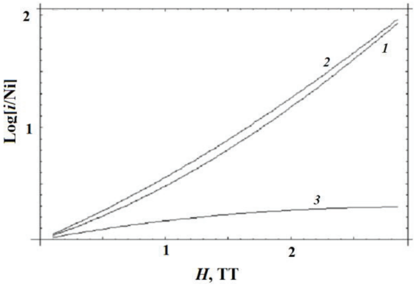


Fig. 2. Magnetic field dependence of yield ratio [i/Ni] of ^{56}Ni and ^{44}Ti - 1, ^{48}Cr -2, and ^{60}Zn - 3.

1. V.N.Kondratyev // Phys. Lett. B 2018. V.782. P.167.

THE FIRST MODELS OF FRIABLE NUCLEAR MATTER IN THE FORM OF NUCLEAR-MOLECULAR ACTIVATED COMPLEXES AND NUCLEAR-MOLECULAR CRYSTALS

Kopysov Yu.S.
Institute for Nuclear Research, Moscow, Russia
E-mail: yu.s.kop@yandex.ru

In a number of works [1-3] in connection with the problems in nuclear and neutrino astrophysics, as well as in the theory of cold transmutation of atomic nuclei, the problem of the possibility of the existence of friable nuclear matter (FNM) was raised. To date, there is an understanding that the most important and obvious is the nuclear-molecular form of FNM. This form appears when several nuclei consisting of a skeleton (nuclear core) and a nucleon halo are combined into a single island system, which is a nuclear molecule, in which each pair of nuclear skeletons is outside the paired Coulomb barrier, but all are connected by a common nuclear molecular halo. In this paper, the possibility of significant compensation of the Coulomb barrier by the nucleon halo (the process of cumulative overcoming the Coulomb barrier) is shown by the example of a double-core molecule. Calculations of this effect for reactions of the type

$$^{9}\mathrm{Be} + {}^{9}\mathrm{Be} \rightarrow [{}^{18}\mathrm{O}^{*}] \rightarrow \begin{cases} {}^{14}\mathrm{C} + {}^{4}\mathrm{He} + Q_1 \\ {}^{13}\mathrm{C} + {}^{4}\mathrm{He} + n + Q_2 \end{cases} \tag{1}$$

are carried out. For this purpose, a "Method of nuclear-molecular orbitals in the form of a linear combination of nuclear orbitals" (NMO LCNO) that is similar to the method MO LCAO widely used in quantum chemistry was developed. In reaction (1), $[{}^{18}\mathrm{O}^{*}]$ is a nuclear-molecular activated complex (NMAC) that enables a significant acceleration of the reaction (1).

To study the structure of the nuclear-molecular complex $[{}^{18}\mathrm{O}^{*}]$, it is proposed to conduct a thorough experimental investigation of the reaction (1) at low energies.

The theoretical justification of the principal possibility of formation of nuclear-molecular crystals is also given.

1. Yu.S.Kopysov // AIP Conf. Proc. New York. 1979. V.52. P.28.
2. Yu.S.Kopysov // Proceedings of LI All-Russia. Conf. on problems in dynamics, particle physics, plasma physics and optoelectronics, Moscow, 2015, pp. 56, 236.
3. Yu.S.Kopysov, Yu.I.Stozhkov // Proceedings of LIII All-Russia. Conf. on problems in dynamics, particle physics, plasma physics and optoelectronics, Moscow, 2017. P.125.

NEUTRON BETA DECAY IN THERMAL FIELD AND DARK MATTER PROBLEM

Kopytin I.V., Kornev A.S.
Voronezh State University, Voronezh, Russia
E-mail: i-kopytin@yandex.ru

Recently, in a number of experimental studies on the beta decay of ultracold neutrons [1–3], a difference between the values of the half-life of a neutron obtained at room temperature and those obtained at a temperature near absolute zero was found. At a temperature close to zero, the value of the half-life of a neutron (879.6 ± 0.6 s) was eight *s* less than that at room temperature. In [4], this difference was associated with the emission of a dark matter particle during the decay of an ultracold neutron and suggested several mechanisms for such beta decay. However, before changing the generally accepted theory of beta decay of a neutron, it is necessary to estimate the magnitude of the effect of the thermal field on this process.

We calculated the magnitude of the influence of an electromagnetic field with the Planck frequency spectrum on the beta decay of a neutron in the temperature range from 300 K to $(2.5 \div 5.0)\times10^9$ K. We considered two mechanisms of the influence of the thermal field on this process: photo-beta decay and endothermic beta decay. Topologically, the diagram of the latter process is similar to the diagram of the internal bremsstrahlung during beta decay, but only with the absorption of a photon. We found that at the temperature of 300 K, the total rate of these processes is $8.26\times10^{-6}\ s^{-1}$. As a result, the theoretical beta-decay rate ($7.85\times10^{-4}\ s^{-1}$) increases by 1%. Accordingly, the half-life of a neutron, taking into account thermal effects, decreases by nine s and actually coincides in magnitude with the half-life of ultracold neutrons. This means that the difference in the half-lives of ultracold and ordinary neutrons can only be due to thermal effects on beta decay. For the temperatures corresponding to the combustion of the oxygen layer (2.5×10^9 K) and the silicon core (5×10^9 K) in the matter of massive stars at the stages preceding the supernova explosion, the increase in the neutron decay rate is $(1.5 \div 5.2)$%. Consequently, the concentration of neutrons participating in nucleosynthesis processes will also change.

1. A.Pichlmmaier *et al.* // Phys. Lett. B. 2010. V.693. P.221.
2. A.Steyerl *et al.* // Phys. Rev. C.2012. V.85. P.065503.
3. S.Arzumanov *et al.* // Phys. Lett. B. 2015. V.745. P.79.
4. B.Fornal and B.Grinstein // Phys. Rev. Lett. 2018. V.120. P.191801.

DECOMPOSITION OF THE CHARGE-EXCHANGE STRENGTH FUNCTIONS FOR ^{76}Ge AND ^{74}Ge ISOTOPES

Fazliakhmetov A.N.[1,2], Inzhechik L.V.[1], Koroteev G.A.[1], Lutostansky Yu.S.[3], Tikhonov V.N.[3], Vyborov A.K.[1,2]

[1] *Moscow Institute of Physics and Technology (State University), Dolgoprudny, Russia;*
[2] *Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia;*
[3] *National Research Centre "Kurchatov Institute", Moscow, Russia*
E-mail: koroteev@phystech.edu

For double beta decay investigation in GERDA-like experiments the ^{76}Ge(ν_e, e)^{76}As reaction induces background event which is indistinguishable from the beta decay signal [1]. Numerical estimation on the capture cross section of solar neutrinos $\sigma(E_\nu)$ by the ^{76}Ge nucleus could be found by using the charge-exchange strength function for ^{76}Ge(^{3}He, t)^{76}As or ^{76}Ge(p, n)^{76}As reactions [2]. This method allows taking into account the Gamow-Teller transitions to the low-lying excited levels and to the resonance states including pygmy-structure of ^{76}As.

Most precise data were measured at the RCNP, Osaka University [3] by applying thin self-supporting germanium target isotopically enriched and specified as 86% ^{76}Ge. Experimental strength function contains two main components corresponding to ^{76}Ge and ^{74}Ge.

In this report, we make isotope-associated decomposition of the experimental strength function and determine theoretical strength functions for both ^{76}Ge and ^{74}Ge isotopes in accordance with the self-consistent theory of finite Fermi systems [4]. It will be seen, theoretical and experimental approach are in a good agreement. This method could be applied for improvement of estimation on neutrino capture cross-section for other isotopes.

This work is supported by grants of the Russian Foundation of Basic Research No. 18-02-00670 and Ministry of Education and Science of the Russian Federation under the contract No. 3.3008.2017/PP.

1. K.H.Ackermann, M.Agostini, E.Andreotti, *et al*. // Eur. Phys. J. C. 2014. V.74. P.2764.
2. H.Ejiri and S.R.Elliott // Phys. Rev. C. 2014. V.89. 055501.
3. J.H.Thies *et al.* // Phys. Rev. C. 2012. V.86. P.014304.
4. Yu.S.Lutostansky // Euro. Phys. J. Web of Conf. 2018. V.194. 02009.

VIRTUALITY OF THE DOUBLE BETA DECAY OF NUCLEI

Kadmensky S.G., Lyubashevsky D.E.
Voronezh State University, Voronezh, Russia
E-mail: kadmensky@phys.vsu.ru

In modern nuclear physics, quite a large amount of experimental material has been accumulated [1] on characteristics of the double (ββ) β-decay with the flight of two electrons and two antineutrinos from the ground states of parent even-even nuclei (A,Z) with the formation of the daughter nuclei (A,$Z+2$) ground states, which can be at two possible variants. The first variant is realized in the case of two sequential real β-decays, when at the first stage parent nucleus decay occurs with positive heat $Q_1 > 0$ and the formation of the intermediate nucleus (A,$Z+1$) real state with complex energy accounting the full decay width of this nucleus, which at the second stage experiences β-decay with positive heat $Q_2 > 0$ and daughter nucleus (A,$Z+2$) formation. Another variant is connected with virtuality of the two-step process of ββ-decay, which is possible when at the first stage the β-decay of (A,Z) into the ground state of the nucleus (A,$Z+1$) is prohibited due to negativeness of its heat $Q_1 < 0$ and parent nucleus β-decay is possible only into the virtual state of the intermediate nucleus (A,$Z+1$), and at the second stage β-decay of this virtual state occurs with the formation of the daughter nucleus (A,$Z+2$) ground state with positive decay heat $Q_2 > 0$, at that the ββ-decay heat $Q_{12} = Q_1 + Q_2$ has positive values $Q_{12} > 0$. These energy conditions are realized [2] for even-even parent nuclei at usage of the superfluid nuclear model. Then the total energies T_1 and T_2 of both the electron and the antineutrino emitted at the first and second stages of the ββ-decay process have positive values in the ranges $0 \le T_1 \le Q_{12}$ and $0 \le T_2 \le Q_{12} - T_1$. The existing calculations of the ββ-decays widths are based on theoretical approaches [3, 4] used second-order of the perturbation theory formulas for the weak interaction Hamiltonians without indicating their connection with the virtuality of these decays. These formulas are close to the formulas used in the present work for the virtual variant of ββ-decays, but, unfortunately, at calculating of the analyzed widths they don’t take into account the role of one-nucleon genealogical coefficients of the superfluid atomic nucleus. In the present work, when using of both versions of the theory ββ-decays and taking into account the superfluid characteristics of the investigated nuclei, the widths of these decays were satisfactorily described for the presented in [1] large group of even-even parent nuclei. Thus for the majority of the ββ-decays of nuclei, in which the energies of Q_1 were negative, virtual version of the theory was used. However, for the ββ-decays of two parent nuclei ^{48}Ca and ^{96}Zr, for which the Q_1 energies had positive values, it was demonstrated where the widths of these decays with good degree of accuracy are determined by the first version of the theory realizing the concept of two sequential real β-decays.

1. B.S.Ishkhanov, *Radioactivity* (University Book, Moscow, 2011).
2. S.G.Kadmensky, Y.V.Ivankov // Phys. At. Nucl. 2014. V.77. P.1019. P.1532.
3. L.A.Sliv // JETP. 1950. V.20. P.1035.
4. E.J.Konopinski // Los Alamos Report. 1955. LAMS-1949.

SEARCH FOR *P*,*T*-ODD ELECTRON-NUCLEUS INTERACTIONS AT TRIATOMIC MOLECULES

Maison D.E.[1,2], Skripnikov L.V.[1,2]
[1] *National Research Centre "Kurchatov Institute" B.P. Konstantinov Petersburg Nuclear Research Institute, Gatchina, Russia;* [2] *Saint-Petersburg State University, Saint-Petersburg, Russia*
E-mail: daniel.majson@mail.ru

It is known that spatial and time-invariance symmetries violation can lead to *P*,*T*-odd interactions. Interaction of nuclear magnetic quadrupole moment (MQM) with electron shells is one of them. It was suggested to determine MQM due to corresponding energy levels shift at ^{173}YbOH molecule [1].

Hamiltonian of *P*,*T*-noninvariant interaction of MQM and an electron has the form:

$$H_{MQM} = -\frac{M}{2I(2I-1)} T_{i,k} \cdot \frac{3}{2} \frac{[\vec{\alpha} \times \vec{r}]_i \cdot r_k}{r^5},$$

where M is the MQM value, $I = 5/2$ is the nuclear spin, $T_{i,k} = I_i I_k + I_k I_i - \frac{2}{3} I(I+1)$, $\vec{\alpha}$ are Dirac matrixes and $\vec{r}$ is electron dislocation. Mean value of this operator is, as one can see, proportional to M, and all the rest factors give magnetic nuclear moment constant, which is to be determined. It should be noted, that this interaction exists only for isotopes with $I \geq 1$.

Analysis of electronic structure of molecule considered was performed. Gaussian-type basis sets were used for Dirac-Fock equations solution. Nuclei were considered as frozen at their equilibrium positions. Solution of Dirac-Coulomb equation was obtained by Fock-space coupled cluster approach. For calculation the sought-for constant finite field approach was applied.

Obtained data are necessary to determine MQM of ^{173}Yb nucleus if one has experimental value of energy shift. The result would be important for estimation of *P*,*T*-symmetries violation and may lead to new restrictions to fundamental physical interaction theory.

1. I.Kozyryev, N.R.Hutzler // Physical Review Letters. 2017. V.119. №. 13. P.133002.

PHASE TRANSITIONS IN ALTERNATING PARITY BANDS OF HEAVY NUCLEI WITHIN THE FRAMEWORK OF COLLECTIVE MODEL

Mardyban E.V.[1,2], Shneidman T.M.[1,3], Kolganova E.A.[1,2], Jolos R.V.[1,2]
[1] Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna, Russia; [2] Dubna State University, Dubna, Russia; [3] Kazan Federal University, Kazan, Russia
E-mail: mardyban@theor.jinr.ru

Angular momentum dependencies of the parity splitting and electric dipole transitions in the alternating parity bands of heavy nuclei have been analyzed. It is shown that these dependencies can be treated in a universal way with a single parameter of critical angular momentum, which characterizes phase transition from octupole vibrations to the stable octupole deformation. Using collective model of axially-symmetric reflection-asymmetric mode, the analytical expressions for the parity splitting and electric dipole transitional moment have been obtained for various actinides. The results are in good agreement with the experimental data.

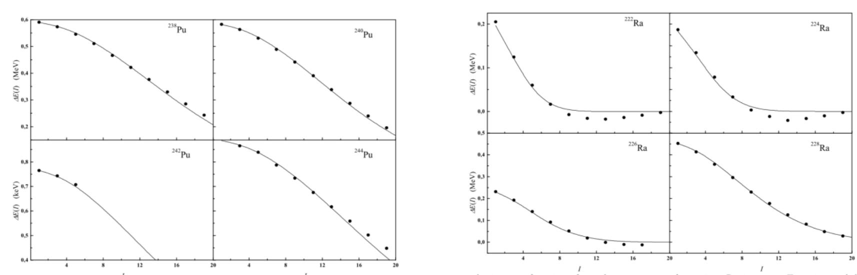


Fig. 1. Parity splitting as a function of angular momentum for various Pu and Ra isotopes. Experimental data (circles), the calculated parity splittings (lines).

1. E.V.Mardyban, T.M.Shneidman, E.A.Kolganova, R.V.Jolos, S.-G.Zhou // Chin. Phys. C. 2018. V.42. 124104.
2. R.V.Jolos and P. von Brentano // Phys. Rev. Lett. C. 2011. V.84. 024312.
3. R.V.Jolos, P. von Brentano, and J.Jolie // Phys. Rev. C. 2012. V.86. 024319.

NUCLEUS DECAY PARAMETER OSCILLATIONS AS POSSIBLE SIGNAL OF QUANTUM MECHANICS NONLINEARITY

Mayburov S.
Lebedev Institute of Physics, Moscow, Russia
E-mail: mayburov@mail.ru

Nucleus radioactivity law is fundamental law of modern physics; in accordance with it, decay parameters for any particular nuclei are constant and independent of environment. Recently, several experiments reported decay rate variations for alpha and beta-decay of heavy nuclei of the order 0.05 % [1, 2]. Beside exponential time dependence of decay rate, they found additional periodic terms corresponding to annual and daily decay rate oscillations. Obtained data suppose that decay rate variation can be related to temporary variation of Sun gravitation potential U resulting from elliptic form of Earth orbit and its daily rotation [1]. We argue that such effects can be explained by the presence of additional nonlinear terms for interaction of quantum systems with external field, proposed first by Kibble [3]. In our approach, modified Doebner-Goldin model [4] used for description of gravitation field influence on decay rate. It's shown that for Gamow alpha-decay theory such nonlinear Hamiltonian induces significant nucleus decay rate variations. In its framework, the best fit to experimental data for Po-214 alpha-decay gives nonlinear term proportional to U time derivative.

1. E.Fischbach *et al*. // Rev. Space Sci. 2009. V.145. P.285; Astrop. Phys. 2014. V.59. 47.
2. E.Alekseev *et al*. // Phys. Part. Nucl. 2016. V.47. P.1803, ibid. 2018. V.49. P.557.
3. T.W.B.Kibble // Commun. Math. Phys. 1978. V.64. P.73.
4. H-D.Doebner, G.A.Goldin // Phys. Rev. A. 1996. V.54. 3764.

SEARCH FOR PERIODICAL VARIATIONS OF Fe-55 ISOTOPE WEAK DECAY PARAMETERS

Mayburov S.
Lebedev Institute of Physics, Moscow, Russia
E-mail: mayburov@mail.ru

Possible temporal variations of nucleus decay parameters studied extensively in the last years, their observation can be the signal of unknown physical effects. Earlier, several experiments reported the annual and daily decay rate oscillations in alpha and beta-decays of some nuclides of the order 0.05 % [1, 2]. BSTU - PhIAN collaboration studies the decay rate variations in inverse beta-decay (*e*-capture) of Fe-55 isotope. In this process K-shell electron absorbed by nuclei and electron neutrino emitted; it accompanied by X-ray with energy 5.9 or 6.4 keV which in our set-up detected by cooled Si-Pin detectors. Measurements of decay rate performed in 2016–2018, demonstrate that together with observed Fe-55 decay exponent with life-time 1004 days, annual oscillation component value is present at the level (0.11 ± 0.02) %. Another period 29.5 ± 1.5 days corresponding to moon month is found with amplitude (0.22 ± 0.04) %. Possible influence of electromagnetic Sun activity on decay rate studied. Simultaneous Fe-55 decay measurements by Si–Pin detectors in orbital flight conditions and in Earth conditions are planned at International Space Station as part of DODO project.

1. E.Fischbach *et al*. // Rev. Space Sci. 2009. V.145. P.285; Astrop. Phys. 2014. V.59. P.47.
2. E.Alekseev *et al*. // Phys. Part. Nucl. 2016. V.47. P.1803; ibid. 2018. V.49. P.557.

TRANSITION DENSITIES AND RADII IN ODD-A NUCLEI

Mishev S.[1,2], Voronov V.V.[3]
[1] New Bulgarian University, Sofia, Bulgaria; [2] Institute for Advanced Physical Studies, Sofia, Bulgaria; [3] Joint Institute for Nuclear Research, Dubna, Russia
E-mail: stoyan.mishev@iaps.institute

Transition densities provide us with a detailed information about the dynamics of the spatial distribution of matter in any finite quantum system. In contrast to even-even nuclei in which these quantities have been studied both analytically and numerically [1, 2] they remain yet unexplored in odd-A systems. We derived formulae for the transition densities in core-plus-particle models of different levels of sophistication [3, 4] and evaluated the particle correlation effects by using a schematic model. The implied trends have been verified against the experimental data on radii of cadmium isotopes [5]. Finally, we briefly online the use of our results to nanoplasma in fullerenes.

1. H.C.Lee // Preprint, AECL-4839, Chalk River, Ontario. 1975.
2. G.R.Satchler, Direct Nuclear Reactions, Oxford University Press, Oxford, 1983.
3. S.Mishev and V.V.Voronov // Phys. Rev. C. V.78. 024310.
4. S.Mishev // Phys. Rev. C. V.87. 064310.
5. M.Hammen *et al.* // Phys. Rev. Lett. V.121. 102501.

DIRAC GAMMA MATRICES CONSTRUCTED FROM OPERATORS OF CREATION AND ANNIHILATION AS THE CAUSE OF ELECTROWEAK INTERACTION

Monakhov V.V.
Saint Petersburg State University, Russia
E-mail: v.v.monahov@spbu.ru

In [1–3], the author developed theory of superalgebraic spinors, which is a development of the theory of algebraic spinors [4–6]. In this study, two types of gamma operators, which are analogs of Dirac matrices, are constructed. Seven gamma operators of the first type are constructed from Grassmann densities and derivatives with respect to them, five of them are superalgebraic analogue of Dirac gamma matrices. There are also two additional gamma operators that have no analogues in Dirac's theory. The rotation operators constructed from four analogs of Dirac matrices are the generators of the Lorentz transformations.

Creation and annihilation operators are generated by the Lorentz rotations of the Grassmann densities and their derivatives. It is shown that in theory there are two nonequivalent variants of Hermitian conjugation, the first relates to Grassmann densities and derivatives with respect to them, as well as gamma operators of the first type, and the second to creation and annihilation operators and gamma operators of the second type.

Seven gamma operators of the second type are constructed from the creation and annihilation operators. These operators reproduce the signature and commutation properties of Dirac gamma matrices, as well as the signature and commutation properties of two gamma operators of the first type that are absent in Dirac's theory. However, unlike the Dirac gamma matrices and gamma operators of the first type, they are Lorentz-invariant – they do not change under the Lorentz transformations.

It is shown that in the tangent bundle, these operators generate the energy-momentum operators of the second quantization theory, charge operators and boson fields of electroweak interaction as well as additional fields that are absent in the Standard Model. A general form of the covariant derivative for spinors is constructed.

1. V.V.Monakhov // Theor. and Math. Physics. 2016. V.186. P.70.
2. V.V.Monakhov // Bull. Russian Academy of Sciences: Physics. 2016. V.80. P.985.
3. V.V.Monakhov // J. of Physics: Conf. Series. 2018. V.1051. P.012023.
4. V.L.Figueiredo *et al.* // Int. J. of Theor/ Physics. 1990. V.29. P.371.
5. P.Lounesto. Clifford algebras and spinors. 2001.
6. V.V.Monakhov // Physics of Particles and Nuclei. 2017. V.48. P.836.

BOHR HAMILTONIAN WITH PÖSCHL–TELLER POTENTIAL FOR GAMMA- UNSTABLE AND AXIALLY SYMMETRIC PROLATE DEFORMED NUCLEI

Chabab M.[1], El batoul A.[1], Hamzavi M.[2], Lahbas A.[1,3], Moumene I.[1], Oulne M.[1]
[1] High Energy Physics and Astrophysics Laboratory, Faculty of Sciences Semlalia, Cadi Ayyad University, P.O.B. 2390, Marrakesh, Morocco; [2] Department of Mathematics and Statistics, University of Texas at El Paso, El Paso, TX, USA; [3] ESMAR, Faculty of Sciences, Mohammed V University, P.O.B. 1014, Rabat, Morocco
E-mail: imane93.moumene@gmail.com

In this work, we solve the Schrodinger equation associated with Bohr Hamiltonian for the Gamma-unstable and axially symmetric prolate deformed nuclei. Analytical expressions for spectra and wave functions are derived by means of asymptotic iteration method (AIM) using the Pöschl–Teller potential. The spectra and *B*(E2) transition rates are compared to the obtained results by Davidson potential and the experimental data.

SPREADING WIDTHS OF GIANT DIPOLE RESONANCES IN THE LEAD REGION

Arsenyev N.N.[1], Nazmitdinov R.G.[1,2], Severyukhin A.P.[1,2], Åberg S.[3]
[1] Joint Institute for Nuclear Research, 141980 Dubna, Russia; [2] Dubna State University, 141982 Dubna, Russia; [3] Mathematical Physics, Lund University, S-22100, Lund, Sweden
E-mail: rashid@theor.jinr.ru

The statistical properties of the isovector dipole excitations in the energy interval 9.5–18 MeV for a few nuclei of the lead regions are analysed thoroughly within the microscopic approach and the Random Matrix Theory [1–3]. The microscopic approach is based on the mean field simulated by means of the Skyrme interaction Sly4 and the volume pairing interaction. The quasiparticle random phase approximation and the coupling between one- and two-phonon states are employed to generate excited states. The comparison of the results obtained with the aid of the coupling, calculated microscopically and by means of the Gaussian random distribution, demonstrates a close similarity in the description of the spreading widths of the Isovector Dipole Resonance of the considered nuclei. A good agreement is obtained with the microscopic description of the decay widths as well if the random distribution is used for the coupling of the one-phonon states with the two-phonon states that are also generated by the Gaussian Orthogonal Ensembles distribution.

1. A.P.Severyukhin *et al.* // Phys.Rev. C.2017. V.95. P.061305(R).
2. A.P.Severyukhin *et al.* // Phys.Rev. C.2018. V.97. P.059802.
3. A.P.Severyukhin *et al.* // Phys.Rev. C.2018. V.98. P.044319.

SPATIAL SYMMETRY BREAKING EFFECTS IN SLOW NEUTRONS INTERACTIONS WITH LEAD NUCLEUS

Oprea A.I., Oprea C.
Joint Institute for Nuclear Research (JINR), Frank Laboratory for Neutron Physics (FLNP), 141980 Dubna, Russian Federation
Email: ionica@nf.jinr.ru

Spatial parity breaking effects in the interaction of slow and resonant neutrons with Lead nucleus will be investigated. For scattering and capture processes spin rotation, asymmetry of emitted neutrons and asymmetry of emitted gamma quanta were evaluated and compared with existing experimental data. Spatial parity violation effects were evaluated in the frame of the formalism of the mixing states of compound nucleus with the same spin and opposite parities [1]. Applying the approach described in [2], from theoretical evaluations related to scattering and capture experimental data, weak matrix element was extracted. Matrix element of weak non leptonic weak interaction is of order of meV and in the range of slow neutrons, parity violation effects are of order of 10^{-6}-10^{-4} and lower. Similar values were obtained in the analysis symmetry breaking effects on other processes and nuclei [2]. From obtained results the existence of a new negative resonance near the neutron threshold it is confirmed [3].

Symmetry breaking effects in the scattering and capture process on Lead nucleus are planned to be measured at basic facilities from FLNP JINR Dubna and from other neutrons research centers from Russia and abroad.

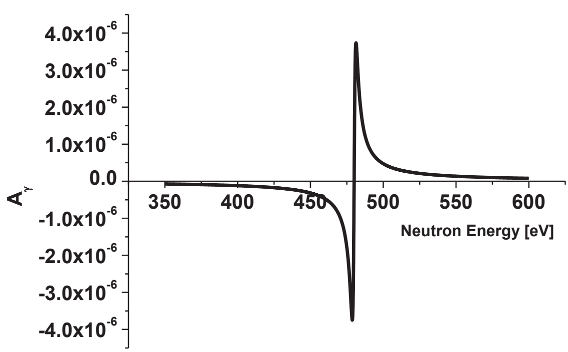


Fig. 1.Asymmetry of emitted gamma quanta in the capture process of slow neutrons by ^{204}Pb.

1. V.V.Flambaum, G.F.Gribakin // Prog. Part. Nucl. Phys. 1995. V.35. P.423.
2. A.I.Oprea, C.Oprea, Yu.M.Gledenov, P.V.Sedyshev, C.Pirvutoiu, D.Vladoiu // Romanian Reports in Physics. 2000. V.63. № 2. P.357.
3. G.A.Lobov // Yadernaya Fizika. 2000. V.63. № 8. P.1465 (in Russian).

AB INITIO STUDY OF MULTI-CHANNELS PROBLEM IN LIGHT NUCLEI

Rodkin D.M.[1,2,3], Tchuvil'sky Yu.M.[2,3,4]
[1] Moscow Institute of Physics and Technology, 141701, 9 Institutskiy per., Dolgoprudny, Moscow Region; [2] Dukhov Research Institute for Automatics, 127055, Moscow, Russia; [3] Pacific National University, 680035, 136 Tikhookeanskaya Str., Khabarovsk, Russia; [4] Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow 119991, Russia
E-mail: rodkindm92@gmail.com

Ab initio approaches for description of light nuclei structure and properties are one of the basic lines of the advancement of nuclear science. In Refs. [1–3] we proposed a method based on a basis of translationally-invariant wave functions of cluster channels suited for analysis of clustered states of light nuclei.

In the present work the proposed method is extended for ab initio calculations of asymptotic characteristics of ground and low-laying levels of light nuclei: asymptotic normalization coefficients of bound states and decay widths of resonance ones. Results of ab initio multi-channel calculations of these values for lower part of ^{7}Li nucleus spectrum are presented. The experimental values of decay widths turn out to be well-reproduced in the proposed approach. The theoretical values of the asymptotic normalization coefficients given by our method are among the most founded to date.

1. D.M.Rodkin, Yu.M.Tchuvil'sky // Journal of Physics: Conference Series. 2018. V.966. P.012022.
2. D.M.Rodkin, Yu.M.Tchuvil'sky // Physics Letters B. 2019. V.788. P.238.
3. D.M.Rodkin, Yu.M.Tchuvil'sky // JETP Letters. 2018. V.108. № 70. P.429.

DINUCLEAR SYSTEM MODEL IN SPONTANEOUS FISSION PROCESS

Rogov I.S.[1,2]
[1] *Joint Institute for Nuclear Research, Dubna, Russia;* [2] *National Research Tomsk Polytechnic University, Tomsk, Russia*
E-mail: isrogov@theor.jinr.ru

The possibility of application of dinuclear system model to spontaneous fission (SF) process is discussed.

In the model the nucleus is represented as dinuclear system (DNS), which can be described with the distance R between the centers of mass of the clusters and charge asymmetry coordinate $\eta_z = (Z_h - Z_l)/(Z_h + Z_l)$, where $Z_{h,l}$ are charge numbers of heavy and light cluster, respectively.

Motion in η_z corresponds to cluster configuration formation; motion in R coordinate describes the decay process.

The determination of the DNS state for given parent nucleus can be obtained by solving the stationary Schrödinger equation with the inertia coefficient $B(\eta_z)$ [1] and potential energy $U(\eta_z)$ [2].

The potential energy and inertia parameter are approximated with step functions, therefore the Schrödinger equation can be directly solve [3].

Using this solution, the spectroscopic factors (the preformation probabilities) are calculated.

To compare the model results with experimental ones, half-lives $T_{1/2}$ are calculated in the one-dimensional WKB approximation [4].

The SF mainly occurs from the DNS configurations corresponding to the minima the driving potentials. These minima are below the potential energy of mother nucleus.

Verification of the model is made for even-even uranium isotopes $^{232-236}U$. The same set of parameters is used for all nuclei considered.

The calculated and experimental [5] half-live times are presented in table below:

	^{232}U	^{234}U	^{236}U
T_{theor}, s	7.43×10^{20}	1.61×10^{22}	1.10×10^{23}
T_{exp}, s	3.73×10^{21}	4.73×10^{23}	6.38×10^{23}

In terms of half-lives, the model presented describes well the experimental values. So, the basic assumption of the model on the collective coordinate for the SF seems to be correct.

1. G.G.Adamian *et al.* // Nucl. Phys. A. 1995. V.584. P.205.
2. G.G.Adamian *et al.* // Int. J. Mod. Phys. E. 1996. V.5. P.191.
3. J.H.Davies // Cambridge University Press, 1998.
4. B.C.Hall // Quantum theory for mathematicians. 2013. V.267. P.305.
5. J.Randrup *et al.* // Phys. Rev. C. 1976. V.13. P.229.

SEARCH FOR β^+EC AND ECEC PROCESSES IN ^{74}Se

Barabash A.S.[1], Brudanin V.B.[2], Klimenko A.A.[2], Konovalov S.I.[1], Rakhimov A.V.[2], Rukhadze E.N.[3], Rukhadze N.I.[2], Shitov Yu.A.[2], Štekl I.[3], Umatov V.I.[1], Warot G.[4]

[1] *NRC "Kurchatov institute" ITEP,Moscow, Russia;* [2] *Joint Institute for Nuclear Research, Dubna, Russia;* [3] *Institute of Experimental and Applied Physics, CTU in Prague, Prague, Czech Republic;* [4] *Laboratoire Souterrain de Modane, Modane, France*

E-mail: rukhadze@jinr.ru

Search for double beta decay processes (β^+EC, EC/EC) of ^{74}Se was performed at the Modane underground laboratory (LSM, France, 4800 m w.e.) using an ultra-low-background HPGe detector OBELIX with sensitive volume of 600 cm^3 [1] and a sample of natural selenium. The sample of natural selenium was powder with a total mass of 1.6 kg containing ~ 0.89% (~ 14.24 g) of ^{74}Se. Selenium was filled in a circular Teflon box and placed on the end cap of HPGe detector. The measurement of selenium sample was lasted during 3040 h. The efficiency of measurement was obtained by using Monte Carlo simulations performed on the base of GEANT 4 and GEANT 3 and then tested by measurement of low active samples placed on the end cap of Obelix detector. Low active samples were prepared on the base of La_2O_3 powder containing ~ 0.09% of ^{138}La ($T_{1/2} \approx 1.02\times10^{11}$ yr) and had activities of −19.3 and 61.8 Bq. The method of efficiency calibration for low background measurements with low active samples was described in details in [2].

The main goals of present investigation were searches for radiative 0νECEC decay of ^{74}Se into the ground 0^+ state of ^{74}Ge, 2νECEC decay of ^{74}Se into 2^+_1, 596 keV and 2^+_2,1204 keV exited states of ^{74}Ge, and β^+EC decay into 2^+_1, 596 keV excited state of ^{74}Ge. Based on preliminary calculations of experimental data new limits on β^+EC and ECEC decays of ^{74}Se into ground 0^+, 2^+_1, 596 keV and 2^+_2,1204 keV exited states of ^{74}Ge was obtained. They are ranged from $T_{1/2} \sim 1\times10^{19}$ yr (90% CL) to $T_{1/2} \sim 5\times10^{19}$ yr (90% CL) and significantly improved previous experimental limits [3, 4].

1. N.I.Rukhadze *et al.* // Izvestia RAN. Ser. Phys. 2013. V.77. P.424.
2. V.B.Brudanin *et al.* // JINST. 2017. V.12. 02204.
3. A.S.Barabash *et al.* // Nucl. Phys. A. 2007. V.785. P.371.
4. B.Lehnert *et al.* // J.Phys.G.Nucl. Part.Phys. 2016. V.43. P085201.

QUARTET STRUCTURE OF SELF-CONJUGATE NUCLEI

Sambataro M.[1], Sandulescu N.[2]
[1] *Istituto Nazionale di Fisica Nucleare, Sezione di Catania, Italy;* [2] *National Institute of Physics and Nuclear Engineering, Magurele, Bucharest, Romania*
E-mail: michelangelo.sambataro@ct.infn.it

A distinctive feature of self-conjugate nuclei is that of carrying an equal number of protons and neutrons distributed over the same single particle levels. In these nuclei, as a consequence of the isospin invariance of the nuclear forces, the isovector proton-neutron (*pn*) pairing is expected to coexist in an equal amount with the proton-proton and neutron-neutron pairing. In addition, *pn* pairing is also expected to manifest itself in an isoscalar form. The treatment of these types of pairing in terms of conventional BCS-type approaches has revealed to be problematic.

We have shown [1–4] that *pn* pairing in self-conjugate nuclei can be very well accounted for in a formalism of $J = 0$, $T = 0$ quartets, namely four-body correlated structures formed by two protons and two neutrons coupled to total angular momentum $J = 0$ and isospin $T = 0$. We have therefore extended the quartet formalism to the treatment of realistic interactions both in the case of even-even [5, 6] and odd-odd [7] self-conjugate nuclei. The role of quartets other than $J = 0$, $T = 0$ in the description of these systems has been investigated and it will be illustrated.

The difficulties associated with a microscopic treatment of $N = Z$ nuclei in a formalism of quartets rapidly grow with increasing the number of active nucleons. To make this formalism accessible also to large systems, we have recently explored an approach where elementary bosons replace quartets with $J = 0$, $T = 0$ and $J = 2$, $T = 0$. This boson architecture, which is clearly analogous to that of the Interacting Boson Model in its simplest formulation (IBM-1), has been employed for an analysis of ^{28}Si [8]. The boson Hamiltonian has been derived with the help of a mapping procedure and the resulting spectrum and E2 scheme have been compared with the experimental data. As a peculiarity, the potential energy surface of this nucleus turns out to be that expected at the critical point of the $U(5)-\overline{SU(3)}$ phase transition of the IBM structural diagram.

1. N.Sandulescu *et al.* // Phys. Rev. C. 2012. V.85. P.061303(R).
2. M.Sambataro and N.Sandulescu // Phys. Rev. C. 2013. V.88. P.061303(R).
3. M.Sambataro, N.Sandulescu, and C.W.Johnson // Phys. Lett. B. 2015. V.740. P.137.
4. M.Sambataro and N.Sandulescu // Phys. Rev. C. 2016. V.93. P.054320.
5. M.Sambataro and N.Sandulescu // Phys. Rev. Lett. 2015. V.115. P.112501.
6. M.Sambataro and N.Sandulescu // Eur. Phys. J. A. 2017. V.53. P.47.
7. M.Sambataro and N.Sandulescu // Phys. Lett. B. 2016. V.763. P.151.
8. M.Sambataro and N.Sandulescu // Phys. Lett. B. 2018. V.786. P.11.

TWO-PHONON STRUCTURES OF BETA-DECAY RATES

Severyukhin A.P.
Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna
E-mail: sever@theor.jinr.ru

The β-decay properties are very important for understanding the nuclear structure evolution at extreme *N*/*Z* ratios, for analysis of radioactive ion-beam experiments, and modeling of the astrophysical r-process. For this reason, the β-decay properties of r-process "waiting-point nuclei" ^{129}Ag, ^{130}Cd, and ^{131}In provides valuable information, with important tests of theoretical calculations. One of the successful tools for nuclear structure studies is the quasiparticle random phase approximation (QRPA) with the self-consistent mean-field derived from the Skyrme interaction. The framework allows to relate the properties of the ground states and excited states through the same energy density functional. On the other hand, it would be desirable to overcome the discrepancies between the theoretical predictions low-energy 1^+ spectrum using the one-phonon QRPA wave functions of the daughter nucleus and the measurements [1]. We have generalized the approach to the coupling between one- and two-phonon terms in the 1^+ wave functions and the tensor force effects on the β-decay rates of neutron-rich nuclei [2]. We applied the influence of the phonon-phonon coupling on the multi-neutron emission probabilities [3]. The even-even Cd isotopes near the r-process paths at $N = 82$ was studied. In the talk we will conclude that the present approach makes it possible to perform the new microscopic analysis of the properties of the 1^+ states of the daughter nuclei ^{126,128,130}In. The model is extended by enlarging the variational space for the 1^+ states with the inclusion of the two-phonon configurations constructed from the 3^+ phonons. We find that the first 1^+ state has the dominant two-phonon configuration composed of the 3^+ phonons.

1. A.Etilé *et al.* // Phys. Rev. C. 2015. V.91. 064317.
2. A.P.Severyukhin, V.V.Voronov, I.N.Borzov, N.N.Arsenyev, Nguyen Van Giai // Phys. Rev. C. 2014. V.90. 044320.
3. A.P.Severyukhin, N.N.Arsenyev, I.N.Borzov, E.O.Sushenok // Phys. Rev. C. 2017. V.95. 034314.

SKYRME-TQRPA CALCULATIONS OF ELECTRON CAPTURE AND BETA-DECAY RATES AT PRESUPERNOVA CONDITIONS

Sidorov S.V.[1,2], Dzhioev A.A.[1], Tretyakova T.Yu.[3]
[1] BLTP, JINR, Dubna, Russia; [2] Physics Faculty, Lomonosov Moscow State University, Moscow, Russia; [3] SINP MSU, Moscow, Russia
E-mail: sv.sidorov@physics.msu.ru

Electron capture and beta-decay reactions play an important role during the pre-supernova phase in the core of massive stars, having a large influence on the distribution of isotopes synthesized at the advanced stages of stellar evolution [1]. Under supernova conditions with high temperature and density, both processes are mainly given by GT transitions and, thus, their reliable determination requires the accurate description of the GT strength distribution in nuclei.

In order to study the influence of thermal effects on weak process rates, the thermal quasiparticle random phase approximation is combined with the Skyrme energy density functional method (Skyrme-TQRPA) [2, 3]. Calculation of GT strength distribution is carried out for isotopes ^{56,78}Ni. Impact of tensor forces is examined in a fashion similar to how it was previously done at zero temperature [4]. It is demonstrated that the increase of temperature of stellar environment leads to the shift of GT strength to lower energies as a result of thermal population of nuclear excited states according to the Boltzmann distribution. The rates of electron capture and beta-decay are shown to increase correspondingly.

1. K.Langanke, G.Martinez-Pinedo // Rev. Mod. Phys. 2003. V.75. P.819.
2. A.Dzhioev, A.Vdovin, Ch.Stoyanov // Phys. of At. Nucl. 2016. V.79. P.1019.
3. A.Dzhioev, A.Vdovin, G.Martinez-Pinedo, *et al.* // Phys. Rev. C. 2016. V.94. 015805.
4. A.Severyukhin, H.Sagawa // PTEP. 2013. 103D03.

CRITICAL PHASE TRANSITION INVESTIGATION BY STATISTICAL MULTIFRAGMENTATION WITH SYMMETRY ENERGY DENSITY PARAMETRIZATION

Sokhna C.A.T.[1,2]
[1] *The Key Laboratory of Beam Technology and Material Modification of Ministry of Education, College of Nuclear Science and Technology, Beijing Normal University, Beijing 100875, China;* [2] *Beijing Radiation Center, Beijing 100875, China*
E-mail: cheikh.sokhn1@mail.bnu.edu.cn

Within the framework of a symmetry energy density dependence of the statistical nuclear model, we have investigated the multifragmentation phase transition of the isotopes of ^{186}Re and ^{168}Re. The produced charge and mass distributions at intermediate energy are analyzed within the statistical multifragmentation model with the critical temperature for the nuclear liquid-gas phase transition T_C as a free parameter. By taking into account to the secondary deexcitation processes of the primary hot fragments with the GEMINI code, the obtained secondary deexcited fragment results compared to the previous theoretical calculation and experimental results give good concordance. Other parameters also have been investigated *N/Z* the second order moment γ_2, the temperature, the isoscaling parameters, with different symmetry energy coefficient.

WIDTH OF OSCILLATOR ENERGY LEVEL, PHOTON SPIN AND NEEDLE-SHAPED CONSTRUCTION OF PHOTON

Sorokin Yu.I.
Institute for Nuclear Research RAS, Moscow, Russia
E-mail: yuransor@yandex.ru

Feynman path integral method it has been gotten wave function of oscillator, stepped up, with external periodic force [1, 2].

In this case probability amplitude depends on strength photon electric field and length photon train and in range width of level inefficient depends on frequency. It is justify workaround integration over frequencies of initial or ending modes for pull off delta function, which appear with Born approximation.

In spite of this mechanism of photoabsorbtion approach due correspond to dipole excitation, result wave function has not define energy, and has not define square full axial moment.

Selection rules for energy may be get, if define excitation energy as square product of strength photon electric field and length photon train.

It may be getting selection rules for projection axial moment of inertia to direct photon motion, [3]. Selection rules for square full axial moment of inertia is not verified.

At so, it was gotten theoretic reasons supporting conception about needle-shaped construction of photon, [1, 3], which A.F. Ioffe and N.I. Dobronravov found experimentally near hundred year ago.

If real photon is ultimate transverse wave, bounded in space, then for wave is necessary to have sources and drains. It may be point dipole: particle antiparticle with parallel magnet moments. As minimum two dipoles is in half wave.

Result wave function may be useful for description photoexcitation of nucleus giant dipole resonance and its decay: photo-neutron [4] and photo-proton [5] reactions.

1. Yu.I.Sorokin // Bulletin of Peoples' Friendship University of Russia, Phys. 2002. № 10. V.1. P.126.
2. Yu.I.Sorokin // Bulletin of Peoples' Friendship University of Russia, Phys. 2005. №1 (13). P.113.
3. Yu.I.Sorokin // Proceedings of the XIV International Seminar on Electromagnetic Interactions of Nuclei. EMIN-2015. Moscow, October 5-8, 2015. Poster Reports. Moscow, 2016. P.16.
4. Yu.I.Sorokin, B.A.Yuriev // Atom. Nucl. Phys. (Sov.J. Nucl. Phys.) 1975. V.20. P.123.
5. Yu.I.Sorokin, V.A.Khrushchev, B.A.Yuryev // Atom. Nucl. Phys. (Sov.J. Nucl. Phys) 1972. V.14. P.622.

THEORETICAL STUDY OF COMPETITION BETWEEN FISSION AND NEUTRON EVAPORATION AT HIGH EXCITATION ENERGIES

Tanaka S.[1,2], Hirose K.[2], Nishio K.[2], Aritomo Y.[1,3]
[1] Graduate School of Science and Engineering, Kindai University; [2] Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Ibaraki 319-1195, Japan; [3] Faculty of Science and Engineering, Kindai University, Higashi-Osaka, Osaka 577-8502, Japan
E-mail: tanaka.shoya9071@gmail.com

Nuclear fission is an extremely complex process, and still not understood completely. Especially, the behavior at high excitation energy has not been explained because of the lack of experimental data. Recently, fission-fragment mass distributions (FFMDs) at high excitation energies were measured by using multinucleon transfer channels at the Japan Atomic Energy Agency tandem facility [1, 2]. A persistence of predominantly asymmetric FFMDs for actinide nuclei was observed up to the highest measured excitation energy (~ 60 MeV) for all the studied nuclides. For highly excited heavy nuclei, there is a competition between fission and neutron emission. To understand the fission from highly excited state, we calculated the FFMDs using Langevin equations by introducing the neutron-evaporation prior to fission, called multi-chance fission (MCF) [2].

In the present work, FFMDs are calculated for twenty-nine compound nuclides $^{231–234}$Th, $^{233–236}$Pa, $^{234–240}$U, $^{236–242}$Np and $^{238–244}$Pu with the excitation energy range from 15 to 55 MeV. The calculation results reproduced the experimental data, and peak position and peak-to-valley ratio agree well for all the measured excitation-energy range by including MCF. Furthermore, three characteristics (excitation energy, atomic number and neutron number dependence) of FFMDs are also reproduced at high excitation energy. It was shown that a reliable understanding of the observed FFMDs can be obtained only by invoking MCF.

1. R.Léguillon *et al*. // Phys. Lett. B. 2016. V.761. P.125.
2. K.Hirose, K.Nishio, S.Tanaka, *et al*. // Phys. Rev. Lett. 2017. V.119. 222501.

PROSPECTS OF AB INITIO STUDIES OF NUCLEAR CLUSTERING

Rodkin D.M.[1,2,3], Tchuvil'sky Yu.M.[1,2,3,4]
[1] *Moscow Institute of Physics and Technology, 141701, Dolgoprudny, Moscow Region;*
[2] *Dukhov Research Institute for Automatics, 127055, Moscow, Russia;* [3] *Pacific National University, 680035, Khabarovsk, Russia;* [4] *Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow 119991, Russia*
E-mail: tchuvl@nucl-th.sinp.msu.ru

As it was demonstrated in papers [1, 2] ab initio approach opens a new avenue of attack on the problem of nuclear clustering. The performed studies revealed, first, a significant contribution of "non-clustered" components to the total binding energy of strongly clustered systems such as ^{7}Li and ^{8}Be nuclei. Second, the developed approach made possible to perform high-precision calculations of habituated cluster characteristics which are the most-used in the nuclear reaction theory: cluster spectroscopic factors, cluster form factors (amplitudes of the spectroscopic factors), asymptotic normalization constants, and widths of resonances decaying to yield of composite fragments.

In the present talk fresh results which has achieved on this way are demonstrated. Prospects of these studies, possibilities for extension of the approach to the areas of widespread interest such as the properties of halo nuclei are discussed.

1. D.M.Rodkin, Yu.M.Tchuvil'sky // Physics Letters B. 2019. V.788. P.238.
2. D.M.Rodkin, Yu.M.Tchuvil'sky // JETP Letters. 2018. V.108. № 7 P.429.

COULOMB BREAKUP OF HALO NUCLEI

Valiolda D.S.[1,2], Janseitov D.M.[1,3], Zhaugasheva S.A.[1]
[1] Al Farabi Kazakh National University, Almaty, Kazakhstan; [2] Joint Institute for Nuclear Research, Dubna, Russia; [3] Institute of Nuclear Physics, Almaty, Kazakhstan
E-mail: Valiolda.dinara@gmail.com

The work is devoted to a theoretical study of the Coulomb breakup of halo nuclei in a quantum mechanical approach. Exotic nuclei are the subject of intensive experimental and theoretical research. Coulomb breakup are relevant for interpretation and planning of experiments in radioactive beams.

The halo is one of the most intensively studied objects in modern low-nucleus physics. The mean radii of certain nucleons orbits may be larger than nuclear interaction range. A characteristic feature of halo nuclei physics is correlations between the mechanism of nuclear reaction and structure [1].

The breakup is one of the important tools for studying halo properties. In these reactions, the information from dissociation of projectile into fragments could be used to conclude about the properties of halo part of wave function. With a good approximation, the breakup could be regarded as a transition from the bound state of two (three) particles to the continuum, due to the changing Coulomb field [2].

The ^{11}Be nucleus is regarded as a neutron halo consisting of ^{10}Be core and one neutron. Energy levels of ^{11}Be were calculated solving Schrodinger equation by means of numerical methods. This work is the initial stage of the work on the investigation of the breakup of halo nuclei. A detailed investigation is planned to research the breakup of the halo nucleus, using the numerical method for solving the nonstationary Schrodinger equation.

1. I.Tanihata. Neutron halo nuclei // J. Phys. G. 1996. V.22. P.157.
2. V.S.Melezhik, D.Baye // Phys. Rev. C. 1999. V.59. P.3232.
3. P.Capel, D.Baye, V.S.Melezhik // Phys. Rev. C. 2003. V.68. 014612.

A MICROSCOPIC TREATMENT OF CORRELATED NUCLEONS: COLLECTIVE PROPERTIES IN STABLE AND EXOTIC NUCLEI

Vasseur O.[1], Grasso M.[1], Gambacurta D.[2]
[1] CNRS-IN2P3, Institut de Physique Nucléaire (IPN), Orsay, France; [2] Extreme Light Infrastructure - Nuclear Physics (ELI-NP), Magurele, Romania
E-mail: vasseur@ipno.in2p3.fr

Collective excitations are a common feature of several many-body systems and a widely observed phenomenon throughout the nuclear chart. A model which is often used to describe collective excitations is the random-phase approximation (RPA), where the excited modes are superpositions of 1 particle–1 hole configurations only. The RPA allows in general for a satisfactory description of excitations in nuclei, both low-lying states and giant resonances.

However, being based on a mean-field or independent-particle picture, the RPA model fails to reproduce the fragmentation and the spreading width of excitations. For example if one wishes to account for the spreading width of resonances, which can be observed experimentally, one has to go beyond this simple mean-field-based model. A possible way to do so is to add 2 particle–2 hole configurations in the model, which is known as Second RPA (SRPA). Yet SRPA in its standard form presents severe drawbacks, such as the double-counting of correlations, instabilities or divergences. All these limitations of SRPA can be overcome by a correction method, consisting in a subtraction, the so-called Subtracted SRPA (SSRPA). A systematic application to the giant quadrupole resonances of selected spherical nuclei, ranging from ^{30}Si to ^{208}Pb, will be shown to demonstrate its corrective power.

A first extension of this scheme can be carried out to treat also open-shell nuclei. A second extension amounts to using a correlated ground state, thereby allowing to include pairing correlations for instance. Such methods will be presented with the corresponding first results.

1. O.Vasseur, D.Gambacurta, M.Grasso // Phys. Rev. C. 2018. V.98. 044313.
2. D.Gambacurta, M.Grasso, O.Vasseur // Phys. Lett. B. 2018. V.777. P.163.
3. M.Grasso, D.Gambacurta, O.Vasseur // Phys. Rev. C. 2018. V.98. 051303(R).

LOCAL MASS RELATIONS FOR BINDING ENERGIES EVALUATION

Vladimirova E.V.[1], Ishkhanov B.S.[1,2], Simonov M.V.[1], Tretyakova T.Yu.[2]
[1] Faculty of Physics, Lomonosov Moscow State University, Moscow, Russia; [2] Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
E-mail: vladimirova.elena@physics.msu.ru

Local mass relations connected with the residual proton-neutron interaction are considered. In previous papers [1, 2], various ratios were considered based on systematics of atomic nuclei and their detailed analysis was carried out in the framework of the shell model. The mass relations for *np*-interactions are widely used for predictions of unknown binding energies of atomic nuclei [2, 3]. Mathematical simplicity and reliable accuracy from 60 keV to 300 keV are significant advantages of this method [4].

The binding energies for experimentally inaccessible nuclides are predicted. Based on our evaluations, one-proton and one-neutron drip lines for several regions of the isotopes chart and α-decay characteristics for isotopes with $Z = 102–106$ are investigated.

Comparison with results of other approaches and with the evaluated data from AME2016 [5] showed reliable accuracy of the method.

1. B.S.Ishkhanov *et al.* // Chinese Phys. C. 2017. V.41. 094101.
2. B.S.Ishkhanov *et al.* // Chinese Phys. C. 2019. V.43. 014104.
3. H.Jiang *et al.* // Phys. Rev. C. 2012. V.85. 054303.
4. J.Janecke *et al.* // At. Data and Nucl. Data Tabl. 1988. V.39. 265.
5. D.Lunney *et al.* // Rev. Mod. Phys. 2003. V.75. P.1021.
6. G.Audi *et al.* // Chinese Phys. C. 2017. V.41. 030001.

SMOOTHNESS OF MASS SURFACE OF ODD NUCLEI AND PAIRING ENERGIES

Vlasnikov A.K., Zippa A.I., Mikhajlov V.M.
Saint-Petersburg State University, Saint-Petersburg, Russia
E-mail: a.vlasnikov@spbu.ru

Analysis of mass surface of even-even nuclei [1] has shown that the surface can be described by the second order equation practically quite satisfactory and parameters of this equation almost overlap, if they are calculated from different groups of even-even nuclei at $\Delta A \le 2$ and $\Delta N \le 4, \Delta Z \le 4$. Therefore for odd nuclei the equation for the smooth part of the mass $\mathcal{M}$ is chosen also as one of the second order. E.g. for odd neutron nuclei:

$$\mathcal{M}(N_o,Z) = M(N_o,Z) - P_n(N_o,Z);$$

$$\mathcal{M}(N_o+s,Z+t) = \mathcal{M}(N_o,Z) + sd_{1n} + td_{1p} + \frac{1}{2}s^2 d_{2n} + \frac{1}{2}t^2 d_{2p} + std_{1n1p};$$

$M(N_o,Z)$ is the empirical odd neutron mass, $P_n(N_o,Z)$ is the pairing energy, N_o and Z are odd and even numbers respectively. Six parameters ($d_{1n}, d_{1p}, d_{2n}, d_{2p}, d_{1n1p}$ and $\mathcal{M}$) are calculated by use of two groups of nuclei: the first (I) includes masses, e.g. for odd neutron nuclei, at fixed even Z and $N_o \pm 1$, $N_o \pm 3$, the second (II) does $N_o \pm 1$, $N_o \pm 3$ too, but $Z \pm 2$ and $Z \pm 4$. All masses in each group (I and II) have differences in *A*, but $\Delta A = 1$ and 3. Deformed odd nuclei have been analysed with $150 \le A \le 190$ [2]. The parameters of groups I and II for $A = 169$ are given in Table (keV).

Nucleus	$\tilde{d}_{1\tau}(\mathrm{I})$	$\tilde{d}_{1\tau}(\mathrm{II})$	$d_{2\tau}(\mathrm{I})$	$d_{2\tau}(\mathrm{II})$	$P_\tau(\mathrm{I})$	$P_\tau(\mathrm{II})$
${}_{71}Lu_{98}$	–4620(10)	–4673(13)	477(7)	496(13)	1072(20)	1040(28)
${}_{72}Hf_{97}$	–8534(16)	–8492(10)	127(7)	174(12)	1154(62)	1227(43)

$\tau = p$ for Lu and $\tau = n$ for Hf. $\tilde{d}_{1\tau} = d_{1\tau} - m_\tau$, m_τ is the proton or neutron mass. Table shows that parameters $\left(\tilde{d}_{1\tau}, d_{2\tau}\right)$ and P_τ calculated with groups of nuclei I and II somewhat distinguish, however differences in P_τ are within the empirical error limits.

1. A.K.Vlasnikov *et al*. // Bull. Russ. Ac. Sci. Phys. 2017. V.81. P.1184.
2. M.Wang *et al*. // Chin. Phys. C. 2017. V.41. 030003.

RELATIVISTIC FORM FACTORS OF THREE-NUCLEON NUCLEI IN THE FRAMEWORK OF THE BETHE-SALPETER-FADDEEV FORMALISM

Bondarenko S.G., Burov V.V., Yurev S.A.
Joint Institute for Nuclear Research, Dubna, Russia
E-mail: yu314156v926@*yandex.ru*

Based on articles [1, 2] a relativistic generalization of formulas for form factors of three-nucleon nuclei was obtained. The formulas for the form factors took into account the orbital moments of the nucleons inside the nuclei from 0 to 2, that is, the *S*, *P* and *D* states. The form factors were calculated as functions of the transmitted momentum of the scattered electron up to 2 GeV. Moreover, for form factors nucleons used the models of the dipole fit, a model of a relativistic harmonic oscillator and a vector dominance model. The solutions of the Bethe – Salpeter – Faddeev equation [4] were used as the amplitudes of the states of the nucleus used to calculate the form factors. At the same time, the potential of the nucleon-nucleon interaction is taken in a separable form using the Yamaguchi functions for form factors of potential [3].

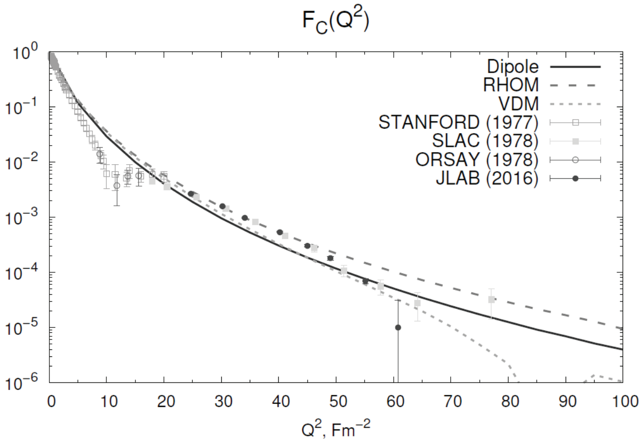


Fig. 1. Helium-3 form factors: Dipole - dipole fit, RHOM - relativistic harmonic oscillator model, VDM - vector dominance model.

This work was partially supported by the Russian Foundation for Basic Research grant no. 18-32-00278.

1. G.Rupp and J.A.Tjon // Phys. Rev. C. 1988. V.37. P.1729.
2. G.Rupp and J.A.Tjon // Phys. Rev. C. 1992. V.45. P.2133.
3. S.G.Bondarenko, V.V.Burov, S.A.Yurev // Phys. Part. Nucl. Lett. 2018. V.15. P.417.
4. S.G.Bondarenko, V.V.Burov, S.A.Yurev. // Phys. Atom. Nucl. 2019. V.82. to be published.

MAGNETIC HYPERFINE ANOMALIES FOR NUCLEAR PHYSICS

Demidov Yu.A.[1,2], Konovalova E.A.[1], Kozlov M.G.[1,2]
[1] *Petersburg Nuclear Physics Institute of NRC "Kurchatov Institute", Gatchina, Russia;*
[2] *St. Petersburg Electrotechnical University "LETI", St. Petersburg, Russia*
E-mail: iurii.demidov@gmail.com

Some spectral properties, e.g. the hyperfine structure (HFS) constants, strongly depend on the behavior of the electron wave function in the vicinity of the atomic nucleus. The comparison of experimentally measured HFS constants for stable and short-lived isotopes allows one to find nuclear g-factors in the latter case. To improve the accuracy of determining g-factors, charge and magnetization distribution inside the nucleus should take into account. All these corrections together are called hyperfine anomaly (HFA). The hyperfine anomaly is often neglected due to the lack of its theoretical estimates; at the same time the HFA is usually small (less than 1%) and only recent measurements for short-lived isotopes have reached this level of accuracy. The HFA provides a unique opportunity to parameterize the change in the magnetization distribution inside the nuclei of the long isotopic chains. This nuclear parameter depends on the nucleons configuration and can provide additional information about the nucleus.

The report discusses the method of hyperfine anomaly calculation [1]. Its verification was performed with the aid of hydrogen-like ions. Calculated hyperfine anomalies in hydrogen-like ions are in good agreement with analytical expressions. Also calculations of the hyperfine anomalies in the neutral atoms of thallium and francium were carried out [1, 2]. The HFA in the francium isotopes leads to nuclear *g*-factor corrections of several tenths of a percent, and inaccuracy in calculated HFA values does not exceed 10%. Thus, estimation of HFA allows one to clarify the nuclear *g*-factors of the francium isotopes approximately by an order of magnitude.

1. E.A.Konovalova, M.G.Kozlov, Yu.A.Demidov, A.E.Barzakh // Rad. Applic. 2017. V.2. P.181.
2. E.A.Konovalova, M.G.Kozlov, Yu.A.Demidov, A.E.Barzakh // Atoms. 2018. V.6. P.39.

FEATURES OF INTERACTION OF A PROJECTILE WITH A SOLID

Filippov G.M.
Chuvash State I.Ya. Yakovlev Pedagogical University, Cheboksary, RF
E-mail: filippov38-gm@yandex.ru

The motion of quantum particle within uniform solid is considered in condition when the elementary excitations can be generated. With the help of the density matrix (DM) $\Gamma(\vec{x}_1, \vec{x}_2', t)$ calculation the analysis of the projectile's wave field (WF) is performed. The creation of specific resonances is obtained. Note, DM depends on six space variables and its form after some short time of interaction with environment presents sufficiently complex. Certain considerations to give physical meaning to the various properties of the MP were made in [1]. In particular, the dependence of DM on the variable $\vec{x} = \vec{x}_1 - \vec{x}_2$ defines the coherence length in WF. The calculation performed in [2] allows to represent a possible explanation of breaking the WF. However, some details of DM remain at present, unappreciated and further work remains to be done to detect and use of all information contained in DM. In the present work some particular properties of DM will be discussed.

1. G.M.Filippov // Nuclear Instruments and Methods in Physics Research. B. 2014. V.326. P.48.
2. G.M.Filippov // NUCLEAR THEORY. eds. M.Gaidarov, N.Minkov, Heron Press, Sofia. 2018. V.37. P.196.

WEAKLY BOUND TRIATOMIC He_2Li MOLECULES

Kolganova E.A.[1,2], Roudnev V.[3]
[1] Joint Institute for Nuclear Research, 141980 Dubna, Russia; [2] Dubna State University, 141982 Dubna, Russia; [3] St Petersburg State University, 199034 St Petersburg, Russia
E-mail: kea@theor.jinr.ru

The Efimov effect is a remarkable phenomenon, which is an excellent illustration of the variety of possibilities arising when we transit from the two-body to the three-body problem. In 1970 V.Efimov [1] proposed that three-body systems with short range interaction can have an infinite number of bound states when none of the two-particle subsystems has bound states but at least two of them have infinite scattering lengths. In such a case the scattering length is much larger than the range of the interaction.

One of the best theoretically predicted three-body system with an excited state of the Efimov type is a naturally existing molecule of the helium trimer $^4He_3$ (see, [2] and refs. therein). The interaction between two helium atoms is quite weak and supports only one bound state with the energy about 1mK and a rather large scattering length about 100 A. Only recently the long predicted weakly-bound excited state of the helium trimer was observed for the first time using a combination of Coulomb explosion imaging and cluster mass selection by matter wave diffraction [3].

There is a growing interest in the investigation of He_2 – alkali-atom van-der-Waals systems that are expected to be of Efimov nature. In addition to the Helium dimer, the He – alkali-atom interactions are even shallower and also support weakly bound states. In triatomic $^4He_2$-alkali-atom systems presence of Efimov levels can be expected. Three-body recombination and atom-molecular collision in Helium-Helium-alkali-metal systems at ultracold temperatures have been studied using adiabatic hyperspherical representation in [4]. Here we use the Faddeev equations in total angular momentum representation to calculate the $^4He_2{}^{6;7}Li$ binding energies and a scattering length, which has not been studied before.

Our results for $^4He_2{}^7Li$ and $^4He_2{}^6Li$ trimers binding energies show that different potential models support two bound states in both trimers. The energy of the excited state is very close to the energy of the lowest two-body threshold. In case of the $He_2{}^6Li$ system the lowest threshold is different for different potentials but the relative energy with respect to the lowest two-body threshold is practically the same.

1. V.Efimov // Phys. Lett. B. 1970. V.33. P.563.
2. E.A.Kolganova, A.K.Motovilov, and W.Sandhas // Few-body Syst. 2017. V.58. P.35.
3. M.Kunitski *et al.* // Science. 2015. V.348. P.551.
4. H.Suno // Phys. Rev. A. 2017. V.96. P.012508.

THE PROPERTIES OF ^{4}He THREE-ATOMIC CLUSTERS

Korobitsin A.A.[1], Kolganova E.A.[1,2]
[1] *Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna, Russia;* [2] *Dubna State University, Dubna, Russia*
E-mail: koroaa@theor.jinr.ru

Clusters of gas atoms are a large class of molecules interacting via van der Waals type potentials. Some weakly bound clusters show universal characteristics and scale invariants related to the famous Efimov effect [1], which was experimentally confirmed in an ultracold gas of the Cs atoms [2]. The helium trimer system has been long considered as an ideal candidate for observing Efimov states. Only recently, after a long and continued research, the Efimov state as the excited state of the $^{4}He_3$, was detected [3]. Also, the wave function of the ^{4}He dimer has been measured via Coulomb explosion technique which enabled to determine its very small binding energy – 151.9 (13.3) neV [4].

There are many realistic He–He potential models which are more and more accurate reproduce two-body data [5]. Very accurate calculation needed in order to evaluate the effect of potential models on the characteristic of three-body system. One of the effective methods for studying triatomic clusters is based on the differential Faddeev equations.

In this work we develop an application based on the Faddeev differential equations for studying the properties of the helium trimer using modern realistic potentials constructed by M. Przybytek *et al.* in 2010 [6] and 2017 [7] years, as well as older potentials – LM2M2 [8] and TTY [9]. The calculated results we compare with the results obtained using different methods by other authors and with the experiment.

1. V.N.Efimov // Phys. Atom. Nucl. 1970. V.12. P.1080; Phys. Lett. B. 1970. V.33. P.563.
2. T.Kraemer *et al.* // Nature. 2006. V.440. P.315.
3. M.Kunitski *et al.* // Science. 2015. V.348. P.551.
4. S.Zeller *et al.* // Proc. Nat. Acad. Sci. 2016. V.113. P.14651.
5. E.A.Kolganova *et al.* // Few-Body Syst. 2017. V.58. P.35.
6. M.Przybytek *et al.* // Phys. Rev. Lett. 2010. V.104. P.183003.
7. M.Przybytek *et al.* // Phys. Rev. Lett. 2017. V.119. P.123401.
8. R.A.Aziz *et al.* // J. Chem. Phys. 1991. V.94. P.8047.
9. K.T.Tang *et al.* // Phys. Rev. Lett. 1995. V.74. P.1546.

MODEL OF THREE-DIMENSION SCATTERING FOR NUCLEAR AND MOLECULAR APPLICATION

Krassovitskiy P.M.[1,2], Pen'kov F.M.[2]
[1] *Joint Institute for Nuclear Research, Dubna, Russia;* [2] *Institute of Nuclear Physics, Almaty, Kazakhstan;*
E-mail: pavel.kras@inp.kz

The problem of scattering for non-centrum forces can be responsible for new interesting effects. It has been showed for examples of resonance scattering of two-atomic rigid molecule [1] or neutron scattering at non-spherical nuclei [2]. The result of scattering at field with axial symmetry is very different one at centrally symmetrical field.

The investigation in this area has been continued. The problem of scattering for axial-nonsymmetry fields has been investigated. The case of mirror symmetry over plane which contain vector of incoming wave has been considered.

The method of solution is reduction of basic equation to three-dimension equation. Wave function is presented as decomposition by azimuthal functions. The problem has been solved numerically by direct discretization two-dimension reduced equation. The additional decomposition of the solution by free equation wave functions on the region of geometrical shadow has been used.

The new result of neutron scattering at non-spherical nuclear and rigid molecular scattering at zone plate target has been received.

The work was supported by grant of Plenipotentiary Representative of the Government of the Republic of Kazakhstan № 434 2018 year.

1. P.M.Krassovitskiy *et al.* // Bull. Russ. Acad. Sci. Phys. 2017. V.81. P.730.
2. P.M.Krassovitskiy *et al.* // Bull. Russ. Acad. Sci. Phys. 2019. V.83. P.420.

COHERENT STATES FORMALISM FOR DESCRIBING STATISTICAL PROCESSES IN A NUCLEAR REACTOR

Kravchenko M.O., Korbut T.N., Kuzmin A.V., Rudak Ed.A., Petrovski A.M.
State Scientific Institution "Joint Institute for Power and Nuclear Research – Sosny" of the National Academy of Sciences of Belarus, Minsk, Belarus
E-mail: m.kravch@sosny.bas-net.by

Earlier [1–3], it was shown that the particles' birth and death model in the linear growth approximation based on solutions of direct Kolmogorov equations can be used to describe the process of interaction of neutrons with a breeding medium. The particles' birth and death model was used to determine the conditions under which the fuel nuclei self-sustaining fission reaction occurs and which correspond to the thermal reactor constant power mode. The results of these studies primarily relate to the time evolution of the "multiplying medium + neutron" system. The final result will eventually be the derivation of a statistical theory to solve the many-body problem (an ensemble of instant and delayed neutrons) in a thermal reactor.

In this paper, we consider the possibility of using the theory of coherent states [4, 5] in solving statistical problems for a thermal nuclear reactor. Coherent states are states of a quantum harmonic linear oscillator, characterized by a wave packet that does not spread out in time and has the minimum uncertainty ratio of the coordinate and momentum $\delta p \cdot \delta x = \hbar/2$. The main attraction of coherent states is that they are similar to the classical states of a harmonic oscillator as much as the minimum value of the uncertainty ratio allows.

1. T.N.Korbut *et al.* // Bull. Russ. Acad. Sci. Phys. 2015. V.79. P.461.
2. M.O.Kravchenko *et al.* // J. Phys.: Conf. Ser. 2018. V.1133.
3. M.O.Kravchenko *et al.* // EPJ Web of Conferences. 2019. V.201. 08004.
4. R.J.Glauber // Phys. Rev. 1963. V.131.
5. A.Perelomov, Generalized coherent states and their applications // Springer, Berlin 1986.

EQUIVALENCE BETWEEN THE COMPLEX ROTATION RESONANCES AND SCATTERING MATRIX RESONANCES

Motovilov A.K.[1,2]
[1] *Bogolibov Laboratory of Theoretical Physics, JINR, Dubna, Russia;* [2] *Dubna State University, Dubna, Russia*
E-mail: motovilv@theor.jinr.ru

We work on a multichannel scattering problem with binary channels and a three-body problem with pairwise interactions. The associated Hamiltonians are written in the momentum representation and become a subject to the complex deformation. The well-familiar complex scaling is a particular case of such a deformation. Isolated non-real eigenvalues of the complexly deformed Hamiltonians are called the complex rotation resonances. For a class of rapidly decreasing and momentum-space analytic interactions, we prove that the complex rotation resonances do coincide with the scattering matrix resonances, that is, with the poles of the scattering matrix analytically continued on the respective unphysical sheet. Our proofs employ the explicit representations [1, 2] that express the *T*- and *S*-matrices on unphysical energy sheets through the values of those same matrices taken exclusively on the physical sheet. Our proofs seem to be more transparent than the ones found in the literature (see [3] and references therein). To make the underlying idea maximally clear, we first present the proofs found in [4] for the simplest case – the Friedrichs-Faddeev model [5].

1. A.K.Motovilov // Theor. Math. Phys. 1993. V.95. P.692.
2. A.K.Motovilov // Math. Nachr. 1997. V.187. P.147.
3. G.A.Hagedorn // Commun. Math. Phys. 1979. V.65. P.181.
4. A.K.Motovilov // Few-Body Syst. 2019. V.60. P.21.
5. L.D.Faddeev // Amer. Math. Soc. Transl. Ser. 2. 1967. V.62. P.177.

HADRONS IN A DENSE AND HOT BARYONIC MATTER

Musulmanbekov G.
Joint Institute for Nuclear Research, Dubna, Russia
E-mail: genis@jinr.ru

One of the main questions relating to heavy ion collisions "How much of incident energy is converted into compression of nuclear matter?" has not found a definite answer yet. This compression should change the initial state of colliding nuclei consisting of protons and neutrons. Starting with the Strongly Correlated Quark Model of a hadron structure, SCQM [1], we demonstrate how the properties of mesons and baryons can be modified in hot and dense nuclear environment. It is shown that at these conditions nucleons are converted into delta-isobars, hyperons and their excitations, and mesons are produced predominantly via vector resonances. Moreover, the properties of vector mesons consisting of light quarks changes drastically. Their masses drop and widths are widening. These in-medium modifications can lead to the observable effects in heavy ion collisions, especially in NICA energy range, such as enhancement of strangeness, like "horn-effect", and enhancement of dilepton invariant mass spectra at 0.2 – 0.7 MeV.

1. G.Musulmanbekov // EPJ WoC, 2019. V.204. P.03007.

FADDEEV'S PERTURBATION SERIES FOR IONIZATION AMPLITUDE OF ATOM BY STRONG LASER PULSE

Piraux B.[1], Popov Yu.V.[2,3], Galstyan A.[1]
[1] *Institute of Condensed Matter and Nanosciences, UCL, Louvain-la-Neuve, Belgium;*
[2] *Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University,Moscow, Russia;* [3] *BLTP, Joint Institute for Nuclear Research, Dubna, Russia*
E-mail: popov@srd.sinp.msu.ru

Time Dependent Schroedinger Equation (TDSE) contains two potentials: electron-atomic (Coulomb) potential and time-dependent dipole potential. The wave function is presented as a sum of two functions following the Faddeev's decomposition. The corresponding perturbation series in each step is compared with the alternative solution of the TDCE. Both calculations are numerical. The special attention was addressed to the problem of gauge-invariance of separate terms [1].

Convergence of the total ionization probabilities were analyzed for different carrier frequencies of the laser field. It was found that the Faddeev's perturbation series converges to the numerical solution of the TDSE up to quite small frequencies. It was also shown numerically that the traditional perturbation series when the Coulomb potential is considered like a perturbation (so called SFA) is divergent.

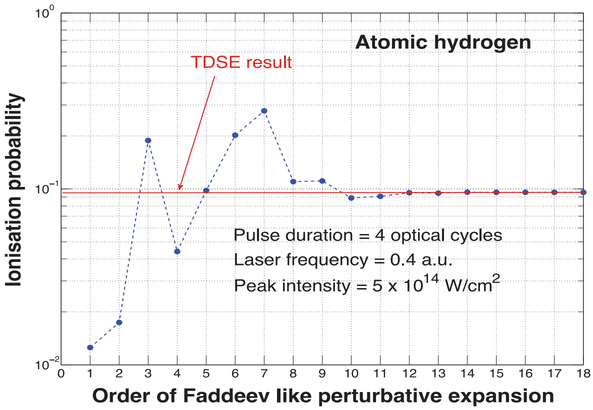


Fig. 1. Ionization probability versus number of perturbation steps. The laser frequency is relatively small.

1. Yu.Popov *et al.* // Eur. Phys. J. D. 2017. V.71. P.93.

INTERCONVERSIONS OF LEPTONS IN NONDIAGONAL PROCESSES

Romanov Yu.I.
A.N. Kosygin Russian State University, Moscow, Russia
E-mail: romanov.yu.i@mail.ru

In the development of [1], nondiagonal lepton processes are investigated within different concepts of the conserved lepton charge.

Among presented results the continuation of analysis of spin correlations in the studying reactions by the theory of longitudinally polarized fermions [2].

1. Within the two-component neutrino theory with left-handed (left) neutrinos the (V – A) description of the reactions $\nu_\mu e^- \rightleftarrows \nu_e \mu^-$, $\tilde{\nu}_e e^- \rightleftarrows \tilde{\nu}_\mu \mu^-$ leads to mutual conversions of neutral (anti)leptons accompanied by left negatively charged leptons:

$$\sigma_{\nu e} = \frac{G^2 s}{16\pi}(1-h_e)^2(1-h_\mu)^2, \tag{1}$$

$$\sigma_{\tilde{\nu} e} = \frac{G^2 s}{12\pi}(1-h_e)(1-h_\mu). \tag{2}$$

Here, as in the total cross sections (3) below, s is the square of the total energy in the center-of-mass system, $h_{e(\mu)}$ is the lepton helicity and G is the Fermi constant.

The (V + A) interaction of forbidden nondiagonal neutral currents $(\bar{\mu}e)$ and $(\bar{\nu}_e \nu_\mu)$ predicts participation of the electrons and muons with wrong, i.e. right-handed (right) helicity in reactions under discussion.

2. The four-component neutrino theory (a muon neutrino is right, the negative muon is treated as an antiparticle) allows inelastic scatterings $\nu\mu^- \rightleftarrows \tilde{\nu} e^-$.

The (V + A) description foretells the $(\nu_e \rightleftarrows \tilde{\nu}_\mu)$ and $(\nu_\mu \rightleftarrows \tilde{\nu}_e)$ transitions with left charged partners. The total cross sections are determined accordingly by formulas (1) and (2).

Mutual conversions $(\nu_e \rightleftarrows \tilde{\nu}_e)$, $(\nu_\mu \rightleftarrows \tilde{\nu}_\mu)$ in the reactions involving charged leptons of opposite helicities are described by

$$\sigma = \frac{G^2 s}{12\pi}(1 \mp h_e)(1 \pm h_\mu), \tag{3}$$

where the upper sign refers to e_L^-, μ_R^- and the lower one to e_R^-, μ_L^-. These transitions are forbidden since (V – A) currents that determine it have irregular structure $(\bar{\nu}_\mu e)$ and $(\bar{\mu}\tilde{\nu}_e)$.

1. Yu.I.Romanov // Bull. Russ. Acad. Sci. Phys. 2018. V.82. P.757.
2. B.K.Kerimov // Bull. Acad. Sci. USSR. Phys. Ser. 1961. V.25. P.161.

PHILLIPS LINES FOR WEAKLY BOUND TRIATOMIC He_2Li MOLECULES

Roudnev V.[1], Kolganova E.A.[2,3]
[1] St Petersburg State University, 199034 St Petersburg, Russia, [2] Joint Institute for Nuclear Research, 141980 Dubna, Russia, [3]Dubna State University, 141982 Dubna, Russia
E-mail: v.rudnev@spbu.ru

There are two observations that were made in the very end of 1960-s and have been atrracting the few-body community's attention for a long time: the Phillips line [1] and the Efimov effect [2]. The Phillips line -- the linear correlation between the neutron-deuteron scattering length and the triton bound state energy -- constitutes a phenomenological observation for a very particular three-body system, whereas the Efimov effect is a universal theoretical prediction: it emerges for any three-body system which holds at least two subsystems with the two-body scattering lengths larger than all the other length scales. The latter case is often called ``the universal interaction regime'' in which only the leading orders of the two-body effective range expansions govern the three-body dynamics. The both observations can serve as an indication of the universal interaction regime.

One of the best theoretically predicted three-body system with an excited state of the Efimov type is a naturally existing molecule of the helium trimer $^4He_3$ (see, [3] and refs. therein). The close proximity of this system to the modified dimensionless Phillips line has been demonstrated in [4], which confirms the universal interaction regime for this system.

Another set of Efimov system examples that are not yet confirmed experimentally could be taken from He_2 – alkali-atom van-der-Waals trimers. The dimensionless Phillips plots for these systems differ, however, from the fully symmetric Helium trimer due to the dependence of the plot on the mass ratio of the constituent particles.

Here we use the Faddeev equations in total angular momentum representation to calculate the $^4He_2{}^{6;7}Li$ binding energies and a scattering length, which has not been studied before. The proximity of these systems to the universal Efimov regime is demonstrated on the base of analyzing the modified Phillips line for non-symmetrical systems.

1. A.C.Phillips // Nucl. Phys A. 1968. V.107. P.209.
2. V.Efimov // Phys. Lett. B. 1970. V.33. P.563.
3. E.A.Kolganova, A.K.Motovilov, and W.Sandhas // Few-body Syst. 2017. V.58. P.35.
4. V.Roudnev, M.Cavagnero // Physical Review Letters. 2012. V.108. P.110402.

RELATIVISTIC NUCLEAR CALCULATIONS IN THE CLOTHED-PARTICLE REPRESENTATION

Shebeko A.V.
Institute for Theoretical Physics, NSC KIPT, Kharkiv, Ukraine
E-mail: shebeko@kipt.kharkov.ua

Starting from the instant form of relativistic quantum dynamics for a system of interacting mesons and nucleons, where amongst the ten generators of the Poincaré group (Π) only the Hamiltonian H and the boost operator $\boldsymbol{B}$ carry interactions, we have proposed [1-2] a constructive way of ensuring the relativistic invariance in field models with cutoffs in momentum space. In contrast to the Lagrangian formalism, in which the generators of Π are determined as the Noether integrals of the energy-momentum tensor density, our purpose is to find these generators as elements of the Lie algebra of Π for a typical situation where the total Hamiltonian interaction density $H_I(x)$ in the Dirac picture includes a Lorentz-scalar part $H_{\rm sc}(x)$. Using purely algebraic means, we show that operator $\vec{B}$ can be decomposed into the Belinfante operator built of $H_{\rm sc}(x)$ and the operator which accumulates the chain of recursive relations in the second and higher orders in $H_{\rm nsc}(x) = H_I(x) - H_{\rm sc}(x)$. Moreover, in combination with the method of unitary clothing transformations [1] the proposed approach enables us to get the interactions between the clothed particles (in particular, physical mesons and nucleons) simultaneously in the H and $\boldsymbol{B}$. The derived interactions are Hermitian and energy independent including the off-energy-shell and recoil effects (the latter in all orders of the $1/c^2$–expansion). Doing so, we have built up the $\boldsymbol{B}$ with specific nonlocal extensions of the primary Yukawa-type couplings in a system of the π-, η-, ρ-, ω-, δ- and σ-mesons and nucleons. The consideration is topical once we will, on the one hand, to perform convergent calculations getting rid of ultraviolet divergences inherent in local field models and, on the other hand, to meet the requirements of special relativity. Explicit expressions for the boosts need [3] in relativistic calculations where the center-mass-motion of a system is not separated from its internal degrees of freedom. Then, for example, the dipole magnetic moment of a nucleus in the state with the total angular momentum J is determined by the expectation $\mu=\frac{1}{2}\langle \mathbf{0};J|[\boldsymbol{B}\times\boldsymbol{J}(0)]^z|\mathbf{0};J\rangle$ in the rest frame, where $\boldsymbol{J}(0)$ is the current density operator at the time-space point $x = (t, \boldsymbol{x}) = 0$. We would like to show applications of the approach in the theory of the nucleon-nucleon scattering below the pion production threshold and when calculating the deuteron and triton binding energies with the so-called Kharkov potential (see another contribution to this conference).

1. A.Shebeko // Chapter I in: *Advances in Quantum Field Theory*. ed. S.Ketov. InTech 2012. P.3.
2. A.Shebeko, P.Frolov // Few-Body Syst. 2012. V.52. P.125.
3. A.Shebeko, I.Dubovik // Few-Body Syst. 2013. V.54. P.1513.

CALCULATION OF PLASMADYNAMIC PARAMETERS OF THE TARGET FOR MAGNETO-INERTIAL FUSION WITH A COMBINED EFFECT

Kuzenov V.V.[1,2,3], Shumaev V.V.[1]
[1] *Bauman Moscow State Technical University, Moscow, Russia;* [2] *A.Yu. Ishlinsky Institute for Problems in Mechanics RAS;* [3] *N.L. Dukhov VNIAA of SC "ROSATOM", Moscow, Russia*
E-mail: svryzhkov@bmstu.ru

The work is devoted to theoretical calculation of the compression of a plasma target by pulsed jets in an external magnetic field [1–12]. The results of calculating the interaction of intense pulses with a two-layer cylindrical target are presented.

The considered dynamics of processes can be described in the form of several structural phases. All these phases are explained by the hydrodynamic nature of target compression, when the flow incident on the target deforms and accelerates the target walls, generates a system of shock waves interacting with each other and the axis of symmetry in the plasma of the central part of the target, leading to compression of the magnetic field frozen in it.

A mathematical model of plasma compression of a cylindrical target has been developed by a cumulative (due to the flow of a system of pulsed jets onto it) by a liner with a capacitive energy storage. This model is consistent with the parameters of the external electrical circuit and modeling gas. In the work, a numerical simulation of plasma-gas-dynamic processes of interaction of powerful energy flows (a system of pulsed jets) with a thermonuclear target is carried out. The main thermophysical characteristics of a magnetized target plasma during a system of pulsed jets of duration 10 ns (rectangular pulse), energy flux density 10^{11}–10^{12} W/cm^2, pulse velocity 40–100 km/s are calculated.

The work is funded by the Russian Minobrnauki (Project 13.5240.2017/8.9).

1. V.V.Kuzenov, S.V.Ryzhkov, V.V.Shumaev // Prob. Atom. Sci. Tech. 2015. №4. P.53.
2. S.V.Ryzhkov // Bull. of the Russian Academy of Sciences. Physics. 2014. V.78. P.456.
3. V.V.Shumaev // Phys. Atom. Nucl. 2016. V.79. P.1.
4. V.V.Kuzenov // Phys. Atom. Nucl. 2017. V.80. P.1683.
5. I.Yu.Kostyukov, S.V.Ryzhkov // Plasma Physics Reports. 2011. V.37. №13. P.1092.
6. A.Yu.Chirkov, S.V.Ryzhkov // Journal of Fusion Energy. 2012. V.31 (1). P.7.
7. V.V.Kuzenov, S.V.Ryzhkov // Bull. Russian Academy Sci. Phys. 2016. V.80. P.598.
8. V.V.Kuzenov, S.V.Ryzhkov // Mathematical Models Computer Simulations. 2018. V.10. P.255.
9. V.V.Kuzenov, S.V.Ryzhkov, V.V.Shumaev // Applied Physics. 2014. V.3. P.22.
10. V.V.Kuzenov, S.V.Ryzhkov, V.V.Shumaev // Prob. Atom. Sci. Tech. 2015. №1. P.97.
11. S.V.Ryzhkov, V.I.Khvesyuk, A.A.Ivanov // Fusion Science and Technology. 2003. V.43. № 1. P.304.
12. S.V.Ryzhkov, A.Yu.Chirkov, A.A.Ivanov // Fusion Science and Technology. 2013. V.63. № 1. P.135.

APPLICATIONS OF THE VLASOV EQUATION TO DISSIPATIVE SYSTEMS

Perepelkin E.E.[1], Sadovnikov B.I.[1], Inozemtseva N.G.[2], Suchkov D.A.[1]
[1] *Faculty of Physics, Moscow State University, Moscow, Russia;* [2] *Dubna State University, Dubna, Moscow region, Russia*
E-mail: pevgeny@jinr.ru

This paper revises phenomenological approaches to the application of Vlasov equation to describe the dissipative systems. The classical Vlasov equation cannot be used to describe the dissipative systems. The original Vlasov equation contains a non-zero right side, derived from the first principles. In this work is shown that the original Vlasov equation can describe systems with dissipation.

In this paper several types of the dissipative systems are considered. For these systems, the exact solutions are constructed by the characteristics. Also, a numerical simulation of a system of many particles is performed. Numerical integration of the motion equations is performed on the massively parallel computing architecture of GPU graphics processors. In conclusion, the main results and conclusions of the paper are presented.

1. A.A.Vlasov Many-Particle Theory and Its Application to Plasma, New York, Gordon and Breach, 1961, ISBN 0-677-20330-6; ISBN 978-0-677-20330-0.
2. E.E.Perepelkin, B.I.Sadovnikov, N.G.Inozemtseva, The new modified Vlasov equation for the systems with dissipative processes // Journal of Statistical Mechanics: Theory and Experiment. 2017. 053207.
3. E.E.Perepelkin, B.I.Sadovnikov, N.G.Inozemtseva, The properties of the first equation of the Vlasov chain of equations // Journal of Statistical Mechanics: Theory and Experiment. 2015. 05019.

ASYMPTOTIC FORM OF THE WAVE FUNCTION OF FEW-PARTICLES IN THE CONTINUUM

Yakovlev S.L.
St Petersburg State University, St Petersburg, Russia
E-mail: s.yakovlev@spbu.ru

The asymptotic form of the wave function of a few-particle system in the continuum is described. The contribution of the rescattering processes in the leading terms of the asymptotic behavior of the wave function is analyzed. The hyperradial asymptotic behavior of the wave function is found after averaging over the hyperspherical angular variable. The perspective of applications to the analysis of the few neutron system is discussed.

1. S.L.Yakovlev // Theor. Math. Phys. 2016. V.186(1). P.126.

MODERN METHODS FOR DETERMINING THE SIZES OF NEUTRON-EXCESS NUCLEI

Galanina L.I.[1], Morzabayev A.K.[2], Alibayeva A.G.[2]
[1] *Research Institute of Nuclear Physics, Moscow State University, Moscow, Russia;*
[2] *L.N.Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan*
E-mail: alibayeva.aidana@gmail.com

A huge amount of experimental data has been accumulated to study the unusual properties of neutron-excess nuclei. The spatial structure of these nuclear systems can be represented as some compact *core*, in the field of which one or several neutrons move on the periphery.

The ambiguity of the data on the *root-mean-square radius* r_{rms} is due to the fact that the lifetime of most neutron-excess isotopes is extremely short and usually amounts to several milliseconds. Therefore, to work with short-lived isotopes, completely new techniques are required.

The latest advances are related to *collinear* and *anticollinear* laser beam technologies (CACLB) of the European Center for Nuclear Research (CERN). Today, at the ISOLDE facility, radioactive isotopes up to $Z = 10$ are synthesized at CERN in the collision of 1.4 GeV protons with a uranium carbide target [1].

One of the newest methods [2] developed using the *Penning effect* complements the data on elastic scattering.

The status of the most accurate method was obtained by *laser spectroscopy* based on measurements of charge and mass radii for isotopes ^{7,9,10}Be and ^{11}Be [1, 3]. In the near future we can expect data for ^{11}Li, too.

Our interest lies within the ^{11}Li isotope, which is a *configuration of excess neutrons* in the field of the ^{7}Li compact core. Research for the charge radius, momentum distributions, and charge form factors of ^{11}Li are discussed in [4–7]. Our determination of the size of the neutron periphery and its *root-mean-square radius* r_{rms} is based on an analysis for the soft mode effect of the dipole resonance [8].

1. K.M.Lynch, S.G.Wilkins, *et al.* // Phys. Rev.C. 2018. V.97. 0243098.
2. M.Smith, M.Brodeur, *et al.* // Phys. Rev. Lett. 2008. V.101. 202501.
3. S.Schmidt, M.Willig, *et al.* // Journal of Physics: Conf. Ser. 2018. V.1138. 012010.
4. I.A.M.Abdul-Magead, *et al.* // arXiv:1901.03875v1 [nucl-th] 12 Jan 2019.
5. Arkan R.Ridha and Zaid M.Abbas // Iraqi Journal of Phys. 2018. V.16. No.36. P.29.
6. Ahmed N.Abdullah // Iraqi Journal of Science, 2018. V.59. No.2C. P.1057.
7. M.K.Gaidarov, V.K.Lukyanov, *et al.* // EPJ Web of Conf. 2016. V.107. P.08003.
8. J.Tanaka, R.Kanungo, *et al.* // Phys. Lett. B. 2017. V.774. P.268.

NUCLEAR STRUCTURE CALCULATIONS OF $N = 126$ ISOTONES

Benrachi F., Laouet N.
Laboratoire de Physique Mathématique et Subatomique, Frères Mentouri Constantine 1 University, Algeria
E-mail: fatima.benrachi@umc.edu.dz

In this work, we have investigated some spectroscopic properties of heavy neutron-rich nuclei located 'South-West' from ^{208}Pb region. The calculations included few valence hole–protons (2 to 8) are performed by means of shell model code NushellX@MSU [1]. The jj56*pn* valence space used consists of eleven proton and neutron orbitals with new single particle energies in ^{132}Sn doubly magic core. Kuo-Herling empirical interaction updated recently is adopted [2]. Energies of the low-lying states and transition probabilities of these isobars have been determined. The obtained results are then compared with the available experimental data [3].

1. B.A.Brown // Nuclear Data Sheets. 2014. V.120.
2. J.Wrzesiński *et al*. // Phys. Rev. C. 2015. V.92. 044327.
3. S.I.Sukhoruchkin and Z.N.Soroko, Landolt-Börnstein - Group I Elementary Particles, Nuclei and Atoms, Springer materials. 2013.

CHARGE SYMMETRY BREAKING IN THREE-NUCLEON SYSTEM: PHENOMENOLOGICAL APPROACH

Filikhin I.N., Suslov V.M., Vlahovic B.
North Carolina Central University, Durham, NC, USA
E-mail: ifilikhin@nccu.edu

The three-nucleon system (*ppn* or *nnp*) may be considered as a system of identical particles within a framework of the isospin formalism (AAA model). Here we propose to treat the system as a system with only two identical particles (AAB model) as a natural way to take into account the charge dependence of the nucleon-nucleon interaction. This model allows us [1] to propose charge dependent part of *NN* interaction for the phenomenological *s*-wave MT-I-III potential, which has been originally constructed as charge independent. The adjusted parameters for the spin singlet *nn*, *pp*, and *np* components of *NN* potential were chosen to reproduce corresponding set of singlet *NN* scattering lengths. The set of values of the nn scattering length has significant uncertainty, we used values from [2–6]. Based on this model, we studied dependence of the CSB effect for three-nucleon bound states versus nn scattering length. The CSB energy for ^{3}H and ^{3}He is relatively small and is about 50 keV, for the "recommended" set of the scattering lengths where a_{nn}=18.95±0.40 fm [2]. The alternative value for a_{nn}, which was discussed in Ref. [3] ([4]), is 16.2 fm (15.8 fm). Taking these values, we have adjusted the spin-singlet *nn* potential. A corresponding three-body calculation leads to the opposite sign (minus) for the charge symmetry breaking effect for ^{3}H and ^{3}He nuclei. This result confirms prediction of the work [6].

Preliminary results for charge independent AV14 potential will be presented.

This work is supported by the National Science Foundation grant HRD-1345219 and NASA grant NNX09AV07A.

1. I.Filikhin, V.M.Suslov and B.Vlahovic // Int. J. Mod. Phys. E. 2016. V.25. P.1650042.
2. Q.Chen *et al.* // Phys. Rev. C. 2008. V.77. P.054002.
3 E.S.Konobeevski *et al.* // Bulletin of the Russian Academy of Sciences. Physics. 2011. V.75. P.443.
4. E.S.Konobeevski *et al.* // Phys. Atom. Nucl. 2018. V.81. P.595.
4. M.M.Nagels, T.A.Rijken, Y.Yamamoto // 2018. NN-online; nn-online.org/eprints/pdf/18.01.pdf
6. E.S.Konobeevski, S.V.Zuyev, V.I.Kukulin, and V.N.Pomerantsev // arXiv: 1703.00519v1 [nucl-th].

ON THE ORIGINS OF GIANT RESONANCES FRAGMENTATION

Goncharova N.G.
Lomonosov Moscow State University, Moscow, Russia
E-mail:n.g.goncharova@gmail.com

In the multiparticle shell model (MSM) multipole resonances (MR) are considered as a result of the interaction of virtual “doorway” states, usually constructed on the extreme single particle shell model (ESPSM) representation on nuclear structure. Experimental investigation of MR has shown that calculations of MR strength and distribution on energy axis are much more complicated than ESPSM predictions even for magic nuclei, e.g. ^{16}O or ^{40}Ca.

The fragmentation of MR in magic nuclei is influenced by the deviation of their structure from ESPSM predictions, which could be revealed in pick-up reactions on the nucleus at rather high energies of projectiles. Such reactions have shown the splitting of the deep shells, e.g. of $1d_{5/2}$ subshell in ^{40}Ca [1]. The calculations of MR strengths distributions could be performed in the Particle-Core Coupling version of shell model (PCCSM) [2]. In the Fig.1 are shown the PCCSM results for M6 resonance in ^{40}Ca; high fragmentation of M6 formfactor explains the problem of detection M6 in this nucleus [3]. Splitting of $1d_{5/2}$ subshell leads as well to fragmentation of E1 resonance in ^{32}S [4].

Fragmentation of E1 resonance in ^{16}O was not explained in multiparticle ESPSM in spite of right interpretation of the E1 strength’ shift upwards. It could be done when deviations from ESPSM were taken into account due to results of ^{16}O(p,d) reaction [5]. In spite of smallness of these deviations (there are about 6–7%) their influence on distribution of E1 strength is considerable; namely, the splitting of the main peak [6] could be interpreted.

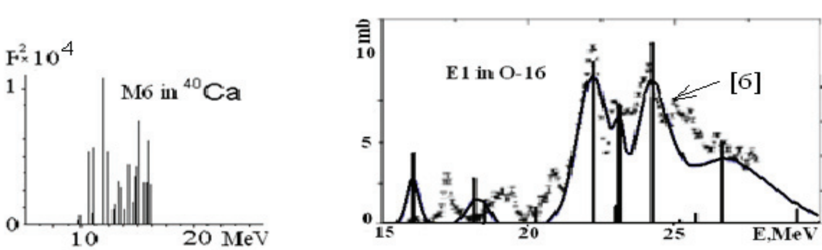


Fig.1

1. P.Doll *et al.* // Nucl. Phys. A. 1976. V.263. P.210.
2. N.G.Goncharova // Phys. At. Nuclei. 2009. V.72. P.1745.
3. B.L.Clausen *et al*. // Phys. Rev. C. 1988. V.38. P.589; 1993. V.48. P.1632.
4. N.G.Goncharova // Phys. At. Nuclei. 2019. V.82. P.50.
5. M.A.Firestone *et al*. // Nucl.Phys. A. 1976. V.258. P.317.
6. B.L.Berman *et al.* // Phys. Rev. C. 1983. V.27. P.1.

BETA-DECAY OF ^{134}In AND PROPERTIES OF ODD-ODD NEUTRON EXCESS In ISOTOPES AT $N \geq 81$

Isakov V.I.
National Research Center "Kurchatov Institute", Petersburg Nuclear Physics Institute, Gatchina, Russia
E-mail: visakov@thd.pnpi.spb.ru

Odd-odd nuclei offer specific interest for theoretical research as results of calculations are extremely sensitive both to the employed approach as well as to the effective interaction used in calculations. Here, we consider odd-odd isotopes of In, from ^{130}In to ^{138}In that are close to the "remote" double-magic nucleus ^{132}Sn. By now, fragmentary experimental information is available only for ^{130,132}In isotopes. In regard to ^{134}In, only the value of its ground state spin is known with great uncertainty $(4^- \leq I^\pi \leq 7^-)$, as well as the half-life, of this nucleus. Data on the heavier isotopes are absent. Calculations of the β-transition rates performed in the framework of the multiparticle two-group shell model with effective two-body interaction and allowing for pairing lead to the partial β-decay half-lives shown in the Table. Here, $R = B(^{134}\text{In}, \lambda=1; I_i \to I_f) / B_{\text{sp}}(\lambda=1; \nu 2f_{7/2} \to \pi 1g_{9/2})$. The decay $^{131}\text{Cd} \to ^{131}\text{In}$ [1] was used as a reference mark for definition of a single-particle transition matrix element. We considered $|I_i\rangle$ to be the ground state of ^{134}In, while the $|I_f\rangle$ ones are experimental excited states of ^{134}Sn. Analysis based on the available experimental data on the decay of ^{134}In and data of the Table shows that the most probable ground state of ^{134}In is the 6^- one, while the transition goes to the excited 6_1^+ state of ^{134}Sn. Spectra of In isotopes and electromagnetic transition rates are also calculated by using different effective interactions.

$(\nu 2f_{7/2})^3(\pi 1g_{9/2})^{-1}; I_i$	$(\nu 2f_{7/2})^2; I_f$	R	$B(I_i \to I_f)$	$T_{1/2}(I_f), s$
7	6	0.32796	2.785E-02	0.13(3)
6	6	0.07686	6.526E-03	0.57(11)
5	6	0.00699	5.933E-04	6.31(1.26)
5	4	0.25435	2.160E-02	0.162(32)
4	4	0.13322	1.131E-02	0.309(61)
3	4	0.02196	1.865E-03	1.878(376)
3	2	0.19325	1.641E-02	1.190(38)

1. J.Taprogge *et al*. // Eur. Phys. J. A. 2016. V.52. P.347.

BINDING ENERGIES OF FEW-BODY DIPOLAR COMPLEXES IN TWO SPATIAL DIMENSIONS

Koval E.A.[1], Koval O.A.[2]
[1] *Joint Institute for Nuclear Research, Dubna, Moscow Region, Russia;* [2] *Obukhov Institute for Atmospheric Physics, Moscow, Russia*
E-mail: e-cov@yandex.ru

The bound states of dipolar particles moving in two spatial dimensions are analyzed. The system models polar molecules and atoms with large magnetic moments in 1D optical traps or dipolar excitons in semiconductor heterostructures two-body bound states.

The low-lying energy states are calculated by the proposed numerical algorithm, that was successfully applied to the investigation of the 2D Hydrogen in a tilted magnetic field and the anisotropic scattering in two dimensions [1-4]. The effects of the different short-range potentials and Van-der Waals attraction on the resulting spectrum of the system are shown.

The long-range attractive dipolar interaction is particularly interesting due to the possibility of a control of the dipole moment and the resulting potential interaction and du to prospects of a creation of a scalable quantum computer based on dipolar systems as qubits [5].

1. E.A.Koval *et al.* // J. Exp. Theor. Phys. 2017. V.125. No.1. P.35.
2. E.A.Koval *et al.* // Physica E. 2017. V.93. P.160.
3. E.A.Koval *et al.* // Phys. Rev. A. 2014. V.89. P.052710.
4. E.A.Koval *et al.* // Eur. Phys. J. WoC 2018. V.173. V.06008–1.
5. J.L.Bohn *et al.* // Science. 2017. V.357. P.1002.

A = 101 ISOBARS NUCLEAR STRUCTURE PROPERTIES NEAR RP-PROCESS PATH

Laouet N., Benrachi F.
Laboratoire de Physique Mathèmatique et Subatomique, Frères Mentouri Constantine 1, Constantine, Algeria
E-mail: nadjet.laouet@umc.edu.dz

In this study, we aim to estimate nuclear structure properties of $A = 101$ odd nuclei near rp-process path.

The investigation of these properties is based on the understanding of the monopole interaction effect on the single particle energies and the shell evolution [1]. This interaction has a particular interest in the study of nuclear structure and in the comprehension of the appearance of new magic numbers [2].

In this context, we have performed some spectroscopic calculations in the framework of nuclear shell model using NuShellX@MSU code [3], and effective interaction in ^{100}Sn mass region constructed taking into account the monopole effect. The obtained results are in agreement with the available experimental data [4].

1. J.B.McGrory, B.H.Wildenthal and E.C.Halbert // Phys. Rev. C. 1970. V.2. P.186.
2. O.Sorlin and M.G.Porquet // Prog. Part. Nucl. Phys. 2008. V.61. P.602.
3. B.A.Brown // Nuclear Data Sheets. 2014. V.120.
4. S.I.Sukhoruchkin and Z.N.Soroko // Landolt-Börnstein - Group I Elementary Particles, Nuclei and Atoms. Springer materials. 2013.

ON THE SPECTRUM OF THREE-BODY STATES IN THE ONE-DIMENSIONAL HARMONIC TRAP

Kartavtsev O.I.[1], Malykh A.V.[1], Zhang P.[2]
[1] Joint Institute for Nuclear Research, Dubna, 141980, Russia; [2] Institute of Modern Physics, Lanzhou 730000, China
E-mail: maw@theor.jinr.ru

The system of three identical particles with contact two-body interactions in the one-dimensional harmonic trap is considered. One of possible applications is an optional study of non-stationary problems, in particular, to elucidate the quasi-integrability of the experiments in the quantum Newton's cradle set-up [1].

Up to 30 energy levels of even-parity totally symmetric states are calculated as a function of the interaction strength λ. The calculations show that energy levels form a number of bunches, in which they becomes degenerate for two limiting values $\lambda=0$ and $\lambda\to\infty$, where the system is integrable. The wave-function structure is demonstrated by plotting the nodal lines for different levels and interaction strength. The critical values λc are found, for which topological properties of nodal lines change thus indicating the different wave-function structure if λ crosses these values.

The highly excited states are calculated via quasi-classical approach. The properties of the full spectrum is analysed.

1. T.Kinoshita, Tr.Wenger, D.S.Weiss, A quantum Newton's cradle // Nature. 2006. V.440. P.900.

DENSITY DEPENDENCE OF NUCLEAR MATTER SYMMETRY ENERGY

Manisa K.[1], Erdoğan M.[2], Bircan H.[1]
[1] *Kütahya Dumlupınar University Arts and Sciences Faculty Physics Department, Kütahya, Turkey;* [2] *Selçuk University Sciences Faculty Physics Department, Konya, Turkey*
E-mail: kaan.manisa@dpu.edu.tr

A Variational Monte Carlo (VMC) method [1, 2] is employed to investigate the density dependence of the symmetry energy of isospin asymmetric nuclear matter. The realistic Urbana V14 nucleon-nucleon interaction potential of Lagaris and Pandharipande [3] was used in the VMC calculations with addition of a phenomenological density-dependent term to simulate many-body interactions. The symmetry energy is obtained for different densities and compared with data found in literature, and it was observed that the results obtained in this study reasonably agree with the results found in the literature, and is found to increase almost linearly with the density.

1. K.Manisa *et al*. // Int. J. Mod. Phys. E 2005. V.14. P.255.
2. K.Manisa *et al*. // Cent. Eur. J. Phys. 2003. V.8. P.587.
3. I.E.Lagaris and V.R.Pandharipande // Nucl. Phys. A. 1981. V.359. P.331.

NUMBER-PROJECTED SPECTROSCOPIC FACTOR OF ONE-NEUTRON PICK-UP REACTIONS, IN THE ISOVECTOR PAIRING CASE, IN $N \approx Z$ NUCLEI

Benbouzid Y., Allal N.H., Fellah M., Oudih M.R.
Laboratoire de Physique Théorique, Faculté de Physique, USTHB, Algiers, Algeria
E-mail: ybenbouzid@usthb.dz

Expressions of number-projected spectroscopic factors (SFs) of one-neutron pick-up reactions, including the isovector neutron-proton (*np*) pairing correlations, have been established. With this aim, we used a schematic definition of the SF [1] and the Sharp-BCS (SBCS) particle-number projection method [2]. It was shown that these expressions do generalize the ones obtained when only the pairing between like-particles is taken into account.

The SFs have then been numerically calculated for $N \approx Z$ nuclei using the single-particle energies of a deformed Woods-Saxon mean-field. Each FS was calculated using four different approaches: the conventional BCS [3] and SBCS [4] methods (i.e. by taking into account only the pairing between like-particles) and the generalized BCS and SBCS approaches [2] (i.e. by taking into account the isovector pairing correlations). By comparing the results obtained by these various approaches, it was found that the SFs strongly depend on both the *np* pairing correlations and the particle-number fluctuations for this kind of reaction.

1. Y.Benbouzid *et al.* // Chinese Phys. C. 2018. V.42. P.084104.
2. N.H.Allal *et al.* // Eur. Phys. J. A. 2006. V.27. P.301.
3. J.Bardeen *et al.* // Phys. Rev. 1957. V.106. P.162.
4. M.Fellah *et al.* // Phys. Rev. C. 1973. V.8. P.1585.

β-DECAY RATES OF HEAVY NEUTRON-RICH NUCLEI AND THE r-PROCESS

Panov I.V.[1,2], Lutostansky Yu.S.[1]

[1] NRC "Kurchatov institute" – Institute for Theoretical and Experimental Physics, Moscow, Russia; [2] National Research Center "Kurchatov institute", Moscow, Russia

E-mail: Igor.Panov@itep.ru

Comparison of theoretical beta-decay rates with experimental ones made in 2008 [1], show that existed beta-decay rates calculations [2] has sometimes overestimate the values for strongly neutron-rich nuclei of chemical elements beyond Bi. Phenomenological correction of beta-decay rates for the isotopes from this region and their application to the r-process calculations show [1], that with corrected beta-decay rates the agreement between r-process calculations and observations became significantly better for the nuclei with $140 < A < 180$. This finding became the basis for the recalculation of beta-decay rates for all heavy nuclei involved into the r-process with the help of modified simple model [3]. Results of beta-decay rates calculations [4], made with the utilization of up-to-date models for mass excess predictions, have shown the decreasing of beta-decay rates mainly for the nuclei region, where due to nuclear systematic they were overestimated.

New beta-decay rates calculations were done for all nuclei, not only for those, for which systematic overabundance in rates values were shown. But calculated abundances of heavy nuclei in neutron star merger scenario, fulfilled with new predictions of beta-decay rates, differ significantly in compare with previous results (in part [1]), based on QRPA rates [2]. The region of nuclei with short beta-decay rates was expanded and this region included the vicinity of third peak at abundance curve either. As a result, the total time of nucleosynthesis wave propagation from fission remnants region till actinides became shorter leading to worse agreement of predicted heavy nuclear abundances with observations in compare with abundance predictions made earlier with phenomenological corrected beta-decay rates [1] – more faster beta-decay rates used in r-process calculations lead to faster beta-delayed fission and changes in fission products mass distribution. These changes made worse the agreement between theoretical predictions and observations.

This work was supported in part by the Russian Foundation for Basic Research (projects no. 18-02-00670, 18-29-21019).

1. I.V.Panov, I.Y.Korneev, F.-K.Thielemann // Astronomy Letters. 2008. V.34. P.189.
2. P.Möller, J.R.Nix, K.-L.Kratz // At. Data Nucl. Data Tables. 1997. V.66. P.131.
3. V.G.Aleksankin, Yu.S.Lyutostanskii, I.V.Panov // Phys. Atomic Nucl. 1981. V.34. P.804.
4. I.V.Panov, Yu.S.Lutostansky, F.-K.Thielemann // Nucl. Phys. A. 2016. V.947. P.1.

BOHR-WEISSKOPF EFFECT IN THE THALLIUM ATOM

Prosnyak S.D.[1,2], Maison D.E.[1,2], Skripnikov L.V.[1,2]
[1] National Research Centre Kurchatov Institute B.P. Konstantinov Petersburg, Nuclear Physics Institute, Gatchina, Leningrad District, Russia; [2] Saint Petersburg State University, 7/9 Universitetskaya nab., St. Petersburg, 199034 Russia
E-mail: prosnyak.sergey@yandex.ru

Methods of modern spectroscopy make it possible to measure hyperfine splittings of electronic states of atoms and molecules with high accuracy, resulting in a large amount of data for the analysis and interpretation. To reproduce accurately experimental values of hyperfine splitting energy in heavy atoms with uncertainty of the order of 1% one has to take into account nuclear structure contributions. These are contributions from the distribution of the charge (Breit-Rosental effect) [1, 2] and magnetization (Bohr-Weisskopf effect) [3, 4] over the nucleus. We show that these effects can be taken into account using the Gaussian basis set for electronic structure calculations.

In addition, a study was made of the hyperfine magnetic anomaly – a special combination of hyperfine constants and *g*-factors of 2 different isotopes, sufficiently sensitive to differences in the distribution of magnetization. As is known, the ratio of anomalies for two different electronic states is stable with respect to the choice of the nuclear model and its parameters. This fact is employed to predict the magnetic moments of short-lived isotopes. The obtained values are in a good agreement with the previously obtained estimates.

Atomic calculations were performed with the support of the grant of the Russian Science Foundation (project 18-12-00227). The calculation of the matrix elements of the hyperfine structure was carried out with the support of the grant of the President MK-2230.2018.2

1. J.E.Rosenthal and G.Breit // Phys. Rev. 1932 V.41. P.459.
2. M.Crawford // Phys. Rev. 1949. V.76. P.1310.
3. A.Bohr and V.Weisskopf // Phys. Rev. 1950. V.77. P.94.
4. A.Bohr // Phys. Rev. 1951 V.81. P.134.

THE INFLUENCE OF THE ISOSCALAR QUASIPARTICLE INTERACTION ON ZERO-SOUND EXCITATIONS

Sadovnikova V.A.
NRC "KI", Petersburg Nuclear Physics Institute, Gatchina, Russia
E-mail: sadovnik@thd.pnpi.spb.ru

We continue to investigate the electrical dipole zero-sound excitations in the isospin asymmetric nuclear matter (ANM) started in [1]. Excitations of this type appear due to quasiparticle interaction: $F^{nn} = F^{pp} = F + F'$, $F^{np} = F^{pn} = F - F'$. Here F, F' are isoscalar and isovector Landau-Migdal parameters. In [1] the three complex branches of the solutions $\omega_{s\tau}(k,\beta)$, $\tau = p, n, np$ of the dispersion equations for zero sound in ANM were obtained with $F = 0, F' = 1.0$. Now the influence of the isoscalar F parameter is investigated. For the branches considered, the isoscalar interaction 1) changes the beginning points of branches $\omega_{sp}(k,\beta)$ and $\omega_{sp}(k,\beta)$ [1], 2) noticeably changes $\omega_{s\tau}(k,\beta)$ at $k \approx p_F$, 3) in the *np* channel results in appearance of an additional unphysical branch. Besides, the structure functions $S(\omega, k_A)$ of the electrical dipole excitations in nuclei obtained on the basis of $\omega_{s\tau}(k,\beta)$, appeared to be rather sensitive to *F,* Fig. 1. To find $S(\omega, k_A)$ we use the Steinweder-Jenssen model to define k_A [1] and the method given in [2]. We consider two nuclei with the same asymmetry parameter β_0=0.167: $^{72}\mathrm{Zn}$ and $^{48}\mathrm{Ca}$. For the both nuclei $S(\omega, k_A)$ has two maxima, the left (right) one corresponds to the contribution of $\omega_{sp}(k_A, \beta_0)$ ($\omega_{sn}(k_A, \beta_0)$); $\omega_{snp}(k_A, \beta_0)$ contributes into $^{48}\mathrm{Ca}$ (solid curve) only. The width of maxima are determined by the imaginary parts of $\omega_{s\tau}(k_A, \beta_0)$.

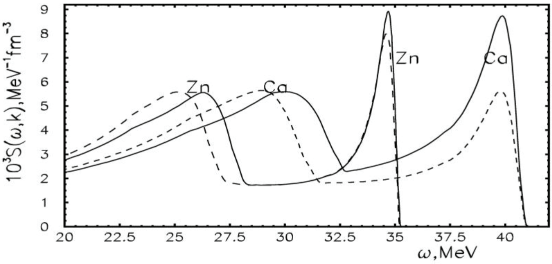


Fig.1 The structure functions $S(\omega, k_A)$ *for* $^{72}\mathrm{Zn}$ *and* $^{48}\mathrm{Ca}$. *The dash curves are obtained with* $F = 0, F' = 1.0$, *the solid ones with* $F = 0.1, F' = 1.0$.

1. V.A.Sadovnikova *et al*. // Bull. Russ. Acad. Sci.: Phys. 2017. V.81. P.1338; eprint 1807.09580.
2. A.Pastore, D.Davesne, J.Navarro // Phys. Rept. 2014.V.563. P.1.

BINDING ENERGY OF NUCLEAR MATTER IN TERMS OF QCD CONDENSATES

Drukarev E.G., Ryskin M.G., Sadovnikova V.A.
NRSC "KI", Petersburg Nuclear Physics Institute, Gatchina, Russia
E-mail: drukarev@thd.pnpi.spb.ru

We continue our studies of nuclear matter employing the QCD sum rules method. The previous reports to this Conference and more detailed results are published in [1]. The earlier results are presented in [2].

The single-particle nucleon characteristics in nuclear matter (vector and scalar self-energies) are presented in terms of the in-medium expectation values of the QCD operators. Unlike the approach of [1, 2] we assume the nuclear matter to be a system of interacting relativistic nucleons moving in self-consistent scalar and vector fields. The system is placed in the QCD vacuum. We assume that in the in-medium change of the scalar condensate the relativistic motion of the nucleons is more important than the influence of the pion cloud. As well in [1, 2] the results depend on the value of the nucleon sigma-term $\sigma_N = (45 \pm 8)$ MeV.

In Fig. 1 we show the change of nucleon parameters during the successive inclusion of the condensates with increasing dimension. The lowest local scalar and vector condensates with $d = 3$ (dashed lines) provide reasonable results. Inclusion of the nonlocal condensates ($d = 4$) together with the nonlogarithmic radiative corrections (dashed-dotted lines) and of the four-quark condensates ($d = 6$) (solid lines) make the results more accurate. On the contrary, the binding energy $\varepsilon(\rho)$ shown in Fig. 2 obtains reasonable values only if all condensates with $d \le 6$ are included. At $\sigma_N = 45$ MeV the curve $\varepsilon(\rho)$ obtains the minimal value –25 MeV signaling on the equilibrium of the matter. More detailed studies of saturation are going on.

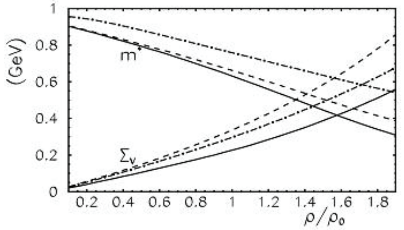


Fig.1. The vector self-energy Σ_V and the Dirac effective mass m.*

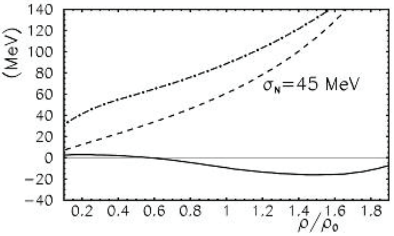


Fig. 2. The binding energy $\varepsilon(\rho)$.

1. E.G.Drukarev, M.G.Ryskin, V.A.Sadovnikova // Bull. Rus. Acad. Sci. Phys. 2017. V.81. P.1192; Nucl. Phys. A. 2017. V.959. P.129; V.968. P.350.
2. E.G.Drukarev, M.G.Ryskin, V.A.Sadovnikova // Phys. Atom. Nucl. 2012. V.75. P.334.

ON THE COHERENT ELASTIC SCATTERING OF POLARIZED LEPTONS BY HALF-INTEGER SPIN NUCLEI

Safin M.Ya.
Peoples' Friendship University of Russia, Moscow, Russia
E-mail: misafin@gmail.com

In the case of nuclei with half-integer spin $J \le 5/2$ we calculate analytical expressions for multipole expansion of the differential cross section of the electron and neutrino scattering. Nucleus structure is described [1, 2] in the framework of the Rarita-Schwinger formalism by invariant form factors of the electro–magnetic and weak vertex functions ($n = 1, 2, \ldots j+1,\ j = J-1/2$)

$$\Gamma^{\mu(\alpha)_j(\beta)_j}_{em,\,weak} = \sum_{n=1}^{j+1} Q_n^{(\alpha)_j(\beta)_j} \Gamma^{\mu}_{em,\,weak;n},$$

$$\Gamma^{\mu}_{em;n} = \gamma_\alpha \left(F_M^{(n)} + \frac{q^2}{M^2} G_1^{(n)} \gamma_5 \right) - \frac{P_\alpha}{2M} \left(F_2^{(n)} - i G_2^{(n)} \gamma_5 \right), \Gamma^{\mu}_{weak;n} = \gamma^{\mu} \left(g_M^{(n)} + g_A^{(n)} \gamma^5 \right) - \frac{P^{\mu}}{2M} f_V^{(n)}.$$

The values $Q_n^{(\alpha)_j(\beta)_j}$ are homogeneous functions of the components of the momentum transfer q of order $2(n-1)$, and are obtained by proper symmetrization of the following compositions

$$Q_{n0}^{(\alpha)_j(\beta)_j} = \prod_{i=1}^{n-1} \left(\frac{q^{\alpha_i}}{2M} \right) \left(\frac{q^{\beta_i}}{2M} \right) \prod_{k=n}^{j} g^{\alpha_k \delta_k}.$$

In the framework of the effective electroweak nuclear current (see e.g. [3]), we have obtained expressions for the differential cross section for elastic scattering of leptons, which depends on the structure functions of the hadron tensor. In the case of scattering of longitudinally polarized leptons, this cross section takes the form

$$\frac{d\sigma}{d\Omega} = \sigma_{Mott} \left\{ W_1(\tau) + 2\,\mathrm{tg}^2 \frac{\theta}{2} W_2(\tau) - \zeta\tau \left[\frac{M}{E} + \left(1 + \frac{M}{E} \right) \mathrm{tg}^2 \frac{\theta}{2} \right] W_4(\tau) \right\}.$$

Then we obtain and discuss expressions for the right-left asymmetry A_{RL}, as well as the spin correlations of transversely polarized incident and scattered leptons. It is shown, that this scattering is helicity conserving due to smallness of the lepton mass, and right-left asymmetry contains contribution from anapole moment of the target, whereas transverse correlations arise only with simultaneous polarization of incident and scattered leptons.

1. Yu.P.Bogdanov, B.K.Kerimov, M.Ya.Safin // Izv. Acad. Sci. SSSR. Ser.Fiz. 1980. V.44. No.11. P.2337.
2. Yu.P.Bogdanov, B.K.Kerimov, M.Ya.Safin // Izv. Acad. Sci. SSSR. Ser.Fiz. 1983. V.47. No.1. P.103.
3. M.Ya.Safin // Bull. Russ. Acad. Sci.: Phys. 2018. V.82. No.6. P.752.

PHENOMENOLOGICAL STRUCTURE OF THE LEPTON CURRENTS AND POLARIZED MUON DECAY

Safin M.Ya.
Peoples' Friendship University of Russia, Moscow, Russia
E-mail: misafin@gmail.com

In one of our previous paper [1] we investigated processes of muon decay

$$\mu^{\mp} \to e^{\mp} + \nu_{\mu}\left(\bar{\nu}_{\mu}\right) + \bar{\nu}_{e}\left(\nu_{e}\right)$$

(along with corresponding inverse processes) taking into account muon polarization $(\vec{s})$ and electron (positron) helicity $(\zeta = \pm 1)$ under assumption of most general (S, P, T, V, A) weak charged currents interaction.

$$H_{cc} = \frac{G_F}{\sqrt{2}} \sum_{j=S,P,T,V,A} \left[\bar{e} O_j \left(C_j + C'_j \gamma^5\right) \nu_e\right] \left(\bar{\nu}_{\mu} O_j \mu\right) + H.C.$$

Since then a number of experimental results were obtained on the parameters, describing muon decay spectrum with substantially improved accuracy [2].

Here we recalculate angular and energy spectra of polarized muon decay, taking into account not only electron (positron) helicity, but the helicities of (anti)neutrino produced, assuming that Standard Model weak $(V-A)$-charged currents interaction

$$H_{SM} = \frac{G_F}{\sqrt{2}} \left[\bar{e} \gamma_{\alpha} \left(1 + \gamma^5\right) \nu_e\right] \left[\bar{\nu}_{\mu} \gamma^{\alpha} \left(1 + \gamma^5\right) \mu\right]$$

is modified by (S, P, T)-charged currents interaction

$$H_{SPT} = \frac{G_F}{\sqrt{2}} \sum_{j=S,P,T} \left[\bar{e} O_j \left(c_j + c_j^5 \gamma^5\right) \nu_e\right] \left(\bar{\nu}_{\mu} O_j \mu\right).$$

Standard Model interaction H_{SM} is responsible for production of the usual left-handed neutrino and right-handed antineutrino while generation of the (anti)neutrino with opposite helicity is suppressed due to smallness of the neutrino mass. Nonstandard interaction H_{SPT} may be responsible for deviation from the Standard Model, and may cause generation of the right-handed neutrino and left-handed antineutrino. Using experimental data available on the Michel parameters [2], we estimate the bounds on the (S, P, T)-coupling constants, and probability of generation of the neutrino with irregular helicity.

1. B.K.Kerimov *et al*. // Vestnik Mosk. Univ. Fizika. Astron. 1982. V.23. No.5. P.77.
2. J.Beringer *et al.* // Phys. Rev. D. 2012. V.86. P.010001.

NUCLEAR STRUCTURE OF EVEN-EVEN Zn, Ge, Se, Kr AND Sr ISOTOPES AROUND ^{78}Ni

Saifi H.[1], Benrachi F.[1], Majeed F.A.[2]

[1] Laboratoire de Physique mathématique et Subatomique, Université Frères Mentouri, Constantine 1 – Algeria; [2] Department of Physics, College of Education for Pure Sciences, University of Babylon, Iraq

E-mail: saifi.hanane@umc.edu.dz, fatima.benrachi@umc.edu.dz, fouadattia@gmail.com

Shell model calculations have been performed for $^{80–84}$Zn, $^{82–90}$Ge, $^{84–94}$Se, $^{86–100}$Kr and $^{88-106}$Sr isotopic chains, in the full *pfg*- and *gds*-model spaces for protons and neutrons respectively without any restrictions imposing on the valence nucleons outside the core.

Excitation energies, transition probabilities, deformation parameter and quadrupole moment were conducted by employing an effective interaction derived on the basis of similarity [1].

Calculations have been realized using NuShellX@MSU shell model code, taking ^{78}Ni as inert core, in order to insight our knowledge about properties of nuclei situated at the frontier of neutron drip-line. Also to test the effective interaction in describing the nuclear structure for this very exotic part of nuclear chart.

We obtain satisfactory results in comparison with the available experimental data [2].

1. J.M.Allmond *et al*. // Phys. Rev. C. 2014. V.90. 014322.
2. National Nuclear Data Center, www. nndc.bnl.gov.

STUDY OF GROUND STATES OF ^{6,7,9,10}Be NUCLEI BY FEYNMAN'S CONTINUAL INTEGRALS METHOD

Samarin V.V.[1,2], Naumenko M.A.[1]
[1] Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia; [2] Dubna State University, Dubna, Russia
E-mail: samarin@jinr.ru

The wave functions of the ground states of few-body nuclei ^{6,7,9,10}Be are calculated by Feynman's continual integrals method in Euclidean time [1–3]. The algorithm of parallel calculations was implemented in C++ programming language using NVIDIA CUDA technology [4]. Calculations were performed on the NVIDIA Tesla K40 accelerator installed within the heterogeneous cluster of the Laboratory of Information Technologies, Joint Institute for Nuclear Research, Dubna.

The studied isotopes are considered as cluster nuclei with the following configurations: ^{6}Be ($\alpha + p + p$), ^{7}Be ($\alpha + n + p + p$) ^{9}Be ($\alpha + n + \alpha$), and ^{10}Be ($\alpha + n + n + \alpha$) The probability density distribution for ^{9}Be ($\alpha + n + \alpha$) nucleus in the Jacobi coordinates with the vectors **x**, **y**, and the angle θ between them is shown in Fig. 1. This distribution is used for interpretation of experimental data for reaction ^{9}Be(d, ^{4}He)^{7}Li [5].

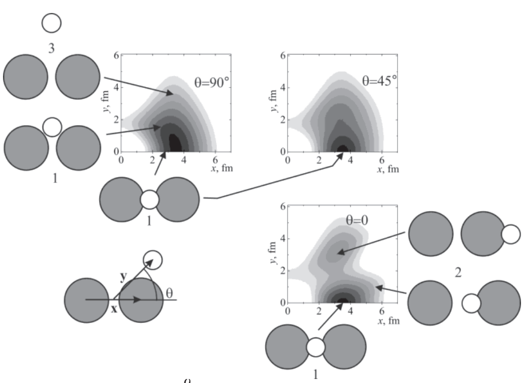


Fig. 1. The probability density for the ^{9}Bei nucleus and the vectors in the Jacobi coordinates; neutrons and α-clusters are denoted as small empty circles and large filled circles. The most probable configuration is $\alpha + n + \alpha$ (1). The configurations $\alpha + {}^5$He (2) and $n + {}^8$Be (3) are less probable.

1. R.P.Feynman and A.R.Hibbs. Quantum Mechanics and Path Integrals (McGraw-Hill, New York, 1965).
2. E.V.Shuryak and O.V.Zhirov // Nucl. Phys. B. 1984. V.242. P.393.
3. V.V.Samarin, M.A.Naumenko // Phys. Atom. Nucl. 2017. V.80. P.877.
4. M.A.Naumenko and V.V.Samarin // Supercomp. Front. Innov. 2016. V.3. P.80.
5. S.M.Lukyanov, A.S.Denikin, M.A.Naumenko, *et al.* // Journ. Phys.: Conf. Ser. 2018. V.1023. 012027.

GRAVITY IN THE SHADOW OF STABLE ATOMS AND THEIR THREE INTERACTIONS

Seshavatharam U.V.S.[1], Lakshminarayana S.[2]

[1] *Honorary Faculty, I-SERVE, Hitech city, Hyderabad-84, Telangana, India;* [2] *Department of Nuclear Physics, Andhra University, Visakhapatnam-03, AP, India*

E-mail: seshavatharam.uvs@gmail.com, lnsrirama@gmail.com

Even though materialistic atoms are having independent existence in this current accelerating universe, they are not allowing scientists and engineers to explore the secrets of gravity at atomic scale. This may be due to incomplete unification paradigm, inadequacy of known physics and technological difficulties etc. In this challenging scenario, in an analogical and semi empirical approach, each atomic interaction can be allowed to have its own gravitational constant [1–8] and [9, 10]. Proceeding further, with respect to strong coupling constant of high energy nuclear physics, Planck's constant of electromagnetic interaction and Fermi's coupling constant of weak interaction, we tried to fit the Newtonian gravitational constant. It's estimated value seems to fall in the range of $(6.67–6.68)\text{x}10^{-11}$ $m^3/kg/sec^2$. By considering experimental nuclear charge radii and binding energy of stable isotopes, it is possible to improve the accuracy of estimation. With further study, a practical model of materialistic quantum gravity can be developed.

1. U.V.S.Seshavatharam and S.Lakshminarayana // Materials Today: 3/10PB, Proceedings 2016. V.3. P.3976.
2. U.V.S.Seshavatharam and S.Lakshminarayana // Journal of Nuclear Physics, Material Sciences, Radiation and Applications. 2017. V.4(1). P.1.
3. U.V.S.Seshavatharam and S.Lakshminarayana // International Journal of Mathematics and Physics. 2016. V.7(1). P.117.
4. U.V.S.Seshavatharam and S.Lakshminarayana // Journal of Nuclear Sciences. 2017. V.4(1). P.7.
5. U.V.S.Seshavatharam and S.Lakshminarayana // International Journal of Physical Research. 2017. V.5(2). P.104.
6. U.V.S.Seshavatharam and S.Lakshminarayana // Proceedings of the DAE Symp. on Nucl. Phys. 2018. V.63. P.72.
7. U.V.S.Seshavatharam and S.Lakshminarayana // Proceedings of the DAE-BRNS Symp. On Nucl. Phys. 2017. V.62. P.106.
8. U.V.S.Seshavatharam and S.Lakshminarayana // Proceedings of the DAE-BRNS Symp. on Nucl. Phys. 2015. V.60. P.850.
9. Abdus Salam and C.Sivaram // Modern Physics Letters. A. 1993. V.8(4). P.321.
10. Roberto Onofrio // Modern Physics Letters. A. 2013. V.28. 1350022.

NEUTRON LIFE TIME ENIGMA IN THE LIGHT OF ELECTROMAGNETIC AND WEAK GRAVITATIONAL CONSTANTS

Seshavatharam U.V.S.[1], Lakshminarayana S.[2]
[1] Honorary Faculty, I-SERVE, Hitech city, Hyderabad-84, Telangana, India; [2] Department of Nuclear Physics, Andhra University, Visakhapatnam-03, AP, India
E-mail:seshavatharam.uvs@gmail.com, sln@auvsp.edu.in

One fundamental question to be answered is: Is Newtonian gravitational constant having a physical existence? We would like to suggest that, it's a man created empirical constant and is having no physical existence. Clearly speaking, it's not real but virtual. In the same way, each atomic interaction can be allowed to have its own virtual gravitational constant. With further study, the three atomic virtual gravitational constants can be validated and their magnitudes can be reviewed for a better fit and understanding of the nature [1-5]. With reference to our accepted contribution [6] for Nucleus-2019, and by considering a formula $t_n \cong G_e^2 m_n^2 \big/ G_w \left(m_n - m_p\right) c^3 \cong 874.94 \text{ sec}$, where $\left(G_e, G_w\right)$ represent electromagnetic and weak gravitational constants respectively, we tried to fit the bottle method of neutron life time [7]. Relativistic mass of neutron [8] seems to play a crucial role in understanding the beam method of increasing neutron life time [8]. It can be understood with a formula

$$t_n \cong \left[G_e^2 m_n^2 \big/ G_w \left(m_n - m_p\right) c^3 \right] \Big/ \left(1 - \left(v^2/c^2\right)\right) \cong 874.94 \text{ sec} \Big/ \left(1 - \left(v^2/c^2\right)\right).$$

1. U.V.S.Seshavatharam and S.Lakshminarayana // Prespacetime Journal. 2018. V.9(1). P.58.
2. U.V.S.Seshavatharam and S.Lakshminarayana // Journal of Nuclear Physics, Material Sciences, Radiation and Applications. 2017. V.4(1). P.1.
3. U.V.S.Seshavatharam and S.Lakshminarayana // International Journal of Mathematics and Physics. 2016. V.7(1). P.117.
4. U.V.S.Seshavatharam and S.Lakshminarayana // Materials Today: 3/10PB, Proceedings 2016.V.3. P.3976.
5. U.V.S.Seshavatharam and S.Lakshminarayana // Universal Journal of Physics and Application. 2015. V.9(5). P.210.
6. U.V.S.Seshavatharam and S.Lakshminarayana // Accepted for presentation in Nucleus2019, Dubna, Russia.
7. R.W.Pattie Jr *et al.* // Science. 2018.V.360(6389). P.627.
8. M.Scott Dewey // NIST Fundamental Neutron Physics Summer School. 2015 Knoxville, TN. (Slide 23: Spectrum of Neutrons).

TOPOLOGICAL PHASE AND TOPOLOGICAL SECTORS

Sitdikov A.S., Sungatullina Z.Yu.
Kazan State Power Engineering University, Kazan, Russia
E-mail: airat_vm@rambler.ru

The appearance of the topological Berry phase in fast-rotating nucleus was studied in [1]. Each eigenvalue $\varepsilon(\lambda,\omega)$ of the mean field Hamiltonian of the cranked shell model at this consideration forms surface over a two-dimensional parametric plane (λ,ω). According to the no-crossing theorem of Wigner and von Neumann two one-dimensional levels with the same symmetry should never cross, but two-dimensional surfaces touch at certain points, called diabolic points. The passing around closed path encircling diabolic point produce a Berry phase equal to -1 in the two-dimensional case. The appearance of diabolical points shows the topological nature of the spectrum of the CHFB Hamiltonian in the internal system, which leads to interesting phenomena and in particular, to the diabolical pair transfer, which can serve as a nuclear analogue of the Josephson effect in metal superconductors [2].

From the technical point of view, it is convenient to study nonintegrable topological phases by means of line bundles [3], where the base space is a manifold of certain parameters (for example, (λ,ω)), and the standard fiber in total space is a one-dimensional vector space. The sections of the bundle correspond to state vectors, fixing their phase determined by the holonomy of the line bundle.

In this work we consider the nucleus in a relativistic approximation and study the topological sectors generated by the algebra of the observables, where the observables taken as gauge invariant part of algebra generated by all $\psi(f)$ and $\psi(f)^*$. A Dirac spinors f correspond to the sections of the bundle. We show, to the each topological sector correspond the representation of the observable algebra in Hilbert bundle and the cocycle providing the isomorphism of the fibres. This leads to description of topological phases by using observable quantities.

1. R.S.Nicam, P.Ring // Phys. Rev. Lett. 1987. V.58. P.980.
2. W.Satula, R.A.Wyss // Rep. Prog. Phys. 2005. V.68. P.174.
3. B.Simon // Phys. Rev. Lett. 1983. V.51. P.2167.

INVESTIGATION OF THE PROPERTIES OF NUCLEI WITH EXTREMAL NEUTRON EXCESS IN THE NEIGHBORHOOD OF NEUTRON MAGIC NUMBER *N* = 184

Tarasov V.N., Kuprikov V.I., Tarasov D.V.
NSC, Kharkov Institute of Physics and Technology, Kharkov, Ukraine
E-mail: vtarasov@kipt.kharkov.ua

The properties of the ground state of even-even nuclei were calculated in a wide range of mass numbers, including nuclei with proton and neutron excess. The properties of these nuclei were investigated using the self-consistent relativistic Hartree-Bogolyubov (RHB) method based on the Lagrangian models DD-PC1 and DD-ME2 taking into account axial deformation of the nuclei. We applied for the calculations the computer code DIRHBZ from the DIRHB software package [1]. Special attention was paid to the nuclei beyond the theoretically known neutron drip line (NDL), which in the (*N, Z*) space form the peninsula of stability (POS) of nuclei that are stable with respect to the emission of one or sometimes two neutrons for $N = 184$ (See Fig. 1). Restoration of stability beyond the NDL for the considered isotones with $N = 184$, which form the POS, is associated with the complete filling of the $1j_{15/2}$ neutron subshell with a large angular momentum and the intruding of the corresponding neutron levels into the region of discrete bounded states. It is shown that the end of POS for $N = 184$ and the DD-PC1 force is nucleus of ^{246}Sm. The comparison was made with the results of our earlier calculations based on the Hartree-Fock method (HF) with the Skyrme forces [2]. It is shown that the value of *N*, which determines the position of the POS in (*N, Z*) space, does not depend on the choice of the method of calculating RHB or HF.

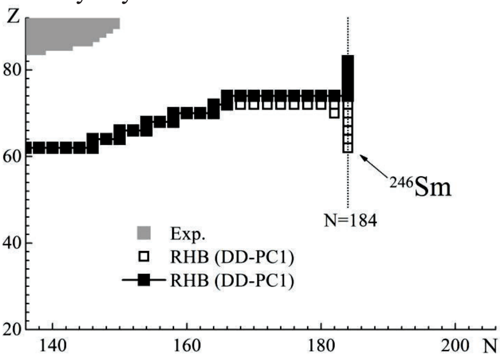


Fig. 1. NZ diagram of nuclei. The gray region contains nuclei known from experiments. The open boxes represent our calculations for nuclei stable against the emission of one neutron. Closed boxes are calculations [3].

1. T.Nikšić *et al*. // Comp. Phys. Com. 2014. V.185. P.1808.
2. V.N.Tarasov *et al*. // Int. J. Mod. Phys. E. 2013. V.22. P.1350009.
3. S.E.Agbemava *et al*. // Phys. Rev. C. 2014. V.89. P.054320.

COULOMB SCATTERING WITH TRANSVERSAL CONFINEMENT

Vinitsky S.I.[1], Chuluunbaatar O.[1], Gusev A.A.[1], Derbov V.L.[2], Krassovitskiy P.M.[1,3]
[1] Joint Institute for Nuclear Research, Dubna, Russia; [2] Saratov State University, Saratov, Russia; [3] Institute of Nuclear Physics, Almaty, Kazakhstan
E-mail: vinitsky@theor.jinr.ru, gooseff@jinr.ru

We study the Coulomb scattering problem of two charged particles with reduced mass $\mu = 1$ and charge q (in scaled units) in transversal oscillator confinement potential $V(\rho,z) = 2q / (\rho^2+z^2)^{1/2} + (\gamma / 2)^2\rho^2$. For a system of two similar or opposite charged particles with equal ratios of charges to masses, the motion of the center of mass of the system is separated and the scattering problem is formulated for the three-dimensional Schrödinger equation in a spherical coordinate system [1]. For solution of the scattering problem including the calculation of the wave function of the continuous spectrum and the matrices of reflection and transmission coefficients in open channels the set of algorithms and program complex KANTBP are elaborated (see [2] and references therein).
Non-monotonic resonance dependences of transmission $|T|^2$ and reflection $|R|^2$ coefficients for similar and opposite charged particles vs. collision energy E is revealed. It produces by finite and countable series of the metastable states imbedded in continuum. A new resonance behavior of enhancement coefficient $(C(E))^2 / (C_0(E))^2$ of probability density vs. collision energy E in pair collision point corresponding to maxima or minima of transmission coefficients $|T|^2$ for similar or opposite charged particles is revealed This behavior is different with nrespect to the conventional one, $(C_0(E))^2 = 2\pi\zeta / (\exp(2\pi\zeta) - 1)$, $\zeta = q / p$, $p = (2E)^{1/2}$, known for the pure Coulomb scattering [3], for an example, see Fig.1.

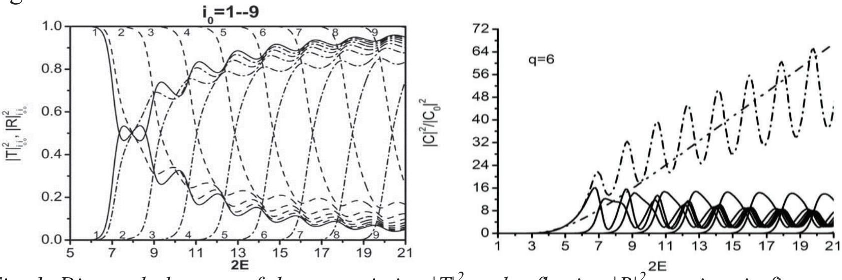


Fig. 1. Diagonal elements of the transmission $|T|^2$ and reflection $|R|^2$ matrices in first open channels (i_o =1-9) (left), enhancement coefficient $(C(E))^2/(C_0(E))^2$, partial (solid), total (dash-dotted) and analytic (right) vs. collision energy E for similar charged particles (q=6, γ=1).

1. O.Chuluunbaatar *et al.* // Phys. Atom. Nucl. 2009. V.72. P.768.
2. A.A.Gusev *et al.* // Comput. Phys. Commun. 2014. V.185. P.3341; https://www1.jinr.ru/programs/jinrlib/kantbp/indexe.html.
3. L.D.Landau, E.M.Lifshitz. Quantum mechanics: non-relativistic theory. V.3. 1981 Oxford, Pergamon Press.

RESONANT STATES IN ELASTIC SCATTERING OF NUCLEONS BY HELIUM ISOTOPES WITHIN THE NO-CORE SHELL MODEL

Mazur A.I.[1], Shirokov A.M.[1,2,3], Mazur I.A.[1,4], Kim Y.[5], Shin I.J.[5], Maris P.[3], Vary J.P.[3]

[1] Department of Physics, Pacific National University, Khabarovsk, Russia; [2] Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia; [3] Department of Physics and Astronomy, Iowa State University, Ames, Iowa, USA; [4] Center for Extreme Nuclear Matters, Korea University, Seoul, Korea; [5] Institute for Basic Science, Daejeon, Korea

E-mail: mazur@khb.ru

We study resonant states in elastic scattering of nucleons by helium isotopes within SS-HORSE method. The SS-HORSE method [1] extends the *ab initio* No-Core Shell Model (NCSM) [2] on the case of nuclear resonant states.

In the framework of the SS-HORSE-NCSM approach we investigate resonant states in ^{5}Li and ^{5}He nuclei ($3/2^-$ and $1/2^-$) and resonant states in ^{7}He nuclei ($5/2^-$, $3/2^-$ and $1/2^-$). The spectra of ^{4}He, ^{6}He, ^{5}Li, ^{5}He, and ^{7}He nuclei are calculated in NCSM with realistic NN interactions JISP16 [3] and Daejeon16 [4].

1. A.M.Shirokov, A.I.Mazur, I.A.Mazur, and J.P.Vary // Phys. Rev. C. 2016. V.94. 064320.
2. B.R.Barrett, P.Navrátil, and J.P.Vary // Prog. Part. Nucl. Phys. 2013. V.69. P.131.
3. A.M.Shirokov, J.P.Vary, A.I.Mazur, and T.A.Weber // Phys. Lett. B. 2007. V.644. P.33.
4. A.M.Shirokov, I.J.Shin, Y.Kim, M.Sosonkina, P.Maris, and J.P.Vary // Phys. Lett. B. 2016. V.761. P.87.

Theory of nuclear reactions

- **Theory of direct and statistical nuclear reactions, theory of multiple scattering;**
- **Theory of reactions involving clusters and heavy ions;**
- **Theory of relativistic nuclear collisions;**
- **Theory of polarization phenomena in nuclear reactions;**
- **Theory of proton, two-proton, cluster radioactivity and fission of nuclei.**

ESTIMATION OF SYNTHESIZING NEW SUPERHEAVY ELEMENTS USING DYNAMICAL MODEL

Aritomo Y.[1], Amano S.[1], Okubayashi M.[1], Yanagi B.[1], Nishio K.[2], Ohta M.[3]
[1] *Faculty of Science and Engineering, Kindai University, Higashi-Osaka, 577-8502, Japan;*
[2] *Japan Atomic Energy Agency, Tokai, Ibaraki, 319-1195, Japan;* [3] *Konan University, Okamoto 8-9-1, Kobe, Hyogo, 658-8501, Japan*
E-mail: aritomo@ele.kindai.ac.jp

Experiments on the synthesis of superheavy elements using heavy ion collisions have recently been successful in finding several new elements, and the known area in the nuclear chart is approaching the 'Island of Stability' step by step [1–4]. In order to success the synthesis of superheavy elements, it is indispensable to clarify the fusion-fission mechanism, which is included a role of the nuclear structure of colliding nuclei and the deformation of them in the fusion process. To synthesis of new superheavy elements $Z \geq 119$, we try to clarify the mechanism of whole the dynamical process and take advantage of the shell structure in fusion process.

For this purpose, a large amount of experimental data is available, including the mass and total kinetic energy distribution of fission fragments, excitation function of each cross section, mass-angle distributions and so on. Using such experimental data, we verify of the model and establish a reliable model to describe the fusion-fission process.

To describe heavy-ion fusion reactions around the Coulomb barrier with an actinide target nucleus, we propose a model which combines the coupled-channels approach and a fluctuation-dissipation model for dynamical calculations. Fusion-fission, quasi-fission and deep quasi-fission are separated as different Langevin trajectories on the potential energy surface.

Also, we develop the dynamical model to apply the transfer reaction and estimate the probability to produce new superheavy nuclei. We calculate the mass-angle distribution of the fragments in the reactions and investigate the fusion-fission or quasi-fission process in heavy and superheavy mass region. The fusion-fission mechanism of the process is discussed.

1. W.D.Myers and W.J.Swiatecki // Nucl. Phys. 1966. V.81. P.1; A.Sobiczewski, F.A.Gareev, and B.N.Kalinkin // Phys. Lett. 1966. V.22. P.500.
2. Yu.Ts. Oganessian *et al*. // Nature 1999. V.400. P.242; Phys. Rev. Lett. 1999. V.83. P.3154.
3. S.Hofmann and G.Muzenberg // Rev. Mod. Phys. 2000. V.72. P.733.
4. K Morita *et al*. // J. Phys. Soc. Jpn. 2004. V.73. P.2593; J. Phys. Soc. Jpn. 2007. V.76. 043201.

ASYMPTOTIC NORMALIZATION COEFFICIENTS, ANALYTIC CONTINUATION OF SCATTERING DATA, AND ASTROPHYSICS

Blokhintsev L.D., Savin D.A.
Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
E-mail: blokh@srd.sinp.msu.ru

Asymptotic normalization coefficients (ANC) are fundamental nuclear characteristics important both in nuclear reaction and nuclear structure physics. In the present work, the meaning of ANCs and their role in determining the cross sections for astrophysical nuclear reactions inaccessible for direct measurement due to the large Coulomb barrier are discussed. Both theoretical calculations of ANCs and various methods for determining ANCs from experimental data are considered. Special attention is paid to methods of finding ANCs by analytically continuing partial-wave amplitudes of elastic scattering to the point of the pole corresponding to a bound state located in the region of negative energies. Two different methods for implementing such a continuation are compared: the traditional effective range function (EFR) method and the recently proposed [1] Delta method. It is shown that, in contrast to the ERF method, the Delta method is not mathematically correct, as it corresponds to the analytic continuation not of the entire scattering amplitude but only of its real part. Nevertheless, the Delta method can be used for practical purposes in the case of sufficiently large charges and masses of colliding particles. A quantitative criterion of applicability of the Delta method is found. The validity of this criterion is verified on specific nuclear systems. A new method for analytic continuation of data for neutron scattering is proposed.

It is noted that, in contrast to the ANCs, the spectroscopic factors often used in describing cross sections of nuclear processes cannot be reliably extracted from experimental data.

The Trojan horse method is also discussed, which allows obtaining information on astrophysical binary reactions from the data on the processes with three-particles in the final state.

1. O.L.Ramírez Suárez, J.-M.Sparenberg // Phys. Rev. C. 2017. V.96. 034601.

THE NEW CLASS OF THE NUCLEAR DECAYS AND REACTIONS WITH PARTICIPATION OF THE VIRTUAL STATES OF INTERMEDIATE NUCLEI

Kadmensky S.G., Kostryukov P.V., Lyubashevsky D.E.
Voronezh State University
E-mail: kadmensky@phys.vsu.ru

In [1] at the first time it has been demonstrated the possibility of sequential theoretical description of the parent nucleus (*A*, *Z*) two-proton (*pp*) decay characteristics based on the representation that this decay corresponds to new class of nuclear decays – virtual nuclear decays (VND). Earlier *pp*-decay was analyzed on the basis of the three-body concept developed in [2], which is being built by taking into account of the simultaneous flight of two protons from nucleus (*A*, *Z*) and daughter nucleus (*A* – 2, *Z* – 2). The representation [1] is based on the fact that *p*-decay of the parent nucleus (*A*, *Z*) with the formation of the real state of the intermediate nucleus (*A* – 1, *Z* – 1) has negative decay heat $Q_1 < 0$, but the *p*-decay of this intermediate nucleus with the formation of the daughter nucleus has positive heat $Q_2 > 0$ at that $Q_{12} = (Q_1 + Q_2) > 0$. Then the virtual two-step *pp*-decay of nucleus (*A*, *Z*) is possible, when at the first stage the *p*-decay of this nucleus takes place the formation of the virtual state of intermediate nucleus and emission of the proton with kinetic energy T_1 in the range $0 \le T_1 \le Q_{12}$ and at the second stage the *p*-decay of the intermediate nucleus with emission of the proton with the energy T_2 in the range $(Q_{12} - T_1) \ge T_2 \ge 0$ and the formation real state of the nucleus (*A* – 2, *Z* – 2). These energy conditions are realized [1] for *Z*-even parent nuclei at usage of the superfluid nuclear model.

To the VND class, it can be attributed the well-studied double β-decays [3], whose characteristics can be successfully described by taking into account the virtual mechanism within the framework of the superfluid nuclear model. Also to *VND* class it can be attributed multistep spontaneous nuclear decays such as ternary (α*f*) and quaternary (αα*f*) fission with the flight of one or two α-particles, for which the heat α-decays Q_α have a positive values that are significantly lower than the height of the Coulomb barrier *B* for emitted α-particles. Due to the strong dependence of the Coulomb barrier permeability factors from energy Q_α, it's profitable to make α-decays by virtual processes with emission of α-particles at kinetic energies $T_\alpha \approx B$, when these factors ≈ 1, and formation virtual states of intermediate nuclei. $(T_\alpha - Q_\alpha)$ Energy is taken by reducing of the intermediate nucleus binary fission heat Q_f by $(T_\alpha - Q_\alpha)$ compared with the heat of binary fission Q_{0f}, which for nuclei-actinides ≈ 170 MeV. The theoretical analysis of low-energy α*f* and αα*f* fission using of named above representation makes it possible to successfully describe their characteristics.

1. S.G.Kadmensky, Y.V.Ivankov // Phys. At. Nucl. 2014. V.77. P.1019. P.1532.
2. L.V.Grigorenko // Phys. of Elem. Part. and At. Nucl. 2009. V.40. P.1273.
3. B.S.Ishkhanov, *Radioactivity* (University Book, Moscow, 2011).

ROLE OF STRING COLLECTIVITY IN THE MULTIPARTICLE PRODUCTION IN ULTRARELATIVISTIC COLLISIONS OF HADRONS AND NUCLEI

Kovalenko V.N.
Saint Petersburg State University, Saint Petersburg, Russia
E-mail: v.kovalenko@spbu.ru

The multiparticle production in the hadronic and nuclear collision at high energy is often described using a two-stage approach. At the first stage, a certain number of quark-gluon strings is produced, and the final particles are produced by strings decay. The formation and fragmentation of strings is implemented in various Monte Carlo generators, such as PYTHIA, HIJING, FRITIOF, AMPT, UrQMD, etc. However, a lot of new and precise measurements from the LHC experiments on multiplicity dependence of the transverse momentum, forward-backward correlations, charge and particle ratio correlations and fluctuations, strangeness and charm production do not fit into the picture of the individual, non-interacting strings.

In this work, we studied the influence of the interaction between strings on the various observables in *pp*, *p*A, and AA collisions using a dipole-based Monte Carlo model [1, 2], in which the interaction between strings is implemented according to string fusion model [3, 4]. For the particle species discrimination, the modified Schwinger mechanism is used [5], where the effective string tension, according to the string fusion prescription, depends on the string density. The results show that the inclusion of string fusion significantly improves the agreement of the model with experimental data. By analyzing the string fusion predictions and comparing with other approaches (String Ropes), we provide the manifestations of different realizations of string collectivity.

The reported study was funded by the Russian Foundation for Basic Research according to the research project 18-32-01055_mol_a.

1. V.N.Kovalenko // Phys. Atom. Nucl. 2013. V.76. P.1189.
2. V.Kovalenko, V.Vechernin // PoS (Baldin ISHEPP XXI). 2012. P.077.
3. M.A.Braun, C.Pajares // Nucl. Phys. B. 1993. V.390. P.542.
4. N.S.Amelin, N.Armesto, M.A.Braun, *et al*. // Phys. Rev. Lett. 1994. V.73. P.2813.
5. J.Schwinger // Phys. Rev. 1951. V.82. P.664; T.S.Biro *et al.* // Nucl. Phys. B. 1984. V.245. P.449.

DISSIPATION AND TUNNELING IN HEAVY-ION REACTIONS AROUND THE COULOMB BARRIER

Piasecki E. for the Barrier Collaboration
Heavy Ion Laboratory of University of Warsaw, Poland
E-mail: piasecki@fuw.edu.pl

Influence of couplings to collective excitations on fusion process has been well established experimentally and theoretically. Much less is known on influence of dissipation caused by transfer reactions, even less due to noncollective excitations. We will present comparison of experimental barrier distributions measured by our collaboration with the CC + RMT model calculations taking into account noncollective excitations, in which the stationary coupled channels method is merged with a statistical approach based on the random matrix theory. In spite of many assumptions and approximations, we find that the model works well for medium systems without fitting parameters describing influence of dissipation on tunneling. However, for heavier systems this mechanism does not appear to be sufficient. This points to importance of other dissipation mechanisms for these systems, such as nucleon transfer processes.

TIME-DEPENDENT DESCRIPTION OF NUCLEON AND α-CLUSTER TRANSFER REACTIONS

Samarin V.V.[1,2]
[1] *Flerov Laboratory of Nuclear Reactions, JINR, 141982, Dubna, Russia;* [2] *Dubna State University, 141982, Dubna, Russia*
E-mail: samarin@jinr.ru

The numerical solution of the time-dependent Schrödinger equation [1, 2] provides the possibility of intuitive study of dynamics of complete and incomplete fusion, α-cluster, single- and multi-nucleon transfer processes in nucleus-nucleus collisions at energies near and above the Coulomb barrier [3]. The evolution of the wave functions of the halo-proton of ^{8}B (Fig. 1) and skin-neutrons of ^{8}He were used for calculation the transfer and breakup cross sections for collisions with ^{28}Si nucleus. These processes are similar to analogies processes for halo-neutrons of ^{11}Li nucleus [4]. The evolution of the wave functions the outer nucleons of both colliding nuclei and α-clusters of ^{18}O in the reaction ^{18}O + ^{197}Au [3] was used for calculation of cross sections of the formation of the reaction products. The analysis of outer nucleons rearrangement during fusion and grazing collisions of ^{64}Ni, ^{70}Zn nuclei with ^{249}Cf nucleus are made.

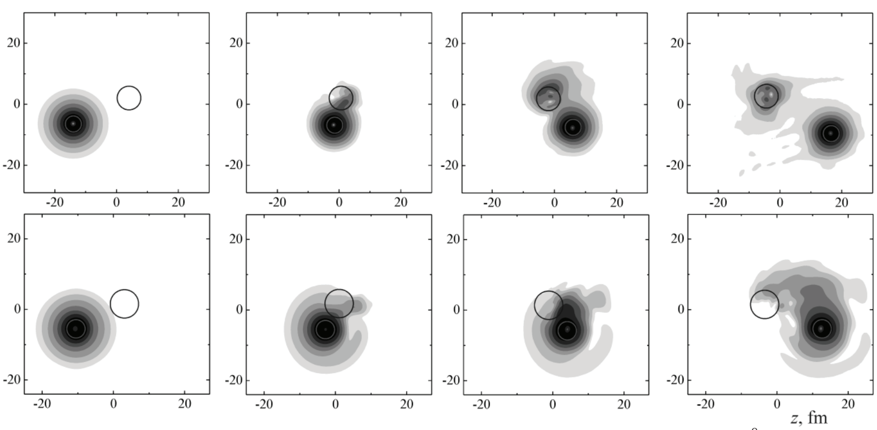


Fig. 1. The evolution of the probability density $\rho(\mathbf{r},t)$ of external protons of the ^{8}B nucleus in its collision with the ^{28}Si nucleus (circle) at energy E_{lab}= 10 A MeV (on top) and 64 A MeV (below); the course of time corresponds to panels from left to right.

6. V.I.Zagrebaev, V.V.Samarin and W.Greiner // Phys. Rev. C. 2007. V.75. 035809.
7. V.V.Samarin // Phys. At. Nucl. 2015. V.78. P.128.
8. V.V.Samarin // Phys. At. Nucl. 2018. V.81. P.486.
9. Yu.E.Penionzhkevich, Yu.G.Sobolev, V.V.Samarin, *et al*. // Phys. Rev. C. 2019 V.99. 014609.

SYSTEMATIC OF FUSION INCOMPLETENESS IN α CLUSTER PROJECTILE INDUCED REACTIONS

Ali S.[1], Gull M.[2], Rizvi I.A.[2]
[1] *MANUU Polytechnic Darbhanga, Maulana Azad National Urdu University, Hyderabad, India;* [2] *Department of Physics, Aligarh Muslim University, Aligarh, India*
E-mail: sabir@manuu.ac.in

Study of fusion reaction induced by α cluster projectile has created a resurgent in the field of heavy ion induced reactions. Fusion reaction induced by tightly bound α cluster projectile has the minimal probability of transfer reaction and maximizing the chances of fusion and fusion-fission reaction. The mechanism of breakup fusion or incomplete fusion reaction can be best explored in terms angular momentum involved. In order to investigate the role of input angular momentum in influencing the degree of fusion incompleteness was carried out by K. Siwek-Wilczynska *et al*. [1] and sum rule model was put forward.

In the present work a systematic study of fusion reaction induced by α cluster projectile over the medium and heavy mass targets has been carried out to investigate the degree of fusion incompleteness and its dependence on various entrance channel parameters viz. breakup threshold energy of the projectile, mass asymmetry, Coulomb repulsion and input angular momentum. The degree of contribution arising from the CF process is approximated by carrying out the coupled channels calculations performed using the code CCFULL [2]. In order to further confirm the degree of fusion incompleteness the extracted fusion function were exposed to universal fusion function [3].

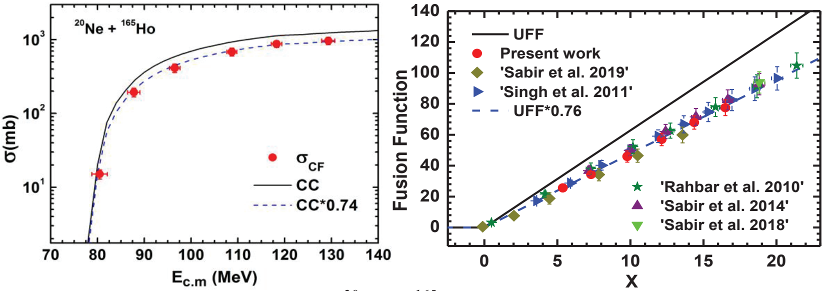


Fig. 1. (a) CCFULL calculation for the ^{20}Ne + ^{165}Ho system and (b) UFF calculation for the ^{20}Ne induced reaction over ^{165}Ho, ^{55}Mn and ^{51}V targets.

1. K.Siwek-Wilczynska *et al.* // Phys. Rev. Lett. 1979. V.42. P.1599.
2. K.Hagino *et al.* // Comput. Phys. Commun. 1999. V.123. P.143.
3. L.F.Canto *et al.* // Nucl. Phys. A. 2009. V.821. P.51.

FUSION PROCESS IN TRANSFER REACTIONS WITH LANGEVIN CALCULATION

Amano S., Aritomo Y., Miyamoto Y., Ishizaki S., Okubayashi M.
Faculty of Science and Engineering, Kindai University, Higashi-Osaka, 577-8502 Japan
E-mail: 0a4m1a9@gmail.com

To produce new neutron rich nuclei, heavy and superheavy nuclei, the transfer reaction is proposed [1–3]. We developed the dynamical model to apply the transfer reaction and estimate the probability which produces new neutron rich nuclei, heavy and superheavy nuclei.

We calculate the mass distribution of fission fragments of the compound nuclei, which are produced by nuclear transfer reaction. To investigate the fusion-fission or quasi-fission process in heavy and superheavy mass region, we also calculate the mass-angle, mass-TKE (total kinetic energy) and angle-TKE distribution of the fragments in the reaction.

Moreover, by analyzing the trajectory in the deformation space, we investigate these process in more detail. We would like to discuss the mechanism during the fusion process.

1. V.I.Zagrebaev and W.Greiner // Phys. Rev. Lett. 2008. V.101. 122701.
2. A.V.Karpov and V.V.Saiko // Phys. Rev. C. 2017. V.96. 024618.
3. V.I.Zagrebaev, Yu.Ts.Oganessian, M.G.Itkis and W.Greiner // Phys. Rev. C. 2008. V.73. 122701.

STRONGLY INTENSIVE FLUCTUATIONS BETWEEN MULTIPLICITY AND TOTAL TRANSVERSE MOMENTUM IN RELATIVISTIC P + P and P + Pb COLLISIONS FROM MULTI-POMERON EXCHANGE APPROACH

Andronov E.V., Kovalenko V.N.
Saint Petersburg State University, Saint Petersburg, Russia
E-mail: e.v.andronov@spbu.ru

Analysis of fluctuations of hadron production properties is often performed in terms of the so-called strongly-intensive quantities Σ and Δ, that allow suppressing trivial volume fluctuations originating from a collision geometry. In this work, we perform calculations of these quantities for multiplicity, N, and total transverse momentum, P_T using the multi-pomeron exchange approach for $p + p$ interactions with collision energies varying from SPS to LHC energies.

This model effectively takes into account the interaction between strings originating from cut pomerons, which becomes stronger with the growth of collision energy leading to non-trivial energy dependence of the considered observables. Moreover, the model is extended to describe p + Pb collisions and also the fluctuations for different hadron species.

The reported study was funded by the Russian Foundation for Basic Research according to the research project 18-32-01055_mol_a.

THEORETICAL ANALYSIS OF NEUTRON TRANSFER AND BREAKUP IN (^{11}Li + ^{9}Be) AND (^{11}Li + ^{12}C) REACTIONS AT LOW ENERGIES

Azhibekov A.K.[1,2], Samarin V.V.[2,3], Kuterbekov K.A.[1]
[1] L.N. Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan; [2] Joint Institute for Nuclear Research, Dubna, Russia; [3] Dubna State University, Dubna, Russia
E-mail: azhibekoaidos@gmail.com

We calculated neutron transfer and nucleus breakup cross sections in reactions of ^{11}Li-nucleus with ^{9}Be and ^{12}C at $E_{\text{c.m.}}$ = 3–50 MeV. The evolution of probability density of external weakly bound neutrons of ^{11}Li and the probabilities of neutron transfer and nucleus breakup are determined based on numerical solution of the time-dependent Schrödinger equation. We carried out theoretical analysis of neutron rearrangement in fusion and transfer reactions by approach proposed in [1, 2]. Such approach makes it possible to obtain a microscopic description of dynamics of nuclear fusion [1, 2], neutrons stripping and pick-up [3], and breakup of nuclei [4]. Figure 1 present the example of the evolution of probability densities of external neutron of ^{11}Li in the collision with ^{12}C. The time-dependent Schrödinger equation allowed us to access visually the dynamics of taking place processes. The external neutrons of ^{11}Li nucleus may be removal during two processes: transfer to target nucleus and break up to unbound states of continues energy spectrum.

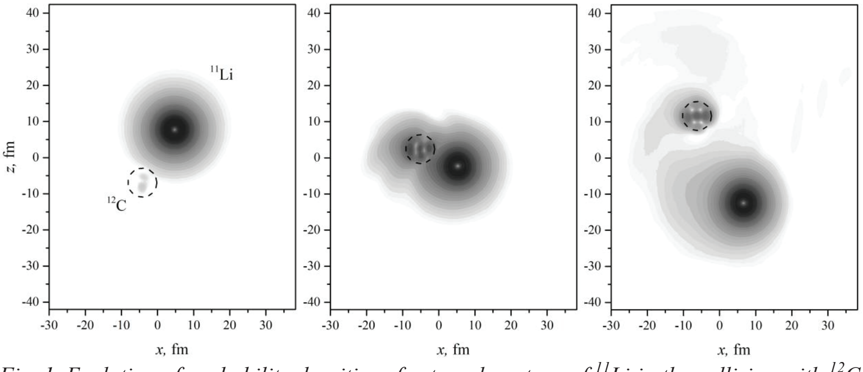


Fig. 1. Evolution of probability densities of external neutron of ^{11}Li in the collision with ^{12}C at $E_{c.m.}$ =18 MeV. Impact parameter b=9 fm. Time scale from left to right. Dash circle is ^{12}C nucleus.

1. V.I.Zagrebaev, V.V.Samarin // Phys. Atom. Nucl. 2007. V.70. P.1003.
2. V.I.Zagrebaev, V.V.Samarin, W.Greiner // Phys. Rev. C. 2007. V.75. P.035809.
3. V.V.Samarin // EPJ Web of Conf. 2015. V.86. P.00040.
4. Yu.E.Penionzhkevich, Yu.G.Sobolev, V.V.Samarin, *et al.* // Phys. Rev. C. 2019. V.75. P.014609.

THEORETICAL ANALYSIS OF THE EXPERIMENTAL DATA ON FRAGMENT ANGULAR ANISOTROPY FOR NEUTRON-INDUCED FISSION AT ENERGIES UP TO 200 MEV

Barabanov A.L.[1], Vorobyev A.S.[2], Gagarski A.M.[2], Shcherbakov O.A.[2], Vaishnene L.A.[2]

[1] *NRC "Kurchatov Institute", Moscow, Russia;* [2] *NRC "Kurchatov Institute", B.P. Konstantinov Petersburg Nuclear Physics Institute, Gatchina, Leningrad district, Russia*

E-mail: barabanov_al@nrcki.ru

The angular anisotropy of nuclear fission fragments carries an information on the deformation of the nucleus at the barrier, as well as on the contributions of channels with different values of K to the fission cross section, where K is the projection of the nuclear spin on the deformation axis. In the early stage of fission studying, extensive data on the angular anisotropy of fragments were obtained in neutron-induced fission of a number of fissile isotopes at energies up to 20 MeV. Later, some studies were carried out in this area at the neutron energies above 20 MeV (see, in particular, [1]). However, recently the results appeared of systematic measurements performed for a number of isotopes at incident neutron energies from 1 to 200 MeV. It is about a natural mixture of Pb isotopes (nat-Pb), and on nuclei ^{209}Bi, ^{232}Th, ^{233}U, ^{235}U, ^{238}U, ^{239}Pu (see [2, 3] and references therein).

In Ref. [1] along with the results of measurements of the angular anisotropy of fragments from the fission of ^{232}Th and ^{238}U isotopes by neutrons at energies from 20 to 100 MeV, an attempt was presented to interpretate the data. However, to describe all the details of the fission process of spin-oriented nuclei, some assumptions, in particular, on the role of pre-equilibrium processes, are needed. Therefore, the conclusions of the authors of [1], based on a limited amount of data, are of preliminary character.

This work is devoted to analysis of the more complete amount of data on the angular anisotropy of fragments. For evaluating the cross sections and angular anisotropy of the fragments, the modified TALYS program [4] is used. Our modification of TALYS makes possible the calculation of the spin orientation of the states of all residual nuclei formed from the initial compound states in the process of multiple emission of particles, which allows us to establish contributions to the angular anisotropy from isotopes formed at all stages of the decay of the compound nucleus. As a result, our analysis provides additional information on the ratio of equilibrium and pre-equilibrium processes in reactions at intermediate energies.

1. I.V.Ryzhov *et al.* // Nucl. Phys. A. 2005. V.760. P.19.
2. A.S.Vorobyev *et al.* // Bull. Russ. Acad. Sci. Phys. 2018. V.82. P.1240.
3. A.S.Vorobyev *et al.* // JETP Lett. 2018. V.107. P.521.
4. A.J.Koning, S.Hilaire, M.C.Duijvestijn // "TALYS-1.0". Proc. Int. Conf. on Nuclear Data for Science and Technology (2007, Nice, France); EDP Sciences. 2008. P.211.

MULTIRAGMENTATION LEADING TO PRODUCTION OF NUCLEI AND HYPERNUCLEI

Buyukcizmeci N.[1], Ogul R.[1], Botvina A.S.[2,3]
[1] Department of Physics, Selcuk University, 42079 Kampus, Konya, Turkey; [2] FIAS and ITP J.W. Goethe University, D-60438 Frankfurt am Main, Germany; [3] Institute for Nuclear Research, Russian Academy of Sciences, 117312 Moscow, Russia
E-mail: nihal@selcuk.edu.tr

Multifragmentation reactions are dominating processes for the decay of highly excited nuclei produced in heavy-ion collisions. We present the unified statistical multifragmentation model (SMM) and demonstrate the description of many experimentation data and novel predictions for relativistic nuclei collisions. In particular, we show important examples of a very good reproduction of the fragment yields (their charges, isotope compositions), their multiplicity in events, their correlations. We determine the size and thermodynamical parameters of excited nuclear matter produced in these reactions. In addition, from comparison with experiment we extract the modified properties of nuclei, e.g., their symmetry energies [1] in dense nuclear environment, which is relevant for astrophysical cases (neutron stars, supernova explosions) also. At the collisions energies above 1 *A* GeV strange particles are abundantly produced. A novel development of SMM is its generalization for the hyper-matter which is formed in the hyperon capture [2]. The SMM can describe the disintegration into normal and hyper-nuclei too. These hyper-nuclei have a broad distribution in masses and isospin. They reach beyond the neutron and proton drip lines. We demonstrate the mechanisms of such processes including the evaporation and fission of hyper-nuclei at low energies. It is suggested that some properties of hyper-nuclei (e.g., their binding energies) can be effectively evaluated from the comparison of the isotope yields [3]. This method can be applied for multi-strange hyper-nuclei which properties are very difficult to measure in traditional hyper-nuclei experiments. The multi-hyperon nuclear matter can be naturally produced in future GSI/FAIR and JINR/NICA experiments.

1. R.Ogul *et al.* // Phys. Rev. C. 2011. V.83. P.024608.
2. N.Buyukcizmeci *et al.* // Phys. Rev. C. 2013. V.98. P.064603.
3. N.Buyukcizmeci *et al.* // Phys. Rev. C. 2018. V.98. P.064603.

HEAVY-ION DOUBLE-FOLDING INTERACTION BARRIERS WITH THE RELATIVISTIC MEAN FIELD NUCLEAR MATTER DENSITIES

Chushnyakova M.V.[1], Gontchar I.I.[1,2], Bhuyan M.[3,4], Khmyrova N.A.[2]
[1] Omsk State Technical University, Omsk, Russia; [2] Omsk State Transport University, Omsk, Russia; [3] University of Malay, Kuala Lumpur, Malaysia; [4] Instituto Tecnológico de Aeronáutica, São Paulo, Brazil
E-mail: maria.chushnyakova@gmail.com

In Ref. [1] it was demonstrated that the above barrier part of the experimental heavy ion capture excitation functions could be reproduced using a dynamical model accounting for conservative and dissipative forces. Later [2, 3] the model was supplemented by the fluctuation forces. The basis of the model was the double folding approach for the nucleus-nucleus potential. In order to pursue calculations within this approach, one needed the effective nucleon-nucleon interaction as well as the nuclear matter densities of the target and projectile nuclei. In [2, 3], the well-known M3Y nucleon-nucleon density dependent effective interaction was used whereas the nuclear matter densities came from the microscopic Hartree-Fock calculations [4] with the SKX parameters [5].

Presently a better method for obtaining the microscopic densities is available, namely the relativistic mean field approach [6, 7]. The question arises to what extent the nucleus-nucleus interaction barrier parameters (i.e. the barrier height U_{B0} and radius R_{B0} for s-wave) are sensitive to the version of the density used.

In the present work we study systematically this problem making systematic calculations of the interaction potential for light projectile nuclei and spherical heavy target nuclei. The M3Y nucleon-nucleon density dependent interaction is employed whereas the nuclear densities are obtained from the relativistic mean field approach. The double-folding code DFMSPH [8] is employed to determine U_{B0} and R_{B0} for a wide range of reactions involving ^{12}C, ^{16}O, ^{28}Si, ^{32}S, and ^{36}S as projectiles and ^{92}Zr, ^{144}Sm, ^{204}Pb, and ^{208}Pb as targets. We compare the barrier parameters with those obtained using the SKX Hartree-Fock densities. These calculations enable us to make conclusions on the impact of the version of the microscopic nuclear matter density to the description of the above barrier heavy ion capture cross sections.

1. M.V.Chushnyakova, I.I.Gontchar // Phys. Rev. C. 2013. V.87. P.014614.
2. I.I.Gontchar *et al.* // Phys. Rev. C. 2014. V.89. P.034601.
3. M.V.Chushnyakova *et al.* // Phys. Rev. C. 2014. V.90. P.017603.
4. R.Bhattacharya // Nucl. Phys. A. 2013. V.913. P.1.
5. B.A.Brown // Phys. Rev. C. 1998. V.58. P.220.
6. S.Typel, B.A.Brown // Phys. Rev. C. 2001. V.64. P.027302.
7. M.Bhuyan // Phys. Rev. C. 2018. V.97. P.024322.
8. I.I.Gontchar, M.V.Chushnyakova // Comput. Phys. Comm. 2010. V.181. P.168; Comput. Phys. Comm. 2016. V.206. P.92.

SEARCH FOR ^{4}He GLOBAL OPTICAL POTENTIAL AT LOW COLLISION ENERGIES

Denikin A.S.[1,2], Song Y.-H.[3]
[1] Dubna State University, Dubna, Russian Federation; [2] Joint Institute for Nuclear Research, Dubna, Russian Federation, [3] RISP, Institute for Basic Research, South Korea
E-mail: denikin@jinr.ru

Modelling the reactions with participation of the light exotic nuclei within modern theoretical approaches involves usually the cluster concept treating weakly bound projectiles as a few-body nuclear systems, for instance, $^{6}\mathrm{He} = \alpha + n + n$, $^{9}\mathrm{Be} = \alpha + \alpha + n$ and others. The α-clusters are usual constituents of such models.

Application of the theoretical models requires determination of cluster-target interactions, which is generally chosen in the form of corresponding optical potential. However, in the case of the α particle scattering the optical model does not provide appropriate description of the experimental data at low energies where anomalous large angle scattering (ALAS) takes place [1]. Within this work, we propose to construct the ^{4}He global optical potential taking the ALAS effects into account semiclassically. In this case, the corresponding contribution to the α particle elastic scattering cross section can be described introducing an additional *l*-dependent imaginary term into the optical potential in order to simulate the high-spin quasimolecular α particle states in compound nuclear system. We perform the systematical analysis of the large amount of available experimental data on the α particle elastic scattering in order to provide explicit form of the corresponding global optical potential.

1. M.Brenner. Clustering Phenomena in Atoms and Nuclei, edited by M.Brenner, T.Lonnroth, and F.B.Malik // Springer-Verlag, Berlin, Heidelberg. 1992. P.327.

EMISSION OF HIGH-ENERGY PROTONS AND GAMMA QUANTA IN HEAVY ION COLLISIONS IN HYDRODYNAMIC APPROACH

D'yachenko A.T.[1], Mitropolsky I.A.[2]
[1] *Emperor Alexander I. Petersburg State Transport University, St. Petersburg, Russia;* [2] *NRC "Kurchatov Institute", B.P. Konstantinov Petersburg Nuclear Physics Institute, Gatchina, Russia*
E-mail: dyachenko_a@mail.ru

We consider collisions of heavy ions at intermediate energies in a hydrodynamic approach with a non-equilibrium equation of state [1–3], which takes into account the correction from the micro-canonical distribution to describe the high-energy "tails" of the spectra of secondary particles.

This allowed, in the absence of free parameters, to describe the high-momentum spectra of protons [4] and gamma quanta [5] obtained by the ITEP accelerator in the reaction $^{12}C + {}^{9}Be \rightarrow p\ (\gamma) + X$ at the energies of ^{12}C ions 2 GeV/nucleon and 3.2 GeV/nucleon. These spectra are related to the cumulative region and are not quite well described by molecular dynamics and other cascade models [4].

In the hydrodynamic approach for the description of the high-momentum component of the particle spectra, the area of a hot spot is formed as a result of the interaction of the overlapping parts of colliding nuclei, which brings this mechanism closer to the long-standing mechanism of the flucton-flucton interaction [5].

1. A.T.D'yachenko, K.A.Gridnev, W.Greiner // J. Phys. G. 2013. V.40. P.085101.
2. A.T.D'yachenko, I.A.Mitropolsky // Bull. Russ. Acad. Sci. Phys. 2016. V.80. P.916.
3. A.T.D'yachenko, I.A.Mitropolsky // Bull. Russ. Acad. Sci. Phys. 2017. V.81. P.1521.
4. B.M.Abramov *et al.* // Phys. Atom. Nucl. 2015. V.78. P.373.
5. I.G.Alekseev *et al.* // Phys. Atom. Nucl. 2015. V.78. P.936.

SPECTRA OF PROTONS AND SUBTHRESHOLD PIONS IN HEAVY-ION COLLISIONS IN THE HYDRODYNAMIC APPROACH WITH A NON-EQUILIBRIUM EQUATION OF STATE

D'yachenko A.T.[1], Mitropolsky I.A.[2]

[1] Emperor Alexander I. Petersburg State Transport University, St. Petersburg, Russia; [2] NRC "Kurchatov Institute", B.P. Konstantinov Petersburg Nuclear Physics Institute, Gatchina, Russia

E-mail: dyachenko_a@mail.ru

The emission of pions in collisions of heavy ions at energies below the threshold of their production – 300 MeV in free nucleon-nucleon collisions - is possible due to the collective intra-nuclear movement of nucleons. The influence of this motion is naturally taken into account in the framework of the hydrodynamic approach, which explicitly includes the multiparticle character of the collision of heavy ions. However, at subthreshold energies, the traditional nuclear hydrodynamics needs to be modified to take into account the non-equilibrium equation of state describing the transition from the initial non-equilibrium state of the system to the state of a local thermodynamic equilibrium.

In this approach (see, for example, [1–3]) we have described the observed double differential cross sections of protons and light fragments formation in collisions of heavy ions at intermediate energies. In the development of this approach for the collisions of ^{16}O ions with different nuclei at energies of 94 MeV/nucleon, we calculated the double differential cross sections for the production of π^+-mesons, which are compared with available experimental data. The calculation of the hydrodynamic evolution of the resulting hot spot in the process of nucleus-nucleus collisions was performed with the effects of nuclear viscosity. In this process, we distinguish [1–3] the compression stage, the expansion stage and the freeze-out stage with the formation of secondary particles (pions, protons and fragments). Agreement with the experimental energy spectra of pions and protons is achieved without the introduction of fitting parameters and is more successful than in our previous work [4].

1. A.T.D'yachenko, K.A.Gridnev, W.Greiner // J. Phys. G. 2013. V.40. 085101.
2. A.T.D'yachenko, I.A.Mitropolsky.// Bull. Russ. Acad. Sci. Phys. 2016. V.80. P.916.
3. A.T.D'yachenko, I.A.Mitropolsky // Bull. Russ. Acad. Sci. Phys. 2017. V.81. P.1521
4. A.T.D'yachenko, O.V.Lozhkin // Nucl. Phys. A. 1997. V.626. P.81.

SIMILARITY AND DISTINCTION IN ELASTIC PROTON - PROTON AND PROTON - ANTIPROTON SCATTERING'S DESCRIPTION WITH TWO RELATIVISTIC AMPLITUDES AT HIGH ENERGY

Golovanova N.F.[1], Golovanov A.A.[2]
[1] *The Kosygin State University of Russia, Moscow, Russia;* [2] *Independent researcher Moscow, Russia*
E-mail: nina4110@yandex.ru

Previously there were shown the description of the elastic p-p scattering data at energy 62 Gev [1] and 7000 Gev [2]. The results of differential and total cross section's computations were obtained in the mathematical eikonal method (MME) [3] with two relativistic spin amplitudes: the singlet amplitude which involving the proton's formfactor and the triplet one that is Lippman–Schwinger equation solution for particle's scattering in the complex field.

The mathematical eikonal profile functions have the same form as for the triplet so singlet amplitudes in papers [1, 2] but with different sets of parameters values. The proton's formfactor is the best analytic fitting for the experimental data in *e–p* scattering.

This report has been presented the results of the elastic proton-antiproton scattering differential cross section's calculations with amplitudes so as for proton-proton scattering at the energy 53 Gev. But the triplet proton-antiproton amplitude has the shape of the singlet proton-proton one. So is for the singlet proton-antiproton amplitude. This is connected with the negative antiproton's parity and that the internal proton-antiproton wave function is symmetrically. The analysis of these results displays that the triplet spin amplitude takes major contribution to the diffraction cone and next minimum in the elastic $p-\bar{p}$ scattering. The proton formfactor is used for the description of the internal antiproton's structure in the amplitudes of the elastic $p-\bar{p}$ scattering. These results are in a good agreement with the experimental data [4] at the wide region of transfer momentum. The accordance of the theoretical distribution with the experimental data confirms the correctness of the assumption about the meson distribution's similarity of those particles.

1. N.F.Golovanova // Bull. Russ. Acad. Sci. Phys. 2014. V.78. № 11. P.1425.
2. N.F.Golovanova // Russian Physics Journal, 2018. V.60. №9. P.1476.
3. N.F.Golovanova, A.A.Golovanov // Rus. J. Math. Phys. 2003. V.10. P.31.
4. M.Bertini, M.Giffon // Fiz. Elem. Chast. Fiz. Yadra. 1995. V.26. №1. P.32.

NULL-TEST FOR TIME-REVERSAL INVARIANCE IN BINARY NUCLEAR REACTION WITH SPIN-ORIENTED PARTICLES

Kadmensky S.G., Kostryukov P.V.
Voronezh State University
E-mail: kadmensky@phys.vsu.ru

In the paper [1], for the first time it has been constructed the *T*-invariance condition, which relates the differential cross sections $d\sigma_{b,a}/d\Omega_{\mathbf{k}_b}$ initial $a\to b$ and $d\sigma_{\bar{a},\bar{b}}/d\Omega_{\bar{\mathbf{k}}_a}$ time-reversed $\bar{b}\to\bar{a}$ binary nuclear reactions with arbitrary spin-oriented particles, which, when represented, are given through the sum of their components $\left(d\sigma_{b,a}/d\Omega_{\mathbf{k}_b}\right)_i$ and $\left(d\sigma_{\bar{a},\bar{b}}/d\Omega_{\bar{\mathbf{k}}_a}\right)_i$ connected at fixed index *i* with unified and, as a rule, known mechanism of their appearance, is expressed by the formula of the form: $\left(d\sigma_{b,a}/d\Omega_{\mathbf{k}_b}\right)_i = C\left(d\sigma_{\bar{a},\bar{b}}/d\Omega_{\bar{\mathbf{k}}_a}\right)_i$ (1), where *C* is a constant defined in [1]. Now taking into account space-time symmetries for analyzed quantum systems the cross section component $\left(d\sigma_{b,a}/d\Omega_{\mathbf{k}_b}\right)_i$ can be represented by the formula $\left(d\sigma_{b,a}/d\Omega_{\mathbf{k}_b}\right)_i = \varphi_i(\mathbf{k}_a,\mathbf{P}_a,\mathbf{P}_A;\mathbf{k}_b)$ where the function φ_i depends on wave vectors $\mathbf{k}_a$ and $\mathbf{k}_b$ initial and final channels, as well as polarization vectors $\mathbf{P}_a$ and $\mathbf{P}_A$ particles *a* and *A* of the channel *a* and has scalar (pseudoscalar) character. Then the value on the right in the formula (1) can be represented through the same function $\varphi_i(-\mathbf{k}_b;-\mathbf{k}_a,-\mathbf{P}_a,-\mathbf{P}_A)$, arguments of which are time-reversed vectors $-\mathbf{k}_a, -\mathbf{k}_b, -\mathbf{P}_a, -\mathbf{P}_A$ taking into account the transition from the initial $a\to b$ to the reverse reaction $b\to a$. In this case the *T*-invariance condition (1) is transformed to the new formula: $\varphi_i(\mathbf{k}_a,\mathbf{P}_a,\mathbf{P}_A;\mathbf{k}_b) = \varphi_i(-\mathbf{k}_b;-\mathbf{k}_a,-\mathbf{P}_a,-\mathbf{P}_A)$ (2), the right side of which can be represented as $\pm\varphi_i(\mathbf{k}_a,\mathbf{P}_a,\mathbf{P}_A;\mathbf{k}_b)$, where the signs + and – correspond to cases of scalarity or pseudoscalarity of the function φ_i. Then equation (2) leads to the vanishing of the function $\varphi_i(\mathbf{k}_a,\mathbf{P}_a,\mathbf{P}_A;\mathbf{k}_b)$ in the case of its pseudoscalarity for the initial reaction $a\to b$. This result at accounting of the *T*-invariance condition contradicts to the theorem about absence of null-test obtained in [3, 4] for the for any observable in the cross section of the initial reaction with usage of the *S*-matrix representation for the analyzed reactions, taking into account only the general conservation laws at the “dynamically independent” approach, which oriented not only to known, but also to still unknown mechanisms of the realization of these reactions. The *T*-invariance condition (2) allows not only to make choice of the analyzed reactions mechanisms, but also to investigate the role of the *T*-non-invariant interactions in nuclear systems.

1. S.G.Kadmensky, P.V.Kostryukov // Book of Abstracts NUCLEUS-2019.
2. S.G.Kadmensky, P.V.Kostryukov // Phys. At. Nucl. 2018. V.81. P.403.
3. F.Arash, M.J.Moravcsik, G.Goldstein // Phys. Rev. Lett. 1985. V.54. P.2649.
4. H.E.Conzett // Phys. Rev. C. 1995. V.52. P.1041.

THE *T*-INVARIANCE CONDITIONS FOR DIFFERENTIAL SECTIONS OF BINARY NUCLEAR REACTIONS WITH PARTICIPATION OF SPIN-ORIENTED NUCLEI AND PARTICLES

Kadmensky S.G., Kostryukov P.V.
Voronezh State University
E-mail: kadmensky@phys.vsu.ru

The *T*-invariance condition leads [1, 2] to the coupling of the amplitude $F_{b,a}$ of the initial binary reaction $a \to b$, at that the index a is represented as $a = |a\mathbf{k}_a sm\rangle$, where is the $\mathbf{k}_a$ wave vector of the relative motion of particles in the initial channel, s and m is the total spin and its projection for the indicated particles, and the amplitude $F_{\bar{a},\bar{b}}$ of the time reversed reaction $\bar{b} \to \bar{a}$ the equation of the form: $F_{b,a} = F_{\bar{a},\bar{b}}$. The usage of this equality makes it possible to take into account the *T*-invariance condition for differential cross sections of named above reactions involving arbitrary non-spin-oriented particles using the formula corresponding to the detailed balance principle [2]: $\left(d\sigma_{b,a}/d\Omega_{\mathbf{k}_b}\right)_i = C\left(d\sigma_{\bar{a},\bar{b}}/d\Omega_{\bar{\mathbf{k}}_a}\right)_i$ (1), where $C = \left(\frac{k_a}{k_b}\right)^2 \frac{(2s_a+1)(2s_A+1)}{(2s_b+1)(2s_B+1)}$. The differential cross $d\sigma_{b,a}/d\Omega_{\mathbf{k}_b}$ section of the initial reaction with spin-oriented particles in the initial channel *a* is represented [1] as $\frac{d\sigma_{b,a}}{d\Omega_{\mathbf{k}_b}} = \sum_{\sigma\mu,sm,s'm'} \rho_a(sm,s'm')\langle b\mathbf{k}_b\sigma\mu|F|a\mathbf{k}_a sm\rangle\langle b\mathbf{k}_b\sigma\mu|F|a\mathbf{k}_a s'm'\rangle^*$ (2), where ρ_a is the normalized spin density matrix in channel *a*. To sequentially accounting of the time reversal, the cross section of the time reversed reaction $d\sigma_{\bar{a},\bar{b}}/d\Omega_{\bar{\mathbf{k}}_a}$ should be expressed by a formula similar to (2) $d\sigma_{\bar{a},\bar{b}}/d\Omega_{\bar{\mathbf{k}}_a} = \sum \rho_{\bar{b}} F_{\bar{a},\bar{b}} F^*_{\bar{a},\bar{b}}$, where the spin density matrix $\rho_{\bar{b}}\left(\overline{\sigma\mu},\overline{\sigma'\mu'}\right)$ in the channel $\bar{b}$ is connected with the normalized density matrix ρ_b of the final channel *b* of the initial reaction $a \to b$, which is constructed through the density matrix $\rho_a(sm,s'm')$ of the initial channel [1]: $\rho_b(\sigma\mu,\sigma'\mu') = \left(d\sigma_{b,a}/d\Omega_{\mathbf{k}_b}\right)^{-1} \sum_{sm,s'm'} \rho_a \langle b\mathbf{k}_b\sigma\mu|F|a\mathbf{k}_a sm\rangle\langle b\mathbf{k}_b\sigma'\mu'|F|a\mathbf{k}_a s'm'\rangle^*$. Then the *T*-invariance condition for the cross sections of the investigated reactions is expressed by formula $d\sigma_{b,a}/d\Omega_{\mathbf{k}_b} = C \cdot d\sigma_{\bar{a},\bar{b}}/d\Omega_{\bar{\mathbf{k}}_a}$ (3), in which the constant *C* coincides with the analogous constant of formula (1). The *T*-invariance condition (3) obtained for the first time in the form for the binary reactions with spin-oriented particles can be used for analysis of the mechanisms of the various asymmetries appearance in the investigated cross sections and characteristics estimation of the *T*-non-invariant interactions in nuclear systems.

1. A.S.Davydov, *Theory of atomic nuclei* (FML, 1958).
2. A.Bohr and B.Mottelson, *Nuclear Structure* (W.A. Benjamin, NY, 1977) V.1.
3. F.Arash, M.J.Moravcsik, G.Goldstein // Phys. Rev. Lett. 1985. V.54. P.2649.
4. H.E.Conzett // Phys. Rev. C. 1995. V.52. P.1041.

TRANSFER PRODUCTS ACCOMPANYING COMPLETE FUSION

Kalandarov Sh.A.[1], Adamian G.G.[1], Antonenko N.V.[1], Heinz S.[2]
[1] *Joint Institute for Nuclear Research, Dubna, Russia;* [2] *GSI, Darmstadt, Germany*
E-mail: shuhrat@jinr.ru

The product yields of multinucleon transfer reaction is analyzed in low-energy collisions of $^{48}Ca + ^{nat}Cm$ at $E_{lab} = 5.63$ MeV/nucleon. The transfer products accompany the complete fusion. While the collisions with low angular momenta contribute to the production of very neutron-deficient isotopes, the collisions with high (near and above critical angular momentum) angular momenta result in the production of heavier isotopes. The model describes rather well the yields of isotopes with $N > 126$. The possible reasons of discrepancy for the lighter isotopes are suggested.

IMPACT OF *NN*-FORCES ON THE CHARACTERISTICS OF HEAVY-ION COLLISION BARRIER

Gontchar I.I.[1,2], Khmyrova N.A.[2], Bhuyan M.[3,4], Chushnyakova M.V.[1]
[1] Omsk State Technical University, Omsk, Russia; [2] Omsk State Transport University, Omsk, Russia; [3] University of Malay, Kuala Lumpur, Malaysia; [4] Instituto Tecnológico de Aeronáutica, São Paulo, Brazil
E-mail: nata_ruban@mail.ru

It is well known that the penetration probability of the interaction barrier for colliding nuclei depends upon its height, radius, and curvature. As a consequence, the capture and/or fusion cross-section depends upon these characteristics as well.

In the present study, we compare the interaction barriers obtained within the double-folding approach [1] using two different widely used density-dependent effective nucleon-nucleon (*NN*) forces: M3Y [2, 3] and Migdal [4].

The crucial ingredient for the double-folding approach is the matter density distribution within the projectile and target nuclei. We apply three different versions for these distributions. The first one is the phenomenological two-parameter Fermi parametrization of Ref. [5]. The second one arrives from the microscopic Hartree-Fock calculations [6] performed with the SKX parameters [7]. The third one is obtained from another microscopic method: the relativistic mean field approach [8, 9].

The following characteristics of the barriers are compared systematically: the height, radius, curvature, and skewness. The comparison is made for the set of reactions covering a wide range of parameter $B_Z=(Z_P + Z_T)/(A_P^{1/3} + A_T^{1/3})$ which can be considered as a rough estimate of the Coulomb barrier height: $B_Z \approx 10 \div 150$.

This analysis allows us to make conclusions on the impact of the version of the effective *NN* interaction upon the penetration probability of the barrier and heavy ion capture cross sections in the cases of different density distributions used in the calculations.

1. I.I.Gontchar, M.V.Chushnyakova // Comput. Phys. Comm. 2010. V.181. P.168; Comput. Phys. Comm. 2016. V.206. P.92.
2. S.G.Satchler, W.G.Love // Phys. Rep. 1979. V.55. P.183.
3. D.T.Khoa, G.R.Satchler // Nucl. Phys. A. 2000. V.668. P.3.
4. A.B.Migdal. Theory of Finite Fermi Systems and Applications to Atomic Nuclei (New York: Interscience). 1967.
5. V.I.Zagrebaev *et al.* // Phys. Elem. Part. At. Nucl. 2007. V.38. P.469.
6. R.Bhattacharya // Nucl. Phys. A. 2013. V.913. P.1.
7. B.A.Brown // Phys. Rev. C. 1998. V.58. P.220.
8. S.Typel, B.A.Brown // Phys. Rev. C. 2001. V.64. 027302.
9. M.Bhuyan // Phys. Rev. C. 2018. V.97. 024322.

SURVIVABILITY OF COMPOUND NUCLEI FORMED IN ^{48}Ca AND ^{50}Ti INDUCED REACTIONS WITH ^{176}Yb

Khuyagbaatar J.[1,2], Brand H.[2], David H.M.[2], Di Nitto A.[2,3], Düllmann Ch.E.[1,2,3], Götz M.[1,2,3], Götz S.[1,2,3], Jäger E.[2], Kindler B.[2], Krier J.[2], Kurz N.[2], Nechiporenko Y.[4], Lommel B.[2], Lens L.[2], Scharrer P.[1,2,3], Schausten B.[2], Yakushev A.[2]

[1] Helmholz Institute Mainz, 55099 Mainz, Germany; [2] GSI Helmholtzzentrum für Schwerionenforschung, 64291 Darmstadt, Germany; [3] Johannes Gutenberg-Universität Mainz, 55099 Mainz, Germany; [4] Saint Petersburg State University, St. Petersburg, 198504 Russia

E-mail: J.Khuyagbaatar@gsi.de

The survivability of excited heavy nuclei against fission, via evaporation of light particles, is the one of the most important aspects of heavy ion induced reactions, in which exotic nuclei are produced.

The nuclei of heaviest elements have mostly been produced in fusion-evaporation reactions. They are referred to as cold (hot), depending on the low (high) excitation energies of their compound nuclei (CN), which have large (small) angular momenta [1,2].

In the last two decades, fusion–evaporation reactions with ^{48}Ca projectiles and actinide targets, in which the formed CN have relatively low excitation energy but relatively high angular momenta have successfully been used for syntheses of the elements Cn–Og (Z = 112–118) [3]. However, elements beyond Og can be produced only by using heavier projectiles, e.g., ^{50}Ti.

It is still unknown how the change from ^{48}Ca to ^{50}Ti will affect the production cross sections of fusion-evaporation reactions leading to the formation of the heaviest elements [4].

I will present the results of studies of ^{48}Ca and ^{50}Ti induced reactions with ^{176}Yb targets for studying the effects of the projectile and CN on the fusion-evaporation cross sections [5].

The presented results are based on the experiment U308, which was performed at the beam line X8/TASCA at the GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt (Germany) in the frame of FAIR Phase-0.

1. S.Hofmann and G.Münzenberg // Rev. Mod. Phys. 2000. V.72. P.733.
2. K.Morita *et al.* // Jour. Phys. Soc. Jap. 2012. V.81. P.103201.
3. Yu.Ts.Oganessian and V.K.Utyonkov // Rep. Prog. Phys. 2015. V.78. P.036301.
4. J.Khuyagbaatar // EPJ Web of Conf. 2017. V.163. P.00030.
5. J.Khuyagbaatar *et al.* // Phys. Rev. Lett 2015. V.115. P.242502.

THE PHQMD MODEL FOR THE FORMATION OF NUCLEAR CLUSTERS AND HYPERNUCLEI IN HEAVY-ION COLLISIONS

Kireyeu V.[1], Aichelin J.[2], Bratkovskaya E.[3], Le Fevre A.[3], Leifels Y.[3], Kolesnikov V.I.[1]

[1] JINR Dubna, Russia; [2] Subatech Nantes, France; [3] GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

E-mail: vkireyeu@jinr.ru

Modeling of the process of the formation of nuclear clusters in hot nuclear matter is a challenging task. The PHQMD (Parton-Hadron-Quantum-Molecular-Dynamics) model is a transport approach incorporating explicit partonic degrees-of-freedom (quarks and gluons), an equation-of-state from lattice QCD, as well as dynamical hadronization and hadronic elastic and inelastic collisions in the final reaction phase. An *n*-body quantum molecular dynamic type propagation of hadrons which allows choosing of the equation of state with different compression modulus was recently complemented with a number of routines for the formation of nuclear clusters and hypernuclei in the reaction final state.

We present first results from PHQMD on the study of the production rates of strange hadrons, nuclear clusters and hypernuclei in heavy-ion collisions at NICA energies. In particular, sensitivity of hadronic anisotropic flow harmonics on the “hard” and “soft” equation of state within the PHQMD model was investigated.

DISPERSIVE OPTICAL MODEL POTENTIALS FOR A DESCRIPTION OF (*d,p*) TRANSFER REACTIONS

Klimochkina A.A., Bespalova O.V., Rubtsova O.A., Spasskaya T.I.
Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow, Russia
E-mail: klimochkina@sinp.msu.ru

Recently, a new set of parameters of the nucleon-nucleus Dispersive Optical Model Potential (DOMP) has been found [1] for Ca and Ni isotopic chains. This approach allowed to reproduce the single-particle properties of the nuclei including density distributions and root-mean square radii. At the same time, being extended to continuous spectrum, these potentials give a good description of nucleon-nucleus scattering data as well. It has been shown also, that the DOMPs can be efficiently used in practical calculations for the transfer reactions (*d,p*) [2]. One of the expected advantages of the usage of such type nucleon-nucleus potentials instead of the conventional global optical potentials is a more accurate and consistent definition of spectroscopic factors. In the present study, we have examined our DOMPs in (*d,p*) reactions with Ca isotopes where a rather good agreement of angular distributions with experimental data has been found (see Fig.1). For practical calculations, three techniques are used: the distorted wave Born approximation (DWBA), the adiabatic-wave approximation (ADWA) and the coupled-channel scheme based on the stationary wave-packet technique [3]. The developed approach will be applied to ^{56}Ni(*d,p*)^{57}Ni reaction where new experiments are forthcoming. Also the DOM treatment should be very perspective for study of reactions with rare isotopes where employment of global optical potentials could lead to rather big uncertainties.

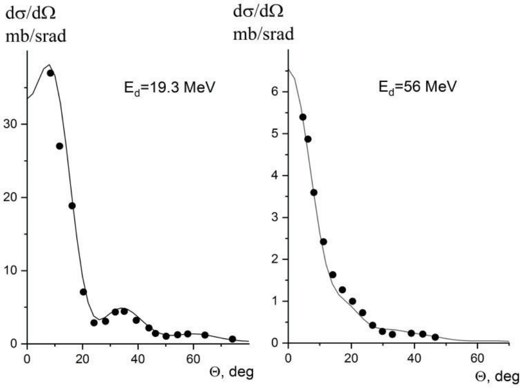


Fig. 1. Angular distributions of the $^{48}Ca(d,p)^{49}Ca$ reaction at E_d = 19.3(left) and 56 (right) MeV found with the DOMP via DWBA approach.

1. O.V.Bespalova, A.A.Klimochkina // Phys. Atom. Nucl. 2017. V.80. P.919.
2. N.B.Nguyen *et al.* // Phys. Rev. C. 2011. V.84. 044611.
3. O.A.Rubtsova *et al.* // Ann. Phys. 2015. V.360. P.613.

LOW-ENERGY NUCLEAR REACTIONS WITH LIGHT EXOTIC NUCLEI

Lekala M.L.
Department of Physics, School of Science, College of Science, Engineering and Technology, University of South Africa, Science Campus, Florida Park, 1709, South Africa
E-mail: lekalml@unisa.ac.za

Breakup reactions are useful tool to study the structure of exotic nuclei, such as halo nuclei. However, because halo nuclei are loosely bound, they break very easily. This makes them interesting objects to study their nuclear structures. In this work, we consider the breakup cross sections of light exotic nuclei, and study the influence of the breakup process on reaction channels such as fusion, elastic scattering and transfer. For fusion, we investigate both the complete and incomplete fusion mechanisms.

In order to further understand better the aforementioned breakup processes we study the effects of the Coulomb and nuclear interactions on the projectile breakup, i.e. which interaction (Coulomb or nuclear) plays a major role in the breakup. The nature and the role of the Coulomb-nuclear interferences in the breakup process, as well as the continuum-continuum couplings, are investigated.

Most studies treat the projectile as a two-body structure [1]. In our previous work, we treated the projectile as having at most a three-body structure [2]. In this work, in addition to the two-body and three-body structure projectiles, projectiles that can be treated as having a four-body structure are considered.

Theoretically, our calculations are based on the differential Faddeev and Faddeev-Yakubovsky equations formalisms. To obtain the breakup cross-sections, the discretized equations are numerically solved by employing the fast GPU-based algorithms. Preliminary calculations show the results in agreement with other usual techniques such as CDCC, however, with fast convergence as expected.

1. I.Tanihata // J. Phys. G: Nucl. Part. Phys. 1996. V.22. P.157.
2. B.Mukeru and M.L.Lekala // Phys. Rev. C. 2015. V.91. 064606.

ENERGY DEPENDENCE AND SURFACE CONTRIBUTION OF THE NUCLEON-NUCLEUS OPTICAL POTENTIAL

Maridi H.M.[1,2]
[1] *Alternative Energy Technology Department, Philadelphia University, Amman, Jordan;*
[2] *Physics Department, Faculty of Applied Science, Taiz University, Taiz, Yemen*
E-mail: h.maridi@gmail.com

The M3Y folding optical potential (OP) is used to analyze ^{9}Be (p, p) ^{9}Be elastic scattering at energies from few to 1000 MeV/nucleon. The M3Y folding-model is used for the real part whereas the volume and surface imaginary parts of OP are taken within the high-energy approximation model that based on the Glauber theory. In addition, the Brieva-Rook approximation is used for the spin-orbit OP.

In the present work, the angular distributions for elastic-scattering cross sections, reaction, and total cross sections, are calculated using the optical model analysis with the partial-wave expansion method.

This results show that these experimental data are reproduced well at a wide range of energy. In addition, clear and interesting energy dependencies are found for the different parts of the OP.

A new behavior of the surface imaginary is found at scattering at high energies where the results show that the surface contribution to the imaginary part is very important at high energies as well as at low energies.

The energy dependencies of the volume integrals can be used to construct a local energy-dependent microscopic OP which able to reproduce the scattering data over the considered energy range.

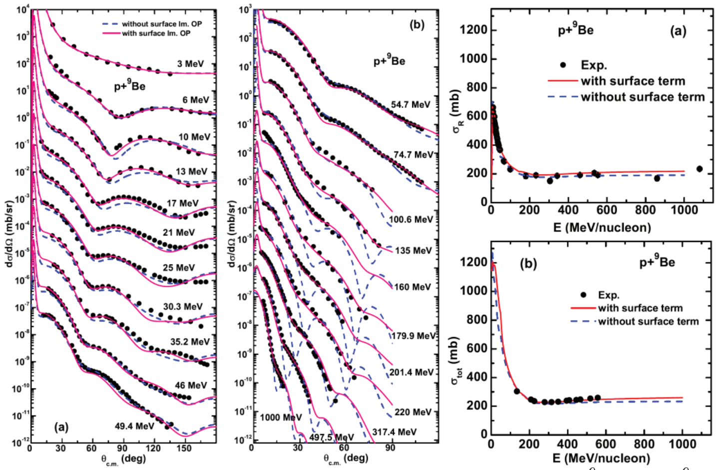


Fig. 1. Calculated angular distributions and cross sections of the ^{9}Be(p, p) ^{9}Be elastic scattering at a wide energy range in comparison with the experimental data.

CHARGED KAON EMISSION FROM 1.9 *A* GeV Ni + Ni INTERACTIONS

Matulewicz T., Piasecki K., FOPI Collaboration
Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Poland
E-mail: tomasz.matulewicz@fuw.edu.pl

The emission of strangeness containing K mesons from nucleus-nucleus collisions is believed to provide an insight on the modification of hadron masses in nuclear medium (see e.g. [1]).

The FOPI Collaboration at the GSI SIS-18 synchrotron measured charged kaons from central and semicentral collisions of Ni + Ni at a beam energy of 1.91A GeV [2, 3]. The yield of kaons in influenced by the $\varphi(1020) \rightarrow K^+ K^-$ decay (50%) and of Lambda(1520) → pK^- (45%). We obtained the distribution of the K^-/K^+ ratio on the energy vs polar angle plane in the nucleon-nucleon center-of-mass frame, with and without subtraction of the contribution to the K^- yield due to the $\varphi(1020) \rightarrow K^+ K^-$ decay. The acceptance of the current experiment is substantially wider compared to the previous measurement of the same colliding system. Recent results obtained by the HADES Collaboration at 1.23 *A* and 1.76 *A* GeV indicate that after inclusion of the φ meson decay contribution to the K^- production no difference between the slopes of the K^- and K^+ energy spectra is observed within uncertainties [4,5]. For our data a linear fit to this ratio obtained after subtraction of the φ meson contribution still shows a decrease with kinetic energy, although a constant value cannot be rejected. The contribution of Lambda(1520) → pK^- decays estimated from fitting the thermal model to the experimental yields appears to be of moderate relevance.

1. W.Cassing, E.L.Bratkovskaya, U.Mosel, S.Teis, A.Sibirtsev // Nuclear Physics A. 1997. V.614. P.415.
2. K.Piasecki *et al*. (FOPI Collaboration) // Physical Review C. 2019. V.98. 052001.
3. K.Piasecki *et al*. (FOPI Collaboration) // Physical Review C. 2016. V.94. 014901.
4. M.Lorenz (HADES Collaboration) // 2010. PoS Bormio2010 P.38.
5. J.Adamczewski-Musch *et al*. (HADES Collaboration) // Physics Letters B. 2018. V.778. P.403.

THE HINDRANCE TO COMPLETE FUSION OF NUCLEI RELATED WITH THE NUCLEON TRANSFER MECHANISM

Nasirov A.K.[1,2], Kayumov B.M.[2], Mandaglio G.[3,4], Giardina G.[5], Kim K.[6], Kim Y.[6]

[1] BLTP, Joint Institute for Nuclear Research, Dubna, Russia; [2] Institute of Nuclear Physics, Tashkent, Uzbekistan; [3] Dipartimento di Scienze Chimiche, Biologiche, Farmaceutiche ed Ambientali, University of Messina, Messina, Italy; [4] INFN Sezione di Catania, Catania, Italy; [5] Dipartimento di Scienze Matematiche e Informatiche, Scienze Fisiche e Scienze della Terra, University of Messina, Messina, Italy; [6] Rare Isotope Science Project, Institute for Basic Science, Daejeon Republic of Korea

E-mail: nasirov@jinr.ru

The difference between observed cross sections of the evaporation residues (ER) of the $^{34}S + ^{208}Pb$ and $^{36}S + ^{206}Pb$ reactions formed in the $2n$ and $3n$ channels has been explained by two reasons related with the entrance channel characteristics of these reactions. The first reason is that the capture cross section of the latter reaction is larger than the one of the $^{34}S + ^{208}Pb$ reaction since the nucleus-nucleus potential is more attractive in the $^{36}S + ^{206}Pb$ reaction due to two more neutrons in isotope ^{36}S. The second reason is the difference in the heights of the intrinsic fusion barrier $B^*_{\rm fus}$ appearing on the fusion trajectory by nucleon transfer between nuclei of the DNS formed after the capture. The value of $B^*_{\rm fus}$ calculated for the $^{34}S+^{208}Pb$ reaction is higher than the one obtained for the $^{36}S + ^{206}Pb$ reaction. This fact has been caused by the difference between the *N/Z*-ratios in the light fragments of the DNS formed during the capture in these reactions. The *N/Z*-ratio has been found by solution of the transport master equations for the proton and neutron distributions between fragments of the DNS formed at capture with the different initial neutron numbers $N = 18$ and $N = 20$ for the reactions with the ^{34}S and ^{36}S, respectively. The nature of the hindrance to complete fusion in the case of the $^{34}S + ^{208}Pb$ reaction has been done in Ref. [2], where the authors have used new fission measurements and existing evaporation residue and fission excitation function data for reactions forming Cf isotopes to investigate the dependence of the quasifission probability and characteristics of fission products on the properties of the entrance channels. But authors of [1, 2] could not explain the reason of hindrance to complete fusion in $^{34}S+^{208}Pb$ and they restricted by assuming fusion probability $P_{\rm CN} = 0.1$ to reproduce the measured xn ER cross sections for the $^{34}S + ^{208}Pb$ reaction by the statistical model calculations. We will demonstrate (see Ref. [3]) that the difference in the reaction mechanism is related in the yield of the projectile-like quasifission products in these reactions.

1. J.Khuyagbaatar *et al.* // Phys. Rev. C. 2012. V.86. P.064602.
2. J.Khuyagbaatar *et al.* // Phys. Rev. C. 2015. V.91. P.054608.
3. A.K.Nasirov *et al.* // Eur. Phys. Jour. A. 2019. V.55. P.29.

CALCULATION OF FRAGMENT ANGULAR DISTRIBUTION IN UNDER THRESHOLD FISSION OF ^{234}U BY NEUTRONS

Onegin M.S.
Petersburg Nuclear Physics Institute of "Kurchatov Research Center", Gatchina, Russia
E-mail: Onegin_MS@pnpi.nrcki.ru

Under threshold fission of ^{234}U in the energy range 0.2–0.9 MeV has a resonance like behavior, with the sharp variation of the fission fragment angular distribution [1] (See Fig.1). This behavior of the cross section is usually attributed to the presence of the resonance like vibrational excitations of class III in the second isomeric potential well. The cross section and angular distribution of fission fragments were calculated in the framework of Hauser-Feshbach model and R-matrix approach using code TALYS. Calculated cross section of fission and the anisotropy of the fragments are compared with the experiment. Quantum numbers of the vibrational states for highly deformed nuclear were deduced.

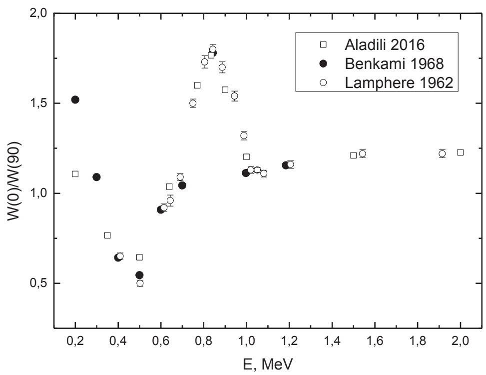


Fig. 1. Anisotropy of ^{234}U fission fragments for different neutron energies.

1. A.Al-Adili *et al.* // Phys.Rev. C. 2016. V.93. 034603.

NUCLEAR REACTION MECHANISMS OF ^{143}Nd (n_{fast},α)^{140}Ce

Oprea C., Oprea A.I.
Joint Institute for Nuclear Research (JINR), Frank Laboratory for Neutron Physics (FLNP), 141980 Dubna, Russian Federation
Email: coprea2007@yahoo.co.uk

Nuclear reactions induced by fast neutrons starting from 0.5 MeV up to 25 MeV with emission of alpha particles were investigated. Cross sections, angular correlations and forward – backward asymmetry effects were evaluated with Talys [1] and own computer codes. Contribution to the cross section of nuclear reaction mechanisms like direct, compound and pre-equilibrium together with discrete and continuum states of residual nuclei were determined. Theoretical evaluations are compared with existing experimental data and parameters of nuclear potential in incident and emergent channels are obtained. Using cross section and angular correlation data from Talys, forward – backward effect are obtained for different incident neutron energies and target with finite dimensions. Simulated forward – backward asymmetry coefficient is sensible lower than the effect measured in the experiment [2]. The difference can be explained by the presence of other emergent channels including alpha particles and not by the presence of so-called non-statistical effects suggested in [2].

The present work was realized in the frame of fast neutrons scientific program from FLNP JINR Dubna.

1. A.J.Koning, S.Hilaire and M.C.Duijvestijn // TALYS-1.0, Proceedings of the International Conference on Nuclear Data for Science and Technology, April 22 - 27, 2007, Nice, France, editors O.Bersillon, F.Gunsing, E.Bauge, R.Jacqmin, S.Leray, EDP Sciences. 2008 P.211.
2. Yu.M.Gledenov *et al.* // Phys. Rev. C. 2009. V.80. 044602.

FAST PROTON INDUCED REACTIONS ON NATURAL In

Oprea C., Oprea A.I.
Joint Institute for Nuclear Research (JINR), Frank Laboratory for Neutron Physics (FLNP), 141980 Dubna, Russian Federation
Email: coprea2007@yahoo.co.uk

Nuclear reactions induced by fast protons with emission of neutrons on natural Indium were investigated. Cross sections, for incident protons energies from neutron threshold up to 25 MeV were evaluated with Talys [1]. For each cross section, decomposition into different nuclear reaction mechanisms and type of residual nuclei states (discrete, continuum) was realized. Theoretical evaluations and existing experimental data are in a satisfactory agreement and this allowed to extract the isomer ratios in the ^{113}In(p,n)^{113m,g}Sn and ^{115}In(p,3n)^{113m,g}Sn reactions and parameters of optical potential for incident and emergent channels. Isomer ratios were obtained further by using cross sections [2] calculated with Talys and considering a target with finite dimensions.

Cross sections and isomer ratios measurements will be effectuated based on this research proposal at FLNP JINR Dubna basic facilities.

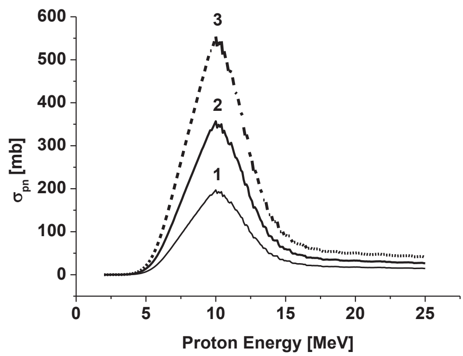


Fig.1. Cross section (XS) of ^{113}In(p,n)^{113m,g}Sn reaction. 1) XS of ground state production 2) XS of isomer state production 3) Total XS of ground + isomer states production.

1. A.J.Koning, S.Hilaire and M.C.Duijvestijn // TALYS-1.0, Proceedings of the International Conference on Nuclear Data for Science and Technology, April 22 - 27, 2007, Nice, France, editors O.Bersillon, F.Gunsing, E.Bauge, R.Jacqmin, S.Leray, EDP Sciences. 2008 P.211.
2. B.S.Ishkhanov, S.Yu.Troschiev // Moscow University Physics Bulletin 2010. №65. V.1. P.39.

PSEUDORAPIDITY DEPENDENCE OF MULTIPLICITY FLUCTUATIONS AND CORRELATIONS

Prokhorova D.S., Kovalenko V.N.
Saint Petersburg State University, Saint Petersburg, Russia
E-mail: daria.prokhorova@cern.ch

Multiplicity correlations and fluctuations in two separated pseudorapidity intervals are used to be studied in terms of strongly intensive variables [1–3]. In this work, the model with quark-gluon strings as objects extended in pseudorapidity space and acting as particle emitting sources was considered. To describe fluctuations at collision energies corresponding to SPS and future FAIR and NICA accelerators, a toy model with strings of fluctuating length has been developed, what allows one to abandon the assumption of the translation invariance in rapidity. The model gives results that are in a good agreement with the available data from the NA61/SHINE experiment. Moreover, the model is also extended to include the mechanism of string fusion [4], which is more relevant for the LHC energies, allowing to study the simultaneous effect of the formation of strings of a few different types together with the string ends fluctuations. The dependence of strongly intensive observables on the width of acceptance windows and the pseudorapidity separation between them is studied.

The reported study was funded by the Russian Foundation for Basic Research according to the research project 18-32-01055_mol_a.

1. M.I.Gorenstein, M.Gazdzicki // Phys. Rev. C. 2001. V.84. P.014904.
2. M.Gazdzicki, M.I.Gorenstein, M.Mackowiak-Pawlowska // Phys. Rev. C. 2013. V.88. P.024907.
3. E.V.Andronov // Theor. Math. Phys. 2015. V.185, no.1. P.1383.
4. M.A.Braun, R.S.Kolevatov, C.Pajares, V.V.Vechernin // Eur. Phys. J. C 2004. V.32. P.535.

SECONDARY NUCLEI FROM PERIPHERAL AND ULTRAPERIPHERAL COLLISIONS OF RELATIVISTIC HEAVY-IONS

Pshenichnov I.A.[1], Dmitrieva U.A.[1,2], Svetlichnyi A.O.[1,2]
[1] Institute for Nuclear Research, Russian Academy of Sciences, Moscow; [2] Moscow Institute of Physics and Technology, Dolgoprudny, Russia
E-mail: pshenich@inr.ru

In a peripheral collision of high-energy nuclei a fireball resulting from the overlap of collision partners coexists with relatively cold spectator matter. Moreover, in ultraperipheral interactions with impact parameters exceeding the sum of nuclear radii the colliding nuclei can be considered entirely as electromagnetically excited spectators. Expected moderate excitation energy of spectator matter created in relativistic heavy-ion collisions suggests the similarity of its decays to ones in low-energy nuclear reactions with accounting for an appropriate Lorentz-boost. In this work we model the production of heavy secondary nuclei in ^{129}Xe–^{129}Xe and ^{208}Pb–^{208}Pb collisions at the LHC and in ^{197}Au–^{197}Au collisions at NICA. Peripheral hadronic interactions are modeled by Glauber Monte Carlo code [1] which estimate the volume of spectator matter on the event-by-event basis. Subsequents decays of this matter are simulated by means of the evaporation and statistical multifragmentation models from Geant4 library [2] designed similarly to the well-known SMM model [3]. The cross sections of production of secondary nuclei in hadronic interactions of nuclei at the LHC and NICA were calculated with this set of models. Despite of the simplicity of the present approach it is equally successful in describing AGS and CERN SPS data on charge-changing cross sections as a more sophisticated JAMQMD model [4]. The production of secondary nuclei in ultraperipheral heavy-ion collisions is simulated with the RELDIS model [5], which predicts the dominance of neutron emission in the considered ^{129}Xe–^{129}Xe, ^{208}Pb–^{208}Pb and ^{97}Au–^{197}Au collisions. As also found from calculations, Te, I and Au, Hg, Tl nuclei are frequently produced, respectively, in decays of ^{129}Xe and ^{208}Pb excited electromagnetically at the LHC. In contrast, mostly isotopes of Au are produced in ultraperipheral collisions at NICA. Possibilities to measure the production of heavy secondary nuclei at the above-mentioned facilities are discussed.

The work has been carried out with financial support of RFBR within the project 18-02-40035-mega.

1. C.Loizides *et al.* // Phys. Rev. C. 2018. V.97. P.054910.
2. J.Allison *et al.* // Nucl. Inst. Meth. A. 2016. V.835. P.186.
3. J.P.Bondorf *et al.* // Phys. Rep. 1995. V.257. P.133.
4. T.Ogawa *et al.* // Phys. Rev. C. 2018. V.98. P.024611.
5. I.A.Pshenichnov // Phys. Part. Nucl. 2011. V.42. P.215.

MECHANISM OF *N*/*Z* EQUILIBRATION IN ^{58}Ni, ^{40}Ca + ^{208}Pb REACTIONS AT NEAR-BARRIER ENERGIES

Saiko V.V.[1,2], Karpov A.V.[1,2]
[1] *Flerov Laboratory of Nuclear Reactins, Joint Institute for Nuclear Research, Dubna, Russia;* [2] *Dubna State University, Dubna, Russia*
E-mail: saiko@jinr.ru

An essential feature of ^{58}Ni, ^{40}Ca + ^{208}Pb reactions is the significant difference in the *N*/*Z* ratio of the projectile and target. It leads to the nucleon redistribution at the initial stage of reaction called *N*/*Z* equilibration or isospin relaxation. This particular feature of dynamics of collisions of heavy nuclei affects the *N*/*Z* values of formed fragments and can be observed in the isotopic distributions of the multinucleon transfer (MNT) reaction products.

Investigation of the *N*/*Z* equilibration process in the MNT reactions was done on the basis of Langevin-type dynamical model [1]. It allow one to achieve a good agreement in complex description of experimentally observable characteristics of the MNT reactions such as energy, angular and mass distributions of the binary products [2].

The ^{58}Ni, ^{64}Ni + ^{208}Pb reactions have been compared in order to define better system for production of heavy nuclides. An influence of the neutron-deficient projectile or the *N*/*Z* equilibration on isotopic yields in these collisions are discussed.

This work was supported by RSF Grant No. 19-42-02014.

1. A.V.Karpov and V.V.Saiko // Phys. Rev. C. 2017. V.96. P.024618.
2. V.V.Saiko and A.V.Karpov // Phys. Rev. C. 2019. V.99. P.014613.

ANALYSIS OF VARIOUS DECAY MODES OF RADIOACTIVE NUCLEUS ^{242}Cm

Sharma Kanishka, Sharma Manoj K.
School of Physics and Materials Science, Thapar Institute of Engineering & Technology, Patiala-147004, India
E-mail: kanishka.sharma@thapar.edu

Experimental half-lives for one of the isotope of Cm i.e. ^{242}Cm are available for alpha decay, cluster radioactivity and spontaneous fission processes. In the present work, we have made an attempt (i) to address the half-lives of α-, cluster and spontaneous fission of ^{242}Cm within the methodology of Preformed Cluster-decay Model (PCM), which was applied recently for adequate addressal of various radioactive decay channels [1], (ii) to identify the most probable emission fragments in different decay channels. It is relevant to mention here that although spontaneous fission half-lives are available but the most probable fission fragments are not identified [2]. The fragmentation analysis of the emission fragments is depicted in Fig. 1, and it is observed that the magicity effect (shell closure property) of complementary heavy fragments play important role to govern the exit channel. The cluster, having lowest fragmentation potential is observed as ^{34}Si (+ ^{208}Pb i.e. doubly magic) which is in line with the experimental data. In case of spontaneous fission, minima in the potential is seen for ^{108}Ru + ^{134}Te (i.e. neutron magic at $N = 82$). The PCM calculated half-lives show nice agreement with the experimental data at optimal neck value. In addition to this, the predictions on half-lives of heavy clusters are also made which lie within the range of work by Poenaru *et al*. [3].

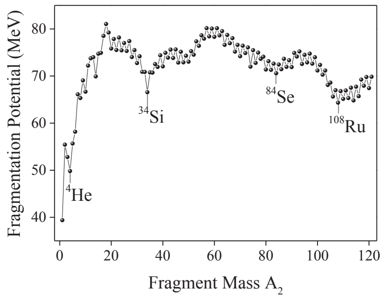


Fig. 1. Fragmentation potential as a function of fragment mass A_2 for the decay of ground state parent nucleus ^{242}Cm.

1. K.Sharma, G.Sawhney and M.K.Sharma // Phys. Rev. C. 2017. V.96. 054307.
2. S.Usuda and Hirokazu Umezawa // Int. Jour. Rad. Appl. and Inst. 1989. V.16. P.4.
3. D.N.Poenaru, R.A.Gherghescu, W.Greiner // Phys. Rev. C. 2012. V.85. 034615.

ELASTIC SCATTERING AND RADIATIVE CAPTURE IN THE ^{4}He + ^{3}H AND ^{4}He + ^{3}He SYSTEMS

Solovyev A.S.[1,2], Igashov S.Yu.[1]
[1] Dukhov Research Institute of Automatics (VNIIA), Moscow, Russia; [2] Pacific National University, Khabarovsk, Russia
E-mail: alexander.solovyev@mail.ru

The nuclear ^{4}He + ^{3}H and ^{4}He + ^{3}He systems being of great importance to nuclear astrophysics are investigated within a microscopic approach [1] based on cluster aspects of nuclear structure and dynamics and formalism of expansions over the oscillator basis. Elastic scattering and radiative captures that proceed in these systems are considered in a wide energy range from ultralow energies to intermediate ones covering the low-lying resonance states. The most important quantities for the corresponding processes are obtained. In particular, the total and partial cross sections (astrophysical S factors) for the radiative capture reactions are calculated. The nuclear phase shifts for the elastic scattering and the energies together with the widths for the lowest resonances are also computed. A comparison of the obtained results with experimental data and with results of other theoretical works is performed.

1. A.S.Solovyev, S.Yu.Igashov // Phys. Rev. C. 2017. V.96. 064605.

CALCULATION OF PHOTONUCLEAR CROSS SECTIONS USING THE CMPR MODEL

Bykhalo G.I.[1], Orlin V.N.[2], Stopani K.A.[2]
[1] *Faculty of physics, Lomonosov Moscow State University, Moscow, Russia;* [2] *Skobeltsyn Institute of Nuclear Physics, Moscow, Russia*
E-mail: gi.bykhalo@physics.msu.ru

Recent developments of the combined model of photonuclear reactions CMPR [1] are described. The intended use of the model is calculation of photonucleon cross sections as well as the energy distributions of outgoing nucleons in photonuclear reactions in the energy range from the nucleon separation energy up to the meson production threshold on medium and heavy nuclei for the purpose of evaluation of experimental photonuclear cross sections [2] and data analysis. The model is based on semi-microscopic description of photoabsorption process followed by decay of the intermediate excitation via a pre-equilibrium or evaporative process. In contrast with other statistical nuclear reaction models such distinctive features of the giant dipole resonance (GDR) as isospin splitting and the structure of the doorway excitation wave function are explicitly taken into account. It follows from comparison with experimental data and calculations performed using other models that proper account of these effects is essential for accurate description of observed photoproton cross sections.

We present a modification of the exciton pre-equilibrium model to describe the long-lived nature of the GDR phonon. When a dipole photon absorption results in formation of a coherent excitation state, the decay of such state into 2-*ph* configurations takes longer than formation of subsequent *ph* pairs. As a result the yield of energetic semi-direct photonucleons is increased.

The CMPR model is being released for the first time as a publically available source code with user documentation and supplementary materials.

1. B.S.Ishkhanov, V.N.Orlin // Phys. Part. Nucl. 2015. V.78. P.601.
2. V.V.Varlamov, B.S.Ishkhanov, V.N.Orlin, and K.A.Stopani // Eur. Phys. J. A. 2014. V.50. P.114.

STUDIES OF VALIDITY OF QUASICLASSICAL APPROACH TO THREE-BODY DECAYS

Sukhareva O.M.[1], Grigorenko L.V.[2,3,4], Kostyleva D.A.[5,6], Zhukov M.V.[7]
[1] *Omsk State Technical University, Omsk, Russia;* [2] *Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia;* [3] *National Research Nuclear University "MEPhI", Moscow, Russia;* [4] *National Research Centre "Kurchatov Institute", Moscow, Russia;* [5] *II. Physikalisches Institut, Justus-Liebig-Universität, Giessen, Germany;* [6] *GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany;* [7] *Department of Physics, Chalmers University of Technology, Göteborg, Sweden*
E-mail: o.m.sukhareva@gmail.com

Conventional method of width determination for resonant states, such as elastic phase shift energy dependence, or via *S*-matrix pole position in the complex energy plane could be technically complicated for very small widths $\Gamma \ll E$. Therefore studies of radioactive decays require specific methods for the decay width determination. Among them are "natural" width definition via WF with pure outgoing asymptotics [1], Kadmensky type integral formulas [2], and quasi-classical approach of Gamow type [3].

Use of quasi-classical approach of Gamow type for the decay width evaluation $\Gamma \sim exp\left[-\int_{r_1}^{r_2} p\, dr\right]$; requires reduction of few-body problem to a single-channel formalism of some form, where Gamow integral over the sub-barrier trajectory $\{r_1; r_2\}$ can be defined. Here both the validity of the few-body problem reduction and the applicability of the quasiclassical approximation for barriers of specific shape can be questioned.

Formalism of the Gamow type has been repeatedly used in the recent years for determination of three-body decay widths (e.g. [3,4]). We examine the validity of this approximation by example of the width of the first excited $3/2^-$ state of ^{17}Ne, which is known to decay via so-called "true" two-proton decay mechanism. The width of this state is important for determination of the astrophysical capture rate for $^{15}O + p + p \rightarrow {}^{17}Ne + \gamma$ reaction [5]. Theoretical calculations of this width so far have produced considerable controversy [2–4, 6]. Recently this issue was revisited experimentally [7] providing improved limits for the width value and looking for realistic methods to further improve measurements of this quantity. This activity also urges improved theoretical treatment of the case.

Our results question validity of the widths obtained in [4].

1. M.Pfützner *et al.* // Rev. Mod. Phys. 2012. V.84. P.567.
2. L.V.Grigorenko, M.V.Zhukov // Phys. Rev. C. 2007. V.76. P.014008.
3. E.Garrido *et al.* // Nucl. Phys. A. 2005. V.748. P.39.
4. E.Garrido *et al.* // Phys. Rev. C. 2008. V.78. P.034004.
5. Yu.L.Parfenova *et al.* // Phys. Rev. C. 2018. V.98. P.034608.
6. L.V.Grigorenko *et al.* // Nucl. Phys. A. 2003. V.713. P.372.
7. P.G.Sharov *et al.* // Phys. Rev. C. 2017. V.96. P.025807.

FREE AND BOUND SPECTATOR NUCLEONS IN HADRONIC INTERACTIONS OF RELATIVISTIC NUCLEI

Svetlichnyi A.O.[1,2], Pshenichnov I.A.[2]
[1] Moscow Institute of Physics and Technology, Dolgoprudny, Russia; [2] Institute for Nuclear Research, Moscow, Russia;
E-mail: aleksandr.svetlichnyy@phystech.edu

Hot and dense mater is created in the domain of overlap of colliding relativistic nuclei. The rest of nuclear mater remain relatively cold and thus termed spectator matter. The total volume of spectator matter is directly correlated with the impact parameter *b* defined as the minimal distance between the centers of colliding nuclei. In nucleus-nucleus collision experiments forward spectator nucleons are detected to estimate *b* and classify events according to their centrality. However, the determination of centrality is complicated by the presence of nucleons bound in spectator nuclear fragments [1].

In this work a computer code based on the abrasion-ablation mechanism of nucleus-nucleus collisions has been developed. The Glauber Monte Carlo model [2] is employed at the abrasion step to define the numbers of participant and spectator nucleons. It was assumed that moderately excited spectator matter (prefragment) with the excitation energy defined by the numbers of nucleons removed from initial nuclei is created. Its decays were simulated at the ablation step by means of evaporation and SMM [3] models implemented in Geant4. The fraction of free nucleons and their n/p ratio as a function of the impact parameter has been calculated, see Fig. 1. Various characteristics of spectator matter, in particular, the correlations between spectators from both nuclei colliding at NICA can be modeled event-by-event with this code.

The work has been carried out with financial support of RFBR within the project 18-02-40035-mega.

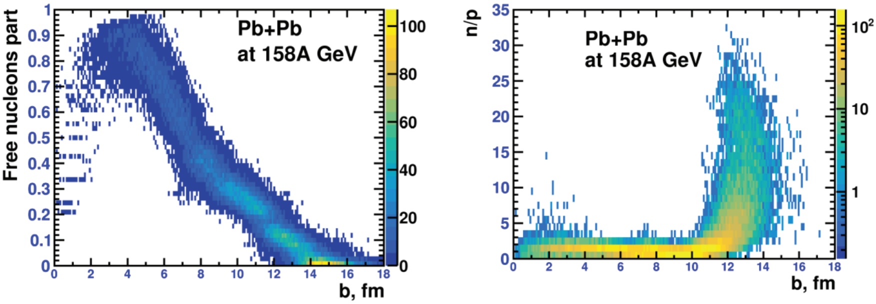


Fig.1. The fraction of free nucleons (left) and the n/p ratio calculated for free nucleons (right) in $^{208}Pb + ^{208}Pb$ collisions at 158 GeV per nucleon.

1. H.Appelshauser *et al.* // Eur. Phys. J. A. 1998ю V.2. P.383.
2. C.Loizides *et al.* // Phys. Rev C. 2018. V.97. P.054910.
3. A.S.Botvina *et al.* // Nucl. Phys. A. 1995. V.584. P.737.

TRUE TERNARY FISSION AS VIRTUAL PROCESS

Kadmensky S.G., Titova L.V., Zemlyanukhina A.P.
Voronezh State University, Voronezh, Russia
E-mail: kadmensky@phys.vsu.ru

In spontaneous ternary fission of the nucleus-actinide (A, Z) with the formation of primary light and heavy fission fragments the long-range third particle, for example α-particle, occurs, and it's motion energy E_α in the flight moment significantly exceeds the α-decay heat Q_α of the nucleus (A, Z) and is close to the Coulomb barrier height B_α, which leads to the value of α-particle barrier penetrability factor close to 1. Currently it has considered two mechanisms that describe ternary fission properties. The first mechanism uses the representation [1] of the simultaneous flight from the fissile nucleus of all three fission products without discussing the reason for the appearance of such high energies of emitted α-particles. The second mechanism [2] considers ternary fission as two-step process, at the first stage of which, under the action of the time-dependent non-adiabatic potential of the nucleus, long-range α-particles with energies $E_\alpha \approx B_\alpha$ are released from the parent nucleus, and the residual nucleus is formed, at the second stage this nucleus decays onto two fragments. In this approach, the problem of describing the kinetic energies of the primary fission fragments, which sufficiently decreases with increasing of the emitted α-particle energy E_α from Q_α to B_α, arises. Using the results of [3], a new virtual mechanism of spontaneous ternary fission of a nucleus (A, Z), considered as a two-step process, when α-particle with the energy of motion $E_\alpha \approx B_\alpha$ comes out the nucleus with the formation of a virtual states of the intermediate nucleus $(A–4, Z–2)$, which at the second stage undergoes binary fission. In this approach, part of the emitted α-particle energy $(E_\alpha - Q_\alpha)$ is taken by reducing the heat of the indicated fission of the intermediate nucleus Q_f by an amount $(E_\alpha - Q_\alpha)$ compared with the binary fission heat Q_{f0} of the parent nucleus (A, Z), which for nuclei-actinide takes high values ≈ 170 MeV. The development of indicated mechanism is also carried out for the case of ternary fission reactions of nuclei-actinide induced by cold neutrons. When generalizing the previously developed virtual two-step mechanism for two-proton decay of nuclei [4] to the case of low-energy ternary nuclear fission and using the α-decay theory [5] of the atomic nuclei, taking into account their superfluid properties, it is possible successfully describe the characteristics of various asymmetries arising in differential cross sections and processes probabilities for this type of fission.

1. A.L.Barabanov, *Symmetries and spin-angular correlations in reactions and decays* (FML, Moscow, 2010).
2. O.Tanimura, T.Fliessbach // Z. Phys. A. 1987. V.328. P.475.
3. S.G.Kadmensky, P.V.Kostryukov, D.E.Lyubashevsky *Book of Abstracts* NUCLEUS-2019.
4. S.G.Kadmensky *et al.* // Phys. At. Nucl. 2014. V.77. P.1019; P.1532; 2017. V.80. P.903.
5. S.G.Kadmensky, W.I.Furman, *Alpha decay and related nuclear reactions* (M. Energoatomizdat, 1985).

CLUSTER FORMATION CALCULATIONS FOR SYMMETRIC FISSION OF ACTINIDES

Unzhakova A.V., Granichin O.N.
Saint Petersburg State University, Saint Petersburg, Russia
E-mail: a.unzhakova@spbu.ru

The nuclear fission process can be the best example of a radical rearrangement of a complex system consisting of many identical nucleons. More than 70 years after its discovery, fission has been the subject of numerous new experimental and theoretical studies [1–3].

Nuclear fission of actinides is mostly asymmetric; when, without the quantum shell effects, these nuclei would fission symmetrically. Conventional potential energy surface (PES) calculations show that valley of stability for symmetric mode is higher in energy than the asymmetric one. Nucleon localization relative to the cluster formation could be studied based on the realistic mean field calculations in high-dimensional deformation space [4, 5].

Choices of the shape parameterization appropriate for the description of the heavy nuclei fission and a unique possibility to use a system asymmetry as a constraint in PES calculations are significantly important for the success of the theoretical model. Results of our calculations show that a ternary clusterization could take place in symmetrical fission valley of Californium at large elongations in case if modeled nuclear system surface is flexible enough and preserves the thickness unchanged.

The fissioning nucleus possesses nucleonic and collective degrees of freedom. The nucleonic degrees of freedom are considered equilibrium at any bottom point of the fission valley. Whereas collective degrees of freedom should be treated dynamically, in our static PES calculations they change discretely at each step in elongation and asymmetry. Accordingly, in our quasidynamic modeling of the nuclear fission process, ternary cluster configurations are possibly formed within the symmetrical valley. This is confirmed by the surprisingly large asymmetry of the local energy minima in high-dimensional PES. The complexity of the many nucleons fissioning system leads to the multistability of the emerging cluster configurations [4, 6]. It could be of particular interest for the study of fragment formation and fragment identification in the fission process.

1. W.Nazarewicz *et al.* // Phys. Rev. C. 2016. V.94 P.064323.
2. Y.Aritomo // EXON 2018 Book of Abstracts. 2018. P.92.
3. H.Pasca *et al.* // Nucl. Phys. A. 2018. V.969. P.226.
4. V.V.Pashkevich // Proc. LEND. 1995. EPS XV Nucl. Phys. Div. Conf. P.161.
5. A.V.Unzhakova *et al.* // Proc. ICFN6. World Scientific. 2017. P.582.
6. A.Proskurnikov, O.Granichin // Cybernetics and Physics. 2018. V.7. P.102.

THE MECHANISMS OF NUCLEAR REACTIONS INDUCED BY INTERACTION OF ^{3}He WITH ^{9}Be NUCLEI

Urazbekov B.A.[1,2,3], Denikin A.S.[2,3], Itaco N.[1], Janseitov D.M.[3,4], Lukyanov S.M.[3], Mrazek J.[5], Mendibayev K.[3,6], Sakhiyev S.K.[6,7], Trzaska W.H.[8], Tursunbayev N.T.[2,3]

[1] Università Degli Studi della Campania Luigi Vanvitelli, Naples, Italy; [2] Dubna state university, Dubna, Russia; [3] Joint institute for nuclear research, Dubna, Russia; [4] Al-Farabi kazakh national university, Almaty, Kazakhstan; [5] Nuclear Physics Institute CAS, Řež, Czech Republic; [6] Gumilev Eurasian national university, Nur-Sultan, Kazakhstan; [7] Abai national pedagogical university, Almaty, Kazakhstan; [8] Department of Physics, University of Jyväskylä, Jyväskylä, Finland

E-mail: bakytzhan.urazbekov@gmail.com

Scattering of a simplest projectile, such as ^{1,2}H or ^{3,4}He, on a target is a standard tool of fundamental studying the structure of nuclei. This method involves the measurement of angular distribution of products of the nuclear reactions. An experiment has been carried out to investigate the cluster structure of ^{9}Be in Physics Department of Jyväskylä University (Jyväskylä, Finland). Beams made out of ^{3}He have been injected and bombarded the target at laboratory energy $E(^{3}\text{He})$ = 40 MeV. The experiment identified and extracted angular distribution of the particles: p, d, t, ^{3}He, ^{6}Li and ^{7}Be.

The data have been analyzed by means of Coupled Reaction Channel method implemented in FRESCO code [1]. A semi microscopic potential for entrance channel has been used in the analysis. The potential has been built up within the Double Folding model using the three body wave function of ^{9}Be [2]. Spectroscopic amplitudes for p-shell nuclei have been obtained by means of ANTOINE code [3] with the effective Cohen-Kurath interaction.

Two step transfer mechanisms have been also considered in the coupling scheme along with the direct transfer mechanisms. Preliminary calculations have revealed an importance of taking into account of the two step mechanisms in nuclear reactions caused by interaction of ^{3}He with ^{9}Be nuclei.

1. I.J.Thompson // Comput. Phys. Rep. 1988. V.7. P.167.
2. B.A.Urazbekov, A.S.Denikin, S.K.Sakhiev and N.T.Burtebaev // Bull. Rus. Acad. Sci. Phys. 2016. V.80. P.247.
3. E.Caurier, G.Martínez-Pinedo, F.Nowacki, A.Poves, A.Zuker. // Rev. Mod. Phys. 2005. V.77(2). P.427.

TOWARD APPLICATION OF THE HIJING MODEL FOR SIMULATIONS OF NUCLEUS-NUCLEUS INTERACTIONS AT $E_{\mathrm{CMS,NN}}$ ~ 5–15 GeV

Galoyan A.[1], Uzhinsky V.[2]
[1] *Veksler and Baldin Laboratory of High Energy Physics, JINR, Dubna, Russia;* [2] *Laboratory of Information Technologies, JINR, Dubna, Russia*
E-mail: uzhinsky@jinr.ru

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory is one of the two remaining operating hadron colliders in the world. It is expected that FAIR (GSI, Darmstadt, Germany) and NICA (JINR, Dubna, Russia) facilities will start operations in the nearest future. All of them are aimed to study nucleus-nucleus interactions at nucleon-nucleon center-of-mass energy $E_{\mathrm{CMS,NN}}$ ~ 5–15 GeV in order to find critical point in the hot nuclear matter equation of state. RHIC is planning to investigate Au + Au interactions at 5–20 GeV (BES-2 project) in 2019–2020. Correct simulation of the interactions in the pointed energy range is very important for design of experimental setups and theoretical analyses of data. RHIC is going to use A Multi-Phase Transport (AMPT) model [1] based on the HIJING model [2] for the aim. FAIR and NICA are mainly using Ultra-relativistic Quantum Molecular Dynamic (UrQMD) model [3].

We have studied application of the HIJING model for the pointed energy range, and started from a description of proton-proton interaction data presented by the NA61/SHINE collaboration [4]. It was found that a satisfactory description of the data can be reached at a change of baryon production model, at an inclusion of multiple processes di-quark → di-quark' + meson, at an increasing of a probability of diffraction dissociation processes, and at an adjustment of hadron transverse mass distributions. Most of the changes have to be done in the string fragmentation code. The changes reflect on calculated properties of hadron-nucleus and nucleus-nucleus interactions.

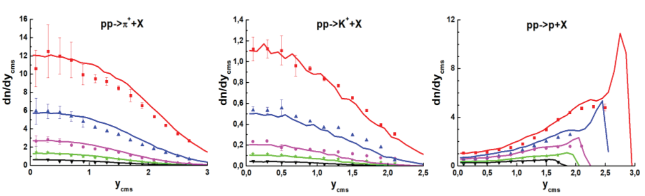


Fig.1. Rapidity distributions of particles in pp interactions at 158, 80, 40, 31, 20 GeV/c (from top to bottom, rescaled by 16, 8, 4, 2, 1). Points are exp. data [4], lines are calculations.

1. Z.-W.Lin *et al.* // Phys. Rev. C. 2005. V.72. 064901.
2. X.-N.Wang and Miklos Gyulassy // Phys. Rev. D. 1991. V.44. P.3501; M.Gyulassy and X.-N.Wang // Comput. Phys. Commun. 1994. V.83. P.307.
3. S.A.Bass *et al.* // Prog. Part. Nucl. Phys. 1998. V.41. P.225; M.Bleicher *et al.* // J. Phys. G. 1999. V.25. P.1859.
4. NA61/SHINE Collab. (A.Aduszkiewicz *et al.*) // Eur. Phys. J. C. 2017. V.77. P.671.

SHORT-RANGE NN CORRELATIONS IN THE REACTION $^{12}C + p \to {}^{10}A + pp + N$

Uzikov Yu.N.[1,2,3]
[1] *DLNP, Joint Institute for Nuclear Researches, Dubna, Russia;* [2] *Dubna State University, Dubna, Russia;* [3] *Physics Department of M.V. Lomonosov Moscow State University, Moscow, Russia*
E-mail: uzikov@jinr.ru

Nucleon pairs in the region of the repulsive core play an important role in structure of atomic nuclei. Properties of such pairs determined by nucleon-nucleon interaction at short distances between nucleons ($R_{NN} \leq 0.5$ fm) are not yet well established and studied experimentally in many nuclear centers using electron and proton beams. A principal new method was suggested at BM@N in JINR [1] where an inverse kinematics of the reaction $^{12}C + p \to {}^{10}A + pp + N$ is used with a beam of the ^{12}C nuclei at energy of 4 GeV/nucleon interacting with the hydrogen target. The detector system allows to detect the scattered proton, the knock-outed from the short-range *NN* pair nucleon, the residual nucleus ^{10}B or ^{10}Be and the recoil nucleon *N*.

We start here to develop a mathematical formalism for calculation of the differential cross sections of these reactions. Spectroscopic amplitudes for *NN*-pairs in the ground state of the ^{12}C nucleus are calculated using parentage coefficients for translation-invariant shell model [2] and the results of numerical calculations with accounting for mixing configurations [3]. Only ground states of internal motion in the *NN*-pairs corresponding to harmonic oscillator quantum numbers $n = 0$, $l = 0$ are taken into account with the spin-isospin states ST=01 and 10. The states of the residual nucleus with the s^4p^6 configuration are taken into account, whereas the states with holes in the *s*-shell are neglected because transitions to these states are suppressed by absorption of in-coming and out-coming waves. The matrix element for transition $p + \langle NN \rangle \to p + N + N$ requires to account for relativistic effects and re-scatterings in the initial and final states. These effects are considered in the line of the approach developed in Ref. [4] for the reaction $pd \to (pp)(^1S0) + n$.

This work is supported in part by the RFBR grant № 18-02-40046.

1. SRC@BMN proposal: http://bmnshift.jinr.ru/wiki/doku.php
2. Yu.F.Smirnov, Yu.M.Tchuvil'sky // Phys. Rev. C. 1977. V.15. P.84.
3. A.N.Boyarkina, 1*p*-shell nuclei structure // MSU. 1973. 63 p.
4. J.Haidenbauer, Yu.N.Uzikov // Phys. Lett. B. 2003. V.562. P.227.

THE ALGEBRAIC MOLECULAR MODEL IN ^{12}C AND ITS APPLICATION TO THE ALPHA + ^{12}C SCATTERING: FROM DENSITIES AND TRANSITION DENSITIES TO OPTICAL POTENTIALS, NUCLEAR FORM FACTORS AND CROSS SECTIONS

Casal J.[1,2], Fortunato L.[1,2], Lanza E.G.[3], Vitturi A.[1,2]
[1] *Dipartimento di Fisica e Astronomia, Padova, Italy;* [2] *INFN, Sezione di Padova, Padova, Italy;* [3] *INFN, Sezione di Catania, Catania, Italy*
E-mail: vitturi@pd.infn.it

The three-alpha algebraic molecular model is used in ^{12}C to construct densities and transition densities connecting low-lying states of the rotovibrational spectrum, first and foremost those belonging to the rotational bands based on the ground and the Hoyle states. These densities are then used as basic ingredients to calculate, besides electromagnetic transition probabilities, nuclear potentials and form factors to be used to describe elastic and inelastic alpha + ^{12}C scattering processes. The calculations confirm the role played by nuclear inelastic processes as a basic tool for investigating nuclear structure properties, as complementary to electromagnetic probes. In this respect our calculations give support to the use of algebraically-based molecular models in the description of cluster-like nuclei.

The calculated densities, transition densities and resulting cross sections are also compared with those obtained within the Antisymmetrized Molecular Dynamics (AMD) model and, alternatively, with those obtained by directly solving the problem of three interacting alpha's within a three-body approach where continuum effects, relevant in particular for the Hoyle state, are properly taken into account.

APPLICATION OF THE FINITE ELEMENT METHOD IN THE COUPLED-CHANNELS CALCULATIONS FOR HEAVY-ION FUSION REACTIONS

Wen P.W.[1,2], Chuluunbaatar O.[1,3], Gusev A.A.[1], Nazmitdinov R.G.[1,4], Nasirov A.K.[1,5], Vinitsky S.I.[1,6], Lin C.J.[2,7], Jia H.M.[2], Góźdź A.[8]

[1] *Joint Institute for Nuclear Research, 141980 Dubna, Russia;* [2] *China Institute of Atomic Energy, Beijing 102413, China;* [3] *National University of Mongolia, 14202 Ulan-Bator, Mongolia;* [4] *Dubna State University, 141982 Dubna, Russia;* [5] *Institute of Nuclear Physics, Ulugbek, 100214, Tashkent, Uzbekistan;* [6] *RUDN University, 117198 Moscow, Russia;* [7] *Department of Physics, Guangxi Normal University, Guilin 541004, China;* [8] *Institute of Physics, University of M. Curie-Sklodowska, Lublin, Poland*

E-mail: wenpeiwei@hotmail.com

Fusion of two nuclei that occurs at strong coupling of their relative motion to surface vibrations is analyzed. To this aim a new efficient finite element method, that improves the KANTBP code [1], is used to solve numerically coupled-channels equations. With the aid of this method, the important role of boundary conditions, corresponding to the total absorption (e.g., [2,3]), is shown. A comparison of the presented results with available experimental data demonstrates the advantage of the modified KANTBP code with respect to the wildly used numerical method, known in literature as the CCFULL [4]. The deep sub-barrier fusion cross sections of some reaction systems have been successfully described. It is confirmed that multiphonon excitations play important role in the description of the spectroscopic factor (see Fig.1).

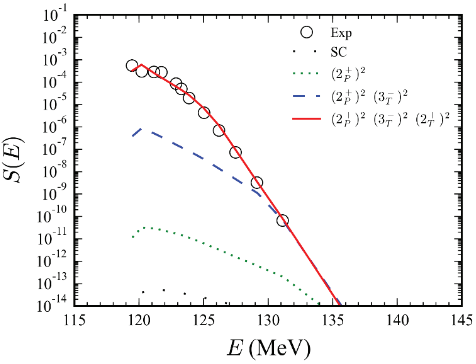


Fig. 1. Spectroscopic factor representation of the $^{64}Ni + ^{100}Mo$ fusion reaction data. The circles denote the experimental data. The left two circles are the experimental upper limits. Different lines are the theoretical calculations considering different excitations.

1. O.Chuluunbaatar *et al*. // Comput. Phys. Commun. 2007. V.177. P.649.
2. V.I.Zagrebaev *et al*. // Phys. Atom. Nucl. 2004. V.67. P.1462.
3. V.V.Samarin *et al*. // Nucl. Phys. A. 2004. V.734. P.E9.
4. K.Hagino *et al*. // Comput.Phys.Commun. 1999. V.123. P.143.

THE SPECTROSCOPIC AMPLITUDES IN THE ^{27}Al → t + ^{24}Mg AND ^{28}Si → p + ^{27}Al DISINTEGRATION VERTEXES

Zelenskaya N.S.
Lomonosov Moscow State University, Skobeltsyn Institute of Nuclear Physics (SINP MSU), Moscow, Russia
E-mail: ns-zelenskaya@yandex.ru

In Nilsson's model a nuclei ^{24}Mg (^{28}Si) own is possible to consider as completely filled two (three) orbitals in $1d_{5/2}$ shell, and ^{27}Al – as a hole configuration of an orbital (No.5) in this shell with positive quadrupole deformation (β_2 = 0.25 for ^{27}Al and 0.4 for ^{24}Mg, ^{28}Si) [1]). In [2, 3] we calculated in Nilsson's model the spectroscopic amplitudes (SA) $\theta_{\Lambda s_t j}$ of a triton in disintegration vertex ^{27}Al(J = 5/2) → ^{24}Mg(0^+, 2^+) + t (Fig. 1a). In the present work calculations of SA $\theta_{\Lambda s_p j}$ of a proton in disintegration vertex ^{28}Si (0^+, 2^+) → ^{27}Al(J = 5/2) + p (Fig. 1b) are carried out. Received $\theta_{\Lambda s_p j}$ are compared with $\theta_{\Lambda s_t j}$.

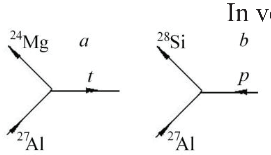


Fig. 1. The diagrams, illustrating disintegration ^{27}Al(J = 5/2) → ^{24}Mg(0^+, 2^+) + t (a) and ^{28}Si (0^+, 2^+) → ^{27}Al(J = 5/2) + p (b).

In vertex of Fig. 1a overlapping of Nilsson's wave functions (WF) nuclei ^{27}Al and ^{24}Mg (0^+, 2^+), despite different deformation of these nuclei, it is almost equal to unit. As a result $\theta_{\Lambda s_p j}$ is generally defined the Talmi's coefficient (TC), which transfers WF of three $1d$-nucleons occupying in ^{27}Al (J = $5/2^+$) an external Nilsson's orbital with the main quantum number N = 6 and the orbital moments Λ = 0, 2, 4, to internal WF of a triton. The full transferred moment of j can have values j = 1/2–9/2.

In vertex of Fig. 1b by transfer of a proton Λ can have only two values: 0 and 2, so $\theta_{\Lambda=4 s_p j} \equiv 0$ that KT is equal to unit. Overlapping of Nilsson's WF of ^{27}Al ($5/2^+$) and ^{28}Si (0^+, 2^+) is close to unit only for ^{28}Si (0^+). For ^{28}Si (2^+) it are equal 0.402 for Λ = 0 and 0.796 for Λ = 2, providing distinction of the corresponding SA. The full transferred j moment in can accept only two values 3/2 and 5/2. It means that SA of a triton $\theta_{\Lambda s_t j}$ has the bigger number a component, than SA of a proton $\theta_{\Lambda s_p j}$.

1. S.G.Nilsson // *"In Book "Deformation of atomic nuclei"*. (Foreign Lit. Press., Moscow, 1958). p. 232 (in Russian).
2. Nuclear dates CDFE. http://cdfe.sinp.msu.ru/services/radchart/radmain.html/.
3. L.I.Galanina *et al*. // Bull. Russ. Acad. Sci. Phys. 2016. V.80. P.304.
4. L.I.Galanina *et al*. // Phys. Atom. Nucl. 2019. V.82. P.338.

STUDY OF THE ^{27}Al(α, p)^{30}Si REACTION MECHANISM AT E_α = 30.3 MeV

Galanina L.I.[1], Zelenskaya N.S.[1], Lebedev V.M.[1], Orlova N.V.[1], Spassky A.V.[1], Tiurin I.S.[2]
[1] *Skobeltsyn Institute of Nuclear Physics Lomonosov Moscow State University (SINP MSU), Moscow, Russia;* [2] *Faculty of Physics, M.V. Lomonosov Moscow State University, Russia*
E-mail: galan_lidiya@mail.ru

Protons differential cross section angular distributions of the reaction ^{27}Al(α, p)^{30}Si at E_α = 30.3 MeV were measured at the 120-cm cyclotron of SINP MSU. Measurements made in the proton emission angle range θ_p = 20–160° (lab.) with the formation of a residual nucleus in the ground (0^+) and first excited (2^+, 2.23 MeV) states.

The experimental results were compared with the calculations for the triton cluster stripping mechanism in the method of coupled channels (CC, code FRESCO [1]) and in the compound nucleus model (CN, code CNDENSY [2]).

The spectroscopic factors amplitudes for the vertex ^{30}Si $\rightarrow$ ^{27}Mg + t were calculated using the 1d–2s-shell model with Nilsson wave functions taking into account the deformation of the nuclei and the spin-orbit interaction.

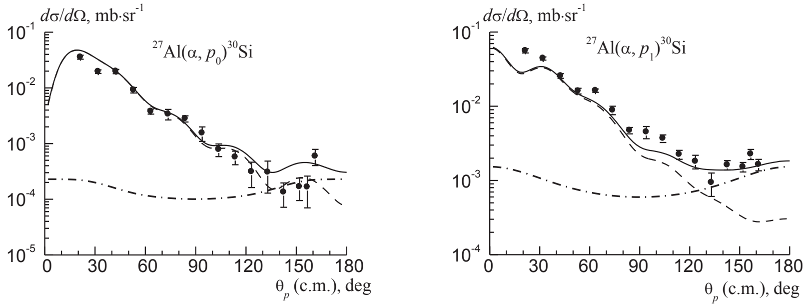


Fig. 1. Angular distributions of ^{27}Al(α, p)^{30}Si reaction for transitions to the ground and first excited states of ^{30}Si. Presented calculation of CC (dashed line), CN (dotted-dash) and their incoherent sum (solid)

Comparison of the differential cross sections calculating results with experiment (Fig. 1) shows that the CC mechanism, implemented in the FRESCO code, using the obtained spectroscopic amplitudes, basically describes both the absolute cross sections and the shape of the differential cross section angular distributions. The contribution of the CN mechanism is noticeable only at large proton emission angles.

1. http://www.fresko.org.uk/.
2. T.L.Belyaeva, N.S.Zelenskaya *et al.* // Comp. Phys. Comm. 1992. V.73. P.161.

PRODUCTION OF HEAVY AND SUPER-HEAVY NUCLEI BY MULTI-NUCLEON TRANSFER REACTION

Zhang G.[1,2]
[1] *The key laboratory of Beam Technology and Material Modification of Ministry of Education, College of Nuclear Science and Technology, Beijing Normal University, Beijing, China;* [2] *Beijing Radiation Center, Beijing, China*
E-mail: zhanggen@mail.bnu.edu.cn

The calculated production cross sections in ^{136}Xe + ^{249}Cf by DNS model [1-3] with Gemini++ code [4-5] reproduce the experimental data [6] very well. Especially in proton pickup channel, its agreement is better than other models. The cross sections of primary products become larger with increasing incident energy, but the final yield is almost the same at different energy. This is because fission is the dominant de-excitation mechanism and fission probability enhances with higher energy. 1.10 time Coulomb barrier is a suitable incident energy to produce super-heavy nuclei.

The production cross section of neutron-rich nuclei in the reaction ^{238}U + ^{252}Cf is larger than ^{238}U + ^{249}Bk, which is because ^{252}Cf has larger neutron number and *N/Z* ratio. Using neutron-deficient projectile-target combination, ^{124}Xe + ^{248}Cf and ^{124}Xe + ^{247}Bk have larger advantage to generate unknown neutron-deficient nuclei that other reactions with beam ^{129}Xe.

1. G.G.Adamian, N.V.Antonenko, and W.Scheid // Nucl. Phys. A. 1997. V.618. P.176.
2. G.G.Adamian, N.V.Antonenko, W.Scheid, and V.V.Volkov // Nucl. Phys. A. 1998. V.633. P.409.
3. Z.Q.Feng, G.M.Jin, J.Q.Li, and W.Scheid // Phys. Rev. C. 2007. V.76. P.044606.
4. R.J.Charity // Phys. Rev. C. 2010. V.82. P.014610.
5. D.Mancusi, R.J.Charity, and J.Cugnon // Phys. Rev. C. 2010. V.82. P.044610.
6. K.E.Gregorich, K.J.Moody, D.Lee, W.K.Kot, R.B.Welch, P.A.Wilmarth, and G.T.Seaborg // Phys. Rev. C. 1987. V.35. P.2117.

ALPHA DECAY HALF-LIVES of Os and Re ISOTOPES

Alavi S.A., Dehghani V., Ghorbani F.
Department of Physics, University of Sistan and Baluchestan, Zahedan, Iran
E-mail: s.a.alavi@phys.usb.ac.ir

By using semiclassical WKB method and taking into account the Bohr–Sommerfeld quantization condition and alpha preformation probability, the alpha decay half-lives of Os and Re isotopes have been calculated. The double-folding nuclear and Coulomb potentials, and centrifugal potential have been considered for effective potential [1]. The alpha particle preformation probabilities were determined by using the preformed cluster model (PCM) [2].

1. C.Xu, Z.Ren // Phys. Rev. C. 2006. V.74. 014304.
2. G.Sawhney *et al.* // Eur. Phys. J. A. 2014. V.50. P.175.

STUDY OF CLUSTER STRUCTURE OF ^{11}B NUCLEUS

Zhusupov M.A.[1], Kabatayeva R.S.[1,2], Kopenbayeva A.S.[1]
[1] *IETP, al-Farabi Kazakh National University, Almaty, Kazakhstan;* [2] *International Information Technology University, Almaty, Kazakhstan*
E-mail: raushan.kabatayeva@gmail.com

Within the multiparticle shell model [1] the authors have calculated the α-particle and deuteron spectroscopic *S*-factors leading to a formation of the ground and the excited states of ^{11}B nucleus. In an experiment these quantities can be obtained in reactions with lithium ions like (^{6}Li, α), (^{7}Li, *t*) and other. Due to small binding energy of ^{6}Li nuclei in α*d*-channel and ^{7}Li nuclei in α*t*-channel the main mechanism is the clusters' transfer. The *S*-factors are in form of multipliers in the cross sections of the processes.

The peculiarity of structure of ^{11}B nucleus is that the lowest threshold of decay for the nucleus is the α-particle one (Q = 8.665 MeV), and the following, proton one is situated 3 MeV higher. In this range the three near-threshold energy levels with small partial Γ_α-widths are of peculiar interest. Thus, the peculiarity of the γ-transition from the level of ^{11}B nucleus at E = 8.920 MeV to the ground state of ^{11}B ($5/2^- \rightarrow 3/2^-$) is an anomalous small total width of the level $\Gamma = \Gamma_\alpha + \Gamma_\gamma = 4.37$ eV, practically equal to the radiation width since the calculated value is $\Gamma_\alpha = 0.006$ eV. A small value for this quantity is due to the small value of the S_α-factor which is proportional to the width. In this case the transition from the $5/2^-$ level at energy E = 8.920 MeV, whose main components of the wave function have Young [421] scheme, to the ground state of ^{7}Li nucleus with Young [43] scheme (the weight of this component is 98 %) is forbidden by the selection rules and $S_\alpha \neq 0$ is due to only small components of the wave function of ^{7}Li nucleus.

Thus, the structure of the levels of ^{11}B nucleus leads to a large yields of monochromatic γ-quanta with energies E_γ = 8.920, 9.185 and 9.275 MeV in the reactions of radiation ^{7}Li(α, γ)^{11}B capture and confirms the possibility of the use of this process for diagnostics of *dt*-plasma by adding lithium isotopes [2].

1. A.N.Boyarkina // Structure of 1*p*-shell nuclei. M.: MSU. 1973. 62 p.
2. F.E.Cecil // Rev. Sci. Instrum. 1988. V.57. P.1777.

CLUSTER STRUCTURE OF ^{10}B NUCLEUS LEVELS

Zhusupov M.A.[1], Zhaksybekova K.A.[1], Kabatayeva R.S.[1,2]
[1] *IETP, al-Farabi Kazakh National University, Almaty, Kazakhstan;* [2] *International Information Technology University, Almaty, Kazakhstan;*
E-mail: raushan.kabatayeva@gmail.com

In the framework of the multiparticle shell model [1] the authors have calculated spectroscopic *S*-factors for α-particles and tritons leading to the ground and the excited states of ^{10}B nucleus. These quantities define the cross sections of excitation in the reactions of cluster transfer like (^{6}Li, α), (^{7}Li, *t*) and (^{7}Li, α) on ^{6,7}Li isotopes. A comparison with an experiment shows that the theory describes correctly the maxima in the cross sections of lithium reactions of cluster transfer leading to different states of ^{10}B nucleus.

The distinctive feature of ^{10}B nucleus is that for this nucleus like for other strongly clusterized light nuclei, the α-decay channel opens first ($Q = 4.4596$ MeV), and the following, deuteron-escape channel is situated a little higher $Q = 6.0265$ MeV. In intermediate energy region there are levels for which two decay channels are open only – the α-particle and the radiation one. At that due to small decay energies for the near-threshold states and also due to structure peculiarities of the levels being excited the partial Γ_α widths can be comparable to and even less than the radiation ones. Such a situation arises for the γ-decay from the level (2^+,1) at E = 5.1639 MeV to the ground state. The small value for Γ_α in this case is due to small value of the spectroscopic S_α factor. According to the selection rules on isospin the α-decay is allowed only due to additive to the (2^+,1)-level's wave function of the component with $T = 0$ and $J^\pi = 2^+$. This additive is small and the width calculated by the authors is $\Gamma_\alpha \approx 0.01$ eV. That is why the total width of the level $\Gamma = 2.87$ eV is completely coincides with the radiation one and that leads to the large value for the cross section of γ-quanta yields σ = 5.8 mb. Such resonance γ-quanta can serve for diagnostics of *dt*-plasma when adding to it a particular amount of ^{6}Li nuclei [2].

1. A.N.Boyarkina // Structure of 1*p*-shell nuclei. M.: MSU. 1973. 62 p.
2. F.E.Cecil // Rev. Sci. Instrum. 1988. V.57. P.1777.

MAGNETIC AND THERMAL EFFECTS IN NEUTRINO SCATTERING IN HOT AND DENSE NUCLEAR MATTER

Kondratyev V.N.[1,2], Dzhioev A.A.[1], Vdovin A.I.[1], Cherubini S.[3], Baldo M.[3]
[1] Bogolubov Laboratory of Theoretical Physics, JINR, 141980-RU Dubna, Russia; [2] Physics Department, Taras Shevchenko National University of Kyiv, 03022-UA Kyiv, Ukraine;
[3] Department of Physics and Astronomy "Ettore Majorana", University of Catania, Italy
E-mail: vkondrat@gmail.com

Neutrino nuclear scattering in ultramagnetized matter relevant for supernovae, neutron star mergers, magnetar crusts and heavy-ion collisions is considered. At finite temperature neutrino exhibits exo- and endo-energetic scattering on nuclear species due to the neutral-current Gamow-Teller interaction component. From an analysis of energy transfer and straggling cross sections it is demonstrated that additional noticeable mechanisms in equilibrating neutrinos with matter originate from magnetic effects. Average energy transfer, i.e., ratio of energy transfer and scattering cross sections, depends nearly linearly on neutrino energy and changes from positive to negative value. For hot nuclear material such cross over between acceleration and stopping regimes occurs when neutrino energy is about factor four of a temperature. Similar features are revealed for neutrino scattering on hot atomic nuclei. Possible effects in neutrino spectra are discussed.

THEORETICAL STUDY OF PROTON RADIOACTIVITY

Oudih M.R., Fellah M., Allal N.H.
Laboratoire de Physique Théorique, Faculté de Physique, USTHB BP 32, El Alia, Bab Ezzouar, Algiers 16111, Algeria
E-mail: mroudih@usthb.dz

The phenomenon of particle emission is generally considered as a result of the quantum-mechanical-tunneling through a potential barrier taken as the sum of the Coulomb potential, the centrifugal potential and the nuclear potential between the daughter nucleus and the emitted particle. In recent studies, a modified Woods–Saxon (MWS) potential based on the Skyrme energy density functional and the extended Thomas–Fermi approach has been considered as the nuclear part of the potential barrier. The model has been very successful in describing alpha decay and the half-life of cluster decay [1, 2].

In the present work, this model is used to study the proton decay of spherical proton emitters from the ground and isomeric states using the WKB approximation in the framework of the unified fission model. The results of our calculations are compared to those obtained by other theoretical models as well as experimental data. It is shown in Fig. 1 that the unified fission model with the MWS nuclear potential can be successfully used to evaluate the proton decay half-lives.

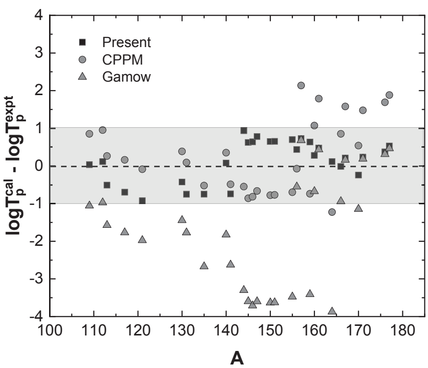


Fig. 1. The Decimal logarithm deviations of calculated half-lives with the experimental values versus the mass number of proton emitters. The squares denote the present model calculations, the circles correspond to the results from the Coulomb proximity potential model (CPPM) and the triangles correspond to the Gamow model [3].

1. M.Ouhachi, M.R.Oudih, M.Fellah and N.H.Allal // Int. J. Mod. Phys. E. 2018. V.27. P.1850059.
2. F.Saidi, M.R.Oudih, M.Fellah and N.H.Allal // Mod. Phys. Lett. 2015. V.30. P.155010.
3. K.P.Santhosh and Indu Sukumaran // Phys.Rev. C. 2017. V.96. P034619.

R-MATRIX ANALYSIS OF REACTIONS WITH EXCITATION OF ^{10}B COMPOUND NUCLEUS AT 6-18 MeV ENERGY

Generalov L.N., Selyankina S.M.
Russian Federal Nuclear Center – All-Russian Research Institute of Experimental Physics, Sarov, Russia
E-mail: otd4@expd.vniief.ru

Performed is the R-matrix analysis (description) [1] of differential and integrated cross-sections of ^{9}Be(p,p_0)^{9}Be, ^{9}Be(p,p_1)^{9}Be* (1.670 MeV), ^{9}Be(p,p_2)^{9}Be* (2.430 MeV), ^{9}Be(p,n_0)^{9}B, ^{9}Be(p,α_0)^{6}Li, ^{9}Be(p,α_2)^{6}Li* (3.563 MeV), ^{9}Be(p,d_0)^{8}Be, ^{7}Li(^{3}He,p_0)^{9}Be reactions. The program code AZURE2 [2] is used. New ^{10}B levels are determined and characteristics of already detected states are improved.

Differential $d\sigma/d\Omega$ (by angle θ in the centre-of-mass system) and total σ cross-sections [3] of ^{9}Be(p,α_2)^{6}Li*(3.563 MeV) reaction at proton energy E_p are given in Fig.1. The values of differential cross-sections of the reaction at E_p = 2.3844–4.5334 MeV are obtained from the description [3] of γ-line shape with Doppler broadening. In this case proton energies shift by 7.4 keV according to the results of new experimental studies [4] in data [3].

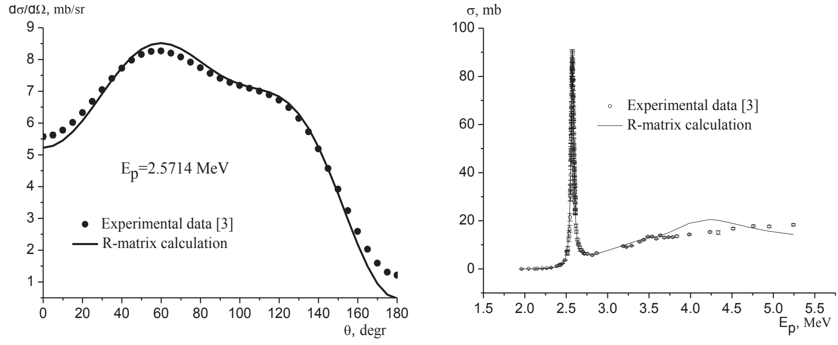


Fig.1. Description of differential and total ^{9}Be(p,α_2)^{6}Li(3.563MeV) reaction cross-sections.*

1. A.Lein, R.Tomas Theory of nuclear reactions under low energies. Moscow: Edit. Inostr. Lit., 1960.
2. R.E.Azuma, E.Uberseder, E.C.Simpson *et al.* // Phys. Rev. C. 2010. V.81. 045805.
3. L.N.Generalov, S.N.Abramovich, A.G.Zvenigorodskii *et al.* // Izv. RAN. Ser. Fiz. 2003. V.67. №10. P.1462; L.N.Generalov, S.N.Abramovich // Izv. RAN. Ser. Phys. 2005. V.69. №11. P.1629.
4. L.N.Generalov, I.A.Karpov, D.A.Fedotov // Book of abstracts of Conference “Nucleus-2014”, Minsk, Belarus. 2014. P.202.

CLUSTER STATES IN $^{12}C + ^{16}O$ SCATTERING

Maltsev N.A., Torilov S.Yu., Zherebchevsky V.I.
St.Petersburg State University, Saint-Petersburg, Russia
E-mail: n.maltsev@spbu.ru

Cluster states in ^{28}Si were considered in heavy ions resonances approach. Experimental results available today for the position of the states of the rotational bands determination were considered. The analysis of the angular distributions allowed us to identify possible positions for states that have the structure of $^{12}C + ^{16}O$. The obtained results were compared with model calculations with an optical potential [1].

A comparison was made of the results obtained with calculations within the framework of a potential model [2]. It was shown that for potentials close to the folding potential we can reproduce the position of the observed resonances. The data on the position of the new cluster resonances are obtained.

1. K.A.Gridnev, N.A.Maltsev, N.Burtebaev, *et al*. // Bull.Rus.Acad.Sci.Phys. 2012. V.76. P.934.
2. S.Ohkubo, K.Yamashita // Phys. Lett. B 2004. V.578. P.304.

Application of nuclear physics methods in related fields of science and technology

- Prospects for development of nuclear medicine;
- Nuclear physics research methods in field of nanophysics and nanotechnology;
- Radiation technologies for micro- and nanoelectronics and production of new materials;
- Problems of radiation reliability and radiation resistance of microelectronics products and spacecraft systems.

PROSPECTS OF APPLICATION OF MODERN TECHNOLOGIES OF NUCLEAR PHYSICS IN MEDICINE

Chernyaev A.P.[1,2], Borschegovskaya P.Yu.[1], Varzar S.M.[1], Lykova E.N.[1,2], Zheltonozhskaya M.V.[1,2], Nisimov S.U.[3], Bliznuk U.A.[1], Rozanov V.V.[1], Elagina V.M.[1]

[1] Faculty of Physics, M.V.Lomonosov Moscow State University, Moscow, Russia; [2] Skobeltsyn Institute of Nuclear Physics, M.V.Lomonosov Moscow State University, Moscow, Russia; [3] Fund of Infrastructure and Educational Programs (RUSNANO Group), Moscow, Russia.

E-mail: alexeevapo@mail.ru

Application of the latest achievements of nuclear and accelerator physics in medicine is one of the effective directions of method development of diseases treatment and diagnostics. In the field of Oncology especially noticeable is the role of nuclear physics technologies.

A coordinated interaction between a doctor and a medical physicist is necessary for successful work on radiation treatment of patients.

Very specific and deep training requires for successful work of such a specialist in the field of radiation therapy.

The training in the educational program of professional retraining of specialists in the field of radiation therapy for the development, operation and use of high-tech systems in clinical institutions provides based on the Faculty of Physics, Moscow State University, the Department of Physics of Accelerators and Radiation Medicine.

The training program was developed at the Department of physics of accelerators and radiation medicine of the faculty of physics. M. V. Lomonosov. The RUSNANO Foundation for Educational Programs participated in financing of the program.

At the end of the full-time lecture module of the program, students attend internships are trained in the departments of the P. Herzen Moscow Oncology Research Institute, Academician N. N. Burdenko Main Military Clinical Hospital, European Medical Center. In addition, an internship is offered in clinics in Germany. Practical exercises and internships are conducted using modern medical accelerators, dosimetry monitoring and patient fixation tools, computer dosimetry planning systems and other radiotherapy equipment.

After graduation, graduates gain skills for professional activity in physical and mathematical support of radiotherapy treatment methods as a medical physicist.

1. D.V.Volkov *et al.* // Visualization of digestion process using 19f mri. Applied Magnetic Resonance. 2018. V.49. No.1. P.71.
2. A.P.Chernyaev *et al.* // Radiation Technology in Medicine: Part 2. Using Isotopes in Nuclear Medicine. Moscow University Physics Bulletin. 2016. V.71 (4). P.339.
3. A.P.Chernyaev *et al.* // Radiation technology in medicine. Part 1. Medicine accelerators. Moscow University Physics Bulletin. 2015. V.70 (6). P.457.

STATE-OF-THE-ART OF NEUTRON ACTIVATION ANALYSIS AT FLNP JINR

Frontasyeva M.V.
Joint Institute for Nuclear Research, Dubna, Russia
E-mail: marina@nf.jinr.

The history of the development of neutron activation analysis in the Laboratory of Neutron Physics at Joint Institute for Nuclear Research is briefly outlined [1]. Created under initiative of Academician I.M. Frank in the 1960s, a small group now turned into a large international team involved in projects in the framework of programs coordinated and supported by IAEA, the European Union, the Russian Fund for Basic Research (RFBR), as well as grants of Plenipotentiaries of JINR member states. Modernization of the pneumatic system equipped with three automatic sample changers and created NAA database to automate the measurement and processing of gamma spectra of induced radionuclides are described [2]. Experience in the Life Sciences and Materials Science is summarized. Examples are given of projects related to the monitoring of atmospheric deposition of heavy metals and radionuclides carried out in the framework of the United Nations Program on Long-Range Transboundary Air Pollution in Europe (UNECE ICP Vegetation) [3], a project to assess the state of the environment in Egypt, based on the analysis of soil and the sediment basin of the river Nile, as well as project on monitoring trace elements in aquatic ecosystem in the Western Cape, South Africa ("Mussel Watch Program"), etc. In combination with microscopy, the synthesis of nanoparticles of various metals via biotechnology is studied. Our investigations on applying NAA to solve the problem of industrial wastewater treatment were awarded Gold Medals by the European Union, in 2013 and 2015. New areas of research – study of natural medicinal plants and search for cosmic dust in natural planchettes (Arctic and Antarctic mosses, Siberian peat bog cores, *etc.*) – reflect the public and scientific interest in these topics. Future extensions of the sector´s research is connected with the radioecological studies using precision gamma-spectrometry and a low-background laboratory for carrying out measurements of natural and anthropogenic radioactivity. Perspective of creating the Centre of Collective Usage at the planned Dubna Neutron Source of the fourth generation (DNS-4) to be put into operation in 2035-2036 is mentioned.

1. M.V.Frontasyeva // Physics of Particles and Nuclei. 2011. V.42. No.2. P.332. http://www.springerlink.com/content/f836723234434m27/
2. S.S.Pavlov, A.Yu.Dmitriev, M.V.Frontasyeva // JRNC. 2016. V.309. No.1. P.27. http://link.springer.com/article/10.1007/s10967-016-4864-8
3. M.V.Frontasyeva, E.Steinnes, and H.Harmens // Chapter in a book "Biomonitoring of Air Pollution Using Mosses and Lichens: Passive and Active Approach – State of the Art and Perspectives", Edts. M.Aničić Urošević, G.Vuković, M.Tomašević, Nova Science Publishers, New-York, USA, 2016.

PROMISING RADIOSENSITIZERS FOR PHOTON THERAPY

Abdullaeva G.A., Kulabdullaev G.A., Kim A.A., Djuraeva G.T., Juraeva N.B.
Institute of Nuclear Physics, Academy of Sciences Uzbekistan, Tashkent
E-mail: abdullaeva@inp.uz

Many efforts in Radiation Oncology have focused on approaches that aim to preferentially sensitize tumours to radiation whilst minimizing effects in normal tissues. An approach to maximize the differential response between tumour and normal tissue response, termed therapeutic ratio, is through the introduction of high-atomic number (*Z*) material into the target.

Samarium, gadolinium, bismuth and gold are the promising radiosensitizers in this regard due to its high atomic number and mass energy coefficient relative to soft tissue The mass energy absorption coefficients of these elements are ~150–170 times greater than that of soft tissue in the keV energy range. Consequently, there is an increased probability of photoelectric interaction at lower energy levels, resulting in increased energy deposition at the target site. However, considering the depth dose limitations of keV X-rays, MV energies are used as the clinical standard for external beam radiotherapy. At these energies, significant radiosensitization would not be expected based on the ratio of mass energy absorption coefficients of this elements and soft tissue. The μ_Z / μ_{st} calculations results and $\mathbf{E_B}$ values (the binding energy of K shell) of elements (radiosensitizers) for comparison are presented in Table 1.

Tab.1 – The μ_Z/μ_{st} maximum values for elements (radiosensitizers).

Element	μ_Z/μ_{st}	**E** (keV) for maximal μ_Z/μ_{st}	$\mathbf{E_B}$ (keV)
Sm	149.26	60	46.835
Gd	144.67	60	50.239
Au	153.69	40	80.725
Bi	173.92	40	90.526

Thus, calculations results show, that for achievement of the maximum radiosensitization at the expense of the K shell photoeffect of investigated elements, energy of x-ray source should be in a range 60–100 keV. It is necessary to notice, that the most simple and convenient way is use x-ray apparatus as photon source. Our final goal was to optimize the choice of a radiosensitizers for obtaining the maximal dose-enhancement in radiotherapy for the treatment of brain tumors. From previous studies the dependence of Magnevist (GdCA) concentration in the irradiation place depending on time was experimentally determined [1]. Based on obtained data, we have concluded that radiosensitization of GdCA could be attributed to two mechanisms. First, the photoelectric effect enhancement in the keV energy range, and second to biological interaction of GdCA with the cells.

1. G.A.Kulabdullaev *et al.* // Open Phys. 2015. V.13. P.183.

DISTRIBUTION OF NEUTRONS IN THE EARTH ATMOSPHERE FROM PLANE RADIOACTIVE SOURCE

Abdullaev H.Sh.[1], Najafov B.A.[2], Masimov E.A.[1], Guseynzadeh Kh.E.[1]
[1] *Baku State University;* [2] *Institute of Radiation Problems of the National Academy of Sciences of Azerbaijan*
Email: bnajafov@inbox.ru

The question of the spatial distribution of fast and thermal neutrons in the Earth's atmosphere is considered. The fields of fast neutrons from a flat radioactive source with a source energy not exceeding 1 MeV are correctly described by the age theory. The effect of atmospheric in homogeneity affects the height of the source, exceeding 20–25 km. The flux density of slow neutrons falls almost to zero at a distance of about two parameters of the atmospheric in homogeneity.

From the point of view of the problem of pollution of the Earth's atmosphere and the control of it, it is of interest to know the spatial-energy distribution of neutrons in the atmosphere and some of its functional that determine side effects, such as secondary gamma radiation, from radioactive sources of various types.

The intensity of the interaction of neutrons with air depends on the density of air molecules, which is different at different heights. In this regard, in the upper layers of the atmosphere, the non-uniformity of the atmosphere will exert on the distribution of neutrons. The effect of in homogeneity is significant at those altitudes at which the neutron mean free path turns out to be comparable with the characteristic size of the atmosphere in homogeneity. For the model of an exponential atmosphere with a characteristic parameter h = 8 km, this occurs at altitudes of 20–25 km above the Earth's surface. By the nature of the interaction with air molecules, neutrons can be divided into two broad categories: fast and thermal. The fast neutrons include those neutrons whose energy significantly exceeds the thermal energy of the movement of air molecules. In this case, we can assume that neutron scattering occurs on immobile molecules. Thermal neutrons are those neutrons whose energy is comparable to or even less than the thermal energy of air molecules. In this case, when considering the scattering of neutrons by air molecules, it is necessary to take into account the thermal motion of the latter [1].

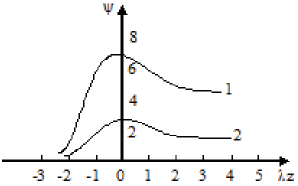


Fig 1. the result of the calculation of this work,

The spatial distribution of slow neutrons, obtained by considering the effect height h = 40 km is presented in Fig. 1.

1. G.Ya.Trukhanov "Methods for calculating thermal neutron fields". M. Atomizdat, 2004.

CALCULATION OF ELECTRIC FIELD GRADIENT TENSOR FOR COMPLEX OXIDE COMPOUNDS

Andrianov V.A.[1], Gorkov V.P.[2]
[1] Lomonosov Moscow State University, Scobeltsyn Institute of Nuclear Physics, 119991 Moscow, Russia; [2] Lomonosov Moscow State University, Faculty of Computational Mathematics and Cybernetics, Moscow, Russia
E-mail: andrva22@mail.ru

In the Mössbauer studies of complex multicomponent compounds in which the Fe atoms occupy several nonequivalent positions, the question arises of identifying the components of the spectrum from the quadrupole splitting. The quadrupole hyperfine splitting is determined by the product of the nuclear quadrupole electric moment and the electric field gradient (EFG) in the region of the nucleus of an atom. Since the quadrupole moment of the nucleus is well defined, the calculation of quadrupole splitting is reduced to the calculation of the EFG tensor.

Currently, a two approach is proposed for calculating the EFG tensor: 1) semi-empirical, based on the model of external charges, in which the polarization of atomic electrons is taken into account by introducing some coefficients [1], and 2) first-principle calculations based on electron density functional. Unfortunately, calculations from the first principles, as a rule, are limited to 10 - 20 atoms in the unit cell. We have developed a computer program for calculating the EFG tensor based on the model of external charges for an unlimited number of atoms in the unit cell. The calculations took into account the electric field of the point charges, as well as the additional contribution from dipole moments of the atoms (for example, oxygen atoms). It was assumed that the dipole moment $\boldsymbol{p}$ is related to the electric field $\boldsymbol{E}$ by a scalar constant. The magnitude of the field $\boldsymbol{E}$ was calculated in a self-consistent way. The EFG calculation program used atomic position tables, which were calculated in the PowderCell crystallographic package.

The report will present the calculation data and compare with the experiment for $Pb_3Mn_7O_{15}$ manganite, for which the hexagonal phase contains 100 atoms in the unit cell and 4 nonequivalent Fe positions, and the orthorhombic phase contains 200 atoms and 9 nonequivalent Fe positions.

1. R.M.Sternheimer // Phys. Rev. 1963. V.130. P.1423.

SORPTION OF REDUCED FORMS OF TECHNETIUM-99M ON ALUMINUM OXIDE

Ashrapov U.T., Khujaev S.S.
The Institute of Nuclear Physics of the Academy Sciences, Tashkent, Republic of Uzbekistan
E-mail: ashrapov@inp.uz

From the stationary radionuclide generator of technetium-99m pertechnetate $(^{99m}TcO_4)^{-1}$ sodium solutions have been received and processed by chemical reducing agents (Sn(+2), Fe(+2), ascorbic acid) reduced forms of Tc-99м were received. Than in dynamic mode the Tc-99м reduced forms on aluminum oxide were sorbet. Experimental results showed, that concentration of the Tc-99м reduced forms in the presence of oxidizing agents are increases, and Sn (+2) has the greatest reducing ability, which has the lowest electron detachment energy [1].

Table 1. Tc-99м reduced forms sorption on Al_2O_3 at presence of reducing agents.

Reducing agent	Concentration of the reducing agent solution, mole per liter	Tc-99m reduced forms sorption on Al_2O_3, %	Electron detachment energy, electronvolt
Sn(II)	$5.2 \cdot 10^{-4}$	99.9	3.95
Sn(II)	$5.2 \cdot 10^{-4}$	93.4	-//-
Sn(II)	$5.2 \cdot 10^{-4}$	81.4	-//-
Fe(II)	$5.2 \cdot 10^{-4}$	84.0	4.53
Ascorbic acid	$5.2 \cdot 10^{-4}$	89.9	4.41
Control solution without reducing agent	–	69.0	

From the table 1 it is possible to see, that Tc-99м reduced forms have greatest sorption on aluminum oxide (99,9 %) at use reducing agent divalent tin. Sorption of Tc-99m reduced forms on aluminum oxide (69%) from control solution without reducing agent is connected with regenerative action to Tc-99m (+7) hydrotized electrons e_{aq}^{-1}, which are arise at radiolysis of water [2] in the radiating environment of stationary generator column.

Thus, reason for the decrease of equation efficiency of sodium $(^{99m}TcO_4)^{-1}$ pertechnetate solution from stationary generating column is reduced Tc-99м (+7) up to Tc-99м (+6) and Tc-99м (+4), therefore is necessary to include Tc-99м oxidizing agents in eluent or in sorbent, that will provide saving the maximum oxidizing valency of Tc-99м (+7) and maximal output of pertechnetate $(^{99m}TcO_4)^{-1}$ sodium solution from stationary generator column of Tc-99m.

1. A.N.Terenin Photonics dye molecules and related organic compounds // Leningrad. Science. 1967. P.375-382.
2. A.K.Pikaev Modern radiation chemistry. Radiolysis gases and liquids // Moscow. Science. 1986. P.193.

REACTIONS ON W WITH OUTGOING NEUTRONS: EXPERIMENTAL VERIFICATION OF GEANT4 MONTE-CARLO SIMULATION

Belyshev S.S.[1], Bykhalo G.I.[2], Stopani K.A.[1], Khankin V.V.[1]
[1] Skobeltsyn Institute of Nuclear Physics, Moscow, Russia; [2] Faculty of physics, Lomonosov Moscow State University, Moscow, Russia
E-mail: gi.bykhalo@physics.msu.ru

The method of proton and ion beam therapy is one of the promising areas in the treatment of cancer. A characteristic feature of the beams of protons and light ions is the presence of the Bragg peak in a function of the specific energy loss at different depths in the substance. This allows to localize the process of energy release during radiotherapy irradiation with high accuracy. Compared to radiation therapy using gamma-ray beams, when protons and ions with energies of several hundred MeV interact with matter, significantly more complicated processes occur, leading to the generation of secondary particles (in particular, neutrons) and rescattering effects. An inherent part of the procedure is computer simulation, which is used for irradiation planning and dosimetry monitoring. Currently, simulation packages based on the Monte Carlo method are widely used for a detailed calculation of the transport of particles of ionizing radiation in proton therapy.

The present work considers nuclear reactions leading to the emission of secondary neutrons on stable W isotopes. Multileaf collimators (MLC), made of tungsten, are used in nuclear medicine to form a beam in close proximity to the patient, and in the process of irradiation this can become a source of increased neutron background for him. In this work, using the method of induced activity at the facility [1], experimental yields of reactions with the neutron emission occurring in a tungsten target under the action of an electron beam with an energy of 55 MeV were obtained. These results are compared with the calculations of the generation of secondary neutrons, performed using the Monte-Carlo GEANT4 package [2], as well as with the yields of the corresponding photonuclear reactions, calculated on the basis of the available tabular and theoretical cross sections. The obtained data provide a measure of the accuracy of neutron dose calculation in GEANT4 when used for prediction of irradiation exposure in radiation therapy.

1. K.A.Stopani *et al.* // Nucl. Instrum. Meth. in Phys. Res. A. 2014. V.745. P.133.
2. S.Agostinelli *et al*. // Nucl. Instrum. Meth. in Phys. Res. A. 2003. V.506. P.250.

COSMIC PROTON INDUCED NUCLEAR FRAGMENTATION EFFECTS ON SPACECRAFT ELECTRONICS

Novikov N.V., Chechenin N.G., Chuvilskaya T.V., Chumanov V.Ya., Shirokova A.A.

Skobeltsyn Institute of Nuclear Physics Lomonosov Moscow State University, Moscow, Russian Federation

E-mail: chechenin@sinp.msu.ru

Evaluation of the radiation effects in the onboard electronics of spacecraft under impact of high-energy protons on the basis of modern models of nuclear reactions and software codes are requested [1]. The single event effects on onboard electronics can occur not only from direct medium ionization by primary protons, but also from the effect of charged fragments of the nuclear reactions on the sensitive volumes of electronic circuit assemblies.

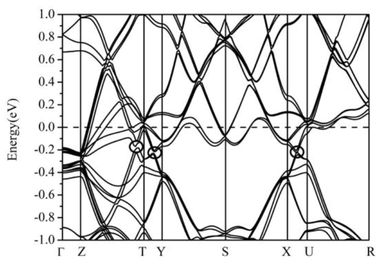
The charge, mass, and energy distributions of nuclear reaction fragments in the collision of protons with a silicon nucleus are studied in the energy range from 0.1 to 1 GeV. The calculations have been carried out using the EMPIRE [2] and TALYS [3] program codes and the results are compared with those of Monte-Carlo simulation [4].

1. V.Ya.Chumanov, A.G.Kadmenskii, N.G.Chechenin // J. Surface Investigation X_ray, Synchrotron and Neutron Techniques. 2014. V.8. P.1265.
2. M.Herman, R.Capote, B.Carlson, *et al.* // Nucl. Data Sheets. 2007. V.108. P.2655.
3. A.J.Koning, D.Rochman // Nucl. Data Sheets. 2012. V.113. P.2841. http://www.talys.eu
4. J.Allison, K.Amako, J.Apostolakis, *et al.* // NIM A. 2016. V.835. P.186. geant4.web.cern.ch

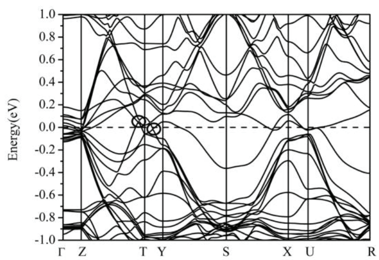
THEORETICAL CALCULATIONS OF H IRRADIATED TANTALUM PHOSPHIDE

Cheng W., Zhang F.S.
The Key Laboratory of Beam Technology of Ministry of Education, College of Nuclear Science and Technology, Beijing Normal University, Beijing 100875, China
E-mail: chengwei@bnu.edu.cn

Defects of a kind of semimetal tantalum phosphide induced by H irradiation were studied theoretically [1]. The calculations are based on density functional theory. Dispersion curves and density of states were analyzed. Topological properties of semimetal can be affected by defects. Concentration of defects is an important factor. Various kind of defects have different impacts on Weyl points. The positions of Weyl points in reciprocal space do not change by the defect as shown in Fig. 1. It was found that tantalum atoms play an important role to prevent the Weyl points to be destroyed by defects. Compare Fig. 1a and Fig. 1b, one tantalum atom is missing in the unit cell, some Weyl points disappear as a result.



(a)



(b)

Fig. 1. Dispersion curve of $HTa_{32}P_{32}$ (a) and $HTa_{31}P_{32}$ (b). Circles indicate the Weyl points.

1. Wei Cheng *et al*. // Chin. Phys. Lett. 2017. V.34. P.127101.

USE OF MOLYBDENITE NANOPARTICLES FOR PHOTONUCLEAR PRODUCTION OF Tc-99m

Dikiy N.P.[1], Lyashko Yu.V.[1], Medvedev D.V.[1], Medvedeva E.P.[1], Uvarov V.L.[1], Fedorets I.D.[2]
[1] *NSC "Kharkov institute Physics and Technology", Kharkov, Ukraine;* [2] *V.N. Karazin Kharkov National University, Kharkov, Ukraine*
E-mail: ndikiy@kipt.kharkov.ua

Nuclear reaction $^{100}Mo(\gamma,n)^{99}Mo$ was used to obtain ^{99m}Tc. Samples of molybdenite nanoparticles were activated by bremsstrahlung from a linear electron accelerator with $E = 39$ MeV and $I = 4$ μA within 2 hours (Fig. 1). Isotope activity is measured by a Ge(Li)-detector. It is known that the diffusion coefficients of molybdenum and technetium in molybdenite are different [1]. This feature was used to isolate technetium-99m using chemicals with the tropism to technetium (Fig. 2) [2].

The possibility of separating ^{99m}Tc from a NaOH solution is shown. To isolate ^{99m}Tc, electrolysis was carried out in 2 N sodium hydroxide solution. The part of isotopes ^{99m}Tc deposited on the cathode is about 3%.

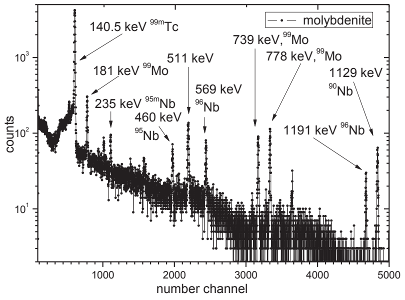


Fig. 1. The spectrum of molybdenite nanoparticles after irradiate by bremsstrahlung with E_{max}=39 MeV

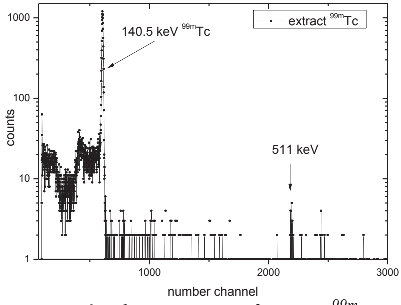


Fig. 2. The spectrum of extract ^{99m}Tc

This work supported by IAEA Research Contract No: UKR-22435 "Production of Tc-99m on Electron Accelerators".

1. H.-P.Komsa, A.V.Krasheninnikov Native defects in bulk and monolayer MoS_2 from first principles // Phys. Rev. B. 2015. V.91. 125304.
2. S.M.Bulatovic *Handbook of Flotation Reagents: Chemistry, Theory and Practice: Flotation of Sulfide Ores.* "Elsevier Science &.Technology Books". 2007. 446 p.

METHODS OF IR- AND GAMMA SPECTROSCOPY FOR CONTROL OF ^{153}Sm–OXYBIPHOR TREATMENT OF BONE METASTASES

Dikiy N.P., Bereznyak E.P., Medvedeva E.P.
NSC "Kharkov institute Physics and Technology", Kharkov, Ukraine
E-mail: ndikiy@kipt.kharkov.ua

Radionuclide therapy (RNT) is one of the effective treatment for palliate painful bone metastases. Isotope ^{153}Sm is a powerful β-emitter, presence of γ-rays allow facile visualization of its distribution in the human body using bone scan.

^{153}Sm-oxybiphor (quality certificate №85, series №026251114, with radiochemistry purity 99.2%, Uzbekistan) was used for the treatment of bone metastases with a variety of primary tumors. The therapeutic dose of ^{153}Sm–oxybiphor (the average value of administered activities of ^{153}Sm is 2630.0 ± 970.0 MBq) allows optimizing the radionuclide bone therapy (RNBT) and prevents hematotoxicity. The most effective complex of prognostic indicators of possible complications of radionuclide therapy of bone metastases was determined by the method of IR-spectroscopy. This is displayed in structural changes and the composition of the transmission spectra.

The patients with painful bone metastases have been treated by RNT. Gamma spectrum for blood these patients was measured by Ge(Li)-detector, volume 50 cm^3 with the energy resolution 3.25 keV. Ge(Li)-detector was equipped by the three-layer (Pb-Cu-Al) background protector. For registration of IR-spectra of patients' blood with bone metastases was used spectrometer IRS-29 with spectral range 400–4000 cm^{-1}. For comparison, IR-spectroscopic examination of molecular structure patients' blood before and after RBT the range 1100–1700 cm^{-1} was picked out. There is frequencies response of peptides, lipids, and group-NH_2.

The frequencies responses for donor blood were 1130, 1250, 1300, 1425, 1470. 1570 and 1680 cm^{-1} and for blood patients after RNT the intensity of these frequencies (3260–3400 cm^{-1}) was reduced.

In the course of radionuclide therapies, the decrease in intensity of bands of absorption is marked. These bands of absorption are responsible for vibrations of structures of protein and amides III, and CH_3 groups of lipid component. It testifies to infringement of the structure of molecules of blood. In IR spectra of the blood of patients after radionuclide therapy, the tendency to normalization of a molecular structure of blood subsequently is marked.

CALCULATION OF SELF-ABSORPTION CORRECTION FACTOR OF SOME CHEMICAL FERTILIZERS IN THE ENERGY RANGE FROM 80 TO 1332 keV

Eke C.
Akdeniz University, Faculty of Education, Department of Mathematics and Science Education, Division of Physics Education, 07058, Antalya, Turkey
E-mail: ceke@akdeniz.edu.tr

The purpose of this study is to calculate self-absorption correction factor of some chemical fertilizers used from Antalya in Turkey. Eight different types of chemical fertilizers with densities varying from 1.043 to 1.485 $g{\cdot}cm^{-3}$ were investigated experimentally using Transmission Method which has been suggested by Cutshall *et al*. [1].

Self-absorption correction factors of some chemical fertilizers were calculated using point sources which are ^{133}Ba, ^{137}Cs, ^{22}Na and ^{60}Co in the energy range from 80 to 1332 keV. The point sources were counted for 1000 seconds using a high purity germanium (HPGe) detector. Spectra were analyzed using computer software. Self-absorption correction factor versus energy graphics were obtained and compared with air and ultrapure water.

The self-absorption correction factors depend on the density and composition of the investigated material [2, 3]. It was concluded that the self-absorption correction factors of some chemical fertilizers are high at low gamma-ray energies whereas at higher gamma-ray energies, it has smaller values and tends to be steady subsequently.

1. N.H.Cutshall *et al.* // Nucl. Instrum. Meth. 1983. V.206. P.309.
2. J.P.Bolivar *et al*. // Appl. Radiat. Isot. 1997. V.48(8). P.1125.
3. T.Boshkova and L.Minev // Appl. Radiat. Isot. 2001. V.54. P.777.

EFFECTS OF RADIATION ON THE DEFECTNESS OF THE SEMICONDUCTORS STRUCTURE

Gitlin V.R., Kadmensky S.G., Hamad Amin A.S.
Voronezh State University
E-mail: nuc@phys.vsu.ru

The performance of microelectronic products largely depends on the presence and type of point defects in the semiconductor material, which form deep levels in the forbidden zone. The radiation effect leads to the change in the defective structure of semiconductors [1].

In this paper, it has been studied the effect of radiation on the electrophysical parameters of deep levels in semiconductors by the non-stationary Deep Level Transient Spectroscopy (DLTS) method. The objects of the study were Schottky diodes formed on Si and GaAs crystals grown by the Czochralski method. For the substrates it have been used the polished KFE-7.5 silicon plates with an <111> orientation and n-type gallium arsenide with a carrier concentration of $2 \cdot 10^{16}$ cm^3 and an <111> orientation. Samples were irradiated with gamma-quanta with an energy of 1.25 MeV from the ^{60}Co source. The crystals degree of perfection was monitored by measuring the energy spectra of the back-scattered channeled helium ions and the change in the lifetime of minority charge carriers the characteristic most sensitive to the presence of point defects in the crystal.

At the performing work using the DLTS method, which is the most informative method for studying the electrophysical parameters of deep levels, the effect of "healing" of electrically active defects in silicon and gallium arsenide under the action of gamma radiation was discovered. The effect is explained by the interaction of radiation-induced point defects with the original vacancy complexes in semiconductor crystals.

1. T.Figielski // Phys. Stat. Sol. (a). 1987. V.102. P.493.

RADIATION TESTING OF PRODUCTS WITH THE MOS STRUCTURE

Gitlin V.R., Kadmensky S.G., Hamad Amin A.S.
Voronezh State University
E-mail: nuc@phys.vsu.ru

The development of methods for predicting the radiation resistance of microelectronic products to the effects of low-intensity cosmic radiation remains an urgent problem. The complexity of the prediction is due to the fact that carrying out full-scale tests is not possible because of the long testing time, commensurate with the time of operation of the chip. In this case, it is of interest to develop a forecast based on radiation testing of the response of the MOS structure to the ionizing radiation effects with the high dose rate.

It has been proposed the method of radiation testing of MOS integrated circuits based on the effects of accumulation of radiation-induced hole charge in the volume of the gate oxide and generation of surface states at the boundary of the semiconductor substrate and the gate oxide, as well as relaxation processes of thermal and tunneling charge discharge in the oxide and annealing of surface states. The testing process includes the determination of microscopic and phenomenological parameters from experimental dose curves, as well as from the temperature-time dependence of relaxation. Based on the obtained parameters, it is possible to predict the change in the characteristics of the integrated circuit under the influence of radiation exposure with any dose rates, including small ones (cosmic radiation conditions).

MODERN AERO-GAMMA SURVEY FACILITIES AND VALIDATION OF RECEIVED DATA

Kozhemyakin V.A.
ATOMTEX SPE, Minsk, Belarus
E-mail: info@atomtex.by

The report elaborates on materials concerning the development and production of modern aero-gamma survey equipment for use as part of various aircraft: manned helicopters, small-sized unmanned vehicles – quadcopters, octocopter, gliders, etc.

Aero-gamma survey equipment has a functional purpose of real-time measurement of radiation levels at aircraft flight altitude with either subsequent automatic reduction of measurement results to the 1-meter level above ground using altitude conversion factors by onboard equipment, or when the data has been transmitted to a ground processing station, where the procedure to reduce the flight-level measurement results to the ground-level altitude is performed.

Several types of equipment for manned and unmanned systems have been developed, as well as a representative line of gamma-radiation detection units (radiation sensors) for use in unmanned small-sized aircraft, which have already found their practical use.

The remote method of measurement inherent in aerial radiation survey is characterized by the presence of multiple factors affecting the reliability of obtained data, which can be intrinsically divided into methodological, instrumental and related to difference of real conditions from the ideal model of radioactive fallout.

The process of equipment design and assessment of anticipated performance was effectively facilitated by mathematical modeling of gamma-radiation transfer from the radioactive fallout land area to the detection point at flight altitude, as well as the detection device response functions, taking into account the entire range of factors affecting the results of remote measurements.

The field tests of detection devices in flights over radioactively contaminated land to test the mathematical model and finally determine the performance in terms of obtained results validity were the most important element in the design process.

The data about the developed aero-gamma survey equipment, results of mathematical modelling, materials on field tests in radioactively contaminated areas, as well as data on the detection and localization of point radioactive sources are cited in the report. Intrinsic and complementary measurement errors are analysed and evaluated taking into account the laws of distribution of their components, the values of gross error depending on the initial conditions for an areal radioactive source are given.

INVESTIGATION OF GADOLINIUM ACCUMULATION IN HUMAN BRAIN GLIAL TUMORS FOR GdNCT

Kulabdullaev G.A.[1], Kim A.A.[1], Abdullaeva G.A.[1], Djuraeva G.T.[1], Sadikov I.I.[1], Yarmatov B.H.[1], Salimov A.I.[1], Kadyrbekov R.T.[2], Alimov D.R.[2], Kadyrbekov N.R.[2], Mavlyanov I.R.[3]

[1] Institute of Nuclear Physics of Uz AS, 100214, Tashkent, Uzbekistan; [2] Republican Scientific Center of Neurosurgery, Tashkent, Uzbekistan; [3] Tashkent Medical Academy, Uzbekistan

E-mail: gkulabdullaev@inp.uz

Gadolinium is one of the promising elements for use in modern binary technologies of radiotherapy of malignant tumors. One such binary radiotherapy technology is gadolinium-neutron capture therapy (GdNCT). GdNCT is the younger direction of neutron-capture therapy, that therapy which showed favorable results in the treatment of high-grade tumors [1–2]. However GdNCT is not used in a clinical practice due to unsolved problems, one of which is the uncertainty of the absorbed dose.

The aim of our pilot clinical study was direct determination of gadolinium accumulation in glial tumors of human brain after single intravenous injection of Magnevist. This is necessary for further treatment procedures. The study was carried out on samples removed during standard surgery operations of glial tumors of the human brain. Samples of five patients with glial tumors and single intravenous injection of the Magnevist at different times before the operation were studied. Samples of two patients with glial tumors and without intravenous injection of Magnevist and other gadolinium containing compounds were studied as control. Gadolinium content in samples of tumor tissues was analyzed by method of neutron activation analysis. Gadolinium was found to be present in a concentration of 0.0093 to 0.2384 ng / in 1 mg (ppm) of tumor tissue in all five tested samples. In control samples, the gadolinium has not been detected. These concentrations indicate its correlation with the number of carried out MRI. Such amounts of Gd accumulation in tumors after MRI are not sufficient to significantly affect the therapeutic absorbed dose at radiotherapy of glial tumors of human brains. At present time, the clinical importance of detected effect of gadolinium accumulation in brain tumors after intravenous injection of pharmacological chelate compounds of gadolinium is not clear enough. Since free gadolinium is toxic, so the establishment of fact of gadolinium accumulation in brain tumors can appear significant for interpretation of various unexpected clinical effects in the future.

1. R.F.Barth *et al*. // Radiation Oncology. 2012. V.7. P.46.
2. H.Shiba *et al*. // Book of abstracts 17 th ICNCT. 2016. P.73.

ABOUT MODELING OF ^{nat}U + Th NEUTRON SOURCE ON THE BASIS OF D + T NEUTRON GENERATOR

Khushvaktov J.[1,2], Yuldashev B.[1], Kulabdullaev G.A.[1], Artemov S.[1], Abdullaeva G.A.[1], Bozorov E.[1], Sitanov H.[1]
[1] *Institute of Nuclear Physics, Uzbekistan Academy of Sciences, Tashkent;* [2] *Joint Institute for Nuclear Research, Dubna, Russia*
E-mail: khushvaktov@jinr.ru

The experimental research of various aspects of ADS on the basis of low energy accelerators – cyclotrons, microtrons, as well as deuterium or tritium ions accelerators – neutron generators of high intensity is of great importance. Such experimental studies must precede the calculations of neutron spectra with application of MCNP [1] and GEANT4 [2] codes. In given work the calculation results on modeling of the neutron source on the basis of D + T neutron generator are presented. With application of GEANT 4 code the preliminary model calculations are executed with use of experimental information on energy dependence and angular distribution of secondary neutrons from mixtures of fission materials. IonPhysicsPHP and NeutronHP models were used in calculation. The results normalized on one deuteron with energy 105 keV hitted the $TiT_{1.5}$ neutron target. The simulated angular distribution of neutrons yield from the neutron target shows that neutrons are emitted from the target isotropic. The neutron flux values on distance of 10 cm from center of the neutron target as well as at the studied sample and detector positions were calculated.

The dependences on scattering angle of integral fluence of secondary neutrons normalized to one incident neutron at irradiation of thin ^{232}Th and $^{232}Th + ^{233}U$ (50/50%), and thick $^{232}Th + ^{233}U$ samples were calculated. Also the dependence of such fluence on the thickness of $^{232}Th + ^{nat}U$ (50/50%) mixture sample is investigated. From Fig.1 it is clear that maximal yield of secondary neutrons is reached at 15 cm radius of such metallic sample. So we can conclude that central part of the high intensive neutron source intended for applied studies and constructed as the $^{232}Th + ^{nat}U$ (50/50%) core irradiated by neutron flux of D + T neutron generator, must have a form of the sphere with radius 15 cm.

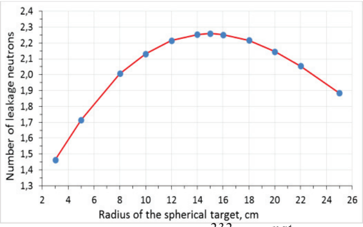


Fig. 1. The dependence of full fluence from $^{232}Th+^{nat}U$ (50/50%) target thickness.

1. J.F.Breismeister // ed. LA-13709-M. Los Alamos National Laboratory. 2000.
2. J.Apostolakis *et al.* // Radiation Physics and Chemistry. 2009. V.78. P.859.

THE STUDY OF THE RADIATION-THERMAL DECOMPOSITION OF WATER IN THE nano-ZrO_2 + nano-SiO_2 SYSTEM USING IR SPECTROSCOPY

Melikova S.Z., Agayev T.N.
Institute of Radiation Problems of the National Academy of Sciences of Azerbaijan
E-mail: sevinc.m@rambler.ru

This paper presents the results of Fourier IR spectroscopic studies of the radiative decomposition of water in a heterogeneous nano-ZrO_2 + nano-SiO_2 + H_2O system at different temperatures $T = 373 \div 673$ K under the influence of γ-quanta in order to establish the role of intermediately active particles (ion-radical groups) in these processes. The ratio of nano-ZrO_2 + nano-SiO_2 nanopowders varied: 0.015 g + 0.015 g (1 : 1), 0.005 g + 0.025 g (1 : 5) and 0.025 g + 0.005 g (5 : 1). The FTIR absorption spectra were recorded on a Varian 640FT-IR spectrometer in the range 4000–400 cm^{-1} at room temperature. For this purpose, tablets 50–100 μm thick were pressed from ZrO_2 and SiO_2 nanopowders. The IR spectra of the samples were measured in a special quartz cuvette with CaF_2 windows, which makes it possible to obtain the spectra of adsorbed water decomposed under the action of γ-radiation.

Radiation decomposition of water in the nano-ZrO_2 + nano-SiO_2 + H_2O system was carried out at different temperatures. Samples were irradiated at a ^{60}Co isotope source with a dose rate of $dD_\gamma / dt = 0.11$ Gy / s. Dosimetry of the source was carried out with ferrosulfate and methane dosimeters. Absorbed radiation dose in the studied systems is determined by comparing the electron density. The exposure time τ = 25 h ($D_\gamma = 10$ kGy).

Information on the effect of the second component on the surface physicochemical and radiation-catalytic properties of the nano-ZrO_2 + nano-SiO_2 binary system is limited. Therefore, using infrared Fourier spectroscopy, the interactions between the components of nano-ZrO_2 and nano-SiO_2, the mechanisms of water adsorption and radiation-thermal radiolysis of water in the presence of a mixture of nano-ZrO_2 + nano-SiO_2 have been studied. Using Fourier IR transform spectroscopy, we studied the radiation-thermal decomposition of water in the nano-ZrO_2 + nano-SiO_2 + H_2O system in the temperature range ($T = 373 \div 673$ K) under the influence of γ-rays. It is shown that water adsorption in zirconium and silicon nanooxides occurs by the molecular and dissociative mechanisms. Intermediate-active products of radiation-heterogeneous decomposition of water – zirconium and silicon hydrides, hydroxyl groups – have been registered. The values of the velocities and radiation-chemical yields of molecular hydrogen during the radiolysis of water in the presence of nano-ZrO_2 + nano-SiO_2 mixtures were determined. It was revealed that the values of the velocities and radiation-chemical yields decrease on going from nano-ZrO_2 to nano-SiO_2. The stimulating role of radiation in the radiation-thermal decomposition of water in the temperature range ($T = 373 \div 673$ K) is shown.

THE FOOT EXPERIMENT: MEASURING PROTON AND LIGHT NUCLEI FRAGMENTATION CROSS SECTIONS UP TO 700 MeV/*A*

Scavarda L.[1] on behalf of the FOOT Collaboration
[1] *Istituto Nazionale di Fisica Nucleare, Section of Turin, Italy*
E-mail: lorenzo.scavarda@to.infn.it, scavarda@to.infn.it

Charged Particle Therapy has been demonstrated as a highly effective method for treating deep-seated tumours. Thanks to the energy release pattern of charged particles, characterized by the Bragg peak, the dose delivered to healthy tissues surrounding the tumour is minimized. However, secondary particles produced by beam-tissue nuclear interactions make an additional hazard that must be carefully taken into account in clinical treatment planning system. Indeed, with proton beams, target fragmentation generates low energy (few MeV) and short-range (few μm) nuclear fragments with a high Linear Energy Transfer. In case of carbon beams, projectile fragmentation is also relevant, as it produces longer-range fragments that release dose in healthy tissues after the tumour. The measurement of the differential cross sections of these processes up to the fragment's energies of 400 MeV/*A* is the main goal of the FragmentatiOn Of Target (FOOT) collaboration. Proton- and light nuclei-induced nuclear fragmentation is also a relevant issue in the evaluation of radiation doses produced by the exposure to galactic cosmic rays. This is the main health risk for astronauts in deep space missions and is a relevant topic given that current space programs focus on the exploration of the Solar system. For risk assessment and mitigation, Monte Carlo or deterministic transport codes are commonly used to calculate organ doses through different shielding materials. By measuring differential fragmentation cross sections of high-energy light ions up to 700 MeV/*A*, the FOOT experiment will provide input required to improve the accuracy of the transport codes.

The detector is optimized for identification of heavy fragments through the measurement of their momentum, energy and time of flight, as well as the trajectory of the incident beam particle. The experiment is under construction and the final design aims to measure the differential cross sections with ~5% uncertainty for different beam-target combination. In order to obtain this precision also in the target fragmentation processes, the strategy of the inverse kinematics approach will be used to detect low range fragments.

The present status of the development and performance of its components will be discussed.

PROTON BEAM INDUCED RADIOACTIVITY OF HUMAN-LIKE TISSUES

Sękowski P., Skwira-Chalot I., Matulewicz T.
Faculty of Physics, University of Warsaw, Warsaw, Poland
E-mail: przemyslaw.sekowski@fuw.edu.pl

Particle therapy is the most promising form of radiation therapy of tumours, but there still remain unresolved puzzles which indicates that our understanding of the complexity of hadron therapy is not complete. The aim of this work is to measure radioactivity induced in the human body during tumor treatments with using particle beams and assessment of its influence on therapy effects and causation of secondary tumors.

In order to find the sources of induced radioactivity in the patient's body, the targets (materials similar to humans tissues like pig liver) were irradiated with beams commonly used in hadrontherapy (60 MeV protons and nuclear reactor neutrons). After irradiation the samples were measured using low-background spectrometer. Based on Geant4, the Monte Carlo simulations were simultaneously performed to estimate the dose from induced radioactivity.

The results of our experiments show that during irradiation various short-lived radioactive nuclei are produced. In addition, the dose originating from these nuclei cannot be omitted in treatment plans.

DECAY OF ^{152}Eu AND ^{239}Np IN THE PROCESS OF MICROWAVE AND LASER IRRADIATION

Shafeev G.A.[1,2], Barmina E.V.[1], Simakin A.V.[1], Stegailov V.I.[3], Tyutyunnikov S.I.[3], Scherbakov I.A.[1]

[1] Prokhorov General Physics Institute, RAS, 119991, Moscow, Vavilov Str., 38; [3] National research nuclear University, MEPhI, Moscow; [2] Joint Institute for Nuclear Research, 141980 Dubna, Russia

E-mail: tsi210647@yandex.ru, shafeev@kapella.gpi.ru

Some experiments, which have been carried out in the frames of "Energy and Transmutation" project and directed to solve tasks of studying the nuclear-physical processes' characteristics, ensuing on nuclei ^{152}Eu and ^{239}Np under the influence of coherent electromagnetic radiance, have been discussed in the report.

The aim of the experiments [1] is to study the mechanisms of influence of electromagnetic radiation of microwave range and laser radiation on the probability of the nuclear decay (curve in Fig.1).

The influence of laser irradiation on the gamma-activity of aqueous solutions of both ^{152}Eu and ^{239}Np is experimentally studied in presence of Au nanoparticles at laser intensity of order of 10^{12} W/cm^2. It is found that laser irradiation reduces the gamma-activity of both nuclides. This decrease is not accompanied by excessive gamma radiation in the spectral range of gamma-activity of their spontaneous decay. Possible mechanisms are discussed of the influence of laser radiation on the activity of isotopes.

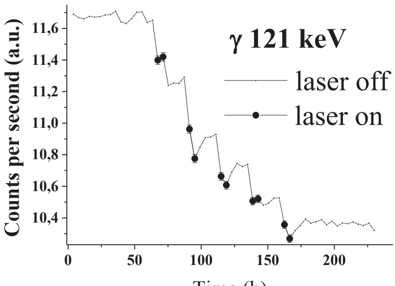


Fig.1.The change in the intensity of the gamma line 121 keV ^{152}Eu.

1. E.V.Barmina, A.V.Simakin, V.I.Stegailov, S.I.Tyutyunnikov, G.A.Shafeev, I.A.Shcherbakov // Quantum electronics. 2017. V.47. P.627.

PREPARATION OF THE Sn(60%)Pb(40%) SOLDER ON THE BASIS OF ARCHAEOLOGICAL LEAD

Temerbulatova N.T.[1,2], Filosofov D.V.[1], Karaivanov D.V.[1,3], Mirzayev N.A.[1,4], Ponomarev D.V.[1], Rakhimov A.V.[1], Rozov S.V.[1], Yakushev E.A.[1]

[1] Joint Institute for Nuclear Research, Dubna, Russia; [2] Institute of Nuclear Physics, Almaty, Kazakhstan; [3] Institute for Nuclear Research and Nuclear Energy (Bulgarian Academy of Sciences), 72 Tzarigradsko chaussee, Blvd., BG – 1784 Sofia; [4] Institute of radiation problems of the National Academy of Sciences of Azerbaijan, Baku, Azerbaijan

E-mail: tnargiza@jinr.ru

Modern experiments with aim of investigation or search of ultra-rare events, for example neutrino or Dark Matter interaction within a low background detector, places high demands for the radiation purity of the materials used, even for those used in small quantities. These include materials used for soldering elements in detector systems, i.e. a solder and flux. Radioactive purity of the materials is crucially important since their location in a close proximity to the detector's body inside of the shields. Radionuclide purity of commercial solders does not meet the requirements because they are made of natural lead which contains the radioisotope ^{210}Pb ($T_{1/2}$ = 22.3 y.) on a level of 1÷100 Bq/kg. Therefore, it is advisable to manufacture a solder based on archaeological Roman lead that does not contains the ^{210}Pb since its activity decreased by 1000 times each 220 years.

In this work we report on production of solder made from the raw archaeological lead [1] which chemical purity investigation performed in [2] and commercial tin of high purity (99,9999%) [3]. Melange of the solder components has been performed in a crucible made from beryllium oxide that radionuclide purity verification been performed in advance by gamma-ray screening with HPGe low background spectrometer. Two ingot tin-lead solders with a mass of 100 grams each were produced. The solder composition is: 60% of Sn and 40% of Pb. In addition, a sample of the same weight made from usual lead and high purity tin was also produced for intercomparison measurements. The work on the production of the solder was carried out in a specially equipped clean room in JINR (Dubna). The solder ingots were transferred to the Modane underground laboratory for further measurements of their radioactivity levels.

1. Michel L'Hour // Rev. Archéol. de l'Ouest. V.4. 1987. P.113.
2. Petr S.Fedotov *et al*. // Talanta. 2019. V.192. P.395.
3. Tin with chemical purity 99.9999% purchased from the “URAL-OLOVO” metallurgical company.

EXPERIMENTAL BACKGROUND OF A LARGE URANIUM TARGET (A QUASIINFINITE TARGET ^{238}U) ON PROTON BEAM

Tyutyunnikov S.I., Adam I., Furman V.I., Svoboda I., Solnyshkin A.A., Stegailov V.I., Tihii P., Zeman M., Khushvaktov J., Yuldashev B.
Joint Institute for Nuclear Research, Joliot-Curie 6, Dubna, Moscow region, 141980, Russia
E-mail: tsi210647@yandex.ru

The problem of efficient utilization of the worked-off nuclear fuel (WNF) has become a basic topic in the discussion of future global energetic last years. Developed countries start to discuss seriously the utilization of electro-nuclear systems (in international terminology- Accelerator Driven Systems-ADS) as an alternative and perspective method of resolution of this problem. A quite energy stiffness of the neutron spectra in the comparison with the divinable one, that would permit instead of the traditional for the nuclear reactors reactions (*n*, f), and (*n*, γ) to use efficiently a complex of multistep cascade reactions, a high energetic proton, meson and neutron division, and also a threshold reactions of the type (*n*, *xn*)-associated with the producing of neutrons has been supposed in the project. A neutron spectrum of this type would permit “to burn” efficiently threshold minors of Actinides and transmute the long-living pieces of nuclear division into the WNF downloading in the active zone (AZ) (Figs. 1, 2).

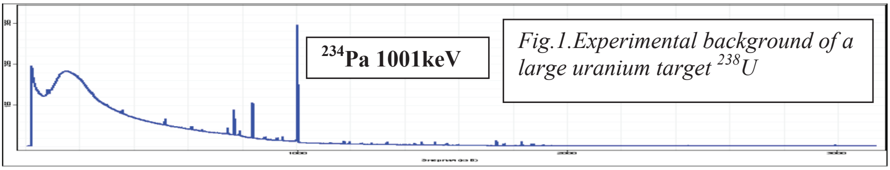


Fig.1.Experimental background of a large uranium target ^{238}U

Basic scientific and methodologic results of the project are discussed in the report.

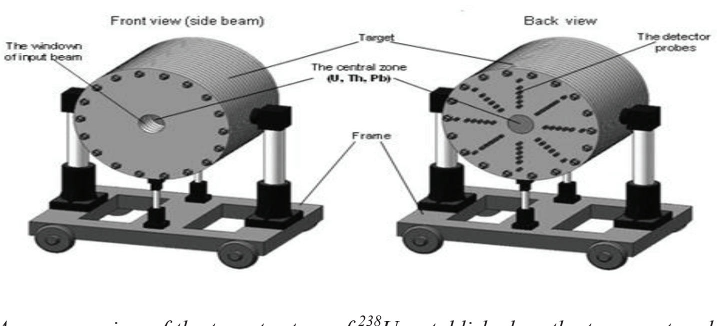


Fig. 2. A common view of the target set up of ^{238}U, established on the transport and adjusted platform in the centre of the proton beam 660meV, in the Phasotron LNP, JINR.

1. R.G.Vasilkov *et al.* // At Energy 1978. V.44. P.4 (In Russian).

DISTRIBUTION OF EMPIRICAL DISTRIBUTIONS OF RADIATION FLUX PARTICLE COUNTS

Babenko A.G., Vakhtel V.M., Rabotkin V.A.
Voronezh State University, Voronezh, Russia
E-mail: vakhtel@phys.vsu.ru

Sequences of $N > 10^4$ counts $K(\Delta t)$ at intervals $\Delta t > 0.04$ c of alpha-particles of source Pu-238, obtained by the method considered in [1], were divided by computer scanning by $M = N / n$ sequential samples of the same volume n with mean $\overline{K}(\Delta t) > 1$. Each of M of such samples corresponds to an empirical distribution of type j $\mathrm{ED}(\cdot)_{ij}$, i.e. a random vector $(n_{0j}, n_{1j}, n_{ij}, n_{lj})$, where $n_{ij}(K_i(\Delta t) = i)$ – the number of similar $K_i(\Delta t)$ in a sample of type j, while $0 \le n_{ij} \le n$ for $i < l$ and $0 < n_{ij} \le n$, where l – a random value, $n = n_{0j} + n_{1j} + n_{ij} + n_{lj}$. A set of M of such distributions consists of S of various types of $\mathrm{ED}(\cdot)_j$ randomly distributed in the sequence. Each type includes $M_j \ge 1$ identical to $\mathrm{ED}(\cdot)_j$ and $M = \sum_{j=1}^{S} M_j$ where S, M_j are random values.

Even at $n < 20$, $l < 20$, $S > 10^4$, $M > 10^5$ analysis and classification of $\mathrm{ED}(\cdot)_j$ by types with such values of M and S is a complex problem, taking into account that the known homogeneity and fitting criteria at $n < 20$ are not applicable.

It is suggested that sequence $\mathrm{ED}(\cdot)_j$ is analyzed using distribution of random functional $ID(\cdot)_j = a_0 n_{0j} + \ldots + a_i n_{ij} + \ldots + a_l n_{lj}$, where coefficients $a_i \ge 1$ are mutually simple natural, $l(n, M, S)$. Discrete random values $ID(\cdot)_j$ are uniquely determined by the type of $\mathrm{ED}(\cdot)_j$, i.e. by a specific random vector $(\overline{n}_{01}, \ldots, \overline{n}_{l1})$. This allows obtaining distributions $M_j(ID(\cdot)_j)$, i.e. distributions $\mathrm{ED}(\cdot)_j$ by S types. Maximal values M_j of each distribution peak $ID(M_j)$ correspond to the most consistent with the theoretical component of peak of $\mathrm{ED}(\cdot)_j$ with theoretical vector $(\overline{n}_{01}, \ldots, \overline{n}_{l1})$. Let us emphasize that depending on the set values of coefficients a_i it is possible to obtain distributions in the form of grouping into peaks of the related $\mathrm{ED}(\cdot)_j$, and the peaks into groups of homogeneous distributions by l and by n_{l-m} or by n_0, n_m, $m = 1, 2, \ldots, l-1$. The suggested method efficiently allows analyzing large sequences of $\mathrm{ED}(\cdot)_j$ for homogeneity, periodicity and other factors.

1. E.V.Akindinova, A.G.Babenko, V.A.Rabotkin, V.M.Vakhtel *et al.* // Proceedings of the International Symposium on Exotic Nuclei. 2014. P.651.

TIME COINCIDENCE OF EMISSIONS OF INDEPENDENT RADIATION FLUX PARTICLE COUNTS

Babenko A.G., Vakhtel V.M., Muratov I.V., Rabotkin V.A.
Voronezh State University, Voronezh, Russia
E-mail: vakhtel@phys.vsu.ru

During beta-decay of Cs-137, Co-60 in [1] were observed periodic abnormal emissions of rate and number of counts of gamma-quanta $K(\Delta t)$ over time Δt of gamma-radiation of daughter nuclear, which was attributed to the accelerating impact of some external unknown factors on the decay.

In our work, this phenomenon was studied during alpha-decay of Pu-238 by the synchronicity observation method, i.e. time coincidence of equal values of emissions $K(\Delta t)$ in three fluxes of alpha-radiation from one source. The angles between the three fluxes were 60°. A three-channel spectrometer allowed obtaining time distributions of sequences $K(\Delta t)$, emissions $K(\Delta t) \geq 3\bar{K}(\Delta t)$ and coincidences of identical emissions between the fluxes at mean $\bar{K}(\Delta t) = 1-2$.

Presence of an external impact on the alpha-decay may generate time coincidences of count emissions in three radiation fluxes $K_1(\Delta t)$, $K_2(\Delta t)$, $K_3(\Delta t)$. For the number of counts in the channels $T/\Delta t = N(\Delta t) \geq 10^7$, $\Delta t \geq 0.05$ s, mean $\bar{K} \geq 1$ it was determined that over time T the numbers of coincidences N_C between the emissions in the sequence pairs $K(\Delta t)$ correspond to the quadratic parabolic dependence on the emission rate.

$$M(1) \simeq M(2) \simeq M(3) = M,\ N_C(1,2) \simeq N_C(1,3) \simeq N_C(2,3) \sim 2M^2\tau T,$$

where $\tau = \alpha \cdot \Delta t$ – effective coincidence time, $\alpha =$ 0.5; 1; 2; 4. The number of coincidences between the similar emissions of three sequences $K(\Delta t)$ corresponded to the cubic parabola – $N_C(1,2,3) \simeq 3M^3\tau^2$. As is well known, this corresponds to the randomness of coincidences between the emissions.

In this connection, we should note that in case of external impact on decay of the nuclei that are in the same local source we should expect synchronization of nuclei decays within time intervals $t > \Delta t$ and, as is known, linear dependence of the number of coincidences on the emission rate $N_c(\bullet) \sim M$, at least for the exposure duration $t \geq \tau$ and exposure repetition periods $T_0 > t$ and, in particular, T_0 divisible by 24 hours.

1. Yu.A.Baurov *et al*. // Phys. At. Nucl. 2007. V.70. P.1875.

PRODUCTION OF A MEDICAL SOURCE ^{131}Cs IN PHOTONUCLEAR REACTIONS

Zheltonozhskaya M.V., Lykova E.N., Remizov P.D., Chernyaev A.P.
Lomonosov Moscow State University, Moscow, Russia
E-mail: zhelton@yandex.ru

The possibility of production ^{131}Cs medical isotope in photonuclear reaction was investigated. For this purpose, a natural cesium target was irradiated with the pulsed microtron accelerator of the Skobeltsyn Institute of Nuclear Physics of Lomonosov Moscow State University with the 55 MeV boundary electron energy. Measurements of irradiated targets were carried out by semiconductor spectrometers with HPGe detectors with an energy resolution of 1.8–2 keV on ^{60}Co γ-lines.

In the spectra, products of ^{133}Cs(γ,n)^{132}Cs, ^{133}Cs(γ,2n)^{131}Cs, ^{133}Cs(γ,pn)^{131m}Xe, ^{133}Cs(γ,4n)^{129}Cs reactions are reliably identified. It was found only the ^{131}Cs and ^{132}Cs isotopes make a tangible contribution to the irradiated target activity. However, ^{131}Cs decays only by electron capture and its decay is not accompanied by the gamma rays release. Thus, we estimated its activity by contribution to total ^{131}Cs and ^{132}Cs X-ray peaks at 29 and 34 keV by tracing the changes in the intensity of these peaks associated with the half-life of ^{131}Cs and ^{132}Cs. For this purpose, we studied the sample activity on a semiconductor spectrometer at 9.8 days after activation and at 21.73 days after activation. As the result, experimental cross-sections were received for the reactions: ^{133}Cs(γ,n)^{132}Cs – 13(1) mb and ^{133}Cs(γ,2n)^{131}Cs – 8(2) mb.

The theoretical integrated cross-section were obtained with software codes TALYS-1.9: ^{133}Cs(γ,n)^{132}Cs reaction – 15.4 mb and ^{133}Cs(γ,2n)^{131}Cs reaction – 4.4 mb. The obtained results are discussed.

ANALYSIS OF NEUTRON SPECTRUM DURING OPERATING A 20 MeV MEDICAL ACCELERATOR

Lykova E.N., Zheltonozhskaya M.V., Chernyaev A.P.
Lomonosov Moscow State University, Moscow, Russia
E-mail: iv-kate@yandex.ru

High-energy linear accelerators operating at energies higher than 8 MeV generate neutron fluxes when interacting with accelerator elements and with structural materials of the room for treating patients. Neutrons can form at the accelerator head (target, collimators, smoothing filter, etc.), procedure room devices, etc. Because of the high radiobiological hazard of neutron radiation, its contribution to the total beam flux, even at a few percent level, substantially increases the dose received to a patient.

Secondary neutron fluxes were investigated during the operating process of the Varian Trilogy and Clinac 2100 linear medical accelerators with the photoactivation method using (γ,n) and (n,γ) reactions on the natural tantalum (^{181}Ta) detection targets. Tantalum foils with 10×10 mm^2 dimensions and with 350 microns thickness were placed at different positions in the treatment room to measure neutron fluxes. The accelerators were operated at 18 MeV and 20 MeV photon mode and the gantry and collimator angle were positioned at 0° vertically oriented, pointing down at the floor. Some tantalum foils were placed under the beam in Bonner spheres: spherical retarders of pure polyethylene with 70 mm, 120 mm, 200 mm, 300 mm in size. Measurements of irradiated targets were carried out by semiconductor spectrometers with HPGe detectors with an energy resolution of 1.8–2 keV on ^{60}Co γ-lines. In the spectra, γ-transitions of the ^{180}Ta decay from ^{181}Ta$(\gamma,n)^{180}$Ta reaction and γ-transitions of the ^{182}Ta decay from ^{181}Ta$(n,\gamma)^{182}$Ta reaction were reliably identified.

As a result of processing the obtained data, the neutron spectrum from Varian Trilogy linear medical accelerator operating with 20 MeV mode was restored. It was determined the neutron flux on the tantalum target is about 5% of the gamma-ray flux. The experiment results are discussed.

STUDY OF METAL REMOVAL FROM COPPER-CONTAINING EFFLUETNS USING AAS AND NAA TECHNIQUES

Zinicovscaia I.[1,2], Yushin N.[1], Abdusamadzoda D.[1], Grozdov D.[1], Vergel K.[1], Ostrovnaya T.[1], Rodlovskaya E.[3], Kristavchuk O.[1]

[1] *Joint Institute for Nuclear Research, Joliot-Curie Str., 6, 1419890 Dubna, Russia;* [2] *Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering, 30 Reactorului;*
[3] *N.Nesmeyanov Institute of Organoelement Compounds of Russian Academy of Sciences, Vavilova Str., 28, 119991, Moscow, Russia*

E-mail: zinikovskaia@mail.ru

Saccharomyces cerevisiae, waste biomass originated from beer fermentation industry, was used to remove metal ions from four copper-containing synthetic effluents: Cu-Fe, Cu-Fe-Ni, Cu-Fe-Zn, and Cu-Fe-Ni-Zn. The effect of pH, initial copper concentration, equilibrium time, and temperature on copper, iron, nickel and zinc ions biosorption was studied. Metal adsorption by biomass was assessed using neutron activation analysis and atomic absorption spectrometry. Langmiur, Freundlich, Temkin and Dubinin–Radushkevich equilibrium models have been assessed to describe the experimental sorption equilibrium profile, while pseudo-first order, pseudo-second order, Elovich and the intra-particle diffusion models were applied to describe experimental kinetics data. Maximum sorption capacities have been calculated by means of Langmuir equilibrium model and mean free sorption energies through the Dubinin-Radushkevich model. Thermodynamic analysis results showed that the adsorption of copper, iron and zinc was spontaneous and endothermic in nature, while of nickel exothermic. *Saccharomyces cerevisiae* can be successfully applied for complex wastewater treatment.

This work was supported by the Russian Foundation for Basic Research (RFBR) [grant numbers 18-29-25023 мк].

SOURCE VELOCITY IN COLLISIONS OF 3.6 GeV PROTONS WITH GOLD TARGET

Avdeyev S.P.[1], Karcz W.[1], Kirakosyan V.V.[1], Rukoyatkin P.A.[1], Stegailov V.I.[1], Botvina A.S.[2]
[1] *Joint Institut1 for Nuclear Research, Dubna, Russia;* [2]*Frankfurt Institute for Advanced Studies Johann Wolfgang Goethe University, Frankfurt am Main, Germany*
E-mail: avdeyev@aol.com

One way of evaluating the degree of equilibration in a reaction, as well as determining the average source velocity, is through invariant cross section analysis as a function of longitudinal and transverse velocity.

In the present work the source characteristics of multifragmentation are investigated for the *p* + Au collisions at 3.6 GeV. Beam of 3.6 GeV protons were obtained from the Dubna superconducting accelerator NUCLOTRON. Invariant cross sections of carbon fragments from target spectator were measured with the 4π setup FASA [1]. Fig. 1 shows the longitudinal versus transverse velocity plot ($\beta_\perp$ vs $\beta_\parallel$) along points of constant invariant cross section for carbon fragments. The lines in Fig. 1 are fits to the data for a constant value of invariant cross section in the ($\beta_\perp$ vs $\beta_\parallel$) plane.

It was found to a good approximation that the data for a given invariant cross section are isotropic; i.e., they can be described by a circle with fixed locus, corresponding to a single average source velocity. This suggests that the system is at least in "kinetic equilibrium" prior to fragment emission. Mean source velocity ($\beta = v/c$) of target spectator is 0.0095 ± 0.0003.

The research was supported by the Russian Foundation for Basic Research, Grant No. 19-02-00499.

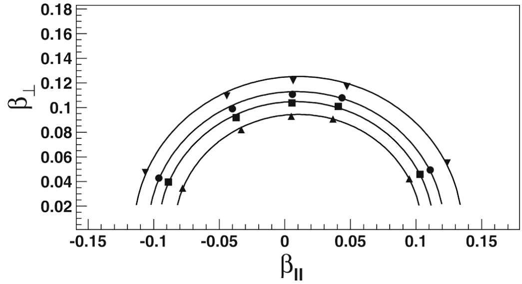


Fig. 1. Longitudinal versus transverse velocity plot along points of constant invariant cross section for carbon fragments. Points - experiment. Lines are fits to the data for a constant value of invariant cross section in the ($\beta_\perp,\beta_\parallel$) *plane.*

1. V.V.Kirakosyan *et al.* // Instr. and Exp. Techn. 2008. V.51. No.2. P.159.

DEVELOPMENT OF TIME-OF-FLIGHT SYSTEM FOR AUTOMATIC MEASURING PROJECTILE ENERGY FOR SEPARATOR DGFRS-2 EMPLOYING NI LabVIEW

Barinova S.[1,2], Schlattauer L.[1,3]

[1] *Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, 6 Joliot-Curie, Dubna, Moscow region, 141980, Russia;* [2] *Department of Elementary Particles, Faculty of Physics, Moscow State University, Moscow, Russia;* [3] *Department of Experimental Physics, Faculty of Science, Palacký University, 17. listopadu 1192/12, 771 46 Olomouc, Czech Republic*

E-mail: barinovasofiia@gmail.com

The paper presents ready-to-use software for automatic online measurement of ion beam energy and recording the relevant data in long-term experiments.

Reactions of complete fusion of actinide targets and ions like ^{48}Ca and still heavier ones are to be used in experiments aimed at the production of the new heaviest nuclides in the domain of superheavy elements. The nuclei of interest are produced with reasonable yield in rather narrow range of energy of the bombarding particles. In view of the extremely low production cross sections typical for the nuclei under study, setting up an appropriate energy of beam particles, its accurate measurement and continuous control becomes a crucial part of such experiments.

A time-of-flight technique is to be used in heavy-element research at the DGFRS-II separator in order to determine energy of the ion beams delivered by DC-280 cyclotron of the SHE-Factory at FLNR, JINR. Structurally, the beam of accelerated ions produced by the cyclotron consists of rather narrow bunches of particles that are well separated in time and, accordingly, along their flight path. When traversing the pick-up electrodes such a bunch of charged particle generates a detectable electronic signal. Thus, the energy of beam particles can be determined by measuring their time of flight through a pair of pick-up electrodes mounted at a known distance.

The developed software is an important component of the control systems employed in experiments with the separator DGFRS-II.

DETECTOR ARRAY FOR THE LOW-ENERGY FISSION STUDY

Bezbakh A.A.[1], Zachary C.J.[2], Krupko S.A.[1], Popeko G.S.[1], Fomichev A.S.[1], Golovkov M.S.[1], Hamilton J.H.[2], Ter-Akopian G.M.[1]

[1] Flerov Laboratory of Nuclear Reactions, JINR, Dubna, 141980 Russia; [2] Department of Physics, Vanderbilt University, Nashville, TN 37235, USA

E-mail: bezbakh@jinr.ru

Significant progress in the study on the low-energy fission process can be achieved by combining prompt γ ray spectroscopy with the measurements of the masses and energy distributions of fission fragments. This enables one to obtain direct data on the fragment excitation energy spectra and the distribution between collective and internal degrees of freedom as well as the actual deformation at the instant of scission.

Design was made for a new setup suitable for the study of ^{252}Cf spontaneous fission using the Gammasphere facility [1] and a new fission fragment TKE chamber. It houses a ^{252}Cf source deposited on a 10 μm platinum backing and placed at a distance of 19 mm from a $LaBr_3$ scintillator (25.4 mm diameter, 76.2 mm length). Placed on the open source side, 450 mm away, is an array of 24 plastics EJ-212 (each being 0.025 mm thick and 20 mm on a side mounted on its PMT R7600U). Gamma-ray signals coming from the Gammasphere for the moving fragments will be Doppler corrected. Fig. 1 gives the event distribution on the plot showing the fragment time of flight (TOF) versus the γ-ray amplitudes measured by the $LaBr_3$ detector for the ^{252}Cf fission fragments. The two event groups, seen in Fig. 1 on the right side, pertain to the heavy and light fragments. On the left of them is the pattern created by the α decay of ^{249}Cf which is present in the source. The two photo-peaks detected for the 388- and 333-keV γ rays emitted at the α decay of ^{249}Cf, as well as their Compton spectrum, were used for precise estimation of the 200-ps RMS resolution obtained for the fission-fragment TOF. The velocity spectrum obtained for the fission fragments of ^{252}Cf is presented in Fig. 2.

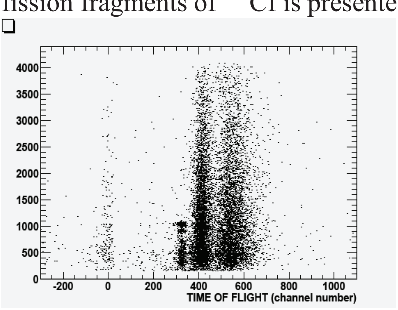


Fig. 1. Plot showing fragment TOF vs amplitude of detected gamma rays.

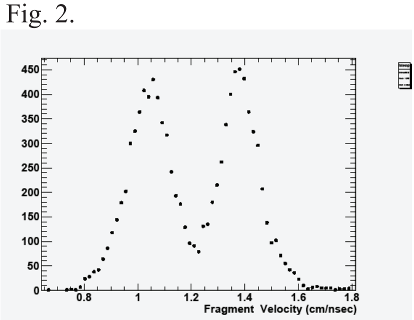


Fig. 2. The measured velocity spectrum of ^{252}Cf fission fragments.

1. https://www.anl.gov/phy/gammasphere

DIGITAL SYSTEMS FOR MULTI-PARAMETRIC ANALYSIS IN PHYSICS APPLICATIONS

Bredikhin I.S.
Gammatech LLC, Moscow, Russia
E-mail: ivan@gammatech.pro

The advantages of the digital approach in research are obvious - excellent stability and reproducibility, the ability to reprogram and adapt algorithms to the application, the ability to store signal information throughout the data acquisition chain, flexibility, etc. All in one device. In fact, having only one device – you replace all possible and impossible combinations of experimental assemblies with it.

As part of this report, we would like to talk about a line of systems for digitization, which can as digitize data with a fractions of nanoseconds time resolution as provide live analysis of the data obtained. Therefore, providing researchers only the information that is of use for the researches.

Such approach (especially, advanced by “smart logic circuits”) lead to a significant speed up of the research due to the possibility of using the same board for various experiments. Shown on a figure 1 is an example of the virtual laboratory interface brought by smart software interfaces by CAEN SpA. What is of most importance - it allows significantly reduce of the overall expenses, significantly reducing/optimizing the amount of the electronics required for the experiment.

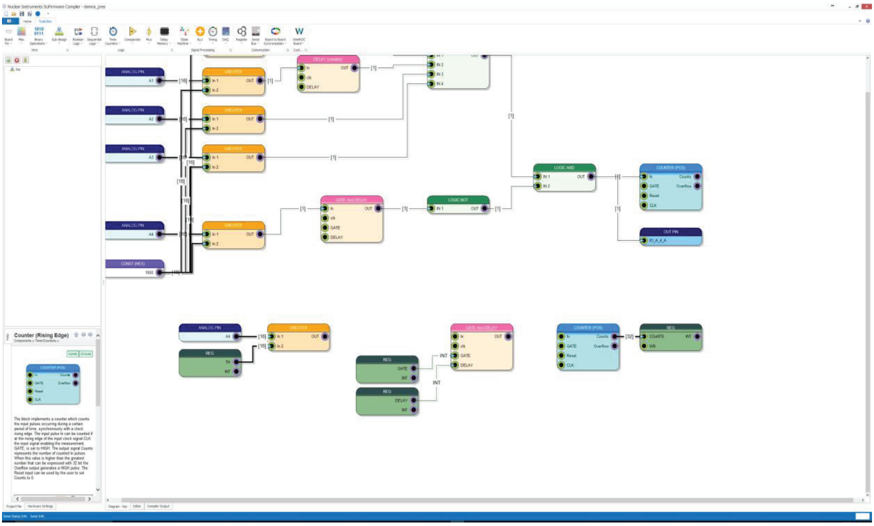


Fig. 1. Image of the virtual laboratory interface introduced in SCI-Compiler software in DT5550SE digitizer by CAEN SpA.

EFFICIENCY OF SOLID ISOL METHOD FOR FUSION-EVAPORATION REACTIONS

Rodin A.M.[1], Chernysheva E.V.[1], Dmitriev S.N.[1], Gulyaev A.V.[1],·Kamas D.[2], Kliman J.[2],·Krupa L.[3], Novoselov A.S.[1], Oganessian Yu.Ts.[1],·Opíchal A.[4], Podshibyakin A.V.[1], Salamatin V.S.[1],·Stepantsov S.V.[1], Vedeneev V.Yu.[1], Yukhimchuk S.A.[1]

[1] Flerov Laboratory of Nuclear Reactions, JINR, Dubna, 141980, Russia; [2] Institute of Physics SASc, Dubravskacesta 9, 84228 Bratislava, Slovakia; [3] Institute of Experimental and Applied Physics, Czech Technical University in Prague, Czech Republic, Horska 3a/22, 128 00 Praha 2; [4] Palacký University in Olomouc, Czech Republic

E-mail: elenachernysheva@jinr.ru

The experiments devoted to investigation of applicability of the solid ISOL method for separation of products of heavy ion induced reactions were carried out at the mass separator MASHA [1]. The measurements of the efficiency and separation time were made for short-lived isotopes of mercury and radon produced in the fusion-evaporation reactions $^{40}Ar + ^{144}Sm$, ^{166}Er.

The restriction of the method with respect to the separation efficiency were found at beam intensities of ~ 0.5 pμA. A working stability of the hot catcher made of porous graphite was studied. The prospects of use of carbon nanotube paper as material of the hot catcher are shown. The times of mercury beam formation were measured for three coverings of the vacuum chamber of the ECR ion source aimed at increasing the separation efficiency. A new design of the ECR ion source and hot catcher is proposed for experiments on the mass measurement of isotope ^{283}Cn, produced as an α-decay product of ^{287}Fl in the reaction $^{48}Ca + ^{242}Pu$. A special chemical inert glass-enamel coating will be used to cover the inner surface of the vacuum pipelines and chambers with the purpose to increase the separation efficiency. The whole separation system will be heated up to 300°C.

1. A.M.Rodin *et al*. // Instr.Exp.Tech. 2014. V.57. No.4. P.386.

CONVERSION OF ULTRARELATIVISTIC ELECTRONS TO POSITRONS IN THICK TARGETS

Belyshev S.S.[1], Dzhilavyan L.Z.[2]
[1] *Physics Faculty of Lomonosov Moscow State University, Moscow, Russia;* [2] *Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia*
E-mail: dzhil@inr.ru

Beams of ultrarelativistic positrons are an essential tool for experimental studies in physics of elementary particles and atomic nuclei. Mainly positrons for these beams are produced by conversion of ultrarelativistic electrons to positrons in thick targets-converters. Positrons from converters have broad energy spectra. In one variant of considered technique some magnetic system separates from all positrons those which have necessary energy without additional acceleration of positrons from converters (see, e.g., [1, 2]). In another variant of this technique initial positrons, emitted from converters with rather low energies, undergo acceleration up to necessary energies (see, e.g., [3, 4]).

The most important characteristic of positron generation in converters is a coefficient of conversion $K(E^{-}, E^{+}, T, Z) = N^{+} / (N^{-}\cdot\Delta\Omega^{+}\cdot\Delta E^{+})$ for a "needle-like" beam of electrons, normally incident on a converter, and for a positron emission angle $\theta^{+} \approx 0$. Here: E^{-} and E^{+} – kinetic energies of electrons and positrons; T – a converter thickness; Z – an atomic number of a converter material; N^{-} and N^{+}– numbers of incident electrons and emitted positrons; $\Delta\Omega^{+}$·and ΔE^{+} – small considered values of a solid angle and an energy spread for emitted positrons.

Experimental data on $K(E^{+}, E^{-}, T, Z)$ for E^{-} from 9 MeV and up to 1000 MeV for converters from Cu, Ta, Pt, and Pb may be found in [5–8]. But there are serious troubles in measuring these values especially at low E^{+}.

In the present work the calculations were made using GEANT-4 [9] for the pointed out conversion coefficients K at mentioned above values of E^{-} and close to optimal values of T.

The calculated values of $K(E^{+}, E^{-}, T, Z)$ (and especially for low E^{-}) may be very useful in modeling and designing equipment for matching emittances of positron beams and acceptances of additional positron accelerators.

1. J.Miller, C.Schuhl, C.Tzara, G.Tamas. // J. Physique Rad. 1960. V.21. P.755.
2. L.Z.Dzhilavyan, N.P.Kucher. // Sov. J. Nucl. Phys. 1979. V.30. P.151.
3. C.P.Jupiter, N.E.Hansen, R.E.Shafer, S.C.Fultz. // Phys. Rev. 1961. V.121. P.866.
4. L.Z.Dzhilavyan, A.I.Karev. Proc. VII Sov. Part. Accel. Conf. JINR. 1981. V.1. P.209.
5. M.Bernardini *et al.* // CEA n° 2212. Centre d'Etudes Nucleaires de Saclay. 1962.
6. T.L.Aggson, L.Burnod // LAL.27. Laboratoire de l'accelerateur lineaire. Orsay. 1962
7. J.Haissinski // Nucl. Instrum. and Methods. 1967. V.51. P.181.
8. L.Z.Dzhilavyan, A.V.Lelekov // Lebedev Phys. Inst. Kratkie soobshch. 1979. №8. P.37.
9. GEANT-4. Version: geant4 9.5.0 (December, 2011) // Physics Reference Manual.

LOW-ENERGY NUCLEAR ELECTRON SPECTROMETRY AND ITS APPLICATION IN THE KATRIN NEUTRINO PROJECT

Kovalík A.[1,2], Inoyatov A.Kh.[1], Vénos D.[2], Zbořil M.[2,3], Dragoun O.[2], Filosofov D.V.[1], Perevoshchikov L.L.[1], Lebeda O.[2], Ryšavý M.[2]
[1] *Laboratory of Nuclear Problems, JINR;* [2] *Nuclear Physics Institute AS CR, Řež;*
[3] *Physikalisch-Technische Bundesanstalt, Braunschweig, Germany*
E-mail: inoyatov@jinr.ru

The current stage of development of the nuclear electron spectrometry is also connected with the direct determination of the rest mass of the electron antineutrino from the analysis of the tritium beta spectrum near its endpoint (E_0 = 18.6 keV). The aim of the neutrino project KATRIN [1] is to achieve the sensitivity of 0.2 eV/c^2 for this quantity after the full measuring time of 1000 days. One of the conditions for achieving the declared sensitivity is to ensure the stability of the electrostatic retarding potential in the mass-sensitive region of the beta spectrum from $E_0 - 30$ eV to $E_0 + 5$ eV at the level of several tens of mV. It was estimated that the instability of the retarding potential within ±60 mV may create about 40% of the total allowable systematic uncertainty at which the aimed mass sensitivity of 0.2 eV/c^2 is still achievable. One of the ways to control the stability of the retarding potential of the main KATRIN spectrometer is to monitor the position of the reference electron line produced by a natural source with an energy close to E_0 on the same type satellite spectrometer. This source has to ensure the stability of the reference line energy within ±60 meV during the two-month measurement cycle. The use of solid-state radioactive sources for this purpose requires a detailed study of all factors (physical and chemical) affecting the energy of the reference electrons. In the presentation, the results of our extensive studies of the influence of the local physicochemical environment of atoms for different radioisotopes on both the energy of the emitted conversion and Auger electrons and the structure of their energy spectra are given. The narrow K conversion electron line (17824.3(5) eV) of the 32 keV nuclear transition in ^{83m}Kr generated in the ^{83}Rb decay was proposed as the suitable reference line. Our investigations shown that the ^{83m}Kr/^{83}Rb sources prepared by ion implantation into polycrystalline platinum foils meet the requirement of the KATRIN project for the reference line.

1. www.katrin.kit.edu

UPGRADE OF THE ALICE INNER TRACKING SYSTEM

Lazareva T.V., Feofilov G.A., Maltsev N.A., Nesterov D.G., Rahmatullina A.R., Zherebchevsky V.I. on behalf of the ALICE collaboration
Saint Petersburg State University, Saint Petersburg, Russia
E-mail: tatiana.lazareva@cern.ch

The expected increase in the luminosity of the Large Hadron Collider up to $\mathcal{L} = 6 \cdot 10^{27}\ \mathrm{cm}^2\,\mathrm{s}^{-1}$ for Pb–Pb collisions during the Long Shutdown 2 will provide a considerable extension of the scientific program of the ALICE experiment. Future studies of rare processes: heavy-flavour production, quarkonia and low-mass dileptons at low momenta (< 1 GeV/c) impose strict requirements on the upgrade of the ALICE detector and the Inner Tracking System (ITS).

In order to provide precise measurements of secondary vertices of short-lived particles containing heavy quarks at high interaction rates, the development of a new ITS is based on the application of fast detectors with high granularity. The current strategy of the ALICE ITS upgrade is based on using Monolithic Active Pixel Sensors (MAPS) ALPIDE developed by the ALICE collaboration with 0.18 μm TowerJazz technology. The upgraded ITS consists of seven layers of these sensors, mounted on ultra-lightweight carbon support structures with an embedded cooling system. This allows a reduction of the material budget down to the 0.3% X_0 for the inner layers and 1% for the outer layers. Ongoing qualification and characterization of single sensors and full-scale assemblies of sensors validate the declared properties of the detector, including detector efficiency (> 99.9 %) and low noise occupancy level (< $10^{6}\frac{hits}{pixel\cdot event}$) [1].

This talk will present the general strategy and design of the ALICE ITS upgrade, testing procedure for the detector qualification and current status of the detector production and assembly. Possible applications of the technologies, developed by the ALICE collaboration, will be also considered for the NICA project.

The reported study was supported by RFBR, research project No. 18-02-40075\19.

1. B.Abelev *et al.* // J. Phys. G. 2014. V.41. 087002.

INVESTIGATION OF ANTI-RADIATION MATERIALS AND PERSONAL PROTECTIVE EQUIPMENT WITH NEW MULTI-CHAMBER ELECTRON DETECTOR

Burmistrov Yu.M.[1], Lifanov M.N.[1], Potashev S.I.[1], Albats E.A.[2]
[1] *Institute for Nuclear Research of the Russian Academy of Sciences, Moscow;* [2] *Joint Stock Company "PTS", Moscow*
E-mail: mikelifanov@bk.ru

Study of radiation field in accidents at nuclear power plants [1] led to the creation of new personal protective equipment (PPE, in form of protective garments) and production industry. Also the methods to control the anti-radiation properties of materials and products are developed [2]. The protective garments shield rescuers working in a radiation accident from the exposure of several factors, including beta-radiation. Beta-radiation has a low penetrating ability – less than 1 cm in the biotissue in comparison with photons. However, large dose can cause radiation burn, aggravating the course of radiation sickness. The efficiency of beta-protection is estimated using the attenuation coefficient of beta-radiation, that is determined by the irradiation of the test sample from isotope source $^{90}Sr(^{90}Y)$.

It is proposed to use a new multi-chamber electron detector developed and manufactured in INR RAS to register beta radiation. The detector gives a possibility to measure not only the beta particle attenuation coefficient but the gradient of it. The detector consists of several sensitive gas chambers located one after another. An electron is detected only in first chamber or in a several series chambers depending on particle energy. The device can be used to study the protective properties of materials in order to optimize the mass of PPE to grade up their ergonomic performance. It also can be used to simulate and investigate the depth-dose distribution within biotissue after appropriate calibration. The multi-chamber electron detector has a high sensitivity. It can be operated in combination with sources of low activity, that are commensurate with the natural radioactivity. Thus, the radiation safety of the metrological personnel and the environment are ensured.

1. E.E.Gogin, V.M.Emelianenko, B.A.Benetskii, V.N.Filatov, Sochetannye radiacionnye porazhenija. M.: Izvestija, 2000.– 240 p. (text in Russian)
2. B.A.Benetskii and M.N.Lifanov, Basics of designing, testing, and checking of the combined-radiation protection garments for firefighters. // Bulletin of the Russian Academy of Sciences: Phisics. 2009. V.73. No.2. P.256.

LITHIUM-LOADED PLASTIC SCINTILLATORS

Nemchenok I.B.[1,2], Kamnev I.I.[1], Egorov V.G.[1,2], Suslov I.A.[2], Kazartsev S.V.[1]
[1] Joint Institute for Nuclear Research, Dubna, Russia; [2] Dubna State University, Dubna, Russia
E-mail: nemch@jinr.ru

The present investigation is devoted to obtaining and studying the properties of new lithium-loaded plastic scintillators (Li-PS) which are interesting as materials for the thermal neutron detection. Li-loaded organic scintillators have several advantages in comparison with the more using for this purpose gadolinium-loaded materials. The main advantage is that the thermal neutron capture by ^{6}Li produces ^{4}He and ^{3}H, which may be registered locally, within a few micrometers from the capture point, and unlike the use of gadolinium, gives the coordinates of the event.

Currently known lithium-loaded plastic scintillators have significant drawbacks: low transparency [1, 2–5], laborious [6] and unstable production technology [7].

Features of the properties of lithium (high polarity of the formed bonds, inability to form complex compounds, instability of organometallic compounds) sharply limit the range of its compounds for use as a lithium-loaded additives for Li-PS. However, we have developed a method for obtaining lithium-loaded PS based on copolymer of styrene and methacrylic acid. As the lithium-loaded additive one of its carboxylates was used. At the present investigation the light output and transparency of experimental samples of new materials were measured, their composition was optimized and the possibility and necessity of using naphthalene as a secondary solvent to improve scintillation characteristics were evaluated.

1. E.E.Baroni // Nuclear Electronics. 1962. V.1. P.131 (in Russian).
2. I.Sen // IEEE Transactions on nuclear science. 2011. V.58. No.3. P.1386.
3. I.Sen // IEEE Transactions on nuclear science. 2012. V.59. No.4. P.1781.
4. A.N.Mabe // Journal of Composites. 2013. V.2013. P.1.
5. A.N.Mabe // Radiation Measurements. 2014. V.66. P.5.
6. A.N.Mabe // Nuclear Instruments and Methods in Physics Research A. 2016. V.806. P.80.
7. R.D.Breukers // Nuclear Instruments and Methods in Physics Research A. 2013. V.701. P.58.

MAIN MAGNETIC FOCUS ION SOURCE: DEVICE WITH HIGH ELECTRON CURRENT DENSITY

Ovsyannikov V.P.[1], Nefiodov A.V.[2], Stegailov V.I.[1], Tyutyunnikov S.I.[1]
[1] *Joint Institute for Nuclear Research, Dubna, Russia;* [2] *Petersburg Nuclear Physics Institute, National Research Center "Kurchatov Institute", St. Petersburg, Russia*
E-mail: v.ovsyannikov@yandex.com

The Main Magnetic Focus Ion Source (MaMFIS) is a compact room temperature device of the next generation. The MaMFIS technology is based on the use of the local ion traps, which appear in crossovers of rippled electron beam [1, 2]. The current density j_e of the focused electron beam can reach extremely high values of about 20 kA/cm^2. Thus far a whole family of pilot models of ion source has been developed and tested. In recent experiments performed in Veksler and Baldin Laboratory of High Energy Physics at JINR, the x-ray spectra emitted due to the electron radiative recombination into the M- and L-shells of Ar, Ir, Ce and Bi ions are recorded (curve in Fig. 1).

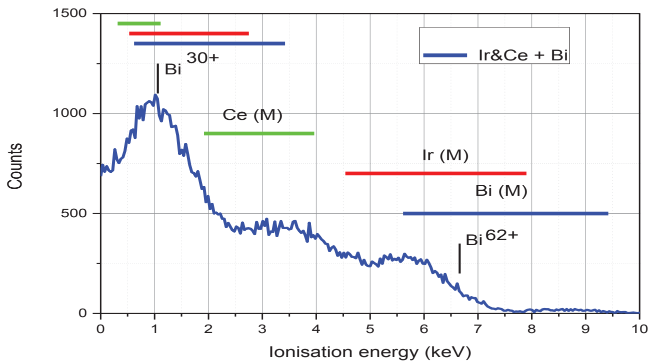


Fig. 1. Spectrum of radiation recombination of High Charge Ions of Ir, Ce and Bi.

A very promising application of the ion source is the charge breeding of short-lived radioactive isotopes. The deep ionization of electron shells allows one to eliminate the conversion decay channels. In this case, the life-time of nucleus can be increased by many orders of magnitude, so that the use of mass spectrometry become feasible. The extremely high electron current density realized in the MaMFIS results in very short ionization times and efficient production of highly charged ions of heavy elements. In particular, the time required for complete ionization of argon ions is about 1 ms, which is consistent with the current density $j_e \sim 20$ kA/cm^2.

1. V.P.Ovsyannikov and A.V.Nefiodov // Nucl. Inst. Meth. B 2016. V.370. P.32.
2. V.P.Ovsyannikov, A.V.Nefiodov and A.A.Levin // J. Physics: Conf. Series 2017. V.798. P.012170.

MODERN NEUTRON DETECTORS BASED ON INORGANIC SCINTILLATORS AND THEIR APPLICABILITY FOR LOW NEUTRON FLUX MEASUREMENTS

Ponomarev D.V.[1], Kalaninova Z.[1,2], Rozov S.V.[1], Rozova I.E.[1], Filosofov D.V.[1], Shakhov K.[1], Yakushev E.A.[1], Evsenkin V.[1]

[1] *Dzhelepov Laboratory of Nuclear Problems, JINR, Joliot-Curie 6, 141980 Dubna, Russia;*
[2] *Department of Nuclear Physics and Biophysics, Comenius University, 84248 Bratislava, Slovakia*

Email: ponom@jinr.ru

The crystals CLLB ($Cs_2LiLaBr_6$: Ce), CLYC (Cs_2LiYCl_6: Ce), NaIL(NaI:(Tl + Li)) are a new basis for modern radiation detectors. With such detectors it is possible to measure not only gamma radiation, but also neutron fluxes. Neutron's detection become possible thanks to the lithium in the crystals which has huge 940 barn cross section for thermal neutron's capture in the reaction $n + {}^6Li \rightarrow T + \alpha$. Because of such the advantage, these double purpose detectors are becoming common in a various number of experiments. Their applicability for measuring gamma and neutron backgrounds in low-background experiments yet to be properly studied. In such experiments, detectors must satisfy for more strong requirements: in particular, they have be able to measure low neutron and gamma fluxes, that could be partly achieved by highly efficient Pulse shape discrimination (PSD) of neutrons from gammas. In the same time, their intrinsic radiation background is crucial.

With this in mind, measurement of ambient neutron background is anything adequate test of the detectors. In this work characteristics of CLLB [1], CLYC [2] and NaIL [1] detectors were investigated from measurements of the natural ambient neutron background at JINR (which is on the level of $\sim 10^{-3}$ n cm^{-2} s^{-1}). The detectors' shape is right cylinder crystal with following sizes: 38 mm for the CLYC in which ^{6}Li enrichment is 96%, 51 mm for the CLLB that is loaded with natural lithium and 102 mm for NaIL in which the ^{6}Li atomic mass content is ~ 1%. The efficiency of neutron registration and possibility for PSD of neutron pulses from gamma and alpha events for each of the detectors and their contamination by radioactive isotopes were thoroughly studied during the measurements.

The work was partly supported by RFBR grant N 18-02-00159 A.

1. Produced by Saint-Gobain Crystals: https://www.crystals.saint-gobain.com
2. Produced by Scionix: https://scionix.nl

COVARIANCE BETWEEN SIGNALS OF PHOTODETECTORS AND SPECTROMETRIC CHARACTERISTICS OF SCINTILLATION SPECTROMETER

Samedov V.V.
National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow, Russian Federation
E-mail: v-samedov@yandex.ru

The exact mathematical description of processes occurring in a scintillation detector with several photodetectors allows receiving the correct formulae for the spectrometric characteristics of the scintillation detector. In addition to the formulae for the mean value and the variance of the amplitude at the output of each photodetector and the sum signal, the formula for the covariance between signals of scintillation spectrometer photodetectors was derived. From the analysis of this formula, which does not depend on the noise of electronics, it follows that under fulfillment of condition of local absorption of low energy X-rays, there is possibility of determining the contributions to the energy resolution of the scintillation detector from the electron-hole pairs statistics in the scintillation crystal and the fluctuations of the scintillation light yield caused by nonproportionality.

MEASUREMENT OF THE TOTAL REACTION CROSS SECTION ON THE DETECTION SETUP "MULTI"

Siváček I.[1,2], Penionzhkevich Yu.E.[1], Sobolev Yu.G.[1], Stukalov S.S.[1], Naumenko M.A.[1]
[1] *Flerov Laboratory of Nuclear Reactions of the Joint Institute for Nuclear Research, Dubna, Russia;* [2] *Nuclear Physics Institute of the Czech Academy of Sciences, Řež, Czech Republic*
E-mail: sivacek@ujf.cas.cz

Development in radioactive beams uncovered the opportunities to perform experimental research of nuclear properties in the region of nuclei far from β-stability line. Beams of light, neutron-rich nuclei can provide isotopes with high N/Z ratio, which allows the phenomena like neutron skin and neutron halo to be investigated. The portable spectrometer MULTI assembled at the beamline of the ACCULINNA in-flight separator in the FLNR JINR provide valuable data for total reaction cross section measurement ("bump" in the total reaction cross section in the region of ~ 17 A MeV), which are subject of further theoretical research. Spectrometer MULTI consists of an in-beam telescope for the projectile identification and a gamma spectrometer for the event tagging (Fig. 1). Construction of the spectrometer, principles of operation based on the modified transmission method and the event tagging with prompt gammas and neutrons accompanying the nuclear reactions, together with the experimental setup characteristics are discussed.

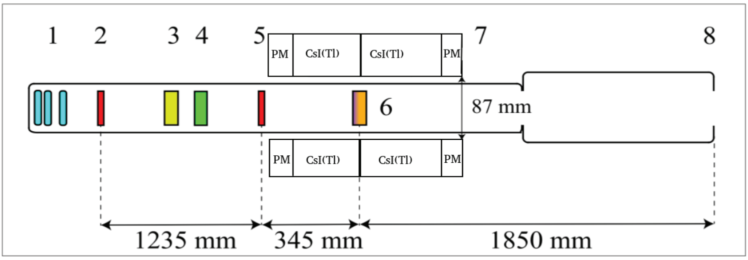


Fig. 1. Scheme of the detector setup "MULTI": 1 – degrader; 2 – active collimator AC1; 3 – 300 µm silicon pixel detector ΔE "16X-16Y"; 4 – 380 µm silicon detector ΔE_0; 5 – active colimator AC2; 6 – 243 µm active target Si – PIN; 7 – 12x CsI(Tl) gamma spectrometer; 8 – remote beam dump.

"MULTI" SET-UP FOR SPECTROSCOPY NUCLEAR REACTIONS

Stukalov S.S.[1], Penionzhkevich Yu.E.[1,2], Siváček I.[1,3], Sobolev Yu.G.[1]
[1] *Joint Institute for Nuclear Research, Dubna, Russia;* [2] *National Nuclear Research University MEPhI, 115 409 Moscow, Russia;* [3] *Nuclear Physics Institute, ASCR, Řež, Czech Republic*
E-mail: stukalov@jinr.ru

The detector setup "MULTI" is a multi-module 4-π γ-spectrometer designed for spectroscopy nuclear reactions and nuclear spectroscopy studies. Spectrometer is consist of γ part (9 $CeBr_3$–NaI(Tl) phoswitch scintillation detectors), neutron part (16 ^{3}He counters with hydrogenous moderators for decreasing energy of neutrons) (Fig. 1).

To measure the total cross sections, as well as the outputs of individual reaction channels, the addition of a $CeBr_3$–NaI(Tl) detectors 12 with a modular γ-spectrometer built at FLNR is provided. Spectra and response functions on n-γ radiation will be presented. In particular, it is planned to carry out measurements on the MAVR installation [1].

The spectrometer is continuously developed for achieving better detection parameters. Previous upgrade raised detection efficiency. Actual aim is to enhance gamma identification with precise, high-resolution gamma detectors for spectroscopy of prompt gamma. Parameters of the setup with ^{3}He counters and $CeBr_3$ detectors in various geometries (Fig. 1) are investigated with Monte Carlo method in Geant4. The efficiency of He_3 neutron counters is about 13% for neutrons with energy of 10 MeV (Fig. 2). Efficacy $CeBr_3$–NaI(Tl) detector was about 64% for gamma rays with an energy of 2 MeV. The efficiency at the peak of the total absorption is about 15% for 2MeV gamma quanta.

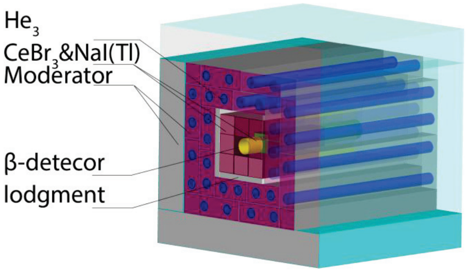


Fig. 1. Various geometries MULTI.

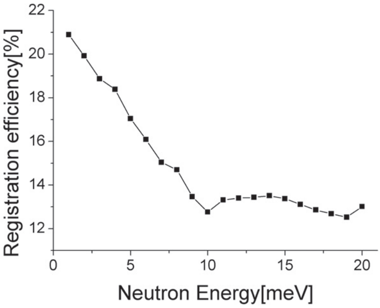


Fig.2. Efficiency of registration of neutrons of various energies.

1. G.D.Kabdrakhimova, Yu.G.Sobolev, I.N.Kuhtina, K.A.Kuterbekov, K.O.Mendibaev, Yu.E.Penionzhkevich // Phys. Atom. Nucl. V.80. P.32; Yad. Fiz. 2017. V.80. P.33.

NUCLEAR EMULSION IN LOW ENERGY STUDIES

Zarubin P.I.
Joint Institute for Nuclear Research (JINR), Dubna, Russia
E-mail: zarubin@lhe.jinr.ru

An overview of recent results obtained using the nuclear track emulsion (NTE in low energy applications is given. Developed half a century ago it remains a universal and cost-efficient detector [1]. With an unsurpassed spatial resolution of about 0.5 μm this technique provides observations from fission fragment up to relativistic particles tracks. NTE deserves further applications in fundamental and applied researches at modern accelerators and reactors as well as with radioactivity sources including natural ones. The application of NTE is grounded in experiments where tracks of nuclear particles cannot be reconstructed using electronic detectors.

The possibility of α spectrometry was verified and the ^{8}He atom drift effect was established in measurement of decays of ^{8}He nuclei implanted in NTE (Fig.). Correlations of α particle trios in ^{12}C nucleus splitting by 14.1 MeV neutrons as well as ^{7}Li and ^{4}He nuclei produced in ^{10}B breakups by thermal neutrons in boron-enriched NTE were studied. In this series of experiments, the NTE resolution proved to be perfect as expected physical effects in invariant mass distributions of reaction product ensembles were clearly observed. NTE samples are calibrated using 1.2 and 3 A MeV Kr and Xe ions. NTE surface exposures to a ^{252}Cf source allowed finding and measuring events containing fragment pairs and long range α particles, as well as fragment triples (Fig.). Implantation of uranium compounds into NTE performed recently allows one to expand experimental means of nuclear fission studies. The ^{8}Be accompanied channel of the ternary fission can become the "Golden key" for experimental verification of hypothesis of the collinear cluster tri-partition.

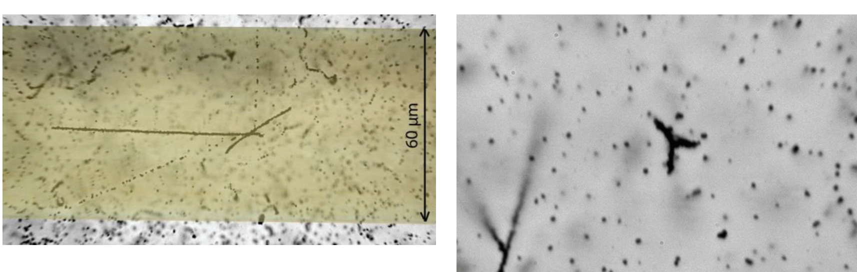


Fig. Macro photographs of hammer-like decay of the ^{8}He nucleus stopped in the nuclear track emulsion (left; superposed on a macro photograph of a human hair 60 μm thick) and Cf ternary fission (right).

1. P.I.Zarubin // Phys. At. Nucl. 2016 V.79 P.1525; arXiv:1902.04407.

STUDYING THE DISTRIBUTION OF THERMAL NEUTRONS FROM THE NEUTRON CHANNEL OF THE W-Be PHOTONEUTRON SOURCE OF INR RAS

Afonin A.A., Konobeevski E.S., Mordovskoy M.V., Ponomarev V.N., Solodukhov G.V., Zuyev S.V.
Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia
E-mail: afonin@inr.ru

W-Be photoneutron neutron source IN-LUE INR RAS [1] contains an extracted channel of thermal and fast neutrons located at an angle of 67º relative to the direction of the electron beam. Neutrons are extracted from the source through a collimator with a diameter of 30 mm.

The neutron flux was measured at distances of 0.7–4 m from the neutron source center. At each distance, the distribution of the flux density relative to the axis of the extraction channel was measured, using 11 activation detectors located along the line perpendicular to the channel axis with distances between them 5-15 cm.

The measurements were performed at average electron current of 50 μA. The activities of the irradiated $KMnO_4$ samples were measured in a low-background chamber [2] using a high purity germanium gamma spectrometer (HPGe).

The thermal neutron flux densities along the lines perpendicular to the axis of the collimator are measured. The flux density distributions were approximated by Gaussians, whose parameters depended on the distance of the samples from the center of the source. The approximation of these dependences by simple functions allowed us to obtain a picture of the spatial distribution of thermal neutrons relative to the axis of the output channel of the photoneutron source.

1. A.V.Andreev *et al.* // Bull. Russ. Acad. Sci.: Phys. 2017. V.81. P.748.
2. A.V.Andreev *et al.* // Nucl. Phys. and Eng. 2013. V.4. P.879.

MICROSTRUCTURE ANALYSIS OF STRIPPED CHAMBER CATHODE SAMPLES AFTER LIFE TESTS

Buzoverya M.E.[1], Karpov I.A.[1], Gavrilov G.E.[2]
[1] Russian Federal Nuclear Center – All-Russian Research Institute of Experimental Physics, Sarov, Russia; [2] Petersburg Institute of Nuclear Physics SRC "I.V. Kurchatov Institute", Gatchina, Russia
E-mail: otd4@expd.vniief.ru

Conducted is a complex study of cathode samples in prototypes of muonic proportional chambers CMS under their long-term irradiation by electrons from ^{90}Sr β-source. Morphology of copper surface of cathode samples is described and radiation defects are detected. The sample surface element composition is determined. The analysis of structure evolution as a function of irradiation conditions is fulfilled.

^{228}Ra - ^{228}Ac - ^{228}Th RADIONUCLIDE GENERATOR BASED ON A REVERSE-TANDEM SEPARATION SCHEME

Dadakhanov J.A.[1,2], Velichkov A.I.[1,3], Karaivanov D.V.[1,3], Temerbulatova N.T.[1,4], Marinov G.M.[1], Filosofov D.V.[1]

[1] Joint Institute for Nuclear Research, ul. Joliot-Curie 6, Dubna, Moscow region, 141980 Russia; [2] Institute of Nuclear Physics, Academy of Sciences of Uzbekistan Republic, Ulugbek, Tashkent, 100214 Uzbekistan; [3] Institute for Nuclear Research and Nuclear Power Engineering, Bulgarian Academy of Sciences, Tsarigradsko shose 72, Sofia, 1784 Bulgaria; [4] Institute of Nuclear Physics of the Kazakhstan Republic, ul. Ibragimova 1, Almaty, 050032 Kazakhstan

E-mail: dadakhanov@jinr.ru

Ac-228 is formed as a daughter decay product of Ra-228. The aim of the work is to separate ^{228}Ac and ^{228}Th from the parent isotope ^{228}Ra, and simultaneously from each other. The distribution coefficients of ^{225}Ac, ^{227}Th and ^{223}Ra between cation- exchange resin Dowex 50W × 8 200-400 mesh, NH_4^+ form, Chelex-100 Resin 200-400 mesh, NH_4^+ form, TODGA and UTEVA on the one hand and mixed solutions of CH_3COOH – CH_3COONH_4, on the other. A number of modifications of the operation of the ^{228}Ra-^{228}Ac-^{228}Th generator based on reverse separation schemes have been investigated. As chemical basis were used the studied generator systems: cation exchanger - ammonium acetate solution and acetic acid solution. As a tandem was selected a column with TODGA resin. The optimal operation setup of the ^{228}Ra-^{228}Ac-^{228}Th generator based on the reverse-tandem scheme with periodic transfer of the parent radionuclide to the liquid phase has been determined.

COMPARISON OF THE NEUTRON FLUX PERFORMED BY PhiTs AND THE EXPERIMENTALLY OBTAINED FLUXES MEASURED BY ^{3}He-GASEOUS PROPORTIONAL DETECTORS

Axelrod L.A.[1], Belov S.E.[2], Didenko G.P.[1], Ershov K.V.[1], Zinoviev V.G.[1]
[1] Petersburg Nuclear Physics Institute named by B.P.Konstantinov of NRC "Kurchatov Institute"; [2] V.G. Khlopin Radium Institute
E-mail: ershov_kv@pnpi.nrcki.ru

Development of radiation protection system and neutron moderator for Pu-Be neutron source gives rise to special problem of modeling spectrum of such source. The problem is not so simple, because the sources like this have continuous spectrum from some keV up to 10 MeV and more. The neutron flux depends on neutron energy, size of plutonium dioxide grains and other technology factors. In [1] the simulation of Pu-Be source had been made according with factory specification sheet data. The software PhiTs version 3.02 was used for calculations. The PhiTs is a software package which uses Monte Carlo calculation of particle and heavy ion transport. The core of package uses code MTC/JAM, which utilizes MCNP4 code for calculation of the neutron and photon transport.

The results of simulation of neutron spectra are presented in Fig. 1. A neutron spectrometer with gas-filled proportional detector SNM-50 was used to verify the correctness of the simulation. This counter is intended for registration of slow neutrons, so a variety of moderators (borated and "pure" polyethylene) had been used to reduce neutron energy. At the same time, the protective properties of a standard vessel for Pu-Be source were evaluated.

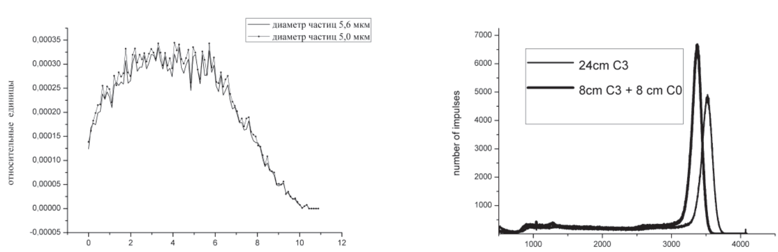


Fig. 1. On the left neutron spectrum from [1], on the right example of the experimental amplitude spectra for two different moderators.

1. K.V.Ershov // PNPI Preprint. 2018.

DATA PROCESSING IN THE TIME-OF-FLIGHT MASS-SPECTROMETRY OF HEAVY IONS

Kamanin D.V.[1], Pyatkov Yu.V.[1,2], Goryainova Z.I.[1], Zhuchko V.E.[1], Alexandrov A.A.[1], Alexandrova I.A.[1], Malaza V.[3], Kuznetsova E.A.[1], Strekalovsky A.O.[1], Strekalovsky O.V.[1,4]

[1] Joint Institute for Nuclear Research, 141980 Dubna, Russia; [2] National Nuclear Research University "MEPHI", 115409 Moscow, Russia; [3] University of Stellenbosch, Faculty of Military Science, Military Academy, Saldanha 7395, South Africa; [4] Dubna State University, 141980 Dubna, Russia

E-mail: zoyag@yandex.ru

Experimental studies of the rare multibody decays of the low excited heavy nuclei carried out in our group [1] require specific methods: registration of the pairs of fission fragments with a short follow-up interval; detailed analysis of the shapes of the spectrometer signals related to the events of interest caused the formation of short detector signals; use of fast multichannel digitizers such as flash-ADC DT5742. Data processing algorithms are an integral part of the experimental technique. Two of these algorithms that provide respectively energy and time spectrometry of heavy ions using PIN diodes are considered in this report. The algorithms were tested recently in the special experiment at the beam of the IC-100 accelerator, FLNR, JINR.

1. D.V.Kamanin, Yu.V.Pyatkov, "Clusters in Nuclei - Vol.3" ed. by C.Beck, Lecture Notes in Physics 875, pp.183-246 (2013).

SiC NUCLEAR RADIATION DETECTORS

Hrubčín L.[1,2], Zat'ko B.[1], Gurov Yu.B.[2,3], Boháček P.[1], Sandukovsky V.G.[2], Rozov S.V.[2], Ivanov O.M.[2], Skuratov V.A.[2], Schlattauer L.[2,4]

[1] Institute of Electrical Engineering, Slovak Academy of Sciences, Bratislava, Slovak Republic; [2] Joint Institute for Nuclear Research, Dubna, Russia; [3] National Research Nuclear University (MEPhl), Moscow, Russia; [4] Palacky University, Olomouc, Czech Republic

E-mail: ladislav.hrubcin@savba.sk

Silicon carbide (SiC) is a promising material for fabrication radiation-tolerant electronics, high-temperature electronics as well as for nuclear radiation detectors working in harsh environments. Mainly, 4H-SiC polytype is mostly investigated for its physical properties, e.g.: the band gap energy is 3.26 eV, the mean energy of electron-hole pair creation is 7.78 eV, the electron saturation drift velocity is $2x10^7$ cm/s and the breakdown voltage is $2x10^6$ V/cm at room temperature. Detectors based on high quality epitaxial layer of 4H-SiC show a high radiation resistance [1, 2] and good spectroscopic performance, at room and also at elevated temperatures (> 300°C) [3].

Detector structures [4] were prepared from a 70 μm thick nitrogen-doped 4H-SiC layer (donor doping ~ 1 x 10^{14} cm^{-3}) grown by the liquid phase epitaxy on a 3" 4H-SiC wafer (donor doping ~ 2 x 10^{18} cm^{-3}, thickness 350 μm). The Schottky barrier contact (Au/Ni with thicknesses 30 and 10 nm) with diameter of 2.0 mm was formed on the epitaxial layer through a contact metal mask, while full area contact from Ti/Pt/Au was evaporated on the other side (substrate).

Electrical characteristic of prepared SiC detectors were measured using Keithley measuring complex, which consisted of 4200A-SCS Parameter Analyzer, 4200A-CVIV Multi-Switch, 2657A High Power System and CVU-3K-KIT, which allow to perform high voltage I-V and C-V measurements up to 3000V.

SiC detectors were used in experiments at the IC-100 cyclotron of the Joint Institute for Nuclear Research in Dubna. The degradation of SiC detectors under impact of the high-energetic beam of heavy ions of xenon were studied, as well as the effect, which is known in the literature as Pulse Height Defect [5]. The radiation resistance of SiC detectors was almost a hundred times higher as for Si detectors. High radiation resistance of SiC detectors and their good energy resolution allow one to use these devices for long-term monitoring of heavy ion beams.

1. E.V.Kalinina // Semiconductors. 2007. V.41. P.745.
2. F.H.Ruddy and J.G.Seidel // NIM in Phys. Res. B. 2007. V.263. P.163.
3. E.V.Kalinina *et al*. // Tech. Phys. Lett. 2008. V.34. P.210.
4. B.Zat'ko *et al.* // Applied Surface Science. 2018. V.461. P.276.
5. B.D.Wilkins *et al.* // Nucl. Instrum. & Meth. 1971. V.92. P.381.

DATA CORRECTION METHOD FOR IMPROVING SPATIAL RESOLUTION OF NEUTRON POSITIONAL SENSITIVE ^{10}B-DETECTOR

Karaevsky S.Kh.[1], Potashev S.I.[1], Drachev A.I.[2], Burmistrov Yu.M.[1]
[1] *Institute for Nuclear Research of Russian Academy of Sciences, Moscow, Russia;* [2] *State Research Institute for Chemistry and Technology of Organoelement Compounds, Moscow, Russia*
E-mail: karaevsky@inr.ru

High spatial resolution with good uniformity is required in the study of nanoparticles by small-angle scattering and diffraction of neutron. The accuracy of determining the neutron coordinate by the charge division method for a position-sensitive detector with an active layer of boron-10 depends on the signal-to-noise ratio and the nonlinearity of amplifier path at a signal processing [1]. The nonlinearity leads to the fact that the spatial resolution depends on signal amplitudes and coordinates [2]. An improved data correction method is proposed. It takes into account an additional factors affecting the uniformity of the detector spatial resolution. As a result, the spatial resolution was uniform within of values 2 and 3.5 mm on X and Y correspondingly.

Fig.1 on the left shows the dependence of the sum of pulse heights from two amplifiers which are connected to two ends of distributed resistance versus the coordinate. Fig.1 on the right shows the dependence of such sum of amplitudes versus the amplitude of the input signal for various coordinates. Taking into account a both of these, it is possible to determine the real magnitudes of the signal amplitude and the neutron coordinate.

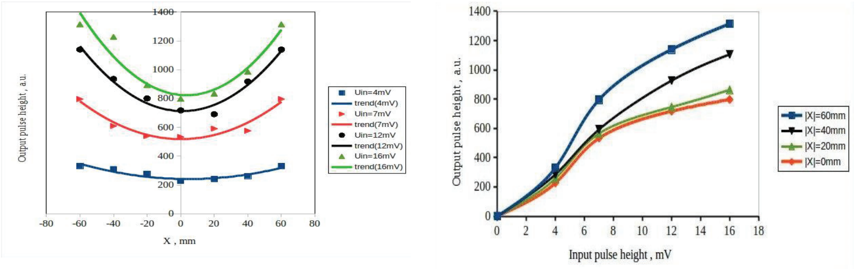


Fig.1. The sum of pulse heights from two amplifiers which are connected to two ends of distributed resistance versus the coordinate (on the left) and the amplitude of the input signal.

1. S.I.Potashev, Yu.M.Burmistrov, A.I.Drachev, S.Kh.Karaevsky, V.Solodukhov // J. of Surface Investigation: X-ray, Synchrotron and Neutron Techniques. 2018. V.12. P.627.
2. S.Kh.Karaevsky, S.I.Potashev, A.I.Drachev, Yu.M.Burmistrov // Bull. Russ. Acad. Sci. Phys. 2018. V.82. P.748.

DOSIMETRIC MEASUREMENTS IN CAPTURE GAMMA RADIATION FIELD WITH ENERGIES UP TO 10 MEV

Guzov V.D., Kozhemyakin V.A., Komar D.I., Lukashevich R.V.
ATOMTEX SPE, Minsk, Belarus
E-mail: info@atomtex.by

The use of dosimeters calibrated in reference fields with corresponding energies for correct estimation of dose loads for personnel working in high-energy gamma-radiation fields with energies above 3 MeV is required. The creation of reference fields with gamma-radiation energies up to 7 MeV is essential for photon radiation dosimetry at nuclear power plants, where a significant gross dose rate component is stipulated by the radiation with an energy of 6.13 MeV associated with the $^{16}O(n, p)^{16}N$ reaction in the water cooling loop. Apart from nuclear power plants such tasks occur on electron accelerators, widely used for therapeutic, industrial and other purposes.

The state verification schedule (Republic of Belarus and Russian Federation) stipulates the use of ^{241}Am (0.06 MeV), ^{137}Cs (0.662 MeV) and ^{60}Co (1.250 MeV) radionuclides for reference dosimetry measurements of gamma radiation in the range from 0.06 to 3 MeV. No standard calibration and verification is performed for nuclear physics equipment in bremsstrahlung with an energy above 3 MeV generated by accelerators. Dosimeters calibrated in the radionuclide sources fields may not measure the dose rate from high-energy gamma radiation correctly. At the same time, there is a nomenclature list of instruments with various detector types, where the energy range has to be expanded to 7 MeV or 10 MeV following the relevant research is carried out.

High-energy capture gamma-radiation fields with energies up to 7 MeV (titanium target) and up to 10 MeV (nickel target) to calibrate the energy scale and verify the energy dependence of developed spectrometric and dosimetric measuring instruments were generated by AT140 Neutron calibration facility for radiation monitoring instruments according to the requirements of international standard ISO-4037:2019.

The report presents the results of experimental studies. The standard dosimeter AT5350/1 with a highly sensitive ionization chamber TM32002 was used to determine the air kerma rate and ambient dose equivalent rate of gamma radiation.

DEFECT FORMATION IN AlN AFTER IRRADIATION WITH He^{2+} IONS

Kozlovskiy A.L.[1], Zdorovets M.V.[1,2,3]
[1] *The Institute of Nuclear Physics of Republic of Kazakhstan, Almaty, Kazakhstan;*
[2] *L.N. Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan;* [3] *Ural Federal University, Yekaterinburg, Russia*
E-mail: artem88sddt@mail.ru

In modern nuclear power engineering, special attention is paid to the development and use of new structural materials in the reactor core as the first wall. Also, one of the important requirements for this class of materials is high radiation and corrosion resistance to effects of various types of ionizing radiation, as well as to the accumulation in the structure of gas inclusions, such as helium and hydrogen, which are formed as a result of nuclear reactions during irradiation [1–3].

The paper presents results of studies on defect formation processes, radiation resistance, changes in the conductive and insulating characteristics of AlN ceramics under irradiation with 40 keV He^{2+} ions. The radiation fluence ranged from 10^{15} to $5\cdot10^{17}$ ion/cm^2. Using the method of X-ray structural analysis, it has been established that an increase in the irradiation fluence leads to a decrease in intensities of diffraction peaks and a change in lines shape, which indicates an increase in the concentration of distortions and stresses in the crystal structure. The change in concentration of deformation in the structure is due to the increase in the content of introduced helium and the formation of cascades of secondary defects and vacancies. At large fluences of irradiation (above 10^{17} ions/cm^2), diffraction patterns show the formation of a halo characteristic of X-ray amorphous or highly disordered impurity inclusions and the formation of spherical inclusions in the surface layer, the average size of which varies from 50 to 100 nm. The decrease in resistance and thermal conductivity as a result of irradiation and the formation of helium inclusions in the structure indicates a degradation of structural characteristics, as well as a decrease in radiation resistance, which is caused by a drop in strength characteristics.

1. A.L.Kozlovskiy *et al*. // Vacuum. 2018. V.153. P.254.
2. W.J.Weber // Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms. 2000. V.166. P.98.
3. K.Dukenbayev *et al*. // Vacuum. 2019. V.159. P.144.

IDENTIFICATION OF NUCLIDES IN ^{237}Np, ^{238}U TARGETS AFTER THEIR IRRADIATION BY THE "QUINTA" NEUTRON FIELD

Tyutyunnikov S.I.[1], Kilim S.[2], Szuta M.[2], Strugalska-Gola E.[2], Solnyshkin A.A.[1], Stegailov V.I.[1], Kryachko I.A.[1], Khushvaktov J.[1], Shakun N.G.[1], Tran T.N.[1], Guseva S.V.[1], Perevoshchikov L.L.[1], Balandin A.S.[1]

[1] Joint Institute for Nuclear Research, Joliot-Curie 6, Dubna, Moscow region, Russia, 141980; [2] National Centre for Nuclear Research ul. Andrzeja Sołtana 7, 05- 400 Otwock, Poland

E-mail: tsi210647@yandex.ru, stegajlov2013@yandex.ru

The aim of this work is to study the gamma spectra of the nuclei produced in the ^{238}U and ^{237}Np targets. The experiments were carried out within the framework of the project "Energy and Transmutation of RAW" and aimed at solving the problem of the transmutation of actinides - neptunium, americium and plutonium.

The aim of this paper is to compare the cross sections for the capture and fission reactions at different radii of the "Quinta" setup and to determine their ratio [1] for the residual nuclei in the ^{237}Np (Fig.1), ^{238}U targets in the neutron field [2, 3] at different radii (R max ~ 150 mm) of uranium (^{238}U) assembly "Quinta" with its irradiation by protons with energy 660 MeV.

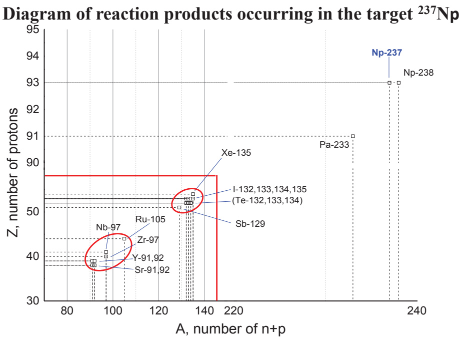


Fig.1. Diagram of reaction products occurring in the target ^{237}Np.

There are two channels for the interaction of actinides with neutrons – fission and capture [1]. The activity of the formed products is determined by registration of the gamma radiation by germanium detectors.

In the report, the experimental results are compared with calculations for different neutron energies.

1. S.Kilim *et al*. // Nucleonica. 2018. V.63(1). P.17.
2. S.I.Tyutyunnikov // 24-Inter. Baldin Seminar, Russia, Dubna, September, 17-22, 2018.
3. A.A.Smirnov, V.I.Stegailov, S.I.Tyutyunnikov, *et al.* // "Nucleus2015", St-Petersb. P.257.

ELECTRON CAPTURE AFTER-EFFECTS IN COMPLEXES OF ^{111}In AND ^{152}Eu INVESTIGATED BY PERTURBED ANGULAR CORRELATION

Kurakina E.S.[1,2], Inoyatov A.Kh.[1], Karaivanov D.V.[1,3], Radchenko V.[4], Velichkov A.I.[1,3], Magomedbekov E.P.[2], Filosofov D.V.[1]

[1] Joint Institute for Nuclear Research, Dubna, Russia; [2] D. Mendeleev University of Chemical Technology, Moscow, Russia; [3] Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria; [4] TRIUMF, Vancouver, Canada

E-mail: kurakina@jinr.ru

One of the key components of radiopharmaceuticals for Targeting Imaging and Therapy is a stable bifunctional chelating system with radionuclide attached. After-effects of the radioactive decay can cause a release of radionuclide from the complex with a chelating agent [1]. Perturbed angular correlation (PAC) of γ-rays is one of the few effective techniques to study local environment of the nucleus in liquids with very small concentration of the probe up to 10^{-12} M [2, 3].

Herein, two radionuclides ^{111}In ($T_{1/2}$ = 2.8 d) with following parameters: intermediate half-life $t_{1/2}$ = 85 ns, nuclear spin I = +5/2, cascade 171–245 keV and ^{152}Eu (13.5 y) with parameters: $t_{1/2}$ = 1.4 ns, I = 2 and cascade 1408–122 keV complexed with diethylenetriaminepentaacetic acid (DTPA) are investigated by PAC.

The after-effects of electron capture decay which lead to complex disintegration are studied using nuclei mentioned above. Potential mechanism of post-decay processes for f-elements is presented.

1. K.P.Zhernosekov *et al.* // Radiochim. Acta. 2007. V.95. P.319.
2. L.Hemmingsen, T.Butz // Encycl. Inorg. Bioinorg. Chem. 2011. P.1.
3. D.V.Filosofov *et al.* // Jahresbericht Inst. für Kernchemie. 2004. V.3. P.51.

USE OF 120-CM CYCLOTRON FOR THE STUDY OF THE ACCELERATED DEUTERONS AND HYPOMAGNETIC ENVIRONMENT COMBINED EFFECT ON THE LETTUCE SEEDS

Lebedev V.M.[1], Platova N.G.[2], Spassky A.V.[1], Trukhanov K.A.[2], Zagirdinova E.F.[3]

[1] Skobeltsyn Institute of Nuclear Physics Lomonosov Moscow State University, Moscow, Russia; [2] Institute of Biomedical Problems of the RAS, Moscow, Russia, [3] Faculty of Physics, M.V. Lomonosov Moscow State University, Russia

E-mail: aspass@yandex.ru

At the 120-cm cyclotron of the SINP MSU the effects of deuterons were studied on seeds of lettuce Lactuca sativa L. of the strain “Moskovskiy parnikoviy”. Seeds were irradiated in flat cuvettes with walls of thin mylar films. The energy of deuterons falling on seeds was 13.8 MeV. The magnitude of the linear energy transfer (LET) is close to that of the LET of the relativistic nuclei of the galactic cosmic rays carbon group, which makes it possible to simulate the effect of galactic cosmic rays in long-range and long-term space flights on biological objects. Seeds irradiated by deuterons in doses of 70, 580 and 5800 Gr were germinated under normal and hypomagnetic environment (HME) with values of the geomagnetic field attenuation of 50 and 1000 times. To weaken the geomagnetic field, a camera made of magnetic material (permalloy) was used. Dependencies are given of the seeds germination rate and the length of the root on the 7th day of these conditions. Irradiation of lettuce seeds with deuterons in the above doses leads to a delay in the onset of germination and a decrease in the number of germinated seeds. In the process of seed germination in the HME, the radiation response of the irradiated seeds changes depending on the dose.

The work was performed using equipment acquired at the expense of the Moscow University Development Program and with the support of the Fundamental Research Program of the Russian Federation State Research Center – Institute of Biomedical Problems of the Russian Academy of Sciences (IBMP RAS).

LOW RADIOACTIVE NH_4Cl FLUX

Mirzayev N.A.[1,2], Filosofov D.V.[1], De Jésus M.[3], Karaivanov D.V.[1,4], Marinov G.M.[1], Rakhimov A.V.[1], Rozov S.V.[1], Temerbulatova N.T.[1], Yakushev E.A.[1]

[1] Joint Institute for Nuclear Research, DLNP, 141980 Dubna, Russian Federation; [2] Institute of Radiation Problems of Azerbaijan National Academy of Sciences, Baku, Azerbaijan; [3] Univ Lyon, Université Lyon 1, CNRS/IN2P3, IPN-Lyon, F-69622, Villeurbanne, France; [4] Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

E-mail: mirzayev@jinr.ru

Solder wire connection remains the basis of reliable contacts. This is relevant for experiments that require minimizing the amount of structural materials, such as searching for and investigating rare phenomena in low-background environments. At the same time, despite the minimum quantities used, the solder and flux must meet the requirements of radioactive purity. The report about radioactive-less solder [1] depicts a problem with unacceptable radioactive contamination of commercially available fluxes.

In this work we report production of low-radioactive NH_4Cl inorganic flux from highly purified components. $NH_3 + HCl \rightarrow NH_4Cl$ reaction was chosen for synthesis as satisfying to the two main requirements: the minimum quantity of initial components with higher purity can be used and simplicity of implementation. Main stages of the production were: 1) purification of the acid; 2) transfer of gas phase ammonia to the acid (synthesis of ammonium chloride solution); 3) obtaining NH_4Cl in a solid state by drying in a vacuum under room temperature. All the processes were performed in a clean room (JINR, Dubna) with using chemically resistant vessels made from radio-pure materials. The final product obtained is a dry salt of ammonium chloride in form of white granules. A pure HCl mass of 250 grams and 500 grams of NH_4OH were used to obtain 80 grams of the salt.

A γ-ray spectrometry screening has been performed to estimate the radioactivity level of the final product with a sample of 50 grams of ammonium chloride. An ultra-low background HPGe n-type detector (210 cm^3), part of the EDELWEISS experiment [2] infrastructure in the LSM underground laboratory, was used for these purpose. The detector sensitivity is on a level of mBq for main natural radio-isotopes (U/Th/K). After 35 days of counting, no detectable excess was observed above the detector internal background. An ICP-MS elemental analysis also did not reveal the presence of any unexpected admixture to the synthesized ammonium chloride.

Given the successful results on the tested solders made using the home-made ammonium chloride salt as the flux, the objective of creating a low-radioactive flux was achieved.

The work was partly supported by RFBR grant N 18-02-00159 A.

1. D.S.Akerib *et al.* // NIM A. 1997. V.400. P.181.
2. E.Armengaud *et al.* // JINST. 2017. V.12(08). P08010.

GEANT4 SIMULATIONS OF THE HIGH-ENERGY NEUTRON BEAM OF GNEIS TOF-FACILITY

Nakin A.V., Vorobyev A.S., Shcherbakov O.A.
Petersburg Nuclear Physics Institute of National Research Centre "Kurchatov Institute", Gatchina, Russia
E-mail: andrey.nakin@mail.ru

The computer simulations of proton-induced neutron source are proceeded using GEANT4 toolkit. The simulation program models the geometry of high-energy neutron beam of the time-of-flight spectrometer GNEIS [1,2] and uses the corresponding primary proton energy of 1 GeV. In this facility, a thick lead target is used as a neutron source. The distance between the target and the neutron detector is 36 meters.

An intensity, energy spectrum and angular distribution of simulated neutrons in a range of 1 to 1000 MeV are obtained and compared with the measured characteristics of the neutron beam.

The different high-energy nucleon-nucleus interaction models implemented in GEANT4 coupled with a high precision neutron model were found to reproduce satisfactorily the experimental data thus providing the confidence on the use of GEANT4 for simulation of the GNEIS facility.

1. N.K.Abrosimov *et al.* // Nucl. Instr. Meth. A. 1985. V.242. P.121.
2. O.A.Shcherbakov *et al.* // IEEE Trans. Nucl. Sci. 2016. V.63. P.2152.

THERMOGRAVIMETRIC ANALYSIS OF P(VDF-TeFE)/nano-Si COMPOSITS WITH GAMMA RADIATION

Nuruyev I.M.[1], Nuruyev S.M.[2,3], Nuriyev M.A.[2]
[1] Center for Strategic Scientific Research of ANAS, Baku, Azerbaijan; [2] Institute of Radiation Problems of ANAS, Baku, Azerbaijan; [3] Joint Institute for Nuclear Research, Dubna, Russia
E-mail: nuruyev_ibrahim@mail.ru

Initial and modified composites based on 1% and 12.7% silicon with polyvinylidenefluoride copolymer (P(VDF-TeFE)) with gamma irradiation have been studied by thermogravimetric analysis (TGA) method [1]. On the basis of analysis of the obtained results, the interaction between composite components has been studied.

The results obtained from the thermodynamic region of TGA spectra of composites presented in the table.

Calculated parameters of P(VDF-TeFE)/nano-Si composites from TGA spectra

Volume, %	D, kGy	M_{start}, %	M_{final}, %	T_{start}, °C	T_{final}, °C	Δm, %	ΔT, °C	$v=\Delta m/\Delta T$, %/min.	Δm_{res}, % (540°C)
0%	0	98	39.5	440	493	58.5	53	1.10	26.6
1%	0	95	31	465	497.2	64	32.2	1.99	32
	100	92.7	34.3	449.5	487	58.4	37.5	1.56	33.7
	300	92	40	434	480	52	46	1.13	40.5
12.7%	0	98	30	469	492	68	23	2.96	29
	100	98.6	37.8	441	479.7	60.8	38.7	1.56	35.9
	300	96	39	426.4	477.6	57	51.2	1.11	39.6

As shown in the table, for initial P (VDF-TeFE) thermal degradation starts at 440°C and continues to ~ 493°C. The polymer matrix loses most of its mass around this temperature. The results of the polymer and composites in the table indicate that the beginning of degradation of the composites is moving towards higher temperatures. This is an indication of the higher exploitability of composites. Gamma irradiation reduces the cleavage rate of composites ($v = \Delta m/\Delta T$), increases the residual mass (Δm_{res}) [1]. The changing parameters of irradiated composites related the crosslinking processes in the polymer and the structural changes in the composite, which related increased interphase interaction in the polymer-filler boundary.

The observed changes of after gamma radiation show improving of crystallization phase, mechanical and thermal properties of composite structures.

1. E.Mansfield // "Modeling, Characterization, and Production of Nanomaterials". 2015. P.167. https://doi.org/10.1016/B978-1-78242-228-0.00006-5.

AUTOMATED SYSTEMS TO REGISTER FLUENCE OF NEUTRONS WITH ENERGIES HIGHER THAN 0.1 MEV IN REAL TIME SCALE FOR RADIATION RESISTANCE TESTING

Beloshitskiy K.A., Koshelev A.S., Mochkaev M.V., Ovchinnikov M.A., Pikulina G.N., Piskorskij I.M., Raspopov N.V., Yukhnevich V.A.
Russian Federal Nuclear Center – All-Russia Research Institute of Experimental Physics, Sarov, Russian Federation
E-mail: otd4@expd.vniief.ru

Radiation testing combines with the measurements of neutrons fluence at a sample location. There are considered the parameters and concepts of two automated systems providing the fluence detecting of neutrons with energies higher than 0.1 MeV. The measurements are made in radiation zone of a research nuclear facility in real time scale. The first system measures the time variation of neutron fluence during irradiation using registration technique of neutron flux density by fission chambers with threshold radiators [1]. The second system uses silicon transistors as neutron detectors. Collectors of the transistors are connected by a common bus and their base current is measured taking into account temperature impact into operating mode of detectors [2]. There are analyzed the highs and lows of both systems.

1. L.E.Dovbysh *et al.* // Vopr. At. Nauki Tekh., Ser.: Fiz. Yad. Reakt., 2014. V.3. P.83.
2. M.A.Ovchinnikov *et al.* // RF Patent # 2650810. Published 17.04.2018 Bulletin V.11

THE CURRENT STATE AND DIRECTIONS OF FURTHER DEVELOPMENT OF HIGH-TECH METHODS OF RADIATION STERILIZATION

Matveichuk I.V.[1], Rozanov V.V.[1,2], Chernyaev A.P.[2], Nikolaeva N.A.[3], Krasnov S.A.[1]

[1] Scientific and Educational-Methodical Center of Biomedical Technology of the all-Russian Research Institute of medicinal and aromatic plants, [2] Physical Faculty of Lomonosov Moscow State University, Moscow Russia, [3] M.K.Ammosov North-Eastern Federal University, Yakutsk, Russia

E-mail: vrozanov@mail.ru

The successes achieved in nuclear physics are finding an ever wider practical application in related fields of science and technology. They are important for biomedical applications, in particular, sterilization. This opens up prospects for the creation of modern health-saving technologies based on the use of high-tech methods of influencing biological tissues and the study of their response.

Analysis of the current state of the applied methods of biological tissue sterilization indicates the need for their improvement with the introduction of new high-tech, highly efficient and safe technologies into practice.

The authors carried out experimental approbation of a number of innovative technologies for the sterilization of bone implants, based both on the use of ozone-oxygen mixtures [1] and the combined effects on biological tissues of ozone in combination with radiation treatment with a stream of fast electrons at various doses [2]. The efficiency of the two-stage sterilization technology has been established, which allows more than twice reducing the dose of radiation exposure from its generally accepted value of 25 kGy to 11 kGy.

The results confirm the need for further development of effective radiation technologies, the study of the possibility of reducing the absorption dose without compromising the sterility of bioimplants through the use of X-rays along with gamma rays and fast electron beams [3]. An important issue is a thorough study and consideration of possible changes [4] in the morphology, physical and osteinductive properties of bone implants.

1. V.V.Rozanov *et al.* // Revista Española de Ozonoterapia. 2018. V.8. № 2. suppl. 1. P.74.
2. I.V.Matveichuk *et al*. // Patent of Russian Federation № 2630464, (29.07.2016).
3. U.A.Bliznyuk *et al*. // Bulletin of the Russian Academy of Sciences: Physics, V 82. №6. P.740.
4. Nguyen Huynh *et al.* // Bone. 2013. №57. P.194.

STUDY OF THE POSSIBILITY OF CONTROLLING THE DOSE DISTRIBUTION DYNAMICS IN RADIATION THERAPY ON PHOTON AND POSITRON BEAMS

Sinelnikov A.G., Chernyaev A.P., Morozova E.P.
Lomonosov Moscow State University, Moscow, Russia
E-mail: sinelnikov1995@gmail.com

Radiation therapy occupies a significant place in the treatment of cancer. In recent years, radiotherapy techniques have been introduced and aimed at improving the existing nuclear-physical methods in medicine [1].

We propose to develop a method that can become a way of assessing the dose distribution in the patient's body during irradiation. The method is similar to that used in PET-tomography and is based on the registration of annihilation photons. The production of electron-positron pairs is one of the processes that occurs when photons interact with matter. The resulting positrons annihilate further, forming photons. By registering such photons, it is possible to obtain information that after appropriate processing will allow us to conclude that the dose distribution in dynamics.

To study the proposed method a cycle of computer experiments was performed using the Geant4 package. As part of the work performed the correlation between the distribution of the absorbed dose of photon and positron radiation and the distribution of positron annihilation points was estimated. The energy spectra of the bremsstrahlung and annihilation photons were analyzed. A function that allows the calculation of the dose distribution from the distribution of positron anigilation points was obtained.

A discussion of the data is conducted.

1. Su Jung An, Cheol-Ha Beak, Kisung Lee, Yong Hyun Chung. “A simulation study of a C-shaped in-beam PET system for dose verification in carbon ion therapy” // Nuclear Instruments and Methods in Physics Research A.

ESTIMATION OF THE ABSORBED DOSE IN FOOD DURING ELECTRON IRRADIATION

Avduhina V.M., Bliznuk U.A., Borschegovskaya P.Yu., Chernyaev A.P., Ipatova V.S., Leontiev V.A., Semenova M.N., Studenikin F.R.
Physics Department, Lomonosov Moscow State University, Moscow, Russia
E-mail: f.studenikin@gmail.com

Currently, the international community has a growing interest in foodstuff irradiation to extend the shelf life [1, 2]. A recent series of researches suggest that food treated with up to 10 kGy retains its nutritional value and contain no toxic substances [3]. However, to enable consistent quality of the product, it is important to carefully monitor the absorbed radiation dose. Failure to ensure the required dose can lead to undesirable changes in physical, chemical and organoleptic parameters.

This study provides the algorithm for the estimation of absorbed dose during 1 MeV electron irradiation. The experiment used minced trout homogenate. Samples were treated by 1 MeV electron beam using the industrial electron accelerator UELR-1-25-T-001. Each time during irradiation the total charge absorbed by the plate was monitored to determine the required dose of irradiation. The samples were irradiated with 7 different doses.

The programming code GEANT 4 based on Monte-Carlo method was used to estimate the dose absorbed by samples. The simulation took into account the electron spectrum as well as the geometry of samples.

The dose during irradiation was monitored using ferrous sulfate (Fricke) dosimeter. The radiation scheme corresponded to the irradiation of samples with minced trout homogenate.

To calculate the dose absorbed by the minced trout homogenate the following algorithm was used. During the simulation the water phantom in cylindrical polypropylene tubes of the same geometry was replaced with the Fricke solution, in which the absorbed dose was calculated in the same way as in the water phantom.

It can be concluded that the conversion algorithm to convert the dose measured with dosimeter to the dose absorbed by homogenate can be used provided that the geometry and composition of dosimetry solution and samples coincide. If products a different geometry are used the dose in dosimeter should be converted to the dose absorbed by the products using programming code.

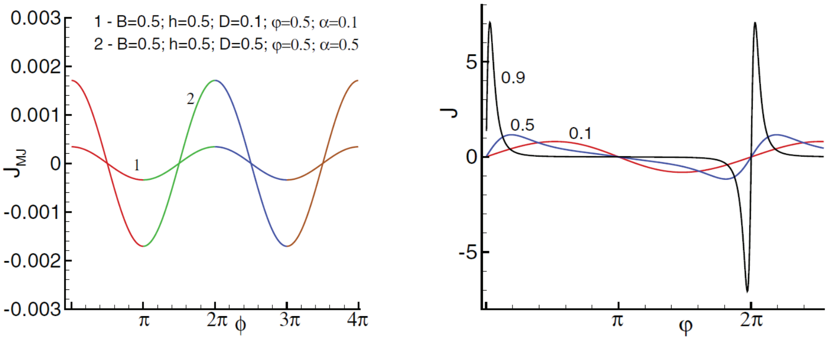
1. N.I.Sanzharova *et al*. // Rad. Tech. in Agric. and Food Ind. 2015. V.5. P.87.
2. U.A.Bliznyuk *et al*. // Rad. Tech. in Agric. and Food Ind. 2018. V.5. P.176.
3. K.H.Chadwick // IAEA. 1979. V.23.P.2228.

SUPERCONDUCTING TUNNEL JUNCTIONS AS DETECTORS IN NUCLEAR AND PARTICLE PHYSICS

Suleymanli B.D., Naumov P.Yu.
National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow, Russia;
E-mail: BSuleimanly@mephi.ru

Josephson current through the junction prepared from topological one-dimensional nanowires is studied in the present work. It was shown that Majorana quasi-particles emerge at the end of the superconductors in the presence of external magnetic fields and Rashba spin-orbit interaction [1]. The amplitude and the period of the current due to tunneling of these quasi-particles through the dielectric junction were shown to be changed, provided that the charge of Majorana quasi-particle is equal to half of a normal electron charge [2].

Two different magnetic fields, affected to the electronic spin through Zeeman effect, are considered: one of the field, B, is placed on the plane of the junction, whereas other one, h, is directed perpendicular to the Josephson junction. The dependence of Josephson current on the parameters such as Rashba spin-orbit coupling constant α, the values of the external magnetic fields, B and h, and the value of the superconducting gap Δ is considered. The period of Josephson current was shown to change from the conventional 2π to 4π when Majorana fermions vanish and appear by varying the system parameters α, *B*, *h*, and Δ. The dependence of the magneto-Josephson current on the spin-orbit coupling constant α, the magnetic fields and Δ is studied analytically.



a) *b)*

Fig. 1. a) Spin current as a function of magnetic field orientation, b) transformation of current-phase relation.

1. J.Alicea // Rep. Prog. Phys. 2012. V.75. 076501.
2. H.-J.Kwon, K.Sengupta, and V.M.Yakovenko // Eur. Phys. J. B. 2004. V.37. P.349.

FEATURES OF ELECTROMAGNETIC FIELD GENERATED BY INTERACTION OF HIGH ENERGY ELECTRONS WITH GAS MEDIUM TAKING INTO ACCOUNT SECONDARY PROCESSES

Valiev F.F.
Saint-Petersburg State University, Saint-Petersburg, Russia
E-mail: valiev@hiex.phys.spbu.ru

Changes in the components of the electromagnetic field at different observation angles in the space-time representation are calculated within the framework of a quasi-classical approach to describing the characteristics of the electromagnetic fields of electrons arising from the interaction of ionizing radiation with the environment [1].

The distribution of electrons in the phase space was obtained using the GEANT4 package [2] in a model experiment describing the interaction of electrons with an energy of 300 MeV with argon, xenon and krypton. The calculation of electromagnetic fields formed by electrons passing through a substance is performed.

We applied the technique previously used for calculation of fields produced by ionizing particles in gas and liquid medium [3, 4]. The principle of superposition and model of linear current were used.

It is shown that the calculated angular distribution of energy changes is in a good correspondence with the experiment [5].

This work was performed using equipment at the St. Petersburg State University Computer Resource Center.

1. F.F.Valiev // Bull. Russ. Ac. Sci. Phys. 2011. V.75(2). P.1001.
2. GEANT. Detector description and simulation tool. UserGuide. CERN. Geneva. 1993.
3. V.V.Borisov, F.F.Valiev // VANT: Phys. 2002. V.1/2. P.25.
4. F.F.Valiev // Bull. Russ. Ac. Sci. Phys. 2016. V.80(8). P.951.
5. Y.Ruzhichka // Thesis on the degree of Doctor of Physical and Mathematical Sciences. 1993. P.212.

GAMMA-RADIATION DETECTION UNIT BASED ON SRI_2(EU) CRYSTAL

Antonov A.V., Antonov V.I., Tolkachev A.N., Nichiporchuk A.O., Kozhemyakin V.A., Komar D.I., Verhusha Y.A.

ATOMTEX SPE, Minsk, Belarus

E-mail: info@atomtex.by

Energy resolution of spectrometric instruments for radiation control systems today should be below 4.5% as required by international standards. The Rosenergoatom standard STO 1.1.1.01.001.0875-2017 requires a spectrometric detection unit with a resolution of not above 4.5% for ^{137}Cs radionuclide to be used at the radiation monitoring station ASCRO-1. The American national standard ANSI N42.34-2015 also introduces a requirement for the resolution of RIID spectrometer channel to be not above 4%.

ATOMTEX SPE developed a spectrometric detection unit based on scintillation SrI_2(Eu) detector with dimensions of Ø38.1×38.1 mm. According to the results of detection, unit spectrometric test the typical resolution for the 662 keV line of the ^{137}Cs radionuclide was 3.3%.

The classical LED stabilization system is used to minimize the effect on characteristics of the spectrometric tract introduced by external factors. Superimposed pulses from an ADC are corrected by rejection.

The developed spectrometric detection unit based on the SrI_2(Eu) scintillator can become widely used both in fixed radiation control systems and in mobile devices with a function of radionuclide identification.

NEUTRON TESTING FACILITY FOR RADIATION HARDNESS STUDIES OF ELECTRONIC COMPONENTS AT THE SC-1000 SYNCHROCYCLOTRON IN NRC KI – PNPI

Shcherbakov O.A.[1], Vorobyev A.S.[1], Gagarski A.M.[1], Vaishnene L.A.[1], Nakin A.V.[1], Ivanov E.M.[1], Anasin V.S.[2]

[1] B.P. Konstantinov Petersburg Nuclear Physics Institute of National Research Centre "Kurchatov Institute", Gatchina, Russia; [2] National Research Centre "Kurchatov Institute", Moscow, Russia; [3] Branch of JSC "United Rocket and Space Corporation"- "Institute of Space Device Engineering", Moscow, Russia

E-mail: shcherbakov_oa@pnpi.nrcki.ru

A description of the testing facility ISNP with neutron spectrum resembling that of terrestrial neutron radiation developed at the Petersburg Nuclear Physics Institute (NRC "KI") in collaboration with the Institute of Space Device Engineering (JSC "URSC") is presented. The spallation neutron source of the facility [1, 2] is based on the 1 GeV proton synchrocyclotron SC-1000 of the PNPI. The internal neutron-production lead target produces 10 ns pulses of neutrons with a repetition rate of 45-50 Hz and average intensity up to $3\cdot10^{14}$ n/s (in 4π solid angle). The irradiation area located at a distance of 36 m from the neutron source is characterized by a high-quality collimated neutron beam with a broad energy spectrum 1–1000 MeV and neutron flux of $4\cdot10^{5}$ n/cm^2/s suitable for the accelerated single-event soft error testing of the electronic components. During irradiation, a control of the neutron beam energy spectrum / intensity and spatial profile is carried out by means of the fission ionization chamber (beam monitor) and position sensitive multiwire proportional counter (beam profile meter). The data acquisition system of the ISNP facility utilizes the 250 MS/s 12-bit waveform CAEN digitizers for monitor and profile meter signals processing based on the neutron time-of-flight technique [3].

In the report, parameters of the ISNP testing facility are discussed in comparison with the analogous world-class facilities, as well as requirements and recommendations of the standards used in this field.

1. N.K.Abrosimov *et al.* // Nucl. Instr. Meth. A. 1985. V.242. P.121.
2. N.K.Abrosimov *et al.* // Instr. Exp. Tech. 2010. V.53. P.469.
3. O.A.Shcherbakov *et al.* // IEEE Trans. Nucl. Sci. 2016. V.63. P.2152.

STUDY OF THE EFFECT OF IRRADIATION WITH Fe^{7+} IONS OF THIN TiO_2 FOILS

Zhumataeva I.Z.[1], Kozlovskiy A.L.[2], Zdorovets M.V.[1,2,3]
[1] L.N. Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan; [2] The Institute of Nuclear Physics of Republic of Kazakhstan, Almaty, Kazakhstan; [3] Ural Federal University, Yekaterinburg, Russia
E-mail: artem88sddt@mail.ru

The interest in studying foils and films based on titanium dioxide is associated with their unusual physical and chemical properties, such as sensory and optical properties, catalytic activity, and biological compatibility [1, 2]. Moreover, TiO_2 is one of the most promising transparent conductive oxides and is widely used in various semiconductor devices due to the high transmittance of the visible region of the emission spectrum, a large value of the refractive index of light, controlled by the specific conductivity [3, 4]. As a rule, thin TiO_2 foils are obtained in the form of three crystal structures: rutile, brookite, and anatase. However, the most rarely occurring phase in nature is brookite due to the complexity of its preparation, which served to a small number of works devoted to the study of its physical-chemical, structural properties, as well as its radiation resistance to various types of ionizing radiation.

Thin foils based on the TiO_2 phase of brookite, 620 nm thick, were obtained by magnetron sputtering. The samples were irradiated at the DC-60 heavy ion accelerator of the Nur-Sultan branch of the Institute of Nuclear Physics with Fe^{7+} ions with energy of 85 MeV with a fluence of 1×10^{11} to 1×10^{14} ions/cm^2. The dependences of the change in the concentration of defects in the structure of thin films on the radiation dose are established. It has been established that an increase in the irradiation fluence of up to 10^{14} ions/cm^2, characteristic of the formation of defect overlap regions, leads to a sharp decrease in the degree of crystallinity and an increase in the lattice parameters. That is caused by the formation of a large number of disorder regions and displaced atoms in the structure, which migrate along the crystal lattice to additional distortions and voltages, with the subsequent formation of hillocks.

1. A.L.Kozlovskiy *et al.* // Materials Research Express. 2018. V.5(6). P.065502.
2. M.Kaliekperov *et al.* // Materials Research Express. 2018. V.5(5). P.055008.
3. K.Dukenbayev *et al.* // Vacuum. 2019. V.159. P.144.
4. A.Barman *et al.* // Journal of Physics D: Applied Physics. 2018. V.51.6. P.065306.

A STUDY OF *pp*-CORRELATIONS IN $d+{}^1H \rightarrow p + p + n$ REACTION

Konobeevski E.S.[1,2], Afonin A.A.[1], Kasparov A.A.[1], Lebedev V.M.[3], Mitcuk V.V.[1,2], Mordovskoy M.V.[1,2], Spassky A.V.[3], Zuyev S.V.[1]
[1] *Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia;* [2] *Moscow Institute of Physics and Technology, Moscow, Russia;* [3] *Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow, Russia*
E-mail: vyacheslav.mitsuk@phystech.edu

The charge symmetry breaking (CSB) of nuclear forces, i.e. the difference between the nuclear *nn* and *pp* interactions is manifested, in particular, in the difference between the low-energy characteristics of the *nn* and *pp* interactions – the singlet scattering lengths and the energies of the virtual ${}^1S_0$ state. In [1], it was suggested that the discrepancies in $a_{\rm nn}$ values (from –16 to –22 fm), obtained in reactions with three particles in the final state, may be associated with a large effect of 3*N* forces.

It can also be assumed that the values of the proton-proton scattering length a_{pp} and the energy of the virtual ${}^1S_0$ state $E_{\rm pp}$ extracted from the experiment with three or four particles in the final state will differ from the values obtained in the free *pp* scattering. To test this assumption, a study of $d+{}^1H\rightarrow p+p+n$, $d+{}^2H\rightarrow p+p+n+n$ and $p+{}^2H\rightarrow p+p+n$ reactions is planned at the Institute for Nuclear Research of RAS.

At the first stage the kinematic simulation of $d+{}^1H\rightarrow p+p+n$ reaction was carried out using programs developed at the INR RAS. As a result of the simulation, the parameters of experimental setup − angles of installation of neutron and proton detectors were determined. The spectra and ΔE-E diagrams for protons were also calculated for comparison with experimental data. The possibility of extracting $E_{\rm pp}$ and $a_{\rm pp}$ values from the experimental spectra was shown.

The test experiment of $d+{}^1H\rightarrow p+p+n$ reaction was performed using deuteron beam with energy of 15 MeV at the SINP MSU. A polyethylene film with a thickness of 2 mg cm^{-2} was used as a hydrogen target. The protons were detected by ΔE–E telescope set at the calculated angle $\Theta_{\rm p}$ = 18º. Neutrons were detected by EJ-301 liquid hydrogen scintillator at the angle $\Theta_{\rm n}$ = 38º. The neutron energy was determined by the time of flight of neutrons to the detector, while the time signal from *E*-detector was used as the start signal. The dependence of the pulse shape on the type of particles detected in the EJ-301 scintillator allows the *n*-γ separation procedure.

To obtain the final information about the energy of the virtual proton-proton state, data inquisition system based on digitizers DT5742 and DT5720 was used. Obtained, in coincidence with the neutrons, spectra of protons, whose shape depends on the energy of the virtual state energy, are presented.

1. Konobeevski E.S. *et al*. // Physics of Atomic Nuclei. 2018. V. 81. P. 595.

AUTHOR INDEX

A

B

C

D

H

I

J

K

L

M

N

O

P

Q

R

S

T

U

V

Научное издание

LXIX INTERNATIONAL CONFERENCE “NUCLEUS-2019”
ON NUCLEAR SPECTROSCOPY AND NUCLEAR STRUCTURE

“Fundamental Problems of Nuclear Physics,
Nuclei at Borders of Nucleon Stability,
High Technologies”

Book of Abstracts

LXIX МЕЖДУНАРОДНАЯ КОНФЕРЕНЦИЯ «ЯДРО-2019»
ПО ЯДЕРНОЙ СПЕКТРОСКОПИИ И СТРУКТУРЕ АТОМНОГО ЯДРА

«Фундаментальные проблемы ядерной физики,
ядра у границ нуклонной стабильности,
высокие технологии»

Аннотации докладов

Ответственные за подготовку сборника к печати *В. В. Самарин, М. А. Науменко*.

Сборник отпечатан методом прямого репродуцирования с оригиналов,
предоставленных оргкомитетом.

E4,7,15-2019-36

Подписано в печать 14.06.2019
Формат 60×90/16. Бумага офсетная. Печать офсетная
Усл. печ. л. 24,25. Уч.-изд. л. 34,80. Тираж 280 экз. Заказ № 59710

Издательский отдел Объединенного института ядерных исследований
141980, г. Дубна, Московская обл., ул. Жолио-Кюри, 6.
E-mail: publish@jinr.ru
www.jinr.ru/publish/