Dedicated to the 60th anniversary of
JINR and 10 years of
the SA – JINR collaboration

4th SOUTH AFRICA – JINR SYMPOSIUM

Few to Many Body Systems: Models and Methods and Applications

JINR Dubna, September 21-25, 2015

Monday, 21 September 2015

International Conference Hall in Dubna

10:00 Opening the Week of South Africa at the JINR

I. *Words of Welcome*:

JINR Director V.A. Matveev
JINR: important events in International activity

Deputy Director general of the Department of Science and Technology Th. Auf der Heide
Bird's eye view of the South African National System of Innovation

Deputy Minister of Education and Science of the Russian Federation L.M. Ogorodova
To Be Announced

Acting CEO of SKA Rob Adam

Minister-counselor of the Embassy of South Africa in Moscow

II. *Reports*:

D. Adams (South Africa) 30'
An Overview of the SA-JINR Collaboration: Impact on Human Capital and Research Capacity Development

G. Trubnikov (JINR) 30'
International large research infrastructure of JINR. NICA megaproject: challenges and perspectives

- *International large research infrastructure of JINR. NICA megaproject: challenges and perspectives*

  G.V. Trubnikov

  JINR Dubna, Russia

  The NICA (Nuclotron-based Ion Collider fAcility) project is now under active realization at JINR, Dubna. The main goal of the project is a study of hot and dense strongly interacting matter in heavy ion (up to Au) collisions at centre-of-mass energies up to 11 GeV per nucleon. Two modes of operation are foreseen, collider mode and extracted beams, with two detectors: MPD and BM@N. The both experiments are in preparation stage. An average luminosity in the collider mode is expected as 10^{27} cm^{-2} s^{-1} for Au (79^{+}). Extracted beams of various nuclei species with maximum momenta of 13 GeV/c (for protons) will be available. A study of spin physics with extracted and colliding beams of polarized deuterons and protons at the energies up to 27 GeV (for protons) is foreseen with the NICA facility. The proposed program allows to search for possible signs of the phase transitions and critical phenomena as well as to shed light on the problem of nucleon spin structure. Wide program for applied research is foreseen at NICA."

Monday, 21 September 2015

International Conference Hall in Dubna

15:00 Opening the 4th South Africa - JINR Symposium Few to Many Body-Systems: Models, Methods and Applications (co-chairmen):
Director of the BLTP V.V. Voronov
Director of the SKA Rob Adam

JINR Seminar

Chairman: J. Cleymans

15:10 R. Adam (SKA South Africa) 55'+5'
Doing transformational science with the Square Kilometre Array (SKA)

Session: Prospects of JINR and South African basic facilities

Chairman: J. Cleymans

16:40 V. Aynutdinov (INR Moscow) 25'+5'
Baikal-GVD: results, status and plans

17:10 S. Wyngaardt (Stellenbosch U.) 25'+5'
Towards the South African Underground Laboratory (SAUL)

17:40 M. Shirchenko (DLNP JINR) 25'+5'
Neutrino experiments at the Kalinin Nuclear Power Plant

- *Doing transformational science with the Square Kilometre Array (SKA)*

  Rob Adam

  SKA, South Africa

  The SKA: will be one of the great physics machines of 21st Century and, when complete, one of the world's engineering marvels. The instrument will be able to conduct transformational science, breaking new ground in astronomical observations to investigate:

  - Einstein's theory of relativity to the limits
  - How thevery first stars and galaxies formed just after the Big Bang
  - Themysterious force known as dark energy, the discovery of which gained the 2011 Nobel prize for physics
  - The powerful magnetic fields which permeate the cosmos
  - Whether we are alone in the universe

  The SKA will use thousands of dish antennas and up to a milliondipole antennasthat will enable astronomers to monitor the sky in unprecedented detail and survey the entire sky muchfaster than any system currently in existence. This will give the SKA unrivalled scope in observations, exceeding the image resolution quality of the Hubble Space Telescope. The SKA will also image hugeareas of sky with an unprecedented level of sensitivity.

  South Africa's Karoo region andWestern Australia's MurchisonShirewere chosen as cohosting locations for many scientific and technical reasons, from the atmospherics above the desert sites, through to the radio quietness, which comes from being some of the most remote locations on Earth. South Africa's Karoo semi desert will hostthe core of the high and mid frequency dishes, ultimately extendingover the African continent.Australia's Murchison Shirewill hostthe low frequency antennas.

  Is there any relevance to high energy physics and nuclear physics in the SKA? Pulsars are the obvious place to start exploring this, but other applications exist too, such as determining the constraints on dark matter, the origin of high energy cosmic rays and particle acceleration in extra galactic relativistic jets.

- *Baikal-GVD: results, status and plans*

  V. Aynutdinov

  INR, Moscow, Russia

  The future next-generation neutrino telescope Baikal-GVD will be km^3-scale array aimed at detection of astrophysical neutrino fluxes. It will have modular structure and consist of functionally independent sub-arrays - clusters of strings of optical modules. The prototyping phase of the project has been concluded in 2015 with deployment of the first

cluster of Baikal-GVD in Lake Baikal. We discuss a current status and perspectives of Baikal-GVD project.

- *Towards the South African Underground Laboratory*

  S. M. Wyngaardt and R. T. Newman, P. Papka

  Department of Physics, Stellenbosch University, Stellenbosch, South Africa

  Over the past four years there has been discussion among South African physicists about the possibility of establishing a deep underground physics laboratory to study low level radiation phenomena. In my presentation I will discuss phase 1 of establishing activities in underground physics programmes in South Africa. In this first phase we intend to identify and set up a few small projects which will investigate the feasibility of the Huguenot Tunnel in the Du Toitskloof Mountains near Paarl (Western Cape, South Africa) as a possible site for the first South African Underground Laboratory (SAUL) facility. Such a study will help us to define future projects in low level radiation physics which be performed at the SAUL facility. The research activities performed at the Huguenot underground tunnel facility will provide an opportunity to train students as well as provide training and skills development which will be required for the second phase of the SAUL facility which is the establishment of a dedicated research facility in one of South Africa's gold mines.

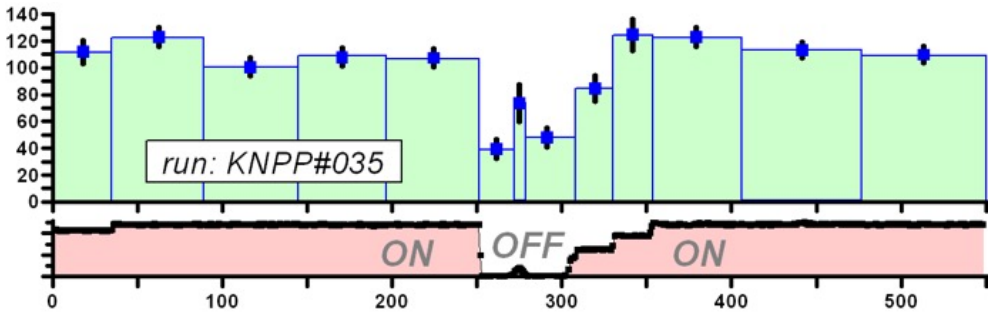
- *Neutrino experiments at the Kalinin Nuclear Power Plant*

  M. Shirchenko on behalf of DANSS collaboration

  DLNP, JINR Dubna, Russia

  The current status of the neutrino experiments at the Kalinin Nuclear Power Plant (KNPP) is presented. Two main activities are devoted to the measurement of the neutrino flux from the reactor with never before reached statistics (≈ 9000 / day) and the determination of antineutrino magentic moment (or at least establishing a stringent constrain).

  The first experiment (DANSS) is quite uniqe since it targets three main goals. First, the detector can be used as a reactor monitoring facility. Second, being located at a moveable platform it could solve the puzzle of the reactor neutrino deficit known as reactor neutrino anomaly. This deficit might be explained either by an uncorrect calculation of the fission products or by presence of sterile neutrinos. Third, by measuring the time evolution of the neutrino spectrum one could distinguish uranium and plutonium concentrations, i.e., giving chance for nonproliferation analysis. Even by the pilot version of DANSS experiment the detection of reactor antineutrinos has been clearly achieved [1] as it is shown in figure. The second experiment (GEMMA) is based on the survey of the low-energy part of the background spectrum with high purity germanium detector. This part is extremely sensitive to the elecro-magnetic cross section of scattering of neutrinos on atomic electrons. The first phase of the experiment have established the world best limit



on the (anti)neutrino magnetic moment $\mu_\nu < 2.9 \times 10^{-11}\mu_B$ [2]. By the second and third phases (and with new type of detectors) of the GEMMA experiment the contrain on the magnetic moment of neutrinos is expected to be pushed down by an order of magnitude.

[1] I. Alexeev *et al*. http://arxiv.org/abs/1305.3350; DANSSino: a pilot version of the DANSS neutrino detector. *http://arxiv.org/abs/1305.3350*

[2] A.G. Beda *et al*. Gemma experiment: The results of neutrino magnetic moment search. http://link.springer.com/article/10.1134/S1547477113020027; Physics of Particles and Nuclei Letters Volume 10, Issue 2, pp 139-143, (2013).

Tuesday, 22 September 2015

Conference Hall of the Flerov Laboratory of Nuclear Reactions (FLNR)

Nuclear Reactions sessions (Fission and Clustering)
Conveners: D. Kamanin, S. Mullins

Chairman: A. Karpov

9:00 D. Kamanin (JINR) 18'+2'
Status and prospects of CCT study

9:20 N. Mkaza (Stellenbosch U.) 18'+2'
Programme for LISSA setup in the University of Stellenbosch

9:40 O. Falomkina (Moscow State University/JINR) 18'+2'
Modern mathematical methods in processing of low-statistics data

10:00 A. Yeremin (FLNR) 18'+2'
Spectroscopy of SHE at Dubna: Results and plans

10:20 A. Nasirov (BLTP JINR) 18'+2'
Theoretical study of a possible mechanism of the true ternary fission

Chairman: A. Popeko

11:00 A. Karpov (FLNR JINR) 18'+2'
Ternary clusterization of heaviest nuclear systems

11:20 F. Karpeshin (Mendeleyev Inst., S-Peterburg) 18'+2'
Many-phonon states and true ternary fission

11:40 Yu. Panebratsev (FLNR) 18'+2'
Virtual laboratory of fission

12:00 V. Sargsyan (BLTP, JINR) 18'+2'
Fusion reactions at near and sub-barrier energies

12:20 S. Zemlyanoy 18'+2'
Gas-cell based setup for production and study of heavy neutron rich nuclei

12:40 L. Grigorenko (FLNR JINR) 18'+2'
Theoretical studies of few-body dynamics in the dripline nuclei and recent experimental results

- *Status and prospects of CCT study*

D.V. Kamanin[1], Yu.V. Pyatkov[2,1], A.A. Alexandrov[1], I.A.Alexandrova[1], N. Mkaza[3], N.A.Kondratyev[1], E.A. Kuznetsova[1], V. Malaza[3], G. V. Mishinsky[1], A.O. Strekalovsky[1] , O.V. Strekalovsky[1], V.E. Zhuchko[1]

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[2] National Nuclear Research University "MEPHI", 115409 Moscow, Russia
[3] University of Stellenbosch, Faculty of Military Science, Military Academy, Saldanha 7395, South Africa

Our program of studying of ternary decays of heavy nuclei dedicated basically to the collinear cluster tri-partition process [1] discovered by us earlier is extended due to the theoretical predictions presented in [2] and our own experimental findings. In the frame of a three-centre phenomenological model developed by the authors [2] new minimum of a short-lived molecular state is revealed in the deformation energy at a separation distance very close to the touching point of the constituents of ternary chain-like configuration. The half-live of the quasi-molecular state which could be formed in ^{12}C accompanied fission of ^{252}Cf is roughly estimated to be the order of 1 ms. We have planned to verify this prediction experimentally using COMETA-R spectrometer installed at the IBR-2 reactor. The experiment is in progress and first results obtained will be reported.

The experiments in the second direction to be continued are aimed at investigating of new shape-isomeric states in fission fragments. One of the perspective goals consists in estimating of a typical life time of these states lying presumably in a microsecond range. We are planning to gain this goal using VEGA (V-E Guide based Assembly) setup to be installed at the IBR-2 reactor. Project details will be discussed.

At last very short lived fission isomers forming in a sequential fission process are under discussion. Experimental indications of such decay channel were obtained recently at COMETA-R spectrometer.

Thus, studies of rare ternary decays let us find new perspective field for investigation namely searching for unknown manifestations of shape-isomer phenomenon.

[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)

[2] D N Poenaru, B Dobrescu et al., J. Phys. G: Nucl. Part. Phys. 26 (2000) L97-L102.

- *Modern mathematical methods in processing of low-statistics data*

O. Falomkina

Moscow State University and JINR Dubna, Russia

In the experiments at the FOBOS spectrometer [H-G.Ortlepp, et al., NIM A 403 (1998) 65] dedicated to study of the spontaneous fission of the 248Cm and 252Cf nuclei in the mass correlation distribution of fission fragments new unusual structures bounded

by magic clusters were observed for the first time. The structures were interpreted as a manifestation of a new exotic decay called collinear cluster tri-partition (CCT). These pioneer results were confirmed and detailed later in the series of experiments at different time-of-flight spectrometers [D.V. Kamanin, Yu. V. Pyatkov, "Clusters in Nuclei - Vol.3" ed. by C. Beck, Lecture Notes in Physics 875, pp. 183-246 (2013)]. Interpretation of the results obtained needs estimation of the statistical reliability of the structures mentioned above. The report presents the results of the solution of the problem of estimation of statistical reliability of linear point structures on the basis of methods of morphological image analysis [Pyt'ev Yu.P. Morphological Image Analysis. - Pattern Recognition and Image Analysis. V.3. No 1. 1993, pp. 19-28.].

- *Spectroscopy of SHE at Dubna: Results and plans*

A. Yeremin[1], A.G. Popeko[1], O.N. Malyshev[1], V.I. Chepigin[1], A.I. Svirikhin[1], A.V. Isaev[1], S. Mulins[2], P. Jones[2], S. Ntshangase[2]

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[2] iTEMBA LABS, Somerset West, South Africa

In the past, various types of reactions and identification techniques were applied in the investigation of formation cross sections and decay properties of transuranium elements. The fusion - evaporation reactions with heavy targets, recoil - separation techniques and identification of nuclei by the parent – daughter generic coincidences with the known daughter-nuclei after implantation into position - sensitive detectors were the most successful tools for production and identification of the heaviest elements known presently.

With γ and β detector arrays, installed at the focal plane of the VASSILISSA separator, detailed spectroscopy of Fm - Lr isotopes was performed during last 5 years.

In the years 2004 - 2012 using the GABRIELA (**G**amma **A**lpha **B**eta **R**ecoil **I**nvestigations with the **EL**ectromagnetic **A**nalyser) set-up the experiments aimed to the gamma and electron spectroscopy of the transfermium isotopes, formed at the complete fusion reactions with accelerated heavy ions were performed. Isotopes of No and Lr, synthesized at the ^{48}Ca+^{207,208}Pb $\rightarrow$ ^{255,256}No*, ^{48}Ca+^{209}Bi $\rightarrow$ ^{257}Lr*, ^{22}Ne + ^{238}U $\rightarrow$ ^{260}No* reactions were studied.

Accumulated experience allowed us to perform ion optical calculations and to design the new experimental set up, which will collect the base and best parameters of the existing separators and complex detector systems used at the focal planes of these installations. New experimental set up (SHELS, the velocity filter) on the basis of existing VASSILISSA separator was developed for synthesis and studies of the decay properties of heavy nuclei [1,2]. During the last test experimental campaign (March 2014) the new double sided silicon detector (DSSD) was used at the focal plane of the SHELS separator (128x128 strips, 100x100 mm2). The detector demonstrated high stability and ensured a high resolution (0.2 %) of alpha particle registration. In many cases of poor statistics the only method of alpha particle detection with high resolution allow to define energy of

transitions (gamma) from excited states to ground state and to evaluate the position of the excited levels in nuclei to be studied.

In the close future it is planned to perform model experiments using method of high resolution alpha spectroscopy and gamma quanta detection to study decay properties of the Rf and Db in the reactions ^{50}Ti + ^{208}Pb $\rightarrow$ ^{257}Rf + 1n and ^{50}Ti + ^{209}Bi $\rightarrow$ ^{258}Db + 1n.

These experiments will help us to prepare full scale spectroscopy experiment aimed to the study of decay properties of the isotopes in the decay chain of ^{288}115 formed in the complete fusion reaction ^{48}Ca + ^{243}Am $\rightarrow$ ^{288}115 + 3n.

[1] A.V. Yeremin *et al*., PEPAN Letters, 12, 35 (2015).

[2] A.V. Yeremin *et al*., PEPAN Letters, 12, 43 (2015).

- *Theoretical study of a possible mechanism of the true ternary fission*

A. Nasirov[1,2], R.B. Tashkhodjaev[2,3], and W. von Oertzen[4,5]

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[2] Institute of Nuclear Physics, Tashkent, Uzbekistan
[3] Inha University in Tashkent, Uzbekistan
[4] Helmholtz-Zentrum Berlin, Germany
[5] Fachbereich Physik, Freie Universität, Berlin, Germany

Ternary fission, when a third light particle is emitted perpendicular to the binary fission axis, has also been studied extensively [1,2]. The name "ternary" fission has been used so far for such decays by the emission of light charged particles with mass numbers M $<$ 38. A possibility of formation of the three reaction products having comparable masses at the spontaneous fission of ^{252}Cf is theoretically explored. This work is aimed to study the mechanism leading to observation of the reaction products with masses M_1 =136-140 and M_2 =68-72 in coincidence by the FOBOS group in the Flerov Laboratory of Nu- clear Reactions of JINR [3,4]. The third product is not detected due to technical reasons or/and kinematics of this true ternary fission. A mechanism of the sequential ternary decay with a very short time between the ruptures of two necks connecting the middle cluster of the ternary nuclear system and outer fragments has been studied theoretically in Ref. [6] by the trinuclear system model. The importance of the Coulomb field of the first massive fragment, which separates during the first step of the fission, to reduce the pre-scission barrier in the second step of the residual part of the ternary system is showed. The results show that the yield of a heavy cluster such as $^{68-70}$Ni would be followed by a product of A =138-148 with a large probability as observed in the experimental data The landscape of the potential-energy surface shows that the configuration of the Ni + Ca + Sn decay channel is lower by about 12 MeV than that of the Ca + Ni + Sn channel. This leads to the fact that the yield of Ni and Sn is large. Two reasons causing the missing the third light product in the tripartition reactions ^{252}Cf(sf,fff) and ^{235}U(nth,fff) discussed in Ref. [3] are discussed. The first one is the theoretical results [5,6] about smallness of the velocity of the middle fragment in the collinear tripartition channel of the reactions

under consideration. The second reason is the deviation from the collinearity of the middle product in the Ni + Ca + Sn chain which is seen from the landscape of the potential energy surface calculated as a function of the coordinates x and y on the decay plane.

[1] F. Gnnenwein, Nucl. Phys. A 734, 213, (2004).

[2] F. Gnnenwein, in Europhysics News 36/1, 11 (2005).

[3] Yu. V. Pyatkov et al., Eur. Phys. J. A. 45, 29 (2010).

[4] Yu. V. Pyatkov et al., Eur. Phys. J. A. 48, 94 (2012).

[5] W. von Oertzen et al., Phys. Lett. B 746, 223 (2015).

[6] R. B. Tashkhodjaev et al., Phys. Rev. C 91, 054612 (2015).

- *Ternary clusterization of heaviest nuclear systems*

A. Karpov

Flerov Laboratory of Nuclear Reactions, JINR, 14980 Dubna, Russia

The term "true ternary fission" is used for a simultaneous decay of heavy nucleus into three fragments of comparable masses. The true ternary fission is considered as a process similar to the binary fission connected with large-scale evolution of the nuclear shape from the compact shape of initial nucleus through formation of two necks and final division into three fragments. This talk is devoted to studying the processes of the true ternary fission and quasifission and, in particular, to discussion of the possibility of their experimental discovery. We present here a three-center shell-model which was formulated recently. Basing on this model we will explain the vanishing probability of the symmetric (with equal outer fragments) true ternary fission of heavy actinide nuclei. At the same time we found few asymmetric combinations of heavy clusters which have similar barriers towards fission as the barrier of binary fission. These combinations are correlated with recent experimental observations concerning true ternary fission of the ^{252}Cf nucleus [1].

We found also that the symmetric true ternary fission is quite possible for superheavy nuclei due to the strong shell effects leading to a three-body clusterization with the two double-magic tin-like cores [2]. The simplest way to discover this phenomenon in the decay of excited superheavy nuclei is a detection of two tin-like clusters with appropriate kinematics in low-energy collisions of medium mass nuclei with actinide targets. The ternary quasifission process could be even more pronounced for giant nuclear systems formed in collisions of heavy actinide nuclei. In this case a three-body clusterization might be proved experimentally by detecting two coincident lead-like fragments in low-energy U+U collisions.

[1] D.V. Kamanin and Y.V. Pyatkov, Lecture Notes in Physics, Clusters in Nuclei, **3**, 183 (2014).

[2] V.I. Zagrebaev, A.V. Karpov, and Walter Greiner, Phys. Rev. **C81** 044608 (2010).

- *Many-phonon states and true ternary fission*

F.F. Karpeshin

D.I. Mendeleyev Institute for Metrology, Saint-Petersburg, Russia

Ternary fission is usually understood as the nuclear fission into two normal fragments accompanied with emission of the third light charged particle, usually alpha particles. For a long time it had been considered that at low energies of the fissile nuclei under tens MeV, fission into three comparable fragments is extremely improbable. Only rather recently, the idea of collinear fission into three fragments gained distribution. Purposeful searches for this mode resulted in experimental values of relative probability of about $P_{3f} \approx 10^{-3}$ as compared to the binary fission [1]. This revives old interest in the question.

Usually two mechanisms are considered which can realize this type of fission. One of them is, at first sight, obvious: consecutive nuclear fission, at first on two fragments, one of which in turn undergoes fission into two others. Both events can be considered occurring in a random way, independently from each other. The other mechanism is usually called true ternary fission (TTF). However, for a long time this mechanism was not concretized. In work [2] it is shown that this mode can be related with the corresponding doorway states. In the case of binary fission, these states are n-phonon vibrations, with n increasing during evolution of deformation from 1 to 10 [3]. The deformation is $\sim \sqrt{n}$. We show that TTF is caused by the hexadecapole deformation of the nuclear surface, as binary fission occurs through evolution of the quadrupole prefission oscillations. Estimates on the mass relations of the fragments are received as 1 : 1.87 : 1. Dynamics of formation and scattering of collinear fragments is shown. The calculated probability of TTF correlates with the observed values.

[1] D. V. Kamanin and Yu. V. Pyatkov, Lect. Notes in Phys. **3**, 183 (2013); Yu. V. Pyatkov, D. V. Kamanin, A. A. Alexandrov *e*t al., in *International Symposium on*

Exotic Nuclei EXON-12, Vladivostok, Russia, 1-6 October 2012, Conference proceedings. Ed. by Yu. E. Penionzhkevich and Yu. G. Sobolev (World Sci., 2013), p. 407.

[2] F. F. Karpeshin, A. Vieira, C. Fiolhais, and J. da Providencia Jr., Europhys. Lett. **42**, 149 (1998).

[3] D. F. Zaretsky, F. F. Karpeshin, Yad. Fiz. **50**, 1546 (1989). *Engl. transl.* Sov. J. Nucl. Phys. **50**, 959 (1989).

- *Gas-cell based setup for production and study of heavy neutron rich nuclei*

S. Zemlyanoy[1], V. Zagrebaev[1], E. Kozulin[1], Yu. Kudryavtsev[2], V. Fedosseev[3], and R. Bark[4]

[1] Joint Institute for Nuclear Research, Dubna 141980, Russia
[2] Instituut voor Kern- en Stralingsfysica, Leuven, Belgium
[3] CERN, Switzerland
[4] iThemba LABS, Nat. Research Foundation, South Africa

A new setup, based on stopping nuclei in the gas cell and subsequent resonance laser ionization and separation by magnetic field is under stage of realization at Flerov lab. JINR. This setup devoted to synthesis and study of new neutron rich heavy nuclei formed in low energy multi-nucleon transfer reactions. These heavy neutron rich nuclei is very important for nuclear physics investigations, for the understanding of astrophysical nucleosynthesis and r-process. In this region is the closed neutron shell N=126 located which is the last so-called "waiting point". Study of the structural properties of nuclei along the neutron shell N = 126 could also contribute to the present discussion of the quenching of shell gaps in nuclei with large neutron excess.

A creation and launch of this facility will open a new field of research in low-energy heavy-ion physics, and new horizons in the study of unexplored "north-east" area of the nuclear map. It could be helpful also for finding a new way for production heavy and superheavy nuclei.

The current status of this setup will be discussed.

- *Theoretical studies of few-body dynamics in the dripline nuclei and recent experimental results*

L.V. Grigorenko

Flerov Laboratory of Nuclear Reactions, JINR, Joliot-Curie 6, Dubna, RU-141980 Russia National Research Nuclear University "MEPhI", Kashirskoye shosse 31, RU-115409 Moscow, Russia; National Research Centre "Kurchatov Institute", Kurchatov sq. 1, RU-123182 Moscow, Russia.

Two-proton radioactivity is the most recently discovered mode of radioactive decay. It belongs to a broader class of true few-body decays well described in terms of few-body dynamics. These phenomena are characterized by simultaneous emission of particles because of specific separation energy conditions. Nowadays this class of phenomena is under active investigation, providing new decay cases, detailed correlation data, and new qualitative theoretical results. The current status of experimental and theoretical studies of the $2p$ radioactivity and true few-body decays is reviewed [1]. The problems and prospects of these studies are discussed. In particular, the following issues are of interest:
(i) Systematics of three-body correlations for true 2p/2n emitters. Three-body correlations in the decays (aligned systems) and reactions (non-aligned systems) [2-5].
(ii) Three-body Coulomb continuum problem. Effects of the long-range Coulomb interactions in 2p decays [6-7].
(iv) Status and prospects of 2-neutron and 4-neutron radioactivity search [8-10].
(iii) Isobaric symmetry violation and Thomas-Ehrman shifts in the s-d shell 2p emitters [12-13].
(iv) Strong "initial state" effects in the reactions leading to population of three-body continuum states beyond the neutron and proton driplines [4,5,11].

We specially discuss the recent results obtained at ACCULINNA fragment separator of FLNR, JINR and the prospective studies at this facility.

[1] M. Pfutzner *et al.*, Rev. Mod. Phys. **84**, 567 (2012).

[2] A.S. Fomichev *et al.*, Phys. Lett. B **708**, 6 (2012).

[3] I.A. Egorova et al., Phys. Rev. Lett. **109**, 202502 (2012).

[4] S.I. Sidorchuk et al., Phys. Rev. Lett. **108**, 202502 (2012).

[5] L.V. Grigorenko *et al.*, Phys. Rev. C **86**, 061602(R) (2012).

[6] L.V. Grigorenko *et al.*, Phys. Lett. B **677**, 30 (2009).

[7] K.W. Brown *et al.*, Phys. Rev. Lett. **113**, 232501 (2014).

[8] L.V. Grigorenko *et al.*, Phys. Rev. C **84**, 021303(R) (2011).

[9] L.V. Grigorenko *et al.*, Phys. Rev. Lett. **111**, 042501 (2013).

[10] L.V. Grigorenko *et al.*, Phys. Rev. C **91**, 064617 (2015)

[11] P.G. Sharov *et al.*, Phys. Rev. C **90**, 024610 (2014).

[12] L.V. Grigorenko *et al.*, Phys. Rev. Lett. **88**, 042502 (2002).

[13] L.V. Grigorenko *et al.*, Phys. Rev. C **91**, 024325 (2015).

Tuesday, 22 September 2015

Conference Hall of the Flerov Laboratory of Nuclear Reactions (FLNR)

Few Body Systems session
Conveners: A. Motovilov, S. Rakityanski

Chairman: S. Rakityansky

14:30 E. Kolganova (BLTP, JINR) 25'+5'
Ultracold atomic clusters and Efimov effect

15:00 L. Lekala (Univ. of South Africa) 25'+5'
Cluster approach for determining spectroscopy for light hypernuclei

15:30 V.S. Melezhik (BLTP JINR) 25'+5'
Ultracold resonant processes in atomic traps

Chairman: L. Lekala

16:30 S. Rakityansky (Univ. of Pretoria) 25'+5'
Nuclear fusion d + $Li^6 \rightarrow Be^{8*}$ induced by X-rays in Lithium-Deuteride crystal

17:00 A. Malykh (BLTP JINR) 25'+5'
Universal description for few two-species particles

17:30 B. Mukeru (Univ. of South Africa) 25'+5'
Coulomb and nuclear breakups in the ^{11}Be and ^{208}Pb

18:00 S. Vinitsky (JINR) 25'+5'
Tunneling of composite particles through repulsive barriers

- *Ultracold atomic clusters and Efimov effect*

  E.A. Kolganova and A.A. Korobitsin

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  The rare gas clusters represent a typical example of van der Waals systems which unusual properties attract a lot of attention of many researches recently. These systems are weakly bound and may be of Efimov nature [1]. In fact, the development of the technology gives a possibility to study ultracold gases with fully controlled interatomic interaction and to find some universal correlations between observables [2-4]. To investigate Efimov phenomena in three-atomic clusters necessary to have good knowledge of a dimer systems [5]. Here we treat the spectrum of van der Waals dimers of rare gases calculated with modern realistic potentials. We also calculate the Efimov spectra of the ^{4}He trimer and analyzed the universality of the Efimov systems. We investigate some universality in the ^{4}He trimer system and in the nuclear system ^{3}H.

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- *Cluster approach for determining spectroscopy for light hypernuclei*

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  Several few-body methods exist for describing few-body bound state problems. Examples include Faddeev equations method, Gaussian expansion approach, Monte Carlo method, etc. All these methods can produce good results. Their differences lie primarily in their numerical complexity in solving the equations involved. Thus some trade-off between accuracy and easy of computation is sometimes necessary. In principle a simple method that generate reliable results and additionally give insight into the dynamics of the system is desirable. Such a method is the two-variable integro-differential method (IDE) pioneered by Fabre de la Ripelle[1-3]. Recently, in [4], we have shown that combining the IDE method with the hypervirial approach method [5] an in-situ method is that permits the study of the dynamics of light hypernuclear system is possible. In particular we were able to investigated the contributions to the binding energy for the different light hypernuclear ssyems. In this work we extend the aforementioned method to study dynamics of larger hypernuclear systems. Preliminary results are reported.

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- *Ultracold resonant processes in atomic traps*

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Impressive progress of the physics of ultracold quantum gases has stimulated the necessity of detailed and comprehensive investigations of collisional processes in the confined geometry of atomic traps. Here the free-space scattering theory is no longer valid and the development of the low-dimensional theory including the influence of the confinement is needed. In our works we have developed a computational method [1-3] for pair collisions in tight atomic waveguides and have found several novel effects in its application: the confinement-induced resonances (CIRs) in multimode regimes including effects of transverse excitations and deexcitations [2], the so-called dual CIR yielding a complete suppression of quantum scattering [1], and resonant molecule formation with a transferred energy to center-of-mass excitation while forming molecules [4]. Our calculations have also been used for planning and interpretation of the Innsbruck experiment on investigation of CIRs in ultracold Cs gas [5]. Recently, we have calculated the Feshbach resonance shifts and widths induced by atomic waveguides [6].

We plan to discuss the Heidelberg experiment [7], which recently confirmed the mechanism, we predicted in [4], of resonant molecule formation in tight quasi-1D atomic traps, and the prospects to extend the consideration for the quasi-2D geometry of the trap.

In the frame of our approach we have predicted dipolar CIRs in quasi-one dimensional geometry of atomic traps [8]. The exact knowledge of the positions of dipolar CIRs may pave the way for the experimental realization of, e.g., Tonks-Girardeau-like or super-Tonks-Girardeau-like phases in effective one-dimensional dipolar gases. We have also analyzed the collisional dynamics of the polarized as well as unpolarized polar molecules in pancake-like traps [9]. This analysis can resolve the puzzle with the position of the 2D CIR measured recently [5], which is under intensive discussions.

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- *Nuclear fusion d + Li^6 $\rightarrow$ Be^{8*} induced by X-rays in Lithium-Deuteride crystal*

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The nuclei sitting at the nodes of a crystalline lattice, are at the atomic distances from each other. The energy of their relative motion is practically zero, i.e. near the threshold. If supplied with additional kinetic energy, they can penetrate through the potential barrier that separates them, and thus can fuse. Such a fusion process should be more probable for nuclear pairs whose compound nucleus has a resonance state overlapping with the threshold energy of the pair. An example of such a system is the solid compound $^6\mathrm{Li} - {}^2\mathrm{H}$ (lithium-deuteride), which we used in our experiment. The corresponding compound nucleus, $^8\mathrm{Be}$, has a wide resonance state at the energy $22.2\,\mathrm{MeV}$, which practically coincides with the $(^6\mathrm{Li} - d)$-threshold. In order to give the nuclei the required kinetic energy, we irradiated the crystal with the X-rays whose spectrum covered the interval from 15 to $100\,\mathrm{keV}$. The sample was exposed to the X-rays for 112 hours, which resulted in registering of 88 fusion events. For the event identification, we looked for the appropriate tracks left by the α-particles in a polymer detector. These α particles (with the energy $\sim 11\,\mathrm{MeV}$) emerge from the decay of the compound nucleus.

- *Universal description for few two-species particles*

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The overview of advances in describing a system of few two-component particles is presented. Particular attention is paid to the consideration of two non-interacting identical particles of mass m and a distinct particle of mass m_1 with zero-range interaction between different particles. It was shown that for the sector of angular momentum and parity L^P, an additional three-body parameter b should be introduced for the mass ratio $\mu_r \leq m/m_1 \leq \mu_c$ ($\mu_r = 8.619, \mu_c = 13.607$ for $L = 1$; $\mu_r = 32.948, \mu_c = 38.630$ for $L = 2$, etc.) so as to provide unambigous description of the three-body problem. The three-body energies for an arbitrary b and mass ratio is calculated for a few lowest angular momenta L. In addition, the topics considered include rigorous treatment of the few-fermion problem in the limit of zero-range interaction.

- *Coulomb and nuclear breakups in the ^{11}Be and ^{208}Pb reaction*

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  In this work we analyze effects of the first-order and higher-order interferences on the Coulomb-nuclear interference and on the impact parameter distributions breakup cross sections for the $^{11}\mathrm{Be} + {}^{208}\mathrm{Pb}$ breakup reaction. It is first shown that although the nuclear breakup contribution is negligible, especially at higher excitation energies, the Coulomb-nuclear interference is quite significant as the coherent sum of the Coulomb and nuclear breakup cross sections fits well experimental data. On the other hand, we show that the first-order interference reduces the Coulomb-nuclear interference and affects its nature, while this Coulomb-nuclear interference is increased owing to the higher-order interference without affecting its nature. Considering the impact parameter distributions cross sections, it is obtained that the first-order interference produces a strong nuclear absorption in the surface region, which is attenuated by the effects of the higher-order interferences.

- *Tunneling of composite particles through repulsive barriers*

  S. Vinitsky and A. Gusev

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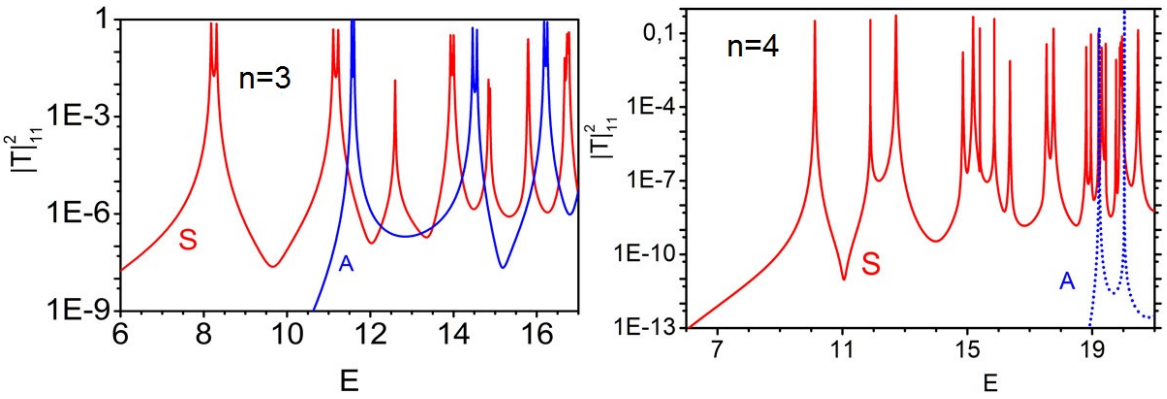

Figure 1: The transmission coefficient $|T|^2_{11}$ vs collision energy E (osc. u.) of symmetric (S) and antisymmetric (A) states for composite system of three (n=3) and four (n=4) identical particles tunneling through narrow repulsive Gaussian barrier $V(x_i) = \alpha/(2\pi\sigma^2)1/2\exp(-x_i^2/\sigma^2)$, $\alpha = 20$, $\sigma = 0.1$.

The description of quantum tunneling and channeling of composite systems of several identical particles through the repulsive barriers in a coupled-channel approximation of the new symmetrized-coordinate representation of harmonic oscillator basis is presented [1-3]. In this approach a multichannel scattering problem for the Schrödinger equation is reduced to a set of the coupled second-order ordinary differential equations with third-type boundary conditions and solved by the FEM. Efficiency of the proposed approach is

demonstrated by analysis of metastable states of composite systems in 1D-space leading to a quantum transmittance effect (for example, see Fig.) of the barriers in dependence on a number of identical particles and type of the permutation symmetry of their states.

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Tuesday, 22 September 2015

Conference Hall of the Frank Laboratory of Neutron Physics (FLNP)

Applied Nuclear Physics session
Conveners: M.Frontasyeva, R. Newman

I. Materials science: radiation stability, materials modifications

Chairman: M.Frontasyeva

9:00 L. Petrik (Western Cape University) 18'+2'
Applied Research - new trends in collaboration of SA with JINR

9:20 V. Skuratov (FLNR JINR) 18'+2'
High resolution electron microscopy studies of nuclear ceramics and oxides irradiated with heavy ions of fission fragment energy

9:40 A. Janse van Vuuren (Nelson Mandela Metropoliten U.) 18'+2'
Swift heavy ion irradiation effects on He agglomeration in solids

10:00 A. Nechaev 18'+2'
Sensors for toxic contaminants analyses based on the track membranes with surface enhanced Raman spectroscopy properties as a new activity in frame of RSA-JINR collaboration

10:20 A. Rossouw, (Stellenbosch U.) 18'+2'
Titanium Dioxide Modified Track-Etched Membranes Using Reactive Magnetron Sputtering for Photocatalytic Water Treatment

II. Environmental studies

Chairman: L. Petrik

11:00 M. Frontasyeva (FLNP JINR) 18'+2'
An overview of collaboration with SA for the period of 2010-2015

11:20 D. Pavlov (Inst. of Biology of Inland Waters) 18'+2'
Monitoring of trace elements in marine ecosystems: "Mussel Watch" approach

11:40 J. Bezuidenhout (Stellenbosch U.) 18'+2'
Results of various element content analyses of invasive black mussels (Choromytilus meridionalis) in the coastal waters around the industrial port of Saldanha, SA

12:00 R. Newman (Stellenbosch U.) 18'+2'
Air pollution studies in the Western Cape area. An overview

12:20 Z. Ndlovu (iThemba) 18'+2'
Elemental analysis of mosses and lichens from the western cape (South Africa) using NAA and ICP-MS

12:40 C. Eze (Western Cape U.) 18'+2'
Elemental composition of coal flyash: Matla coal power station in the Mpumalanga province in South Africa case study using nuclear and related analytical techniques

- *Applied Research - new trends in collaboration of SA with JINR*

  L. Petrik

  Department of Chemistry, University of the Western Cape, South Africa

  Advances in functional nanomaterials and their convergence with conventional technologies open up opportunities in designing hybrid nanotechnology- enabled multifunctional processes capable of performing multiple tasks; e.g., water disinfection, decontamination, and separation; in one reactor. Multifunctional systems can enhance the overall performance by creating synergy, avoiding redundancy, simplifying operation, and reducing the system footprint and cost. Nanomaterials are uniquely suitable for multifunctional systems, since nanomaterials of different functions can be easily assembled together, even on very small carriers such as nanofibers. Membranes are a good and extensively studied platform for multifunctional devices as they provide a physical barrier for many constituents based on their size, allowing use of unconventional water sources. The performance of membrane systems is largely decided by the membrane material. Incorporation of functional nanomaterials into membranes offers an opportunity to improve the membrane permeability, fouling resistance, mechanical and thermal stability, as well as to render new functions for contaminant degradation and self-cleaning. Track etched membranes produced by the ion-track approach represent important types of currently used and commercially available polymeric membranes. Track etched membranes made from different polymeric and inorganic materials with different functional groups on their surfaces give the unique possibility of surface modification in order to impart predetermined physical-chemistry characteristics and, as a consequence, the predominated selective characteristics. At the same time membrane modification must not lead to the disappearance of the unique track etched properties that distinguish these materials from traditional network membranes. Track etched membranes can also serve as templates for making various micro- and nanostructures. The methods we have investigated over several years include vacuum sputtering of inorganic materials (metals and metal oxides) for gas separation applications and self-cleaning membranes as well as using track etched membranes as templates for making various micro- and nanostructures. It is envisaged that new directions will include the methods of covalent binding and self-assembly of nanoparticles and nanofibers on the track-etched membranes. These materials will be designed for applications such as: porous matrices applicable in Surface Enhanced Raman Spectroscopy (SERS) for ultra-fast detection of water contaminants and pathogens by enhancing Raman scattering of the adsorbed molecules on the nanostructured roughened track etched membrane substrate; photocatalytic track etched membranes for hybrid water treatment processes; high affinity nanofiber composite track etched membranes for toxic ion removal; and micro -and ultrafiltration antimicrobial track etched membranes. Thus the envisaged future directions encompass development of track etched membranes for applications in novel analytical protocols, hydrometallurgy, photocatalysis and waste water purification.

- *High resolution electron microscopy studies of nuclear ceramics and oxides irradiated with heavy ions of fission fragment energy*

  V.A. Skuratov[1], J.H. Neethling[2], J.H. O'Connell[2], Arno Janse van Vuuren[2], A.S. Sohatsky[1]

  [1] FLNR JINR, Russia
  [2] CHRTEM, NMMU, Port Elizabeth, South Africa

  Aim of this presentation is to review the results of collaborative work aimed at studies of radiation damage in nuclear ceramics and oxides induced by 1-3 MeV/nucleon heavy ions using high resolution transmission electron microscopy (HTREM). We will discuss the following:

  - Radiation tolerance of nanostructured ZrN coatings against swift heavy ion irradiation.
  - Dense ionization effects on pre-existing defect structure in SiC formed by convenient radiation (hundred keV ion irradiation), that is most reliable case of fission product damage simulation.
  - Latent track formation and radiation stability of Y-Ti and Y-Al nanooxides in oxide dispersion strengthened alloys.

- A. Janse van Vuuren, V.A. Skuratov, V.V. Uglov, J.H. Neethling, J.H. O.'Connell, A.S. Sohatsky: *Swift heavy ion irradiation effects on He agglomeration in solids*

  Centre for HRTEM, Nelson Mandela Metropolitan University, South Africa

  Recent studies have shown that swift heavy ion irradiation may significantly modulate hydrogen and helium behaviour in certain materials [1-2]. This phenomenon is of considerable practical interest for various ceramics and semiconductors, specifically for materials with applications in current and future nuclear reactors. Ceramics employed in the nuclear reactor core will potentially be used in applications such as inert matrices for fission product burn-up and as protective coatings for structural materials. The purpose of both these applications is to improve safety and also the economic viability of nuclear energy. Materials in the reactor core accumulate helium via (n,α) reactions and will also be subjected to irradiation by high energy fission fragments [3]. The inherent properties of ZrN, TiN and AlN ceramics have led to their identification as a candidate materials for the aforementioned applications [4,5].

  Ceramic layers with varying compositions were produced for this investigation. ZrN and TiNZrN layers were produced via vacuum arc-vapor deposition and TiN/AlN multilayered structures were produced via reactive sputtering. The layers have the following thicknesses ZrN - 20 μm, TiNZrN - 4 μm and the TiN/AlN-multilayers - approximately 400 nm. The TiNZrN layers were deposited on zircaloy and the ZrN and TiN/AlN-multilayers on silicon wafers.

  In this study low energy He ions (10-30 keV) were used to simulate the effects of α-particles. High energy Xe (167 MeV) and Bi (695 MeV) ions were used to simulate the effects of fission fragments. The combined effects of low and high energy radiation were also studied, since these materials will be subjected to both types of radiation in the

nuclear reactor core. The microstructural evolution of these samples were investigated by transmission electron microscopy.

As for most metals and ceramics the results of this investigation suggest that these nitride ceramics are prone to the formation of He gas bubbles/blisters. The formation of these blisters may ultimately lead to material failure, which will be of great concern for materials with nuclear applications. These effects may however be mitigated by the electronic excitation effects from certain high energy heavy ions such as fission fragments.

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- *Sensors for toxic contaminants analyses based on the track membranes with surface enhanced Raman spectroscopy properties as a new activity in frame of RSA-JINR collaboration*

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The development of a waterborne pathogen detection method that is rapid, multiplex sensitive, and specific, would be of great assistance for water treatment facilities and would help protect water consumers from harmful pathogens. One of the advanced approaches is to combine the principles of surface enhanced Raman spectroscopy (SERS) and membrane separation in a sensitive multiplex pathogen detection method. The objective of this work was to develop flow-through SERS-active substrates by selfassembling arrays of silver nanoparticles on the surface of track-etched polyethylene terephthalate (PET) membranes. Track-etched membranes were attributed as a one of the promising porous support due to their well-defined surface porous structure. Our approach included the use of polyethyleneimine (PEI) as the chemical promoter between membrane surface and silver nanoparticles. Stable aqueous suspensions of silver nanoparticles with a diameter of approximately 15 nm were prepared using spark discharge technique in water without applications of surfactants. UV-VIS spectrum of the silver nanoparticles solution demonstrated a plasmon resonance at 400 nm.

The track etched membranes with pore diameter of 100 nm were shaken up in a 0.05 % w/w solution of PEI for 3 hours. After incubation in PEI, the membranes were rinsed in 0.01 M HCl for 10 minutes and finally immersed in silver hydrosol for 48 hours.

Investigation of electrokinetic properties confirmed inversion of the PET surface charge from negative to positive. Under the hydraulic conditions used in our experiments, particles were not removed from the membrane surface. Surface modification by silver resulted in a reduction of hydrophobic properties. Contact angle measurements with ul-

trapure water of pristine and modified TM showed decreasing the angle from 75 to 50 degrees.

SERS enhancing properties of the resulting membrane-supported arrays were tested and compared with those of source nanoparticle suspensions using Rhodamine 6G as an analyte relevant for pathogen detection and inactivation techniques. The Raman signal enhancement factor of the modified track-etched membranes was uniform and found to be 210^6 (laser excitation wave length 532 nm).

The reported findings indicate the potential benefit of combining highly specific SERS-active systems and the flow-through design for the development of analytical sensors for the trace detection of pollutants in water. Based on obtained data, our future approaches also will include:

- "top-down" nanofabrication approach based on nanosphere PVD technique (Thermo-evaporation of Ag layer (50 nm) / SiO_2 nanospheres (15 nm) / Ag thin film (6 nm) on the TM surface);
- non-fluorescent track etched membranes fabrication for "top-down" nanofabrication approach;
- hybrid technology based on "top-down" nanofabrication and "bottom-up" chemical synthesis approaches.

All functionalized SERS substrates will be manufactured and characterized using FTIR, 1H and 13C NMR and elemental analysis as well as be characterized using TEM, SEM, AFM, FT-IR RAMAN, XRD and XPS in close collaboration with our partners from the University of the Western Cape.

- *Titanium Dioxide Modified Track-Etched Membranes Using Reactive Magnetron Sputtering for Photocatalytic Water Treatment*

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[3] Dubna International University, Dubna, Russia

In the last decades, great attention has been paid to the methods of water purification based on advanced oxidation processes (AOPs). These methods can be accomplished using photocatalytic materials both consolidated or in suspension. Composite membrane-photocatalyst systems allow to mineralize organic substances absorbed on the membrane surface during water filtration. The present work is devoted to the fabrication and investigation the properties of photocatalytic track-etched (TM) polyethylene terephthalate (PET) membranes modified with silver and titanium dioxide for the water purification processes.

Titanium dioxide (TiO_2) thin films were obtained by inverted cylindrical magnetron sputter (ICMS) deposition on silver coated microfiltration PET TM. The conditions of the thin

layers deposition (current, time, O_2/Ar ratio, gas flux in chamber) have been optimized to obtain a 40 nm thick TiO_2 film. The structural, morphological and optical transmission properties of these nanocomposite layers as well as the effects of their exposure to UV were studied. The films were highly transparent, nearly matching that of the PET substrate itself. X-ray diffraction analysis (XRD) indicated that the films were orthorhombic by nature and the full width at half maximum (FWHM) of the (210) peaks of the films indicated small crystallite sizes in the vicinity of 6.5 nm. The composition of the Ag-TiO_2 layer determined by Rutherford backscattering spectroscopy (RBS) appeared homogeneous despite the porous PET substrate. By assuming a direct band gap transition, the initial band gap values of 3.05 eV for TiO_2 was reduced to 2.76 eV with the addition of thermally evaporated silver (Ag). It was suggested that the observed low band gap values obtained in this study could be attributed to the silver incorporation in the films as well as the formation of interfacial layers during this two stage deposition process. The high transparency and band gap values support the idea that the films could be good candidates for photocatalytic applications such as water treatment.

Physico-chemical properties (streaming potential, hydraulic permeability, dyes adsorption) and photocatalytical properties of the modified membranes were investigated. It was found that the composite membranes have photocatalytic activity induced by UV-light irradiation. By studying the behavior of the water contact angle under UV radiation, it was found that under the influence of UV irradiation the composite TiO_2, Ag/TiO_2 thin films gained "super-hydrophilic" properties.

The culmination of this research is the development of the multifunctional TMs with "low-absorptive", "low-fouling", "super-hydrophilic", and "self-cleaning" surface properties. These photocatalytic composite TMs are a prospective material for future water treatment processes.

- *An overview of collaboration with South Africa for the period of 2010-2015*

M.V. Frontasyeva

Sector of Neutron Activation Analysis and Applied Research, Division of Nuclear Physics, Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Research, RussiaI

A brief historical review of collaboration of Sector of Neutron activation Analysis and Applied Research (SNAA&AR) with NECSA, which started in 2006 and then extended to Stellenbosch University (2012) and Western Cape University (2014) is given.

Experience in applying conventional and epithermal neutron activation analysis (NAA) at the reactor IBR-2 of FLNP, JINR and research reactor SAFARI-1 at NECSA, Pelindaba, for some challenging areas of the life sciences is reviewed.

Successful joint activity is illustrated by most prominent international publications [1-4] and presentations at conferences marked with an award [5].

Training opportunities for graduate and undergraduate students and young scientists from different universities of South Africa provided by SNAA&AR with its chemical laboratory and modern radioanalytical complex REGATA at the reactor IBR-2 are described.

Perspectives of collaborative projects for 2016-2018 with Stellenbosh University and Westerncape Universities are discussed.

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- *Monitoring of trace elements in marine ecosystems: "Mussel Watch" approach*

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In 1975 bivalve mollusks were proposed to be used as sentinel organisms for monitoring the levels of environmental pollutants - the approach then named as "**Mussel Watch**" (MV). The MW utilizes ability of bivalve mollusks to accumulate a range of potentially hazardous environmental pollutants. Nowadays the combination of the MW with such state-of-the-art analytic technique as neutron activation analysis (NAA) allows for development and establishing of modern systems of environmental monitoring of fresh and marine waters. For South Africa such system is topical in view of many potential sources of which may negatively affect an environment and a range of economically-important activities. The results of the studies carried out under the frames of the proposed topic revealed high applicability of both NAA and MW approach for environmental monitoring in SA. This presentation describes briefly the main results of the research carried under proposed SAR MW " umbrella" and designates the future efforts to be made.

- *Results of various element content analyses of invasive black mussels (Choromytilus meridionalis) in the coastal waters around the industrial port of Saldanha, South Africa*

  J. Bezuidenhout, M.V. Frontasyeva, D. Pavlov, A. Botha, Z. Goryinova, N. Dames

  School of Science and Technology, Stellenbosch University, South Africa

  Environmental monitoring is essential to identify and minimizing negative human impacts on the environment. This is particularly true for the Saldanha Bay-Langebaan lagoon system which seen considerable development in the last two decade. Invasive black mussels (*Choromytilus meridionalis*) where chosen as biomonitors due to the fact that they are farmed as well as grown naturally in and around Saldanha Bay. This makes biomonitoring on these species an excellent tool to measure the impacts of the developments on the system. A biomonitoring study that ran since 2012 provided results which can be used as a base line for further research. Neutron activation analyses (NNA) were complemented by ICP-MS analyses to accurately determine the element content in the flesh and the shells of the mussels. Comparisons were made between the elements of mussels from the industrial port of Saldanha, the Langebaan lagoon and the bordering coast line of the area. A several elements gave notable results and a few will be discussed.

  Zinc showed much higher concentrations in the tissue than in the shell, whereas the opposite were true for most other elements like sodium, chlorine and calcium. There was also a significant drop of element concentrations in the flesh of the mussels; during the summer months (see the ICP-MS graphs for arsenic as example). This may be due to the spawning that generally occurs during the summer months. Arsenic demonstrated the highest concentrations in the flesh of the natural mussels in Danger Bay, but the concentrations of mussels from the other areas were also elevated. The results for the farms in Saldanha Bay showed levels lower than the permissible 2 mg/kg only during the summer months. Most elements demonstrated higher concentrations in natural Danger Bay mussels than the farm grown Saldanha Bay mussels. This may be due to the fact that they grow slower in the more exposed habitat and consequently accumulate more elements during maturing.

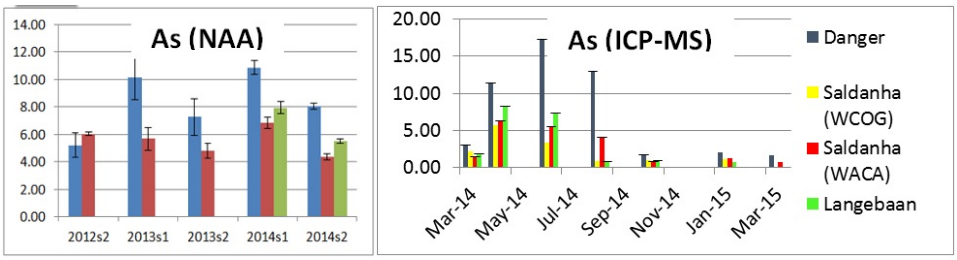

Figure 2: Arsenic concentrations in the flesh of mussels as determined through NAA and ICP-MS.

The cadmium levels were also generally higher that the permissible level of 3 mg/kg. This is probably due to the high levels of natural cadmium that occurs in the area of Saldanha Bay. The results of the NNA correlated well with that of the ICP-MS. The objective is

to continue with the project in order to identify long term tenancies and the basic causes thereof.

- *Air pollution studies in South Africa - an overview and prospects*

  R. Newman

  Physics Department, Stellenbosch University, South Africa

  An overview of studies conducted to measure air pollution (including radionuclides) in South Africa are presented. The measurement methods are discussed and the results of these studies are contextualized with reference to guidelines of the World Health Organization, the Environmental Protection Agency (USA) and the EU. The scope in South Africa to expand air pollution monitoring is discussed.

- *Elemental analysis of mosses and lichens from the western cape (South Africa) using NAA and ICP-MS*

  N.B. Ndlovu[1,3], M.V. Frontasyeva[2], R. T. Newman[1], P.P. Maleka[3], I. Zinicovscaia[2] and Z. Goryainova[2]

  [1] Stellenbosch University, South Africa
  [2] Joint Institute of Nuclear Research, Russia
  [3] iThemba LABS, South Africa

  Application of mosses and lichens as biomonitors, analyzed by nuclear and related techniques, has been extensively used in the European countries to study atmospheric deposition of heavy metals and other trace elements [1] but not in South Africa. For the present study, a total of 64 samples (39 mosses and 25 lichens) were collected in selected areas over the Western Cape region of South Africa. Collected samples were analysed by the multi-elemental non-destructive Instrumental Neutron Activation Analysis (INAA) as well as the Ion-Coupled Mass Spectrometry (ICP-MS) and the results were compared. In passive biomobitoring, 29 sample were analysed and a total of 44 elements (Na, Mg, Al, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Zn, As, Se, Br, Rb, Sb, I, Cs, La, Ce, Nd, Sm, Tb, Hf, Ta, W, Th, U, Ni, Cu, Sr, Mo, Cd, Sn, Ba, Hg, Pb, B, Li, P, Si) were determined. In active biomobitoring (moss- and lichen-bags), a total of 47 elements (Al, Ca, Fe, K, Mg, Na, Ti, V, Cr, Mn, Co, Ni, Zn, As, Se, Sr, Mo, Sb, Ba, Cl, I, Br, La, Sm,W, U, Sc, Rb, Zr, Cs, Ce, Nd, Gd, Tb, Tm, Hf, Th, B, P, Si, Li, Be, Cu, Cd, Sn, Hg, Pb) were determined from 35 samples. Active biomonitoring presented itself to be a sufficient tool for monitoring the collection efficiency for different biomonitors in different controlled conditions and for a well-defined exposure time [2]. In general, mosses showed the highest bioaccumulation capacity for metals and presented a rather more constant and linear accumulation trend than lichens. Due to their differences in their metal uptake and retention, better results were achieved from using mosses and lichens concurrently. This study was undertaken in the framework of the SA-JINR co-operative program with Stellenbosch University.

  [1] M. V. Frontasyeva, Physics of Particles and Nuclei 42, 332-378 (2011).

[2] N. B. Ndlovu, M. V. Frontasyeva, R. T. Newman and P. P. Maleka. Proceedings of SAIP2013: the 58th annual conference of the South African Institute of Physics 307-312 (2013).

- *Elemental composition of coal flyash: Matla coal power station in the Mpumalanga province in South Africa case study using nuclear and related analytical techniques*

  C. P. Eze, O. Fatoba, G. Madzivire, T. M. Ostrovnaya, L. F. Petrik, M. V. Frontasyeva and A. N. Nechaev

  University of the Western Cape, South Africa

  Fly ash is the major waste generated from coal combustion in thermal power stations to produce electricity. Worldwide huge amounts of coal fly ash are generated in order to meet energy demands and about 70% of fly ash is disposed as waste. Fly ash has been studied extensively to understand the environmental impacts associated with its disposal, management and reuse. Analysis of coal fly ash compositions has shown that rare earth elements, toxic elements and radionuclides are present in this solid waste. An accurate method of determining the chemical composition of fly ash is fundamental in the qualitative and quantitative analysis of the elements of toxicity and value in fly ash in order to effectively manage fly ash disposal and utilisation. The analytical methods widely used in determining the elemental compositions of fly ash are X-ray Fluorescence (XRF) spectroscopy; inductively coupled plasma - optical emission spectrometer/Mass Spectrometry (ICP-OES/MS); Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) and instrumental neutron activation analysis (INAA). The aim of this study was to determine the total elemental composition of Matla coal fly ash using these analytical techniques in order to establish the technique that is best suited for determining the different categories of elements that are contained in fly ash. A total of 54 major, trace and rare earth elements were accurately determined in the fly ash using the different analytical techniques. It was shown that the elemental content of Matla fly ash was of the same order as the SRM NIST coal fly ash 1633b. The comparative study of the four analytical techniques established that that XRF is best suited for the determination of the major and minor elements, whilst the LA ICP-MS is reliable for trace elements determination. That ENAA simplest and most accurate technique to determine the major, minor and trace elements in coal fly ash.

Tuesday, 22 September 2015

Conference Hall of the Frank Laboratory of Neutron Physics (FLNP)

Student session

Conveners: S. Pakuliak, N. Jacobs

Chairman: N. Jacobs

14:30 O. Adeniyi (Western Cape Univ.) 13'+2'
Swift heavy ion irradiation of polyester and polyolefin polymeric film for gas separation application

14:45 I. Zinicovscaia (FLNP JINR) 13'+2'
Biotechnology of gold and silver nanoparticle production: results of collaborative study with South Africa (necsa)

15:00 Z. Goryainova (FLNP JINR) 13'+2'
New results on NAA of mussels from South Africa

15:15 T. Lamula (iThemba) 13'+2'
Neutron activation analysis of thin Bi targets with 90 and 140 MeV neutrons.

15:30 K. Kornieieva (FLNR JINR) 13'+2'
Structural and micromechanical examination of ODS alloys irradiated with 1-3 MeV/nucleon heavy ions

15:45 R. Rymzhanov (FLNR JINR) 13'+2'
Latent tracks and mechanical stresses in Al_2O_3 irradiated with swift heavy ions

16:30 R. Botha (Univ. of Western Cape) 18'+2'
Radon in-air measurements within wine-cellars of the Western Cape (South Africa) and its associated exposure dosage

16:50 M. Mokgolobotho (Univ. of western Cape) 13'+2'
Determining the spectroscopic quadrupole moment (Q_s) of the first 2^+ state in ^{40}Ar

17:05 C. Mehl (Univ. of western Cape) 13'+2'
Developing a sorting code for Coulomb excitation data analysis

17:20 M. Segal (Univ. of Cape Town/iThemba LABS) 13'+2'
Liquid Metal Ion Source Assembly for External Ion Injection into an Electron String Ion Source (ESIS)

17:20 Discussion of the presentations of young scientists

- *Ion track modification of polyester and polyolefin films for production of asymmetrical polymeric membrane*

  O. Adeniyi, Yuri Kochnev, Leslie Petrik, Alex Necheav, Vladimir Teplyakov, Pavel Apel, Dasha Syrtsova

  University of the Western Cape, South Africa

  This study considered the generation of a porous asymmetrical layer in polymer membranes using heavy ion bombardment and chemical etching approach. Two classes of commercial polymers were selected, namely a polyolefin called polymethyl pentene (PMP) and a polyester namely polyethylene terephthalate (PET). The PMP polymer film was '*layered*' with PET foil while PET polymer film was '*layered*' with Al foil. The '*layered*' polymers were irradiated with Xe ions for PET and Kr ions for PMP polymer films under vacuum at room temperature and then chemically etched. The irradiated '*layered*' PET was etched in 1 M NaOH at 80 C between 0 to 12 minutes while irradiated '*layered*' PMP was etched in acidified chromium oxide (7 M H_2SO_4 + 2.5 M CrO_3) solution between 25 C to 80 C. The time of chemical etching was varied between 40 minutes and 2 hours 30 minutes. The selection of etching temperature gradient for irradiated 'layered' PMP polymer film was due to the ambiguity from available literature on its glass transition temperature. In the case of track-etching the layered PET film the asymmetrical membranes were formed within 12 minutes of chemical etching. Track-etching the layered PMP polymer films resulted in the formation of asymmetrical structures at 70 C and 80 C but only after an extended period of etching time (2 hours 30 minutes). The physico-chemical properties of track-etched PET and PMP polymer films were investigated using thermogravimetry (TGA) analysis, infra-red spectroscopy, x-ray diffraction and morphology was analyzed by scanning electron microscopy. The TGA results of track-etched PET and PMP polymer films show that there was an improved thermal stability of both polymer films. Also, IR analysis indicated that there was an overall degradation in the functional groups of PET while the PMP polymer showed selective degradation of side chains than the backbone structure. X-ray diffraction measurement did not indicate any significant change in the crystallinity track-etched PMP polymer as compared with the ion irradiated PMP whereas the crystallinity properties of track-etched PET was observed to decrease as a function of increase in etching time. The SEM surface morphological analysis of both track-etched polymers showed the emergence of pores with dominant radial and ordered configuration for track-etched PMP polymer films while PET pores were observed to transform from ordered to highly undefined pores after an excessive increase in etching time. This study revealed that track-etching of PET polymer resulted in overall degradation for both side chain and backbone structure. However, effects of track-etching on PMP polymer were dominant with the side chains than its corresponding backbone structure. The variation in physico-chemical properties after track-etching PET and PMP polymer films was mainly due to the susceptibility of specific functionalities within the polymer matrix as well as their structural configurations.

- *Biotechnology of gold and silver nanoparticle production: results of collaborative study with South Africa (necsa)*

  I. Zinicovscaia[1], M. V. Frontasyeva[1], S. S. Pavlov[1], T. L. Kalabegishvili[2,3], E. I. Kirkesali[2], A. Faanhof[4]

  [1] Joint Institute for Nuclear Research, 6 Joliot-Curie Str., 1419890, Dubna, Russia
  [2] E. Andronikashvili Institute of Physics, I. Javakhishvili State University, 6 Tamarashvili str., Tbilisi, 0177, Georgia
  [3] Ilia State University, 3/5 K. Cholokashvili Ave., Tbilisi 0162, Georgia
  [4] North-West University (Mafikeng Campus), Private Bag X2046, Mmabatho, South Africa

  Actinomycete strain Streptomyces glaucus 71 MD isolated from a soy rhizosphere in Georgia and microalga Spirulina platensis were used to study the biotechnology of synthesis of gold and silver nanoparticles. The experimental conditions of gold and silver nanoparticles production by the cells of studied strains in aqueous chloroauric acid ($HAuCl_4$) and in silver nitrate ($AgNO_3$) solutions, respectively, were determined. To characterize formed nanoparticles UV-vis spectrometry, Transmission electron microscopy, Scanning electron microscopy, and Energy-dispersive analysis of X-rays were used. To characterize gold and silver accumulation by microbial biomass neutron activation analysis was applied. The obtained results show that studied microorganisms are capable of producing gold and silver nanoparticles of spherical shape extra- and intracellularly when exposed to suitable compounds. The microbial biomass with gold and silver nanoparticles can be for industrial as well as medical and pharmaceutical purposes.

- *New results on NAA of mussels from South Africa*

  Z. Goryainova, J. Bezuidenhout, D. Pavlov, M. Frontasyeva

  Joint Institute for Nuclear Research, 6 Joliot-Curie Str., 1419890, Dubna, Russia

  Samples of bivalve mollusks, Mediterranean mussels were repeatedly collected in three bays of the Atlantic coast of the Western Cape area (Danger Bay, Saldanha Bay, and Langebaan Lagoon) from 2012 to 2014. Soft tissues and shells of the sampled mussels were separated for further chemical analysis. The samples were analyzed using neutron activation analysis (NAA) at the reactor IBR-2 in Dubna determine macro and trace elements including potentially toxic ones. When studying the results of the NAA statistically significant differences were observed between the sampling spots. Also there were revealed statistically significant seasonal and year-to-year variations in the elemental content of the sampled mussels.

- *Neutron activation analysis of thin Bi targets with 90 and 140 MeV*

  T. P. Lamula[1,2], P.P. Maleka[2], S.S. Ntshangase[1], M.R. Nchodu[2] and N.B. Ndlovu[2,3] neutrons.

[1] University of Zululand, South Africa
[2] NRF-iThemba LABS, South Africa
[3] Stellenbosch University, South Africa

Neutron induced cross section measurements for the (n, 3-8n) reactions of various target materials using quasi mono-energetic neutron beams are being conducted at iThemba LABS to improve and extend the International Reactor Dosimetry Fusion File (IRDFF) library. These set of reactions are very important for neutron fluence monitoring and spectra unfolding at the high energy accelerator driven neutron sources. The iThemba LABS neutron beam facility (D-line vault) can produce quasi mono-energetic neutron beams in the energy range of 30 - 200 MeV using lithium (Li) or beryllium (Be) targets, i.e. (p, n) reactions. More detailed information on the quasi-monoenergetic fields at the iThemba LABS facility can be found in various papers [1,2]. Measurements of crosssections for neutron-induced reactions in copper were made at neutron energies of 70.7 and 110.8 MeV by [3] and in ^{x}Ge(n,jn)^{68}Ge reactions by [4] with 39.9 MeV neutrons. Recently, various thin foils (including $^{\mathrm{nat}}$Bi) were irradiated with neutrons of energies of about 90 and 140 MeV and are currently being analyzed using gamma-ray spectroscopy method. For this contribution we will report on the ongoing gamma-ray analysis of the activated 209Bi(n, xn) reactions.

[1] M.Mosconi, E.Musonza, A.Buttler, R.Nolte, S.Rottger and F.D. Smit. Journal 45, 369-373 (2002).

[2] R.Nolte, M.S.Allie, P.J. Binns, F. Brooks, A.Buttler, V.Dangendorf, J.B. Meulders, F.Roos, H.Schuhmacher and B. Wiegel. Journal 476, 1342-1345 (2010).

[3] .M.Sisterson, F.D Brooks, A.Buttler, M.S.Allie, D.T.L Jones and M.B.Chadwick. Journal 240, 617-624 (2005).

[4] A.R.Domula, D.Gehre, K.Zuber, M.S.Allie, J.C.Drohe, N.Nankov, A.J.M.Plompenk, C.Rouki, M.Stanoiu, A.Klix, A.Buffler, D.Geduld, F.D.Smit, C.Vermeulen, P.Maleka, R.T.Newman, R.Nolte and A.Wallner Journal 120, 44-47 (2014).

- *Structural and micromechanical examination of ODS alloys irradiated with 1-3 MeV/nucleon heavy ions*

K. Kornieieva[1], A.S. Sohatsky[1], J.H. O'Connell[2], V.A. Skuratov[1], J.H. Neethling[2]

[1] FLNR JINR, Russia
[2] CHRTEM, NMMU, Port Elizabeth, South Africa

Oxide dispersion strengthened (ODS) steels are considered to be the most perspective materials for the Generation IV nuclear reactors due to their enhanced radiation resistance and creep resistance at high temperature comparably to conventional reactor steels [1]. To consider ODS steels as cladding materials one demands careful examination of their mechanical properties and nanoparticles structure stability under fission fragments impact. However, at the present time, most of the data of the ODS steels radiation tolerance are gathered using neutron and low energy ion irradiation [2,3], while there are

only few works devoted to stability under swift heavy ions irradiation simulating fission fragments exposure [4,5].

In the present work, the results of structure stability of three types of ODS steels irradiated with 107 MeV Kr, 167 MeV Xe and 700 MeV Bi ions were obtained using transmission electron microscopy (TEM). Radiation hardening of ODS steels was studied by nanoindentation techniques.

The latent track formation was observed in $(Cr,W)_{23}C_6$, $Y_2Ti_20_7$ and Y_2TiO_5 particles under Bi, Xe and Kr irradiation up to a fluence of 10^{12} cm^{-2}. Subsequent irradiation in the ion track overlapping regime results in particle amorphization. At the same time, $Y_4Al_2O_9$ (YAM) nanoparticles demonstrate more stable behavior under Bi irradiation: a slight difference in structural response was observed depending on the size of oxide particles. Xe irradiation to a fluence of 10^{14} cm^{-2} results in amorphization in YAM nanoparticles, the following irradiation with 10^{15} cm^{-2} fluence results in dislocation loops formation in ferrite.

Nanoindentation of the ODS steels irradiated with Kr ions in continuous stiffness measurement (CSM) mode allows to indicate the valid region of radiation hardening examination with respect to indentation and soft substrate size effects. Radiation hardening for a damage dose of 1 dpa is in the range of 10-25%. Since the hardness is at the same level irrespectively of the fluence rate, the observed radiation hardening is not due to nanoparticles structure instability.

[1] Ukai S., Fujiwara M., Journal of Nuclear Materials, 307-311, 749-757 (2002).

[2] Yamashita S. et al., Journal of Nuclear Materials, 307-311, 283-288 (2002).

[3] Monnet I. et al., Journal of Nuclear Materials, 335, 311-321 (2004).

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[5] Certain A. et al., Journal of Nuclear Materials 434, 311-321(2013)

- *Latent tracks and mechanical stresses in Al_2O_3 irradiated with swift heavy ions* J.H. O'Connell[1], R.A. Rymzhanov[2], V.A. Skuratov[2], and N.S.Kirilkin[1]

[1] CHRTEM, NMMU, University way, Summerstrand, Port Elizabeth, South Africa
[2] FLNR, JINR, Joliot-Curie 6, 141980 Dubna, Russia

We studied the morphology of latent ion tracks induced by high energy heavy ions in Al_2O_3 using a combination of high resolution TEM (HRTEM), exit wave reconstruction, geometric phase analysis and numerical simulations. Single crystal α-Al_2O_3 crystals were irradiated with 700 MeV Bi and 167 MeV Xe ions along the c-axis to fluences between 1 x 10^{10} and 1 x 10^{13} cm^{-2}. Planar TEM lamella were prepared by FIB. The geometrical phase analysis was applied to the phase image of the reconstructed complex electron wave at the specimen exit surface in order to estimate the latent strain around individual track cores. In addition to the experiments, material excitation in a SHI track was numerically simulated combining Monte-Carlo code (TREKIS) describing excitation

of the electron subsystem with the classical molecular dynamics of Al_2O_3 atoms in the nanometric proximity of the ion trajectory.

Experiment and calculation both demonstrated that the relaxation of the excess lattice energy results in the formation of a cylinder-like structure-modified region of about 4 nm in diameter consisting of an underdense disordered core surrounded by an overdense shell. Modeling of the passage of a second ion in the vicinity of this region demonstrates partial restore of this damaged area into a near-crystalline state.

Estimations of the maximal effective distance between the ion trajectories providing with such recrystallization give the values of about 6 nm for 167 MeV Xe ions which are of the same order as those estimated from the saturation density of latent ion tracks detected by TEM (1.1 x 10^{12} cm^{-2} for 167 MeV Xe).

- *Radon in-air measurements within wine-cellars of the Western Cape (South Africa) and its associated exposure dosage*

R. Botha

Stellenbosch University, iThemba-LABS, University of Western Cape Applied Nuclear Physics, Environmental/Radiation/Health Physics

Measurements were made for radon (222Rn) in-air activity concentration within nine selected active wine cellars in four wine districts of the Western Cape (South Africa) to determine the associated radiation exposure risks during two measurement series (F1 and F2) for personnel. Three E-PERM electret ion chambers (EIC) were deployed per measurement location within the wine cellar to obtain the average radon in-airactivity concentration (F1 and F2). Two RAD-7 detectors were utilized toper form continuous radon and thoron (220Rn) in-air activity concentrations (F2).The radon in-air levels ranged from 12 $\pm$ 7 Bq/m^3 to 820 $\pm$ 40 Bq/m^3 within nine wine cellar. During the first measurement series (F1); a general overview of average radon in-air levels were surveyed. Eight of the nine wine cellars (exclude high outlier) had an average radon in-air activity concentration of 45 $\pm$ 8 Bq/m^3, which originates from the radon within the atmosphere. During the second measurement series (F2); extensive radon and thoron in-air levels measurements were performed within the one wine cellar with the elevated radon in-air levels (820$\pm$ 40 Bq/m^3) detected during the first measurement series (F1).The mean radon in-air activity (E-PERM detectors) values ranged from 386 $\pm$ 24 Bq/m^3 to 510 $\pm$ 30 Bq/m^3 measured at different locations within this wine cellar (F2). The continuous synchronized radon and thoron in-air activity concentrations (RAD-7 detectors) ranged respectively from 70 $\pm$ 22 Bq/m^3 to 732 $\pm$ 70 Bq/m^3 (222Rn) and below the lower level of detection to 1520 $\pm$ 190 Bq/m^3 (220Rn) for the two detectors. In the Paarl wine district, geological factors such as permeable granite structures (containing 226Ra) was the primary cause for elevated radon in-air levels. Activity concentration measurements (HPGe-detector) of the granite yielded a concentration 226Ra: 93 $\pm$ 11 Bq/kg. The inhalation ionization radiation exposure risk due to radon in-air and its daughter products within wine cellars expressed as an effective annual dose ranged from 0.03 $\pm$ 0.01 mSv to 2.1 $\pm$ 0.1 mSv. In general

most of the wine cellars pose negligible associated health risk due to ionization radiation exposure from the inhalation of radon and its daughter products.

- *Determining the spectroscopic quadrupole moment (Q_s) of the first 2^+ state in ^{40}Ar*

  M. Mokgolobotho

  University of the Western Cape, South Africa

  The present study aims at determining the spectroscopic quadrupole moment Qs, for the first 2+ excited state in 40Ar by carrying out the first order Coulomb-excitation reorientation-effect measurements of 40Ar beams at safe energies. Only one such measurement [1] was done in the 1970's with unsafe beam energies. We have used the 208Pb (40Ar, 40Ar*)208Pb* reaction at 143.2 MeV, for which the minimum distance of closest approach between the nuclear surfaces is 6.6 fm. The first 2+ state at 1460 keV in 40Ar is populated via Coulomb-excitation and the de-excited ?-rays are detected using the AFFRODITE clover detector array [2] which comprises of 8 HPGe detectors (5 at 900 and 3 at 1350). The scattered particles are detected in coincidence with ?-rays using a double sided S3 silicon detector which consists of 24 rings (for angular distribution) on one side and 32 sectors (for Doppler correction) on the other. These measurements were done at low beam currents of 0.5 nA and with the target (1mg.cm-2 208Pb) positioned at 10.05 mm from the S3 detector at backward angles to be sensitive to Qs. The integrated ?-ray yields per ring carry information about the Qs(2+) value and will be compared with the semi-classical coupled-channel Coulomb-excitation code GOSIA [3].

  [1] Sphears et al.,

  [2] AFRODITE

  [3] GOSIA

- *Developing a sorting code for Coulomb excitation data analysis*

  C. Mehl

  University of the Western Cape, South Africa

  This work aims at developing a sorting code for Coulomb excitation studies at iThemba LABS. In Coulomb excitation reactions, the inelastic scattering of the projectile transfers energy to the partner nucleus (and vice-versa) through a time-dependent electromagnetic field. At energies well below the Coulomb barrier, the particles interact solely through the well known electromagnetic interaction, thereby excluding nuclear excitations from the process [1,2]. The data can therefore be analysed using a semiclassical approximation [3].

  The sorting code was used to process and analise data acquired from the Coulomb excitation of ^{20}Ne beams at 73 MeV and 96 MeV, onto a 3mg/cm2 ^{194}Pt target. The detection of gamma rays was done using the AFRODITE HPGe clover detector array, which consists

of 9 clover detectors, in coincidence with the 20Ne particles detected with an S3 double-sided silicon detector. The new sorting code includes Doppler-correction effects, charge-sharing, energy and time conditions, GEANT simulations, kinematics and stopping powers, among others, and can be used for any particle-gamma coincidence measurements at iThemba LABS. Other Coulomb excitation measurements at iThemba LABS will also be presented. This work aims at developing a sorting code for Coulomb excitation studies at iThemba labs. Coulomb excitation is the inelastic scattering of charged particles transfer energy to an nucleus through the at time dependent electromagnetic field. The charged particles and nucleus interact solely through the well known electromagnetic interaction, thereby excluding nuclear excitations from the process. For this purpose, the Coulomb excitation measurement must be conducted at beam energies well below the Coulomb barrier.

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[2] D.C. Kean, Lecture Notes in Physics (Springer) **92**, 80 (1979).

[3] J.N. Orce, Phys. Rev. C **86**, 041303(R) (2012).

- *Liquid Metal Ion Source Assembly for External Ion Injection into an Electron String Ion Source (ESIS)*

  M. Segal

  Univ. of Cape Town and iThemba LABS, South Africa

  An assembly for a commercial Ga+ liquid metal ion source (LMIS) in combination with an ion transportation and focusing system, a pulse high-voltage quadrupole deflector and a beam diagnostics system has been constructed in the framework of the iThemba Labs (Cape Town, South Africa) JINR (Dubna, Russia) collaboration. First results on Ga^+ ion beam commissioning will be presented. Outlook of further experiments for measurements of charge breeding efficiency in the electron String Ion Source (ESIS) with the use of external injection of Ga+ and Au+ ion beams will be reported as well.

Thursday, 24 September 2015

Conference Hall of the Flerov Laboratory of Nuclear Reactions (FLNR)

Nuclear Structure session
Conveners: R. Nazmitdinov, W.D. Heiss

Chairman: F. Šimkovic

9:00 R. Nazmitdinov (BLTP, JINR) 25'+5'
Symmetry effects in mesoscopic systems

9:30 V.O. Nesterenko (BLTP, JINR) 25'+5'
Deformation effects in the dipole and quadrupole giant resonances: Skyrme RPA theory and iThemba experiments

10:00 J. N. Orce (University of the Western Cape, SA) 25'+5'
Nuclear polarizability: the sleeping beauty of nuclear physics

Chairman: R. Nazmitdinov

11:00 P. Schuck (Orsay, France) 25'+5'
Selfconsistent RPA meets Time-Dependent Density matrix

11:30 F. Šimkovic (BLTP, JINR) 25'+5'
QRPA with non-linear operator

12:00 N. Arsenyev (BLTP, JINR) 18'+2'
Complex configuration effects on properties of pygmy resonance

12:30 K. R. Mukhi (University of the Western Cape, SA) 18'+2'
Coulomb excitation reorientation-effect measurements in ^{12}C

- *Symmetry effects in mesoscopic systems*

  R.G. Nazmitdinov[1], W.D. Heiss[2], and N.S. Simonović[3]

  [1]JINR, Dubna, Russia and UIB, Palma de Mallorca, Spain
  [2]Institute of Theoretical Physics, University of Stellenbosch, South Africa
  [3] Institute of Physics, University of Belgrade, Belgrade, Serbia

  We discuss symmetry effects produced by interplay of regular and chaotic dynamics of particles confined by effective potentials of various shapes in finite quantum systems. It is demonstrated that dynamical symmetries emerging from this interplay in classical and quantum systems are related to existence of conserved quantities of the dynamics and integrability. Important role of these symmetries are illustrated on a broad class of mesoscopic systems that include octupole deformed nuclei and two-electron quantum dots in a magnetic field (see for a review [1]).

  [1] J.L. Birman, R.G. Nazmitdinov, and V.I. Yukalov, Physics Reports **526**,1 (2013).

- *Deformation effects in the dipole and quadrupole giant resonances: Skyrme RPA theory and iThemba experiments*

  V.O. Nesterenko

  Bogoliubov laboratory of theoretical physics, JINR

  The description of deformation effects in the isovector dipole E1(T=1) and isoscalar quadrupole E2(T=0) giant resonances (GR) within the Skyrme RPA approach is reviewed. In connection with recent (p,p') experiments at iThemba LABS, a large attention is paid to E1(T=1) and E2(T=0) GR in deformed Nd isotopes. Applicability of the comparative (theory + experiment) wavelet analysis for revealing deformation effects in these GR is discussed.

- *Nuclear polarizability: the sleeping beauty of nuclear physics*

  J.N. Orce

  University of the Western Cape, South Africa

  In 1944 Arkadii Migdal predicted the existence of the giant dipole resonance and related the (-2) moment of the total photoabsorption cross section to the nuclear polarizability. More than 60 years later, Migdal's insight based on the hydrodynamic model and second-order perturbation theory is shedding new light onto our current understanding of the nuclear structure and maybe challenging the cornerstone of nuclear physics: the shell model. It is time to wake up nuclear polarizability from its long hibernation.

- *Selfconsistent RPA meets Time-Dependent Density matrix*

  P. Schuck

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We include the 3-body correlation function in the BBGKY hierarchy for1-body and 2-body density matrices approximately deducing for it a quadratic form of 2-body density matrices. The equations of motion are, therefore, closed leading, for instance, to a non-linear equation for the 2-body density matrix. The small amplitude approximation thereof leads to Self-Consistent RPA (SCRPA) coupled to the 2-body sector (extended 2nd RPA). The theory is applied to several exactly solvable many body models and results compared with exact solutions. Appearance of Goldstone modes and fullfilment of sum rule is shortly discussed.

- *QRPA with non-linear operator*

F. Šimkovic[1,2,3] and A. Smetana[2]

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[3] Czech Technical University in Prague, 128-00 Prague, Czech Republic
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We propose a novel extension of the standard quasiparticle random phase approximation (QRPA) with a new form of phonon operator, which allows to describe also states of multiphonon origin. We denote this method as QRPA with non-linear operator (nlQRPA) and apply it to the proton-neutron Lipkin model. For considered phonon operator with the simplest non-linear extension the QRPA equation is transformed to a standard form which guarantees the orthonormality and completeness of the QRPA states of one-phonon and three-phonon origin. A rather good agreement is found both for energies and beta transition amplitudes with those obtained by a diagalization of the schematic Hamiltonian. There is straightforward way to extend this approach also for a realistic nuclear structure calculations.

- *Complex configuration effects on properties of pygmy resonance*

N. N. Arsenyev[1], A. P. Severyukhin[1], V. V. Voronov[1], Nguyen Van Giai[2]:

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[2] Institut de Physique Nucléaire, CNRS-IN2P3, Université Paris-Sud, F-91406 Orsay Cedex, France

The new spectroscopic studies of pygmy dipole resonances (PDR) [1] in neutron-rich nuclei stimulate a development of the nuclear models. One of the successful tools for describing the PDR is the quasiparticle random phase approximation (QRPA) with the self-consistent mean-field derived by making use of the Skyrme effective nucleon-nucleon interaction [2]. Such an approach describes the properties of the low-lying states less accurately than more phenomenological ones, but the results are in a reasonable agreement with experimental data. Due to the ahnarmonicity of vibrations there is a coupling between one-phonon and more complex states. The main difficulty is that the complexity of calculations beyond standard QRPA increases rapidly with the size of the configuration space, so one has to work within limited spaces. Using a finite rank separable approximation for the residual interaction obtained from the Skyrme forces that has been

suggested in [3,4,5] one can overcome this problem. We study the properties of the low-lying dipole states in the even-even nuclei $^{126-130}$Pd, $^{128-132}$Cd, $^{130-134}$Sn, $^{132-136}$Te, and $^{134-138}$Xe [6]. Effects of the shell structure and the neutron skin are studied in a systematic way. This reveals a number of characteristic features of the low-energy E1 modes. In particular, we find the impact of the shell closure on the low-energy E1 strength.

This work was partly supported by the IN2P3-JINR agreement and the Heisenberg-Landau program.

[1] D. Savran, T. Aumann, A. Zilges, Prog. Part. Nucl. Phys. **70**, 210 (2013).

[2] N. Paar, D. Vretenar, E. Khan, G. Colò, Rep. Prog. Phys. **70**, 691 (2007).

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- *Coulomb excitation reorientation-effect measurements in ^{12}C*

K. R. Mukhi

University of the Western Cape, South Africa

The shape is one of the fundamental property of an atomic nucleus which reflects the underlying shell structure of nucleons. The direct information about the shape and degrees of quadrupole collectivity of even-even nuclei comes mainly from measuring the electromagnetic reduced transition matrix element B(E2; $0_1^+ \rightarrow 2_1^+$) between the ground state and the first 2_1^+ excited state and diagonal matrix element $\langle 2_1^+ \mid\mid \hat{E2} \mid\mid 2_1^+ \rangle$ of the excited first 2_1^+ state. The re-orientation effect plays an important role in low energy coulomb excitation measurements as it provides information on diagonal matrix elements, thereby one can measure spectroscopic quadrupole moment (Q_s) with its sign precisely.

In the present work, we aimed at determining the sign and magnitude of the spectroscopic quadrupole moment of the first 2_1^+ excited states in ^{12}C using the reorientation effect in a safe energy Coulomb excitation measurement. Only one such measurement was performed in 1983 [1] using an unsafe minimum distance of closest approach between nuclear surfaces which resulted in a large uncertainty in the measured quadrupole moment [$Q_s(2_1^+)$ = +6(3) efm^2]. Only singles particles were detected. In the present work, the first 2_1^+ state at 4438 keV is excited through the Coulomb excitation of ^{12}C beams at $\approx$ 4.97 MeV/u energy impinging on a 1 mg/cm^2 ^{194}Pt target. The de-excited γ-rays are detected with highly efficient segmented TIGRESS HPGe γ-ray detector array [2] at TRIUMF, Canada. The scattered particles are detected in coincidence with γ-rays using double-sided silicon detector (S2 CD-type) which comprises 24 rings and 32 sectors. The particle detector covers an angular range between $\approx 37^\circ$ - 67°. The data has been calibrated using radioactive sources ^{241}Am at low energies and Geant4 simulation of elastic peaks to cover higher energies. The particle-γ coincidence data is corrected for Doppler effects, energy losses and broadening inside the target material. The resulted γ-ray spectra shows the

excited 2^+ state in ^{12}C with reasonable yields. Progress on this work will be presented during the symposium.

[1] W. J. Vermeer *et al*., Phys. Lett. B 122, 23 (1983).

[2] TIGRESS, Technical progress report (August 2007)

Thursday, 24 September 2015

Conference Hall of the Flerov Laboratory of Nuclear Reactions (FLNR)

Physics at Underground Laboratory session
Conveners: F. Šimkovic, S. Wyngaardt

Chairman: F. Šimkovic

14:30 D. Naumov (DLNP, JINR) 25'+5'
Neutrino Physics program at the JINR

15:00 R. Newman (Stellenbosch U.) 18'+2'
Towards SAUL - perspectives, progress and prospects for establishing enhanced low-level radioactivity measurement capability

15:20 O. Smirnov (DLNP, JINR) 18'+2'
Neutrino geophysics

15:40 A. Zakharov (ITEP Moscow) 18'+2'
Possible alternatives for models of the Galactic Centre

- *Neutrino Physics program at the JINR*

  D. Naumov

  Dzhelepov Laboratory of Nuclear Problems, JINR Dubna, Russia

  JINR caries a wide Neutrino Program covering almost all aspects of modern neutrino physics in both experiment and theory. The Program will be shortly described emphasizing the contribution of JINR, development of new facilities and stressing possible areas of the collaboration.

- *Towards SAUL - perspectives, progress and prospects for establishing enhanced low-level radioactivity measurement capability*

  R. Newman, S. Wyngaardt, P. Papka, T. Ackerman, D. Dawam, P. Maleka*, R. Nchodu*

  Physics Department, Stellenbosch University, South Africa
  * Themba LABS NRF, Faure, South Africa

  An important thrust of the foreseen research program of a South African Underground Laboratory (SAUL) is linked to low-level radioactivity measurements. After presenting some examples of research linked to low-level measurements made using existing facilities, we discuss progress and prospects for establishing enhanced measurement capability inside the Huguenot Tunnel, near Paarl (Western Cape, South Africa).

- *Neutrino geophysics*

  O. Smirnov

  Dzhelepov Laboratory of Nuclear Problems, JINR Dubna, Russia

  Geoneutrino are electron antineutrino accompanying β-decays of nuclear isotopes present in the Earth. The interest in geoneutrino have raised very recently in parallel with development of large volume scintillator detectors, able to detect their tiny fluxes. The main scientific outcome expected from these measurements is the distribution of radioactive elements deep inside the Earth, beyond the reach of direct measurements by sampling.

  Models used by geophysicists to predict geoneutrino fluxes will be compared to the experimental results, and future experiments will be discussed.

- *Possible alternatives for models of the Galactic Centre*

  A. Zakharov

  Institute of Theoretical and Experimental Physics, Moscow, 117218, Russia
  Bogoliubov Laboratory of Theoretical Physics, JINR, Dubna, Moscow region, Russia

  Now there are two basic observational techniques to investigate a gravitational potential at the Galactic Center, namely, a) monitoring the orbits of bright stars near the Galactic Center to reconstruct a gravitational potential; b) measuring a size and a shape of shadows around black hole giving an alternative possibility to evaluate black hole parameters in

mm-band with VLBI-technique. At the moment one can use a small relativistic correction approach for stellar orbit analysis (however, in the future the approximation will not be not precise enough due to enormous progress of observational facilities) while now for smallest structure analysis in VLBI observations one really needs a strong gravitational field approximation. We discuss results of observations, their conventional interpretations, tensions between observations and models and possible hints for a new physics from the observational data and tensions between observations and interpretations. We will discuss an opportunity to use a Schwarzschild metric for data interpretation or we have to use more exotic models, for instance, Reissner – Nordström or Schwarzschild – de-Sitter (Kottler) metrics for better fits.

Thursday, 24 September 2015

Conference Hall of the Flerov Laboratory of Nuclear Reactions (FLNR)

Condensed Matter Physic session
Conveners: Yu. Shukrinov, A.E. Botha

Chairman: A. Povolotsky

16:30 Yu. Shukrinov (BLTP JINR) 20'+5'
Theoretical Models for Superconducting Nanostructures

16:55 A. E. Botha (Univ. of South Africa) 20'+5'
Imperfect chimeras in a stack of intrinsically coupled Jospehson junctions

17:20 I. Rahmonov (BLTP JINR) 20'+5'
Numerical Study of Josephson Nanostructures Using Parallel Computing Based on Cloud Center LIT JINR

17:45 E. Benecha (Univ. of South Africa) 20'+5'
Simulation of Topologically Nontrivial DC-SQUID

18:10 K. Kulikov (BLTP JINR) 20'+5'
Superconducting structures with Majorana fermions

- *Theoretical models for superconducting nanostructures*

  Yu. Shukrinov

  BLTP, JINR, Dubna, Russia and International University of Nature, Society and Man "Dubna", Dubna, Russia

  We discuss the theoretical models for intrinsic Josephson junctions in high temperature superconductors and superconducting structures with shunting. Short review of our recent results are presented. Particularly, a variation of longitudinal plasma wavelength under external electromagnetic radiation [1] and its experimental testing is discussed. We demonstrate the principal difference in the reaction of the system of coupled junctions to the external radiation in compare with a case of single Josephson junction [2,3]. The IV-characteristics of a Josephson junction under external electromagnetic radiation show the devil's staircase within different bias current intervals [4,5]. It is found that the observed steps form very precisely continued fractions. We discuss an algorithm for the appearance and detection of subharmonics with increasing radiation amplitude and demonstrate that the staircase structures registered in many well-known experiments and by simulations form also the continued fractions. We study an effect of external radiation on the dynamics of Josephson junction shunted by an LC circuit. When the Josephson frequency is equal to the frequency of the circuit, additional stable resonant circuit branches appear in the IV -characteristic of the junction. We show that the amplitude dependence of the Shapiro step width crucially changes when the Shapiro step is on the resonant circuit branch. These effects might give very important advantages for methods and technologies that exploit the response of Josephson junctions to microwave fields [6].

  [1] Yu. M. Shukrinov, I. R. Rahmonov, M. A. Gaafar - Phys. Rev. B, 86, 184502 (2012).

  [2] Yu. M. Shukrinov and H. Abdelhafiz- JETP Letters, 98, 551 (2013).

  [3] Yu.M. Shukrinov, H.Azemtsa-Donfack, A.E.Botha.- Pisma v ZhETF, 101, 269 (2015)

  [4] Yu. M. Shukrinov, S. Yu. Medvedeva, A. E. Botha, M. R. Kolahchi, A. Irie - Phys. Rev. B, 88, 214515 (2013).

  [5] Yu. M. Shukrinov, A. E. Botha, S. Yu. Medvedeva, M. R. Kolahchi, A. Irie - Chaos, 24, 033115 (2014).

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- *Imperfect chimeras in a stack of intrinsically coupled Jospehson junctions*

  A. E. Botha,[1] Yu. M. Shukrinov,[2] S. Emadi,[3] F. Osanloo,[3] and M. R. Kolahchi [3]

  [1]University of South Africa, South Africa,
  [2]Joint Institute for Nuclear Research, Russia,
  [3]Institute for Advanced Studies in Basic Sciences, Iran

  It is shown that a stack of intrinsically coupled Josephson junctions, as may be realized in a high temperature superconductors, has the potential to sustain imperfect chimera

states [1,2]. In this study the coupling within the CCJJ+DC model [3] is extended to include nonlocal interaction between the junctions. The modified equations are: $\mathrm{d}V_\ell/\mathrm{d}t = I + I_\ell^n - \sin\varphi_\ell - \beta\mathrm{d}\varphi_\ell/\mathrm{d}t$, and $\mathrm{d}\varphi_\ell/\mathrm{d}t = V_\ell + 2\alpha\sum_{m=1}^{N} H_{\ell m}V_m$, where N is the number of junctions and $H_{\ell m}$ is the generalised coupling, shown in Fig. 3.

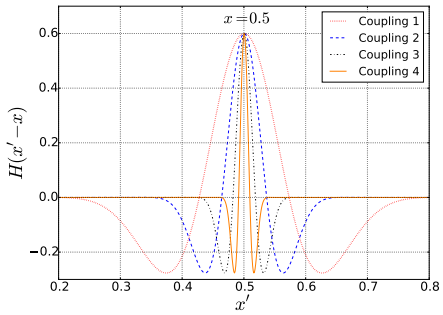
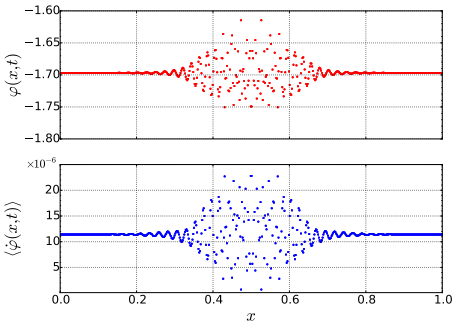


Figure 3: Generalised coupling at four coupling ranges. Junctions are positioned in a ring (periodic boundary conditions) withing the interval [0,1), where x_ℓ is the position of the ℓth junction. For mathematical convenience the coupling is treated as a continuous function: $H_{\ell m} \equiv H(x_\ell - x_m)$. The coupling in the original model is reproduced exactly when the continuous coupling range is on the order of one junction separation, i.e. $\sim 1/N$.

Figure 4 shows the result of a numerical simulation for $N = 512$, using Coupling 3.

Figure 4: Visualisation of the imperfect chimera state. The top figure shows the instantaneous phase differences for each junction at $t = 10\,000$. The bottom figure shows the time averaged velocities of the junctions, averaged over $\Delta t = 1000$. Junctions between about 0.35 and 0.65 are characterized by incoherence among their phases, while those in the remaining region rotate coherently. The scale on the vertical axis of the lower figure runs from 3.990930 to 3.990955.



Such imperfect chimera states have recently been observed experimentally in systems of coupled metronomes [2] and could in principle be detected in the present system through interference measurements.

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[2] T. Kapitaniak *et al.*, Scientific Reports **4**, 6379 (2014).

[3] Yu. M. Shukrinov, F. Mahfouzi, and P. Seidel, Physica C **449**, 62 (2006).

- *Numerical study of Josephson nanostructures using parallel computing based on cloud center LIT JINR*

I. R. Rahmonov[a,b], Yu. M. Shukrinov[a,d], E. V. Zemlyanaya[c,d] and M. V. Bashashin[c,d]

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[b]Umarov Physical and Technical Institute, Dushanbe, Tajikistan

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The layered high-Tc superconducting materials such as $Bi_2Sr_2CaCu_2O_{8+\delta}$ (BSCCO) can be considered as a stack of coupled Josephson junctions (JJs) [1]. We investigate the phase dynamics of the stack of long JJs, which length exceeds the Josephson penetration depth λ_J, taking into account the inductive and capacitive couplings and diffusion current [2,3,4]. Numerical simulation of current–voltage characteristics is based on numerical solution of a system of nonlinear partial differential equations by the fourth order Runge–Kutta method, finite-difference approximation. The calculations are performed using MPI technique for parallel implementation. We have shown that in the system of long JJs, the charge travelling wave coexists with the fluxons.

The methodical calculations on CICC multi-processor cluster (LIT JINR) with different number of parallel MPI-processes are performed. For these calculations we put number of JJs $N = 10$, the JJ length $L = 5\lambda_J$ and $L = 10\lambda_J$; $\Delta x = 0.05$; $\Delta I = 0.005$. The boundary conditions along x–axis are defined by external magnetic field. Along the stack we have chosen the periodic boundary conditions. Table 1 shows the calculation time (in minutes) of the CVC per number of processes for the stacks with the $N = 3$, $N = 10$ JJs and with length $L = 5\lambda_J$, $L = 10\lambda_J$. One can see that the developed parallel algorithm provides for the case of $N = 10$ and $L = 5$ seven time acceleration in comparison with serial simulation, when we calculate using 10 processes.

Table 1: Simulation time of CVC in minutes per number of processes

P	1	2	4	6	8	10	12
L=5, N=10	106.2	46.8	27.3	25.7	19.5	14.4	16.7
L=10, N=10	213	92.5	62.5	44.4	42.3	32.4	37.2
L=10, N=3	37.1	19.9	11.3	8.6	7.5	6.4	6.4

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[3] M. Machida and S. Sakai, Phys. Rev. B **70**, 144520 (2004).

[4] Yu. M. Shukrinov and I. R. Rahmonov, JETP **115**, 289–302 (2012).

- *Simulation of topologically nontrivial DC-SQUID*

E. Benecha[a], I .R. Rahmonov [b,c], Yu. M. Shukrinov [b,d], R. Dawood [e]

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[c]Umarov Physical and Technical Institute, Dushanbe, Tajikistan
[d]Dubna International University for Nature, Society and Man, Dubna, Russia
[e]Cairo University, Giza, Egypt

Josephson junctions with topologically nontrivial barriers host Majorana bound states [1,2]. Candidates with high potential for the detection and manipulation of the Majorana fermion [3]

are superconducting quantum interference devices (SQUIDs) [4,5]. The appearance of Majorana bound states in superconducting junctions enables tunneling of quasiparticles with charge e across the junction, which doubles the Josephson periodicity $I_c = I_0 \sin(\varphi/2)$ [1]. We study in detail the behavior of DC-SQUIDs with topologically nontrivial barriers and compare the results with the trivial case.

The current voltage characteristics and the critical current dependence on the external magnetic flux for the dc SQUID with trivial and nontrivial barriers are presented. Fig. shows the current –voltage characteristics of the DC-SQUIDs with the trivial and nontrivial barriers for the model parameters $\beta_c = 10$, $\beta_L = 1$ and external magnetic field $\varphi_{ext} = \Phi/\Phi_0 = 1$. We have shown that so-called beating solutions at the frequency [6] $\omega = \sqrt{1/(\beta_c\beta_L)}$ of DC-SQUID with nontrivial barriers shifts on $\sqrt{2}$ in comparison with the case of trivial barriers. We consider that this fact might be useful in the experimental detection of Majorana fermions.

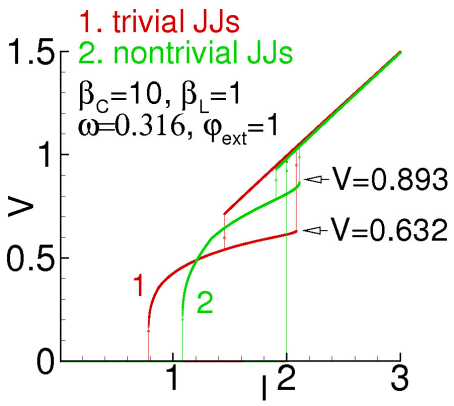

Figure 5: Current–voltage characteristics of the SQUIDs with trivial and nontrivial barriers for the model parameters $\beta_c = 10$ $\beta_L = 1$ and $\varphi_{ext} = 1$.

[1] L. Fu and C.L. Kane, Phys.Rev.Lett. **100**, 096407 (2008).

[2] Y.Tanaka, T. Yokoyama, and N. Nagaosa, Phys.Rev.Lett. **103**, 107002 (2009).

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[6] W. -D. Schmidt, P. Seidel, and S. Heinemann, Phys.Stat.Sol.(a) **91**, K155 (1985).

- *Superconducting structures with Majorana fermions*

K. V. Kulikov[1,2], M. Maiti[1], K. Sengupta[2] and Y. M. Shukrinov[1,2]

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[2] BLTP, JINR, Dubna, Russia
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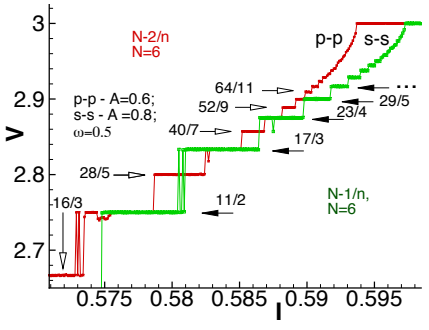
We demonstrate that the current-voltage (I-V) characteristics of resistively and capacitively shunted Josephson junctions (RCSJs) hosting localized subgap Majorana states provides a phase sensitive method for their detection. The I-V characteristics of such RCSJs, in contrast to their resistively shunted counterparts, exhibit subharmonic odd Shapiro steps; such steps occur even in the absence of any 2π periodic terms in the current-phase relation of these junctions. These steps, owing to their subharmonic nature, exhibit qualitatively different properties compared to harmonic odd steps of conventional junctions. In addition, the RCSJs hosting Majorana bound states also display an additional sequence of steps in the devil staircase structure seen in their I-V characteristics [1].

We find that for conventional junctions, the steps corresponding to second level fractions occur at $V = N(1-1/n)\omega$ (V-voltage of Josephson junction (JJ), ω-frequency of external radiation, N-number of JJ). In contrast, for junctions hosting Majorana subgap states, the steps correspond to $V = (N \mp 2/n)\omega$ (see figure) leading to several additional steps within a given range of A amplitude of external radiation [2]. This difference in structure lead us to hypothesize that in contrast to conventional Josephson junctions, the steps for the junctions with Majorana bound states show additional fractions. We therefore suggest that the presence of these additional specific continued fractions may be considered as a signature of Majorana fermions.

The specific example of this phenomenon is presented in Figure. In this figure, we find that the continued fraction $V = N(1-1/n)\omega$ with $N = 6$ which appears in s-wave Josephson junctions at $\beta = 0.2, \omega = 0.5$ and $A = 0.8$. In contrast, as clearly demonstrated in figure, the steps for the p-wave junction occur at $V = (N \mp 2/n)\omega$ with $N = 6$, and several n. Further, as shown in Ref.[1], the continued fraction $V = N(1 - 1/n)\omega$ with $N = 6$ appears for conventional Josephson junctions at $A = 0.9$.



[1] Y. M. Shukrinov, S. Y. Medvedeva, A. E. Botha, M. R. Kolahchi, and A. Irie, PRB **88**, 214515 (2013).

[2] M. Maiti, K. M. Kulikov, K. Sengupta and Y. M. Shukrinov, arXiv:1507.00010, (2015).

Thursday, 24 September 2015

Conference Hall of the Veksler and Baldin Laboratory of High Energy Physics (VBLHEP)

NICA session

Conveners: A. Sorin, J. Cleymans

Chairman: A. Sorin

9:00 A. Sidorin (VBLHEP, JINR) 18'+2'
NICA collider complex: challenges and perspectives

9:20 V. Kolesnikov (VBLHEP, JINR) 18'+2'
Prospects for dense baryonic matter research at NICA: Status of the MPD

9:40 M. Kapishin (VBLHEP, JINR) 18'+2'
Prospects for dense baryonic matter research at Nuclotron: Status of the BM@N

10:00 B. Mellado (Witwatersrand) 18'+2'
High-throughput electronics for the NICA complex and the ATLAS Experience

Chairman: J. Cleymans

10:50 J. Cleymans (Univ. of Cape Town) 18'+2'
The physics case for the NICA project

11:10 A. Sorin (VBLHEP, JINR) 18'+2'
Vortical structures and strange hyperon polarization in heavy-ion collisions

11:30 A. Muronga (Univ. of Johannesburg) 18'+2'
Relativistic Fluid Dynamics for Heavy Ion Collisions and Astrophysics

11:50 D. Blashke (Univ. of Wroclaw) 18'+2'
Cluster virial expansion for quark/nuclear matter within the 2PI formalism

12:10 A. Trunin (BLTP, JINR) 18'+2'
Equation of State for quark-gluonic matter from Nf=2+1+1 lattice QCD

- *NICA collider complex: challenges and perspectives*

  A. Sidorin, I. Meshkov, G. Trubnikov

  VBLHEP, JINR Dubna, Russia

  The project of Nuclotron-based Ion Collider fAcility NICA under development at JINR (Dubna) is presented. The general goals of the project are providing of colliding beams for experimental studies of both hot and dense strongly interacting baryonic matter and spin physics (in collisions of polarized protons and deuterons). The first program requires providing of heavy ion collisions in the energy range of Ö/s_{NN} / = 411 GeV at average luminosity of $/L/ = 1 \times 10^{27}$ cm$^{-2}\times$ s^{-1} for ^{197}Au$^{79\ +}$ nuclei. The report contains description of the facility scheme and characteristics in heavy ion operation mode, status and plans of the project development.

- *Prospects for dense baryonic matter research at NICA: Status of the MPD project*

  V.I. Kolesnikov

  VBLHEP, JINR, Dubna

  The main mission of the NICA physics program is an experimental investigation of nuclear matter properties under extreme conditions. In my talk, I'll overview the current status of the MPD project aimed in study of heavy-ion collisions at NICA. In the beginning, I'll discuss the NICA prospects and MPD physics cases with an emphasis to study of strangeness production and modification of dilepton spectra in dense matter. A theoretical motivation will be accompanied by results of realistic Monte-Carlo simulation of the proposed experimental setup. In the following, I'll briefly describe the elements of the MPD detector [1] and present R&D results for MPD subsystems.

  [1] K.U. Abraamyan et al. Nucl. Instrum. Meth. A 628, 99 (2011).

- *Prospects for dense baryonic matter research at Nuclotron: Status of the BM@N*

  M. Kapishin

  VBLHEP, JINR Dubna, Russia

  BM@N (Baryonic Matter at Nuclotron) is the first experiment to be realized at the accelerator complex of NICA-Nuclotron-M. The aim of the BM@N experiment is to study interactions of relativistic heavy ion beams with fixed targets. The present status the BM@N set-up development and future plans for the BM@N experimental program are presented.

- *High-throughput electronics for the NICA complex and the ATLAS Experience*

  B. Mellado

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Today's large-scale science pro jects have always encountered challenges in processing large data flow from the experiments, the ATLAS detector records proton-proton collisions provided by the Large Hadron Collider (LHC) at CERN every 50 ns which results in a total data flow of 10 Pb/s. These data must be reduced to the science data product for further analysis, thus a very fast decisions need to be executed, to modify this large amounts of data at high rates. The capabilities required to support this scale of data movement is development and improvement of high-throughput electronics. The upgraded LHC will provide collisions at rates that will be at least 10 times higher than those of today due to it's luminosity by 2022. This will require a complete redesign of the read-out electronics in the Tile-calorimeter (TileCal) of the ATLAS experiment. Within this effort two boards are being developed: the super Readout Driver (sROD) and the Processing Unit (PU). Both boards fulfil different functions in terms of throughput and processing complexity. The feasibility of implementing the sROD and the PU in the NICA complex is discussed.

- *The physics case for the NICA project*

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  The NICA project will enable discoveries about properties of super-dense nuclear matter. The understanding of the properties of matter under extreme conditions of high density and temperature is absolutely necessary and has great value not only for nuclear physics, but also for astrophysics, cosmology, condensed matter physics and development of new technologies.

  The main goal of the NICA project is searching for a possible manifestation of the mixed phase formation and critical endpoint in heavy ion collisions. These investigations are relevant to understanding of the evolution of the Early Universe after the Big Bang, formation of neutron stars, and the physics of heavy ion collisions. The new facility makes it possible to reach a new level in studying polarization phenomena in few-body nucleon systems. The beam energy of the NICA is particularly interesting; it is considerably lower than the region covered by the Large Hadron Collider (LHC) in Geneva but it sits right on top of the region where the baryon density at the freeze-out is expected to be the highest. In this energy range the system occupies a maximal space-time volume in the mixed quark-hadron phase (the phase of coexistence of hadron and quark-qluon matter similar to the water-vapor coexistence-phase). The net baryon density at LHC energies (ALICE experiment) will be lower because of a phenomenon called nuclear transparency: at very high energies nuclei fly "through" each other, produce a very large number of mesons and, therefore, reach very high energy densities but due to a large number of mesons achieve fairly low baryon densities. The energy region of NICA will allow analyzing the highest baryonic density under laboratory conditions.

- *Vortical structures and strange hyperon polarization in heavy-ion collisions*

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  We study vorticity and hydrodynamic helicity in semi-peripheral heavy-ion collisions using the kinetic model of Quark-Gluon Strings. The angular momentum, which is a source of P-odd observables, is preserved with a good accuracy. We observe formation of the specific toroidal structures of the vorticity field. Their existence, accompanied by the strange chemical potential, is mirrored in the polarization of hyperons of the percent order.

- *Cluster virial expansion for quark/nuclear matter within the 2PI formalism*

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  The investigations exploring the phase boundary between nuclear and quark matter are in the dilemma that a proper theoretical basis is missing: a unified approach which can describe both phases on the same footing and deal properly with the transition between them. We suggest that a cluster virial expansion for quark-nuclear matter [1] formulated within the Φ-derivable approach [2] to many particle systems with strong correlations can fill this gap. We define a generic form of Φ-functionals that is fully equivalent to a selfconsistent cluster virial expansion up to the second virial coefficient for interactions among the clusters. As examples we consider nuclei in nuclear matter and hadrons in quark matter, with particular attention to the case of the deuterons in nuclear matter and mesons in quark matter. We derive a generalized Beth-Uhlenbeck equation of state for two-particle states in quark matter [3], and outline how the quasiparticle virial expansion is extended to include arbitrary clusters. The approach is applicable to nonrelativistic potential models of nuclear matter as well as to relativistic field theoretic generalizations of models for quark/nuclear matter like the string-flip model [4]. It is particularly suited for a description of cluster formation and dissociation in dense hadronic matter in compact star interiors and in heavy ion collisions such as planned for FAIR and NICA.

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- *Equation of State for quark-gluonic matter from Nf=2+1+1 lattice QCD*

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  We present results for the Equation of State of quark-gluonic matter obtained in our project for a lattice study of QCD thermodynamics with two generations of dynamical quarks. We employ the Wilson twisted mass implementation for fermionic fields and use in the gauge sector the improved Iwasaki gauge action. The fixed-scale approach is used with three lattice spacings and charged pion mass fixed around 370 MeV. The values for pseudocritical temperature are obtained from the chiral susceptibility and subtracted chiral condensate analysis. We compare our Equation of State with inclusion of the heavier doublet with analogous results obtained with only $N_f = 2$ degenerate light flavours.