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ABSTRACTS

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Abstracts

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CONTENTS

MEAN CHARGE VALUES OF HEAVY ATOMS IN DILUTE HYDROGEN
Yu.Ts.Oganessian, V.K.Utyonkov, Yu.V.Lobanov, F.Sh.Abdullin, A.N.Polyakov, R.N.Sagaidak, I.V.Shirokovsky, Yu.S.Tsyganov, A.N.Mezentsev, K.Subotic, K.J.Moody, J.F.Wild, N.J.Stoyer, M.A.Stoyer, R.W.Lougheed, D.A.Shaughnessy and J.M.Kenneally 11

STRUCTURE OF EXOTIC NUCLEI VIA DIRECT REACTIONS
N.Alamanos, A. Gillibert, N. Keeley, V. Lapoux, A. Obertelli and F. Skaza 12

ION-TRACK MEMBRANES AND THEIR USE IN BIOLOGICAL AND MEDICAL APPLICATIONS
P.Apel, S.N.Dmitriev, G.Gulbekian, B.Gikal, O.Ivanov, V.Skuratov 13

CLUSTERING IN PERIPHERAL FRAGMENTATION OF LIGHT RELATIVISTIC NUCLEI IN NUCLEAR TRACK EMULSION
D.A. Artemenkov and P.I. Zarubin 14

CHARACTERISTICS OF SYMMETRIC AND ASYMMETRIC MODES AS A FUNCTION OF THE COMPOUND NUCLEUS EXCITATION IN THE PROTON - INDUCED FISSION OF ^{233}Pa, ^{239}Np AND ^{243}Am
M. Beresova, A.A. Bogatchev, O. Dorvaux, I.M. Itkis, M.G. Itkis, S. Khlebnikov, J. Kliman, G.N. Kniajeva, N.A. Kondratiev, E.M. Kozulin, L. Krupa, V. Lyapin, I.V. Pokrovsky, W. Rubchenia, L. Stuttge, W. Trzaska, D. Vakhtin 15

MASS MEASUREMENTS OF HEAVY RADIONUCLIDES AT SHIPTRAP.FIRST RESULTS AND FUTURE PERSPECTIVES
M. Block, D. Ackermann, K. Blaum, A. Chaudhuri, S. Eliseev, F. Herfurth, F.P.Heßberger, S. Hofmann, H.-J. Kluge, A. Martın, G. Marx, J.B. Neumayr, Y.Novikov, W.R. Plaß, S. Rahaman, C. Rauth, D. Rodrıguez, C. Scheidenberger, L.Schweikhard, P.G.Thirolf, G.Vorobjev, C.Weber and the SHIPTRAP Collaboration 16

WEAK-INTERACTION RATES OF NEUTRON-RICH NUCLEI NEAR EXOTIC SHELL-CLOSURES
I.N.Borzov, K.Langanke, A.Keli'c, G.-M.Pinedo, N.Zinner 17

STUDY OF EXTREMELY NEUTRON-RICH LIGHT ISOTOPES. EXPERIMENTAL OBSERVATION OF ^{7}H
M.Caamano, D.Cortina-Gil, W.Mittig, H.Savajols, L.Caballero, M.Chartier, C.E.Demonchy, B.Fernandez, A.Gillibert, B.Gomez Hornillos, B.Jurado, O.Kiselev, R.Lemmon, A.Obertelli, F.Rejmund, M.Rejmund, P.Roussel-Chomaz and R.Wolski 18

PRODUCTION OF NEUTRON-RICH ISOTOPES NEAR N=126 IN COLD-FRAGMENTATION REACTIONS INDUCED BY RELATIVISTIC ^{208}PB PROJECTILES
T.Kurtukian-Nieto, J.Benlliure, L.Audouin, F.Becker, E.Casarejos, D.Cortina-Gill, M.Fernandez-Ordonez, J.Giovinazzo, D.Henzlova, B.Jurado, J.Pereira, F.Rejmund, K.-H.Schmidt, O.Yordanov 19

FISSION AND NUCLEAR LIQUID-GAS PHASE TRANSITION
E.A. Cherepanov, V.A. Karnaukhov and H. Oeschler 20

ISOMERIC CROSS-SECTION RATIOS IN THE REACTIONS WITH RADIOACTIVE BEAMS
T.V.Chuvilskaya, A.A.Shirokova, M.Herman 21

ASPECTS OF LOW ENERGY BINARY REACTIONS
L.Corradi (for the Prisma-Clara collaboration) 22

STATUS AND PROSPECTS OF SEARCH FOR COLLINEAR CLUSTER TRIPARTITION
D.V. Kamanin, Yu.V. Pyatkov (for the FOBOS collaboration) 23

PHYSICAL PRESEPARATION: A POWERFUL NEW METHOD FOR TRANSACTINIDE CHEMISTS
Ch. E. Düllmann 24

THE PRISMA-CLARA SETUP: EXPERIMENTAL RESULTS AND FUTURE PLANS
E. Fioretto (for the PRISMA-CLARA collaboration) 25

SEARCH FOR RESONANCES IN ^{4}n, ^{7}H AND ^{9}He VIA TRANSFER REACTIONS
E.Rich, S.Fortier, D.Beaumel, E.Tryggestad, R.Wolski, E.Becheva, Y.Blumenfeld(1), F.Delaunay, A.Fomichev, N.Frascaria, S.Gales, L.Gaudefroy, A.Gillibert, J.Guillot, F.Hammache, N.Keeley, K.W.Kemper, E.Khan, V.Lapoux, V.Lima, L.Nalpas, A.Navin, A.Obertelli, E.C.Pollacco, U.Datta Pramanik, P.Roussel-Chomaz, D.Santonocito, J.-A.Scarpaci, F.Skaza, O.Sorlin, S.V.Stepantsov, G.M.Ter-Akopian 26

STIMULATION MECHANISMS OF LOW ENERGY NUCLEAR REACTIONS USING SUPERLOW ENERGY EXTERNAL FIELDS
F.A. Gareev, I.E. Zhidkova 27

NEUTRON DETECTORS WITH HELIUM-FILLED COUNTERS IN DIFFERENT EXPERIMENTS'
D.Gibinski, E.Sokol, Ch.Briancon, S.Dmitriev, Yu.Pyatkov, Yu.Penionzhkevich, A.Yeremin 28

TERNARY FISSION AS A TOOL TO OBSERVE THE ROTATION OF NUCLEI HAVING CAPTURED POLARIZED NEUTRONS
F. Gönnenwein, A. Gagarski, I. Guseva, M. Mutterer, G. Petrov, V. Sokolov, V.Nesvizhevsky, O. Zimmer 29

SUPERHEAVY ELEMENTS IN THE NATURE: NUCLEOSYNTHESIS SIGNATURES AND SEARCH IN COSMIC RAYS
G.N.Goncharov 30

CLUSTER ASPECTS OF BINARY AND TERNARY FISSION
A.V.Andreev, G.G.Adamian, N.V.Antonenko, S.P.Ivanova, W.Scheid 31

γ(TAGS)-n(He-3)- β COINCIDENCE SPECTROMETER FOR β-DELAYED NEUTRON DECAY STUDY
I.N. Izosimov 32

THE INTERACTION OF ^{6}He WITH ^{197}Au AND ^{206}Pb
Yu.E. Penionzhkevich, R.A. Astabatyan, N.A. Demekhina, G.G. Gulbekian, R.Kalpakchieva, A.A. Kulko, S.M. Lukyanov, E.R. Markaryan, V.A. Maslov, Yu.A.Muzychka, Yu.Ts. Oganessian, R.V. Revenko, N.K. Skobelev, Yu.G.Sobolev, D.A. Testov, T. Zholdybaev 33

NEW SYSTEM OF ROUTINE CONTROL OF BEAM PROFILE FOR THE SEPARATOR COMBAS
Yu. Teterev, A. Budzanowski, G. Kaminski, E. Kozik, S. Myalski, I. Sedykh, Phi Thanh Huong 34

CARBON BEAM RADIO-THERAPY AND RESEARCH ACTIVITIES AT HIMAC
Mitsutaka Kanazawa 35

FORMATION OF HEAVY COMPOUND NUCLEI, THEIR SURVIVAL AND CORRELATION WITH LONGTIME-SCALE FISSION
S.A. Karamian, A.B. Yakushev 36

TO A POSSIBILITY OF THE ^{178m2}Hf ISOMER ALPHA-DECAY
S.A. Karamian, J.J. Carroll, S. Iliev, S.P. Tretyakova 37

ADIABATIC POTENTIAL ENERGY OF HEAVY NUCLEAR SYSTEM IN LOW-ENERGY FUSION–FISSION PROCESSES
A.V.Karpov, V.I.Zagrebaev, M.A.Naumenko, Y.Aritomo and W.Greiner 38

ON STABILITY OF THE NEUTRON RICH LIGHT NUCLEI
V.G.Kartavenko, T.Burvenich, K.A.Gridnev, Yu.E.Penionzhkevich and W.Greiner 39

NEW INSIGHTS INTO THE FISSION PROCESS BY THE STUDY OF RELATIVISTIC NUCLEAR COLLISIONS
Aleksandra Kelić and Karl-Heinz Schmidt for CHARMS collaboration 40

(p,2p) REACTIONS ON $^{9\text{-}16}$C
T. Kobayashi, K. Ozeki[1], K. Watanabe, Y. Matsuda, Y. Seki, T. Shinohara, T. Miki, Y. Naoi, H. Otsu, S. Ishimoto, S. Suzuki, Y. Takahashi, E. Takada 41

YIELDS OF CORRELATED FRAGMENT PAIRS AND AVERAGE GAMMA-RAY MULTIPLICITIES AND ENERGIES IN ^{208}Pb(^{18}O,f)
A.Bogachev, O.Dorvaux, L.Krupa, E.Kozulin, J.Kliman, M.Itkis, A.Astier, I.Deloncle, D.Curien, G.Duchene, B.J.P.Gall, F.Hanappe, F.Khelfallah, R.Lucas, I.Piqueras, M.-G.Porquet, M.Rousseau, M.Meyer, N.Redon, O.Stezowski and L.Stuttge 42

ALPHA DECAY AND CLUSTER RADIOACTIVITY IN DINUCLEAR SYSTEM MODEL
S.N. Kuklin, G. Adamian, N.V. Antonenko 43

EXCITATION FUNCTIONS FOR COMPLETE FUSION AND TRANSFER REACTIONS IN THE INTERACTION OF ^{4}He NUCLEI WITH ^{197}Au
A.A. Kulko, N.A. Demekhina, R. Kalpakchieva, Yu.A. Muzychka, Yu.E.Penionżhkevich, D.N. Rassadov, N.K. Skobelev, D.A. Testov 44

PRE-COMPOUND NEUTRON EVAPORATION IN LOW ENERGY HEAVY-ION FUSION REACTIONS
Ajay Kumar, I.M. Govil, Hardey Singh, Rajesh Kumar, K.S. Golda, R.P. Singh, B.K.Yogi and S.K. Datta 45

PROJECT OF A NEW IRRADIATION FACILITY AT THE MICROTRON MT25
D.V. Kamanin, E.A. Kuznetsova, F. Belloni 46

MULTI-CHANNEL SCATTERING OF A NEUTRON BY ^{11}Be NUCLEUS
Yuliya Lashko and Gennady Filippov 47

NEUTRON SPECTROSCOPIC FACTORS FROM TRANSFER REACTIONS
Jenny Lee, M.B. Tsang, and W.G. Lynch 48

SYSTEMATIC COMPARISON OF ISOLDE-SC YIELDS WITH CALCULATED IN-TARGET PRODUCTION RATES
S. Lukić, F. Gevaert, A. Kelić, M. V. Ricciardi, K.-H. Schmidt, O. Yordanov 49

MICROSCOPICAL MODEL ANALYSIS OF THE ^{4,6}He, ^{6,7}Li+^{28}Si TOTAL REACTION CROSS SECTIONS AT THE ENERGY RANGE 5-50 A MeV
K.V.Lukyanov, I.N.Kukhtina, V.K.Lukyanov, Yu.E.Penionzhkevich, Yu.G.Sobolev, E.V.Zemlyanaya 50

INVESTIGATION OF MULTIPOLES FOR SOME ^{134}Ba γ-TRANSITIONS
M. R. Metskhvarishvili, Z.N. Miminoshvili, M.A. Elizbarashvili, I.R.Metskhvarishvili, R.Ya. Metskhvarishvili, L.V. Nekrasova, N.G. Khazaradze, L.R. Khorbaladze 51

YRAST STATES IN EVEN-EVEN OSMIUM NUCLEI
S. Mohammadi 52

ON NUCLEON CORRELATIONS INSIDE NUCLEI
G. Musulmanbekov 53

STATUS OF TOKAI RADIOACTIVE ISOTOPE ACCELERATOR COMPLEX AND FEASIBILITY STUDY FOR TRANSFER REACTIONS USING LOW-ENERGY RNB
N.Imai, S.Arai, Y.Arakaki,Y.Fuchi, Y.Hirayama, H.Ishiyama,S.C.Jeong, H.Kawakami, H.Miyatake, K.Niki,T.Nomura, M.Okada, M.Oyaizu1, M.H.Tanaka, M.Tomizawa, Y.X.Watanabe, N.Yoshikawa, S.Abe, S.Hanashima, T.Hashimoto, S.Ichikawa, H.Ikezoe, T.Ishii, N.Ishizaki, H.Kabumoto, I.Katayama, M.Koizumi, M.Matsuda, S.Mitsuoka, T.Nakanoya, K.Nishio, I.Ohuchi, A.Osa, T.K.Sato, S.Takeuchi, H.Tayama, Y.Tsukihashi, H.Bhang, S.Choi, Y.M.Oh, J.S.Song, K.H.Tshoo, J.H.Ha, Y.K.Kim, S.H.Park 54

A NEW APPROACH FOR DETERMINATION OF R_H FOR BORROMEAN HALO NUCLEI
M. Petrascu 55

ON-LINE SEPARATOR FOR γ-SPECTROSCOPIC STUDIES
A.V. Belozerov, V.I. Chepigin, O. Dorvaux, K. Hauschild, A.P. Kabachenko, A.Korichi, A. Lopez-Martens, O.N. Malyshev, A.G. Popeko, A.V. Shutov, A.I.Svirikhin, A.V. Yeremin 56

SEARCH FOR THE MULTICLUSTER DECAY OF ^{242}Pu* IN THE REACTION ^{238}U+^{4}He (40 MeV)
Yu. Pyatkov, for HENDES and FOBOS collaborations 57

STRUCTURE AND DECAY OF HEAVY AND SUPERHEAVY NUCLEI
Zhongzhou Ren and Chang Xu 58

KINEMATICAL SELECTION OF HEAVY EVAPORATION RESIDUES IN GAS-JET EXPERIMENTS
R.N. Sagaidak, S.N. Dmitriev, V.K. Utyonkov 59

NUCLEAR DISSIPATION STUDIES BY MEANS OF PERIPHERAL HEAVY ION COLLISIONS AT RELATIVISTIC ENERGY WITH RADIOACTIVE BEAMS
Ch. Schmitt, K.-H. Schmidt, A. Heinz, A. Kelic, B. Jurado 60

CHEMISTRY OF SUPERHEAVY ELEMENTS.
LATEST RESULTS AND PROSPECTS
S. Dmitriev, Yu. Oganessian and M. Itkis 61

CHEMICAL IDENTIFICATION OF THE ELEMENT 112 IN THE REACTION ^{48}Ca+^{242}Pu
S.N.Dmitriev, R.Eichler, N.V.Aksenov, A.V.Belozerov, G.A.Bozhikov, V.I.Chepigin, R.Dressler, H.G.Gäggeler, V.A.Gorshkov, F.Haenssler, M.G.Itkis, V.Ya.Lebedev, A.Laube, O.N.Malyshev, Yu.Ts.Oganessian, A.G.Popeko, O.V.Petruschkin, D.Piguet, P.Rasmussen, S.V.Shishkin, A.V.Shutov, A.I.Svirikhin, E.E.Tereshatov, G.K.Vostokin, M.Wegrzecki and A.V.Yeremin 62

GENERATOR COORDINATE Q_n-Q_p STUDY OF LOW-LYING COLLECTIVE STATES IN NEUTRON-RICH OXYGEN ISOTOPES
A.P. Severyukhin, M. Bender, H.Flocard, P.-H. Heenen 63

POSSIBLE ALTERNATIVE PARITY BANDS IN HEAVIEST NUCLEI
T.M.Shneidman, G.G.Adamian, N.V.Antonenko, R.V.Jolos 64

EXPERIMENTAL STUDY OF 3-BODY CORRELATIONS IN ^{6}He IN THE REACTION OF QUASI-FREE KNOCKOUT ^{4}He(^{6}He,2α)2n
S.I. Sidorchuk, A.S. Fomichev, M.S. Golovkov, V.A. Gorshkov, A.V. Gorshkov, S.A.Krupko, Yu.Ts. Oganessian, A.M. Rodin, R.S. Slepnev, S.V. Stepantsov, G.M.Ter-Akopian, R. Wolski, A.A. Korsheninnikov, E.Yu. Nikolskii, P. Roussel-Chomaz, W. Mittig 65

SOME FEATURES OF THE IONIZATION OF NUCLEAR REACTION PRODUCTS
N.K. Skobelev 66

PARITY INVERSION AND DIFFERENT PROPERTIES OF Be^{11} HALO NUCLEI
Indira Mehrotra and Praveen Chandra Srivastava 67

SKYRME-HARTREE-FOCK APPROACH TO SUPERHEAVY NUCLEI WITH DENSITY DEPENDENT DELTA INTERACTION
A. Staszczak, J. Dobaczewski and W. Nazarewicz 68

STORED AND COOLED HIGHLY-CHARGED IONS IN THE REALM OF ATOMIC PHYSICS
Th. Stöhlker 69

HIGH RESOLUTION MAGNETIC SPECTROMETER SHARAQ IN RIBF
S. Shimoura 70

NUCLEAR MATTER RADII AND PRODUCTION CROSS-SECTIONS OF NEUTRON-DEFICIENT Kr ISOTOPES STUDIED VIA RELATIVISTIC-ENERGY HEAVY-ION REACTIONS
T. Suzuki, T. Yamaguchi, T. Ohnishi, K. Summerer, H. Geissel, G.Muenzenberg, F.Becker, M. Fukuda, M. Hosoi, R. Janik, K. Kimura, S. Mandal, S. Nakajima, T.Ohtsubo, A. Ozawa, A. Prochazka, M. Shindo, B. Sitar, P. Strmen, T. Suda, K.Sugawara, I. Szarka, A. Takisawa, M. Takechi, K. Tanaka 71

PERSPECTIVES OF THE USE OF DIFFERENT TYPES OF NEUTRON DETECTORS AT THE FOCAL PLANE OF VASSILISSA SEPARATOR
A.I. Svirikhin, A.V. Yeremin, A.V. Belozerov, M.L. Chelnokov, V.I. Chepigin, V.A. Gorshkov, A.P. Kabachenko, O.N. Malyshev, A.G. Popeko, R.N. Sagaidak, A.V. Shutov, E.N. Sokol, B.I. Zadneprovski, N.V. Eremin, A.A. Paskhalov 72

NEW TREATMENT OF NUCLEAR STRUCTURE BY MEANS OF ANALYTICAL - EMPIRICAL DEVIATION METHOD
N. I. Tarantin 73

MASS AND ALPHA-DECAY WIDTH ESTIMATIONS OF SUPERHEAVY ELEMENTS
O.P Badaev, S.D. Kurgalin, W.Scheid, Yu.M.Tchuvil'sky 74

INVESTIGATION OF DUBNIUM CHEMICAL BEHAVIOUR. RADIOCHEMICAL SEPARATION OF GROUP V ELEMENTS
E.E. Tereshatov, H.Bruchertseifer, G.A.Bozhikov, N.V.Aksenov, S.V. Shishkin, S.N.Dmitriev 75

SYNTHESIS OF SUPERHEAVY NUCLEI IN ^{48}Ca-INDUCED REACTIONS
Yu.Ts. Oganessian, V.K. Utyonkov, Yu.V. Lobanov, F.Sh. Abdullin, A.N. Polyakov, R.N. Sagaidak, I.V. Shirokovsky, Yu.S. Tsyganov, A.A. Voinov, G.G. Gulbekian, S.L. Bogomolov, B.N. Gikal, A.N. Mezentsev, S. Iliev, V.G. Subbotin, A.M. Sukhov, K. Subotic, V.I. Zagrebaev, G.K. Vostokin, M.G. Itkis, K.J. Moody, J.B. Patin, D.A. Shaughnessy, M.A. Stoyer, N.J. Stoyer, P.A. Wilk, J.M. Kenneally, J.H. Landrum, J.F. Wild, and R.W. Lougheed 76

PSEUDO-SPIN SYMMETRY IN THE STRUCTURE OF SUPERHEAVY NUCLEI
R.V. Jolos and V.V. Voronov 77

PROGRESS REPORT OF RIKEN RI BEAM FACTORY PROJECT
Yasushige Yano 78

GAMMA AND ELECTRON SPECTROSCOPY OF HEAVY NUCLEI AT FLNR JINR
A.V. Yeremin, A.V. Belozerov, M.L. Chelnokov, V.I. Chepigin, O. Dorvaux, V.A.Gorshkov, K. Hauschild, A.P. Kabachenko, A. Korichi, A. Lopez-Martens, O.N.Malyshev, Yu.Ts. Oganessian, A.G. Popeko, A.V. Shutov, A.I. Svirikhin 79

ROLES OF SHELL EFFECTS IN FUSION PROCESS FOR SYNTHESIS OF SUPERHEAVY ELEMENTS
Y. Aritomo 80

ELECTRIC QUADRUPOLE MOMENT OF NEUTRON RICH AL ISOTOPE
A. Yoshimi, K. Asahi, H. Ueno, D. Kameda, M. Takemura, G. Kijima, M.Uchida, K.Shimada, D. Nagae, T. Haseyama, T. Arai, T. Takase, T.Inoue, H. Kawamura, J.Murata 81

SUB-BARRIER FUSION OF WEAKLY BOUND NUCLEI
V.I. Zagrebaev 82

ISOTOPIC DEPENDENCE OF NEUTRON EMISSION FROM DINUCLEAR SYSTEM
A.S. Zubov, G.G. Adamyan, N.V. Antonenko, S.P. Ivanova, W. Scheid 83

COMPUTER MOLECULAR DYNAMICS STUDIES ON THE PROTEIN STRUCTURES (Visual Pigment Rhodopsin and Cyclin-Dependent Kinases)
Kholmirzo Kholmurodov 84

A MICROSCOPIC DESCRIPTION OF THE γ-DECAY CHAIN OF THE OBSERVED ODD-ODD NUCLEUS $^{278}113_{165}$
M. Gupta, A. Bhagwat, Y. K. Gambhir 85

THE FAIR PROJECT: A FUTURE ANTIPROTON AND HEAVY IONS INTERNATIONAL RESEARCH FACILITY IN DARMSTADT
A.Bräuning-Demian 86

MEAN CHARGE VALUES OF HEAVY ATOMS IN DILUTE HYDROGEN

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We measured the mean electronic charge $<q>$ of heavy ions with atomic numbers $Z = 89$ through 118 traversing dilute hydrogen gas with velocities ranging from 1 to 2.6 times the Bohr velocity [1, 2]. We observe a strong linear dependence of the average charge on the velocity of the ions, and only a weak dependence on their atomic number Z. A more detailed examination of the experimental results shows that the $<q>$ values reflect the influence of the 5f electron shell on the properties of these elements.

Our new data on mean charge values of latest synthesized superheavy elements with $Z = 115$ [3] confirm previous findings.

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STRUCTURE OF EXOTIC NUCLEI VIA DIRECT REACTIONS

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In order to test the validity of the nuclear models and to improve their predictive power, the exotic properties of the unstable nuclei such as very diffuse nuclear surfaces, low-lying resonances or new magic shells are experimentally investigated using radioactive ion beams. In this talk, the results obtained using the beams delivered by the SPIRAL facility at GANIL will be presented, on both subjects : the low-lying resonances and structure of the weakly-bound nucleus ^{8}He and the evolution of the shell closure in the neutron-rich Ne isotopes.

The direct reactions of ^{8}He on a proton target were measured at Elab = 15.7A.MeV using the charged-particle detector array MUST [1] and the beam detectors CATS. For all the reactions measured simultaneously at the same energy, elastic and inelastic scattering, ^{8}He(p,d)^{7}He$_{gs}$ [2,3] and (p,t), the analysis was carried out in the coupled-reaction framework [4], using the microscopic complex JLM [5] nucleon-nucleus potential. It is shown that the ^{8}He(p,d)^{7}He$_{gs}$ reaction has a strong effect on the ^{8}He(p,p'), this coupling changes deeply the features of the entrance potential and strongly affects the extraction of the structure information [2]. The ^{8}He ground state structure is found well described by a neutron-skin density, similar to the one obtained by the no-core shell model [6]. The excitation spectra for the ^{8}He and the unbound ^{7}He [4] were extracted. A new resonance for ^{8}He, above the known 2^+ at 3.6 MeV, was found around 5.4 MeV.

N = 16 has been recently suggested to be magic near the neutron drip line, both theoretically [7] and experimentally [8]. This may arise from an enhancement with isospin of the gap between the s1/2 and d3/2 of the sd neutron shell. To study the gap across the N=16 possible new shell closure, The spectroscopy of ^{27}Ne was explored using the one-nucleon transfer reaction ^{26}Ne(d,p) in inverse kinematics with the ^{26}Ne SPIRAL beam at 9.7 A.MeV. The ejectiles were detected in the focal plane of the VAMOS spectrometer, in coincidence with the photons emitted in flight at the target [9] and detected in the EXOGAM spectrometer. Below the one neutron emission threshold, 2 transitions were observed, consistent with the decay of 2 excited states towards the ground state. One of them is possibly a low-lying negative parity state from the fp shell. The results are discussed and compared to other experiments done recently in the same mass region. They are found consistent with a possible N=16 shell closure.

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ION-TRACK MEMBRANES AND THEIR USE IN BIOLOGICAL AND MEDICAL APPLICATIONS

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Accelerated heavy ion beams are the unique tool for structuring insulating solids in a controllable manner [1,2]. One of the applications is the so-called ion track technology enabling us to create micro- and nanostructured materials that have found or may find use in life sciences. At FLNR JINR the U-400 cyclotron and the IC-100 cyclotron are employed for irradiation of materials to be modified by the track-etch technique. For practical applications U-400 delivers the ^{86}Kr ion beams with total energies of 250, 350, 430 and 750 MeV, and the ^{136}Xe ion beams with the energy of 430 MeV. The cyclotron is equipped with a specialized channel for irradiation of polymer foils. IC-100 is a compact accelerator specially designed for the technological uses. High-intensity krypton ion beams with the energy of ~1 MeV/u are available now at IC-100. Production of track-etch membranes is an example of mature technology based on irradiation with accelerated ions [2,3]. The track-etch membranes offer distinct advantages over other types of membranes due to their precisely determined structure. One-pore, oligo-pore and multi-pore samples can serve as models for studying the transport of liquids, gases, particles, solutes, and electrolytes in narrow channels.

Plasmapheresis

Ultrafiltration asymmetrical TMs

Track-etch pores are also used as templates for making nanowires, nanotubes or array of nanorods [4]. The micro structures obtained this way may find use in miniaturized devices such as sensors for biologically important molecules. Bulk and surface modification for the production of new composite materials and bodies with special optical properties can also be performed using ion beams. Some recent achievements and promising ideas utilizing accelerated ions are presented in the report.

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CLUSTERING IN PERIPHERAL FRAGMENTATION OF LIGHT RELATIVISTIC NUCLEI IN NUCLEAR TRACK EMULSION

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The degree of the dissociation of the relativistic nuclei in peripheral interactions can reach a total destruction into nucleons and singly and doubly charged fragments. In spite of the relativistic velocity of motion of the system of fragments as a whole, the relative motion of fragments is non-relativistic one. The invariant presentation makes it possible to extract qualitatively new information about few-cluster systems from fragmentation of relativistic nuclei in peripheral interactions. The emulsion technique allows one to observe these systems to the smallest details and gives the possibility of studying them experimentally (http://becquerel.lhe.jinr.ru/).

The results of investigations dealing with the charge topology of the fragments produced in peripheral dissociation of relativistic ^{8}B nuclei in emulsion are presented. Events of peripheral dissociation of the ^{8}B nucleus were selected from the events which do not involve the production of the target-nucleus fragments and mesons ("white" stars). A leading contribution of the $^8B \rightarrow {}^7Be+p$ mode having the lowest energy threshold was revealed on the basis of those events. Information on the relative probability of dissociation modes with a larger multiplicity was obtained. The dissociation of a ^{7}Be core in ^{8}B indicates an analogy with that of the free ^{7}Be nucleus. The transverse momentum distributions of the fragments from the $^8B \rightarrow {}^7Be+p$ dissociation mode were obtained. Their small average value, $\langle P_T^* \rangle = 52$ MeV/c in the c.m.s. reflects a low binding energy of the external proton in the ^{8}B nucleus. An indication for a strong azimuth correlation of the ^{7}Be and p fragments was got.

For the particular case of the 1.2A ^{9}Be nucleus dissociation it is shown that precise angular measurements play a crucial role in the restoration of the excitation spectrum of the alpha particle fragments. This nucleus is dissociated practically totally through the 0^+ and 2^+ states of the ^{8}Be nucleus.

The cluster degrees of freedom in nuclei are deeply associated with the process of their synthesis. The given event of the breakup with simultaneous charge-exchange of the ^{10}B nucleus into 3 He nuclei points to a possible population of the excited states of the ^{10}C nucleus with a deep rearrangement of the cluster structure of this nucleus. Observation of this process can point to the occurrence of an inverse fusion process $2^3He+{}^4He$ in stellar media.

CHARACTERISTICS OF SYMMETRIC AND ASYMMETRIC MODES AS A FUNCTION OF THE COMPOUND NUCLEUS EXCITATION IN THE PROTON - INDUCED FISSION OF ^{233}Pa, ^{239}Np AND ^{243}Am

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Average preequilibrium $<M_n^{preeq}>$, average statistical prescission $<M_n^{stpre}>$ and postscission $<M_n^{post}>$ neutron multiplicities as well as average γ-ray multiplicity $<M_\gamma>$, average energy $<E_\gamma>$ emitted by γ–rays and average energy per one gamma quantum $<\varepsilon_\gamma>$ as a function of mass and total kinetic energy (TKE) of fission fragments were measured in proton induced reactions $p+^{232}Th \rightarrow ^{233}Pa$, $p+^{238}U \rightarrow ^{239}Np$ and $p+^{242}Pu \rightarrow ^{243}Am$ (at proton energy E_p=13, 20, 40 and 55 MeV). The fragment mass and energy distributions (MEDs) have been analyzed in terms of the multimodal fission that supposes these MEDs consist of several independent fission modes. The decomposition of the experimental MEDs onto the MEDs of the distinct modes has been fulfilled in the framework of a method that is free from any parameterization of the distinct fission mode mass distribution shapes [1, 2]. The main characteristics for symmetric and asymmetric modes have been studied in their dependence on the compound nucleus composition and proton energy. The manifestation of multimodal fission in average postscission neutron multiplicities $<M_n^{post}>$ as well as average γ-ray multiplicities $<M_\gamma>$ was also studied in this work.

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Mass measurements of heavy radionuclides at SHIPTRAP First results and future perspectives

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The Penning trap mass spectrometer SHIPTRAP [1] at GSI Darmstadt allows for precision experiments with stopped fusion-evaporation residues after separation by the velocity filter SHIP [2]. In the first phase the focus is on mass measurements of heavy ions. To match the energy of the reaction products to the energy acceptance of the ion trap system a buffer gas stopping cell is used, where the fusion products are stopped in helium at pressures of about 50 mbar. An RFQ ion beam cooler is utilized to improve the emittance of the ion beam extracted from the gas cell. In this device the ions are cooled in collisions with buffer gas atoms within a few ms, before they are extracted as bunched beam. Ions can optionally be stacked in the RFQ cooler. The ion bunches are injected in a double Penning trap system consisting of a purification trap for isobar selection and a measurement trap, where the cyclotron frequency of the radionuclides is measured using the time-of-flight ion cyclotron resonance method.

In a series of on-line experiments between October 2005 and February 2006, mass measurements of proton-rich radionuclides near the drip line were performed. The masses of 18 radionuclides in the rare-earth region around $A = 147$ were measured providing 8 new mass values. For the first time the masses of the ground state proton emitter ^{147}Tm and its daughter ^{146}Er could be measured. The production cross section for ^{147}Tm with a half-live of 580 ms is only 16-30 μb. In another campaign masses of radionuclides in the endpoint region of the astrophysical rp-process above ^{100}Sn were performed. In two runs 11 masses were measured, 2 of them for the first time. In the present series of experiments relative mass uncertainties in the range between δm/m = $5 \cdot 10^{-8}$ and $1 \cdot 10^{-7}$ were achieved.

At present, systematic uncertainties involved in the mass measurements are investigated utilizing carbon cluster ions of different size covering the full mass range to be investigated at SHIPTRAP. Carbon cluster ions are also ideal calibrant ions for mass measurements of very heavy ions where reference ions with well-known mass are lacking. In addition to the studies of the achievable precision, a further increase of the overall efficiency of the system in order to reach more exotic nuclides is important. This is expected for instance by modifications of the buffer gas stopping cell allowing for an operation at higher pressure resulting in an improved stopping of the products. However, already with the present performance a first direct mass measurement of a transuranimum element is in reach. An experiment on ^{254}No is planned for the end of this year.

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Weak-interaction rates of neutron-rich nuclei near exotic shell-closures

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Abstract

A microscopic approaches to the weak interaction rates of need for various astrophysical applications [1] are briefly discussed. An efficient framework to treat the β-strength functions [2] is based on the continuum QRPA approximation, while the ground states are described within the density functional approach.

To elucidate a relative contribution of the Gamow-Teller and first-forbidden transitions, simultaneous calculations of the total β-decay half-lives and β-delayed neutron emission near the Z=28, N=50 and Z=50, N=82 shell-closures have been performed. In the nuclei crossing the closed shells, a generic effect of suppression of these quantities is found [3]. It is due to the high-energy first-forbidden transitions to the states below the neutron-separation threshold in the daughter nuclei.

In a wide region of 150<A<298 nuclei near the N=126, 184 shells, the systematic calculations are undertaken of the total β-decay half-lives and β-delayed neutron emission, ν_e-induced and β-delayed fission, as well as the neutron-induced fission. An analysis is performed of the relevant cross sections, fission fragments distribution, as well as of the number of emitted neutrons.

The calculated total β-decay half-lives for the nuclei near hypothetical r-process paths are found to be considerably (a factor 2 to 5) shorter than the ones calculated from the RPA+semi-statistical ("gross-theory") model [3] which may result in further speeding-up of the r-process in the vicinity of exotic shell-closures.

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Study of extremely neutron-rich light isotopes. Experimental observation of ^{7}H.

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One of the main goals of the nuclear physics nowadays is to understand how does the nuclear force work and build the nuclei. Despite the efforts made to give a complete description of the known nuclei we only have a fragmented vision of the whole picture, with questions about the interaction between the nucleons still unresolved, and different theoretical approximations trying to explain the experimental results.

Systematic measurements of nuclei far from the stability help to test the predictions of the different nuclear models. The localization of the proton and neutron drip lines, as well as the identification of resonances beyond the bounding limit are fruitful sources of information. These studies help to understand the force which holds the nucleons inside the nuclei, one of the main ingredients to build a general description.

We have focused our experimental research on the predictions about the existence of neutron-rich Hydrogen isotopes resonances. The study of these species is a direct test of the strength of the nuclear interaction between protons and neutrons. Recent theoretical predictions [1] as well as experimental evidences [2] point out the possible existence of the ^{7}H resonance as a limit in the nuclear force. Our work has consisted in the experimental search and characterization of this resonance state.

The ^{7}H resonance was produced with one-proton transfer reaction between a ^{8}He beam at 15.4A MeV, prepared at the GANIL-Spiral facility, on a ^{12}C target. The main part of the experimental setup was the Time-Charge Projection Chamber MAYA [3], as a detector for the reaction products. The detector MAYA works essentially as a drift chamber with the filling gas (isobutane C_4H_{10} in this case) playing the role of reaction target. The reaction channel was selected via the identification of the recoil and scattered products, whereas the 3-D tracking of the recoil particle stopped in the gas allowed a complete reconstruction of the reaction kinematics.

The analysis of the data resulted in the positive identification, for the first time, of the ^{7}H state, with an estimated mass around 0.60 MeV above the mass of the ^{3}H+4n subsystem. The width of the resonance is estimated in less than 100 KeV. The total cross-section associated to the process is close to 50 μbarn/sr.

The successful results confirm low-energy transfer reactions as a valuable method for testing nuclear properties in regions far from stability. The concept of active-target detectors proved to be useful, and in many applications a unique tool for studying low cross-section reactions where low-energy recoil particles need to be detected, and a very high efficiency is required.

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Production of neutron-rich isotopes near N=126 in cold-fragmentation reactions induced by relativistic ^{208}Pb projectiles

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One of the major challenges of nuclear physics is to enlarge the present limits of the chart of the nuclides and in particular, to reach the r-process path in the medium- and heavy-mass regions. Promising results have been obtained during the last years in experiments investigating the properties of medium-mass neutron-rich nuclei close to the waiting point around N=82 [1] while the waiting point around N=126 remains unexplored [2]. Fission has been used successfully to produce medium-mass neutron-rich isotopes [3] while the present limits of the chart of the nuclides in the heavy neutron-rich region still lie close to the stability. However, few years ago, cold-fragmentation reactions induced by relativistic projectiles were proposed [4] as the optimum reaction mechanism to populate the heavy neutron-rich side of the chart of nuclides.

In this paper we report on an experiment performed with the FRS at GSI to explore the production of heavy neutron-rich nuclei close to the neutron shell N=126 and to measure their β half-lives. We used cold-fragmentation reactions induced by ^{208}Pb at 1 AGeV impinging a Be target. The isotopic identification was achieved by measuring both the atomic number and the mass-over-charge ratio of each nucleus by means of the measurements of the magnetic rigidities, time-of-flight and energy loss of each fragment passing through the FRS. The identified isotopes were implanted on an active catcher made of four 5 x 5 cm Double-Side Silicon Strip Detectors. The position and time correlation between the implanted isotopes and the subsequent β decay allow to determine their half-lives.

In this measurement we were able to identify for the first time around 30 new neutron-rich isotopes approaching N=126. In addition, the half-life of some of them has been determined. From this work we conclude that cold-fragmentation is a promising reaction mechanism to extent the limits of the chart of nuclides in the region of heavy neutron-rich isotopes, provided that enough primary beam intensities are available. In addition, the implantation technique of fast exotic nuclei on active catchers seems to be a well suited tool to investigate the structure of those heavy neutron-rich nuclei.

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FISSION AND NUCLEAR LIQUID-GAS PHASE TRANSITION

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Critical temperature for liquid-gas phase transition, T_c, is crucial characteristic related to the nuclear equation of state. The main source of the experimental information for T_c is the yield of intermediate mass fragments (IMF, $2<Z<20$) originated in nuclear multifragmentation. In some statistical models of this process the shape of the IMF charge distribution is sensitive to the value of critical temperature. However, different experimental estimations of the critical temperature from multifragmentation data are very controversial [1]. The obtained values of T_c are spread over the range between 6 and 20 MeV depending on the model used in analysis. This is a reason to look for another observable which is sensitive to the critical temperature for the liquid-gas phase transition. It was suggested in [2] to analyze the temperature dependence of the fission probability to estimate T_c.

The fissility of heavy nuclei is determined by the ratio of the Coulomb and surface free energies: the larger the ratio, the smaller the fission barrier. The surface tension *vanishes at the critical temperature*. As temperature approaches the critical one from below, the surface tension (and surface energy) gradually decreases, fission barrier becomes lower. Thus, the measurement of fission probability as a function of the excitation energy gives a chance to estimate how far the system is from the critical point.

In present paper we compare the measured fission cross-sections for $^{4}He + {}^{144}W \rightarrow {}^{188}Os^*$ collisions (at excitation energies from 40 to 117 MeV) [3] with calculated ones. The thermal liquid drop model is applied to find the temperature dependent fission barrier with T_c as a free parameter. The following reliable approximation is used for the surface tension coefficient:

$$\sigma(T) = \sigma(0)\left[\frac{T_c^2 - T^2}{T_c^2 + T^2}\right]^{5/4}$$

To estimate the fission and evaporation rates, the statistical model is used. The multi-step character of the compound nucleus disintegration is taken into account.

It is concluded from the best description of the data that critical temperature is equal to $T_c = (19\pm3)$ MeV.

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ISOMERIC CROSS_SECTION RATIOS IN THE REACTIONS WITH RADIACTIVE BEAMS

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At present the development of investigations of nuclear isomers is expected in the context of the use of unstable nuclear beams. In the present paper we discuss the probability of low-lying high-spin states production in the reactions with light neutron-rich (halo) projectiles.

The ratio of cross sections of a certain pair of isomeric states (high-spin and low-spin respectively) in one and the same nucleus allows to obtain an information on angular momentum dynamics of a preceding reaction and spin dependence of nuclear level density. This dynamics depends on the properties of a target, projectile and emitted particles. It is important to find out optimal reaction parameters to populate high-spin isomer. In the present work we investigate the dependence of its yield on the projectile neutron number and the bombarding energy.

Measurements of isomeric cross-section ratios (ICSR) in the reactions $^{114}Cd(\alpha p)^{117mg}In$ in the energy range 17-29 MeV were carried out by us earlier using off-beam measurements of induced activity of the isomeric pair [1]. The activation method is a reliable tool for identification of reaction products. Here we present for the first time our results improved through the handling of the activation data with the use of the optimal extraction formula from [2].

Calculations of ICSR for the indicated reactions $^{114}Cd(\alpha p)^{117mg}In$, $^{112}Cd(^{6}He,p)^{117mg}In$, $^{110}Cd(^{8}He,p)^{117mg}In$, $^{113}Cd(^{6}Li,2p)^{117mg}In$ and $^{111}Cd(^{8}Li,2p)^{117mg}In$ are performed using the upgraded program EMPIRE-II-19 [3]. This code is based on Hauser-Feshbach version of the statistical theory of nuclear reactions [4]. The field of application of the model is placed over the area of 10 – 50 MeV excitation energy of a compound nucleus, where the widths of resonance are greater than the distances between them..

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ASPECTS OF LOW ENERGY BINARY REACTIONS

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With the advent of large solid angle magnetic spectrometers new possibilities are opened for different kind of studies in low energy heavy ion reactions [1]. In the field of transfer reactions, in particular, one of the most interesting item is how single particle and more complex degrees of freedom, namely pair or even cluster modes, act in the transfer process [2]. This, in inclusive studies, can be probed by looking at the behaviour of the differential and total cross sections and total kinetic energy loss distributions of multineutron and multiproton transfer channels [3,4].

As one moves to bombarding energies close or even below the Coulomb barrier, one has narrower Q-value distributions for multinucleon transfer channels and with high resolution and high efficiency devices one can probe the effect of pair modes close to g.s to g.s. transitions. Even more detailed studies can be performed via gamma-particle coincidences. With the new large solid angles magnetic spectrometers [5] coupled to large gamma arrays [6], it is now experimentally possible to measure the transfer strength to specific final states and valuable information about the structure of those states can be derived from the study of their decay modes. The combination of magnetic spectrometers and gamma arrays installed at radioactive ion beam facilities allow to push these reaction mechanism and spectroscopy studies away from the stability valley, both in the neutron rich and proton rich regions. In this talk a presentation of recent results in the field will be done and hints will be given on interesting new experiments to be done.

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STATUS AND PROSPECTS OF SEARCH FOR COLLINEAR CLUSTER TRIPARTITION

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Nowadays there is a good reason to perform a series of the experiments dedicated to the search for the multi-cluster decays of the actinide nuclei started in the FLNR/Dubna with the FOBOS 4π-spectrometer of charged particles whose capabilities to study the multi-body decays has been clearly shown as applied to the reactions of ^{14}N (53 AMeV) with ^{232}Th and ^{197}Au [1].

The effect under discussion has been observed for the first time in spontaneous fission of ^{252}Cf at FOBOS [2]. This effect was called as "collinear cluster tripartition" (CCT) since the perfectly collinear coincident pairs of the fission-like fragments were registered. The large missing mass characterizing such events was explained by their at least three-body nature. Also measured masses of these fragments correspond to the known spherical and deformed magic nuclei (clusters). This result has been confirmed further both at the spectrometer based on the MCP detectors and PIN diodes in JYFL/Juväskylä [3] and with the mini-FOBOS setup in the FLNR/Dubna.

The reliable data on the collinear multi-cluster decays in the reaction $^{235}U(\alpha,f)$ at the incident energy of 40 MeV have been obtained recently in JYFL [4]. Some hints for presence of collinear cluster tripartition had been found earlier in quasi-fission of ^{40}Ar (243MeV)+ ^{238}U [5]. However, in order to observe the clear manifestations of clustering we will confine our investigation by the low excitation energy, thus reducing the variety of incident particles by gamma rays and light particles ranging from neutrons to alphas. The measurements in the reaction $^{235}U(n,f)$ are already started with the mini-FOBOS setup at the beam-line 6b of the reactor IBR-2 of the FLNP/Dubna. It would be exciting to follow the energy dependence of the yields of different CCT modes in fission of $^{236}U^*$ produced in the series of reactions: in $^{236}U(\gamma,f)$ near the GDR and in $^{232}Th(\alpha,f)$ ranging the energy of alpha-particles from below- to far above the coulomb barrier.

The study of such rare multi-body decays additionally complicated by their collinear geometry is possible with the reasonable statistics in the incomplete kinematics only. Despite of the variety of the independent corroborations of CCT collected by the date, disarming of skeptics requires the independent channels for registration of the physical information. The major advantage of the mini-FOBOS setup compared to the array of silicon detectors consists in its sensitivity to the nuclear charge of the fragments. Another source of the independent information is the high-efficiency neutron detector whose capabilities to select the different CCT channels are already proved [6].

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PHYSICAL PRESEPARATION: A POWERFUL NEW METHOD FOR TRANSACTINIDE CHEMISTS

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In recent years, the concept of physical preseparation of single atoms which are produced in nuclear fusion-evaporation reactions was introduced into the field of nuclear chemistry. Physical preseparation includes the following steps: (i) synthesis of the desired nuclear species in a heavy-ion-induced nuclear fusion reaction, (ii) separation of the evaporation residues from the beam and the majority of the transfer products in a physical recoil separator, (iii) extraction of these "preseparated" isotopes from the separator, (iv) thermalization, e.g., in a gas-filled volume or a heated catcher, and (v) transport to a chemistry setup. Among the most important advantages of preseparation are the drastically reduced background of species that interfere with the unambiguous detection of single atoms (transfer products, products of the beam with various components of the target assembly or target impurities) as well as the beam plasma free conditions in the recoil chamber where the evaporation residues are thermalized.

The transactinide elements ($Z \geq 104$) are a notable class of elements where this concept promises to allow significant progress, as will be shown: liquid-liquid extraction studies of rutherfordium (Rf, element 104) conducted at the Berkeley Gas-filled Separator (BGS) with the automated system SISAK were the first experiments with a preseparated transactinide. Many chemical systems that were no option for transactinide chemists before do now seem to be accessible: in the liquid phase, conventional extraction experiments were restricted to chemical systems that removed all interfering reaction products and left only the element of interest, usually along with its homologs as these behave largely identical in such systems. Preseparation allows using extraction systems that favor selectivity between individual elements of a single group and thus probe the structure of the periodic table in more detail. In the gas phase, the mild conditions in the recoil chamber (without beam-induced plasma) allow for the direct introduction of organic and other thermally unstable compounds into this chamber. Thus, completely new compound classes of the transactinides that were not previously accessible can be studied. These include, e.g., volatile metal complexes or organometallic compounds.

The TransActinide Separator and Chemistry Apparatus (TASCA) is currently being built at GSI by an international collaboration. One of the main foreseen applications of this new gas-filled recoil separator is the use as a preseparator for chemistry experiments. The ion-optical system consists of three magnets and can be operated in two different modes, DQ_hQ_v and DQ_vQ_h where D denotes a dipole and Q a quadrupole magnet with the index referring to vertical (v) or horizontal (h) focusing. While the DQ_hQ_v mode will provide maximum transmission, the DQ_vQ_h mode will result in a very small image size in the focal plane at the cost of a somewhat reduced transmission. This mode will provide improved conditions for chemistry experiments with relatively short-lived species. A differential pumping system has been implemented which will allow a windowless operation with highest beam intensities. The use of highly radioactive actinide targets such as ^{243}Am, ^{244}Pu, or ^{248}Cm is planned, giving access to the most neutron rich isotopes of the heaviest elements. The commissioning experiments with TASCA start in the spring of 2006. An overview of the status and commissioning phase as well as an outline of the envisaged research program at TASCA will be presented.

The PRISMA-CLARA setup:

experimental results and future plans

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Nuclear structure studies in moderately neutron-rich nuclei populated by using binary reactions have been performed at LNL with the magnetic spectrometer PRISMA [1] coupled to the γ array CLARA [2].

The large solid angle of PRISMA, routinely placed around the grazing angle, allows to select and to identify at the focal plane a wide range of nuclear species produced in heavy-ion reactions providing the tagging for the gamma rays following the de-excitation of the fragments. The high granularity of CLARA, combined with the velocity vector reconstructed with the information provided by PRISMA, allows precise Doppler correction for the gamma rays emitted by in-flight recoils.

Several developments are planned around the focal plane detector of PRISMA in order to improve the efficiency for light-ions and to reduce the energy and angular straggling for heavy-ions at low-energies. Moreover, LNL has been selected as the site for the commissioning of the AGATA demonstrator. It will be mounted around the target point of the PRISMA spectrometer replacing the present gamma array CLARA and allowing to carry out a first experimental campaign during 2008.

Recent results concerning studies of medium-mass neutron-rich nuclei and the above-mentioned developments will be presented during the talk.

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STIMULATION MECHANISMS OF LOW ENERGY NUCLEAR REACTIONS USING SUPERLOW ENERGY EXTERNAL FIELDS

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The review of possible stimulation mechanisms of LENR (low energy nuclear reaction) is presented. We have concluded that transmutation of nuclei at low energies and excess heat are possible in the framework of the known fundamental physical laws – the universal cooperative resonance synchronization principle [1] and based on it different enhancement mechanisms of reaction rates are responsible for these processes [2]. The excitation and ionization of atoms may play the role of a trigger for LENR. Superlow energy of external fields may stimulate LENR [3]. Investigation of this phenomenon requires the knowledge of different branches of science: nuclear and atomic physics, chemistry and electrochemistry, condensed matter and solid state physics,...

The puzzle of poor reproducibility of experimental data is the fact that LENR occurs in open systems and it is extremely sensitive to parameters of external fields and systems. The classical reproducibility principle should be reconsidered for LENR experiments. Poor reproducibility and unexplained results do not mean that the experiment is wrong. Our main conclusions:

1) LENR may be understood in terms of the known fundamental laws without any violation of the basic physics. The fundamental laws of physics should be the same in micro- and macrosystems.

2) Weak and electromagnetic interactions may show the strong influence of the surrounding conditions on the nuclear processes.

3) The conservation laws are valid for a closed systems. Therefore, the failure of parity in weak interactions means that the corresponding systems are open systems. Periodic variations (24 hours, 27, and 365 days in beta-decay rates indicate that the failure of parity in weak interactions has a cosmophysical origin. Modern quantum theory is the theory for closed systems. Therefore, it should be reformulated for open systems. The closed systems are idealization of nature, they do not exist in reality.

4) The universal cooperative resonance synchronization principle is a key issue to make a bridge between various scales of interactions and it is responsible for self-organization of hierarchical systems independent of substance, fields and interactions. We give some arguments in favor of the mechanism – ORDER BASED on ORDER, declared by Schrodinger in [4], a fundamental problem of contemporary science.

5) The universal cooperative resonance synchronization principle became a fruitful interdisciplinary science of general laws of self-organized processes in different branches of physics because it is the consequence of the energy conservation law and resonance character of any interaction between wave systems. We have proved the homology of atom, molecule and crystal structures including living cells. Distances of these systems are commensurable with the de Broglie wave length of an electron in the ground state of a hydrogen atom, it plays the role of the standard distance for comparison.

6) First of all, the structure of a hydrogen atom should be established. Proton and electron in a hydrogen atom move with the same frequency that creates attractive forces between them, their motions are synchronized. A hydrogen atom represents radiating and accepting antennas (dipole) interchanging energies with the surrounding substance. The sum of radiate and absorb energy flows by electron and proton in a stable orbit is equal to zero [5] – the secret of success of the Bohr model (nonradiation of the electron on stable orbit). "The greatness of mountains, the finger sized drop, the shiver of a lake, and the smallness of an atom are all related by simple laws of nature" – Victor F. Weisskopf [6]

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TERNARY FISSION AS A TOOL TO OBSERVE THE ROTATION OF NUCLEI HAVING CAPTURED POLARISED NEUTRONS

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Experiments on ternary fission performed at the high flux reactor of the ILL (Grenoble) for the reaction $^{235}U(n,f)$ induced by cold polarised neutrons have revealed new and unexpected phenomena. Coincidences between fission fragments (FF) and ternary particles (TP) were recorded for given polarisation of the neutron. Neutron spin and the symmetry axis of FF and TP detector assemblies were mutually orthogonal. Upon flipping the neutron spin the asymmetries in coincidence count rates observed for the different detector combinations were surprising and not to be explained in terms of any of the existing models for P-even, P-odd or T-odd correlations. Instead, the angular pattern in the asymmetry of TP emission upon spin flip suggested that the present findings have to be interpreted as being due to a collective rotation of the nuclear system ejecting the TP near scission. The rotation is non-uniform and slows down with a time constant of a few 10^{-21} s. The total angle of rotation is very small and well below 1°. Nevertheless the experimental signature is unequivocal.

The experimental observations and their interpretation in terms of a rotation have been corroborated by trajectory calculations for the three-body system composed of two fission fragments and one ternary particle. For the present purpose these calculations were carried out not as usual in a stationary system but in a rotating system. The three bodies are driven apart by Coulomb forces and at least to some extent the rotation of the fission axis is imparted to the TP. It is the shift in the angular distribution of the TPs which becomes accessible to observation. For the new phenomenon the name ROT effect is proposed.

CLUSTER ASPECTS OF BINARY AND TERNARY FISSION

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The formation of ternary system is considered as the following step after the formation of binary system by extracting one or several alpha-particles and neutrons from one or both fragments in the region of their interaction. Based on the potential energy calculations, the charge number distributions for fission of the heavy nucleus ^{252}Cf and the light nucleus ^{56}Ni accompanied by various light charged particles are described. The relative yields of light charged particles are calculated for fission of ^{252}Cf. Based on the calculations of the excitation energy at scission, the neutron multiplicity distributions from the primary fission fragments of ^{252}Cf are obtained. The mean total kinetic energy of fission fragments is also described. The results are compared with the experimental data.

Fission of actinides is described within the scission-point model. Scission configurations are interpreted as dinuclear systems. The potential energy surfaces of scission configurations are analyzed as functions of deformations of the dinuclear system fragments by considering mass and charge asymmetry coordinates as independent ones. It is demonstrated that bimodality in fission of actinides at fixed mass splitting is related to different charge splittings [1]. Experiments are suggested to prove this interpretation of bimodality.

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The interaction of ^{6}He with ^{197}Au and ^{206}Pb

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^{197}Au and ^{206}Pb have been irradiated with the ^{6}He beam from the accelerator complex for radioactive beams DRIBs (JINR). The maximum energy of the incident beam was about 10 MeV/A and the intensity reached 2×10^7 pps. Excitation functions were measured in a wide energy range (from deep below the Coulomb barrier up to 60 MeV) for the production of ^{194}Au, ^{196}Au and ^{198}Au in the interaction of ^{6}He with ^{197}Au, as well as for evaporation residues in the reactions ^{206}Pb(^{6}He,2n)^{210}Po and ^{197}Au(^{6}He,xn)$^{203\text{-}xn}$Tl, where x = 2-7. The stacked foil technique was used directly in the beam extracted from the cyclotron or in the focal plane of the magnetic spectrometer MSP-144. The identification of the reaction products was done by their radioactive γ- or α-decay. Unusually large cross section was observed below the Coulomb barrier for the production of ^{198}Au. Possible mechanisms of formation and decay of transfer reaction products are discussed. The experimental and calculated (within the statistical model) cross sections are in good agreement for the evaporation of x = 3-7 neutrons, except for the high-energy tails. Comparison is made with results for reactions induced by a ^{4}He beam. An increase in the cross section was observed for the fusion reaction with the evaporation of two neutrons compared to statistical model calculations. The analysis of the data in the framework of the statistical model for the decay of excited nuclei, which took into account the sequential fusion of ^{6}He has shown good agreement between the experimental and the calculated values of the cross sections for the case of sub-Coulomb-barrier fusion in the ^{206}Pb + ^{6}He reaction.

NEW SYSTEM OF ROUTINE CONTROL OF BEAM PROFILE FOR THE SEPARATOR COMBAS

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The ionization beam profile monitor (IBPM) for charged particles has been constructed and tested. Its principle of operation based on the ionization of the residual gas in the ion pipe is described. The positive ions in the beamline result from residual gas ionization during the beam passage. Place of ionization determines the kinetics energy which they gain being accelerated in constant electric field. According to kinetics energy IBPM selects them and collects on the collector. Selection is done via applying alternate scanning voltage. After amplification a signal is digitalized and sent to PC. Using Vbeam software the transferred data are displayed determining beam profile. The IBPM has been applied for routine control of the beam profile and beam intensity in experiment performed on the COMBAS separator. Examples of measured ion beam profiles at the ^{11}B beam at energy of 33 MeV/A with intensity of $10^{10} - 10^{12}$ pps are presented. Monitor has been placed directly after the thin production target. It was used for on-line routine control of the horizontal and vertical current distributions in the beamline and the beam position. Scanned area was 8 x 8 cm2 with uniform 1mm spatial resolution over the scanning region. Once calibrated it serves as the useful monitor of the beam profile and its intensity. The IBPM does not affect the beam and for an accelerator operator is a profitable tool for a continuous control of the beam.

CARBON BEAM RADIO-THERAPY AND RESEARCH ACTIVITIES AT HIMAC

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Radio-therapy with carbon ion beam has been carried out since 1994 at HIMAC (Heavy Ion Medical Accelerator in Chiba) in NIRS (National Institute of Radiological Sciences), and over 2600 patients were treated. Now, many types of tumors can be treated with carbon beam with excellent local controls of the tumors. Stimulated with good clinical results, requirement of the dedicated compact facility for carbon beam radio-therapy is increased. To realize this requirement, design study of the facility and the R&D's of the key components in this design are promoted by NIRS. According successful results of these activities, the dedicated compact facility will be realized in Gunma University. In this facility, the established irradiation method is expected to use, which is passive irradiation method with wobbler magnets and ridge filter. Next activity at HIMAC is development of the new irradiation system to get better dose concentration on the tumor. In this presentation, above R&D's will be presented together with clinical results and basic research activities at HIMAC.

TO A POSSIBILITY OF THE ^{178m2}Hf ISOMER ALPHA-DECAY

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Experimental attempt to find α-emission branch in the ^{178m2}Hf isomer decay has been undertaken. This high-spin 16^+ isomeric state decays via strongly converted electromagnetic transition, and its long halflife, 31 years, is mostly due to the K-hindrance factor. The α-decay energy $Q_\alpha = 4.54$ MeV should correspond to a halflife as short as days for Hf nuclei. But the total angular momentum of 16 units generates drastic retardation due to the centrifugal barrier assuming that decay is going to 0^+ ground state of the daughter ^{174}Yb nucleus. One may suppose more probable decay to the higher spin states, i.e. to the yrast levels of the ground state rotational band in ^{174}Yb. The centrifugal barrier must be reducing, but the partial E_α values are decreasing as well, and these two factors influence the decay rate in an opposite directions. Some optimum value of the daughter nucleus spin should exist corresponded to the shortest partial halflife, and it mainly defines the total α-decay branch.

Using semiempirical systematics type of the Geiger-Nuttall plot: $T_{1/2}(Q_\alpha)$, one can estimate the α-halflifes specifically for each member of the ^{174}Yb band. But this does not include the retardation factor due to the spin-change parameter ΔI. Spin must be transferred into the orbital angular momentum of the α-particle, and this is equivalent to its transmission through some centrifugal barrier. A spin-hindrance factor has been evaluated basing on appropriate experimental data and the regular function $F(\Delta I)$ is then applied to estimate the ^{178m2}Hf α-decay lifetimes. The transitions from 16^+ to 6^+ and 8^+ levels were found the most abundant. As a result, the total α-decay halflife is deduced with some moderate accuracy. The reliability of such calculations should be tested after experimental exploration of the problem. One has to keep in mind that K-hindrance factor was not yet taken into account, and it can be same high as $F(\Delta I)$, or significantly lower in a magnitude. The role of K-quantum number in α-decay is not yet well clarified in literature.

In the present experiment, α-emission from the source contained $3 \cdot 10^{13}$ nuclei of ^{178m2}Hf has been looked for using detectors of two types: the solid-state track detectors CR-39 and the Si surface-barrier spectrometer. Until now, only lower limit: $T_{1/2} \geq 10^{10}$ year could be deduced from our measurements, and this does not contradict the estimates described above. Higher sensitivity of the experiment will allow to reach even longer α-halflife limit and will throw some light on the K-hindrance manifestation in α-decay of ^{178m2}Hf.

This work has been supported by US Research Grant via Youngstown State University.

ADIABATIC POTENTIAL ENERGY OF HEAVY NUCLEAR SYSTEM IN LOW-ENERGY FUSION–FISSION PROCESSES

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At incident energies around the Coulomb barrier in the entrance channel the fusion probability is about 10^{-3} for mass asymmetric reactions induced by ^{48}Ca and much less for more symmetric combinations used in the "cold synthesis". Deep inelastic (DI) scattering and quasi-fission (QF) are the main reaction channels here, whereas the fusion probability [formation of compound nucleus (CN)] is extremely small. It is the QF process that inhibits fusion by several orders of magnitude. To estimate such a small quantity, first of all, one needs to be able to describe well the main reaction channels, namely DI and QF. Moreover, the quasi-fission processes are very often indistinguishable from the DI scattering and from regular fission, which is the main decay channel of excited heavy CN. To describe properly and simultaneously the strongly coupled DI, QF and fusion-fission processes of low-energy heavy-ion collisions we have to choose, first, the unified set of degrees of freedom playing the most principle role both at approaching stage and at the stage of fission (quasi-fission) and then to derive the multi-dimensional potential energy surface (depending on all the degrees of freedom) which regulates in general all these processes. Finally, the corresponding equations of motion should be formulated to perform numerical analysis of the studied reactions.

The interaction potential of separated nuclei (deformed and arbitrary oriented) can be calculated rather easily within the folding procedure with effective nucleon-nucleon interaction or parameterised, e.g., by the proximity potential. After contact the mechanism of interaction of two colliding nuclei becomes more complicated. For fast collisions the nucleus-nucleus potential should reveal a strong repulsion at short distances protecting the "frozen" nuclei to penetrate each other and form a nuclear matter with double density (diabatic conditions, sudden potential). For slow collisions at near-barrier energies, when nucleons have enough time to reach equilibrium distribution (adiabatic conditions), the nucleus-nucleus potential energy is quite different. The calculation of the multidimensional adiabatic potential energy surface for heavy nuclear system is a very complicated physical problem, which is not yet solved in full. The macroscopic-microscopic model based on the two-centre shell model [1] for the microscopic part seems to be the most appropriate for calculation of the adiabatic potential energy surface. However, the simplest version of this model does not reproduce correct the ground-state masses of two separated nuclei [2] and, thus, their asymptotic interaction potential. The same holds for the value of the Coulomb barrier and the energy at the contact configuration.

In the talk a new method for calculation of the multi-dimensional adiabatic driving-potential basing on extended version of the macroscopic-microscopic model will be discussed. This potential energy reproduces well the fusion barriers (heights and positions) and gives correct values of the asymptotic energies in all the channels with mass rearrangement. Time transformation of diabatic potential energy into the adiabatic one as well as the difference of potential energies in the entrance (more compact contact configurations) and exit (more elongated ones) channels are also discussed. First results of dynamic calculations using the developed driving-potential and comparison with the corresponding experimental data will be presented.

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On stability of the neutron rich light nuclei

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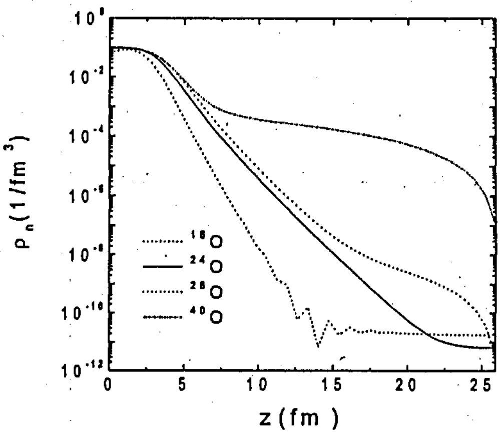
Recent experimental investigations of heavier nuclei in the region of closed neutron shells N= 20 and 28 show that their properties (binding energy and deformation) strongly vary as they move away from the stability line. In addition, new effects manifest themselves, because of the change (decrease or increase) in the stability of these nuclei near the boundaries of nucleon stability [1]. The found effects result in the essentiality to revise the theoretical concepts about the properties of such nuclei, also including the occurrence of new magic numbers characteristic for the shell effects. Our recent preliminary theoretical investigation (Hartree-Fock approach with Skyrme forces Sly4 and Ska) of the decay properties of the neutron drip-line nuclei (isotopes of C,O,N,Mg,Si with the very large neutron excess), show that the border of stability may have more complicate structure, as was assumed before [2].

N	BE	rms	rms_n	rms_p	β_2	$e_{F(n)}$
8	-128.69	2.59	2.58	2.61	0.00015	-12.952
10	-140.97	2.71	2.80	2.60	0.00268	-6.169
12	-152.46	2.81	2.94	2.59	0.00476	-5.732
14	-163.01	2.88	3.04	2.59	0.00228	-4.880
16	-171.56	3.06	3.26	2.62	0.00006	-3.394
18	-175.46	3.22	3.43	2.68	0.00022	-2.178
20	-179.76	3.33	3.55	2.74	-0.00003	0.405
22	-178.86	4.87	5.44	2.74	0.883	0.324
24	-178.04	5.49	6.11	2.74	0.265	0.314
26	-176.72	7.38	8.30	2.74	0.422	0.293
28	-176.45	7.17	8.00	2.74	0.342	0.648
30	-173.88	9.58	10.69	2.74	1.684	0.613
32	-173.59	9.43	10.46	2.74	1.634	0.645

In this contribution we present the results of our investigations of the chains of Oxygen and Magnesium isotopes in the frame of relativistic mean-field (RMF). The table and Figure show binding energy, baryon rms radius, neutron and proton rms radii, the β_2 deformation and the neutron fermi energy of the Oxygen isotopes. We used NL3 RMF force and BSC pairing with a density-independent delta force. The detail description of these mean field models may be found in the review [3].



The plot for the neutron densities shows that after reaching the dripline, the neutrons hit the grid border. With differences in detail, the two RMF forces, NL3 and NL-Z2 (BSC pairing with a density-independent delta force) give quite similar results. Near the neutron drip-line, the neutron–matter distribution becomes very diffuse and of large size giving rise to "neutron halos" and "neutron skins".

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NEW INSIGHTS INTO THE FISSION PROCESS BY THE STUDY OF RELATIVISTIC NUCLEAR COLLISIONS

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Since some years, reactions at relativistic energies induced by light particles (spallation reactions) and heavy ions (fragmentation reactions) have gained a renewed interest for several reasons. For example, spallation reactions lead to the production of unstable nuclei and are actually exploited in ISOL-type facilities. They are also planned to be used in the so-called Accelerator Driven System as an intense neutron source. Additionally, spallation reactions are of interest for astrophysics, e.g. nuclide production via interactions of cosmic rays with interstellar medium, space-technologies and medicine. Moreover, relativistic nuclear collisions, and especially fragmentation reactions, proved to be an excellent tool for studying basic properties of nuclear matter, such as nuclear equation-of-state or thermal instabilities in heated nuclei. Therefore, it is of prime interest to understand the different mechanisms leading to the production of final residues in relativistic nuclear collisions.

In case of heavy nuclei, two mechanisms compete during the deexcitation path of excited prefragments formed in primary interactions between target nuclei and incoming relativistic projectiles – evaporation and fission. While evaporation can rather well be described using different approaches, e.g. Weisskopf-Ewing or Hauser-Feschbach models, fission still remains a puzzle although nuclear fission is the most intensively studied nuclear reaction. One of the reasons is that only few nuclei have been investigated up to very recently. Experiments were restricted to spontaneously fissioning isotopes and primordial or long-lived target nuclei. Except for measurements performed at Lohengrin, where both the mass and nuclear charge of the light fission group were measured with high resolution, from most experiments only information on mass distributions with low resolution is available. Additional problems arise from the theoretical point of view. The fission process corresponds to a large-scale collective motion, and static, e.g. nuclear potential at large deformations, as well as dynamical, e.g. nuclear viscosity, properties are important for the description of nuclear fission. Unfortunately, one still does not have a clear and unique understanding of these properties.

To improve our understanding of the fission process, an experimental and theoretical campaign has been started at GSI. Fission fragments formed in spallation and fragmentation of different nuclei, e.g. ^{238}U, ^{208}Pb, ^{197}Au, were identified using the inverse-kinematics method in both mass and charge, and their velocities have been measured with high precision. Moreover, we also have measured the fragments formed in electromagnetic-induced fission. The waste amount of measured data gave new information on different aspects of the nuclear-fission process, such as nuclear viscosity at small deformation, transient effects, influence of shell effects on mass- and charge-division in fission, pairing correlations. All this lead to a development of a model, which proved successful in describing fragment formation in spallation and fragmentation reactions.

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(p,2p) reactions on ^{9-16}C

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Proton-induced proton knockout reaction, (p,2p), is one of the experimental methods to study the single-particle properties of bound proton in nuclei. We have studied (p,2p) reactions from ^{9-16}C nuclei at 250 MeV/A at the radioactive beam facility at the HIMAC accelerator facility ar NIRS. Carbon isotopes ^{9-16}C were chosen as "targets", since weakly-bound ($S_p(^9C)$= 1.3 MeV) to strongly-bound ($S_p(^{16}C)$=23 MeV) valence protons in $p_{3/2}$ orbital and very strongly-bound (S_p=30-50MeV) protons in $s_{1/2}$ orbital can be studied systematically.

^{12}C and ^{18}O primary beams at 400 MeV/A from the synchrotron were used to produce secondary beams of carbon isotopes at 250 MeV/A. Solid hydrogen target of 5mm thickness was used as "proton" target. Energy and direction of two protons from (p,2p) reactions were measured by two proton telescopes consisting of drift chambers, ΔE scintillator, and 5" thick NaI(Tl). Hole state or its decay products produced in the beam rapidity were measured and identified by the forward magnetic spectrometer consisting of dipole magnet, drift chambers, and scintillator hodoscopes. From four-momenta of protons, proton separation energy S_p and momentum q of bound protons were deduced. Separation-energy resolution was about 1.5 MeV (rms). In the separation-energy distributions, sharp p-hole states and broad s-hole states were clearly observed. Additional information of forward particles was used to tag the decay mode of the hole states

Production of s-hole states was identified by the charged-particle decays from the hole states, i.e. no Boron isotopes were measured in the forward direction. By fitting the separation-energy distributions of s-hole states by a functional form, center and width (FWHM) of the s-hole distributions were obtained. Energy gap between $p_{3/2}$ and $s_{1/2}$ shows minimum at ^{12}C, and increases toward proton and neutron-rich sides. Momentum distributions of protons in p-orbital (to the ground state of B isotopes, and to IAS in $^{8,9}B$) and s-orbitals (to s-hole states) were deduced after two kinds of acceptance correction. Momentum distributions were fitted by the functional form assuming Harmonic oscillator-type wave function, and widths were deduced. Width of p-orbital shows gradual increase from ^9C to ^{16}C, reflecting the separation energy. Width of s-orbital is wider than that of p-orbital, and more or less flat up to ^{12}C and increase toward the neutron-rich side. Mass dependence of the relative knockout cross-sections shows that those of ^{9-10}C are much larger than other isotopes, and the main contribution for the increase comes from the p-orbital components.

In summary, (p,2p) reactions on ^{9-16}C isotopes were measured at 250 MeV/A, and systematic behavior of s-holes state distributions and momentum distributions of p and s orbitals was obtained.

YIELDS OF CORRELATED FRAGMENT PAIRS AND AVERAGE GAMMA-RAY MULTIPLICITIES AND ENERGIES IN $^{208}Pb(^{18}O,f)$

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We studied the fission process of light neutron deficient Th nuclei produced in the reaction $^{18}O + ^{208}Pb \rightarrow ^{226}Th$ at the beam energy E_{lab} = 85 MeV. The measurements were carried out using the γ-ray spectrometer EUROBALL IV coupled with the Inner Ball. Using the γ-γ-γ coincidence method for even-even nuclei we obtained the independent yields of individual secondary fragment pairs of seven different charge splits. In addition, the multiplicity distributions of prompt neutrons from the independent yields of fragment pairs were extracted. Using data from the Inner Ball and EUROBALL IV also the average γ-ray multiplicity and average energy were obtained as a function of single fragment mass.

Alpha decay and cluster radioactivity in dinuclear system model

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The model for the description of cluster decay of cold and hot even-even nuclei, where the quantum oscillations in charge asymmetry coordinate defines the value of spectroscopic factor, is presented. The possible rotations in the formed cluster configuration are taken into consideration in the calculation of penetrability of the Coulomb barrier in the relative distance between the clusters. Finally, the dependence of half-life on the temperature T is $t(T) = \left(\sum_n t_n \exp\left[-E_n/T\right]\right) / \sum_n \exp\left[-E_n/T\right]$, where E_n is the eigenvalue of the Schrödinger equation in the charge asymmetry coordinate and t_n is half-life of cluster emission for each E_n. The known experimental data on cluster radioactivity from the ground state of nuclei are described. The half-lives of cluster emission from neutron-deficient actinides and medium-mass nuclei and the dependence of half-life on the isotopic composition of the parent nucleus are predicted [1].

The theoretical assumption of the charge asymmetry vibrations can be experimentally checked by measuring the probabilities of the emission of different clusters as functions of excitation energy. Irregularities in the increase of the emission of various clusters with excitation reflect the charge asymmetry-vibrational states. The optimal excitation energies for the emission of different clusters are predicted.

In the case of alpha-decay of cold mother nucleus with spin $I \neq 0$ the calculations of half-lives are performed. The difference between decays from odd and even parity states is shown. The possibility of experimental observation of alpha-decays from high-spin levels $I \approx 15-20$ of several neutron-deficient nuclei is demonstrated.

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EXCITATION FUNCTIONS FOR COMPLETE FUSION AND TRANSFER REACTIONS IN THE INTERACTION OF ^{4}HE NUCLEI WITH ^{197}AU

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Excitation functions have been measured for the fusion reaction ^{197}Au(^{4}He,xn)$^{201\text{-}xn}$Tl with the evaporation of *x* neutrons ($0 \leq x \leq 3$) in the energy range 14-36 MeV. The induced-activation method was used for registration and identification of the reaction products. The experimental cross sections for the (1-3)-neutron evaporation residues are in good agreement with the results known from literature. For the radiation capture reaction ^{197}Au(^{4}He,γ)^{201}Tl, the upper limit was obtained essentially lower. The excitation functions for the measured reactions are compared with calculations in the frame of the statistical model, as well as with formerly measured similar data with a ^{6}He beam.

PRE-COMPOUND NEUTRON EVAPORATION IN LOW ENERGY HEAVY-ION FUSION REACTIONS

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The compound nucleus $^{58}Ni^{*}$ is formed in the heavy ion fusion reactions by an asymmetric entrance channel $^{12}C+^{46}Ti$ and the symmetric entrance channel $^{31}P+^{27}Al$ at the same excitation energy of 79.5 MeV. The statistical model calculation can reproduce the neutron energy spectra of the asymmetric entrance channel $^{12}C+^{46}Ti$, using the normal value of the level density parameter a = A/8. The level density parameter (a = A/10) was found to reproduce the exponential slopes of all neutron spectra in coincidence with gamma rays of the residual nuclei for symmetric entrance channel $^{31}P+^{27}Al$. As we know from the dynamically model calculations that symmetric system evolves more slowly towards compound nucleus formation as compared to the asymmetric entrance channel. This may result in the formation of a temperature equilibrated di-nuclear system at higher temperature, which may be responsible for the emission of the neutrons and the subsequent emission of the charged particles at lower temperature corresponding to a=A/8.

PROJECT OF A NEW IRRADIATION FACILITY AT THE MICROTRON MT25

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This paper is devoted to the preliminary project of a new irradiation facility at the beam line of the microtron MT-25. We suppose to use a collimated beam of bremsstrahlung gamma-rays with the advanced spectrometers for the series of experiments under condition of relatively low neutron- and gamma background. The primary horizontal electron beam line will turn up and hit into the radiator positioned between the basement and the first floor inside a local shielding. The collimated vertical channel will guide bremsstrahlung rays to the large experimental cave at the first floor. The beam-dump will be positioned also vertically. Nowadays existing facilities suffer from cramped cave and high radiation and HF-level in the hall of the microtron MT-25.

The scientific program includes measurement of products of photonuclear reactions: spectra of neutrons, protons, alpha particles and fission fragments.

In particular, it is planned to perform the experiments dedicated to the search for multi-cluster decays in photo-fission, which has been observed for the first time in ^{252}Cf(sf) in the FLNR, as a part of a program for study of such intriguing phenomenon [1,2].

1) D.V. Kamanin, contribution to this conference
2) Yu.V. Pyatkov, contribution to this conference

Multi-channel scattering of a neutron by ^{11}Be nucleus

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Influence of the Pauli principle on the relative motion of light neutron-rich nuclei in their collision is investigated within the microscopic method using as an example ^{11}Be+n and ^{10}Be+^{2}n nuclear reactions. An effective nucleus-nucleus interaction caused by changing the relative kinetic energy under the action of the antisymmetrizer is analyzed by the use of the discrete representation of the Pauli-allowed harmonic-oscillator states. Eigenvalues and eigenfunctions of the norm kernels for ^{11}Be+n and ^{10}Be+^{2}n binary cluster systems are obtained in an explicit form.

Cluster systems composed of a p-cluster having one neutron hole in p-shell and a neutron are shown to be characterized by the largest eigenvalue in excess of unity. An effective cluster-cluster attraction at small distance between clusters is most conspicuous in such systems. The ^{11}Be+n cluster configuration of the ^{12}Be nucleus is a good example of such a system. Effective attraction of a neutron and ^{11}Be cluster derived from the kinetic-energy operator modified by the Pauli principle produces a bound state in the ^{12}Be nucleus with an energy $E = -6.3$ MeV below the threshold of the ^{12}Be break-up into ^{11}Be and a neutron. We have drawn the conclusion that the bound state of the ^{12}Be nucleus is formed due to the influence of the exchange effects on the kinetic energy of the relative motion of a neutron and ^{11}Be. Taking into account the potential energy interaction (with its exchange part) between a neutron and the ^{11}Be nucleus depresses effective attraction of the nuclei arising from the kinetic energy operator modified by the Pauli principle. Hence, the binding energy of ^{12}Be nucleus with respect to the lowest decay threshold decreases in absolute magnitude approaching the experimental value.

The structure of the ground state of ^{12}Be obtained in the approximation of ^{11}Be+n and ^{10}Be+^{2}n coupled cluster configurations is discussed. The probability of a particular binary clusterization of the studied nuclear system is shown to be proportional to the eigenvalue of the isolated cluster configuration. The weight of the standard shell-model configuration in the ground state wave function of the ^{12}Be does not exceed 36%, which indicates the diffuseness of the nuclear surface of this nucleus. The cross sections for inelastic scattering, taking into account the excitation of interacting subsystems, and the effective cross sections for reactions involving rearrangement of the colliding nuclei, i.e., ^{11}Be(n,^{2}n)^{10}Be reactions, are estimated.

NEUTRON SPECTROSCOPIC FACTORS FROM TRANSFER REACTIONS

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In general, spectroscopic factors found in the literature show great fluctuations as a result of using different optical model potentials and parameters in the reaction theories. It is therefore difficult to pin down the precise nuclear structure information from experiments. We propose a systematic approach that provides consistent values with minimum parameters and assumptions. The parameters were tested previously by using $^{12}C(d,p)^{13}C$ and $^{13}C(p,d)^{12}C$ reactions.[1]

We apply a three-body model with global optical potentials and standard geometry of n-potential to reanalyze the angular distributions of the ground-state to ground-state transitions from (d,p) and (p,d) transfer reactions on different Ca isotopes, thus obtaining the valence neutron spectroscopic factors from ^{40}Ca though ^{49}Ca. Our results show excellent agreement with the predictions of the Independent Particle Model (IPM) and the Large-Basis Shell Model (LB-SM), reflecting the fact that configuration mixing of $f_{7/2}$ neutrons outside the double magic ^{40}Ca core is well described by a pairing interaction. We extend the method to extract spectroscopic factors for 80 nuclei from Li to Cr. For the 61 nuclei that have been described by LB-SM calculations, most experimental spectroscopic factors are reproduced to within 20%. [2,3]

If we constraint the nucleon-target optical potential and the geometries of the bound neutron-wave function with the modern Hartree-Fock calculations, our deduced neutron spectroscopic factors are reduced by 30% on average, similar to the observed reductions in spectroscopic strength in neutrons and protons nucleon knockout reactions, and for protons knockout reactions from (e,e'p) reactions.[4]

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Systematic comparison of ISOLDE-SC yields with calculated in-target production rates

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Recently, a series of dedicated inverse-kinematics experiments performed at GSI, Darmstadt, has brought an important progress in our understanding of proton and heavy-ion induced reactions at relativistic energies. The nuclear reaction code ABRABLA that has been developed and benchmarked against the results of these experiments has been used to calculate nuclide production cross sections at different energies and with different targets and beams. These calculations are used to estimate nuclide production rates by protons in thick targets, taking into account the energy loss and the attenuation of the proton beam in the target, as well as the low-energy fission induced by the secondary neutrons. The results are compared to the yields of isotopes of various elements obtained from different targets at CERN-ISOLDE with 600 MeV protons, and the overall extraction efficiencies are deduced. The dependence of these extraction efficiencies on the nuclide half-life is found to follow a simple pattern in many different cases. A simple function is proposed to parameterize this behavior in a way that quantifies the essential properties of the extraction efficiency for the element and the target – ion-source system in question.

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Microscopical model analysis of the ^{4,6}He, ^{6,7}Li + ^{28}Si total reaction cross sections at the energy range 5-50 A MeV

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The existing experimental data on total reaction cross sections of ^{4,6}He, ^{7}Li on ^{28}Si [1-5] and also some preliminary results for ^{6}Li+^{28}Si at the energies E=5-50 A MeV are analyzed using microscopic nucleus-nucleus optical potential (OP), calculated in the framework of the double-folding procedure both for its real and imaginary parts. Also, one of the form of OP was obtained basing on the Glauber-Sitenko microscopic theory of high-energy scattering [6]. Two kinds of effective nucleon-nucleon potentials BDM3Y2 and CDM3Y6 [7] are tested with and without their dependence on the nuclear matter density. The unfolded density distributions of the stable nuclei participating in scattering are taken from the known tables (e.g.,[8]) while the ^{6}He and ^{6}Li densities were invoked from the current models [9,10]. Besides, the microscopic double-folding Coulomb potential is treated and its effect on cross sections is studied in comparison with calculations by using the traditional electrostatic potential of the unified charge distribution in the sphere with a dimension of sum of radii of both nuclei. The acceptable theoretical bars of the calculated reaction cross sections are discussed for the applied theoretical models and conclusions are made to plan the further experimental studies.

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INVESTIGATION OF MULTIPOLES FOR SOME ^{134}Ba γ-TRANSITIONS

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By using of magnetic double focusing sector type beta-spectrometer with 0.2% resolution, useful solid angle of 0.3% from 4π and detector with small background of 1 imp/hour internal conversion electron (ICE) spectrum of 795.6, 801.9, 1038.6, 1167 and 1365.2 keV ^{134}Ba γ-transitions was investigated. K and L+M conversion lines was measured for these γ-transitions. For decomposition of L+M conversion lines by its components function presented in [1] was used. For determination of absolute and relative significant of internal conversion coefficients (ICC) relative intensities of γ-beams from [2] and theoretical data of α_K from [3] was taken for pure E2 1167.9 keV transition. For investigated γ-transitions multipolar compounds was established.

795.6, 801.9 and 1365.2 keV transition ($I_i^{\pi_i} = 4^+ \to I_f^{\kappa_f} = 2^+$) is mixed E2+M3 type transition. Using of experimental results given by us and theoretical [2] data for 795.6 keV γ-transition average significant of δ^2 (ratio of intensities of M3 and E2 components) was calculated as $\delta^2 = (3.2 \pm 2) \cdot 10^{-2}$, amount of admixture was $a = (3 \pm 2)\%$. In the case of 801.9 keV γ-transition K conversion line was observed only and δ^2 ($\sim 3.5 \cdot 10^{-2}$) and a parameter ($\sim 3.4\%$) was estimated. Admixture in 1365.2 keV γ-transition must be negligible. According our data a parameter that is admixture of M3 multipole in 1365.2 keV γ-transition is not enough than 0.5%. 103.8 kev γ-transition ($I_i^{\pi_i} = 3^+ \to I_f^{\kappa_f} = 2^+$) is mixed transition also consisting M1 and E2 multipoles. δ^2 and a parameter are 5.21 ± 0.53 and 0.161 ± 0.016 respectively for this transition.

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YRAST STATES IN EVEN-EVEN OSMIUM NUCLEI

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Yrast states in neutron rich nuclei ^{188}Os and ^{190}Os have been populated using the deep inelastic reaction ^{82}Se + ^{192}Os at 460 MeV beam bombarding energy. . The bombarding energy was obtained from the ALPI linear accelerator at Legnaro, Italy, and was chosen to be 20% above the Coulomb barrier of the colliding nuclei. A thick ^{192}Os target (>50 mg/cm^2) with 0.2 mm Ta backing was used to stop all of the recoils in the target, minimizing the broadening of the lines due to Doppler shift. High fold γ-γ coincidences were acquired with the 4π spectrometer GAmma-ray SPectrometer (GASP) detector array, consisting of 40 Compton-suppressed, large-volume germanium detectors with an inner ball consisting of 80 BGO crystals acting as a multiplicity filter and a total-energy spectrometer. The GASP geometry consists of a 122 faces polyhedron, 40 of which are used by Germanium detectors placed at 27 cm from the target, and the others by the BGO ball which cover 80% of the solid angle and are used for measuring the total energy and multiplicity of the gamma cascades.

Three and two dimensional gamma-ray matrices were used to construct level schemes of the nuclei of interest up to an yrast state of 22.

ON NUCLEON CORRELATIONS INSIDE NUCLEI

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Starting with the soliton–quark model of nucleon structure, elaborated by the author [1], in which the valence quarks are strongly correlated with one another within the nucleon, we utilize it for building the nuclear structure. We suppose that nucleons are bound via interactions of quarks. Then we make the following assumptions which have been chosen for keeping an agreement with the shell model symmetry. We assume that two bound quarks from the neighboring nucleons have different flavors and parallel spins at linkage and are in the antisymmetric color state, ($\overline{3}$). We demonstrate that the light nuclei ^2H, ^3H, ^3He and ^4He can be constructed by assuming such correlations of quarks in the neighboring nucleons. Application of the model to larger collections of nucleons reveals the emergence of symmetries at the nuclear level that are implied by the quark–quark interaction - specifically, geometrical shells and subshells that are isomorphic with those known from the independent-particle (shell) model.[2] Significantly, the nuclear texture implied by the strong correlations in the quark model is not a nucleon "gas" or independently orbiting nucleons, but rather a nucleon lattice in which local (quark) interactions are responsible for all aspects of nuclear binding. By constructing larger nuclei in this way, the quark–based lattice model reproduces the main features of the shell and liquid-drop models in a fully self-consistent manner. Because of the predominance of three– and four–body effects in the quark model, medium and heavy nuclei have transient tetrahedral nucleon aggregates that correspond to the alpha configurations of the cluster model. Moreover, namely quark correlations (interactions) result in "pairing" effect in nuclear structure. In general, lattice arrangements of nucleons inside nuclei lead in a natural way to nuclear deformations.
It is shown that quark–quark interactions of adjacent nucleons are responsible for formation of the nuclear configurations that correspond to the exotic (borromean) nuclei. According to the model loosely bound halo neutrons are arranged in triangular configurations bound to one proton of the core nucleus. In this manner we construct the dominating configurations for hydrogen isotopes ^5H, ^7H and helium isotopes ^6He and ^8He. According to our model there is no room for the ground state ^{10}He. We therefore claim that the many liquid–drop, shell and cluster characteristics of nuclear structure are manifestations of interquark correlations. The model has been developed on a qualitative rather than quantitative level, but indicates ways in which the long-standing internal contradictions of nuclear structure theory (long or short mean-free-path, strong or weak nuclear force, solid/liquid/gaseous nuclear phase, etc.) can be resolved on the basis of quark effects.

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Status of Tokai Radioactive Isotope Accelerator Complex and feasibility study for transfer reactions using low-energy RNB

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An ISOL-type radioactive nuclear beam (RNB) facility, Tokai Radioactive Ion Accelerator Research Complex (TRIAC) [1], has been developed under the collaboration of High Energy Accelerator Research Organization (KEK) and Japan Atomic Energy Agency (JAEA). We have started to supply RNBs for experiments since November, 2005. The radioactive nuclei are produced by proton-induced fission reactions of ^{238}U and heavy-ion transfer reactions with the primary beams from the 20MV JAEA tandem accelerator. They are mass-separated as singly-charged ions by the JAEA-ISOL [2], and fed to a charge-breeding 18GHz ECR ion source [3]. The multi-charged radioactive ions are accelerated to the energy of 1.1MeV/nucleon at the maximum by two linear accelerators; a split-coaxial RFQ linac and an inter-digital-H type (IH) linac. We have succeeded to accelerate the RNBs of ^{8}Li^{1+} and ^{138}Xe^{20+}, which were produced by the transfer reaction of the primary beam of ^{7}Li and the proton-induced fission reaction of ^{238}U, respectively. By connecting the IH linac to an existing super-conducting (SC) linac, we can increase the energy of the RNB up to 5~8 MeV/nucleon. The construction of the transport line and the remodeling of the first stage of the SC linac for velocity matching to the IH linac are proceeding now.

When RNBs of 5MeV/nucleon will be provided, one of experiments scheduled is measurements of the transfer reaction on medium nuclei. As a test of the experiment, we have measured the $d(^{124}\mathrm{Sn},^{125}\mathrm{Sn}^*)p$ reaction at 3.7MeV/nucleon under the inverse kinematic condition by using stable ^{124}Sn beam at the JAEA tandem accelerator facility. The same reaction was already measured at 4.5MeV/nucleon at ORNL [4]. According to their result, when the CD_2 target was employed, protons and deuterons emitted from carbons partly covered the protons which were induced by the *(d,p)* reaction. However, the preliminary analysis shows that the background from carbon is negligible at the lower incident energy.

We will present the current status of TRIAC and the feasibility of the transfer reaction using the RNB of several MeV/nucleon.

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A New Approach for Determination of R_H for Borromean Halo Nuclei

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In recent ref. [1,2] the target screening effect on the pre-emission of halo neutrons from ^{11}Li has been analyzed. It was found by sharp cutoff calculation that the yield of neutron pair pre-emission will be, due to the diminishing of the screening effect, about 3.5 times larger in the case of ^{12}C than in the case of Si target. Another important feature to be pointed out is the fact that in ^{12}C target of the same thickness as Si one, the number of nuclei/cm^2 is about two times larger in the case of ^{12}C target than in the case of Si target. These two factors are making the yield of neutron pairs to be about 7 times larger in the case of ^{12}C than in the case of Si target. It is likely that with the aid of such a large statistics of neutron pairs one could solve the standing present problems of C_{nn} correlation function [3,4,5] and also to test a recent new 3-body C_{nn} theory for Borromean halo nuclei [6].

One of the most interesting findings in [1,2], is the observation that the ζ probability used in the sharp cutoff calculation is an observable of the experiment, because it can be directly obtained from measured quantities which are the number of single detected neutrons and the number of detected neutron pairs (see formula (11) in ref. [1] giving $\zeta_{exp.}$). In Fig.1 it is shown the closeness between ζ_{exp} and ζ obtained by sharp cutoff calculation, assuming R_H = 4.8 fm [7]. (In this case, by R_H is denoted the rms radius of ^{11}Li halo). The closeness of ζ_{exp} and ζ values seen in Fig. 1, is indicating that the approach presented here is self contained, that is, it could be applied also to Borromean halo nuclei for which R_H is not known. This means that for such a nucleus one has to calculate ζ for different values of R_H, and to compare each time the calculated ζ with ζ_{exp}, until one finds the closest to ζ_{exp} value. Because at present, there is only one experimental measurement of R_H for ^{11}Li, [7], this approach could contribute to the investigation of R_H for the other Borromean halo nuclei, ^{6}He, ^{14}Be, ^{17}B.

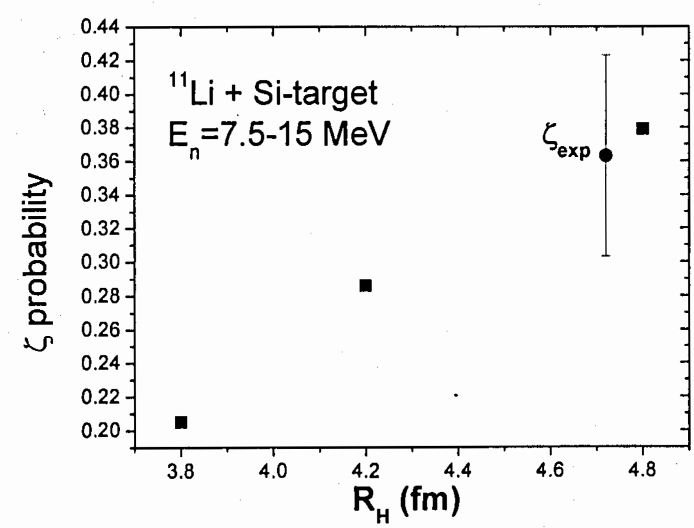

Fig. 1: The solid squares are representing the calculated values of ζ by sharp cutoff, assuming different values of R_H. The point with error bars represents ζ_{exp} obtained from detected numbers of neutron pairs and number of single neutrons (see text).

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ON-LINE SEPARATOR FOR γ-SPECTROSCOPIC STUDIES

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In recent years γ-spectroscopy of heavy nuclei has been very intensively developed in two directions. In the first case one detects prompt γ-rays using 4π-Ge-detector arrays placed around the target [1]. In the second case α-, β- and γ-spectroscopic measurements will be performed with detector arrays placed at the focal plane of an on-line separator [2].

A JINR – IN2P3 collaboration project aimed at the nuclear spectroscopy of transfermium elements using the modernized recoil separator VASSILISSA was launched 2004 at JINR in Dubna. This project was named "GABRIELA" - Gamma Alpha Beta Recoil Investigations with the Electromagnetic Analyser [3].

In the close future the FLNR cyclotron U400M will go through a major upgrade (U400MR) with the goal to deliver heavy ion beams at energies close to the Coulomb barrier in a new experimental area. This possibility is of great importance for the development of the GABRIELA project in the direction of prompt γ-ray spectroscopy at the target position.

To realize new possibilities we plan to construct an on-line electromagnetic separator for spectroscopic studies of nuclei produced in heavy ion induced reactions. The new separator will be of QQED type (where Q1, Q2 stands for quadrupole lenses, ES for electrostatic sector and DI for dipole magnet) and will operate in vacuum mode. The ion optical calculation of the set-up were performed using the COSY [4] computer code.

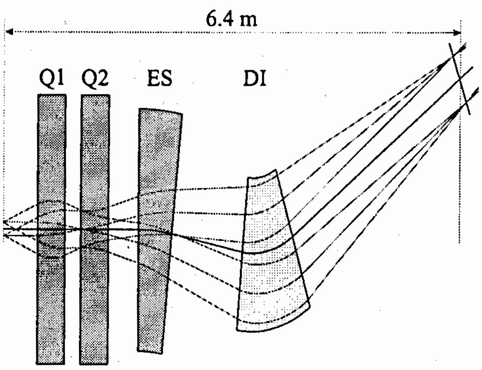

Fig. 1. Ion-optical scheme of the separator.

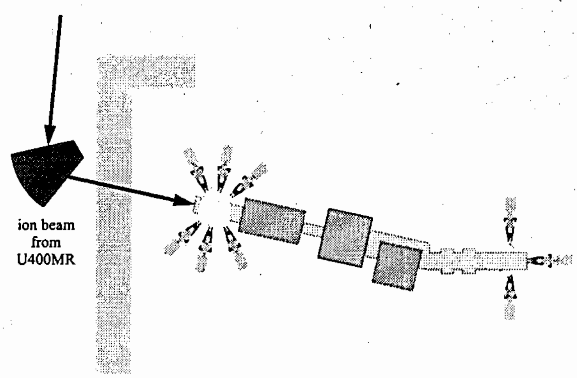

Fig. 2. Disposition of the separator in the experimental hall

The following table illustrates the planned characteristics of the separator:

Maximum beam current on the target	5×10^{12} part/sec
Target thickness	100-500 μg/cm^2
Angular acceptance	± 4.0°
Energy transmission range	±15%
Charge transmission range	±15%
Transmission efficiency for ER's	5 - 50%
Suppression factors for scattered beam	$10^{10} - 10^{12}$
Suppression factor for transfer products	10^3 - 10^4

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Search for the multicluster decay of ^{242}Pu* in the reaction ^{238}U+^{4}He (40 MeV).

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In our previous works [1] multiple indications of a new type of spontaneous ternary decay of the ^{252}Cf nucleus were reported. Unusual fission events manifested themselves forming geometrical structures which look like lines and rectangles in the mass-mass plot of coincident fragments. Two detected partners of such decay fly apart almost collinearly. Their total mass is much smaller than the mass of the decaying nucleus. Thus one can suppose a third, missing, fragment to be in game. We called the decay channel under discussion as "collinear cluster tripartition" (CCT).

In order to detect directly all the CCT partners a double armed time-of-flight spectrometer based on micro channel plate timing detectors and two mosaics 19 PIN-diodes each was used. PIN- diodes delivered both energy and time signals. Reaction ^{238}U+^{4}He (40 MeV) was chosen to make sure that fusion-fission prevail as nuclear reaction channels. The experiment was performed recently in the Accelerator laboratory of University of Jyväskylä (Finland). All in all about $4*10^7$ binary as well as some ternary and quaternary coincident events were registered. For all ternary events selected with the gate Ms≤ 242, where Ms is the mass of all three detected fragments, at least one of them to be a magic nucleus. Only small portion of these events satisfy both momentum and mass conservation laws. Others can be treated as a result of quaternary fission when one of the fragments is missing. The main argument in favor of such hypotheses is that "missing" fragment to be a magic one for all events analysed. It should be stressed as well that total kinetic energy of all four fragments agrees well with corresponding Q-value of the reaction. Some of such events are shown in fig.1. The fragments marked by letters a, b, c were really detected. The mass and energy of the "missing" fragment was calculated using both mass and momentum conservation laws. The following decay schemes correspond presumably to the events presented. Fragments "b" and "c" are shown in brackets.

1. ^{120}Pd + $\underbrace{(^{32}\mathrm{Mg}+^{18}\mathrm{O})}_{^{50}\mathbf{Ca}}$ + ^{72}Ni;
2. ^{108}Mo + $\underbrace{(^{40}\mathrm{Ar}+^{18}\mathrm{B})}_{^{58}\mathbf{V}}$ + ^{72}Ni + 4n;
3. ^{98}Sr + $\underbrace{(^{42}\mathrm{Ar}+^{28}\mathrm{Ne})}_{^{70}\mathbf{Ni}}$ + ^{72}Ni +2n;
4. ^{98}Sr + $\underbrace{(^{40}\mathrm{Ca}+^{30}\mathrm{O})}_{^{70}\mathbf{Ni}}$ + ^{72}Ni + 2n;
5. ^{84}Se + $\underbrace{(^{52}\mathrm{Ca}+^{30}\mathrm{Mg})}_{^{82}\mathbf{Ge}}$ + ^{72}Ni + 4n;

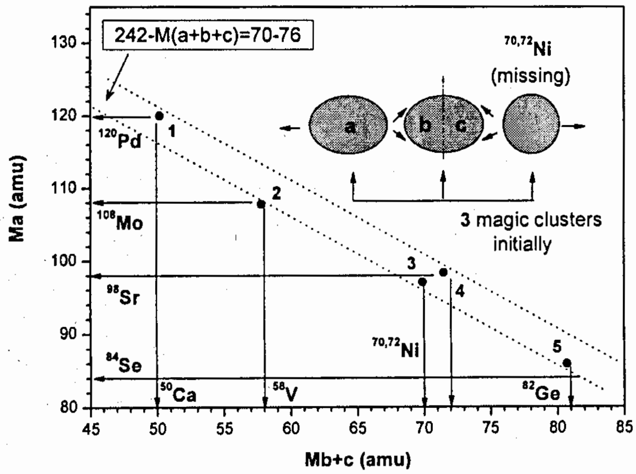

Fig.1. Some presumably quaternary events detected. The fourth "missing" fragment to be a magic isotope of Ni. The fragments "b" and "c" are likely originated from the decay of initially preformed middle magic cluster (see the decay schemes in the text). Magic clusters are marked by the arrows started from the experimental points.

Thus, a possible scenario of the decay consists in preformation of three magic clusters in the body of the compound system, its double rupture setting clusters free and subsequent decay of the middle cluster due to dynamical excitation obtained at the previous stage of the process.

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Structure and decay of heavy and superheavy nuclei

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Abstract

Research on superheavy nuclei is one of the hot points in nuclear physics [1-4]. The structure and decay of heavy and superheavy nuclei are systematically studied by different models [5-12]. New models of α-decay half-lives and new formulae for nuclear binding energies and spontaneous fission half-lives are presented [5-11]. The theoretical results are in good agreement with available data of heavy and superheavy nuclei. The properties of unknown superheavy nuclei are predicted.

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KINEMATICAL SELECTION OF HEAVY EVAPORATION RESIDUES IN GAS-JET EXPERIMENTS

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Extremely low production cross sections for the heaviest (superheavy) nuclei resulted from complete fusion reactions induced by ^{48}Ca [1] impel us to search for new ways of their effective collection for further studies in future experiments. A gas-jet technique, usually used in "chemical" experiments, allows one to obtain relatively high yields of the heaviest atoms due to a higher transmission efficiency of such systems and the use of thicker targets, as compared with the same typical parameters inherent in recoil separators. To increase the selectivity of gas-jet systems, we have proposed to take into account angle and energy distributions of evaporation residues (ER) produced in the (HI, *xn*) reactions in the design of the collection chamber [2]. It is well known that these kinematical characteristics differ strongly from those for target-like nuclei (TLN) produced in multi-nucleon transfer reactions at energies close to the Coulomb barrier [3]. Simulations of angle and range distributions for ER allow ones to minimize the collection-chamber volume and to achieve maximal collection efficiency for the heaviest atoms knocked out from the target. In order to estimate the suppression factor, determining the TLN yields and selectivity of the ER collection, we have used simulations based on the two-step kinematical model proposed earlier for the energy and outlet angle of TLN [4]. Optimization of the ER collection efficiency and the suppression factor for TLN can be performed using simulations for different target and entrance window thicknesses, varying geometry of the collection chamber, the entrance window material and stopping gas media. A technique based on this approach can be used in future experiments on the chemistry of the heaviest elements to provide their maximal collection and preferable selection from the huge background of unwanted TLN produced in transfer reactions with much larger cross sections than those for the desired ER.

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NUCLEAR DISSIPATION STUDIES BY MEANS OF PERIPHERAL HEAVY ION COLLISIONS AT RELATIVISTIC ENERGY WITH RADIOACTIVE BEAMS

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Peripheral heavy-ion collisions at relativistic energy are proposed as a new experimental approach to induce fission and further study the influence of nuclear dissipation on the splitting of a nucleus into two fragments. It will be shown that such a reaction mechanism is especially relevant for tracking down transient effects which are responsible for the inhibition of fission at the early stage of the de-excitation chain. That might constitute a real asset as compared to the commonly used fusion-fission process. Within this frame, the fission properties of hundreds of nuclei produced at various energies by means of fragmentation of 58 radioactive actinides have been studied at GSI, Darmstadt. The inverse kinematics combined to an innovative set-up permitted to detect both fission fragments in coincidence and determine their nuclear charge with high accuracy. The sensitivity of the fragment distribution width •$_Z$ on the transient delay caused by nuclear friction will be demonstrated. The comparison of the newly proposed experimental •$_Z$ signature with elaborate model calculations allows to extract information on the strength ẟ of dissipation and the related transient time ♦$_{trans}$. The unusual broad range of systems investigated strongly constrains the uncertainty of the extracted quantities and allows to draw most reliable conclusions. Furthermore, our study sheds some light on apparently conflicting results obtained in the past. In particular, the influence of temperature and fissility as well as the importance of sizeable initial deformation on properly accounting for transient effects are investigated.

CHEMISTRY OF SUPERHEAVY ELEMENTS. LATEST RESULTS AND PROSPECTS

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Relatively long half-lives of isotopes of elements 104-116 produced in the reactions with ^{48}Ca [1] and chemical properties of SHE predicted theoretically permit new experiments aimed at the chemical identification of SHE, study of their chemical properties and determination of masses of the SHE isotopes.

A first series of experiments was devoted to the chemical identification and study of properties of the isotope ^{268}Db, a final decay product of element 115 synthesized in the reaction ^{243}Am(^{48}Ca,xn) [2]. The isotope ^{288}115 produced in the 3n channel was undergoing 5 sequential alpha-decays. The final product ^{268}Db underwent spontaneous fission (SF) with a half-life of about 1 day. In the fraction of group 4 and 5 elements, chemically separated in the off-line regime, 15 events of spontaneous fission with $T_{1/2}=32^{+11}_{-7}$ hr and the formation cross section $4.2^{+1.6}_{-1.2}$ pb were detected. The total kinetic energy of the fragments was determined as ≈ 230 MeV, the average neutron multiplicity number per fission act was 4.2 [3]. In the second experiment an additional selective separation of the group 4 and 5 elements and in a number of tests that of group 5 elements (Nb and Ta) were performed. Spontaneous fission events were registered only in the fraction of the group 5 elements and in the Ta fraction. The obtained data are the independent evidence for the synthesis of element 115, as well as element 113, in the reaction ^{243}Am+^{48}Ca.

The programme of further research includes:

- off-line experiments for mass determination of ^{268}Db using a Mass Analyzer of Super Heavy Atoms (MASHA) newly created at the FLNR;
- study of chemical properties of the long lived ^{268}Db
- carrying out on-line experiments at MASHA for the determination of chemical and decay properties of isotopes of elements 114 and 112 produced in the reaction of ^{244}Pu and ^{48}Ca.

This work was supported by the Russian Foundation for Basic Research (grants nos. 04-03-32047)

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CHEMICAL IDENTIFICATION OF THE ELEMENT 112 IN THE REACTION $^{48}Ca+^{242}Pu$

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The isotopes of the new elements 112-116 and 118 at most undergo α-decays (one or several) that finally end up in spontaneous fission (SF) .[1]. Their identification is based on their radioactive decay properties and the reaction mechanism. At the same time, chemical identification of isotopes in the observed decay chains could give us the identity of the atomic numbers of nuclei in the decay chain and provide independent evidence for the discovery of a new element (elements). The first such an experiment was successfully carried out for element 115 [2].

The present experiment is designed to confirm the decay properties of the 4s $^{283}112$ reported in [1] and to investigation of chemical properties of element 112. The reaction of ^{48}Ca with ^{242}Pu was investigated at the U-400 cyclotron of Flerov Laboratory. In this reaction the isotope $^{287}114$ is formed in the 3n evaporation channel which decays with $T_{1/2} \approx 0.5$ s to $^{283}112$. Products recoiling from the target are thermalized in a He/Ar gas volume, where $^{287}114$ decayed to $^{283}112$ which is then transported to the Cryo On-Line Detector (COLD) [3]. This detection device represents a rectangular chromatography channel formed by 32 detector pairs, each pair kept at a different temperature between +35°C(#1) and -180°C(#32), respectively. One side of the detector pairs is covered by a thin Au layer. The experiment aims at the determination of the deposition temperature of element 112 on the gold layers. The established temperature range enables to distinguish between a Hg-like behaviour (first detectors) and a Rn-like behaviour (last detectors).

During 3 weeks beam time two decay chains were observed. In the first chain a ≈ 9.50 MeV α-decay was followed 592 ms later by a SF coincidence of TKE ≈230 MeV, in the second chain a ≈ 9.50 MeV α-decay was followed 536 ms later by a SF coincidence of TKE ≈230 MeV. Their decay patterns are unambiguously consistent with decay properties reported earlier [1]. The observed deposition behaviour points to properties of element 112 being more like Hg rather than similar to Rn.

This experiment independently confirmed the synthesis of new super heavy elements with atomic number 114 and 116 also.

This work was supported by the Russian Foundation for Basic Research (grants nos. 04-03-32047) and the National Scientific Foundation of Switzerland.

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GENERATOR COORDINATE Q_n-Q_p STUDY OF LOW-LYING COLLECTIVE STATES IN NEUTRON-RICH OXYGEN ISOTOPES

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The experimental progress in a study of the structure of the exotic nuclei has stimulated to develop models by uncovering novel manifestations of nuclear structure when moving away from the β-stability line, among which new regions of nuclear deformation, the appearance of new magic numbers may be cited. The isoscalar quadrupole mode dominates the standard low-energy large-amplitude collective dynamics. It is of interest to study how it can be affected by a neutron excess. With the present work we start such an exploration with the case of the oxygen isotopes.

Our analysis starts with constrained Hartree-Fock-Bogoliubov (HFB) calculations performed with the Skyrme SLy4 interaction and the density-dependent zero-range pairing interaction. We consider successively i) the usual single constraint on the total axial quadrupole moment generating a deformation energy curve and ii) two independent neutron and proton quadrupole constraints generating a deformation energy surface. The corresponding HFB wave-functions are then projected on the exact number of particle (N,Z) and on the total spin. In this way, we have calculated the 0^+ and 2^+ collective energy curves or surfaces for $^{18,20,22,24}O$. Fig. 1 gives the contour lines of the 0^+ energy surface of ^{20}O as an example. Finally, the properties of the ground and low-lying collective states are computed by means of the configuration mixing performed within the generator coordinate method [1]. As an illustration of the method we concentrate on the isotope ^{20}O.

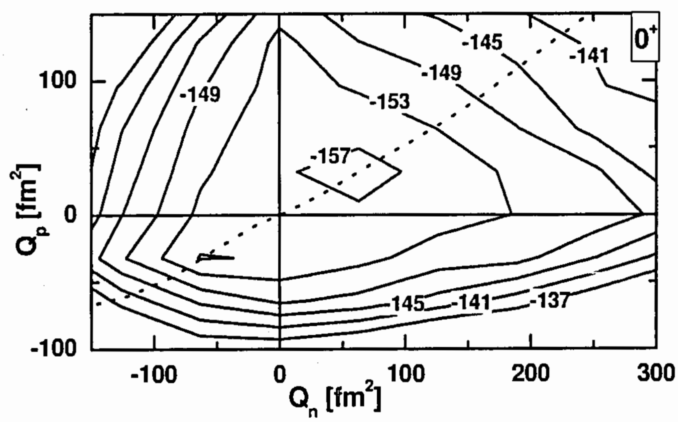

Figure 1: Nucleus ^{20}O; contour lines of the $\{Q_n, Q_p\}$ deformation energy surface for $J = 0$. The curves are labelled by the absolute energy in MeV. The dashed line shows the deformation path associated to the standard isoscalar quadrupole constraint Q, where $Q = Q_n + Q_p$.

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POSSIBLE ALTERNATIVE PARITY BANDS IN HEAVIEST NUCLEI

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The cluster interpetation of collective low-lying alternative parity states of the nuclei with Z≥96 is suggested. The parity splitting and electric dipole, quadrupole and octupole transition moments of heaviest nuclei are calculated within the cluster model. The model is based on the assumption that the dynamics of a reflection-asymmetric deformation of the nuclei can be treated as a collective motion in mass asymmetry coordinate. Such type of collective motion creates simultaneously a deformation with even and odd multipolaties. Our calculation shows that the only α-cluster system gives a sighnificant contribution to the formation of low-energy nuclear states. The model was previously applied for the description of existing experimental data on the low-lying alternative parity states in odd and even mass actinides and lanthanides nuclei [1,2]. The present calculations are performed for ^{239,240}U, $^{241-244}$Pu, $^{243-248}$Cm, $^{245-250}$Cf, $^{247-252}$Fm, $^{249-254}$No, $^{253-256}$Rf, $^{257-258}$Sg. The results are in a good agreement with experimental data if available.

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Experimental Study of 3-body correlations in ^{6}He in the Reaction of quasi-free knockout ^{4}He(^{6}He,2α)2n

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Quasi free reactions with bound particles are a powerful tool for the detailed study of cluster structure of nuclei (see for example [1]). Values for spectroscopic factors and momentum distributions for cluster states of nuclei can be extracted from such experimental data. The simplest two cluster nuclear states of ^{2,3}H, ^{6}Li, ^{9}Be, ^{12}C, ^{16}O and so on have been extensively studied. It was shown by these studies that better correspondence between experimental data and theory predictions can be achieved at higher collision energies. Nevertheless the study of quasi free scattering (QFS) on weakly bound particles (for example α-particle in ^{6}Li) provides reliable information at relatively low energy. This means that QFS probably can be used for the direct observation of multi-body correlations specific for the ground state of halo nuclei. The nucleus ^{6}He is a convenient object to check this assumption as its wave function is believed to be well established in theory. In our experiment we studied the reaction ^{4}He(^{6}He,2α)2n at a ^{6}He beam energy of 25A MeV. Kinematical conditions set in this experiment were optimized for detecting the QFS of α-particle bound in ^{6}He from the target nuclei of ^{4}He.

The experiment was performed in Dubna at the fragment separator ACCULINNA [2]. The secondary beam of ^{6}He bombarded helium target cooled down to a temperature of about 16 K. Two α-particles outgoing from the target in angular ranges of ±(15°-55°) were detected in coincidence by means of two identical ΔE-E telescopes. The telescopes installed symmetrically in respect to the beam direction provided for the measurement of X&Y position and the energy of reaction products. The measured kinematical parameters of the two α-particles allowed us to know the value of kinetic energy gained by the two neutrons in their rest frame and the recoil momentum imparted by the center-of-mass the neutrons to the α-particles.

For the data analysis we performed complete Monte-Carlo (MC) simulation of QFS based on Plane Wave Impulse Approximation which implies the following factorization of a T-matrix

$$\frac{d\sigma}{d\Omega}^{QFS}_{\alpha-\alpha} \propto N_{eff}\left|\psi(\vec{p}_{n-n},\vec{p}_{2n})\right|^2 \frac{d\sigma}{d\Omega}^{Free}_{\alpha-\alpha} d\vec{p}_{n-n}d\vec{p}_{\alpha-\alpha}d\vec{p}_{2\alpha-2n}\delta_{\sum E}\delta_{\sum \vec{p}}$$

where $|\psi(p_{n-n},p_{2n})|^2$ is the squared wave function of ^{6}He in the momentum representation and N_{eff} is the effective number of α-particles in ^{6}He. To compare data obtained in the experiment with the results of the MC simulation we simultaneously fitted experimental distributions of 8 observables: the total momentum of 2n system in the CMS of the projectile and two its projections, the relative energies α-α and n-n, the hyper angle characterizing in Jacoby coordinates the three-body correlations in ^{6}He, the angle of α-α scattering in their CMS and the Treiman-Yang angle. The experimental spectra of above mentioned parameters were found to be very close to the results obtained in the MC simulation. It was shown that N_{eff} depends on the α-α relative energy $E_{\alpha-\alpha}$ and reaches a value of about 0.2 at $E_{\alpha-\alpha}$>40 MeV, while theory gives a spectroscopic factor of ~0.6. Extrapolating the dependence $N_{eff}(E_{\alpha-\alpha})$ to higher energies one could assume completely consistent results at the energy of ^{6}He beam of about 40-50A MeV.

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SOME FEATURES OF THE IONIZATION OF NUCLEAR REACTION PRODUCTS

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By means of broad – range stepped - pole magnetic analyzer charge distributions of accelerated heavy ions of ^{12}C and ^{48}Ca after their passage through thin carbon and gold foils are measured. The review of works on charge – state distribution of heavy ions of the past through solid-state targets and the formed products of nuclear reactions on an output from these targets are given.

Comparison of charge distributions of the accelerated ions and ionization of recoil products from the nuclear reactions caused by these ions on the output from targets with calculated values is lead. It is ascertained, that calculated values of average charges of heavy ions and products of reactions can be used only as estimated.

PARITY INVERSION AND DIFFERENT PROPERTIES OF Be^{11} HALO NUCLEI

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The recent developments of radioactive nuclear beams has opened up the possibility of exploring a wide variety of nuclei far from the valley of beta stability .Of late several theoretical studies have come up in the past for describing nuclei in these exotic region. Extension of traditional shell model techniques to explain the exotic feature in the structure of these nuclei such as, formation of neutron halo, large r.m.s. radii, soft dipole resonances etc. have confirmed the necessity to modify the single particle shell model potential when dealing with nuclei far from stability.

In the present work ground state nuclear structure properties of $_4Be^{11}$ have been calculated in the framework of shell model using analytically soluble mean field potential given by Ginocchio. The potential is highly versatile in nature and depends on three parameters, which define its depth, range and shape. Potential parameters, which generate highly diffuse shape, account for the small binding and halo structure of the valence neutron in Be^{11}. The problem of ground state parity inversion is also addressed.

SKYRME-HARTREE-FOCK APPROACH TO SUPERHEAVY NUCLEI WITH DENSITY DEPENDENT DELTA INTERACTION

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The fission barriers of even-even superheavy nuclei with N = 184 are investigated by the Skyrme-Hartree-Fock approach with an effective force SLy4 in the particle-hole channel and a density dependent δ interaction (DDDI) in the particle-particle channel. We discuss the "volume", "surface" and "mixed" parameterizations of DDDI and compare the results obtained with these zero-range pairing interactions with the ones obtained using the monopole pairing force.

STORED AND COOLED HIGHLY-CHARGED IONS IN THE REALM OF ATOMIC PHYSICS

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The ESR storage ring provides unique conditions for precision investigations in the field of atomic structure and collision physics. This overview first reports on atomic physics experiments addressing QED effects in hydrogenlike high-Z ions. As an representative example, the 1s binding energy in H-like uranium could be determined with an absolute precision of 4.6 eV. This result obtained provides the most stringent test of the bound-state quantum electrodynamics for one-electron systems in the strong field regime. A further improvement by almost one order of magnitude is envisaged by a dedicated transmission x-ray spectrometer which has been developed recently as well as by the implementation of high-resolution micro-calorimeter devices. Both experimental approaches along with the results of first test experiments will be presented.

The ESR has also been proven as a powerful tool for the study the dynamics of atomic collisions in the widely unexplored domain of highest projectile charges. At such conditions, where ion-matter interaction is governed by virtual as well as by real photon fields, the study of magnetically induced electronic transitions are of great importance to test and to advance our basic knowledge about the physics of strong fields. In this context special emphasis will be given to photon polarization phenomena associated with the process of radiative electron capture (REC) , the time-reversed photoionization in heavy-ion collisions. By the application, 2D position sensitive detectors for the hard x-ray regime as efficient Compton polarimeters, the REC radiation is found to be strongly linearly polarized within the scattering plane and that the degree of polarization depends markedly on the beam energy and the observation angle.

High resolution magnetic spectrometer SHARAQ in RIBF

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Missing mass spectroscopy is a source of our knowledge on nuclear ground, bound excited, and continuum states. Conventional missing mass spectroscopy uses light stable beams, such as proton, deuteron, and ^{3,4}He, and high resolution detectors. RI beams can have a variety of isospin (T), internal energy (mass excess, ε), and spin (S), while light stable beams listed above have $T, S \leq 1$ and the minimum internal energies among isobars. With the properties of RI beams, it is possible to reach states which are hardly accessible via the stable-beam induced reactions. In this respect, an RI beam as a probe has in principle abilities that are not available to stable beams.

The energy range of RI beam produced in RIBF, 100–300 MeV per nucleon, is well suited for the spectroscopic study described above. At these energies, the nucleon-nucleon interaction is weakest. As a result of this, distortion effects, which may smear out signatures of interesting phenomena, should be smaller than at lower or higher energies. Additionally, the reaction mechanism becomes simpler at $> 100\mathrm{MeV}/A$. Dominance of single- and two-step processes at these energies should facilitate a rather simpler interpretation of reaction data to deduce the nuclear structure information involved.

To take fully advantages of the unique properties of RI beams at RIBF, the construction of the high-resolution SHARAQ spectrometer and the development of a dispersion-matched beam-line are started.

The charge exchange reactions induced by light, stable nuclear beams have been proven to be effective to investigate excited states at low excitation energies. Exothermal charge exchange reactions induced by RI beams open new possibilities to probe higher excitation states with small momentum transfer. By using these reactions, we will be able to produce states which have been hardly observed so far, for example, multi-neutron systems, isovector spin monopole resonances, and double Gamow-Teller resonances.

In the talk, specifications of the SHARAQ spectrometer and the high resolution RI beamline are presented and some physics programs on the missing mass spectroscopy are discussed.

Nuclear Matter Radii and Production Cross-Sections of Neutron-Deficient Kr Isotopes Studied via Relativistic-Energy Heavy-Ion Reactions

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Precision measurements of the interaction cross-sections (σ_I) at relativistic energies allow us to derive nuclear matter radii [1]. Since nuclear matter radii are directly related to the density distributions, the measurements of σ_I are a good probe to search for unusual nuclear structures. Neutron-deficient Kr isotopes close to the $N = Z$ line attract a particular interest in their structures. Recent γ-ray measurements have shown that large deformation and shape coexistence appear in this region [2]. The proton drip line nuclei in the mass range $60 < A < 100$ are also important to determine the astrophysical rapid proton capture process path [3].

We have performed the precision measurements of the interaction cross-sections for even-mass Kr isotopes, ^{72,76,80}Kr, using the fragment separator FRS at GSI, Darmstadt. We have so far succeeded several experiments to determine nuclear matter radii of light nuclei ($A \leq 40$) [4-6]. The measurements for Kr isotopes are an effort to extend a series of successful experiments to heavier nuclei ($A \simeq 80$).

The result of the interaction cross-sections of Kr isotopes clearly shows that the radii increase as the mass number decreases. This is clearly different from our early observations in the light region. A systematics of the radius change in the medium mass region around the $N = Z$ line is discussed together with recent indirect measurements at GANIL [7].

For exotic nuclei, it is important to know their production cross-sections (σ_F) in order to make the reaction mechanism clear and to assess the feasibility of using them in radioactive beam experiment. It is difficult, however, to predict their σ_F with physical models, such as the abrasion-ablation model [8]. Another approach is to use an empirical parameterization, such as the EPAX formula [9]. The quality of such a parameterization depends on the quality of the experimental data. The present experiment was also performed to extend the current database by studying the fragmentation of the relatively neutron-deficient krypton isotope ^{80}Kr. A systematics of the production cross-sections is compared with various models. The charge pickup reaction cross section will be also reported.

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PERSPECTIVES OF THE USE OF DIFFERENT TYPES OF NEUTRON DETECTORS AT THE FOCAL PLANE OF VASSILISSA SEPARATOR

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Spontaneous fission is one of important modes of radioactive decay of nuclei with atomic number $Z \geq 100$. A big number of isotopes of transfermium elements decay solely by spontaneous fission. Presently available experimental information on spontaneous fission of transfermium elements mainly concerns partial half – lives. In addition, for Fm and No isotopes and for a few Md, Lr and Rf isotopes the total kinetic energy (TKE) and mass distributions of fission fragments from spontaneous fission were also accurately measured [1]. A multiplicity distribution of prompt neutrons emitted in spontaneous fission was measured for elements not heavier than fermium [2], and the only one measurement was performed for the isotope ^{252}No [3]

Recoil in – flight separator VASSILISSA [4] is widely used for the synthesis and study of decay properties of heavy and superheavy nuclei. A neutron detector consisting of 72 ^{3}He filled counters was mounted around the focal plane detector chamber which is a cylinder 210 mm in diameter. The first experiment [5] aimed to acknowledge the old result for ^{252}No [3] and test the new setup was successfully was performed at 2004.

Now, the search of alternative methods of the neutrons detection was realized. During the search, with colleagues from Skobeltsyn Institute of Nuclear Physics (SINP MSU), the properties of some inorganic scintillators, was investigate. Two of them are lithium-borate glasses (LBO) activated by cerium (Ce^{3+}) and europium (Eu^{3+}) [6]. The third kind is pure glassy boron oxide or lithium-borate glass, which contained ZnS(Ag) crystalline powder [7]. The optical and luminescence properties of scintillators have been investigated as well as spectrometric characteristics of detectors on the basis of these materials at registration of neutrons from ^{252}Cf and Pu(Be) sources and of ^{60}Co γ-radiation. Two types of photoreceivers (photomultiplier and silicon p-i-n photodiodes) were used depending on spectral distribution for optical emission of scintillators.

The obtained response functions of detectors are adequate to energy spectra of neutron sources. The results of measurements have confirmed high neutron/γ-radiation discrimination characteristics for these kinds of scintillators.

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NEW TREATMENT OF NUCLEAR STRUCTURE BY MEANS OF ANALYTICAL - EMPIRICAL DEVIATION METHOD

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A different ways are known of identifying nuclear magic numbers. For example, it is use usually the discontinuities in binding energy of two last neutrons or two last protons. For more detailed analysis of nuclear structure we propose a new analytical method, which is based on the analysis of the deviations of the separation energy of one nucleon. For example, for of a neutron we have

$$\Delta S_{1n}(Z, N) = S_{1n}(Z, N) - [S_{1n}(Z, N+2) + S_{1n}(Z, N-2)]/2,$$

where $\Delta S_{1n}(Z, N)$ is the deviation of one-neutron separation energy, $S_{1n}(Z, N) = [M(Z, N-1) + M(0, 1) - M(Z, N+1)]\ c^2$ is actually one-neutron separation energy, $M(Z, N)$ is mass or mass excess of the nucleus and $M(0, 1)$ is mass or mass excess of the neutron. Then

$$\Delta S_{1n}(Z, N) = [M(Z, N+2)-M(Z, N+1)-2M(Z, N)+2M(Z, N-1)+M(Z, N-2)-M(Z, N-3)]c^2/2. \quad (1)$$

Formula (1) give the deviation of one-neutron separation energy from the mean separation energy of two neighbouring neutrons of identical parity and exclude the smooth liquid drop energy and nucleon pairing staggering. The changes in the shell energy is not exclude.

Similar to (1) it is also formula for the deviation of one-proton separation energy.

Two positive deviations where the shell is closed and two negative deviations where the next shell starts reflect the energy gap G between the two shells: $G \approx 2 < |\Delta S_{1n}| >$.

Formula (1) was tested with data on nuclear masses taken from table [1]. One-neutron separation energy deviation was calculated for known isotopes of elements. The formula for one-proton separation energy deviation was applied to a number of series of isotones of elements.

This method confirmed the large gaps after of neighbouring neutron and proton closed shells with well known nucleon numbers 82, 50, 28 and 20. This method enabled also the discovery of some new shells and sub-shells, for example, new shells in nuclear structure with N = 14 and Z = 14. For the nucleus ^{28}Si we obtained the intershell energy gaps $G = 4.0 \pm 0.2$ MeV after Z = 14 and $G = 3.9 \pm 0.6$ MeV after N = 14. Meanwhilein the authors [2] from the proceedings of seminar on Exotic Nuclei obtained from experimental investigations that «in the Si isotopes ...the proton configuration is expected to be more stable due to the Z = 14 sub-shell closure». It is important confirmation of magicity of ^{28}Si.

In the present work the previously calculations of the deviations one-nucleon separation energy were anew repeated with using corrected nuclear mass data (new edition) [3]. It was obtained some new results.

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MASS AND ALPHA-DECAY WIDTH ESTIMATIONS OF SUPERHEAVY ELEMENTS

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Recently a body of experimental data relative to superheavy elements [1] seems to be valid enough to build various phenomenological and semi-phenomenological interpolation-extrapolation approaches which allow one to test interrelation between the different data and to predict the properties of neighboring unexplored isotopes.

In the present work the approaches mentioned in [2] are used for estimations of masses and alpha-decay widths of such unknown superheavy nuclei.

The method of inter- and extrapolation of nuclear masses is based on the representation of the binding energy surface $E(Z,N)$ by a continuous piecewise-smooth function consisting of second order polynomials of Z and N variables. Each polynomial describes the surface inside a rectangle region restricted by the conditions: $Z_{i-1} \leq Z \leq Z_i$, $N_{k-1} \leq N \leq N_k$. The quality of this interpolation procedure can be confirmed by the value of its root mean square deviation δ_E=76 keV for all measured nuclear masses (they are about 300) in the area $82 < Z \leq 104$. Naturally the alpha-decay energy yields Q_α are reproduced still better in this region. Stability of some differential characteristics of the graduated surface $E(Z,N)$ in rather wide areas is used for the extrapolation.

The method of calculation of an alpha-decay width for known value of energy yield Q_α involves the calculation of the value of penetrability of the potential barrier or in more exact terms the value of the wave function in the subbarrier region. The realistic nuclear alpha – daughter nucleus potentials like MacFadden-Satchler (MF-S) and Christensen-Winter (C-W) ones are used. The "experimental" values of the spectroscopic factors W_α are extracted from the practically full data concerning alpha-decay of even-even nuclei by means of the same potentials and averaged. The resulting value $\overline{W}_\alpha$ is used for calculations of unexplored examples. The small root mean square deviation of the values $lg\, W_\alpha$ for the nuclei heavier than ^{208}Pb δ_W = 0.26 (for both MF-S and C-W potentials) makes this procedure reliable. After a small modification the approach turns out to be workable for odd and odd-odd nuclei areas.

The values Q_α, t_α of alpha-decay of the elements $104 < Z \leq 118$ and their masses are predicted in the framework of the presented methods.

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INVESTIGATION OF DUBNIUM CHEMICAL BEHAVIOUR. RADIOCHEMICAL SEPARATION OF GROUP V ELEMENTS

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Chemical behaviour of group V elements in the aqueous hydrofluoric acid solutions was studied. The radiochemical method for the cation exchange separation of Nb (Pa) and Ta from Zr, Hf and lanthanides is presented. The opportunity for ion exchange separation of Zr and Hf is shown. The developed scheme allows to exclude the presence of SF heavy actinides in fractions of separated elements. On the basis of the data of the present work, it is possible to suggest the following order of the stability fluoride complexes of group IV and V elements: Nb (Pa) > Zr > Hf > Ta. The order of the complex formation is in agreement with theoretical predictions. This analytical procedure can be used in future heavy nuclei synthesis experiments for the separation of dubnium (Db) from other reactions products and for its chemical identification.

SYNTHESIS OF SUPERHEAVY NUCLEI IN ^{48}CA-INDUCED REACTIONS

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The existence of an enhanced stability in the region of the neutron-rich superheavy nuclei, located in the vicinity of the closed shells with Z=114 (possibly 120, 122, or 126) and N=184, which has been developed in various theoretical approaches and hypothesized for about 40 years, has been validated by recent experiments. For the production of the heaviest nuclei we used a ^{48}Ca beam delivered by our heavy-ion cyclotron to actinide targets installed in the Dubna Gas-filled Recoil Separator. The new nuclides mainly undergo sequential α-decays terminated by spontaneous fission. The total time of decay ranges from 0.2 ms to about 1 d depending on the proton and neutron numbers in the synthesized nuclei. The masses of evaporation residues have been identified by using the characteristic dependence of their production cross sections on the excitation energy of the compound nucleus (thus defining the number of emitted neutrons) and from cross bombardments, i.e., by varying the mass number of the target nuclei which changes the relative yields of the xn-evaporation channels. The maximum production cross sections for the evaporation of 2-5 neutrons in the complete-fusion reactions were measured to be in the range of 0.5 pb to 5 pb. The atomic numbers of the new elements 115 and 113 were also confirmed by an independent radiochemical experiment based on the identification of the neutron-rich isotope ^{268}Db (T_{SF}≈30 h), the final product in the chain of α decays of the odd-odd parent nucleus ^{288}115.

Decay energies and lifetimes of 29 new nuclides with Z=104-116 and 118 and N=162-177 that have been synthesized in the complete-fusion reactions of ^{238}U, ^{242,244}Pu, ^{243}Am, ^{245,248}Cm, and ^{249}Cf targets with ^{48}Ca beams indicate a considerable increase of the stability of superheavy nuclei with an increasing number of neutrons. A discussion of self-consistent interpretations of all observed decay chains originating from the parent isotopes ^{282,283}112, $^{286\text{-}289}$114, ^{287,288}115, $^{290\text{-}293}$116, and ^{294}118 is presented. The decay properties of the new nuclei are compared with those of previously known heavy nuclei and predictions of the different theoretical models. As a whole, the results of the experiments agree with the predictions of theoretical models concerning the decisive dependence of the structure of superheavy elements and their radioactive properties on their proximity to the closed nuclear shells.

The experiments were carried out at the Flerov Laboratory of Nuclear Reactions in collaboration with the Lawrence Livermore National Laboratory.

Pseudo-spin symmetry in the structure of superheavy nuclei

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The mean field theory of nucleonic interaction plays a role of a basis for the construction of the specific advanced theories of nuclei. It is, therefore of fundamental importance to the whole field of the nuclear structure physics to descover, examine and use the consequences of the underlying symmetries, even if they are approximate.

The spherical shell model orbitals having nonrelativistic quantum numbers $(n_r, l, j = l + 1/2)$ and $(n_r - 1, l + 2, j = l + 3/2)$, where n_r, l and j are the single-nucleon radial, orbital and total angular momentum quantum numbers, respectively, where observed in the stable relatively heavy nuclei to be quasidegenerate. This doublet structure was expressed in terms of a pseudo-spin and pseudo-orbital momentum. Then pseudo-spin symmetry was shown to exist in deformed nuclei as well and has been used to explain features of deformed nuclei, including superdeformation and identical bands.

It was shown latter that the pseudo-spin symmetry arises from a relativistic symmetry of the Dirac Hamiltonian, i.e. from a near equality of the scalar and vector mean fields. Such a near equality has been obtained in relativistic nuclear field theories with interacting nucleons and mesons, in relativistic field theories with nucleons interacting via a Skyrme-type forces. It was shown also that an approximate equality in magnitude of the scalar (attractive) and vector (repulsive) potentials arises from the spontaneous breaking of chiral symmetry. The last fact means that investigating the manifestations of the pseudo-spin symmetry in nuclei we are touching fundamental problems.

It is known from theoretical investigations that the pseudo-spin symmetry improves as the binding energies of the single-particle states decrease. This condition is realized in exotic nuclei removed from the valley of stability. At the same time the results of the recent calculations of the single-particle level schemes of the superheavy nuclei are contradictionary. Some of them demonstrate a presence of the psedo-spin doublets in the spectra of the single-particle states (WS). The other show that pseudo-spin symmetry is comletely broken in nuclei with $Z > 100$.

This means that farther experimental and theoretical investigations of this problem are important.

PROGRESS REPORT OF RIKEN RI BEAM FACTORY PROJECT

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The world-top-class radioactive-isotope-beam (RIB) facility, which is called "RI beam factory (RIBF)", is under construction at RIKEN. This facility is based on the so-called "in-flight RI beam separation" scheme.

Commissioning of a new high-power heavy-ion booster system consisting of a cascade of three ring cyclotrons with K=570 MeV (fixed frequency, fRC), 980 MeV (Intermediate stage, IRC) and 2500 MeV (superconducting, SRC), respectively, is scheduled for late in 2006. This new ring-cyclotron cascade system boosts energies of the output beams from the existing K540-MeV ring cyclotron up to 440 MeV/nucleon for light ions and 350 MeV/nucleon for very heavy ions.

These energetic heavy-ion beams are converted into intense RI beams via the projectile fragmentation of stable ions or in-flight fission of uranium ions by a superconducting isotope separator, BigRIPS. The combination of the SRC and the BigRIPS will expand our nuclear world into presently unreachable region.

Trunk experimental installations are planned to extensively promote exotic nuclear science. Construction of these apparatus is expected to start in 2007.

GAMMA AND ELECTRON SPECTROSCOPY OF HEAVY NUCLEI AT FLNR JINR

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Detailed spectroscopic information of excited nuclear states in deformed transfermium nuclei is scarse. Most of the information available today has been obtained from investigations of fine structure α decay. Although α decay gives access to hindrance factors and lifetimes which are strongly correlated to shell/subshell closures and the presence of isomers, only the combined use of γ and conversion electron spectroscopy allows the precise determination of excitation energy, spin and parity of nuclear levels. In particular, the study of odd isotopes gives crucial information on the single particle states available at and around the Fermi surface [1]. In the following, the preliminary results of decay studies using α – γ and α - β coincidences at the focal plane of the VASSILISSA recoil separator [2,3] are presented.

In the two campaigns using the GABRIELA (Gamma Alpha Beta Recoil Invetsigations with the ELectromagnetic Analyser) set-up, the odd isotopes of ^{253,255}No and ^{255}Lr were produced with an intense (~ 0.6 pμA) ^{48}Ca beam impinging on rotating ^{207,208}Pb and ^{209}Bi targets. During the experiments, calibration runs were regularly performed with ^{164}Dy and ^{174}Yb targets to produce well studied Rn and Th isotopes, in particular the well know 181 μs isomeric state in ^{207}Rn [4] to check the calibration of the electron detectors.

In the case of the $^{253-255}$No evaporation residues, their implantation in the position sensitive detector is followed mainly by α decay. In prompt coincidence with the characteristic α emission of both nuclei, γ quanta as well as conversion electrons were detected in GABRIELA.

The analysis of these data as well as the data collected on ^{255}Lr is still in progress but already modifications to the electronics and focal plane chamber are being performed to increase the efficiency and sensitivity of GABRIELA in view of the next campaign of experiments. In particular, the number of electronic channels for the β detection will be increased in order to measure efficiently β coincidences and the thickness of the Al focal plane chamber will be reduced to increase low energy γ efficiency.

First test experiments using high intensity (~1 pμA) ^{22}Ne beam and ^{209}Bi, ^{238}U targets were performed in the year 2005. It was shown that rather high (~ 5 %) transmission efficiency for slow evaporation residues could be achieved. It means that appropriate statistics for α – γ and α - β coincidences at the focal plane of separator for neutron rich Rf isotopes produced with ^{22}Ne beam and ^{242}Pu target could be collected during one moth of the beam time.

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Roles of shell effects in fusion process for synthesis of superheavy elements

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In heavy ion fusion reaction, with increasing the atomic numbers of the target and the projectile, the fusion hindrance is remarkable. The fusion hindrance mainly is related to the macroscopic part of the potential energy surface. On the contrary, the fusion is enhanced by the nuclear structure effects. In the experiments, especially in cold fusion reactions, these advantages are used to synthesize the superheavy nuclei by choosing the target nucleus as ^{208}Pb which has strong shell effect. To understand fusion mechanism clearly, it is better to treat separately the fusion hindrance and the fusion enhancement, that is to say, the macroscopic aspect and the microscopic one. We investigate the fusion mechanism using the trajectory calculation [1].

First, we focus on the fusion hindrance in the superheavy mass region. We clarify the origin of the fusion hindrance systematically by the trajectory calculation in the deformation parameter space. In this case, we employ the liquid drop part of the potential energy surface. By analyzing the behavior of the mean trajectory, we identify the critical area when the trajectory's destination is determined to be the fusion or the quasi-fission processes. We can see that the fusion probability decreases exponentially as the Z number of the fused system increases. The origin of the fusion hindrance is concluded to be mainly due to the fragment deformation in a system with Z greater than 102, which is very important degree of freedom in the calculation.

Second, as for the nuclear structure effects, we focus on the influence of the shell effect in fusion process. To synthesize the superheavy nuclei, the shell correction energy plays a very important role. It is known that the nuclear shell structure of the projectile and target nuclei correlates not only to the touching probability, but also to the dynamics from the touching point to the compound nucleus region. We introduce the shell correction energy into the potential energy surface which is calculated by two-center shell model. We can see the 'Cold Fusion Valleys' in potential energy surface [2]. By the trajectory calculation, we present that these valleys lead to enhance the fusion probability [1]. Also, due to the shell correction energy, we can see the temporary pocket around the critical area, which discussed in the fusion hindrance. This temporary pocket helps the trajectory to enter the fusion region. Moreover, we discuss the temperature dependence of the shell correction energy and it influences on fusion process.

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Electric quadrupole moment of neutron rich Al isotope

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Many intriguing phenomenon have been reported in the region of neutron-rich *sd*-shell nuclei. Disappearance of magic number at the neutron number $N = 20$ is the typical phenomenon in such the neutron-rich region. Such the phenomenon are considered as manifestations of the deformation induced by the inversion of amplitudes between *sd*- and *pf*-intruder configurations [1]; the region is known as the "island of inversion". It is important to clarify what is the governing parameter whose variation brings about the amplitude inversion at a certain value of the N/Z ratio. Microscopic studies of nuclei close to the "island of inversion" as well as those inside it, would offer a clue to this question. Recently we have measured the magnetic dipole moments μ of ^{30,32}Al [2]. In this talk, we will report on the measurement of the electric quadrupole moment Q of ^{32}Al. Such μ- and Q- moments would be important for microscopic studies of the evolution of the "inversion".

The experiment was performed at RIKEN Ring Cyclotron Facility. A beam of spin-polarized ^{32}Al was produced using the fragment separator RIPS through the fragmentation of ^{40}Ar at an energy of 95 AMeV in a 369 mg/cm^2 thick Nb target by selecting a finite emission angle and a momentum of fragments. The polarized ^{32}Al was implanted in an Al_2O_3 single crystal stopper whose electric field gradient eq is known. The electric quadrupole moment was determined by using the β-NMR method for the implanted ^{32}Al. We will discuss the obtained Q-moment of 24 ± 6 mb (preliminary) with shell model calculation.

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Sub-barrier fusion of weakly bound nuclei

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The reactions with halo neutron-rich nuclei during the past 10 years has been of increased interest from experimental and theoretical point of view. In particular, much effort has been devoted to studying near-barrier fusion of light weakly bound nuclei. Unusual effects are expected here both from the halo structure of these nuclei and from specific tunnelling mechanism of the composed weekly bound system which is also of common interest for quantum theory.

Neutron transfer cross sections are known to be rather large at near-barrier energies of heavy-ion collisions and there is a prevailing view that coupling with the transfer channels should play an important role in sub-barrier fusion of heavy nuclei. For weakly bound nuclei (the two-neutron separation energy for ^{6}He is less than 1 MeV) a strong coupling with the break-up channels is also evident and it should influence significantly the fusion probability. However, while the role of collective degrees of freedom (rotation of statically deformed nuclei and/or vibration of nuclear surfaces) in the sub-barrier fusion reactions is well studied in many experiments and well understood theoretically, the role of neutron transfer and break-up channels is not so clear.

A series of experiments was already undertaken on the near-barrier fusion of ^{6}He with ^{209}Bi [1, 2] and ^{238}U [3, 4]. However, the contradictory conclusions were made concerning a role of weakly bound neutrons in the fusion process and, no matter how surprising it may seem, but until now there is no consensus (neither in theory nor in experiment) on the extent to which the sub-barrier fusion of weakly bound nuclei differs from fusion of ordinary ones.

Recently in Ref. [5] a new mechanism has been assumed for the sub-barrier fusion of weakly bound nuclei, in which an intermediate rearrangement of valence neutrons with positive Q values may lead to a gain in kinetic energy of the colliding nuclei and, thus, to enhancement of the barrier penetrability. Within this "sequential fusion" mechanism, the fusion enhancement in the reactions ^{40}Ca+^{48}Ca (compared with ^{48}Ca+^{48}Ca), ^{40}Ca+^{96}Zr (compared with ^{40}Ca+^{90}Zr) and ^{18}O+^{58}Ni (compared with ^{16}O+^{60}Ni) has been successfully explained. Estimations were also made for the evaporation residue cross sections in the ^{6}He+^{206}Pb and ^{4}He+^{208}Pb reactions leading to the *same* compound nucleus. The yield of polonium isotopes at the same sub-barrier center-of-mass energy of 15 MeV (5 MeV below the barrier) was predicted to be *three orders* of magnitude larger for the first reaction as compared to the second one. This experiment has been performed recently in Dubna [6, 7] at the DRIBs complex. The yield of the ^{210}Po isotope, produced in the 2n-evaporation channel, really demonstrates extremely large enhancement of the sub-barrier fusion cross section as compared with the ^{4}He+^{208}Pb reaction.

The subject will be discussed in the talk along with detailed analysis of the "sequential fusion" mechanism performed within the time-dependent Schrödinger equations. An importance of the effect for synthesis of new superheavy nuclei in future experiments with accelerated neutron-rich fission fragments as well as for astrophysical estimations will be also discussed in the talk.

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ISOTOPIC DEPENDENCE OF NEUTRON EMISSION FROM DINUCLEAR SYSTEM

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Using the statistical approach, we study the isotopic dependence of de-excitation of dinuclear systems formed in the entrance channel of heavy ion reactions $^{62-73}Ni+^{208}Pb$. We estimate the probability P_n of neutron emission from the initial dinuclear system, the process which competes with the quasifission in R from the initial dinuclear system or the quasifission from more symmetrical dinuclear system. We propose two possible ways of the definition of the dinuclear system level density, corresponding to equal and non-equal temperatures of heavy and light fragments.

The calculated values of P_n are of the order of 10^{-2} for the considered reactions and increase by factor of 3 with A_{DNS} from 270 to 281. The probability of neutron emission from the dinuclear system is very sensitive to the dinuclear system excitation energy. Therefore, the measurement of these neutrons in coincidence with quasifission products would help us to define the excitation energy of pre-scission configuration and conclude on its shape.

We also discuss the possible experiment for the observation of the neutron emission from the dinuclear system.

COMPUTER MOLECULAR DYNAMICS STUDIES ON THE PROTEIN STRUCTURES
(Visual Pigment Rhodopsin and Cyclin-Dependent Kinases)

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Molecular dynamics simulations are carried out on the rhodopsin protein to investigate the conformational changes of the protein in relation to the inclusion of the 11-cis chromophore retinal into consideration. Molecular dynamics calculations were performed for the time interval from t=0 to 3000 picoseconds, so that the configuration states of rhodopsin and free opsin were analyzed and compared. It was demonstrated that the adaptation of the chromophore retinal in the opsin site causes a considerable influence on its protein binding pocket, as well as on conformations of the cytoplasmic part, but the extracelluar part of the protein shows a comparably small changes. On the basis of the simulaton results we discuss some molecular mechanisms for the rhodopsin protein function as a G-protein-coupled receptor in the dark state, i.e. for the chromophore retinal as a ligand-agonist stabilizaing the inactive conformation of the rhodopsin.

The central role that cyclin-dependent kinases play in the timing of cell division and repair and the high incidence of genetic alteration of CDKs or deregulation of CDK inhibitors in a number of cancers make CDC28 of yeast Saccharomyces cerevisiae very attractive model for studies of mechanisms of CDK regulation. We have found that certain gene mutations including cdc28-srm [G20S] affect cell cycle progression, maintenance of different genetic structures, checkpoint-controli and increased cell sensitivity to ionizing radiation. A cdc28-srm mutation is not temperature-sensitive mutation and differs from known cdc28-ts mutations because it has the evident phenotypic manifestations at 30oC. This is a third glycine in a conserved sequence GxGxxG in the G-rich loop positioned opposite the activation T-loop. Despite its demonstrated importance, the role of the G-loop has remained unclear. The crystal structure of the human CDK2 has served as a model for the catalytic core of other CDKs, including CDC28. Nanoseconds long molecular dynamics trajectories of the CDK2/ATP complex were analyzed. The MD simulations of substitution CDK2-G16S in conserved G-loop shows an important of this amino acid and a conformational change of CDK2 structure resulting in the moving of the G-loop away from ATP and a new rearrangement of amino acids in the T-loop.

A microscopic description of the α-decay chain of the observed odd-odd nucleus $^{278}113_{165}$

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Abstract

Comprehensive calculations to describe the ground state properties and α-decay half-lives of the observed super-heavy elements with $100 \leq Z \leq 118$ have been presented using the successful RMF+DF+WKB methodology /1/. Here, we show theoretical calculations for the experimentally observed odd-odd nucleus $^{278}113_{165}$. A single event attributed to this nucleus was observed in a cold-fusion reaction with the smallest experimental production cross-section to date of 55 fb *+150 -45* /2/. The assignments were the most probable for the reaction. This nucleus is also of interest as the α-decay chain passes through the region around N$\sim$162 where neutron shell closure is thought to exist.

The computations were done in three steps: First, the ground state properties are obtained in the framework of the self-consistent Relativistic Mean Field (RMF) theory using the NL3 parameter set. In the second step, the calculated point proton and neutron densities are used to derive the α-daughter interaction potential in the double folding approximation incorporating a density dependent M3Y (DDM3Y) effective nucleon-nucleon interaction. This, together with theoretical Q-values are used to calculate the α-decay half life of the parent nucleus using the WKB approximation.

It is seen that qualitative agreement exists between theoretical ground state properties and observations of the nuclei attributed to this α decay chain. However, small variations in Q-values (to within a couple of hundred keV) are seen to dramatically affect theoretical estimates of half-lives resulting in qualitative differences between theory and observations. More data are necessary to facilitate a more detailed and definitive understanding of the nuclear structure of this region. Alpha-decay half-lives are better reproduced if experimental Q-values are used within the WKB approximation, indicating that the chosen interaction potential is accurate.

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The FAIR Project: a future Antiproton and Heavy Ions international research facility in Darmstadt

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The FAIR facility proposed to be built in the next future at GSI in Darmstadt will provide the international science community with an innovative accelerator system which will permit to perform forefront research concerned with the basic structure of the matter and some associated fields like material research and radiation biology. Using an intricate system of heavy ions synchrotrons and storage rings, the facility will provide a large variety of beams from protons and antiprotons to ion beams of all stable elements, up to fully striped uranium. Beams of stable isotopes with 100 times higher intensities then presently available at GSI will support a new generation of nuclear, plasma and atomic physics experiments.
However, the key feature of the accelerator complex will be the generation of high-quality, intense secondary radioactive beams. Advanced methods of separation and beam phase-space handling will increase the available secondary radioactive beams intensity by a factor 10^4. Ion cooling, bunch compression techniques, storage and deceleration of highly charged ions in rings, already developed and used to some extent at GSI, will push ahead the intensity and precision frontiers. Also, the availability of intense, high- and low-energy cooled beams of antiproton will provide exceptional opportunities for matter-antimatter studies.

The scientific goals proposed to be pursued at the FAIR facility encompassed aspects of structure and dynamics of hadronic matter and the understanding of the many-body systems complexity. The research program includes:

a) Investigations of nuclei far from stability, aspects of astrophysics and nucleosynthesis in supernovae, test of fundamental symmetries.
b) The study of hadronic matter, at sub-nuclear level, with antiprotons.
c) Compressed, dense hadronic matter created in nucleus-nucleus collisions.
d) The study of bulk matter in high density plasma state.
e) Studies of Quantum Electrodynamics, of extremely strong field effects and ion-matter interactions.

This contribution is devoted to the presentation of the scientific goals, the accelerator design and the experiments defining the FAIR project.

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