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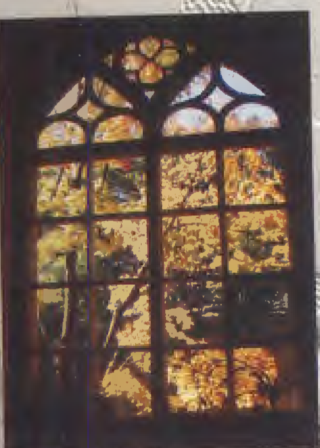
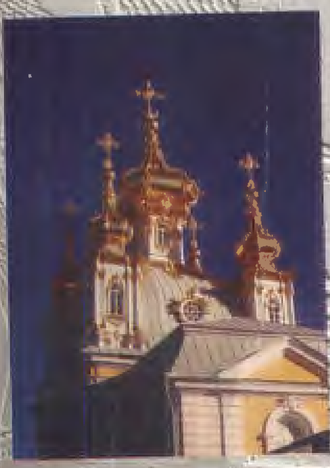
ABSTRACTS





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Peterhof, Lake Ladoga, Russia, July 5–12, 2004

Contributions

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Recent Experimental Studies of Exotic Nuclei

A. A. Korsheninnikov

RIKEN, Hirosawa 2-1, Wako, Saitama 351-0198, Japan
On leave from the Kurchatov Institute, Kurchatov sq. 1, 123182 Moscow, Russia

A review of recent experimental studies of exotic nuclei will be presented. During last years, many interesting experiments were performed in this field. Some of the topics stand out in comparison with other experiments as being the most hot or sometimes problematic, and such selected topics will be reviewed. Namely, the following topics will be discussed:

- investigations of the ^{16}C nucleus structure;

- the two-proton halo in ^{17}Ne and the structure of this nucleus;

- recently discovered two-proton radioactivity and correlations of emitted protons;

- a long standing problem of spectroscopy of ^{4}H;

- a controversial situation in spectroscopic studies of ^{5}H, where many experimental results have been recently obtained;

- a search for superheavy hydrogen ^{7}H;

- a situation in spectroscopic studies of excited states in ^{7}He, where previously existing problems were recently settled.

Exploring halo excitations via correlations

RNBT (Russian-Nordic-British Theory) Collaboration

B.V. Danilin[1], J.S. Vaagen[2], M.V. Zhukov[3], S.N. Ershov[4] and I.J. Thompson[5],

[1]The Kurchatov Institute, 123182 Moscow, Russia,
[2]SENTEF, Department of Physics and Technology, University of Bergen, Norway,
[3] Chalmers University of Technology and Göteborg University, Göteborg, Sweden,
[4]JINR, Dubna, Russia,
[5]Department of Physics, University of Surrey, Guildford GU2 7XH, U.K..

Email: [2]*jans.vaagen@fi.uib.no*

General properties of the ground and three-body scattering states of Borromean halo nuclei are explored in a core + n + n three-body model using the method of hyperspherical harmonics with realistic binary interactions, for the testbench nuclei ^{6}He and ^{11}Li. Different criteria for resonance phenomena in three-body continua [1] are discussed.

Amplification of continuum cross-sections may be caused by,

i) True three-body resonances, which are due to interaction of all three particles in the interior spatial domain;

ii) A long lived binary resonance in one of the constituent pairs;

iii) The response of an extended system to the long-range transition operators used to excite the continuum;

iv) Resonances due to strong coupling between channels (CC resonance in a few channels) or parametric resonance in quantum diffusion with complex coefficients.

We have developed methods of continuum diagnostics:

i) Analysis of the multi-channel three-body effective mean field to explore existence of possible bound and resonant states;

ii) Search for resonance behaviour in interior norms of the continuum wave functions revealed in transitions to continuum states in nuclear reactions;

iii) Analysis of eigenphases of S-matrix for 3− > 3 scattering for possible existence of three-body resonances.

Progress in theoretical and experimental studies is being made by exploring the structure of the halo continuum in terms of two-dimensional energy correlations of constituents, from inelastic and charge-exchange reactions and electromagnetic dissociation of the ^{6}He and ^{11}Li nuclei. General analytic properties of three-body scattering and transition amplitudes as well as analysis of spatial correlations [2] give helpful unique signature of the three-body resonance nature of the bumps in excitation functions. The intrinsic correlated structures of the continuum reveal three-body 2_1^+, 2_2^+, 1_1^+ resonances in ^{6}He, 0_1^+, 0_1^- resonant structure in ^{11}Li, and a lack of resonant structure in soft dipole and monopole excitations in ^{6}He and in the ^{11}Li soft dipole response.

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Interaction at the barrier with ^{17}F, ^{11}Be' ^{6}Li: fusion, breakup, scattering onto ^{208}Pb, ^{209}Bi targets.

C.Signorini

Physics Department of the University and INFN, via Marzolo 8, 35131 Padova, Italy
e-mail: signorini@pd.infn.it

Systematic experiments has been performed by our group, at Coulomb barrier energies, onto ^{208}Pb and ^{209}Bi targets with radioactive ion beams: ^{17}F (S_n=0.60 MeV) scattering, ^{11}Be (halo nucleus with S_n=0.50 MeV) fusion, and ^{6}Li (S_{alpha}=1.47 MeV, the less bound stable nucleus) breakup. The main goal is to see whether the small binding energy, sometimes connected to the halo structure, influences the whole interaction process.

The fusion cross sections in ^{11}Be+^{209Bi} [1] do not differ too much, in the whole energy range, from the ones induced by ^{9}Be and astonishingly also by ^{10}Be, well bound, at difference from expectations.

In ^{6}Li+^{208}Pb [2] the breakup process proceed mainly via the so-called "stripping-breakup", i.e. with only one particle (alpha) in the exit channel and not two (alpha and the deuteron) as expected . If something similar happens with ^{11}Be, as realistically extrapolated, this fact could partly explain the "normal" fusion of ^{11}Be similar to the ^{9,10}Be ones (the real "two-body" breakup process is week and does not influence fusion?).

The ^{17}F+^{208}Pb system: a) its fusion cross section is reported very similar to the ^{19}F+^{208}Pb one [3] i.e. rather normal, b) the scattering data measured recently by us [4] give a total reaction cross section relatively small, comparable to what measured with the well bound nucleus ^{16}O; i.e. the breakup process seems to be not so strong.

From these various experimental data we can conclude for the moment that the breakup process does not influence too much the whole interaction at the barrier contrary to the expectations. Several theoretical approaches explain, on different basis, these results but an "unified" theoretical description is still missing or maybe is too complex for the moment.

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High precision mass measurements of $^{29-33}$Mg and ^{11}Li using the MISTRAL spectrometer at CERN-ISOLDE

C. Thibault[1], G. Audi[1], C. Bachelet[1], H. Doubre[1], C. Gaulard[1], C. Guenaut[1], F. Herfurth,[2], D. Lunney[1], M. de Saint Simon[1], N. Vieira[1] and the ISOLDE Collaboration.

[1]CSNSM-IN2P3-CNRS, Université Paris Sud, Bât. 104-108, F-91405 Orsay-campus, France
[2]CERN, EP Division, Geneva, Switzerland

High precision mass measurements have been performed on the very neutron-rich $^{29-33}$Mg and ^{11}Li nuclides using the MISTRAL radiofrequency mass spectrometer, especially suited to very short-lived nuclides. This method, combined with the powerful tool of resonant laser ionization at CERN-ISOLDE has allowed to significantly reduce the uncertainty in mass of these nuclides. An accuracy of about 6×10^{-7} could be achieved for the weakly produced ^{33}Mg ($T_{1/2}$=90.5ms) and ^{11}Li ($T_{1/2}$=8.75ms). All these nuclei were selected as they stand in regions of special interest.

The isotopic chain $^{29-33}$Mg crosses the $N = 20$ line which is a shell closure for heavier elements, but not for light ones as sodium and magnesium. The results obtained by MISTRAL allow to better study the shell gap evolution around $N = 20$ for magnesium isotopes. In particular, shifts of the order of respectively 125 keV and 250 keV have been observed for the masses of ^{32,33}Mg as compared to the previous adopted values.

The borromean nuclide ^{11}Li is known as a halo nucleus in which two neutrons stray very far from the ^{9}Li core. In order to understand the value of its radius, which is as large as that of ^{48}Ca, three-body nuclear models are required. A critical input parameter of these models is the two-neutron binding energy. The MISTRAL measurement not only improves the accuracy on the mass by a factor 4 (up to 5-6 keV), but also results in a value shifted by about 70 keV. These data bring new constraints to current theoretical developments.

From elastic scattering to sub-barrier fusion with exotic nuclei

N. Alamanos, N. Keeley and V. Lapoux

CEA/DSM/DAPNIA/SPhN Saclay
91191 Gif-sur-Yvette Cedex, France

K. Rusek

Department of Nuclear Reactions,
The Andrzej Soltan Institute for Nuclear Studies,
Hoza 69, 00-681 Warsaw, Poland

A. Pakou

Department of Physics, The University of Ioannina, 45110 Ioannina, Greece

The detailed study of unstable nuclei has been at the forefront of nuclear physics research for the last years. With the continuous improvement of the intensities and optical qualities of secondary radioactive beams, mechanisms such as Coulomb excitation and more recently elastic and inelastic scattering, transfer and knock-out reactions are rapidly becoming standard tools for the investigation of the structure of nuclei far from stability.

Here we are concerned essentially with the simplest of these processes, that is elastic and inelastic scattering for which we will present recent experimental results and we will discuss briefly theoretical developments aiming at obtaining nuclear structure information.

We will discuss also the role played by entrance channel potentials in the case of sub-barrier fusion involving weakly bound nuclei. Indeed, with the advent of the radioactive beam facilities, the interest in such studies with halo nuclei was renewed due to their specific features, like extended neutron densities, low-lying continuum, and also very low energy thresholds for break-up. It is expected that such features should appreciably affect fusion, as other reaction processes.

Structure of light exotic nuclei in Fermionic Molecular Dynamics

H. Feldmeier[1], T. Neff[1], R. Roth[2]

[1] Gesellschaft für Schwerionenforschung, Planckstraße 1, 64291 Darmstadt, Germany
[2] Institut für Kernphysik, TU Darmstadt, Schlossgartenstr. 9, 64289 Darmstadt, Germany

e-mail: h.feldmeier@gsi.de *http://theory.gsi.de/~fmd*

The structure of light nuclei up to the drip lines is studied using the Fermionic Molecular Dynamics model [1]. The calculations make no a priori assumptions about a core or single particle-states and energies. The many-body states are described as parity and angular momentum projected Slater determinants. The single-particle states are given as a single or a sum of two Gaussian wave-packets. The position and width of each Gaussian wave-packet and the orientation of the spins are the variational parameters. FMD states are able to describe shell-model states as well as cluster-model states or states with halo structure.

Intrinsic states are obtained by minimizing the energy under constraints on radius, dipole, quadrupole or octupole deformations. In the spirit of the Generator Coordinate Method we obtain ground and excited states by multiconfiguration calculations with these parity and angular momentum projected intrinsic states.

The same effective interaction derived from the realistic Bonn-A or the Argonne V18 interactions is used for all nuclei. It includes the short-range central and tensor correlations induced by the repulsive core and the tensor force by means of a unitary correlation operator [2]. The correlated interaction no longer connects to high momenta and can thus be used directly within product-state model spaces. The effects of three-body correlations and genuine three-body forces are simulated by an additional two-body force that contains momentum-dependence and spin-orbit forces.

Within this model we study nuclei in the p-shell. In the He-isotopes the soft-dipole mode in form of ground-state correlations is found to be necessary for an understanding of the experimentally observed borromean behaviour of the binding energies and for the matter radii. The soft-dipole mode is also found to be important in other halo nuclei like ^{11}Li.

In many nuclei cluster structures are found and allow a description of observed radii and quadrupole moments. The Be isotopes change their charge distribution quite substantially when adding more and more neutrons.

In ^{12}C the intrinsic structure of the ground state rotational band is found to be an interpolation between a shell model and triangular α-cluster configuration. We are able to describe the binding energy as well as radius and the $B(E2)$-value for the 0^+ to 2^+ transitions. With increasing neutron number the clustering is reduced and for ^{16}C we find an almost round proton distribution and consequently a very small $B(E2)$ value.

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Masses, half-lives, spins and decays of exotic nuclides

G. Audi[a], A.H. Wapstra[b], O. Bersillon[c], J. Blachot[c] and C. Thibault[a]

[a] *Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse, CSNSM, IN2P3-CNRS&UPS, Bâtiment 108, F-91405 Orsay Campus, France*

[b] *National Institute of Nuclear Physics and High-Energy Physics, NIKHEF, PO Box 41882, 1009DB Amsterdam, The Netherlands*

[c] *Service de Physique Nucléaire, CEA, B.P. 12, F-91680 Bruyères-le-Châtel, France*

Abstract

In December 2003, a full collection of atomic masses, AME2003, was published, based on an evaluation of experimental masses. This evaluation compared to the preceding one of 1995 (AME95) contains data obtained in several new ways. While evaluating the atomic masses it was found essential to create the NUBASE evaluation. We finally succeeded in having AME and NUBASE co-ordinated and published for the first time together.

Masses of several very proton-rich nuclides are now determined by Penning trap and Schottky mass spectrometry methods. Investigations of the decay energies in the same region, up to the drip-line, where both alpha and proton decays compete, provides data for long α-decay series. Quite often, the properties of the proton decay of these nuclides yield a good estimate of the spin and parities of the decaying levels. Particularly interesting are nuclides in which both ground-state and isomer decay by proton emission, since precise determination of the excitation energy of the isomer can be determined. In several cases, data have been obtained on chains of isomers in such series. In some cases it becomes clear that earlier measurements thought to apply to ground-states in reality belong to upper isomers. Also, knowledge of the decay of nuclides at and beyond the proton dripline put a stringent constraint on the mass-surface, very far from stability.

The surface of masses on the neutron-rich side, reveals now very clearly that one magic number, namely $N = 28$, is vanishing while moving away from the previously known, close to the stablility, nuclides.

Recently, the relevant authorities accepted the evidence for the discovery of element 110 so that a name could be proposed. Similar evidence for elements 111 and 112, already discussed in our 1995 evaluation, may soon be recognized too.

Abstract submitted to the EXON-2004 conference
http://www.jinr.ru/exon2004/

New mass measurements at the neutron drip-line

H.Savajols, B.Jurado, W.Mittig, C.E.Demonchy, L.Giot, M.Rousseau, P.Roussel-Chomaz, A.Villari, A.Khaouaja
GANIL (DSM/CEA, IN2P3/CNRS), BP 5027, 14076 Caen Cedex 5, France

Y.E. Penionzhkevich, S. M. Lukyanov
FLNR,JINR, Dubna, P. O. Box 79, 101 000 Moscow, Russia

A. Gillibert
CEA/DSM/DAPNIA/SPhN, Saclay, 91191 Gif-sur-Yvette Cedex, France

M. Chartier
Department of Physics, University of Liverpool, Guilford, Surrey GU2 7XH, United Kingdom

Z. Dlouhy, J. Mrazek, D. Baiborodim
Nuclear Physics Institute, ASCR, 25068 Rez, Czech Republic

A.Lepine-Szily
IFUSP-Universidade de Sao Paulo, C.P. 66318, 05389-970 Sao Paulo, Brazil

The evolution of shell closures far from stability is a subject of much actual debate. Deformations, shape coexistence or variations in the spin-orbit strength as a function of the neutron to proton ratio could provoke the modification of magic numbers. Experimentally, nuclear binding energies are very sensitive to the existence of shells and may provide clear signatures of shells closures. Such measurements (SPEG91[1] and SPEG99[2]) have already given a clear signature of the breaking of the N=20 magicity and have shown a change in shell structure around N=28.

More recently, a new mass measurement experiment (SPEG02[3]) has been performed to extend mass beyond the N=20 shell gap, at the neutron drip-line. As a result, the mass resolution of around 20 neutron-rich nuclei has been improved and the masses of more than 15 neutron-rich nuclei have been determined for the first time. The region covered presents a considerable interest to determine both, the boundary of the island of inversion, responsible for the breaking of the N=20 magicity and to extend mass measurements around N=28.

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A New Approach in Building of the Intrinsic Neutron-Neutron Correlation Function for Borromean Halo Nuclei

M. Petrascu, A. Constantinescu, I. Cruceru, M. Giurgiu, A. Isbasescu, H. Petrascu, C. Bordeanu
Horia Hulubei National Institute for Physics and Nuclear Engineering P.O.B. MG-6, Bucharest, Romania
I. Tanihata, T. Kobayashi, K. Morimoto, K. Katori, M. Chiba, Y. Nishi, S. Nishimura, A. Ozawa, T. Suda, K. Yoshida
RIKEN, Hirosawa, 2-1, Wako, Saitama, Japan

It was predicted in ref. [1] that, due to the very large radius of ^{11}Li, and due to the very low binding energy of the halo neutrons, one may expect that in a fusion process on a light target, the halo neutrons may not be absorbed together with the ^{9}Li core, but may be emitted in the early stage of the reaction. Indeed, the experimental investigation of Si(^{11}Li, fusion), has shown that a fair amount of fusion events [2] are preceded by the pre-emission of one or two halo neutrons. In ref. [2] was also found that, in the position distribution of the pre-emitted neutrons, a very narrow neutron peak, leading to transverse momentum distribution much narrower than that predicted by COSMA model [3], is present. Following the preliminary observation of coincident neutrons in this narrow neutron forward peak, it was decided to perform a new experiment aiming to investigate the neutron pair pre-emission in conditions of much higher statistics, by means of a neutron array detector [4]. The new experiment [5], has confirmed with better precision the existence of the narrow neutron peak, corresponding to a solid angle of ~9 msr. Within this peak, a large number of n-n coincidences were observed for ^{11}Li [5], by comparing the data obtained with ^{11}Li and with ^{9}Li beams. Therefore a neutron correlation analysis, based on event by event measurement, has been undertaken [6]. A thorough analysis of the array detector performances through a complete simulation by using the program MENATE [7] was also performed [8,9]. Soon it was observed that there are serious problems with the building of the correlation function, due to the presence of residual correlation of single detected halo neutrons, first mentioned in ref. [10]. Additional direct experimental evidence for residual correlation was presented in [8, 11]. As it is known, the n-n correlation function is sensitive to the $r_{nn}^{rms} = \sqrt{6}r_0$ separation between the neutrons in the halo, r_0 being the variance of Gaussian source assumed in the model of ref. [12]. We have found that r_0=5 fm, (close to the value obtained in ref. [13]), in the case the denominator of the correlation function was built by taking a random distribution of the detectors within the array. In the case we took a distribution of detectors not a random one but a particular distribution corresponding to the measured sample of n-n coincidences, we have found r_0 = 4.2 fm, close to the value obtained in ref. [10]. We interpret the different values obtained for r_0, as being due to the neutron residual correlation effect [8]. In ref. [10], an iterative method was introduced in order to compensate for the residual correlation. By iterative calculation resulted r_0 =2.7±0.6 fm, close the value predicted by COSMA$_{II}$ model [3], (denoted by C$_{II}$ in Fig.1). By applying the iterative calculation we obtained r_0=3.3±0.8 fm [8, 14], close to the value predicted by COSMA$_I$ model [3], (denoted by C$_I$ in Fig. 1). As can be seen in Fig 1 (ii), there is not possible to distinguish between COSMA$_I$ and COSMA$_{II}$, by using the iterative method because the errors in this method are very large [8,14]. We consider that at present, will be a challenging task to try to distinguish between the r_0 values predicted by COSMA$_I$ and COSMA$_{II}$ models, by using a new approach. Such an approach appears to be an experiment aiming to determine the intrinsic correlation function by using ^{11}Li and ^{11}Be halo nuclei. The nucleus ^{11}Be will be an ideal uncorrelated background source, since it contains only one halo neutron. In Fig. 1 (i) are shown the errors expected in this case [14].

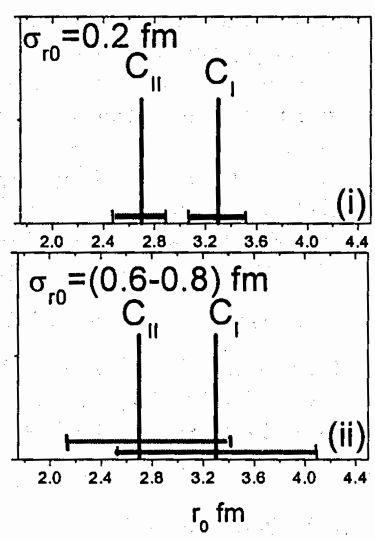

Fig. 1

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A SHELL MODEL REPRESENTATION WITH ANTIBOUND STATES FOR ANALYSING EXOTIC NUCLEI

T. Vertse[1,2], R. Id Betan [2,3], R. J. Liotta [2], N. Sandulescu [2,4]

[1] *Institute of Nuclear Research of the Hungarian Academy of Sciences, H-4001 Debrecen P.O.Box 51, Hungary*

[2] *Royal Institute of Technology, AlbaNova University Center, SE-10691, Stockholm, Sweden*

[3] *Departamento de Fisica, FCEIA, UNR, Avenida Pellegrini 250, 2000 Rosario, Argentina*

[4] *Institute of Physics and Nuclear Engineering "Horia Hulubei", P.O.Box MG-6, Bucharest, Romania*

A new unified shell model scheme is introduced in which the single particle basis is a generalization of the Berggren representation. In the new approach one evaluates simultaneously the contributions of bound single-particle states, Gamow resonances and antibound (virtual) states to processes occuring in the continuum part of nuclear spectra of exotic nuclei..

Long time ago Berggren introduced a complete system of single particle basis functions (Berggren repesentation) composed of bound states, complex energy resonant sates (Gamow states) and a complex continuum of scattering states along a complex contour [1]. For a long time computers were not powerful enough to include the contribution of the contour and only truncated bases were used. The first attempts to use the Berggren representation in the originally suggested form for a shell model desciption of many body resonances in the complex energy plane have been done only recently [2]. An early attempt to generalize the Berggren representation by including antibound states into the basis in RPA calculation was not very succesfull due to the neglect of the complex continuum[3]. In the present work we include antibound poles of the S-matrix into the basis and take into account the complex continuum too in the single particle completeness relation[4]. In this way we use an extended Berggren representation in constructing the shell model (many body) wave function. The unique feature of this approach is that it allows us to study the role of the antibound pole and the corresponding complex continuum separately. In this approach the roles of the antibound states are studied in exotic nuclei being in the drip line region. Our method has a large flexibility in choosing the single particle basis. By changing the single particle contour we can change the members of the Berggren representation used. If the contour is along the real energy axis then we use the standard complete set of the bound states and real energy scattering states. Drawing the contour in the third quadrant of the complex k-plane we can include certain Gamow resonances into the basis. If the contour passes over the negative imaginary k-axis we can also include antibound state and use the generalized Berggren representation.

We applied our model for studying the structure of the halo nuclei ^{11}Li and ^{72}Ca. In both cases we considered two valence neutrons outside cores ^{9}Li and ^{70}Ca, respectively. The effects of the core were simulated by phenomenological Woods-Saxon potentials in which weakly bound antibound poles appeared in the $l = 0$ partial wave. The interaction between the neutrons had a separable form and the strengths of the interaction were adjusted to reproduduce the measured (or estimated) energies of the corresponding ground states. The use of the separable interaction simplified our calculations considerably and we were able to use the dispersion relation for calculating the complex two particle energies (and wave functions) instead of diagonalizing the two particle Hamiltonian. It was found that an antibound state lying close to the threshold has a fundamental importance in building up the halo in the nucleus. We also found that in the ground state of the ^{11}Li the large contribution of the antibound pole was cancelled to a great extent by that of the complex continuum.

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Structure of the neutron-rich nuclei close to N=50 towards ^{78}Ni

D. Verney
GANIL, BP 55027, 14076 Caen Cedex 5, France

F. Ibrahim, O. Bajeat, C. Bourgeois, F. Clapier, E. Cottereau, C. Donzaud, S. Du, M. Ducourtieux, S. Essabaa, S. Galès, L. Gaudefroy, D. Guillemaud-Mueller, F. Hammache, F Hosni, C. Lau, H. Lefort, F. Le Blanc, N. Pauwels, O. Perru, J.C. Potier, F. Pougheon, J. Proust, B. Roussière, J. Sauvage, O. Sorlin
IPN, 91406 Orsay cedex, France

The PARRNe (**P**roduction d'**A**tomes **R**adioactifs **R**iches en **Ne**utrons) experimental program has been part of the recent R&D efforts for the design of the SPIRAL2 project at GANIL. The PARRNe2 set-up installed at IPN-Orsay allows the use of the Tandem as a deuteron driver in order to produce mass separated fission fragments beams. In 2000 an experiment allowed us to measure systematically the yields of the produced nuclei using the PARRNe2 mass separator. The measured yields revealed promising enough to undergo a series of experiments dedicated at studying the structure of nuclei close to magic numbers Z=28 and N=50, Z=50 and N=82 anticipating part of the "very low energy" (i.e. no post-acceleration) program of SPIRAL2. The advantage of such a program is twofold since it allows the preparation, test and improvement of the detection device which will be installed on the SPIRAL2 low energy beam line while providing completely new results of strong physical interest.
Our first works aimed at finding indirect experimental evidence of the doubly magical nature of ^{78}Ni and more generally at studying the influence of the neutron shell closure at N=50 on the structure of the nuclei as one goes far from stability through beta decay experiments. These work can be considered, in a sense, as some kind of continuation of the pioneering work undertaken in this mass region during the late 80's on mass separators operating at high flux neutron reactors like TRISTAN or OSIRIS.
We will report here on two experiments, the first being dedicated at observing the decay of ^{83}Ga (Z=31, N=52) and ^{84}Ga (Z=31, N=53) and the second the decay of ^{81}Zn (Z=30, N=51). Of particular interest in our results are the lines observed in coincidence in the decay of ^{81}Zn which establish the first low lying levels of the singly magical N=50 nucleus ^{81}Ga. This is to our knowledge the present most exotic data on the structure of the N=50 nuclei towards ^{78}Ni. We will compare these experimental results e.g. to a shell model calculation where ^{81}Ga is considered as a ^{78}Ni core + 3 protons using an empirical effective interaction. The position of those first excited levels provides an interesting test for such a representation. At last we will present preliminary results from an internal conversion measurement in ^{78}Ga which aims at determining the parity of the ground state.
This experimental program will by continued on the new ALTO facility at Orsay and in a longer range development on the low energy beam facility of the SPIRAL2 project at GANIL where the study of ^{78}Ni itself will probably be possible.

The surface geometry of exotic nuclei

E. Baldini-Neto[1], B. V. Carlson[1], D. Hirata[2], C. De Conti[3], S. Peru-Desenfants[4], J. F. Berger[4], L. C. Chamon[5]

[1] Depto. de Física, Instituto Tecnológico de Aeronáutica, São José dos Campos, SP, Brazil.
[2] Physics Department, The Open University, Milton Keynes, UK.
[3] Depto. de Física, Universidade Estadual Paulista, Itapeva, SP, Brazil
[4] Centre d'Etudes de Bruyères le Châtel, Bruyères le Châtel, France.
[5] Instituto de Física, Universidade de São Paulo, São Paulo, Brazil.

Contact e-mail: brett@fis.ita.br

New experimental facilities have enabled the measurement of masses, radii and deformations in an ever wider region of the nuclear chart. Studies in this 'terra exotica' have revealed new features such as neutron halos or skins [1] and brought new perspectives to nuclear physics. With the growing number of measurements regarding the radial distributions of neutrons and protons in nuclei far from stability[2, 3], a more detailed analysis of the variations in surface geometry is becoming possible. Theoretically, microscopic mean field models that include pairing are the most appropriate tools for such a study, whether nonrelativistic Hartree-Fock-Bogoliubov (HFB) ones, using a Skyrme or Gogny interaction [4, 5], or relativistic Dirac-Hartree-Bogoliubov (DHB) ones [6, 7]. One extensive study found fair agreement among these models and with the experimental data for masses and rms radii[8]. A common feature of the calculations was a large difference between the rms neutron and proton radii in neutron-rich nuclei. This difference could be due either to a neutron skin or to an extended neutron halo in these nuclei. A recent experimental analysis favors the latter hypothesis, the existence of an extended neutron halo[3].

In this work, we analyze the surface geometry of the isotopic chains of O, Ni, Sn and Pb, using the relativistic DHB approximation and the nonrelativistic HFB-Gogny approximation. We fit a two-parameter Fermi distribution to the neutron and proton densities obtained from the calculations to obtain half-density radii and diffuseness parameters. We found that the half-density radii increase smoothly as the distance from stability increases, confirming the existence of a neutron skin, at least in the theoretical calculations. However, we also found that the diffuseness parameter increases substantially with the distance from stability, although not enough to be considered a halo. The diffuseness parameters display effects of the shell structure, which can be correlated to the binding energy of the single-particle level being filled.

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Recent Study of the ^{3}H(t,p) Reaction Induced by 58-MeV Tritons. Evidences for Excited States in ^{5}H

G.M. Ter-Akopian[a], A.S. Fomichev[a], M.S. Golovkov[a], L.V. Grigorenko[a], Yu.Ts. Oganessian[a], A.M. Rodin[a], S.I. Sidorchuk[a], R.S. Slepnev[a], S.V. Stepantsov[a], R. Wolski[a,b], M.G. Itkis[a], E.M. Kozulin[a], A.A. Bogatchev[a], N.A. Kondratiev[a], A.A. Korsheninnikov[c], E.Yu. Nikolskii[c], V.Bouchat[d], V.Kinnard[d], T.Materna[d], F. Hanappe[d], O.Dorvaux[e], L. Stuttgé[e], P. Roussel-Chomaz[f], W. Mittig[f], A.A.Yukhimchuk[g], V.V. Perevozchikov[g], Yu.I. Vinogradov[g], S.K. Grishechkin[g], and S.V. Zlatoustovski[g]

[a] *Flerov Laboratory of Nuclear Reactions, JINR, Dubna, 141980 Russia*
[b] *Institute of Nuclear Physics, Cracow, Poland*
[c] *RIKEN,Hirosawa 2-1, Wako, Saitama 351-0198, Japan*
[d] *Université Libre de Buxelles, PNTPM,Buxelles, Belgium*
[e] *Institut de Recherches Subatomiques, IN2P3/UniversitéLouis Pasteur, Strasbourg, France*
[f] *GANIL, BP 5027, F-14076 Caen Cedex 5, France*
[g] *RNFC, All-Russian Research Institute of Experimental Physics, Sarov, 607190, Russia*

In 2003 we carried out experiments aimed at the ^{5}H nucleus produced in the ^{3}H+^{3}H reaction, which we studied in kinematical conditions radically different as compared with Refs. [1]. A tritium gas target was cooled to 25K and had thin windows allowing protons, leaving the target at θ_{lab}=173°–155° with energy ≥1 MeV, to be well detected by an annular Si strip detector. This resulted in the selection of ^{5}H nuclei, with excitation energy ≤6 MeV, moving close to zero degree in CM system and having. A particle telescope consisting of 3 annular Si strip detectors and 49 modules of the TOF neutron spectrometer DEMOn detected the triton and, at least, one of the two neutrons emitted at the ^{5}H decay. The arrangement provided for the observation of the ^{5}H decay in the 4π geometry. The detected p-t-n coincidence events carried complete kinematical information about the studied process. Taking into account the selection of kinematical conditions, one comes to a limited choice for the orbital momentum transfer. In addition, the ^{5}H angular momentum tends preferentially to the alignment in the plane perpendicular to the momentum vector of this reaction product.

The complete kinematical reconstruction of the data revealed specific energy and angular correlations peculiar to the ^{5}H decay products. These correlations allow one to identify a broad structure, obtained in the ^{5}H missing mass spectrum at 3-5 MeV, as a mixture of the 3/2$^+$ and 5/2$^+$ states. This structure has been observed also in other experiments [1-3] but some authors [2,3] attributed it to the ground state of ^{5}H. Our identification leaves no doubts about this issue and strongly supports the results of Refs. [1,4] showing that the 1/2$^+$ ground state resonance of ^{5}H is located at a lower energy, at ~1.8 MeV, and is more narrow than the broad structure becoming apparent at 3-5 MeV in the ^{5}H spectrum.

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Matter radii of proton-rich Ga,Ge,As,Se and Br nuclei

G. F. Lima[1,3], A. Lépine-Szily[1], A. C. C. Villari[2], W. Mittig[2], R. Lichtenthäler[1], M. Chartier[2,5], G. Audi[4], N. A. Orr[6], J. C. Angélique[6], J. M. Casandjian[2], A. Gillibert[7], M. Lewitowicz[2], D. J. Vieira[8]

[1] Instituto de Física-Universidade de São Paulo, C.P. 66318, 05315-970 São Paulo, Brazil
[2] GANIL, Boulevard Henry Becquerel, BP 5027, 14021 Caen Cedex, France
[3] FACENS - Faculdade de Engenharia de Sorocaba, C.P. 355, 18001-970 Sorocaba, Brazil
[4] CSNSM (IN2P3-CNRS&UPS), Bâtiment 108,91405 Orsay Campus, France,
[5] University of Liverpool, Department of Physics, Liverpool, L69 7ZE, UK.
[6] LPC, IN2P3-CNRS, ISMRA et Université de Caen 14050 Caen Cedex, France
[7] CEA/DSM/DAPNIA/SPhN, CEN Saclay, 91191 Gif-sur-Yvette, France,
[8] Los Alamos National Laboratory, Los Alamos NM, 87545, USA

Contact e-mail: alinka@if.usp.br

Proton-rich isotopes of Ga, Ge, As, Se and Br had their total reaction cross sections (σ_R) measured at ~55 Mev/nucleon. Root-mean-squared matter radii were determined from Glauber model calculations, which reproduced the experimental σ_R values. For all isotopic series a decrease of the r_{rms} with increasing neutron number was observed. At the same time the matter radii show an anomalously strong increase with Z for several isotonic series. There seems to be no correlation with deformation or with proton separation energy, but with shell effects. The observed features of decreasing matter radii with increasing N, and strong increase in the radii with increasing Z are difficult to explain supposing a larger neutron radius than proton radius.

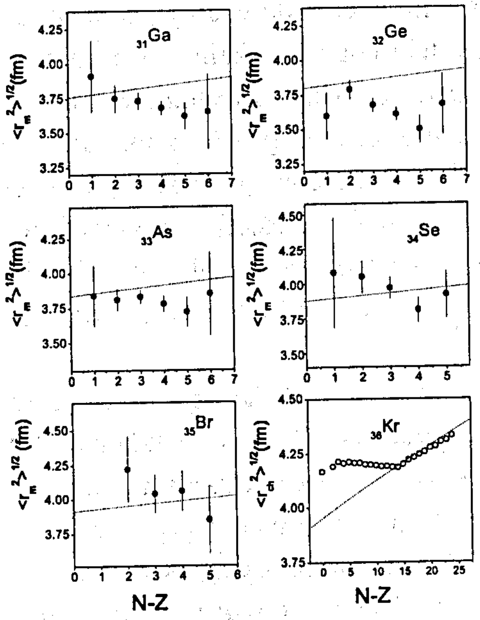

Figure 1: The variation of the r.m.s. matter radii of the proton-rich nuclides with N-Z compared to $R = 0.95A^{1/3}$. The r.m.s. charge radii of Kr are also indicated for comparison.

INTERPLAY BETWEEN FUSION AND BREAKUP PROCESSES: STUDY OF THE $^{6,7}Li + ^{12}C, ^{59}Co$ SYSTEMS

F.A. Souza, N. Carlin, P. Miranda, M.M. de Moura, M.G.Munhoz, A.A.P.Suaide, E.M.Szanto, J. Takahashi and A. Szanto de Toledo
Departamento de Física Nuclear, Instituto de Física da Universidade de São Paulo, C.P. 66318,5315-970 São Paulo, S.P., Brasil

The study of the reaction dynamics involving weakly bound nuclei became one of the most intriguing and challenging problems in low energy Nuclear Physics. The cross section enhancement generally observed at sub-barrier energies is understood in terms of dynamical processes arising from couplings to collective inelastic excitations of the target and/or projectile [1]. However, in the case of reactions where at least one of the colliding nuclei has a sufficient low binding energy so that breakup becomes an important process. Some of the conflicting experimental and theoretical results recently reported in the literature were clarified [2-4]. However the interplay between fusion and breakup processes, which present different behavior depending on the energy regime, still present important opened questions.

The investigation of the $^{6,7}Li$ + ^{12}C, ^{59}Co breakup processes (bu) is used to understand the influence of (bu) on the fusion cross section. These measurements help to establish the effect of the projectile breakup on the fusion process at near-barrier energies and contribute to the determination of how the mass of the target affects the process, as well as the influence of the incomplete fusion yield at energies above the barrier.

It is important to have clear the reference used when an enhancement and/or a suppression is defined. In our case, the reaction cross section has been used Experimental results are compared to prediction of Coupled Channel Calculations.

A final tuning for the coupling of the breakup channel, as well as the correct description of the reaction dynamics, requires the explicit measurement of precise elastic scattering data as well as yields leading to breakup.

The identification of the breakup products has been achieved measuring the three body final state correlations. Coincidence data are used to determine the process Q-value in order to gate exclusively on the projectile breakup channel. Furthermore, the system excitation energy as well as the projectile fragment relative energy are used to identify the exit channel with no ambiguity. Based on those filters, angular correlations are obtained to identify the several processes. This is complemented by measurements of relative energy of the fragments using different rest frame references (like, target, projectile, target + fragment) in order to disentangle the contribution of breakup, incomplete fusion and/or transfer-reemission process. These experimental results are compared to three body kinematics calculations.

Similar data were taken for $^{6,7}Li+^{115}In$. This procedure in unfolding the several light particle emission processes has not been exploited so far in the literature.

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Beta Decay of Odd-Mass As-Ge Isotopes in the Interacting Boson-Fermion Model

L.Zuffi[a], N. Yoshida[b] and S.Brant[c]

[a]Dipartimento di Fisica dell'Università di Milano
and Istituto Nazionale di Fisica Nucleare, Sezione di Milano,
Via Celoria 16, Milano 20133, Italy
[b]Faculty of Informatics, Kansai University, Takatsuki 569-1095, Japan
[c]Department of Physics, Faculty of Science, University of Zagreb, 10000 Zagreb, Croatia

A study of beta decay of nuclei far from the line of stability has two reasons of interest: (i) to test the nuclear model by analyzing the existing data, because the beta-decay rates are very sensitive to the details of the wave functions, and (ii) to provide reliable information for astrophysical applications.

We have analyzed, in the interacting boson-fermion model (IBFM2) [1], the beta decay from As to Ge isotopes of mass numbers $A = 69, 71, 73$ as well as the energy levels and the electromagnetic properties. In our analyses of beta decay, we used, for the transfer operators which construct the Fermi and Gamow-Teller transition operators, both the traditional form [1], which uses fermion states with generalized seniority v less or equal to 2, and the improved transfer operators suggested by J. Barea *et al.*[2], which include extra terms implying the use of the fermion states with v higher than 2. We notice that once the wave functions are determined in IBFM2 calculations of energy levels, the beta decay ratios are obtained in a parameter free calculation.

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Three-body correlations in dissociation ^{6}He

L.V. Chulkov[a,b] for S135 collaboration[a]

a Gesellschaft für Schwerionenforschung (GSI), D–64291 Darmstadt, Germany
b RRC Kurchatov Institute, 123182 Moscow, Russia

The dissociation of ^{6}He in a lead target, where the main contribution is expected to come from the electromagnetic dissociation, has been studied at 240 MeV/u. The three-body correlation distributions have been used for the first time in the analysis. The distributions have been directly compared with the results of calculations using the hyperspherical harmonics method while assuming a dipole mode for the electromagnetic dissociation [1]. The experimental data have also been analysed using a series expansion of the final transition amplitude into hyperspherical functions (HH).

- The complete kinematics data as well as the energy and angular corellations in two different coordinate systems have given new insight into the ground-state structure of the Borromean nucleus ^{6}He.
- The comparison with theoretical calculations based on information on gross properties only was shown to be ambigous and it was also shown that information about all three particles in the final state is essential.
- The experimental continuum energy spectrum and the angular distributions for inelastic scattering of the 240 MeV/u ^{6}He nucleus in a lead target are well described under the assumption of pure dipole dissociation without involving any other reaction mechanisms, while using different theoretical approaches (see Refs. [1, 2, 3]).
- The three-body angular and fractional energy correlations show the importance of both nn and $n\alpha$ final state interactions in the dissociation process. The $n\alpha$ interaction forming the ^{5}He($3/2^-$) resonance is more important than expected from the HH calculations [1]. However, this observation is in line with the results of the complex scaling method [3].
- The analysis of the experimental data gives evidence for a dominant transition of one neutron from the $0p$-shell to the $1s$-shell. This is in agreement with the calculations [1, 3] at low energies, but in the energy region 3-6 MeV, calculations predict a larger contribution from the $0p$-to-$0d$ transition.
- The analysis of the experimental data gives an indication for the existence of a low energy dipole peak with a possible contribution from the ^{6}He resonant state with a $0p_{3/2}1s_{1/2}$ structure at the continuum energy 3 - 6 MeV.

Thus, the new experimental observables pose new questions to the theoretical models for the dissociation of the Borromean nucleus ^{6}He at high energy and give interesting impact on the development in the theory.

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Nuclear Moment Measurements of Spin-Aligned Isomeric Fragments

J.M. Daugas[1], I. Matea[2], M. Hass[3], G. Georgiev[2], R. Astabatyan[4], L.T. Baby[3], D.L. Balabanski[5], G. Bélier[1], D. Borremans[6], F. de Oliveira Santos[2], G. Goldring[3], H. Goutte[1], P. Himpe[6], M. Lewitowicz[2], S. Lukyanov[4], V. Méot[1], G. Neyens[6], Yu.E. Penionzhkevich[4], O. Roig[1], M. Sawicka[2,7]

[1]*CE Bruyères le Châtel, France*
[2]*GANIL, Caen, France*
[3]*The Weizmann Institute, Rehovot, Israel*
[4]*FLNR-JINR, Dubna, Russia*
[5]*St. Kliment Ohridski University of Sofia, Bulgaria*
[6]*University of Leuven, IKS, Leuven, Belgium*
[7]*IEP, Warsaw University, Poland*

Magnetic moment measurements of μs-isomeric states are performed using the well known Time Dependent Perturbed Angular Distribution (TDPAD) method. This technique requires a nuclear spin-aligned system. Previous measurements have been performed using fusion-evaporation like reactions which induce a large amount of spin alignment of the produced residues. But the investigation of nuclei in the neutron-rich side are not possible via this reaction mechanism.

The measurement of magnetic moments using projectile-fragmentation reactions was performed at GANIL facility. In a pioneering experiment the g-factor of ^{67m}Ni and ^{69m}Cu [1] have been extracted. In a recent experiment the same technique was applied in order to measure the g-factor of the isomeric state in ^{61}Fe. The results obtained are in agreement with the expected neutron $g_{9/2}$ structure of ^{61m}Fe.

An important experimental achievement in the study of Electromagnetic moment measurement will be presented. Comparison of the experimental results with shell-model and mean field calculations will be discussed.

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New Structure Problems in Light Exotic Nuclei

H. Sagawa
Center for Mathematical Sciences, University of Aizu,
Aizu-Wakamatsu, Fukushima 965-8580 Japan

We study the ground state and excited states of C isotopes using microscopic models. A deformed Hartree-Fock (HF) + BCS model with Skyrme interactions is performed to study the isotope dependence of deformation properties of C, N and Ne isotopes as a manifestation of Jahn-Teller effect. It is shown that shallow deformation minima appear in both the oblate and the prolate sides in ^{16}C, ^{17}C and ^{19}C having almost the same binding energies. We discuss also shell model calculations to study magnetic moments, electric dipole and quadrupole transitions of B, C and N isotopes. We show clear empirical evidence of the isospin dependence of the effective charges of quadrupole moments in B isotopes in both proton and neutron drip line nuclei. It is also pointed out that the isotope dependence of quadrupole moments and magnetic g-factors in the odd C isotopes will be useful to find out the deformation and unknown spin-parities of the ground states of these nuclei. The low-lying electric transitions of C and Ne isotopes are also discussed.

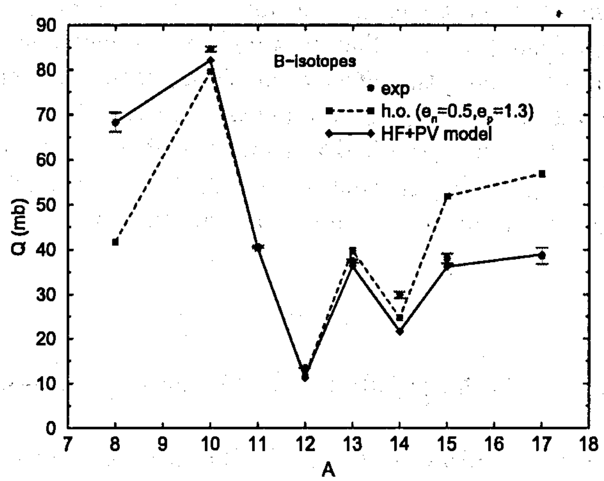

Figure 1: Q-moments of B isotopes. The solid line is obtained by using the core polarization charges of microscopic Hartree-Fock and particle-vibration coupling model, while the dashed line is the results of constant effective charges. The shell model wave functions are calculated with Warburton-Brown effective interaction. The references of experimental data can be found in ref. [1]

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Nuclear-moment measurements of light neutron-rich nuclei

H. Ueno[A], K. Asahi[A,B], D. Kameda[B], H. Miyoshi[B], A. Yoshimi[A], K. Shimada[B], G. Kato[B], S. Emori[B], G. Kijima[B], M. Tsukui[B], H. Watanabe[A], T. Haseyama[A], Y. Kobayashi[A], M. Ishihara[A]

[A] *RIKEN, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan*
[B] *Department of Physics, Tokyo Institute of Technology, Meguro-ku, Tokyo 152-8551, Japan*

From the systematic study on the fragment-induced spin-polarization phenomena, it has been revealed that fragments can be spin-polarized as a function of the outgoing momentum and emission angle of fragments. The mechanism of the fragment-induced spin-polarization is essentially related to the fact that a portion of the projectile to be removed through the fragmentation process has non-vanishing angular momentum due to the internal motion of nucleons. From the general feature of the fragmentation reaction, essentially any fragments can be produced and polarized irrespective of their chemical properties.

Based on the β-NMR method with the spin-polarized radioactive-isotope beams [1], we have been conducting a series of experiments at RIKEN to measure magnetic moments and electric quadrupole moments of light unstable nuclei [2]. So far the measurements have been made in the region of neutron-rich *p-sd* shell nuclei. The obtained experimental nuclear moments have been shown quite effective in discussing the effect of neutron excess on their nuclear structure, where we discussed the deviation of magnetic moments from the Schmidt value [3] and the isospin dependence of the effective charges [4]. To extend the observation into the neutron-rich *sd*-shell nuclear region, we are planning the measurements for those nuclei. In this work we report on the recent progress in the nuclear-moment measurements and analyses.

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Structure of the heavy Ca isotopes and effective interaction in the sd-fp shell

F. Maréchal,[1] F. Perrot,[1] Ph. Dessagne,[1] J.C. Angélique,[2] G. Ban,[2] P. Baumann,[1]
F. Benrachi,[3] C. Borcea,[4] A. Buta,[4] E. Caurier,[1] S. Courtin,[1] S. Grévy,[2] C. Jollet,[1]
F.R. Lecolley,[2] E. Liénard,[2] G. Le Scornet,[5] Ch. Miehé,[1] F. Negoita,[4] F. Nowacki,[1]
N. Orr,[2] E. Poirier,[1] M. Ramdhane[3] and I. Stefan[4]

[1] *Institut de Recherches Subatomiques, BP 28 F-67037 Strasbourg Cedex 2, France*
[2] *Laboratoire de Physique Corpusculaire, IN_2P_3-CNRS, F-14050 Caen Cedex, France*
[3] *University of Constantine, Constantine, Algeria*
[4] *Institute of Atomic Physics, IFIN-HH, Bucharest, Romania*
[5] *ISOLDE Collaboration, CERN, CH-1211 Geneva, Switzerland*

For many years, β-decay experiments proved to be a powerful tool to study nuclear systems. During the last decade, the study of unstable nuclei came to the forefront of nuclear physics research and to this respect, β-decay measurements continue to provide a wealth of information. The $A \geq 50$ calcium isotopes are of interest in regards of their nuclear structure, particularly in terms of their implication on the determination of the nucleon-nucleon interaction in the *sd-fp* shell.

Calcium isotopes can improve our understanding of the neutron-neutron interaction in the *fp* shell. Because of the $Z=20$ shell closure, the lowest energy states in even Ca isotopes are of even parity. These natural parity states are populated either by forbidden transitions or indirectly (radiative deexcitation of populated Gamow-Teller states). Their properties (E_x, decay modes) are governed by the neutron-neutron monopole interaction in the *fp* shell. They are therefore indicative of the neutron sub-shell sequence, and of the evolution of the effective interaction between valence neutrons.

As for the excitation of the lowest Gamow-Teller states in heavy Ca isotopes, it depends strongly on the proton-neutron interaction across the *sd-fp* shell. Because an energy around 4 MeV is necessary to excite these unnatural parity states, one expects the Gamow-Teller states within reach of β decay to be located close to or above the neutron separation energy, giving rise to a large delayed neutron emission. Because of the simplicity of their wave functions, the Ca isotopes correspond to the optimal choice to fix these two-body matrix elements in the $A=50$ mass region. For that, any measurement will have to rely on a very efficient neutron detection.

Little has changed in our knowledge of the heavy potassium decay properties since the first experiments performed at CERN/PS [1] and ISOLDE/SC [2,3], yielding information on half lives, delayed neutron emission and some low-lying states in heavy calcium isotopes. To bring new insights in the description of the $A\sim 50$ nuclei, we have undertaken a study of the neutron-rich calcium isotopes through the β decay of the corresponding neutron-rich potassium precursors. The experiments were performed at CERN using the online mass separator ISOLDE and a very efficient β, n and γ detection system.

We will present the results obtained at ISOLDE for the neutron-rich ^{52}Ca and ^{53}Ca isotopes. An introduction on the physics motivations will be given, the experimental setup and analysis methods will be described and the results presented.

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Exploring light neutron rich nuclei via the (^{7}Li,^{7}Be) reaction

F.Cappuzzello[a], A.Cunsolo[a,b], D.Beaumel[c], S.Fortier[c], A.Foti[b,d], A.Lazzaro[a,b], H.Lenske[e], C.Nociforo[a], S.E.A.Orrigo[a,b], J.S.Winfield[a],

a. INFN - Laboratori Nazionali del Sud, Catania, Italy
b. Dipartimento di Fisica e Astronomia, Università di Catania, Italy
c. Institut de Physique Nucléaire, IN2P3-CNRS, Orsay Cedex, France
d. INFN - Sezione di Catania, Catania, Italy
e. Institut für Theoretische Physik, Universität Giessen, Giessen, Germany

Far from the β stability the standard representation of nuclei, based on the assumption of mean field dynamics, turns out to be often inadequate. From a theoretical point of view the explanation of observed phenomena has been a precious benchmark supporting a strong development of refined theories based on the microscopic description of nuclei. In this context particular attention has been paid to the description of special correlations such as the Dynamical Core Polarisation (DCP), i.e. the coupling of the loosely bound valence nucleon to the excited states of the core. A microscopic treatment of the DCP for example, has been demonstrated crucial to explain the well known inversion between $2s_{1/2}$ and $1p_{1/2}$ orbitals in ^{11}Be ground state [1].

Experimental signatures of the DCP correlations are found in charge exchange reactions. One of the most striking observation is the appearance of very narrow resonances embedded in the continuum (BSEC), where the valence nucleon remains for long time bound to the core even when the energy transferred to the whole nucleus by the direct process would be enough to immediately remove it. Particularly interesting for this phenomenology is the exploration of nuclei for which an integer number of α particles is coupled to three extra neutrons. Examples are represented by ^{7}He, ^{11}Be, ^{15}C, ^{19}O and heavier systems. For these nuclei one can assume that single particle excitations at low energy are mainly due to the three valence neutrons. The pairing of two of the three neutrons to the inner core gives an effective soft core, which can be dynamically polarized, also at low excitation energy, by the interaction with the remaining neutron.

A systematic study of these and other phenomena over the above mentioned chain has been started by our group in the recent years via the (^{7}Li,^{7}Be) reaction at 56 MeV incident energy at the IPN-Orsay. The ^{11}Be and ^{15}C energy spectra were measured via the ^{11}B(^{7}Li,^{7}Be)^{11}Be and ^{15}N(^{7}Li,^{7}Be)^{15}C reactions [2]. In addition the ^{7}He and ^{19}O spectra have been measured with the same technique and the analyses are in progress. Preliminary results will be shown at the Conference.

The observed spectra show the presence of narrow resonances, several MeV beyond the neutron emission threshold together with a broad bump connected to the SDR mode. Microscopic QRPA calculations for ^{11}Be and ^{15}C, fully accounting for the 1p-1h configuration with average inclusion of 2p-2h ones, demonstrate that similar states cannot be described in a similar scheme. More sophisticated calculations in the framework of DCP model [3] indicate the BSEC nature of these resonances.

Conclusive results are also obtained for the reaction mechanism [4] trough a microscopic analysis of the angular distributions and the spin flip probabilities for the ^{11}Be and the ^{15}C cases. The calculations are able to well reproduce both the angular distributions and the spin flip probabilities, showing the negligible role of two-step mechanisms and the dominance of nucleonic spin transfer at these energies.

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Comparative analysis of the ^{178m2}Hf isomer yield at reactions with different projectiles

S.A. Karamian

Joint Institute for Nuclear Research, Dubna, Moscow region, 141980, Russia

The triggered release of the energy stored in nuclear isomers is promising for the creation of pulsed sources of gamma-radiation. For instance, the high-spin $K^{\pi}=16^{+}$ ^{178m2}Hf isomeric state stores a specific energy of about 1.3 MJ/mg with a half-life of 31 years. For applicative purposes and extensive studies on the trigger mechanisms one needs to produce isomers in an amount of milligrams, or even more in extreme. As is known up to now, the largest quantity of the ^{178m2}Hf material was produced in Los-Alamos with 800 MeV protons at the high-current accelerator. The advantage of this method was a possibility to accumulate the isomer as by-product in a massive Ta beam-dump during the operation of the accelerator for other experiments. However, the produced isomeric material contains very high activity of other radionuclides, and the background radiation remains high even after chemical isolation of the Hf fraction. The productivity of the spallation reactions with protons at intermediate energies has been systematically studied for the Ta, W and Re targets at Dubna 660 MeV synchrocyclotron in Ref. [1]. Some recommendations, how to optimize the spallation method have been worked out. However, basic disadvantage of a high contaminating activity is not yet overcome.

The ^{176}Yb (^{4}He,2n)^{178m2}Hf reaction was investigated in Ref. [2], and much better quality sources were produced using a 36 MeV ^{4}He-ion beam and the following chemical processing of the irradiated Yb targets with the mass-separation of ^{178}Hf nuclides at the end. The problem of isomer separation from the stable ^{178}Hf is not yet solved. The method of (^{4}He,2n) reaction has still the disadvantage of much lower productivity as compared to the spallation. So, it can be used for the high-preciseness physical experiments with the ^{178m2}Hf source, but not for the applications. There is known in literature also the producer reaction of ^{179}Hf(n,2n)^{178m2}Hf at a 14 MeV neutron beam. The cross-section of the latter reaction is reasonably good, but the flux of fast neurons generated in the ^{3}H(^{2}H,n)^{4}He reaction is typically not high. Neutron energies of $E_n>10$ MeV are requested for (n,2n) reaction and they are represented in the reactor spectrum with very low yield. Recently, we made an attempt to detect the production of ^{178m2}Hf in the reactor irradiations of the ^{nat}Hf target assuming some reasonable yield due to the ^{178}Hf(n,n$'$) reaction with the neutrons of fission spectrum. However, only upper limit of the cross-section is deduced today because of high activity of other products. More sensitive measurements are expected after longer cooling time. The production of ^{179m2}Hf in (n,n$'$) reaction is nevertheless detected.

The yield of ^{178m2}Hf has been successfully observed [3] in the Ta target exposed to a 4.5 GeV bremsstrahlung at Yerevan synchrotron and newly analyzed using the γ-spectroscopy technics at Dubna. At optimum irradiation scheme, the evaluated productivity turns out to be higher than at the (^{4}He,2n) reaction and lower than at the spallation. However, for definite conclusion, the total cost and radiational safety conditions should also be compared, as well as the technical restrictions on the maximum beam current of electrons or protons.

The yields of all known reactions are compared in their productivity for the accumulation of the ^{178m2}Hf isomer. However, the general conclusion can be formulated that extraordinary high cross-section is not found for any reaction among investigated. This means, that the idea to accumulate grams of the ^{178m2}Hf isomer requires for realization the special high-power systems for the production and use of very dense fluxes of nuclear projectiles. Parameters of the standard research facilities are not enough for this purpose.

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Probing ^{6}He structure from proton elastic and inelastic collisions

R. Crespo*

Departamento de Física, Instituto Superior Técnico,

Taguspark, 2780-990, Oeiras, Portugal

One of the major complexities associated with the study of halo nuclei is the interplay between the structure and the scattering framework.

When describing the scattering of stable from halo nuclei it is crucial to handle its many-body character in order to extract reliable structure information about the halo system [1]. Within any multiple scattering formalism, the fundamental ingredient is the many body scattering amplitude of the projectile on a bound target subsystem. This, can be used within the context of a multiple scattering of the total transition amplitude [1]. Due to the complexity of the many body operator, suitable approximations needed to be performed in order to express the problem in terms of the scattering from the projectile by each of the target subsystems. The effect of these different impulse approximations to the scattering formalismon the calculated elastic scattering cross sections are studied for proton scatering from ^{6}He at 700 MeV/u [2].

Inelastic scattering is a useful process to study the excitation modes of Halo nuclei which is espected to single particular multipolar excitations. It is fair to say that our knowledge of the Borromean resonant continuum sea is today very unconclusive. We shall also present a study of inelastic scattering of ^{6}He at 70 MeV/u [3].

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*Work in collaboration with I.J. Thompson and A.M. Moro

Spin-Isospin Properties of Nuclei and Neutrino-Nucleus Reactions

Toshio Suzuki

Department of Physics, College of Humanities and Sciences, Nihon University Sakurajosui 3-25-40, Setagaya-ku, Tokyo 156-8550, Japan

Recently, the $\tau\tau\sigma\sigma$ interaction is found to play an important role in shell evolution in p-shell nuclei[1]. The spin-isospin component of the interaction has direct relevance to spin-isospin properties of nuclei such as Gamow-Teller (GT) transitions and magnetic moments. Using a modified shell model Hamiltonian with enhanced spin-flip neutron-proton interaction and single-particle energy difference between $0p_{1/2}$ and $0p_{3/2}$ shells, better agreement with experimental values is obtained systematically for the GT transitions and magnetic moments in most of p-shell nuclei[1].

We here investigate low energy neutrino-nucleus reactions, which involve GT and spin-dipole transitions. We study, for example, ^{12}C (ν_e, e^-) ^{12}N reaction[2]. We discuss the effects and consequences of the improvement on the description of the spin-isospin properties obtained for the p-shell nuclei. The effects of the tensor interaction on the magnetic moments, spin-dipole transitions as well as on the neutrino-nucleus reactions are also discussed.

We next study the spin-isospin properties of heavier nuclei such as ^{208}Pb and ^{208}Pb (ν_e, e^-) ^{208}Bi reaction[3]. The quenching and spreading of the GT strength due to the coupling to the 2p-2h configurations are pointed out to be important for the reaction. Neutral current induced reaction, ^{208}Pb (ν, ν') ^{208}Pb, is also investigated for neutrinos from supernovae.

Study on nuclei near drip-lines, where the degree of quenching of the spin-isospin properties can vary considerably, will also be reported.

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STRUCTURE OF LIGHT NEUTRON-RICH ODD Z NUCLEI

Z. Dlouhý, D. Baiborodin, J. Mrázek, G.Thiamová and J.Vincour
Nuclear Physics Institute ASCR, CZ-25068 Řež, Czech Republic
for the GANIL-Orsay-Dubna- Řež -Bucharest collaboration

The nuclear shell model has been successful in the description of various aspects of nuclear structure for nuclei near the valley of stability, and has enabled to involve the magic numbers that has become very important quantities reflecting the nuclear structure. Near the neutron dripline, however, the breaking of magicity has been observed at the N=20 shell closure where an "island of inversion" in shell ordering has been established as well at N=8 where the doubly magic ^{10}He nucleus has been confirmed to be unbound. The study of nuclei far away from the valley of stability is motivated by the efforts to understand the way that single particle energies evolve when one goes from stable nuclei to the neutron and proton drip lines. This would provide us by more precise predictions of the limit of existence of nuclear species, the information on new magic numbers as well as new halo nuclei. However, in the case of light nuclei, the rapid change in the location of the neutron drip line near the O and F species is fully not yet understood. The neutron drip line seems to be reached at N=16 for O isotopes whereas for the neighbouring F isotopes, it extends up to N=22. Though some theoretical calculations predict the existence of new neutron magic numbers N=6, 16 and 34 [1,2] until lately, no experimental evidence about new magic numbers has been obtained.

Recently, two experimental surveys [3,4] resulting in an appearance of the neutron magic number N=16 have been published. We have surveyed [3] experiments performed at GANIL from the point of view of two-neutron separation energies for determination of neutron shells in this region. On the other hand, Ozawa et al. [4] have inspected the information on one neutron separation energies and interaction cross section $\sigma_{(I)}$ measured at RIKEN. Kanungo et al. [5] has published systematics of the beta decay Q-values indicating new regions of shell closures at N=6, 16 and also near 32. We have also confirmed the magicity at N=16 from the analysis of a derivate of the two neutron separation energy [6] and the magicity at N=14 and 16 from the analysis of energies of first excited states in heavy oxygen isotopes [7].

The mass measurement of neutron-rich nuclei at GANIL [8] has enabled us to perform the analysis of triton separation energies of light neutron-rich odd-Z and even-Z nuclei. The deduced separation energies $S_{(t)}$ show the tendency to form the nuclear halo adding a triton to new doubly magic even Z ^{8}He and ^{24}O nuclei forming ^{11}Li and ^{27}F, respectively. An appearance of other neutron-halo odd-Z nuclei in this region, and the connection between doubly magic even-Z nuclei and neutron halo odd-Z nuclei is discussed.

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CHANGE OF ISOVECTOR STRENGTH OF EFFECTIVE INTERACTION FOR LIGHT NEUTRON–RICH NUCLEI

Š. GMUCA

Institute of Physics, Slovak Academy of Sciences, SK-845 11 Bratislava, Slovakia

Abstract

Mean field models are known to fail to predict ground state properties of light neutron–rich nuclei satisfactorily. To elucidate a problem, the relativistic mean field was used for systematic calculations of isotonic chains with neutron numbers N=8,16,20 and 28 from the proton to neutron drip lines. To achieve an agreement with experimental binding energies an enhancement of the isovector coupling strength was observed for nuclei with an extreme N/Z ratio (N/Z≥2). Its phenomenological dependence on N/Z was examined, and possible microscopic explanations of its origin were discussed. The role of an isospin dependence of a bulk nuclear matter symmetry energy coefficient for calculation of drip–line nuclei is stressed rather than its density dependence.

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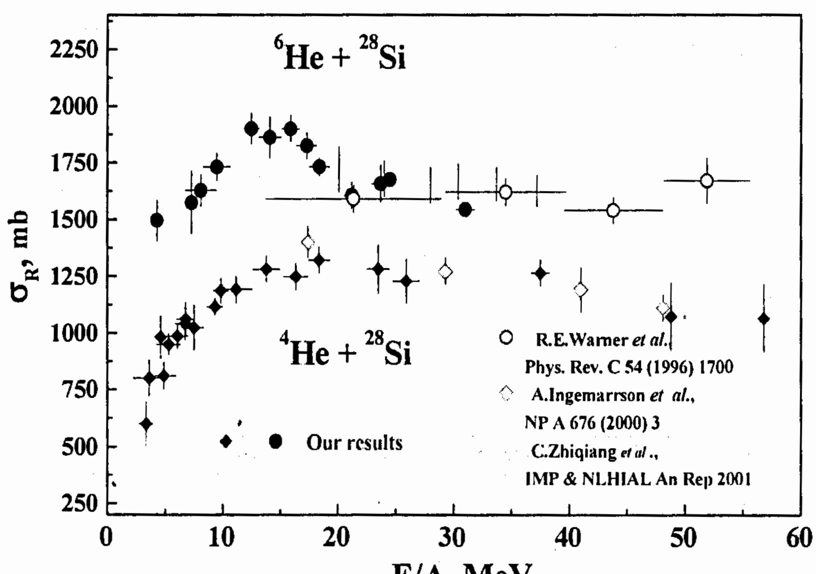
Energy dependence of total reaction cross section of the $^{4,6}He$ - ^{28}Si interaction at 5-30 AMeV

Yu.G. Sobolev [a], Yu.E.Penionzhkevich [a], A.Bialkowski [b], A.Budzanowski [b], R.Kalpakchieva [a], S.V.Khlebnikov [c], A. Kugler [d], A.A.Kulko [a], V.F. Kushniruk [a], K.A. Kuterbekov [e], I.V. Kuznetsov [a], S.P.Lobastov [a], S.M.Lukyanov [a], V.A.Maslov [a], I.Skwirchinska [b], N.K.Skobelev [a], W.H. Trzaska [c], V.Yu. Ugryumov [a], T.K Zholdybaev [e]

[a] *Joint Institute for Nuclear Research, Dubna, Russia*
[b] *H.Newodniczanski Institute of Nuclear Physics, Krakow, Poland*
[c] *University of Jyvaskyla, Jyvaskyla, Finland*
[d] *Institute of Nuclear Physics, Rez, Czech Republic*
[e] *Institute of Nuclear Physics, Alma-Ata, Republic of Kazakhstan*

One of the most exciting recent events in nuclear physics has been the discovery of extended neutron distributions in exotic neutron-rich nuclei such as e.g. ^{6}He via total reaction cross section (σ_R). A σ_R as a function of the energy shows a remarkable sensitivity to the halo structure of the exotic nuclei due to large nucleon-nucleon cross section at low energies [1].

The energy dependence of σ_R for the ^{4,6}He + Si at energies up to 5 AMeV was measured by the transmission technique. We used a silicon multilayer telescope in our experiments. Each detector in the telescope had its own destination. The first two telescope detectors were used to separate particles with an energy E, which consequently could induce various nuclear reactions in the next detector (active target) and hence change their deposition energy. Thus we may separate reaction products from unreacted particles.



Values of the measured σ_R are shown in the figure as filled symbols. It's seeing different behavior of ^{4}He and ^{6}He excitation functions. In the case of ^{6}He there is a wide maximum around 15 AMeV. Known data from literature at higher energies is presented as open points. It was observed the enhancement in cross section ~30% for ^{6}He in the framework of Kox systematic [2]. According to a formulae $\sigma_R(^{6}\text{He}) - \sigma_R(^{4}\text{He})$ the value of two neutron removal cross section were deduced.

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Bound excited states in ^{27}F

Z. Elekes,[1,*] Zs. Dombrádi,[2] A. Saito,[3] N. Aoi,[1] H. Baba,[3] K. Demichi,[3] Zs. Fülöp,[2] J. Gibelin,[4] T. Gomi,[3] H. Hasegawa,[3] N. Imai,[5] M. Ishihara,[1] H. Iwasaki,[5] S. Kanno,[3] S. Kawai,[3] T. Kishida,[1] T. Kubo,[1] K. Kurita,[3] Y. Matsuyama,[3] S. Michimasa,[5] T. Minemura,[1] T. Motobayashi,[1] M. Notani,[5] T. Ohnishi,[5] H.J. Ong,[5] S. Ota,[6] A. Ozawa,[1] H.K. Sakai,[3] H. Sakurai,[5] S. Shimoura,[5] E. Takeshita,[3] S. Takeuchi,[1] M. Tamaki,[5] Y. Togano,[3] K. Yamada,[3] Y. Yanagisawa,[1] and K. Yoneda[1]

[1]*The Institute of Physical and Chemical Research, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan*
[2]*Institute of Nuclear Research of the Hungarian Academy of Sciences, P.O. Box 51, Debrecen, H-4001, Hungary*
[3]*Rikkyo University, 3 Nishi-Ikebukuro, Toshima, Tokyo 171, Japan*
[4]*Institut de Physique Nucléaire, 15 rue Georges Clemenceau 91406 Orsay, France*
[5]*University of Tokyo, Tokyo 1130033, Japan*
[6]*Kyoto University, Kyoto 606-8501, Japan*

One of the most fascinating questions of nuclear structure physics is where the neutron dripline lies, and more importantly, why it is there. In this respect, an intriguing problem is that the dripline of fluorine isotopes is located at least 6 neutrons farther than that of the oxygen isotopes [1]. The naive assumption - according to which adding a proton to the oxygen nuclei makes the $\nu d_{3/2}$ state bound - can explain the bound nature of fluorine isotopes up to ^{29}F only. To make another pair of neutrons bound some kind of shell breaking mechanism like multi-particle-multi-hole excitations across major shells has to be assumed, since the last 2 neutrons above the $N = 20$ shell closure are far unbound in the spherical limit [2]. Neutron 2-particle-2-hole excitations across the N=20 shell are well known in this region, as they form the ground state of $^{32}_{12}Mg$ or $^{30}_{10}Ne$ nuclei. Whatever mechanism makes ^{31}F particle-bound, its traces should be visible in other fluorine nuclei, too. For instance, in ^{27}F the *psd* shell model [3], which can account for the properties of light fluorine nuclei, predicts the first excited state with spin $1/2^+$ at 2.0 MeV energy, much higher than the neutron separation energy of 1.3(4) MeV. On the other hand, some shell breaking or dripline effects acting in ^{31}F can make the energy of this state so low that it falls below the separation energy. According to recent Monte-Carlo shell model calculations it is enough to allow for the possibility of neutron cross shell excitations to have a bound excited state in ^{27}F[2]. To explore the traces of the mechanism which is expected to be responsible for the existence of ^{31}F in lighter fluorine nuclei, and to gain more information on its properties we have searched for bound excited states in ^{27}F.

We have carried out the experiment at RIKEN Accelerator Research Facility using (p,p') process in inverse kinematics. We observed 2-2 γ-ray lines in $^{25,26,27}F$, and assigned them to decays of 2-2 excited states observed for the first time in ^{27}F. The existence of a bound excited state in ^{27}F is a sign for breaking down of the *psd* shell model and is consistent with the Monte-Carlo shell model [2] which contains a special neutron shell breaking mechanism. The presence of an additional bound state is puzzling. A new mechanism, such as lowering of a negative parity state through unusual correlations of proton and neutron cross-shell excitations or some sort of exotic clusterization should be considered to understand this unexpected phenomenon.

* On leave from Institute of Nuclear Research of the Hungarian Academy of Sciences, P.O. Box 51, Debrecen, H-4001, Hungary

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Decoupling of valence neutrons from the core in ^{16}C

Z. Elekes,[1,*] Zs. Dombrádi,[2] A. Krasznahorkay,[2] H. Baba,[3] M. Csatlós,[2] L. Csige,[2] N. Fukuda,[1] Zs. Fülöp,[2] Z. Gácsi,[2] J. Gulyás,[2] N. Iwasa,[4] H. Kinugawa,[3] S. Kubono,[5] M. Kurokawa,[5] X. Liu,[5] S. Michimasa,[5] T. Minemura,[5] T. Motobayashi,[1] A. Ozawa,[1] A. Saito,[3] S. Shimoura,[5] S. Takeuchi,[1] I. Tanihata,[1] P. Thirolf,[6] Y. Yanagisawa,[1] and K. Yoshida[1]

[1] *The Institute of Physical and Chemical Research, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan*
[2] *Institute of Nuclear Research of the Hungarian Academy of Sciences, P.O. Box 51, Debrecen, H-4001, Hungary*
[3] *Rikkyo University, 3 Nishi-Ikebukuro, Toshima, Tokyo 171, Japan*
[4] *Tohoku University, Sendai, Miyagi 9808578, Japan*
[5] *University of Tokyo, Tokyo 1130033, Japan*
[6] *Ludwig-Maximilians-Universität München, D-85748 Garching, Germany*

Due to the strong proton–neutron interaction, the proton and neutron distributions are strongly correlated in nuclei. Although the neutron distribution is determined with a lower accuracy compared to the charge distribution, small differences could be revealed between them except for some specific cases. A large difference in radial distributions have already been found in halo nuclei which raises the possibility of the difference between proton and neutron deformations. The deformations can be characterized by several parameters, the most model independent ones are the transition matrix elements or transition probabilities. Determination of the proton and neutron contributions to the excited states can yield information on the nature of the ground state proton and neutron deformations [1].

Recent calculations [2] suggest different deformations for proton and neutron distributions in carbon nuclei, as well. The proton density is expected to be oblate, while the neutron densities vary with neutron numbers and a prolate shape is predicted for ^{16}C.

Our aim was to search for these possible different proton and neutron contributions to excitation of the first 2^+ state in ^{16}C. For this purpose, we applied the Coulomb–nuclear interference method [3, 4]. In certain conditions of energy and projectile–target combination, both interactions play crucial roles and as a consequence of their interference, a clear minimum is expected in the inelastic scattering cross section. From the place and depth of the minimum, the ratio of the charge and mass deformations can be determined. Using this information and the absolute magnitude of the cross section of the process, both the proton and neutron transition matrix elements can be deduced from a single experiment. In the present study, the angular distribution of the radioactive ^{16}C nuclei scattered on a ^{208}Pb target has been measured in RIKEN at the energy of 52.7 A·MeV, where the interference conditions mentioned above are fulfilled.

We have extracted the charge and mass deformations in ^{16}C from the inelastic angular distribution with Coulomb–nuclear interference. The results lead to very low B(E2) value of 0.28 W.u. and very large $M_n/M_p=7.6 \pm 1.7$. These values show that the 2_1^+ state in ^{16}C practically consists of pure valence neutron excitations. The polarization of the closed ^{14}C core by the valence nucleons is extremely weak, which suggests that the two valence neutrons are basically decoupled from the core. This unusual nature may provide a new aspect of decoupling of neutron and proton distributions in unstable nuclei.

Our results are compared with two other experiments performed in RIKEN. One of them measured the lifetime of the first 2^+ state in ^{16}C and deduced the B(E2) value [5]. The other one determined the cross section of (p,p') reaction in inverse kinematics [6]. From these two experiments, the M_n/M_p ratio could also be determined to be 7.9 ± 1.5 which is in a good agreement with our value.

* On leave from Institute of Nuclear Research of the Hungarian Academy of Sciences, P.O. Box 51, Debrecen, H-4001, Hungary

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Investigation of multipolarity for some γ-transitions of ^{151}Eu

M. Metskhvarishvili, Z. Miminoshvili, R. Metskhvarishvili, I. Metskhvarishvili, N. Khazaradze, L. Khorbaladze, M. Elizbarashvili

By means of double focusing sector type magnetic beta-spectrometer with 0.2% resolution and useful solid angle of 0.3% from 4π (in the case of $1\times30mm^2$ sizes of radioactive source and inlet opening), arrangement ranges of the ^{151}Eu 153.6keV energy conversion lines was investigated for determination of multipolarity of this transition. Two groups of K, L_I, L_{II}, L_{III} conversion lines are observed. From them one group connects to the 153.6keV γ-transition and another to 153.3keV γ-transition. 153.3keV energy conversion lines were not observed earlier. Experimental ratios of internal conversion coefficients (ICC) on L_I, L_{II} and L_{III} shells for both γ-transitions were determined. Analogous theoretical significance was received from the table of [1]. Results are given in the table. On the basis of this data are established that 153.6keV γ-transition is the mixture of M1 and E2 multipoles. Amount of admixture *a* of E2 multipole is (13±2)%. 153.3keV γ-transition is mixture of M2 and E3 miultipoles with admixture of E3, amounting (6±2)%. This transition happens between the levels of 349.8 and 196.5keV [2]. Quantum characteristics of 196.5keV level equals $(3/2)^+$ by [2]. Established by us multipolar compound of 153.3keV (M2+E3) γ-transition enables us to confirm that spin of 196.5keV level must be $(5/2)^+$.

Nuclei	E_γ	ICC ratio	Experiment	Theory		*a*%	Multipolarity
				M1	E2		
^{151}Eu	153.6	L_I/L_{II}	5.1±0.7	12.6	0.561	13±2	M1+(13±2)%E2
		L_I/L_{III}	6.4±0.6	72.4	0.622		
				M2	E3		
	153.3	L_I/L_{II}	4.4±0.2	8.13	0.105	6±2	M2+(6±2)%E3
		L_I/L_{III}	4.2±0.3	7.96	0.135		

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A global non-local optical potential applied to exotic and weakly bound nuclei interactions

Marcos Alvarez

Over the last years some advances have been reached toward obtaining a fundamental free parameter nuclear potential [1-6]. In this work is shown the study based mainly on the Pauli effects (nonlocality and block) associated in the optical model framework to describe respectively the real and imaginary parts of the nuclear potential. The analysis has been extended to interactions including weakly bound and exotic nuclei.

Data have been selected and analyzed in very different energy regions. It is well known that the analysis of low-energy data, close to the Coulomb barrier, is sensitive to a surface region of the potential around the absorption radius. Intermediate energy data refer to refractive scattering, which is sensitive to a wider radial region. The imaginary potential reflects as a function of energy a large variety of physical effects: channel couplings, reactions with various Q-values, dispersion effects etc. Therefore, one could expect that different descriptions may be required for certain regions of mass and energy. Notwithstanding the comments above, it has been demonstrated that it is possible to obtain a reasonable data description just by assuming the non-local model for the real part of the optical potential in conjunction with a very simple model for the imaginary part [6]. This fact is due to the greater sensitivity of the Optical Model calculations to the real part of the interaction, which has been well accounted for by the non-local model. The results suggest using the present model to get reasonable estimates for heavy-ion elastic scattering and reaction cross-sections. Extension of these findings to halo-nuclei was pursued and is presented.

The non-local potential [1-4] for the real part of the nucleus-nucleus interaction has been successfully used with the same validity at low and high energies [1-6] besides presenting an expressive agreement with elastic and inelastic scattering, transfer and fusion data [8,9].

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PARTICLE-NUMBER PROJECTION IN THE T=1 NEUTRON-PROTON PAIRING

N.H. ALLAL[(1,2)], M. FELLAH[(1,2)], M.R. OUDIH[(1)] and N. BENHAMOUDA[(1)]

[(1)]Laboratoire de Physique Théorique, Faculté de Physique, USTHB
BP 32, El-Alia, 16111 Bab-Ezzouar, Alger, ALGERIA
[(2)] Centre de Recherche Nucléaire d'Alger, COMENA
BP399 Alger-Gare, Alger, ALGERIA .

It is well established that the inclusion of the neutron-proton (n-p) pairing is necessary in nuclei such that $N \approx Z$. The aim of this contribution is to present a particle-number projection method for the study of the T=1 n-p pairing.
The usual n-p BCS wave function is simultaneously projected on both the good neutron and proton numbers using a discrete projection operator [1]. An explicit projected wave-function is thus obtained. It allows one to deduce the expectation value of any physical observable that appears then as a limit of convergent sequence.

The influence of the projection on the particle-number fluctuations and the energy of the system is studied within the Richardson schematic model [2]. It is shown on the one hand that the convergence of the method is very fast and on the other hand that the projection significantly reduces both the particle-number fluctuations and the energy value.

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Effective interaction generated by the Pauli exclusion principle in collisions of the light neutron-rich nuclei

G. F. Filippov and Yu. A. Lashko

Bogolyubov Institute for Theoretical Physics, Kiev, Ukraine

Contact e-mail: lashko@univ.kiev.ua

The influence of the Pauli exclusion principle on the collision of light nuclei was shown to be reducible to three factors which affect the dynamics of the cluster-cluster interaction. Firstly, elimination of the forbidden states drastically increases the maximum amplitude of the scattering phase that may be simulated by a repulsive potential at small inter-cluster distances. The larger is the number of the forbidden states, the larger should be the intensity and the radius of such a model potential. Secondly, out of the core some additional effective potential (repulsive or attractive) appears. The latter can significantly affect the scattering phase behaviour. Finally, decreasing or increasing the centrifugal potential occurs in the same region. It also influences the phase shift, especially, at high energy. The inter-cluster distances, within which the Pauli principle is important, depend on the cluster structure and can be several times more than the radius of the cluster interaction induced by the nucleon-nucleon potential.

If there are several open channels, the antisymmetrization effects take part in the formation of the cross-sections of the inelastic scattering accompanied by the excitation of the clusters or their rearrangement. The eigenphases for some multi-channel systems were calculated and the fact of their quasi-intersection was established.

A considerable intensification of the antisymmetrization effects is observed in the case when different cluster configurations are taken into account simultaneously. Special attention is paid to the multi-channel cluster structure ^{6}He+^{6}He as well as to the difficulties arising in the coupled-channel problem (^{6}He+^{6}He and ^{4}He+^{8}He coupled configurations were considered). In the latter case the Pauli principle, even without a participation of the nucleon-nucleon interaction between the nucleons belonging to the different clusters, leads to the inelastic processes and ensures an existence of both the bound state and resonance in the ^{12}Be compound nucleus.

Energy dependence of total reaction cross section of silicon induced by ^{4}He and ^{6}He ions

A. Kulko [a], E.Budzanowski [b], E.Bialkowski [b], A. Kugler [c], I.N. Kuhtina [a], V.F. Kushniruk [a], I.V. Kuznetsov [a], Yu.E. Penionzhkevich [a], I. Skwirchinska [b], Yu.G. Sobolev [a], W. Trzaska [d], V.Yu. Ugryumov [a], T.K Zholdybaev [e]

[a] *Joint Institute for Nuclear Research, Dubna, Russia*
[b] *H.Newodniczanski Institute of Nuclear Physics, Krakow, Poland*
[c] *Institute of Nuclear Physics, Rez, Czech Republic*
[d] *University of Yuvaskyla, Yuvaskyla, Finland*
[e] *Institute of Nuclear Physics, Alma-Ata, Republic of Kazakhstan*

One of the most exciting recent events in nuclear physics has been the discovery of extended neutron distributions in exotic neutron-rich nuclei such as e.g. ^{6}He via total reaction cross section (σ_R). A σ_R as a function of the energy shows a remarkable sensitivity to the halo structure of the exotic nuclei, especially at low energies. The energy dependence of σ_R for the ^{4,6}He + Si was measured by the transmission technique. Neutron and matter density distributions of ^{6}He were obtained on the basis of the analysis of experimental excitation function of σ_R.

In beam γ-ray spectroscopy of light neutron rich nuclei.

M. Stanoiu [a,b], F. Azaiez[b], Zs. Dombradi[c], O. Sorlin[b], B.A. Brown[d], M. Belleguic[b], D. Sohler[c], M.G. Saint Laurent[a], M.J. Lopez-Jimenez[a], Y.E. Penionzhkevich[e], G. Sletten[n], N.L. Achouri[f], J.C. Angelique[f], F. Becker[a], C. Borcea[g], C. Bourgeois[b], A. Bracco[h], J.M. Daugas[a], Z. Dlouhy[i], C. Donzaud[b], J. Duprat[b], Zs. Fulop[c], D. Guillemaud-Mueller[b], S. Grevy[f], F. Ibrahim[b], A. Kerek[j], A. Krasznahorkay[c], M. Lewitowicz[a], S. Leenhardt[b], S. Lukyanov[e], P. Mayet[k], S. Mandal[k], H. van der Marel[j], W. Mittig[a], J. Mrazek[k], F. Negoita[g], F. De Oliveira-Santos[a], Zs. Podolyak[l], F. Pougheon[b], M.G. Porquet[m], P. Roussel-Chomaz[a], H. Savajols[a], Y. Sobolev[e], C. Stodel[a], J. Timar[c], A. Yamamoto[l]

[a]GANIL BP 55027,14076 Caen Cedex 5 France
[b]IPN, IN2P3-CNRS and Universite Paris-Sud, F-91406 Orsay Cedex, France
[c]Institute of Nuclear Research, PO Box 51, H-4001 Debrecen, Hungary
[d]NSCL, East Lansing, MI 48824-1321, USA
[e]FLNR, JINR, 141980 Dubna, Moscow region, Russia
[f]LPC, IN2P3-CNRS, ISMRA et Universite de Caen, F-14050 Caen Cedex, France
[g]IFIN-HH PO-BOX MG-6,76900 Bucharest Magurele Romania
[h]Dipartimento di Fisica, Universita' di Milano and INFN sez. Milano, Italy
[i]Nuclear Physics Institute, 25068 e,z, Czech Republic
[j]Royal Institute of Technology, Alba Nova University Center, S-106 91 Stockholm, Sweden
[k]GSI Postfach 110552, D-64220 Darmstadt, Germany
[l]Department of Physics, University of Surrey, Guildford, GU2 5XH, UK
[m]CSNSM, IN2P3-CNRS and Universite Paris-Sud, F-91405 Orsay Cedex, France
[n]The Niels Bohr Institute, Blegdamsvej 17, DK-2100, Copenhagen, Denmark

In-beam γ-spectroscopy using fragmentation reactions of both stable and radioactive beams have been performed in order to study the structure of excited states in neutron rich oxygen isotopes with masses ranging from A=20 to A=24. For the produced fragments, gamma-ray energies, intensities and γ-γ coincidences have been measured. Based on this information new level schemes have been proposed for ^{21,22}O up to the neutron separation energy. The non observation of any gamma decay branch from ^{23}O and ^{24}O strongly suggested that their excited states lie above the neutron decay thresholds. From this, as well as from the level schemes proposed for ^{21}O and ^{22}O, the size of the N=14 and N=16 shell gaps in oxygen isotopes has been found to be large and consequently ^{22}O and ^{24}O to be doubly magic nuclei. It appeared that while the N=16 shell gap turns out to be larger than 3 MeV in the heaviest oxygen isotopes, it is only of the order of 1 MeV in the Silicon and Magnesium isotopes. This can be accounted for by considering the role of the strong n-p monopole interaction acting between the two spin-orbit partners $\pi d_{5/2}$ and $\nu d_{3/2}$. As the $d_{5/2}$ proton orbital is emptied this interaction is released and the $d_{3/2}$ neutron orbital is shifted towards the fp shell acquiring a smaller binding energy. This generates in the same time the decrease of the N=20 shell gap and the increase of the N=16 gap. Oxygen isotopes are the extreme case where the $\pi d_{5/2}$ orbital being empty no $\pi d_{5/2}$-$\nu d_{3/2}$ is acting and subsequently the N=16 shell gap gets relatively large. This large N=16 gap in oxygen can make the $d_{3/2}$ neutron orbital to be unbound which would explain why heavier oxygen isotopes with neutron numbers N=18 and 20 are unbound in contrast with F and Ne isotopes.

The improvements that EXOGAM and AGATA detector will bring in this type of measurements will be discussed.

$(\alpha,2\alpha)$ quasifree scattering with ^6He and ^8He secondary beams on ^4He target

R. Wolski[1,2], A.S. Fomichev[1] , M.S. Golovkov[1], Yu.I. Orlov[1], A.M. Rodin[1], S.I. Sidorchuk[1], R.S. Slepnev[1], S.V. Stepantsov[1], G.M. Ter-Akopian[1], A.A. Korsheninnikov[3], E.Yu. Nikolskii[3,5], W. Mittig[4], P. Roussel-Chomaz[4], E.A. Kuzmin[5], B.G. Novatsky[5], D.N Stepanov[5] and H. Simon[6],

[1]*Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia*
[2] *Institute of Nuclear Physics, Kraków, Poland*
[3]*RIKEN, Wako, Japan*
[4]*GANIL, Caen, France*
[5]*Kurchatov Institute, Moscow, Russia*
[6]GSI, Darmstadt, Germany

Recently $^6He(\alpha,2\alpha)2n$ and $^8He(\alpha,2\alpha)4n$ reactions have been investigated at FLNR, Dubna. The aim of the experiment is to measure internal α-$2n$ and α-$4n$ impulse distribution for ^6He and ^8He nuclei respectively. The secondary 28 MeV/n ^6He and 25 MeV/n ^8He beams have been provided by a fragmentation of a primary ^{11}B beam on berylium production target and selected by ACCULINNA separator at FLNR, Dubna [1]. A cryogenic helium cell has been used as a scattering target. The both α-particles have been measured in coincidence by a two-arms position sensitive detector telescope system. The telescopes of rather large solid angle were set symmetrically respect to the beam direction at scattering angles where most pronounce $(\alpha,2\alpha)$ quasifree scattering is expected. The preliminary results are discussed in terms of ^6He [2] and ^8He [3] wave functions.

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SPECTROSCOPY AT N=28 : NEW EVIDENCES FOR A LARGE REGION OF DEFORMATION

S. Grévy, for the *TONNERRE* collaboration
Laboratoire de Physique Corpusculaire, IN2P3-CNRS, ISMRA, F-14050 Caen Cedex, France,
GANIL-France, IPNO-France, IreS-France, IFIN-Romania, Univ. of Surrey-U.K.,
Nucl. Phys. Inst.-Czech Republic, Univ. of Mainz-Germany, FLNR-Russia.

The investigation of very neutron-rich nuclei provides a fertile testing ground for our understanding of nuclear structure. In the region of N=28, evidence has accumulated of modifications in the shell structure. In particular, the energies and $B(E2)$ for the lowest $J^{\pi} = 2^{+}$ states in the neutron-rich isotopes of Sulphur ^{38,40,42,44}S, have been measured via Coulomb Excitation [1,2], indicating that $^{40,42,44}S$ are moderately deformed ($|\beta_2| \approx 0.3$) and supporting an earlier suggestion of a weakening of the N=28 shell closure below ^{48}Ca. Most recently, mass-measurements made at GANIL [3] confirmed this tendency with a discontinuity of the S_{2n} values at N=26 for S and P isotopes. Does it mean that the N=28 region below ^{48}Ca is similar to the so-called "island of inversion" at N=20 where intruder configurations are known to dominate the ground-state structure ?

We performed at GANIL several experiments in order to collect precise spectroscopic information which are needed in order to clarify the nature of the effects occuring around N=28 and isolate the underlying mechanisms driving the deformation. We propose to present and discuss the last experimental results obtained through in-beam and decay spectroscopy experiments for the Ar (Z=18), the S (Z=16) and the Si (Z=14) isotopes. From these analysis and comparisons with theoretical predictions, we believe that the mechanisms responsible for the deformation at N=28 below ^{48}Ca are differents than those occuring at N=20.

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Reaction cross section measurements of neutron-rich exotic nuclei in the vicinity of closed shells N=20 and N=28

A.Khouaja[1], A.C.C.Villari[1], H.Savajols[1], W.Mittig[1], P.R.Chomaz[1], M.Benjelloun[3], Nigel Orr[2], Santiago Pitae[1], C.E.Demonchy[1], L.Giot[1], M.Chartier[4], A.Gillibert5, D. Baiborodin[6], Y. Penionzhkevich[6], W.Catford[7], A.Lépine-Szily[8], Z.Dlouhy[9]

[1]GANIL, BP5027, F-14096, CAEN, Cedex 5, France
[2]LPC, ISMRA et Université de Caen, F-6704 Caen, France
[3]LPTN; Faculté des Sciences –El Jadida, BP.20, 24000 El Jadida, Maroc
[4]University of liverpool, GB
[5]CEA/DSM/DAPNIA/SPHN, CEN Saclay, F-91191 Gif-sur Yvette, France
[6]FLNR, JINR, Dubna, P.O.Box 79, 101000 Moscow, Russia
[7]University of Surey, Stoy Fill, Nuclear Physics Dept, Guilford, GU27XH
[8]University of Sao-Paolo, Bresil
[9]Nucl.Phys.Ins., ASCR, 25068 Rez, Czesh Republic

The study of exotic nuclei, especially the so-called magic nuclei, is of great interest to understand the structure and to study the competition between magicity and exoticity of nuclei far from stability, through the evolution of shell structure and matter distribution. From coulomb excitation and mass measurements for such nuclei, and around the N=20 and N=28 magic numbers, it appears that the character of shell closure seems to be weakened. The discovery of isomeric state in the nuclei structure of ^{43}S was the first evidence of shape coexistence around N=28. An "island" of inversion is predicted for the neutron-rich nuclei around N=20. At high energy, from recent measurements of interaction cross section, a new magic number N=16, which appears only in very neutron-rich nuclei, has been discovered. Also, from the correlation between the interaction cross section and separation energy, the anomalous structure, such as the halo and skin, can be studied. A new measurement of interaction cross section at high energy shows the existence of skin effect in the structure of Na and Mg isotopes.

In this context, a new experience of reaction cross section measurement, at intermediate energy was performed at the high resolution magnetic spectrometer SPEG installed at GANIL. The nuclei of interest were produced, in a wide range of neutron-rich nuclei (N→Ar), by the fragmentation of a 60.3 MeV/nucleon ^{48}Ca primary beam on a ^{181}Ta production target. Using a direct method, where the Silicon detector can play a role of an active target, the mean energy integrated reaction cross section was investigated for such nuclei.

Assuming that the energy dependence of the reaction cross section is well described by the parametrization of S.Kox, the reduced strong absorption radius is extracted and compared to other results from literature. We present for the first time the results of 19 new radius measurements (reaction cross sections). By the isotopic, isotonic and isospin dependence, the evolution of the strong reduced radius is studied according to the excess of neutrons. According to the large value of the radius to its neighbours, the existence of halo effect is proposed to the nuclei of ^{35}Mg and ^{44}S. Also, a quadratic parametrization is proposed for the nuclear radius as a function of the isospin in the region of closed shells N=8 and N=28. This parametrization permits to study the evolution of the radii according to the excess of both neutrons and protons, and to give indications on the existence of such structure anomaly: skin and halo.

Structure of heavy Argon isotopes near N=28

for the TONNERRE collaboration

Jaromir Mrazek

Nuclear Physics Institute of ASCR, CZ-25068 Rez, Czech Republic

The behaviour of nuclear structure far from stability belongs to the topics, that attract an attention of the physicists. Magic numbers were, and they still are, an important clue for the understanding the nuclear structure. Climbing up from the 'valley of stability', traditional magic numbers tend to loose their 'magic' behavior and for example 'the good old' magic number N=20 disappears with decreasing number of protons, starting with Z=12 in ^{32}Mg. The region of deformation found in this part of the table of isotopes was named "Island of Inversion" thus pointing out the origin of the effect - a domination of deformed fp-configuration in ground state wave function [1]. The heaviest known fluorine isotopes ^{29,31}F, neighbouring to the Island of Inversion, bind 20 and 22 neutrons and although their structure is not yet studied in experiment, fp-shell and p-n interaction probably play an important role in their binding.

Just the next magic number N=28 is - in the similar manner - getting weaker with the decreasing number of protons. Sulphur isotopes ^{40,42}S were found to be deformed and ^{44}S (N=28 Z=16 nucleus) has the spherical-deformed mixed configuration [2].

The 2p2h excitations across the gap from f7/2 to p3/2 neutron orbits (being the probable reason of the deformation) appear in excited states in Argon isotopes (Z=18) 45,46 that were studied with in-beam gamma ray spectroscopy [3].

We present experimental the data on ^{44,45,46}Ar isotopes obtained with LISE3 spectrometer at GANIL [4]. Decays of ^{44,45,46}Cl were measured by two coaxial HPGe and one four-fold clover detectors, TONNERRE neutron array [5] was used to analyze neutron spectra from beta-n decay branches. New levels and transitions were found in Ar isotopes, the probable second 3/2- state, predicted to carry large intruder strength was observed in ^{45}Ar. Values of log(ft) were deduced.

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Resonance Reactions with Rare Isotope Beams and Nuclear Structure beyond the drip line.

V.Z. Goldberg[b], G.V. Rogachev[a], A. Aprahamian[a], F.D. Becchetti[b], P. Boutachkov[a], G. Chubarian[c], Y. Chen[b], P.A. DeYoung[d], A. Fomichev[e], V.Z. Goldberg[c], M.S. Golovkov[e], J.J. Kolata[a], Yu.Ts. Oganessian[e], G.F. Peaslee[d], M. Quinn[a], A. Rodin[e], B. Skorodumov[a], R.S. Slepnev[e], G. Ter-Akopian[e], W.H. Trzaska[f], R. Wolski[e], A. Wöhr[a]

[a] *Physics Department, University of Notre Dame, Notre Dame, IN 46556, USA.*

[b] *Physics Department, University of Michigan, Ann Arbor, MI 48109, USA.*

[c] *Texas A&M University, College Station, TX 77843, USA.*

[d] *Physics Department, Hope College, Holland, MI 49422, USA.*

[e] *Joint Institute of Nuclear Research, Dubna, Russia.*

[f] *Physics Department, University of Jyväskylä, Jyväskylä, Finland*

Exotic nuclei exhibit qualitatively new phenomena and provide a new testing ground for our understanding of quantum many-body systems. Recent developments of experimental techniques and achievements in the production of Rare Isotope Beams provide a unique opportunity to study these exotic nuclear systems. Resonance reactions in conjunction with Rare Isotope Beams are powerful tools for the spectroscopic studies of light exotic nuclei on both proton and neutron rich sides of the drip line (see Refs. [1,2,3,4,5]).

Resonance elastic scattering of RIBs on protons using thick target and inverse kinematics approach [6] is now a widely used technique. Application of this technique for the spectroscopy of unstable ^{15}F isotope will be discussed. In these measurements evidence was obtained for the increase of the diffuseness parameter of nuclear potential. Until recently only proton rich isotopes were successfully studied via resonance scattering reactions. Now it has been shown that resonance reaction studies can be extended to the neutron rich side. Heavy helium isotopes ^{7}He [5] and ^{9}He [4] were studied through the isobaric analog states in ^{7}Li and ^{9}Li respectively by means of two different resonance reactions (p,p) and (p,n). Resonance yields of n-γ coincidences were observed for the first time in reaction ^{6}He(p,n)^{6}Li(0^+). These results as well as perspectives for such studies will be presented.

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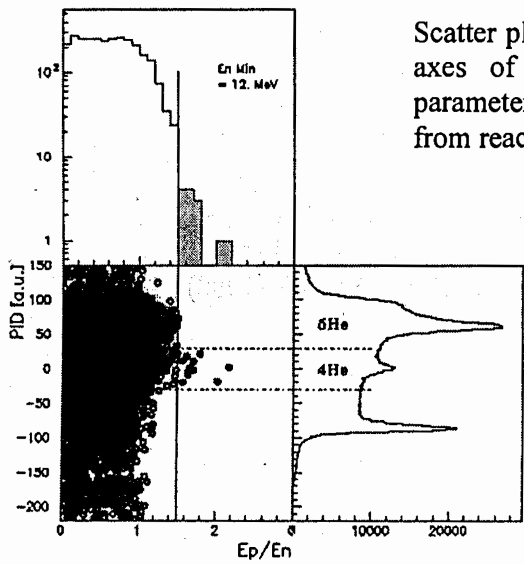
Search For Tetraneutrons In The Breakup Of ^{8}He

V. Bouchat[1], F.M. Marqués[2], F. Hanappe[1], J.C. Angelique[2], C. Angulo[3], N. Ashwood[4], M.J.G. Borge[5], W. Catford[6], N. Clarke[4], N. Curtis[4], P. Descouvemont[1], M. Freer[4], V. Kinnard[1], M. Labiche[7], P. McEwan[4], T. Materna[1], T. Nilsson[8], A. Ninane[3], G. Normand[2], N.A. Orr[2], S. Pain[6], E.V. Prokhorova[9], L. Stuttge[10], C. Timis[6].

[1] Université Libre de Bruxelles, CP226, B-1050 Bruxelles, Belgium
[2] Laboratoire de Physique Corpusculaire, IN2P3-CNRS, ISMRa et Université de Caen, F-14050 Caen cedex, France
[3] Centre de recherche du Cyclotron, UC L, B-1348 Louvain-La-Neuve, Belgium
[4] School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, U.K.
[5] Instituto de Estructura de la Materia, CSIC, E-28006 Madrid, Spain
[6] Department of Physics, University of Surrey, Guildford, Surrey, GU2 7XH, U.K.
[7] Department of Physics, University of Paisley, Paisley PA1 2BB, Scotland
[8] Experimentell Fysik, Chalmers Tekniska Högskola, S-412 96 Göteborg, Sweden
[9] Flerov Laboratory of Nuclear Reactions, JINR, 141980 Dubna, Russia
[10] Institut de Recherche Subatomique, IN2P3-CNRS, Université Louis Pasteur, BP 28, F-67037 Strasbourg cedex, France

Abstract:

A new approach to the production and detection of neutron clusters was recently proposed by the DEMON-CHARISSA collaboration. Its application to the breakup of ^{14}Be into ^{10}Be and 4 neutrons revealed 6 events that exhibited the characteristics of a ^{4}n state, either bound or resonant. We have applied the technique to the breakup of another system that could be seen as a core plus a ^{4}n cluster, ^{8}He. Preliminary results present 12 events in the ^{4}He+^{4}n channel exhibiting the characteristics of a ^{4}n state: an alpha particle in coincidence with the high-energy recoil of a proton in the liquid scintillator of DEMON. The simulations in progress will be discussed in order to clarify the origin of these events. We have also determined the energy surfaces by a microscopic theoretical approach using the Generator Coordinate Method in a four-centre model where the neutrons are located at the apexes of a tetrahedral configuration.



Scatter plot and projections onto both axes of the particle identification parameter PID vs Ep/En for the data from reaction (^{8}He,X+n)

SEARCH FOR "TETRANEUTRON" VIA THE d(^{8}He, ^{6}Li)4n TRANSFER REACTION

D.Beaumel(1), E.Becheva(1), Y.Blumenfeld(1), F.Delaunay(1), A.Fomichev(2), S.Fortier(1), N.Frascaria(1), A.Gillibert(3), J.Guillot(1), F.Hammache(1), E.Khan(1), V.Lapoux(3), V.Lima(1), L.Nalpas(3), A.Obertelli(3), E.Pollaco(3), E.Rich(1), P.Roussel-Chomaz(4), D.Santonocito(5), J-A.Scrapaci(1),F.Skaza(3), O.Sorlin(1), S.V.Stepantsov(2), G.M.Ter-Akopian(2), E.Tryggestad(1), R.Wolski(2)

(1) *Institut de Physique Nucléaire, IN2P3-CNRS, F-91406 Orsay Cedex, France*
(2) *Institute of Nuclear Physics, Cracow, Poland / JINR, Dubna, Russia*
(3) *DSM/DAPNIA, CEA-Saclay,F-91191,France*
(4) *GANIL,CEA-IN2P3,13000 Caen, France*
(5) *LNS Catania, INFN, Italy*

Theoretical calculations as well as previous experimental results from fission, spallation and double charge exchange reactions have concluded against the existence of bound multineutron clusters. But the recent availability of intense neutron-rich RNB provides the opportunity to reinvestigate this long-standing problem ,in a highly selective way. The existence of a bound 4-neutron system has been recently suggested by experimental results on ^{14}Be breakup, six events being compatible with an interpretation in terms of a bound state [1]. If confirmed, the observation of a "Tetraneutron" would require an important revision of the existing models of nuclear forces.

We will report on a recent dedicated experimental search for the Tetraneutron via the α–particle transfer reaction (d,^{6}Li), in inverse kinematics using incident ^{8}He at 15.8 MeV/A delivered by SPIRAL at GANIL and CD_2 targets. This missing mass measurement may treat an eventual bound state and unbound resonance of the 4n system on the same footing, in an unambiguous way, and measure its energy.

Kinetic energies and angles of ^{6}Li ejectiles were measured by the array of position sensitive Si detector MUST [2] coupled with thinner Si detectors for particle identification. Neutrons emitted in coincidence with ^{6}Li were also detected by plastic detectors for background reduction. The accuracy of the excitation energy spectrum determination has been checked, using well-known states in ^{8}Be, produced by ^{12}C(d,^{6}Li) transfer reaction.

The 4n excitation energy spectrum has been measured up to 20 MeV. The high energy region is well reproduced by a 5-body phase space calculation, considering no final state interaction in the 4n system. At low energy, in spite of low statistics, the spectrum exhibits a deviation consistent with a resonant-like structure at 2.5 MeV, which has to be confirmed by a forthcoming experiment.

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Exploring the shell structure of neutron-rich nuclei by means of mass measurements at GANIL

B. Jurado[a], H. Savajols[a], W.Mittig[a], C.E. Demonchy[a], P. Roussel-Chomaz[a], A. Gillibert[b], A. Obertelli[b], F. Rejmund[a], M. Rejmund[a], L. Giot[a], A. Khaouaja[a], A.Villari[a], N. Orr[c], Y.E. Penionzhkevich[d], S.M. Lukyanov[d], Z. Dlouhy[e], D.Baiborodin[e], J. Jaromir[e], M. Chartier[g], A. Lepine[h], W. Catford[i]
a GANIL, B.P.5027, F-14076 Caen cedex 05, France,
b CEA/DSM/DAPNIA/SPhN, CEN Saclay, F-91191 Gif-sur-Yvette, France,
c LPC-ISMRA, Bd. Maréchal Juin, 14050 Caen cedex, France,
d LNR, JINR, Dubna, P.O. Box 79, 101 000 Moscow, Russia,
e Nucl.Phys.Inst., ASCR, 250 68 Rez, Czesh Republic,
g University of Liverpool, GB,
h University of Sao-Paulo, Brasil,
i University of Surrey, GB.

One of the most intriguing questions that emerge from the study of exotic nuclei is the persistence of shell closures, that is, the persistence of regions of exceptional stability. The mass of a nucleus is directly related to its binding energy. Therefore, the systematic study of the nuclear masses along an isotopic chain allows localizing the regions where a reorganisation of the shell structure appears. However, mass measurements of very exotic nuclei represent a real challenge due to the very low production cross sections and short lifetimes.

Since the 80s, the mass measurements carried out at GANIL using the direct time-of-flight technique at the high-resolution spectrometer SPEG have decisively contributed to the determination of the masses of light neutron-rich nuclei [1]. This technique has been recently applied to further extend the mass measurements around shell closures N=20 and N=28 towards the neutron drip line. This region is highly interesting as previous mass measurement campaigns and other spectroscopic studies have evidenced the vanishing of these two shells. In particular, important effects could appear around shell closure N=28 due to the weakening of the Spin-Orbit interaction that is predicted theoretically for very neutron-rich nuclei [2]. This mass measurement technique and the first results of the last campaign with around 9 new masses and the improved resolution of 25 masses will be presented.

One of the big puzzles concerning the structure of light neutron-rich nuclei is the particle instability of O isotopes starting from ^{25}O, while the F isotopes, with just one additional proton, are bounded up to ^{31}F. Several theoretical models state that this jump in the neutron drip line is due to the existence of a shell closure at N=16 for neutron-rich nuclei [3]. However, a quantitative understanding has not yet been achieved. In this context, a fundamental experimental quantity is the mass of the ^{25}O. A new experimental method that has been recently applied at GANIL to measure the mass of the ^{25}O and other neighbouring nuclei will be described. This powerful technique uses the active target MAYA [4] and allows determining masses of bound and unbound nuclei with a precision of around 10^{-6}.

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Interaction of ^6He and ^8Li nuclei with gaseous hydrogen and deuterium targets.

A.M.Rodin, M.S.Golovkov, A.S.Fomichev, S.I.Sidorchuk, R.S.Slepnev,
S.V.Stepantsov, G.M.Ter-Akopian, M.L.Chelnokov,
V.A.Gorshkov, Yu.Ts.Oganessian,
Flerov Laboratory of Nuclear Reactions, JINR, 141980 Dubna, Russia

R.Wolski,
Institute of Nuclear Physics, Cracow, Poland

A.A.Korsheninnikov, E.Yu.Nikolskii
RIKEN, Hirosawa, Wako, Saitama 351-01, Japan

Secondary beam, consisting of ^6He(76%) and ^8Li(24%) nuclei with energies of 132MeV and 222MeV, respectively, was used for studying nucleon transfer reactions on gaseous hydrogen and deuterium targets cooled down to the temperature of about 25K. In the case of ^6He projectile the 1n transfer reaction $^2H(^6He,t)^5He_{g.s.}(\rightarrow{}^4He+n)$ in the angular range $120°\leq\theta_{CM}\leq160°$, as well as the 2n transfer reactions $^1H(^6He,^4He)t$ ($50°\leq\theta_{CM}\leq145°$) and $^2H(^6He,\ ^4He)^4H^*(\rightarrow t+n)$ ($125°\leq\theta_{CM}\leq155°$), were investigated. The results obtained were analyzed in terms of the DWBA method. Besides, the differential angular distribution for the elastic scattering reaction $^2H(^6He,^6He)d$ was obtained for the angular range of $70°\leq\theta_{CM}\leq135°$. The optical potential parameters were determined from these data. As to the ^8Li projectile, the 1n and deuteron transfer reactions $^2H(^8Li,t)^7Li^*$ and $^1H(^8Li,\ ^3He)^6He^*$, respectively, were studied. In the preceding reaction, the population of well-known resonances of ^7Li with the isospin T=1/2 was ascertained through the observation of the $^7Li^*\rightarrow t+{}^4He$ decay mode. The population of the isobaric analogue state of ^7He in ^7Li with the isospin T=3/2 was well seen due to the detection of the $^7Li^*\rightarrow p+{}^6He$ decay mode. In the latter reaction, $^1H(^8Li,\ ^3He)^6He^*$, an indication on the existence of a 2^+ exited state of $^6He^*$ in the ^8Li structure followed from a relatively high probability obtained for the ^3He–^4He coincidence events, where ^4He comes from the $^6He(2^+)\rightarrow{}^4He+n+n$ decay mode.

Parameters of beams of light neutron-excess nuclei (^6He, ^8He, ^8Li, ^9Li, ^{11}Li, etc.) available from the upgraded separator ACCULINNA [1] will be presented in the light of perspectives of using these beams in the further study of transfer reactions.

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^{5}H and ^{5}He (T=3/2) nuclei observed in ^{6}He(d,^{3}He) and ^{6}He(d,t) transfer reactions at 25 AMeV

A.S. Fomichev, S.V. Stepantsov, M.S. Golovkov, A.M. Rodin, S.I. Sidorchuk,
R.S. Slepnev, G.M. Ter-Akopian, M.L. Chelnokov, V.A. Gorshkov,
R. Wolski, and Yu.Ts. Oganessian

Flerov Laboratory of Nuclear Reactions, JINR, 141980 Dubna, Russia

A.A. Korsheninnikov, E.Yu. Nikolskii, and I. Tanihata

RIKEN, Hirosawa, Wako, Saitama 351-01, Japan

Ground state resonance of the ^{5}H nucleus at 1.8±0.2 MeV above the t+n+n decay threshold with the resonance width FWHM=1.3±0.4 MeV was observed in the reaction ^{6}He+d→^{3}He+^{5}H. The position of the resonance agrees with the data of the ^{6}He+p→^{2}He+^{5}H and t+t→p+^{5}H reactions [1,2]. At the same time the reaction ^{6}He+d→t+^{5}He was also studied. Three known ^{5}He resonance states located at E*≈20.0, 21.4 and 24.0 MeV were clearly seen in the decay mode ^{5}He→t+d. Besides, the observation of the decay modes ^{5}He→^{3}He+n+n and ^{5}He→t+p+n revealed a new previously unknown resonance state of ^{5}He lying at excitation energy of 21.6±0.2 MeV. The estimated resonance width is FWHM=2.0±0.4 MeV. One can conclude that this resonance is the T=3/2 isobaric analogue state of ^{5}H observed in ^{5}He. Within the experimental errors, the energy position of this ^{5}He resonance coincides with the energy of the analogue state derived from the ^{5}H ground state energy equal to 1.8±0.2 MeV.

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NEW EMPIRICAL-ANALITICAL TREATMENT OF NUCLEAR LEVEL STRUCTURE

N.I Tarantin

Joint Institute for Nuclear Research, Dubna, Russia

A number of ways are known of identifying features nuclear structure and magic numbers. They use the discontinuities in binding energy, the separation energy of one or two last nucleons – neutrons or protons, two-nucleon pairing energy, α- and β-decay energies and so on. To gain a better insight into the nuclear structure, a new method is proposed [1] that uses the deviations of the separation energy, which is based on experimental data on nuclear masses.. The method allows the smooth liquid drop energy as well as nucleon pairing staggering to be excluded; the changes in the shell energy. This method confirmed uhe existence the known nuclear shells with N=126, 82, 50, 28, 20 and Z=82, 50, 28, 20. This method enabled the discovery of some features in nuclear structure connected with the neutron numbers N=56, 30, 15, 14 . and with the proton numbers Z=15, 14.

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Decay schemes of nuclei far from stability

I.N.Izosimov

Khlopin Radium Institute,
194021 St.Petersburg, 2nd Murinski avn.28,
Russia

Level occupancy after the β-decay, *I(E)*, the half-life $T_{1/2}$ and the β-decay strength function $S_{\beta}(E)$ are connected as [1]:

$$I(E) = S_{\beta}(E)\, T_{1/2}\, f(Q_{\beta} - E)\,,$$

where Q_{β} – is the total energy available for the β-decay, E – excitation energy of the daughter nucleus and $f(Q_{\beta}\text{-}E)$ is the Fermi function. $S_{\beta}(E)$ describe the nuclear part and $f(Q_{\beta}\text{-}E)$ describe the leptonic part of β-transition. Fermi function decrease with excitation energy increasing and as a role the more intensive β-decays populate the levels with low excitation energies. But from the nuclear structure and the weak interaction in the nuclei points of view the most interesting β-transitions populate the levels with sufficiently high (more than 4 MeV) excitation energies where in $S_{\beta}(E)$ a strong resonances or it's tails may be observed. Also a lot of nuclear levels and γ-transitions may not be identified in decay schemes because of high levels density and not so strong β-transitions to the levels at high excitation energy. In the nuclei far from stability the Q_{β} values are high enough for observation resonance structure in $S_{\beta}(E)$.

In this report the applications of the total absorption γ-ray spectroscopy (TAGS) [1-3] and it's combinations with high resolution spectroscopy methods for the β-decay strength function $S_{\beta}(E)$ measurement, for the total β-decay energy Q_{β} determination and for the decay schemes completeness testing are presented. It is shown that in the medium and heavy nuclei more than 30%-50% of the β-decays to the nuclear levels with excitation energies $E>2\text{-}3MeV$ may be not identified in decay schemes. For weak interaction in the nuclei study, for nuclei models testing and for correct decay heat calculations it is necessary to have sufficiently complete decay schemes of nuclei, data on $S_{\beta}(E)$ and Q_{β}. The possibilities of the TAGS spectroscopy in combination with the high resolution γ-spectroscopy for sufficiently complete decay schemes construction are presented.

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Complex Study of the Direct Reactions $^2H(t,p)$ and $^3H(t,d)$ Induced by 58-MeV Tritons

S.I. Sidorchuk[a], A.S. Fomichev[a], M.S. Golovkov[a], Yu.Ts. Oganessian[a], A.M. Rodin[a], R.S. Slepnev[a], S.V. Stepantsov[a], G.M. Ter-Akopian[a], R. Wolski[a,b], E.M. Kozulin[a], A.A. Bogatchev[a], N.A. Kondratiev[a], A.A. Korsheninnikov[c], E.Yu. Nikolskii[c], F. Hanappe[d], T. Materna[d], L. Stuttge[e], A.H. Ninane[f]

[a] *Flerov Laboratory of Nuclear Reactions, JINR, Dubna, 141980 Russia*

[b] *Institute of Nuclear Physics, Cracow, Poland*

[c] *RIKEN,Hirosawa 2-1, Wako, Saitama 351-0198, Japan*

[d] *Universite Libre de Buxelles, B-1050, Belgium*

[e] *Institut de Recherches Subatomiques, F-67037 Strasbourg Cedex, France*

[f] *University of Lovain, Nuclear Physics Department Ch. du cyclotron, 2-1348 Louvain-la-Neuve, Belgium*

Final State Interactions (FSI) and Quasifree Scattering (QFS) on bound nucleons were studied in the reactions $^2H(t,p)$ and $^3H(t,d)$. Data obtained in complete kinematics measurements with a detection system of a large acceptance allowed for a careful consideration of competing processes in the output channels associated with the observation of p-t-n and d-t-n events in the first and second reaction, respectively. In the experiments, we used a primary 58 MeV triton beam delivered from the cyclotron U400M (FLNR, Dubna) and liquid tritium and deuterium as targets.

We have made sure that $FSI_{n\text{-}p}$ and $FSI_{n\text{-}t}$ dominate in the reaction $^2H+t \rightarrow p+t+n$. Besides, QFS of a bombarding triton on a proton bound in deuterium strongly contributes in the p-t-n output channel. Respectively, in the case of the reaction $^3H+t \rightarrow d+t+n$ the main processes are $FSI_{n\text{-}t}$ and QFS of a triton on a deuteron bound in the target tritium nucleus.

The description of the data gave the resonance parameters of the ^4H ground state ($J^\pi = 2^-$): E_{res}=3.05(19) MeV, γ^2=3.03(65) MeV. These values are in good agreement with those found in Ref. [1] by means of charge-symmetric reflection of the ^4Li R-matrix parameters. The pole of S-matrix corresponding to the physical values of energy and width of the 2^- state, E_0=1.99(37) MeV, Γ_0=2.85(30) MeV, was extracted. The differential cross-section of the reaction $^2H(t,p)^4H$ measured in a CM angular range 36° – 50° was found to be uniform and makes 1.8(7) mb/sr.

Intense neutron localization near the origin of the laboratory system was attributed to the QFS of beam tritons on nucleons bound in target nuclei. For both reactions, the measured spectator momentum distributions were consistent with the corresponding wave functions in the momentum presentation. Our data show that, at energy of some tens of MeV, QFS takes place on nucleons corresponding to the tails of the wave functions. The cross-sections of QFS on particles bound in ^2H and ^3H are surprisingly similar: 200 and 180 μb/sr, respectively.

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$N = 16$ subshell closure from stability to the neutron drip line

A. Obertelli[1], A. Alamanos[1], M. A. G. Alvarez[1], F. Auger[1], J.-L. Charvet[1], R. Dayras[1], A. Drouart[1], A. Gillibert[1], M. Girod[2], A. Gorgen[1], H. Goutte[2], B. Jurado[3], N. Kelley[1], W. Korten[1], V. Lapoux[1], W. Mittig[3], X. Mougeot[1], L. Nalpas[1], S. Péru[2], E. Pollacco[1], M. Rejmund[3], P. Roussel-Chomaz[3], H. Savajols[3], F. Skaza[1], C. Theisen[1]

[1]CEA-SACLAY DSM/DAPNIA/SPhN F-91191 Gif-sur-Yvette, France
[2]CEA/DIF/DPTA/SPN B.P. 12 91680 Bruyères-le-Châtel, France
[3]GANIL F-14021 Caen Cedex, France

The sequence of magic numbers for stable nuclei was reproduced for the first time fifty years ago, and is now well understood. However, the strength of shell effects may evolve from stability to the drip lines. It may decrease, as already observed for $N = 20$ in the neutron rich region [1]. It may increase as well, and give rise to new magic numbers not observed at stability. $N = 16$ is suggested to be one of them [2]. In this communication, a complete survey of even-even $N = 16$ isotones from stability to the neutron drip line is presented, including recent theoretical and experimental works.

A study was performed within a microscopic Hartree-Fock-Bogoliubov approach using the Gogny-D1S force [3]. $N = 16$ is found to be a spherical magic number for ^{24}O and ^{22}C. Collective states are obtained from the Generator Coordinate Method with the Gaussian Overlap Approximation. Results are compared to available experimental data.

Spectroscopy of low lying negative parity states of $N = 17$ isotones may give valuable information about $sd - fp$ gap evolution for $N = 16$ nuclei with a decreasing number of protons. Preliminary results of a transfer experiment $^{26}Ne(d,p)^{27}Ne$ at GANIL with the EXOGAM and VAMOS [4] spectrometers will be shown.

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Shell model treatment of neutron-rich nuclei near ^{78}Ni

A. F. Lisetskiy[1], B. A. Brown[1], M.Horoi[2], H. Grawe[3]
[1]National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824-1321
[2] Physics Department, Central Michigan University, Mount Pleasant, Michigan 48859
[3] Gesellschaft für Schwerionenforschung mbH, D-64291 Darmstadt, Germany

Neutron-rich nickel isotopes in the vicinity of $^{78}_{28}$Ni$_{50}$ are currently in the focus of modern nuclear physics and astrophysics studies. The interest in this region is motivated by the doubly magic nature of $^{78}_{28}$Ni and understanding the way in which the neutron excess will affect the properties of nearby nuclei. The shell-model orbitals for neutrons in nuclei with $Z = 28$ and N=28-50 (^{56}Ni-^{78}Ni) are the same as those for protons in nuclei with N=50 and Z=28-50 (^{78}Ni-^{100}Sn). Thus it is of interest to understand the similarities and differences in the properties of these nuclei with valence-mirror symmetry. The astrophysical importance is related to the understanding of the nuclear mechanism of the rapid capture of neutrons by seed nuclei through the r-process. The path of this reaction network is expected in neutron-rich nuclei for which there is little experimental data, and the precise trajectory is dictated by the details of the shell structure far from stability.

This contribution reports on results obtained with new effective interactions for the $pf_{5/2}g_{9/2}$ model space derived from a fit to experimental data for Ni isotopes from $A = 57$ to $A = 78$ and $N = 50$ isotones from ^{79}Cu to ^{100}Sn for neutrons and protons, respectively. Predictions for the $^{72-76}$Ni isotopes are made using the new effective interaction. The calculated structures of the ^{68,70,72,74,76}Ni isotopes and the ^{90}Zr, ^{92}Mo, ^{94}Ru, ^{96}Pd, ^{98}Cd are compared and analyzed with respect to the valence mirror symmetry concept. Our work provides a much improved Hamiltonian for $Z = 28$ over those considered in smaller model spaces and a new Hamiltonian for $N = 50$ that is similar to those obtained previously.

Full configuration mixing calculations for neutrons or protons in this model space are relatively easy. The work we describe here on the $T = 1$ effective interactions will provide a part of the input for the larger model space of both protons and neutrons in these orbits. This proton-neutron model space is computationaly feasible with conventional matrix-diagonalization technigues for many nuclei in the mass region A=56-100, and Monte-Carlo techniques can be used for all nuclei.

NEUTRON DRIP LINE and PECULIARITIES OF O-Mg ISOTOPES

S M Lukyanov, Yu E Penionzhkevich
Flerov Laboratory of Nuclear Reaction, JINR, Dubna, Russia

The neutron drip line in the oxygen-magnesium region has been explored by the projectile fragmentation of a ^{48}Ca beam using the fragment separator LISE at GANIL. New neutron-rich isotopes, ^{34}Ne and ^{37}Na, have been observed together with some evidence for the particle instability of ^{33}Ne and ^{36}Na [1].

Recent data on mass measurements of neutron-rich nuclei at GANIL and some characteristics of binding energies in this region are discussed. Nuclear binding energies are very sensitive to the existence of nuclear shells and together with the measurements of instability of doubly magic nuclide ^{28}O they provide information on changes in neutron shell closures of very neutron-rich isotopes from carbon up to calcium. The conclusion about rearrangements in neutron shell closures is given [2,3].

The spectroscopic measurements can reveal details of the underlying microscopic structures, the in-beam γ-ray spectroscopy is an effective tool to check for shell closures.This result of the γ-ray energies of the first 2^+ level for even-even nuclei for are discussed [3,4].

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Direct Mass Measurements of Short-Lived Neutron-Rich Fission Fragments at the FRS-ESR Facility at GSI

M. Matoš[1], Yu. N. Novikov[2], K. Beckert[1], P. Beller[1], F. Bosch[1], D. Boutin[1], T. Faestermann[3], B. Franczak[1], B. Franzke[1], H. Geissel[1,4], M. Hausmann[5], E. Kaza[1], O. Klepper[1], H.-J. Kluge[1], C. Kozhuharov[1], K.-L. Kratz[7], Yu. A. Litvinov[1], L. Maier[3], G. Münzenberg[1], F. Nolden[1], T. Ohtsubo[6], A. N. Ostrowski[7], Z. Patyk[8], B. Pfeiffer[7], M. Portillo[9], C. Scheidenberger[1], J. Stadlmann[1], M. Steck[1], D. Vieira[5], H. Weick[1], M. Winkler[1,4], H. Wollnik[4], T. Yamaguchi[10]

[1] GSI Darmstadt, D-64291 Darmstadt, Germany
[2] St. Petersburg Nuclear Physics Institute, Gatchina, 188300 Russia
[3] Technische Universität München, D-85748 Garching, Germany
[4] Justus-Liebig Universität Giessen, D-35390 Giessen, Germany
[5] Los Alamos National Laboratory, Los Alamos, NM87545, U.S.A.
[6] Niigata University, Niigata 950-2181, Japan
[7] Johannes Gutenberg Universität, 55099 Mainz, Germany
[8] Institute for Nuclear Studies, 00681 Warsaw, Poland
[9] Michigan State University, East Lansing, Mi 48824, USA
[10] Saitama University, Sakura-ku, Saitama 338-8570, Japan

Masses of more than 280 neutron-rich isotopes have been measured by using Isochronous Mass Spectrometry (IMS) and 41 mass values have been determined experimentally for the first time. Fission of relativistic uranium projectiles in a beryllium target was used as a source of neutron-rich nuclei. They were separated in-flight with the fragment separator FRS and injected into the storage ring ESR that was operated in the isochronous mode as a high-resolution time-of-flight mass spectrometer. Highly-charged ions were identified simultaneously in a mixture of nuclides with well-known masses and with masses to be determined.

In this first production run, a mass resolving power of 2.5×10^5 was achieved. The uncertainties in mass determination were between 140 and 400 keV. Although ^{93}Br with $T_{1/2}$=102 ms was the nuclide with the shortest known half-life that we have observed, the method provides a possibility to measure masses with half-lives as short as 100 μs.

The newly measured masses belong to very neutron-rich nuclei close to the r-process path. These values are essential for better mass value predictions of those nuclides that take part in the r-process. The various mass predictions show significant deviations from the experimental values that increase towards the more exotic neutron-rich regions. The extrapolations [1] are off by 1.5 MeV for ^{109}Nb and ^{114}Tc.

The measurement of fission products covered a large area of nuclides and demonstrated the potential of the IMS technique. This pioneering experiment in the area of neutron-rich nuclides showed that this region is not well described by present theories. Therefore, mass measurements of neutron-rich nuclides remain an important task for nuclear structure physics and astrophysics.

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Identification of neutron-rich nuclei at the PRISMA spectrometer

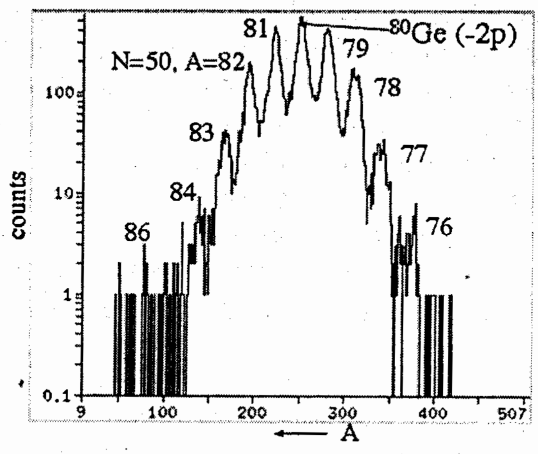
M. Trotta[1†], B.R. Behera[1], L. Corradi[1], E. Fioretto[1], A. Gadea[1], A. Latina[1], S. Szilner[1], A.M. Stefanini[1], S. Beghini[2], G. Montagnoli[2], F. Scarlassara[2], G. Pollarolo[3]

[1] *INFN, Laboratori Nazionali di Legnaro, I-35020 Legnaro, Padova, Italy*
[2] *Dipartimento di Fisica and INFN Sezione di Padova, I-35131 Padova, Italy*
[3] *Dipartimento di Fisica and INFN Sezione di Torino, Torino, Italy*

PRISMA is a magnetic spectrometer for heavy ions [1] recently installed at Laboratori Nazionali di Legnaro. It is designed for the A=100-200, E=5-10 MeV×A beams produced by the positive ion injector PIAVE and by the Linac ALPI. PRISMA consists of a quadrupole singlet followed by a dipole; it has a very large solid angle (80 msr), momentum acceptance (±10%), good mass resolution (1/300) via TOF and can rotate around the target in the range [-30°,+130°]. The ion tracks are software reconstructed using the position, time and energy signals from the entrance and focal plane detectors, and the detailed knowledge of the magnetic fields.

Multinucleon transfer reactions between heavy ions at energies close to the Coulomb barrier are presently considered as a possible tool, at least for certain mass regions, for the production of nuclei far from stability [2,3]. First experiments on heavy-ion grazing collisions were performed recently using PRISMA, so to investigate the dynamics of the reactions and the population of neutron-rich nuclei by such reactions. The A~60 and A~80 mass regions were populated using ^{64}Ni and ^{82}Se beams, respectively, onto ^{238}U targets. Neutron-rich nuclei in such mass regions were identified by PRISMA. A typical (preliminary) mass distribution of Ge isotopes (-2p±xn channels) from the reaction ^{82}Se+^{238}U at 555 MeV is shown in the picture. The coupled operation of PRISMA with the array of Clover γ detectors CLARA allows to perform detailed spectroscopic studies of nuclear structure in those mass regions.

Mass distribution of Ge isotopes from the reaction
^{82}Se (555 MeV) on ^{238}U, $\vartheta_{lab} = 66.7^0 \pm 0.7^0$, $q = 26^+$



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†Present address: *INFN Sezione di Napoli, I-80126 Napoli, Italy*

Elastic and Inelastic Scattering of ^{6}Li on ^{12}C at 63 MeV

V.A.Maslov, R.A.Astabatyan, A.S.Denikin, A.A.Hassan, R.Kalpakchieva, I.V.Kuznetsov, S.P.Lobastov, S.M.Lukyanov, E.R.Markaryan, L.Mikhailov, Yu.E.Penionzhkevich, N.K.Skobelev, Yu.G.Sobolev, V.Yu.Ugryumov, J.Vincour, T.K.Zholdybaev

Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia

The first stage of experiments, designed to study the structure of the ^{6}He nucleus and the mechanism of ^{6}He-induced reactions, is presented. It seems that a correct way to reach this goal is to directly compare reactions induced by ^{6}He and ^{6}Li on different targets. For this reason, as a first step the scattering of a ^{6}Li beam on a ^{12}C-target at 63 ± 0.5 MeV has been studied. The reaction products were analyzed by the FLNR magnetic spectrometer MSP-144 [1] and identified by a focal plane detector consisting of position sensitive proportional counters and an ionization chamber. The angular distribution was measured in the angular range of 10° to 95° in the center-of-mass system (c.m.s.). The inelastic scattering data were taken for exciting the 2^{+} (4.44 MeV) state in ^{12}C. This extends the data, obtained earlier at the same energy [2].

The obtained angular distributions were interpreted in the framework of the optical model. The calculations of the angular distributions of inelastically scattered ^{6}Li nuclei were carried out within the method of DWBA. A parameterization of the phenomenological potential is suggested for the elastic scattering of ^{6}Li on different target nuclei [3]. Good agreement between the calculations and the experimental data is obtained.

In the next experiment we plan to continue these investigations at the accelerator complex for radioactive beams DRIBs FLNR. The first reaction to be studied is ^{6}He + ^{12}C at about 10 MeV/A. The magnetic spectrometer will be used for forward angle measurements, while backward angles will be covered by the kinematic-coincidences method. Comparing the data for this reaction with the previously obtained data for the ^{6}Li + ^{12}C can reveal any possible difference in the optical potential for the two isobaric nuclei ^{6}He and ^{6}Li, which in turn will let us draw conclusions about any difference in their structure. It is also possible that extending the angular range measured for the ^{6}He + ^{12}C reaction it will be possible to check the existence of a nuclear rainbow, which would give additional information on the structure of the ^{6}He nucleus.

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STUDY OF THE $^{7}Li+^{208}Pb$ FUSION-FISSION REACTION

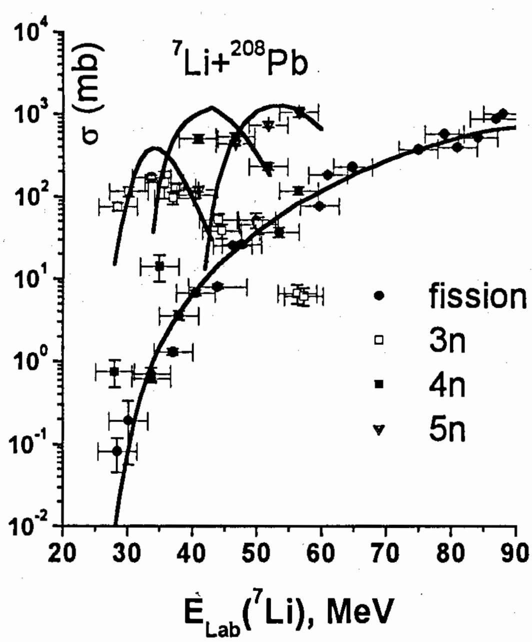
A.A.Hassan[1], R.Astabatyan[1], Z.Dlouhy[2], R.Kalpakchieva[1], S.P.Lobastov[1], S.M.Lukyanov[1], V.A. Maslov[1], E. Markaryan[1], J. Mrazek[2], Yu.A. Muzychka[1], Yu.E.Penionzhkevich[1], N.K. Skobelev[1], Yu.G.Sobolev[1], J. Vincour[2], V.Yu. Ugryumov[1], T.Zholdybaev[3]

1. *Flerov Laboratory of Nuclear Reactions, Dubna, Russia*
2. *Institute of Nuclear Physics, Rez, Czech Republic*
3. *Institute of Nuclear Physic, Almaty, Kazahstan*

The study of fusion reactions near and above the Coulomb barrier involving weakly-bound or radioactive beams is one of the most challenging experimental and theoretical problems in nuclear physics [1].

The $^{7}Li+^{208}Pb$ fusion-fission and evaporation reactions have been investigated at energies near the Coulomb barrier and up to 100 MeV. The ^{7}Li beam was produced by the U400M accelerator at FLNR, JINR.

Excitation functions for the (3n, 4n and 5n) evaporation channels and fission fragments from the ^{215}At compound nucleus were obtained. The analysis of the obtained experimental data was carried out using the theoretical calculation made within the code "ALICE-MP". The free parameters used in the calculations were λ_{cr} (the critical angular momentum) and r_0 (interaction radius) determined the geometrical size of the nuclear part of the interaction potential. The results are compared to existing data for the $^{6}He+^{209}Bi$ fusion-fission and fusion-evaporation reactions.



Excitation functions for the production of evaporation residues and fission fragments (solid curves) in the $^{7}Li+^{208}Pb$ reaction are shown in the Figure. The points denote the experimental data, the curves – the theoretical calculations.

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Heavy Element Research at the GSI SHIP

Sigurd Hofmann

Gesellschaft für Schwerionenforschung, GSI, D-64291 Darmstadt, Germany

The experimental program at SHIP concentrates on the synthesis of elements 113 to 115 using fusion reactions with Pb and Bi targets. In addition, hot fusion reactions using uranium targets will be studied in order to explore new possibilities of SHE production and to synthesize heavy and superheavy nuclei with larger neutron number. In parallel, the detailed spectroscopy of lighter transactinide nuclei will be pursued. Higher beam intensities expected from medium-term accelerator developments can be handled by preparation of a homogenous beam-intensity profile, use of high melting-point chemical compounds as target materials, and additional gas cooling.

At the new SHIPtrap set-up the commissioning phase started. An experimental program will be developed, in particular to perform direct mass measurements and to explore ionization potentials.

Decay of an isotope $^{277}112$ produced by the $^{208}Pb + ^{70}Zn$ reaction

K. Morita[1], K. Morimoto[1], D. Kaji[1], T. Akiyama[2], S. Goto[3], H. Haba[1], E. Ideguchi[4], K. Katori[1], H. Koura[5], H. Kudo[6], T. Ohnishi[1], A. Ozawa[7], T. Suda[1], K. Sueki[7], A. Yoneda[1], and A. Yoshida[1]

[1] RIKEN (The Institute of Physical and Chemical Research) Wako-shi, Saitama 351-0198, Japan

[2] Department of Physics, Saitama University, Sakura-ku, Saitama-shi, Saitama 338-8570, Japan

[3] Center for Instrumental Analysis, Niigata University, Ikarashi, Niigata 950-2181, Japan

[4] Center for Nuclear Science, University of Tokyo, Wako-shi, Saitama 351-0198, Japan

[5] Japan Atomic Energy Research Institute, Tokai, Ibaraki 319-1195, Japan

[6] Department of Chemistry, Niigata University, Ikarashi, Niigata 950-2181, Japan

[7] University of Tsukuba, Tsukuba, Ibaraki 305-8577, Japan

We observed an α-decay chain that can be assigned to subsequent decays from the isotope $^{277}112$ produced by the $^{208}Pb(^{70}Zn,n)$ reaction. A ^{70}Zn beam of 349.5 MeV was supplied from the RIKEN Linear Accelerator. The beam energy at the half-depth of the target was estimated to be 345.9 MeV. A gas-filled recoil ion separator GARIS was used to separate the evaporation residues from lighter ions of beam-like and target-like atoms. Those residues were collected with a semiconductor detector placed at the focal plane of the separator. Following the implantation signal of the evaporation residue, four subsequent α-decays followed by spontaneous fission decay were observed: All six events, implantation, four α-decays and spontaneous fission decay, were observed in the same small area (3.75 mm x 0.3 mm) of the detector. The decays were assigned to the ones of $^{277}112$, ^{273}Ds, ^{269}Hs, ^{265}Sg, and ^{261}Rf, respectively. The present result is the first clear confirmation of the discovery of $^{277}112$ and its α-decay product ^{273}Ds reported previously by a GSI group.

Synthesis and Decay Properties of Superheavy Nuclei

Yu.Ts. Oganessian[1], V.K. Utyonkov[1], Yu.V. Lobanov[1], F.Sh. Abdullin[1], A.N. Polyakov[1], I.V. Shirokovsky[1], Yu.S. Tsyganov[1], G.G. Gulbekian[1], S.L. Bogomolov[1], B.N. Gikal[1], A.N. Mezentsev[1], S. Iliev[1], V.G. Subbotin[1], A.M. Sukhov[1], A.A. Voinov[1], G.V. Buklanov[1], K. Subotic[1], V.I. Zagrebaev[1], M.G. Itkis[1], J.B. Patin[2], K.J. Moody[2], J.F. Wild[2], M.A. Stoyer[2], N.J. Stoyer[2], D.A. Shaughnessy[2], J.M. Kenneally[2], and R.W. Lougheed[2]

[1] *Joint Institute for Nuclear Research, 141980 Dubna, Russian Federation*
[2] *University of California, Lawrence Livermore National Laboratory, Livermore, California 94551, USA*

In previous experiments in which superheavy nuclei close to the predicted neutron magic number N=184 were synthesized, we used the complete-fusion reactions of target and projectile nuclei having the largest available neutron excess: ^{244}Pu+^{48}Ca [1], ^{248}Cm+^{48}Ca [2], and ^{249}Cf+^{48}Ca [3]. In all of these cases, the observed α-decay chains of parent isotopes of elements 114, 116, and 118 were terminated by the spontaneous fission (SF) of previously unknown descendant nuclei with Z=110 [1,2] or 114 [3]. Thus, the method of genetic correlations to known nuclei has limited application in this region for the identification of the parent nuclides. In the present experiments, we identified masses of evaporation residues 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 mass number of the target nuclei which changes the relative yields of the xn-evaporation channels. Both of these methods have been successfully applied in former experiments for the identification of unknown artificial nuclei.

We have studied the excitation functions of the reactions ^{238}U(^{48}Ca, 3-4n), ^{242}Pu(^{48}Ca, 2-4n), and ^{244}Pu(^{48}Ca, 3-5n). The maximum cross sections for the evaporation of 2-5 neutrons in these complete-fusion reactions were measured to be in the range of 0.5 pb to 5 pb. We also report on the observation of new isotopes of element 116, ^{290,291}116, produced in the ^{245}Cm+^{48}Ca reaction with cross sections of about 1 pb. A discussion of self-consistent interpretations of all observed decay chains originating from the parent isotopes ^{282,283}112, $^{286\text{-}289}$114, ^{290,291,293}116, and ^{294}118 is presented. The decay properties of the new isotopes of even-Z elements are compared with those of previously known heavy nuclei and predictions of the macroscopic-microscopic theory.

For the neighboring odd-Z elements, especially their odd-odd isotopes, the probability of α-decay with respect to SF should increase due to hindrance for SF. For such odd-Z nuclei one might expect longer consecutive α-decay chains terminated by the SF of relatively light descendant nuclides ($Z \leq 105$). The decay pattern of these superheavy nuclei is of interest for nuclear theory. In the course of a series of α-decays, the increased stability of nuclei caused by the predicted spherical neutron shell N=184 (or perhaps N=172) should gradually become weaker for descendant isotopes. However, the stability of these nuclei at the end of the decay chains should increase again due to the influence of the deformed shell at N=162. For these investigations, we chose the fusion-evaporation reaction ^{243}Am+^{48}Ca, leading to isotopes of element 115. With 248-MeV ^{48}Ca projectiles, we observed three similar decay chains consisting of five consecutive α decays, all detected in time intervals of about 20 s and terminated at a later time by SF. At the higher bombarding energy of 253 MeV, we registered a different decay chain of four consecutive α decays detected in a time interval of about 0.5 s, also terminated by SF. The decay properties of these synthesized nuclei are consistent with consecutive α-decays originating from the parent isotopes of the new element 115, ^{288}115 and ^{287}115, produced in the 3n- and 4n-evaporation channels with cross sections of about 3 pb and 1 pb, respectively.

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Effect of non-axial shapes of a nucleus on the height of fission barriers of heviest nuclei

Adam Sobiczewski

Soltan Institute for Nuclear Studies
Hoza 69, PL-00 681 Warszawa
Poland

Height of fission barrier is one of the essential factors deciding on the survival of a heavy compound nucleus and, thus, on the cross section for the synthesis of heaviest nuclei. Recent calculations of this height, using a large (multidimensional) deformation space, are usually done with the assumption of axial symmetry of a nucleus. It has been shown, however, that an extension of such a large space (which is difficult for computational reasons) by non-axial degrees of freedom may importantly decrease the height, by up to 1.5-2.0 MeV, significantly reducing (by up to 1.5-2.0 orders of magnitude) the calculated cross sections.

The objective of the paper is a systematic study of this effect for heavy and superheavy nuclei.

Manifestation of Shell Effects in Fission and Quasi-Fission of Super Heavy Nuclei produced in reactions with ^{48}Ca, ^{58}Fe and ^{64}Ni ions

M.G. Itkis
Flerov Laboratory of Nuclear Reactions, JINR,
141980 Dubna, Russia

Results of the experiments aimed at the study of fission and quasi-fission processes in the reactions $^{48}Ca+^{144,154}Sm$, ^{168}Er, ^{208}Pb, ^{238}U, ^{244}Pu, ^{248}Cm; $^{58}Fe+^{208}Pb$, ^{244}Pu, ^{248}Cm, and $^{64}Ni+^{186}W$, ^{242}Pu are presented in the work. The choice of the above-mentioned reactions was inspired by recent experiments on the production of the isotopes $^{283}112$, $^{289}114$ and $^{283}116$ at Dubna [1,2] using the same reactions. The ^{58}Fe and ^{64}Ni projectiles were chosen since the corresponding projectile-target combinations lead to the synthesis of even heavier elements.

The experiments were carried out at the U-400 accelerator of the Flerov Laboratory of Nuclear Reactions (JINR, Russia), the XTU Tandem accelerator of the National Laboratory of Legnaro (LNL, Italy) and the Accelerator of the Laboratory of University of Jyvaskyla (JYFL, Finland) using the time-of-flight spectrometer of fission fragments CORSET [3] and the neutron multi-detector DEMON [4,5], . The role of shell effects and the influence of the entrance channel on the mechanism of the compound nucleus fusion-fission and the competitive process of quasi-fission are discussed.

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Investigating the Region of Super Heavy Elements

Dieter Ackermann

Johannes Gutenberg-Universität Mainz and Gesellschaft für Schwerionenforschung GSI, Planckstr. 1, D-64846 Darmstadt

The search for superheavy elements has yielded exciting results for both the "cold fusion" approach with reactions employing Pb and Bi targets and the "hot fusion" reactions with ^{48}Ca beams on actinide targets. Nevertheless, major questions are still open. The reaction mechanism leading to the formation and survival of those heavy nuclei at cross sections in the range of pbarn is not at all understood. E.g. the empirical trend of exponential decrease of the maximum production cross section [1] is not understood in detail, neither is the deviation from this trend in the recent results for the ^{48}Ca induced reactions, performed at the FLNR of the JINR in Dubna [2,3,4]. For the latter a confirmation of the tentative Z assignment is still missing. On the other hand interesting information on the nuclear structure like a possible K-isomer in ^{270}Ds [5], the population of states at a spin of up to 22 $\hbar$ in ^{254}No [6], and a variety of features have been observed for actinide and trans-actinide isotopes. For a review of the nuclear structure of heavy actinide and trans-actinide nuclei see ref. [7]. Systematic investigation of these two aspects, reaction mechanism and nuclear structure, is essential for the understanding of the observations made for the heaviest nuclei and for a successful progress towards elements with even higher Z. The methods employed to study the reaction mechanism are fusion/fission excitation functions and recently also the compound nucleus partial wave distribution [8] which will be presented. Apart from the classical in-beam experiments and RDT (recoil decay tagging) experiments, radioactive decay studies, i.e. evaporation residue(ER)-α(-α) and ER-α-γ(-γ) coincidences of ER implanted into a solid state detector after a separator, are a powerful tool to investigate the structure of heavy nuclei. Our results obtained at the velocity filter SHIP at GSI for nuclei with an atomic charge of up to Z = 105 will be presented.

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Random Probability Analysis of Recent ^{48}Ca Experiments

J. B. Patin, M. A. Stoyer, J. M. Kenneally, K. J. Moody, D. A. Shaughnessy, N. J. Stoyer, J. F. Wild, and P. A. Wilk
Lawrence Livermore National Laboratory
Livermore, CA 94550 USA

V. K. Utyonkov and Yu. Ts. Oganessian
Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research
RU-141980 Dubna, Moscow Region
Russia

During the past few years, numerous experiments have been performed at the Dubna U400 Cyclotron Facility bombarding various actinide targets (^{238}U, ^{242,244}Pu, ^{243}Am, ^{245,248}Cm, & ^{249}Cf) with ^{48}Ca aimed at producing isotopes of elements 112-118. Recent independent data analysis of the information gathered during these experiments was performed at LLNL and corroborated the results observed at FLNR. The Monte Carlo random probability analysis developed at LLNL for such heavy element experiments was performed for all of the data and the implications from such analysis will be presented.

Much of the support for the LLNL scientists was provided by the US DOE under Contract W-7405-Eng-48.

FUSION, FISSION and QUASI-FISSION: UNIFIED CONSIDERATION

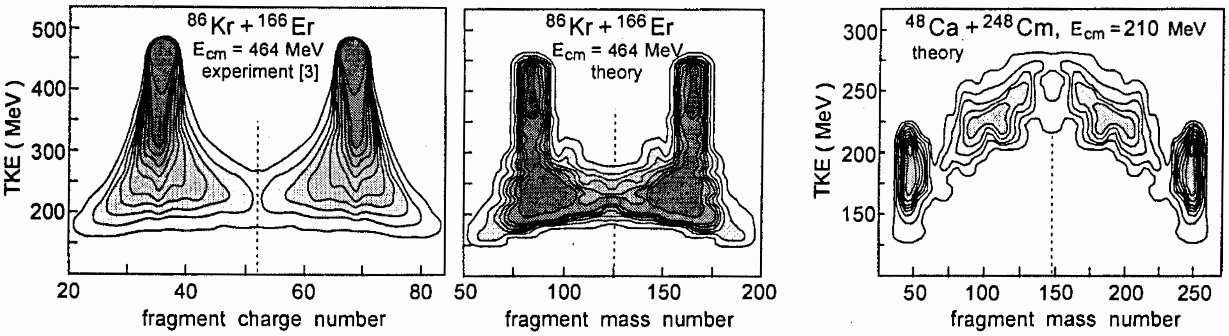
V.I. Zagrebaev[1] and W. Greiner[2]

[1] Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia
[2] Institut für Theoretische Physik, J. W. Goethe-Universität, Frankfurt am Main, Germany

The talk will focus on reaction dynamics of heavy ion collisions at low energies. The aim will be to review the things we have learned from recent experiments [1, 2] on fusion-fission reactions leading to the formation of super-heavy compound nuclei with Z≥102. From extensive theoretical analysis of these data it became especially clear that in the case of interaction of very heavy nuclei all the reaction channels (deep inelastic scattering, quasi-fission, fusion and fission) are strongly coupled and cannot be analyzed separately (independently) bearing in mind different time scale of these processes. The choice of a common set of collective degrees of freedom playing a principal role, the determination of the corresponding multi-dimensional driving potential and the derivation of the dynamic equations of motion regulating the whole evolution of the system in all the reaction channels are the main problems here.

The distance between the nuclear centers (or elongation of the system after overlapping of the nuclear surfaces), dynamic deformations, orientations of the deformed nuclei and mass rearrangement (mass asymmetry) are the most principal and strongly coupled degrees of freedom which can be used both for the entrance and for all the exit channels. On the basis of the two-center shell model idea we derived a common adiabatic driving potential in the entire configuration space which can be used for simultaneous description of the whole evolution process starting from the approaching of two heavy nuclei and ending in a compound nucleus configuration of the system and/or in deep inelastic and fission channels (normal and fast) with formation of fission fragments. This potential includes all the shell effects, it has appropriate asymptotic behavior (experimental masses of separated nuclei), right values of the fusion barriers in the entrance channel, and reasonable (macro-microscopic) values of the fission barrier. Special attention was paid to the transport equation for the mass rearrangement. It is well known that evolution of the other degrees of freedom can be described quite adequately by coupled Schrödinger or Langevin equations. However these equations are not suitable for description of the mass transfer. This discrete variable is described better by the master equation, which, in its turn, is not suitable for continuous variables. We succeeded in reduction of the master equation for the mass asymmetry to the corresponding Langevin type equation (valid also for separated nuclei) strongly coupled with equations for other degrees of freedom. Post and pre-scission nucleon evaporation was added to the obtained set of coupled equations which can be used now for simultaneous description of deep inelastic scattering, quasi-fission, and fusion-fission processes including rather accurate calculation of a probability for formation of super-heavy nuclei.

Results of our first calculations demonstrating good agreement with experimental data (see the figures) as well as the basic physical quantities such as nuclear viscosity and nucleon transfer rate will be discussed in the talk along with a time-scale analysis of the studied processes.



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Gamma spectroscopy of transfermium elements at the VASSILISSA set up

A.V. Yeremin[1], A.V. Belozerov[1], Ch. Briancon[2], M.L. Chelnokov[1], V.I. Chepigin[1], O. Dorvaux[3], V.A. Gorshkov[1], K. Hauschild[2], A.P. Kabachenko[1], A. Korichi[2], A. Lopez-Martens[2], O.N. Malyshev[1], Yu.Ts. Oganessian[1], A.G. Popeko[1], R.N. Sagaidak[1], A.V. Shutov[1], A.I. Svirikhin[1],

[1] - *FLNR JINR, 141980 Dubna, Russia.*
[2] - *CSNSM, IN2P3-CNRS, F-91405 Orsay Campus, France.*
[3] - *IReS, IN2P3-CNRS, F-67037 Strasbourg, France.*

In the recent years gamma spectroscopy of heavy nuclei have been very intensively developed in two directions. The first was the development of very efficient 4 Ge arrays which has allowed the properties of excited nuclear states to be determined via prompt γ-ray spectroscopy around the target. This type of experiment allows one to gain access to such important quantities as E_x, J^{π}, transition rates, deformations, and moments of inertia which can be compared with theoretical predictions. The Recoil Decay Tagging (RDT) method has made it possible to perform in-beam γ-ray and electron-spectroscopy in nuclei which have production cross sections at the order of 1 μb, or even less. The pioneering in-beam γ-ray spectroscopic studies in the transfermium nucleus ^{254}No were performed at the ANL, Argonne USA, [1] and the University of Jyväskylä, Finland, [2]. The ground state rotational band was observed up to a spin of 20 hbar. Recent experiments performed at Jyväskylä have probed nuclei in the Fm – Lr region having formation cross sections down to the 200 nb.

The second direction is the decay and/or isomeric γ and/or electron spectroscopy of daughter products of the evaporation residues implanted into the focal plane detectors of recoil separators. Such experiments were performed at the GSI, Germany with the use of the recoil separator SHIP and a large size Ge detector placed close to the focal plane Si detector array. The decay properties of the ^{256,257}Db and ^{255}Rf evaporation residues were studied and results were obtained for the first excited states in the ^{252,253}Lr and ^{251}No daughter isotopes via γ-ray spectroscopy [3].

A JINR – IN2P3 collaboration project **"Nuclear structure and reaction mechanism studies towards Super Heavy Elements: γ-electron Spectroscopy in very heavy nuclei at Z ~ 104"** was launched last year in Dubna. It is aimed at the study of nuclear spectroscopy of the transfermium elements using high intensity heavy ion beams of the U400 cyclotron, exotic targets and recoil separator VASSILISSA (FLNR JINR).

The first phase of our project will be devoted to the focal plane spectroscopy. The FLNR cyclotrons are capable of producing very intense beams, they can be used on unique radioactive rotating targets which allows one to reach very heavy (neutron rich) nuclei having formation cross sections of higher than 1 nb with appropriate statistics. In our set-up, the recoiling products will be selected by the recoil separator VASSILISSA. They will be then implanted into a position sensitive detector for the identification of their α-decay. In the backward direction from the focal plane detector electron detectors will be placed, it will allow covering 30 % of the hemisphere. In addition, the focal plane detector will be surrounded by 7 Ge detectors. The first full-scale experiment to be carried out during a month is planned for September, 2004. Preliminary it is planned to investigate the reactions leading to the isotopes of Nobelium and Dubnium and their daughter products. At present test experiments using two Ge detectors are underway.

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EVALUATION OF CHARGE DISTRIBUTIONS OF ^{217}Th AND ^{254}No IONS SEPARATED BY VASSILISSA

A.G. Popeko, A.V. Belozerov, V.I. Chepigin, A.P. Kabachenko, O.N. Malyshev, R.N. Sagaidak, A.V. Shutov, A.I. Svirikhin, A.V. Yeremin

Flerov Laboratory of Nuclear Reactions, JINR, 141980 Dubna, Russia

The electrostatic separator VASSILISSA is used since 1987 for the exploring of fusion reactions [1]. In order to improve the mass resolution, VASSILISSA was upgraded: a mass analyzer, based on a 37° dipole magnet and a time-of-flight measuring system was installed behind the separator [2].

Ions leaving the target decay by converted transitions and may have a very broad charge distribution with unknown parameters. A thin (20-30 μg/cm^2) carbon foil placed downstream the target corrects this distribution and makes it predictable. For ER's mean charge <q> calculations semi-empirical formulae by Nikolaev [3] or Shima [4] are usually used. Experimental data on <q> for ions heavier than Pb are very scarce and experimental check of the predictions becomes important.

In our experiments we studied ionic charge distributions of ^{217}Th produced in the ^{174}Yb(^{48}Ca,5n) reaction and those of ^{254}No produced in the ^{208}Pb(^{48}Ca,2n) reaction.

Due to limited angular, energy and charge acceptances of the separator the primary charge distributions of ions passing it will be significantly distorted. To restore the charge distribution to an equilibrium one we placed the second recharging carbon foil immediately upstream the 37° dipole magnet. Ions separated according to their magnetic rigidities (charges) were detected by the position sensitive focal plane detector. Decay rates at different dipole settings were used for the evaluation of the corresponding charge distributions. The results are summarized in the Table.

Table. Charge distribution parameters of ^{217}Th and ^{254}No ions measured at VASSILISSA.

Nucleus	E(MeV)	Shima [4]	Nikolaev [3]		This work	
		<q>	<q>	σ_q	<q>	σ_q
^{217}Th	38.6	20.2	18.5	2.3	20.4±0.2	1.7±0.2
^{254}No	36.6	20.0	18.0	2.3	17.6±0.3	1.9±0.3

The obtained data support an earlier observation that for relatively "light" (Po – Th) "fast" ions the experimental <q> values are more close to Shima's [4] predictions. For heavier "slow" ions (Cf – No) the evaluated data are better described by Nikolaev's formula [3]. We believe that many additional measurements are needed before an adequate semi-empirical formula can be derived. In the meantime, we note that the currently used charge state prediction formulae should be used with caution.

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Fusion-fission dynamics for synthesis of superheavy elements

Y. Aritomo[1], M. Ohta[2], T. Materna[3], L. Stuttgé[4] and F. Hanappe[3]

[1]*Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia,*
[2]*Department of Physics, Konan University, 8-9-1 Okamoto, Kobe, Japan*
[3]*Universite Libre deBruxelless, Belgiue*
[4]*Institut de Recherches Subatomiques, Stasbourg, France*

Recently the production of new superheavy elements are reported at Dubna by hot fusion reaction [1] and GSI by cold fusion reaction [2]. Using the facility in Riken, the nucleus (Z=110 and 111) are produced also in cpld fusion reaction and measured the excitation function of evaporation residue cross section precisely [3].

In the theoretical calculation, the evaporation residue cross section is obtained as a product of the fusion probability forming a compound nucleus and its survival probability in the competition with fission process. In superheavy mass region, an substantial uncertainly becomes to be involved, i.e., the uncertainly of the potential landscape near contact configuration of colliding nuclei affects the estimation of fusion probability, and the uncertainly of the fission barrier height of compound nucleus and the level density parameter used in the statistical calculation affects the estimation of the survival probability. In this sense, the theoretical framework to estimate the evaporation residue cross section is not confirmed now. Here, first we would like to discuss on the fusion process and investigate more accurate estimation of the fusion probability.

Though the reaction mechanism is not well understood, a lot of experimental data were become available. For example, the mass and total kinetic energy distributions of fission fragments were extensively measured at Dubna [4]. The emission of neutrons in coincidence with fission fragments has been studied by DeMon group [5].

Using the fluctuation-dissipation model, we try to investigate the fusion-fission process. In this work, we employ the Langevin equation throughout the fusion-fission process taking into account the neutron emission during the process. We adopt a three-dimensional nuclear deformation space with the two-center parametrization. The three collective parameters are treated as follows: z_0 (distance between two potential centers), δ (deformation of fragments) and α (mass asymmetry of the colliding partner).

By analyzing the mass distribution, we can distinguish between the fusion-fission process (FF) and quasi-fission process (QF). The mechanism of FF and QF are clarified by their trajectory on the 3-dim potential energy surface.

We estimate the neutron multiplicity during the fusion-fission process. The neutron multiplicity directly depends on the time scale of trajectory, so we can investigate the different class of the dynamical process more precisely. We can directly compare the theoretical results with the experimental data. In the reaction ^{58}Ni+^{208}Pb which was measured by DeMon group [2], the neutron multiplicity has two peaks, near 4 and 8 neutron emission. We can see clearly that the first peak is connected with the trajectory of quasi-fission process and second one with fusion-fission process. The multiplicity depends on the traveling time of trajectories from the contact point to the scission point.

Such trajectory calculation in the deformation space is strongly influenced by the potential energy surface. Here we employ the two-center shell model to calculate the potential energy surface. However, in large mass asymmetry region, it seems that the two-center shell model dose not work well near the contact point. So we should investigate precisely the potential energy surface near the contact point and refine it using grand state mass near contact point. We would like to discuss on the point and how to change the trajectory on the refined potential energy surface.

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A Microscopic Description of the α-Decay Chains of Z = 115 and 118

M. Gupta[1,2], A. Bhagwat[2], and Y. K. Gambhir[2]

[1] *Manipal Academy of Higher Education, Manipal-576119, India.*

[2] *Department of Physics, IIT-Powai, Mumbai-400076, India.*

Abstract

Microscopic calculations for nuclei in the α-decay chains of Z=115 and 118 are carried out. The ground state properties are obtained using the self-consistent Relativistic Mean Field (RMF) theory with the NL3 Lagrangian parameter set. The pairing correlations are incorporated in the simple BCS procedure and also through the self-consistent Relativistic Hartree Bogliubov (RHB) prescription employing the finite range Gogny-D1S interaction. The RMF densities are then used to obtain the α-daughter interaction energy in the Double Folding model with the density dependent M3Y (DDM3Y) effective nucleon-nucleon interaction. Finally, the α-decay half-lives ($T_{1/2}$) of the parent nuclei are calculated in the WKB approximation using the Super-Asymmetric Fission Model.

The ground state properties including the α-decay Q-values (Q_α) agree well with the corresponding experimental data as recently reported by the Dubna Group.

It is seen that $T_{1/2}$ is extremely sensitive to small variations in Q_α. If experimental Q-values are used, α-decay half-lives are well reproduced indicating that the interaction potential is reliable.

Similar calculations as those done for the two known Z=115 chains are carried out for an α-decay chain of the currently unknown Element 118, for possible experimental verification in the future.

Systematics of Superheavy Nuclei: Microscopic Description

Y. K. Gambhir[1], A. Bhagwat[1] and M. Gupta[1,2]

[1] *Department of Physics, IIT-Powai, Mumbai-400076.*

[2] *Manipal Academy of Higher Education, Manipal-576119.*

Abstract

Extensive microscopic calculations for the description of the nuclei appearing in α - decay chains of the super-transactinides ($108 \leq Z \leq 118$) have been carried out. The numerical calculations proceed in two steps. First, the ground state properties like binding energies radii, densities, are obtained in the framework of the self-consistent Relativistic Mean Field (RMF). The most successful Lagrangian parameter set NL3 is used and the pairing correlations are incorporated in the simple constant gap approximation (BCS - type) and also self-consistently through the Bogoliubov transformation (Relativistic Hartree Bogliubov (RHB) prescription). The finite range Gogny-D1S interaction for pairing is used while solving the RHB equations. The results, including the α - decay Q - values, agree well with the corresponding experimental data (where available).

Next, the calculated RMF densities are used to derive the projectile-daughter interaction energy using the Double Folding (DF) model with the density dependent M3Y (DDM3Y) effective nucleon-nucleon interaction. This in turn is used together with theoretical Q-values to calculate the α - decay half lives of the parents in the Super - Asymmetric Fission Model (SAFM) in the WKB approximation.

The resulting half lives do agree qualitatively with the experiment. However, the half lives are very sensitive to the explicit Q - values: small variations in Q-values (to within a couple of hundred keV) are seen to dramatically affect the half-lives, sometimes even up to an order of magnitude. It is observed that if experimental Q-values are used, the α - decay half-lives are well reproduced indicating that the interaction potential is accurate and may be employed with confidence in other reaction studies.

To further assess the accuracy of the ground state properties, the RMF densities are used to calculate the charge changing cross sections recently measured with radio-active ion beams. The calculations reproduce the experiment well.

Delayed fission of heavy nuclei

N.K. Skobelev

Joint Institute for Nuclear Research,
Flerov Laboratory of Nuclear Reactions,
141980, Dubna, Russia

Delayed fission is one of the fission modes of low-lying excited states of nuclei along with spontaneous fission and spontaneous fission of shape isomers. The first observation of this phenomena was made in 1966 at JINR in experiments devoted to the synthesis of neutron-deficient heavy nuclei to look for spontaneously fissioning shape isomers.

Fission products with half-life of the order of minutes were observed. The nuclei responsible for fission products were identified and it was concluded that they are the precursors of fissioning nuclides: their daughter nuclei are likely to undergo fission from an excited state after electron capture of the parent nucleus. Detailed interpretation of the decay of the nuclear predecessors ^{228}Np, ^{232}Am and ^{234}Am entering into the delayed-fission process was done also. In addition, other neutron-deficient nuclei in the region from neptunium to mendelevium, as emitters of delayed fission, were synthesized in reactions with heavy ion beams at FLNR.

Also β-delayed fission of neutron-rich nuclei, obtained in nuclear reactions at accelerators, was studied. The full set of experiments showed that delayed fission is a common decay channel of heavy nuclei with sufficiently large Q_{β}.

Now we have possibilities to make a few new delayed fissioning isotopes of neptunium, berkelium and einsteinium daughter products which can undergo fission from excited states.

Structure and decay of heavy and superheavy nuclei

Zhongzhou Ren[1,2] and Chang Xu[1]

[1] *Department of Physics, Nanjing University, Nanjing 210008, China*

[2] *Center of Theoretical Nuclear Physics, National Laboratory of Heavy-Ion Accelerator, Lanzhou 730000, China*

Abstract

The structure and α-decay of heavy and superheavy nuclei are systematically studied. This includes the rare decay from the naturally occurring nuclide ^{209}Bi [Marcillac *et al.*, Nature (London) **422**, 876 (2003)] and the decays of superheavy elements with Z=106-118. Marcillac *et al.* has measured that ^{209}Bi has an α-decay energy $Q_\alpha = 3.137 \pm 0.002$ MeV and a half-life $T_{1/2} = (1.9 \pm 0.2) \times 10^{19}$ years. This half-life is the longest in all known α-decays. The model of α-decay can reproduce this exceptionally long lifetime.

For superheavy elements with Z=110-118 the theoretical half-lives also agree reasonably with the experimental values. This suggests the present experimental data of half-lives are consistent with the experimental data of decay energies. It indicates that the claims of the synthesis of new elements with Z=110-118 at GSI and at Dubna are reliable. The shell effect of superheavy nuclei is also discussed.

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Neutron detector at the focal plane of the set up VASSILISSA

A.I. Svirikhin, 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, A.V. Yeremin.

FLNR JINR, 141980 Dubna, Russia.

Spontaneous fission is one of important modes of radioactive decay of nuclei with atomic number $Z \geq 100$. A big number of even – even isotopes of transfermium elements decay solely by spontaneous fission. Even in the case of some odd – mass heavy nuclei such as, for example, ^{259,261}Lr and ^{261,263}Db the spontaneous fission probability is comparable with the probability of α – decay. 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].

Recoil in – flight separator VASSILISSA [2] is widely used for the synthesis and study of decay properties of heavy and superheavy nuclei. A high level of suppression of beam particles and unwanted reaction products, having high production rates in the region of charge and mass of target nuclei, has been achieved. Slow heavy evaporation residues (ER's) which are studied in complete fusion reactions with heavy ions after passing through such experimental set – up and time – of – flight detectors are implanted in the focal plane semiconductor detectors. It makes possible to measure half – lives of the investigated nuclei together with energies of α – decay and total kinetic energy release of fission fragments from spontaneous fission of transfermium nuclei. In addition, extremely low background conditions at the focal plane of the separator, placed behind a 2 m concrete wall, allow one to build sophisticated detector systems around the focal plane implantation detector.

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 efficiency of detection of one neutron measured using a ^{248}Cm source was 25 %. A multiplicity distribution of prompt neutrons emitted in spontaneous fission of ^{252}No, formed in the reaction ^{48}Ca(^{206}Pb,2n), was measured in test experiments and equaled to 4.43 ± 0.45. This value is in good agreement with that from literature (4.15 ± 0.3) [3].

It is planned in the future to measure the TKE and multiplicity distribution of prompt neutrons in spontaneous fission of other No isotopes and isotopes of heavier elements.

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METHODS OF IDENTIFICATION OF SUPRHEAVY ELEMENTS BASED ON THE ALPHA-DECAY DATA

Badaev O.P.[1], *Kurgalin S.D.*[2], *Scheid W.*[3], *Tchuvil'sky Yu.M*[1].

[1] *Moscow State University, Russia;* [2] *Voronezh State University, Russia;* [3] *Justus-Liebig-University Giessen, Germany*

Two new approaches are introduced into the analysis of the characteristics of superheavy nuclei.

First one is the method of inter- and extrapolation of nuclear masses and as a consequence the energy yields of alpha-decay Q_α. Interpolational procedure is based on the representation of the binding energy surface $E(Z,N)$ inside the certain rectangle region $Z_{i-1} \le Z \le Z_i$ $N_{k-1} \le N \le N_k$ as a second order polinomial of Z and N (continuity of the surface on the boundaries is required). The quality of the interpolation can be demonstrated for the known nuclear masses in the area $82 < Z \le 104$ as an example. Indeed, the values of deviation of the interpolated masses form the experimental ones for 92 per cent cases are less than 100 KeV and in the sole case (among more than 200) this value turns out to be grater than 200 KeV. Stability of some differential characteristics of the surface $E(Z,N)$ in rather wide areas is used for the extrapolation.

The essence of the second approach is as follows. The analysis of the values of the "experimental" spectroscopic factors W_α, extracted from the practically full data concerning alpha-decay of even-even nuclei are concentrated in a very narrow interval if one uses a physically justified potential. In the present work well known MacFadden-Satchler potential is used. Root mean square deviation of the values $lg\, W_\alpha$ is about 0.36 for these data. If one limit himself by the nuclei heavier than ^{208}Pb than this deviation turns out to be about 0.26. Therefore the averaged value W_α (together with the value of penetrability of the barrier created by the discussed potential) can be successfully used for the calculation of alpha-decay width of any even-even nucleus including superheavy one. It should be noted that r.m.s. deviation of the proposed method is smaller than that of the various versions of Geiger-Nuttall approach. Moreover the discussed approach seems to be workable with certain reliability in odd and odd-odd nuclei areas. Naturally in these cases the first step of the analysis is to place investigated alpha-transfer into a certain category of decay (favored, semihindered, etc.).

Known chains of alpha-decay of superheavy elements are studied in the framework of the methods developed. The results do not come into conflict with the conclusions concerning of Z and N values of superheavy isotopes obtained by use of the other procedures.

ON ANALYSIS OF DATA OF RADIOACTIVE DECAYS UNDER CONDITIONS OF POOR STATISTICS AND SMALL OBSERVATION TIME.

Zlokazov V.B.,
FLNP, JINR, RUSSIA. E-mail = zlokazov@nf.jinr.ru

Let a set of radioactive atoms be given, which is equal to N at a time $t = 0$. Events - decays of these atoms - are described by a random quantity ξ, subject to the distribution function

$$P(\xi < t) = 1 - exp(-t/T), \quad t \in [0, \infty), \tag{1}$$

The main problem of the analysis of samples of such events is the evaluation of parameters T and N.
One can show that under the least favorable conditions of the experiment (poor statistics and/or small observation interval $[0, B]$, $B << T$) the chances of a successful solution of this problem are very small.
In particular, the equation of the maximum likelihood estimator for T is practically unsolvable in this case.
Let us introduce two random quantities: n_1 and n_2 - sums of registered decays in intervals $[0, B]$ and $[B, 2B]$, respectively. It is obvious that

$$\hat{E}n_1 = N/(1 - exp(-B/T)), \ \hat{E}n_2 = N/(exp(-B/T) - exp(-2B/T))$$

Here $\hat{E}$ is the operator of expectation. We can build the following estimator of T:

$$\hat{T} = -B/ln(\frac{n_1}{n_2}). \tag{2}$$

Obviously, for the analysis only exponential-like curves are suitable. For instance, use can be made of the following criterion for testing the inequality $n_2 < n_1$ for statistical significance:

$$n_1 > n_2 + 3 \cdot \sigma(n_2). \tag{3}$$

From (3) we can obtain restrictions on

- statistics level N at B/T given
- or the length of the observation interval B at statistics N given,

which provide for a successful analysis of such data.
The restrictions are very hard and often non-realistic. Here an idea of an estimate of a lower parameter bound instead of parameter itself is very fruitful. The lower parameter bound is a quantity, which with a certain (calculable) probability is less than T, but greater than the length of the observation interval B.
In our case such an estimator can be obtained, e.g., from such a relation

$$n_1 - n_2 \leq k\sigma(n_1 + n_2), \text{ on condition that } n_1 > n_2. \tag{4}$$

where k is any number, and σ - deviation function.

Chemistry of SHE: What Allows us to Judge the Bulk Properties of Compounds from the Behavior of Single Molecules?

Ivo Zvára

Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, Dubna, Russian Federation

In studies of chemistry of elements 104 to 107, the only bulk property of compounds derived from one-atom-at-a-time experiments has been the volatility of some halides or oxohalides. The appropriate characteristic quantities are the energies (enthalpies) of sublimation or vaporization, the latter being essentially proportional to the boiling point of liquid. The mere base for evaluation of the required values has been the empirical correlation between the adsorption enthalpies on quartz (measured in gas chromatography experiments) and vaporization (sublimation) energies of the compounds concerned. The correlation holds for a number of compounds of common elements. Moreover, the values of adsorption and vaporization energies prove to be quite similar.

Obviously, in-depth understanding of the origin of the correlation is very desirable, notably because certain difference in volatility of the compound of a very heavy new element and its closest lighter congener might indicate manifestation of relativistic effects in chemical properties. Meanwhile, explanation of the above facts is by no means trivial or evident. On the one hand, we believe to deal with, say, a molecule $TaCl_5$ on the surface of SiO_2, on the other hand – the same molecule in liquid tightly surrounded with 12 its replicas in the first solvation layer. For what reasons might be the energies necessary to make the molecule free in the two cases equal?

We believe that the clue is in the real structure of the column surface which is far from being just alternate sequence of Si and O atoms. Actually, the original surface of "fresh" silica includes up to 5 OH groups attached to Si atoms per 100 Å^2. The carrier gas in the chromatographic experiments contains halogenation agents ($SOCl_2$, HCl, BBr_3, etc.) to produce the required compounds of radioelements. The hydroxyls are quite reactive and the agents further modify the surface to make it to some degree covered by the attached halogen atoms and fragments of the agent molecules. So, the nature of adsorption forces becomes closer to the forces in pure liquid. And finally, the actual surface of the tubular columns is rough, even down to the atomic scale. Hence, the modified surfaces may contain traps in which the adsorbed molecule is almost surrounded by the halogens and fragments mentioned above – almost like the situation in liquid. It means that we can expect the column surface to be heterogeneous in adsorption properties, with the adsorption energies within some limits, the higher being around the vaporization energy. Whatever is the spectrum of the adsorption energies, due to the exponential dependence of retention time in column on E_a/RT, an experiment will yield the effective adsorption energy value approaching the maximum energy in the spectrum.

Thus, the outlined picture of adsorption explains the origin of the correlation of interest. The author will also present more quantitative discussion based on his recent new formula for calculation of the boiling points / vaporization energies.

Future experiments on the chemical properties of superheavy elements

Andreas Türler

Institut für Radiochemie, Technische Universität München, D-85748 Garching

The knowledge and understanding of the chemistry of the superheavy elements, especially of the early transactinides Rf, Db, and Sg and their compounds, both experimentally and theoretically, is nowadays quite extensive as documented by a first textbook entitled "The Chemistry of Superheavy Elements" edited by M. Schädel [1]. While rapid chemical separations in aqueous solution were (and are) the method of choice for detailed investigations of Rf and Db, the development of gas-phase chemical separation methods have allowed first chemical studies of increasingly heavier transactinide elements.

The spectacular results obtained at Flerov Laboratory in Dubna using ^{48}Ca ion beams and targets of ^{238}U, ^{242,244}Pu, ^{243}Am, ^{245,248}Cm and ^{249}Cf to synthesize isotopes of elements 112, 114, 115, and, 116 [2] give chemists the perspective to experimentally investigate the chemistry of even the heaviest known elements. Especially since some of the nuclides and their decay products attributed to elements Rf, Db, Sg, Bh, Hs, Ds, 111, 112, 113, and 114 seem to have half-lives of the order of seconds to even hours.

In the last couple years, chemists have made a quantum leap and are now working with nuclides that can be produced with picobarn (10^{-36} cm^2) cross sections only, as demonstrated by the first chemical investigations of bohrium and hassium [3,4].

This spectacular progress however is limited to a few selected cases which chemically are extremely favorable. One such case is also element 112 in its elemental state. First experiments made in Dubna [5,6] and recently at GSI [7] seem to indicate a quite spectacular difference in chemical behavior between element 112 and its lighter homolog Hg in the elemental state. Compared to chemical investigations of the early transactinide elements Rf through Hs, where always the highest possible oxidation state was investigated, now with elements 112 through 118, which are expected to be moderately to highly volatile in the elemental state, the influence of relativistic effects of the valence electrons should become noticeable in direct experimental investigations. These relativistic effects might be responsible for some quite dramatic differences in chemical behavior as this seems to be the case in the adsorption properties of element 112 compared to its lighter homologue Hg.

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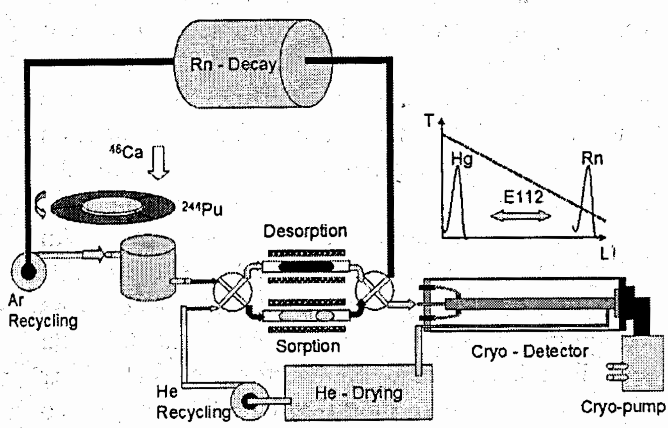
Approaching experiments with element 114
First results of test experiments

A.B. Yakushev[1], W. Brüchle[2], E. Jäger[2], E. Schimpf[2], M.Schädel[2], A. Türler[1], B. Wierczinski[1]

[1] Institut für Radiochemie TUM, München, Germany
[2] Gesellschaft für Schwerionenforschung mbH, Darmstadt, Germany

From its ground state electronic structure, E114 belongs to group 14 of the Periodic Table. Its nearest homologue is Pb. Classical extrapolations predict 114 to behave as a metal with enhanced volatility compared to Pb. Relativistic quantum chemistry predicts stabilized spherical s and $p_{1/2}$ and destabilize $p_{3/2}$- and d- orbitals. Consequently, the chemical behavior of 112 and 114 may approach the one of noble gases in volatility and chemical inertness[1]. The first experiments with 112 indicated qualitatively that 112 is chemically more inert than Hg[2]. However, for a first survey experiment on the chemistry of element 114, one needs to separate element 114 based on both predictions - classical extrapolations and relativistic calculations. Therefore we are developing for the first experiment a combination of two processes: 1) synthesis and rapid chemical separation of 114 by adsorption on a noble metal surface, and 2) desorption, gas transportation and detection of 112 as a daughter nuclide after alpha-decay of element 114. This separates the volatile metals Pb, Bi and Po, as well as the noble gas Rn and allows a unique identification of 114 and 112.



The envisioned approach can be realized with two alternating steps using two columns one for adsorption and one for desorption (see Figure). In a first step, reaction products are transported by He or Ar gas from a recoil chamber to a column kept at "low" temperature. 114 should adsorb on a chemical active surface of the first column and gaseous Rn passes through the column with the flowing gas. Simultaneously, 112, as the 114 decay product, will be evaporated from the second column kept at a high temperature and will be transported to a detection system by pure He gas flow. After a few seconds valves switch positions, the high-temperature column is cooled and the low-temperature column is heated fast. In a second step, 112 as the decay product of the adsorbed 114 is evaporated from the first column and adsorption of E114 takes place at the second column. This process is continuing as a two-step cycle. To develop this approach we are performing test experiments on the gas chromatography of Pb, Hg and Rn to choose suitable materials for chemical filters and for the best temperature regime. First test experiments on gas chromatography of Pd and Hg on a surface of noble metals (Au, Pd, Pt) were done at GSI. The chemical yield of short-lived Pb isotopes from a heated recoil chamber was optimized, as well as adsorption of Pb in chromatographic column and desorption of Hg from noble metal surface. The yield of Hg isotopes was detected by alpha decay using 4 pairs PIPS detectors covered with thin gold layer.

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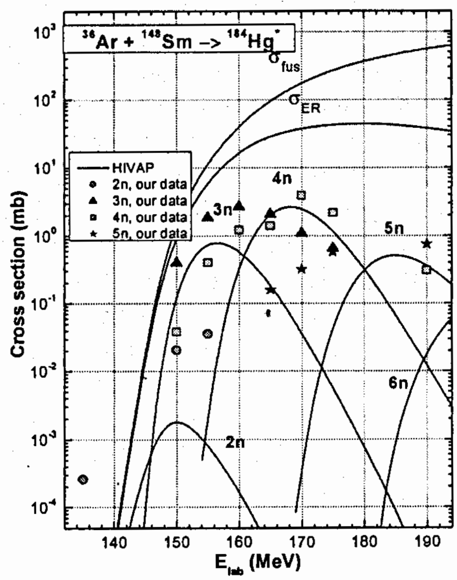
Cross sections measurement in fusion reactions $^{36}Ar(^{148}Sm, xn)$

A. Yakushev [1], W. Brüchle [2], E. Jäger [2], A. Popeko [3], S. Reitmeier [1], E. M. Schädel [2], Schimpf [2], R. Sagaidak [3], A. Shutov [3], A. Türler [1], A. Yeremin [2]

[1] Institut für Radiochemie TUM, München, Germany
[2] Gesellschaft für Schwerionenforschung mbH, Darmstadt, Germany
[3] Flerov Laboratory of Nuclear Reactions JINR, Dubna, Russia

On the way to neutron-rich superheavy elements (SHE) very exciting results were observed in ^{48}Ca induced reactions with heavy actinide targets[1]. These SHE isotopes have life times several orders of magnitude longer than isotopes produced in "cold fusion" reactions. In the future, reactions with neutron-rich radioactive ion-beams may open a possible path for a further increase of the neutron excess in SHE nuclides. It is of great interest to pursue the "hot-fusion" path and to investigate the projectile-isospin dependence of heavy element fusion-evaporation residue cross sections at Coulomb barrier energies. Presently, limited beam intensities do not allow performing systematic studies directly in the region of SHE and heavy actinides with picobarn and nanobarn cross sections, respectively.

The system $_{18}Ar$ on $_{62}Sm$ is a well studied heavy-ion reaction[2]. We opted for this projectile-target-Z combination to extend these studies to probe the neutron excess in radioactive Ar projectiles - up to ^{44}Ar – on the evaporation residue cross section at near barrier energies. While ^{42}Ar and ^{144}Sm have a similar neutron-excess of about 1.32 the N/Z-ratios for the combination ^{36}Ar on ^{148}Sm are 1.00 and 1.39, and for ^{44}Ar on ^{144}Sm they are 1.44 and 1.32, respectively. It is noteworthy to mention that for the latter system the neutron excess of the projectile exceeds the one of the target. A comparison of results from the spherical, n-rich nuclei ^{44}Ar (off-shell, N/Z=1.44) and ^{48}Ca (on-shell, N/Z=1.40) can yield information on the influence of shell effects. An important aspect in the evaluation of the results will be the comparison with calculated cross sections. Based on known experimental data such calculations were performed for $^{42,44}Ar$ projectiles using a modified HIVAP code[3]. To begin our experimental program aiming finally at using n-rich Ar projectiles we selected the $^{36}Ar(^{148}Sm; xn)$ reaction as a first experiment to span a very large range of target-projectile combinations. The isotopes $^{179,180,181,182}Hg$ were measured. Cross sections for these isotopes, evaluated from the measured α-spectra, are compared with cross sections theoretically predicted by R. Sagaidak (see Figure). Low statistics limited the results for the 2n and 5n channels. The experimental data are typically uncertain by a factor of 2.



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Fission and quasifission processes in the reactions $^{44}Ca+^{206}Pb$ and $^{64}Ni+^{186}W$, leading to the formation of compound nucleus ^{250}No

G. Kniajeva[1], A.Chizhov[1], M. Itkis[1], S. Khlebnikov[2], E. Kozulin[1], V. Lyapin[3], V. Rubchenya[3], W. Trzaska[3], V. Voskressenski[1]

[1] *Flerov Laboratory of Nuclear Reaction, Joint Institute for Nuclear Research, Dubna, Russia*
[2]*Khlopin Raduim Institute, St. Petersburg, Russia*
[3]*Department of Physics, University of Jyvaskyla, Finland*

In order to better understand the formation of a compact superheavy compound system, future experiments should clearly separate the fusion-fission from the quasifission component. The competition between compound nucleus fission and quasifission is probably determined by the properties of di-nuclear configuration at contact, where entrance-channel effects are expected to play the major role in the reaction dynamics.

Mass, kinetic energy and angular distributions of fragments were measured in the decay of ^{250}No compound nucleus, formed in two different reactions: $^{44}Ca+^{206}Pb \rightarrow ^{250}No$ (Z_pZ_t = 1640) and $^{64}Ni+^{186}W \rightarrow ^{250}No$ (Z_pZ_t = 2072) at the same excitation energy E^*=40MeV. The measurements were performed by using the large acceptance set-up CORSET, consisting of two time-of-flight telescopes detecting the two correlated fission fragments, placed in the scattering chamber. Four surface-barrier detectors, installed at the 10^0 to the beam line, were used for normalization on Rutherford cross section.

Mass-energy distributions for these systems are different. In the case of the $^{44}Ca+^{206}Pb \rightarrow ^{250}No$ reaction (more mass asymmetric entrance channel) mass distribution is symmetric with small asymmetric "shoulders" and fusion-fission is a dominate process, while in the case of the $^{64}Ni+^{186}W \rightarrow ^{250}No$ reactions mass distribution is asymmetric, quasifission process prevails and its contribution is great than 70 %.

Shell effect manifestation in mass-energy distributions of fission fragments of nuclei with Z=102-116

E.V.Prokhorova[1], A. A. Bogatchev[1], O. Dorvaux[2], G. Giardina[3], F. Hanappe[4], I. M. Itkis[1], M. G. Itkis[1], M. Jandel[1], J. Kliman[1], G. N. Kniajeva[1], N. A. Kondratiev[1], E. M. Kozulin[1], L. Krupa[1], T. Materna[4], Yu. Ts. Oganessian[1], I. V. Pokrovsky[1], N. Rowley[2], Ya. Rusanov[5], L. Stuttge[2], V. M. Voskresenski[1]

[1]*Flerov Laboratory of Nuclear Reactions, JINR, 141980 Dubna, Russia*
[2]*Institut de Recherches Subatomiques, F-67037 Strasbourg Cedex, France*
[3]*Dipartimento di Fisica dell' Universita di Messina 98166 Messina, Italy*
[4]*Universite Libre de Bruxelles, 1050 Bruxelles, Belgium*
[5]*Institute of Nuclear Physics of the National Nuclear Center, 480082, Almaty, Kazakhstan*

The series of experiments devoted to investigation of the process of formation and decay of superheavy nuclei in the reaction $^{48}Ca+^{208}Pb$, ^{232}Th, ^{238}U, ^{244}Pu, $^{58}Fe+^{208}Pb$,^{232}Th were performed at the U400 accelerator of Flerov Laboratory of Nuclear Reactions (JINR, Russia).
The experiments were carried out with use double-arm time-of-flight spectrometer CORSET, and the mass-energy distributions of reaction products and fusion-fission and capture cross-sections were deduced. We study the influence of reaction entrance channel on the competition between fusion-fission and quasi-fission processes. Strong manifestation of the shell effects in mass distributions of quasi-fission products was observed.
The multimodal fission phenomena were found for superheavy nuclei ^{256}No, ^{266}Hs at low excitation energies. Its properties can be explained in the frame of the classical modal approach, based on the valley structure of the potential energy surface in the deformation space of the fissioning nucleus.

MULTIMODAL FISSION IN HEAVY IONS INDUCED REACTIONS

I.V. Pokrovsky[1], S. Beghini[6], A.A. Bogachev[1], L. Calabretta[7], L. Corradi[6], G.G. Chubarian[3], O. Dorvaux[4], F. Hanappe[5], B.J. Hurst[3], M.G. Itkis[1], J.M. Itkis[1], A. Kelic[4], V. Kinnard[5], N.A. Kondratiev[1], E.M. Kozulin[1], K. Lukashin[7], C. Maiolino[7], G. Montagnoli[6], S.I. Mulgin[2], Yu.Ts. Oganessian[1], E.V. Prokhorova[1], N. Rowley[4], A.Ya. Rusanov[2], V.S. Salamatin[1], F. Scarlassara[6], Ch. Schmitt[4], R.P. Schmitt[3], A.M. Stefanini[6], L. Stuttge[4], S. Szilner[6], M. Trotta[6], A.M. Vinodkumar[6], S.V. Zhdanov[2]

1 *Flerov Laboratory of Nuclear Reaction, Joint Institute for Nuclear Research, 141980, Dubna, Russia*

2 *Institute of Nuclear Physics of the National Nuclear Center of Kazakhstan, 480082, Alma-Ata, Kazakhstan*

3 *The Cyclotron Institute, Texas A&M University, 77843, College Station, Texas, USA*

4 *Instutut de Recherches Subatomiques, IN2P3-CNRS/Universite Louis Pasteur, BP28, F-67037, Strasbourg, France*

5 *Universite Libre de Bruxelles, B1050, Bruxelles, Belgium*

6 *Laboratori Nazionale di Legnaro, Istituto Nazionale di Fisika Nucleare, 35020, Legnaro(Padova), Italy*

7 *Laboratorio Nazionale del Sud, Istituto Nazionale di Fisika Nucleare, 95123, Catania, Italy*

The talk presents a review of the experimental works performed in a wide collaboration and dedicated to the study of the multimodal fission phenomenon. Mass and energy distributions of the fission fragments from the fission of $^{216,218,220}Ra$, $^{220,224,226}Th$ and ^{234}Pu compound-nuclei were measured and analyzed with relation to the fission modes presence. Neutron and γ-quanta emissions accompanied the fission process of ^{226}Th compound-nucleus were measured and analyzed the same way.

Neutron Emission in Fission and Quasi-Fission

I.M. Itkis[1], S. Beghini[2], A.A. Bogachev[1], A.Yu. Chizhov[1], G. Chubarian[3], G. Giardina[4], L. Corradi[5], O.Dorvaux[7], F. Hanappe[6], M.G. Itkis[1], J. Kliman[1], V.Kinnard[6], G.N. Knyazheva[1], N.A. Kondratiev[1], E.M. Kozulin[1], I.V. Korzyukov[1], L. Krupa[1], T. Materna[6], G. Montagnoli[2], Yu.Ts. Oganessian[1], I.V. Pokrovski[1], E.V. Prokhorova[1], N. Rowley[7], A.Ya. Rusanov[8], R.N. Sagaidak[1], F. Scarlassara[2], A.M. Stefanini[5], L. Stuttge[7], M. Trotta[5], V.M. Voskressenski[1]

[1]*Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia, e-mail: jitkis@nrmail.jinr.ru*
[2]*Dipartimento di Fisica, Universita di Padova, Padova, Italy*
[3]*Texas A&M University, Cyclotron Institute, College Station, Texas, USA*
[4]*Departament of Physics, University of Messina and INFN, Messina, Italy*
[5]*Laboratorio Nazionali di Legnaro, Instituto Nazionale di Fisica Nucleare, Legnaro (Padova), Italy*
[6]*Universite Libre de Bruxelles, Belgique*
[7]*Institut de Recherches Subatomiques, Strasbourg, France*
[8]*Institute of Nuclear Physics of the National Nuclear Center of Kazakhstan, Almaty, Kazakhstan*

The work presents the results of the study of characteristics of the neutron emission in fission and quasi-fission of heavy and super-heavy nuclei, produced in the reactions with heavy ions. These experiments have been performed at the U-400 accelerator of the Flerov Laboratory of Nuclear Reactions (JINR), tandem accelerator in Legnaro (LNL) and VIVITRON accelerator in Strasbourg (IReS) with the use of the time-of-flight spectrometer of fission fragments CORSET and neutron multidetector DEMON. ^{208}Pb, ^{238}U, ^{168}Er spectrometric layers 120-200 mkg/cm^2 in thickness were used as targets. They were deposited on a 20-50 mkg/cm^2 carbon backings.

Mass-energy distributions (MED) of the ^{48}Ca + ^{168}Er, ^{208}Pb, ^{238}U and ^{18}O + ^{208}Pb reactions products at energies close to and below the Coulomb barrier have been studied. The pre- and post-fission neutron multiplicities as a function of the fragment mass have been obtained.

A significant yield of the asymmetric component observed in the fragment mass distributions in the case of ^{18}O + ^{208}Pb reaction denotes the multimodal nature of the fission process. At the same time an increase in the yield of fragment masses $M_L \cong 75$-85 and $M_H \cong 200$-210 in the case ^{48}Ca+^{208}Pb, ^{238}U reactions and $M_L \cong 75$-85 and $M_H \cong 130$-140 in the case ^{48}Ca+^{168}Er is rather connected with a quasi-fission process. The obtained neutron multiplicities dependences on fragment masses showed the validity of these assumptions.

Shell Correction Effects in Quasi-Fission Reactions Leading to the Synthesis of Superheavy Elements

E. A. Cherepanov*
Joint Institute for Nuclear Research
Flerov Laboratory of Nuclear Reactions
141980, Dubna, Russia

In reactions used for the synthesis of superheavy elements the shell effects are manifested in the mass distribution of quasi-fission products: an increased yield of closed-shell nuclei, such as ^{208}Pb,^{132}Sn, is observed [1].

Quasi-fission (QF) is a nuclear process, which is realized in collisions of two massive nuclei. QF is the disintegration of a double-nuclear system, which is formed at the capture stage and evolves into the symmetric form. Quasi- fission is the dominant channel in nuclear reactions used for the synthesis of superheavy elements. In reactions of synthesis of superheavy elements there are indications for the influence of the nuclear structure of the DNS nuclei on the probability of the system disintegration observed in the mass distribution of quasi-fission products - nuclear fragments with closed shells have the greatest yield.

In the framework of our model [2] quasi-fission is considered as the process of evolution of the double-nuclear system (DNS), formed at the capture stage, in the direction of decreasing its charge and mass asymmetry, accompanied by the decay of the system via all intermediate and final configurations. The evolution of the DNS is handled by the system potential energy - a function of its charge (mass) asymmetry and the interaction angular momentum. In the reactions of synthesis of superheavy elements the DNS energy is small. For this reason in calculations of the potential energy the real (table) masses of the interacting nuclei rather than the liquid drop values are used. In the potential energy curve quite deep minima occur for those DNS configurations for which one of the system nuclei is a doubly magic one. The DNS evolution is retarded in these minima, which in turn leads to an increased yield of the corresponding fragment-nuclei.

Our model offers a clear and realistic interpretation of the quasi-fission process and occurrence of shell effects in the mass distributions. The model based on this concept allows one to reproduce the shell effects in experimental mass distributions of quasi-fission products.

* E-mail - cher@jinr.ru

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The detection system of the Dubna Gas-filled Separator for SHE's search.

V.G.Subbotin, Yu.S.Tsyganov, A.M.Sukhov,
S.N.Iliev, A.N.Polyakov and A.A.Voinov

Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, Russia

The system of the compound nuclei α-decays sequences and spontaneous fission events detection, amplifying, measurement, readout and data accumulation is described. Represented system was successfully applied in our recent experiments aimed to synthesize superheavy elements and to reach "island of stability" nearly predicted spherical shell with $Z \geq 114$ and N=178-184. The questions of "dead time" decreasing and system up grade for present experiments are discussed.

Evidence of Z=120 compound nucleus formation from lifetime measurements in the ^{238}U+Ni reaction at 6.2 MeV/nucleon

J.L. Charvet[1], A. Chbihi[2], M. Chevallier[3], C. Cohen[4], D. Dauvergne[3], R. Dayras[1], A. Drouart[1], C. Escano Rodriguez[2], J.D. Frankland[2], D. Jacquet[5], R. Kirsch[3], P. Lautesse[3], M. Laget[5], A. L'Hoir[4], M. Morjean[2], L. Nalpas[1], C. Ray[3], C. Stodel[2], E.Testa[3], C. Volant[1]

[1] CEA- Saclay DSM/DAPNIA/SPhN – 91191 Gif/Yvette Cedex, France.
[2] GANIL F-14021 Caen Cedex, France.
[3] IPN Lyon - 69622 Villeurbanne Cedex, France.
[4] GPS Jussieu - PS, Campus Boucicaut, 75015 Paris, France.
[5] IPN Orsay -91406 Orsay Cedex, France.

Email : adrouart@cea.fr

The possibility to form super-heavy nuclei with Z = 120 by fusion reactions is still an open question due to the dominant quasi-fission process that presents characteristics very similar to the fusion-fission ones. Nevertheless, quite different lifetimes are predicted for quasi-fission and for fission following fusion. Direct lifetime measurements have therefore been undertaken at GANIL by the blocking technique in single crystals in order to separate the fusion component from the quasi-fission one.

The ^{238}U + Ni reaction at 6.62 MeV/u has been studied using reverse kinematics. The blocking patterns in the nickel single crystal were measured with a resolution of 2.10^{-2} degrees by two specially designed dE-E telescopes. Each of them consists of a low pressure ionization chamber followed by a position sensitive resistive silicon detector. One telescope was located at 11 degrees (inside the projectile grazing angle) in order to detect projectile elastic scattering. The second telescope was located at 20 degrees, and provided us with the atomic number and energy of all the heavy reaction products. The crystal lattice axes were oriented towards the detectors with a goniometer. All the coincident charged products from proton up to uranium were detected and identified in energy and atomic number over a nearly 4π a solid angle by INDRA [1].

The blocking patterns associated with elastic scattering of both the target and the projectile nucleus results from very short interaction times (< 10^{-19} s, shorter than the sensitivity limit of the present blocking experiment around 3.10^{-19}s) and are used as references, much. The interaction time associated with projectile-like fragments arising from deep-inelastic collisions is also found shorter than our sensitivity limit. In contrast, the sequential fission of uranium-like nuclei weakly excited in peripheral collisions is associated with very long lifetimes, in good agreement with previous measurements [2, 3] and with theoretical expectations. The quasi-fission/fusion-fission events exhibit a blocking behavior intermediate between the elastic (and deep-inelastic) one and the sequential fission one. A careful analysis of the reaction products detected in coincidence by INDRA indicates that these quasi-fission/fusion-fission events arise from pure binary reactions in which only light charged particles, with a multiplicity of the order of 0.1, are emitted. The blocking pattern associated with these events cannot therefore result from any sequential emission. It is actually characteristic of the composite system lifetimes. It indicates that at least 20 per cent of the events detected around 20 degrees and corresponding to the quasi-fission/fusion-fission domain have lifetimes longer than about 10^{-17}s, a time scale only compatible with compound nucleus formation. The so-formed Z=120 compound nucleus undergoes an asymmetric fission with an atomic number distribution at 20 degrees centered close to Z = 50 and Z = 70. Considering the rather high initial excitation energy that might be involved, the existence of very long fission times could be an indication of shell effect restoration at low residual excitation energy.

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Nucleosynthesis and search for superheavy elements ($Z \approx 108 \div 126$) in nature: the possible scenario.

G.N.Goncharov.
Department of Geochemisrty, St.- Petersburg State University,
Universitetskaya nab., 7/9, 199034, St.- Petersburg, Russia.
ggontcharov@mail.ru

The yields of fission fragments of superheavy elements (SHE) in peaks at mass numbers 130, 164 and 195 in cosmic atomic mass abundance are considered to be possible on the base of their correlation with spontaneous fission data [1,2] in superheavy region (Z = 100 - 122). We can consider the most intensive peak A=130 as light fragment close to double magic nucleus $^{132}Sn_{82}$ and peaks 164 and 195 as hard fragments of asymmetric fission of superheavy progenitors after neutron emission with multiplicity $\bar{\nu} = 4 \div 8$ [3]. In the result the mass numbers of fissionable natural nuclides can be: 298 ÷ 302 amu and 329 ÷ 333 amu. Using the rules of "unchanged charge density" and equality of β - decay chains for light and hard fragments we receive $Z = 114^{0}_{-1}$ and $Z = 126^{0}_{-2}$ for above mentioned progenitors accordingly. Exceedingly sharp cosmic mass distributions with the full width at half these maximums: ~ 8 amu, can be explained by "cold fission" due to shell effects in region of spherical nuclides [1].

Origin of these nuclides can be connected with upper shell of neutron star, where they can exist in dynamic equilibrium with surrounding dense neutron gas [4]. It is interesting that the harder ($Z \approx 126$) from assumed SHE has the more large abundance of fission fragments in nonmagmatic iron meteorites than in carbonaceous chondrites. The first group of meteorites can be associated with Fe – Ni core and the second one with surrounding shells of Si, O, C in presupernova.

The rest after induced fission of naturally synthesized nuclide close to a spherical shell Z=114, N=184 must undergo mostly the α – decay accordingly to theory [5,6] moving away from the N=184 shell and giving up hope to discovery of elements with Z = 110 – 108(?) in cosmic rays. The spherical shell of another natural nuclide in region close to Z = 126 must include 184 or 196 neutrons [7]. Observed excess of these values in data of cosmic abundances of atomic mass can be explained by neutron capture in r-process and by more stability to spontaneous fission of this progenitor.

The best objects for search of superheavy elements in nature in the assumption of their half-life $T_{1/2} \geq 10^8$ years are ore deposits – giants, connected with intraplate magmatism. The latter is drawing enormous amounts of trace elements from the Earth mantle. The half-life in interval on $10^8 - 10^6$ years set a limit on search for SHE in nature by Phanerozoic history of the Earth only. Influx of SHE on the Earth surface with more probability in that period could be from the nearest Galaxy surrounding of the Solar system. On short parts of the Solar galactocentric orbit in periods and between the epochs of the most extensive mass extinctions of organisms (439 – 367, 250 – 210 and 65 – 56 mln. years ago) could be crossings through the shock wave front and passages through star formation regions [8], where neutron stars and supernovae could be of the SHE source.

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CLUSTER INTERPRETATION OF PARITY DOUBLET ROTATIONAL BANDS IN ODD-MASS ACTINIDES

T.M.Shneidman[1],G.G.Adamian[1,2], N.V.Antonenko[1], R.V.Jolos[1]

[1] *Joint Institute for Nuclear Research, 141980 Dubna, Russia*

[2] *Institute of Nuclear Physics, Tashkent 702132, Uzbekistan*

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The structure of parity doublet rotational bands in odd-mass actinides has been described in a cluster model. The model is based on the assumption that cluster type shapes are produced by the motion of the nuclear system in the mass asymmetry coordinate. The results of calculations of the spin dependence of the parity splitting and of the electric dipole transitions between members of parity doublet are in agreement with the experimental data. This work is a natural continuation of the preceeding consideration on even-mass actinides [1,2].

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Survival probabilities of superheavy nuclei with recent predictions of nuclear properties

A.S.Zubov[1,2], G.G.Adamian[2,3], N.V.Antonenko[2], S.P.Ivanova[2], W.Scheid[1]

[1] *Institut für Theoretische Physik der Justers–Libeling–Universität, D-35392 Giessen, Germany*

[2] *Joint Institute for Nuclear Research, 141980 Dubna, Russia*

[3] *Institute of Nuclear Physics, Tashkent 702132, Uzbekistan*

Using the statistical model and recent theoretical predictions of nuclear properties [1], survival probabilities of superheavy nuclei are calculated. Level densities of the Fermi-gas model and of a model with collective enhancement are used. The survival probabilities obtained for isotops with Z=102–109 with the predictions of [1] are close to those obtained with the predictions of [2]. The evaporation residue cross sections of superheavy nuclei in cold and hot fusion reactions are calculated. The cross sections $\sigma_{(2-3)n}$ for the nuclei with Z=103, 107–109 are predicted. The results obtained with the collective enhancement model are more sensitive to even-odd effects than those obtained with the Fermi-gas model. Taking the nucleus Z=116 as an example, we found the same isotopic trends in σ_{ER} for the hot fusion actinide-based reactions with ^{48}Ca beam with using the predictions of [1] as it was demonstrated in [3] with the predictions of [2].

The dependences of the de-excitation of dinuclear systems on the isotopic configuration of the entrance channel are analyzed. The experiment for observation the neutron emission from the excited dinuclear system is proposed.

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Shape Coexistence, Superdeformation, Triaxiality and Chiral Bands in Neutron-Rich Nuclei

J.H. Hamilton[1], A.V. Ramayya[1], J.K. Hwang[1], S.J. Zhu[1,2], Y.X. Luo[1,3,4], J.O. Rasmussen[3] P.M. Gore[1], E.F. Jones[1], D. Fong[1], K. Li[1], L. Chaturvedi[1,5], R. Q. Xu[2], L.M. Yang[2], Z. Jiang[2], Z. Zhang[2], S. D. Xiou[2], X.Q. Zhang[1], G.M. Ter-Akopian[6], A.V. Daniel[6], Yu. Oganessian[6], V. Dimitrov[7,8], S. Frauendorf[7,8], A. Gelberg[9], J. Kormicki[1], I.Y. Lee[3], W.C. Ma[10], J.D. Cole[11], M.W. Drigert[11], M.A. Stoyer[12], T.N. Ginter[13], S.C. Wu[14], R. Donangelo[15]

[1]Physics Department, Vanderbilt University, Nashville, TN 37235, USA
[2]Deparatment of Physics, Tsinghua University, Beijing 100084, People's Republic of China
[3]Lawrence Berkeley National Laboratory, Berkeley CA 94720, USA
[4]Institute of Modern Physics, CAS, Lanzhou 730000, China
[5]Deparatment of Physics, Banaras Hindu University, Varanasi 221005, India
[6]Joint Institute for Nuclear Research, Dubna 141980, Russia
[7]Department of Physics, University of Notre Dame, Notre Dame, IN 46556, USA
[8]IKH, FZ-Rossendorf, Postfach 510119, D-01314 Dresden, Germany
[9]Inst. für Kernphysik, Universität zu Köln, Germany
[10]Department of Physics, Mississippi State University, Mississippi 39762
[11]Idaho National Engineering and Environmental Engineering, Idaho Falls, Idaho 83415, USA
[12]Lawrence Livermore National Laboratory, Livermore, CA 94550, USA
[13]National Superconducting Cyclotron Laboratory, East Lansing, Michigan 48824, USA
[14]Department of Physics, National Tsinghua University, Hsinchu, Taiwan
[15]Universidade Federal do Rio de Janeiro, CP 68528, RG Brazil

New insights into shape coexistence, superdeformation, triaxiality and chiral bands are observed in neutron-rich nuclei in studies of prompt γ-rays emitted in the spontaneous fission of ^{252}Cf at Gammasphere. Over 6 x 10^{11} triples and higher fold coincidences were collected to allow identification of weakly populated side bands and higher spin states.

In the region of A=100 – 124, the $g_{9/2}$ proton and $h_{11/2}$ neutron orbitals play important roles. Their interplay results in rich structures characteristics of various coexisting nuclear shapes. In the odd-Z nuclei from Z=39 to 47, bands built on $g_{9/2}$ proton orbitals, K= ½ intruder orbitals with large deformation and band crossings related to $h_{11/2}$ neutron are observed. First and second band crossings are observed in ^{112}Ru and ^{116}Pd. Triaxial-rotor-plus-particle model calculations were performed for Tc and Rh nuclei for comparison with our data. The best reproduction of the excitation energies, signature splittings and branching ratios for the Tc isotopes was for ϵ=0.32 and $\gamma = 22.5^{\circ}$ on the prolate side of maximum triaxiality. The best fit to the even-parity bands of the Rh isotopes was for near maximum triaxiality with $\gamma = 28^{\circ}$.

In ^{104,106}Mo, the ground band, one and two phonon γ-vibrational bands and known two quasi particle bands were extended. Several new two quasi particle bands were observed. These nuclei have significant quadrupole deformation and triaxial characteristics. Two pairs of Δ=1 bands in ^{106}Mo are found to have all the characteristics of a new class of chiral vibrational doublets. Tilted axis cranking calculations support the chiral assignment and indicate the chirality is generated by only the neutrons. These first chiral vibrational bands, which have a very different mechanism compared to previously observed chiral bands, help prove the general nature and importance of chiral behavior in nuclei.

By dividing the γ-γ-γ data into different time windows, we could extract by double gating on two of four transitions in a cascade, the lifetime of the lowest state. The lifetime of the 2^+ state and the β_2 deformation were extracted for ^{104}Zr. Its $\beta_2 = 0.45(4)$ establishes the superdeformed character of the heaviest known n-rich Zr nuclei.

T-odd Asymmetries and Ternary Fission

F. Goennenwein,

University of Tuebingen, Germany

In fission reactions induced by polarised neutrons several T-odd asymmetries in the angular distributions of fragments and ternary particles become observable. The T-odd Left-Right Asymmetry of fission fragments with respect to a plane being defined by neutron spin and neutron momentum is known since quite a long time. It has in recent years also been studied in ternary fission where the asymmetry of fragments is analysed in the presence of a ternary particle, e.g. an α-particle. A further T-odd asymmetry, called Triple Correlation, has come into focus in ternary fission. It has been discovered that the emission of a ternary particle has different probabilities of ejection relative to a plane defined by neutron spin and fragment momentum. In the decay of free neutrons this triple correlation serves as a tool to test time reversal invariance. A combined analysis of the two above asymmetries has in the case of fission, however, led to the conclusion that the triple correlation is due to a final state interaction. Several theoretical models have been proposed to identify the character of this final state interaction. A very appealing model is based on the observation that near scission the fissioning compound is rotating and that the ternary particle is, hence, emitted from a rotating system. In such a particle–rotor model the Coriolis force has to be taken into account. Several predictions from this model are in good agreement with experiment.

The experiments have been performed at the Institut Laue-Langevin by a collaboration of teams from Russia (PNPI, KRI, ITEP), Germany(Univ.of Tuebingen, Darmstadt) and Finland (Univ. of Jyvaeskylae). The support by INTAS grants is gratefully acknowledged.

Studies of Fine Structure Decay in Proton Emitters at the Holifield Radioactive Ion Beam Facility

J. C. Batchelder[1], C. R. Bingham[2,3], T. N. Ginter[1,4], C. J. Gross[5], R. Grzywacz[2,3], J. H. Hamilton[2,4], M. Karny[3,7], W. Krolas[4,6,8], A. Piechaczek[9], K. Rykaczewski[2], M. N. Tantawy[3], J. A. Winger[10], and E. F. Zganjar[9]

[1] *UNIRIB, Oak Ridge Associated Universities, Oak Ridge, TN 37831*
[2] *Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831*
[3] *University of Tennessee, Knoxville, TN 37996*
[4] *Vanderbilt University, Nashville, TN 37235*
[5] *Oak Ridge Institute for Science and Education, Oak Ridge, TN 37831*
[6] *Joint Institute for Heavy Ion Research, Oak Ridge, TN 37831*
[7] *Institute of Experimental Physics, Warsaw University, Pl-00681 Warsaw, Poland*
[8] *H. Niewodniczan'ski Institute of Nuclear Physics, PL-31342 Krako'w, Poland*
[9] *Louisiana State University, Baton Rouge, LA 70803*
[10] *Dept. of Physics and Astronomy, Mississippi State University, MS 39762*

The observation of fine structure in proton emission allows one to measure the composition of the parent state's wavefunction and the deformation of the daughter state in nuclei that are inaccessible during in-beam experiments. The emitted proton tunnels through the Coulomb and centrifugal barriers, and the decay probability depends strongly on the energy of the proton and on its angular momentum □. Proton emission from a spherical (odd-Z, even N) nucleus typically occurs to the 0^+ ground state of the even-even daughter. The orbital angular momentum (□) of the emitted proton can often be determined through the use of a simple spherical WKB calculation of the expected rate of the tunneling process, revealing the shell model orbital of the least bound proton of the parent emitting state. The situation with the decay of an odd-odd nucleus to an (even-Z, odd-N) isotope is quite a bit more complicated. The proton emitting state consists of a combination of proton and neutron states, with the final state being a low-energy (not necessarily the ground state) neutron state in the daughter nucleus. The study of fine structure in the decay of these odd-odd nuclei can be used to identify these low-energy neutron levels.

In this talk recent results on fine structure in the proton emission of ^{141}Ho, ^{145}Tm and ^{146}Tm obtained at the Holifield Radioactive Ion beam Facility (HRIBF) at Oak Ridge National Laboratory will be presented. Recoil nuclei of interest were separated spatially according to their mass/charge (A/Q) values by the HRIBF Recoil Mass Spectrometer (RMS). And then implanted into a ~ 60-μm thick double-sided silicon strip detector (DSSD) with 40 horizontal and 40 vertical strips. Signals from the DSSD were then processed with a digital spectroscopy system using 40 MHz flash ADCs and digital signal processors.

In the case of 145Tm, we were able to observe a fine structure proton transition to the 2+ state in 144Er with a branching ratio of 9.6(15)%. Through the use of a particle-core vibration model [1], the wavefunction for ^{145}Tm can be calculated using the experimentally determined energies and half-lives. The results of this calculation show that the structure of the ground state of 145Tm is comprised mostly of $\pi h_{11/2} \otimes 0^+$, while a small (~3%) admixture of $\pi f_{7/2} \otimes 2^+$ is responsible for the fine structure emission to the 2^+ state in the daughter.

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Unexpected Rapid Variations in Odd-Even Level Staggering in Gamma-Vibrational Bands

E.F. Jones[1], P.M. Gore[1], J.H. Hamilton[1], A.V. Ramayya[1], X.Q. Zhang[1], J.K. Hwang[1], Y.X. Luo[1], J. Kormicki[1], K. Li[1], S.J. Zhu[2], W.C. Ma[3], I.Y. Lee[4], J.O. Rasmussen[4], P. Fallon[4], T.N. Ginter[5], M. Stoyer[6], J.D. Cole[7], A.V. Daniel[8], G.M. Ter-Akopian[8], Yu.Ts. Oganessian[8], R. Donangelo[9], and S.J. Asztalos[10]

[1]*Department of Physics and Astronomy, Vanderbilt University, Nashville, TN 37235*
[2]*Department of Physics, Tsinghua University, Beijing, P.R. China*
[3] *Department of Physics, Mississippi State University, Mississippi 39762*
[4] *Lawrence Berkeley National Laboratory, Berkeley, CA 94720*
[5]*NSCL, Michigan State University,*
[6] *Lawrence Livermore National Laboratory, Livermore, CA 94550*
[7] *Idaho National Environmental and Engineering Laboratory, Idaho Falls, ID 83415*
[8] *Flerov Laboratory for Nuclear Reactions, JINR, Dubna, Russia*
[9] *Universidade Federal do Rio de Janeiro, CP 68528, RG Brazil*
[10] *Massachusetts Inst. of Technology, Cambridge, MA 11830*

The γ-vibrational bands in $^{104-108}$Mo, $^{108-112}$Ru, and $^{112-116}$Pd were extended to higher spins in studies of prompt γ rays emitted in the spontaneous fission of ^{252}Cf with Gammasphere. The even-odd spin energy level splittings, e.g. $\Delta E = E_3^+ - E_2^+, E_4^+ - E_3^+$, ..., show striking and rapid variations with spin, e.g. in ^{104}Mo to 12^+ the odd spin is pushed up closer to the even spin with the reverse, i.e., even spin pushed up nearer the odd spin, in ^{108}Mo, and similarly a change in this pattern above spin 14^+ in ^{104}Mo. In ^{108,112}Ru there is the same reversal in patterns as in ^{104,108}Mo, with the differences in adjacent ΔE values becoming increasingly larger to a highest difference of 570 keV. Likewise, ^{112}Pd and ^{114}Pd show the same reversal in patterns with the differences in adjacent ΔE values increasing to 480 keV in ^{114}Pd.

To better understand the behavior of γ-vibrational bands, the ΔE values for known γ-vibrational bands in even-even ^{152,154}Sm, $^{152-160}$Gd, $^{154-166}$Dy, $^{156-170}$Er, $^{162-174}$Yb, $^{168-180}$Hf, $^{170-186}$W, $^{172-192}$Os, and $^{180-196}$Pt were calculated. In general, Sm, Gd, Dy, and Er exhibited little staggering in ΔE, with differences in $\Delta E \leq 40$ keV, up to spin 10^+ except for N = 88 ^{152}Gd, ^{154}Dy, ^{188}Er, where the differences are about 200 keV. At higher spins, differences up to 100 keV are seen. Only in ^{162,166}Yb and ^{176}Hf are γ bands known above 6^+ and in ^{162,166}Yb the differences in adjacent ΔE values reach 200 and 640 keV, respectively. Only in ^{192}Os between 5^+ and 8^+ are significant differences seen. For $^{180-186}$Pt, there is a strong oscillation to the maximum known spin 7^+ which has a reverse pattern to the above cases, e.g., the ΔE adjacent differences start out large, 200 – 300 keV, and get smaller, 100 – 200 keV. In $^{188-196}$Pt, only in ^{192}Pt are the levels known above 6^+ and staggering sets in at 5^+ with an increasing difference to 220 keV.

The role of stable triaxial deformation is likely playing an important role in the rapidly varying and large odd-even spin staggering. Clearly the data call for a more microscopic description of γ-vibrational bands including γ-soft and stable triaxial deformations.

YIELDS AND RARE MODES OF DECAY FOR HEAVY NUCLEI PHOTOFISSION FRAGMENTS

Yu.P. Gangrsky, G.V. Mishinsky, Yu.E. Penionzhkevich, E.A. Sokol, V.I. Zhemenik

Joint Institute for Nuclear Research, Dubna, Russia

The independent yields of photofission fragments are presented. The heavy nuclei ^{232}Th, ^{238}U, ^{237}Np, ^{244}Pu and ^{243}Am are irradiated by bremsstrahlung of microtron with the boundary energy 25 MeV. The produced fission fragments were carried by the gas flow to the detectors. The noble gases Kr and Xe were separated from other fragments by their condensation in cryostat. The identification of isotopes and determination of their yields was performed by the measurements of their γ-spectra. The mass distributions of independent yields for the isotopes of Kr and Xe were measured by this means. The isotopic distributions of complementary fission fragments (Sr, Y, Zr, Ba, La, Pr) were obtained also. The mean mass number and the dispersion of these distributions were determined.

The performed measurements allow to determine the optimal conditions for the production of the most interesting fission fragments. The advantege of the photofission as compared with the thermal neutron fission in the production of the most neutron-rich fragments was showed. The possibilities of the observation of the rare deaxy modes of fission fragments (delayed neutron pair β2n or α-partile βα after β-decay) are discussed. The first indications about these modes of decay are obtained. The perspective of fission fragment structure are discussed.

LASER SPECTROSCOPY OF TRANSURANIUM ELEMENTS

Yu.P. Gangrsky, D.V. Karaivanov, K.P. Marinova, B.N. Markov,
Yu.E. Penionzhkevich, S.G. Zemlyanoi

Joint Institute for Nuclear Research, Dubna, Russia

The perspectives of the study of the transuranium elements nuclear structure by laser spectroscopy methods are considered. These methods alowes to determine the number of important nuclear parameters – charge radii, spins, magnetic dipole and electric quadrupole moments and to refer about single perticle and collective properties of nuclei. The most interesting peculiarities of the transuranium nuclei are the deformed closed shell 152 neutrons and the excited superdeformed states (spontaneously fissioning isomers).

The first experimental results in these region of nuclei are presented: charge radii differences of the Uranium isotopes chain (A = 233 – 238) and the nuclear multiple moments of the odd nuclei (^{233}U, ^{235}U, ^{241}Am, ^{243}Am). The resonance fluorescence detection in parallel atomic beam was used. The smooch dependence of these values on the neutron number is observed. The comparision of these nuclear parameters with calculated ones using different models is performed. The satisfactory agreement with the droplet model predictions is obtained. The influence of these parameters on the transuranium nuclei stability is considered. The correlation of charge radii odd-even staggering and increasing of stability for the odd proton or neutron nuclei is demonstrated. The plans of the forcoming experiments in region of nuclei near closed shell 152 neutrons are discussed.

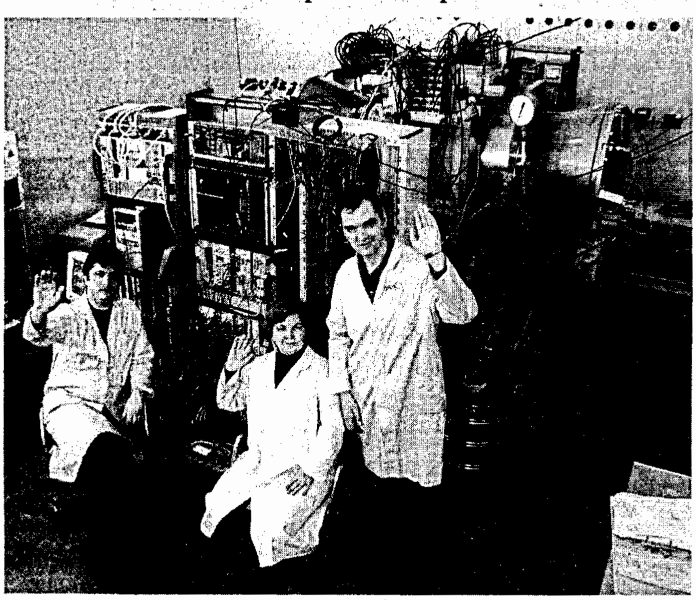
Experimental study of multi-cluster decays at the modified FOBOS and mini-FOBOS setups.

D.V. Kamanin[1], Yu.V. Pyatkov[2], A.A. Alexandrov[1], I.A. Alexandrova[1], S.V. Denisov[1], S.V. Khlebnikov[3], T.E. Kuzmina[3], E.A. Kuznetsova[1], S.V. Mitrofanov[1], V.G. Tishchenko[1], A.N. Tjukavkin[1,2], Yu.V.Ryabov[4], Yu.E. Penionzhkevich[1], E.A. Sokol[1], S.R. Yamaletdinov[1,5]

[1] Joint Institute for Nuclear Research, 141980 Dubna, Moscow region, Russia
[2] Moscow Engineering Physics Institute, 115409 Moscow, Russia
[3] Khlopin-Radium-lnsntute, 194021 St. Petersburg, Russia
[4] Institute for Nuclear Research RAN, 117312 Moscow, Russia
[5] Department of Physics, University of Jyväskylä, FIN-40014 Finland

The unusual fission events have been observed [1] in spontaneous fission of ^{252}Cf measured by the FOBOS setup [2]. An essential improvement of the data reliability has been achieved due to the specially designed experimental equipment and the number of modifications performed [3]. In particular, FOBOS setup has been equipped with the neutron detectors and the specially designed start-detector with the internal ^{252}Cf source. The new electronic channels for measuring drift time in Bragg ionization chambers, i.e. nuclear charge of the fragments, have been included. The data processing procedures have been substantially developed as well.

In the series of experiments performed at the modified FOBOS spectrometer the structures in the energy and mass correlations of the fission fragments obtained on the entire base of $1.4*10^7$ accumulated events are treated as an indication of collinear cluster tripartition (CCT) of ^{252}Cf. This conclusion has been additionally checked by the analysis of the neutron multiplicity measured by the array of 140 ^{3}He-filled proportional counters in the PE moderator, covered the solid angle of $\sim 0.76\pi$ sr [4]. Our conclusions have been additionally insured by the results of the charge analysis. There are also the theoretical indications on the possibility of pre-formation of the third massive fragment within the neck of fissioning system. The structures observed in the mass distributions of the coincident collinear fragments gated by neutrons seems to be defined by the magic numbers [5].



The further study of collinear cluster tripartition is planned at the mobile subset of FOBOS (see fig.), namely, with the modified mini-FOBOS setup (MMF) [6]. Its actual configuration is well suited for both spontaneous fission measurements and for in-beam experiments. The most intriguing check of the CCT events consists in the direct registration of the third massive fragment. The signals from the avalanche counters are specially processed in order to reveal particles, which hit the detectors at the same position shortly after each other. This experiment at the MMF setup is under way.

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Data processing in cluster tripartition experiments.

A. N. Tyukavkin[1], Yu.V. Pyatkov[2,1], S.R. Yamaletdinov[3], D. V. Kamanin[1], W. Trzaska[3], E.A. Sokol[1], E.A. Kuznetsova[1]

[1]*Joint Institute for Nuclear Research, Dubna, Russia*
[2] *Moscow Engineering Physics Institute, Moscow, Russia*
[3]*Department of Physics of University of Jyvaskyla, Finland*

In the experiments at the FOBOS spectrometer [1] some groups of rare events with a large deficit both of the total mass and of the total kinetic energy of the complimentary fragments were observed in the spontaneous fission of ^{248}Cm and ^{252}Cf nuclei. The results obtained have been treated as an indication of the new type of spontaneous decay called collinear cluster tripartition (CCT) [2]. Unfortunately the data suffered from scattering of the fragments (the main source of the background events) and evident shifts in mass calibration. In order to increase a reliability of revealing of the CCT events some improvements were introduced both to the experimental set up and data processing procedure.

Preliminary results mentioned above let one to suppose that a CCT process should be accompanied by almost isotropic emission of neutrons of high multiplicity. For using this feature for an identification of the CCT events the FOBOS set-up was completed by the belt of the 140 ^{3}He neutron counters [3].

Special mathematical formalism was developed for the analysis of experimental distributions on number of tripped neutron counters. The main problem arising is an adequate consideration of the neutron background due to random coincidences when the effect searched for does not exceed 10^{-5} of binary fissions. The problem was solved successfully as it can be inferred from a comparison of the experimental and simulated spectra (fig.1). The "tail" at high multiplicities where experimental values systematically exceed the model predictions is precisely the effect expected for the CCT events.

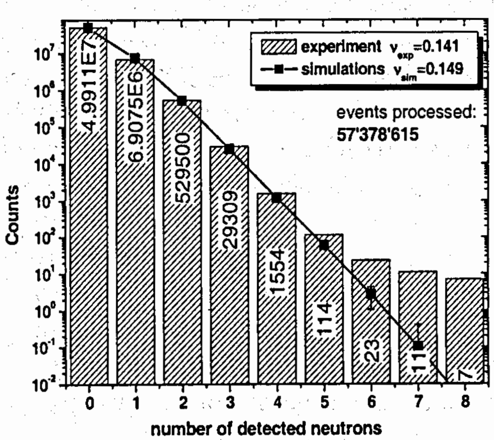

Fig.1. Frequency spectrum of number of tripped neutron counters in comparison with the model predictions.

Thick entrance windows of the high-aperture FOBOS modules used for studies of rare decay modes under discussion put another complicated problem namely restoration of the fragment mass when energy losses in the entrance foils exceed 60% of initial energy. In the frame of the approach developed good linearity and absence of the systematical shifts in mass calibration were achieved. New data processing strategy let us to reveal for the first time some decay modes indubitably connected with the CCT of the ^{252}Cf nucleus (4). We have also reanalysed our data obtained at the FOBOS set up some years ago [2] and obtained clear confirmation of the CCT of the ^{252}Cf and ^{248}Cm nuclei.

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NUCLEUS-NUCLEUS POTENTIALS FROM DEEP SUB-BARRIER FUSION AND CLUSTER DECAY

R.N. Sagaidak[a], S.P. Tretyakova[a], A.A. Ogloblin[b], S.V. Khlebnikov[c], W. Trzaska[d]
[a]*Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia*
[b]*Kurchatov Atomic Energy Institute, Moscow, Russia*
[c]*Khlopin Radium Institute, St-Petersburg, Russia*
[d]*JYFL, University of Jyväskylä, Jyväskylä, Finland*

Cluster radioactivity (CR) occupies an intermediate position between alpha-decay and spontaneous fission of nuclei. Twenty nuclides from ^{221}Fr to ^{242}Cm emitting light nuclei from ^{14}C to ^{34}Si, correspondingly, are known. More than a dozen theoretical models were proposed for the explanation of this phenomenon. Differing in details they describe CR either as an adiabatic "fission-like" or as a sudden two-step "α-decay-like" (cluster) process. However, the real mechanism of CR still remains an open problem. Despite the fact that different models are the bases of these theories, they reproduce measured decay probabilities quite well [1]. The reason for this lies in some compensation of different factors determining the decay probability. At the same time, "fission-like" and "α-decay-like" models predict quite different shapes of the potential barrier. So independent information on the barriers, especially on their internal parts, is of great importance for understanding the mechanism of CR. As both decay products are formed in their ground states, a study of their deep sub-barrier fusion can contribute in solving this problem as well. The aim is to get complimentary information both on nucleus-nucleus potentials and mechanism of CR. The validity of such approach is the ability of the extracted potential to reproduce both the fusion excitation function and cluster decay probability.

At present there are only two available projectile-target combinations leading to the formation of compound nuclei with the measured cluster decay probabilities. These are ^{222}Ra $\rightarrow$ ^{14}C + ^{208}Pb and ^{230}U $\rightarrow$ ^{22}Ne + ^{208}Pb. One can expect that cluster decay probabilities for some nuclides can be predicted rather reliably, e.g., for ^{224}Th. It makes worthwhile to consider the ^{16}O + ^{208}Pb $\rightarrow$ ^{224}Th* combination for which deep sub-barrier fusion cross sections (based on the available evaporation residues and fission excitation functions) could be obtained [2]. The experiment on fission cross section measurements in ^{22}Ne + ^{208}Pb $\rightarrow$ ^{230}U* was recently performed at JYFL with the use of an array of solid-state track detectors [3]. The analysis of both sets of the data was performed in the framework of the HIVAP code successfully applied to the analysis of the ^{12}C + ^{204,206,208}Pb excitation functions [4]. The shape of the fusion barriers extracted from the data [2, 3] belongs to the family of cluster, or "α-decay-like" potentials, and can be approximated by the Woods-Saxon form with the diffusenes parameter similar to that obtained in scattering experiments. Successful description of deep sub-barrier fusion in the ^{16}O and ^{22}Ne reactions allows us to study the ^{28,30}Si + ^{208}Pb $\rightarrow$ ^{236,238}Cm* reactions keeping in mind the ^{34}Si + ^{208}Pb $\rightarrow$ ^{242}Cm* system for future study. The latter is the inverse reaction for which emission of ^{34}Si from ^{242}Cm has been observed. In such consideration the available data on the fission cross sections obtained in reactions with radioactive beams should be taken into account [5]. Moreover, it is of interest to test an applicability of our approach to the analysis of deep sub-barrier cross section data obtained in symmetric combinations, for which some unusual limitations on fusion was recently revealed [6].

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SEARCH OF CLUSTER DECAY OF ^{223}Ac

S.P.Tretyakova for collaboration:
JINR, Dubna; Kurchatov Institute, Moscow; Milano University, Milan; iThemba LABS, Capetown

Cluster radioactivity occupies an intermediate position between alpha decay and spontaneous cold fission. It was observed for a number of nuclei from ^{221}Fr to ^{242}Cm emitting fragments from ^{14}C to ^{34}Si. Especially interesting results are expected for light actinides, first due the presence of the static octupole deformation in their ground states and, secondly due to possible existence of exotic heavy quasimolecules in this region of mass numbers. Experience showed that the decays of odd nuclei are most sensitive to the nuclear structure effects.

Experiment on search of cluster decays of ^{223}Ac with emission of ^{14}C and ^{15}N fragments and measurement of their probabilities is under preparation. Among the possible new objects of cluster radioactivity studies, ^{223}Ac nuclide is of exceptional interest:

1. One of the best evidences of the "α-decay-like" mechanism of cluster emission and of importance of nuclear structure effects was obtained from observation of the fine structure in ^{223}Ra → ^{14}C + ^{209}Pb decay spectrum. As ^{223}Ac is the isobar-analog of ^{223}Ra the study of its decay to ^{14}C + ^{209}Bi provides complimentary information in this most important case. In particular, if the transition hindrance is determined by the change of configurations of the odd nucleons one can expect that the decay ^{223}Ac → ^{14}C to the ground state of ^{209}Bi would be similar to the transition to the ^{209}Pb first excited state.
2. Another important source of information on nuclear structure effects would be the measurement of ^{14}C/^{15}N emission probabilities ratio. It could be especially useful for testing the hypothesis of quasimolecular structure of light actinides. It should be emphasized that the daughter nuclei, ^{209}Bi and ^{208}Pb have well-known structure, what simplifies the theoretical analysis in comparison with the other cases.
3. The combined study of ^{223}Ac cluster decays and the decay products interactions, elastic scattering or fusion-fission of ^{14}C +^{209}Bi and ^{15}N + ^{208}Pb projectile – target combinations can provide unique information on the potential shape in the extremely sub-barrier region.

^{223}Ac will be produced in the reaction ^{232}Th(p,6n)^{227}Pa → (38 min) → ^{223}Ac →(2.2 min) by irradiation of thick (~ 4g/cm^2) thorium targets by ~ 65 MeV protons with the intensity of several tens of μA at the cyclotron of iThemba LABS. Protactinium will be chemically extracted from the targets, and the sources for the array of solid state track detectors (SSTD) will be prepared. The expected amount of ^{14}C tracks in SSTD is several hundreds and the ^{15}N ones several tens, what allows to make comparison with all significant models of cluster radioactivity.

The experiment with ^{223}Ac will make possible the overall comparison of the neighbor cluster decaying nuclei ^{222}Ra, ^{223}Ra and ^{223}Ac and provide new important information both on cluster radioactivity mechanism and structure of light actinides.

The first run is scheduled on October – November.

Neutron and Prompt Gamma Ray Emission in the Proton Induced Fission of ^{239}Np and ^{243}Am and Spontaneous Fission of ^{252}Cf

L. KRUPA[1,7], G.N. KNIAJEVA[1], A.A. BOGATCHEV[1], G.M. CHUBARIAN[6], O. DORVAUX[3], I.M. ITKIS[1], M.G. ITKIS[1], S. KHLEBNIKOV[5], J. KLIMAN[1,7], N.A. KONDRATIEV[1], E.M. KOZULIN[1], V. LYAPIN[4,5], T. MATERNA[2], W. RUBCHENIA[4,5], I.V. POKROVSKY[1], W. TRZASKA[4], D. VAKHTIN[5], V.M. VOSKRESSENSKY[1]

[1]*Flerov Laboratory of Nuclear Reactions, JINR, 141980 Dubna, Russia*
[2]*Universite Libre de Bruxelles, PNTPM, CP229, B1050, Bruxelles, Belgique*
[3]*Institut de Recherches Subatomiques, CNRS-IN2P3, Strasbourg, France*
[4]*Deparment of Physics, University of Jyväskylä, FIN-40351, Jyväskylä, Finland*
[5]*V.G. Khlopin Radium Institute, St.-Petersburg 194021, Russia*
[6]*Texas A&M University, Cyclotron Institute, College Station, Texas, 77843-3366, USA*
[7]*Institute of Physics SASc, Dubravska cesta 9, 84228 Bratislava, Slovak Republic*

Average prescission ν_{pre} and postscission ν_{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 $p+^{242}Pu \rightarrow ^{243}Am$, $p+^{238}U \rightarrow ^{239}Np$ (at proton energy E_p=13, 20 and 55 MeV) and spontaneous fission of ^{252}Cf. The Doppler shift in the laboratory angular distribution of γ-ray emission was utilized to obtain the number and energy of γ-rays as functions of single fragment mass. The results in the case of ^{252}Cf, for both average number and average energy as functions of single fragment mass, are characterized by a sawtooth behavior similar to that which is well known for neutron emission. The similar behavior one can see for proton induced fission of ^{239}Np and ^{243}Am. The fragment mass dependence $\nu_{post}(m)$ and $<M_\gamma>(m)$ shows a clear sawtooth structure that is gradually washed out with increasing proton energy E_p or with decreasing TKE. Using the response matrix technique we were able to distinguish between statistical dipole (E_1) and collective quadrupole (E_2) γ-ray emission of single fission fragments.

Observation of the multicluster decays of the Cf nucleus at the modified FOBOS spectrometer.

Yu.V. Pyatkov[1], D.V. Kamanin[2], W.Trzaska[3], S.R. Yamaletdinov[3], E.A. Sokol[2], A.N. Tjukavkin[1,2], A.A. Alexandrov[2], I.A. Alexandrova[2], S.V. Denisov[2], S.V. Khlebnikov[4], T.E. Kuzmina[4], E.A.Kuznetsova[2], S.V.Mitrofanov[2], Yu.E. Penionzhkevich[2], Yu.V.Ryabov[5], V.G. Tishchenko[2], B.V.Florko[2]

[1] Moscow Engineering Physics Institute, 115409 Moscow, Russia
[2] Joint Institute for Nuclear Research, 141980 Dubna, Russia
[3] Department of Physics of University of Jyvaskyla, FIN-40014 Jyvaskyla, Finland
[4] Khlopin-Radium-Insntute, 194021 St. Petersburg, Russia
[5] Institute for Nuclear Research RAN, 117312 Moscow, Russia

In our previous works [1] we have discussed experimental indications of a new type of nuclear transformation called by us "collinear cluster tripartition" (CCT). The experiments were performed at the 4π- spectrometer FOBOS installed at the FLNR of the JINR [2]. In order to improve a reliability of identification of the CCT events recently FOBOS set up was equipped by neutron detectors and special symmetric start-detector [3]. Data processing procedure was substantially modified as well.

Two groups of FOBOS modules were used as a double-armed TOF-E (time-of-flight-energy) spectrometer which covered ~29% of the hemisphere in each arm. Thus energies and velocity vectors of the coincident fragments were detected. The neutron detector consisting of 140 separate modules comprising a ^{3}He-filled proportional counter in a moderator, covered altogether ~19% of the complete solid angle of 4π. A number of tripped neutron counters were written as an additional parameter of each registered fission event. The overall statistics processed to date is about $2*10^{6}$ events.

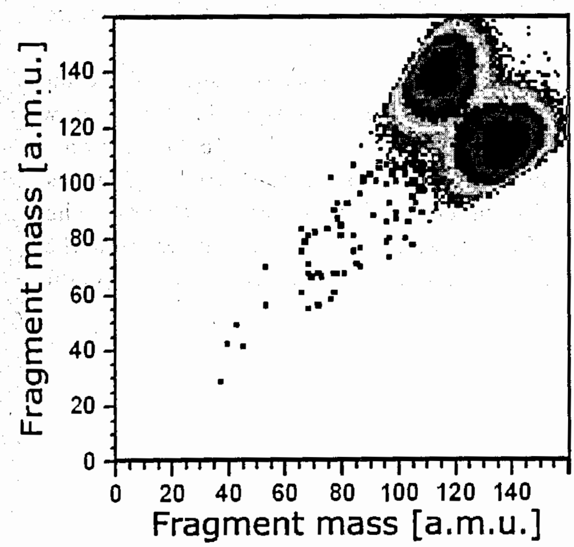

Fig.1. Mass matrix of the complimentary fragments having approximately equal velocities and momenta.

Mass distribution of the coincident collinear fragments under condition that both their velocities and momenta are approximately equal is shown in fig.1. The rectangular like structure below the loci of conventional binary fission attracts attention. As can be inferred from the figure a total mass of two complimentary fragments forming rectangle amounts to 60-85% of the mass of the initial nucleus. The structure observed is bounded by magic fragments namely ^{68}Ni (spherical proton shell Z=28 and neutron subshell N=40) and ^{84}Se (spherical neutron shell N=50). Similar in shape structures but bounded by another magic numbers are observed in the mass distributions of the coincident collinear fragments gated by neutrons. Each structure revealed maps an evolution of the decaying system onto the mass-energy space. Reconstruction of the evolution scenarios sheds new light on the mechanisms of fission and cluster decay.

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Resonance scattering experiments with low-energy radioactive beams produced by an in-flight separator

T. Teranishi[1], S. Kubono[1], J.J. He[1], M. Notani[1], S. Shimoura[1], S. Michimasa[1], K. Ue[1], T. Fukuchi[1], Y. Yanagisawa[2], S. Nishimura[2], M. Nishimura[2], M. Kurokawa[2], H. Iwasaki[3], Y. Satou[4], Y. Gono[5], T. Morikawa[5], Y. Wakabayashi[5], N. Hokoiwa[5], A. Odahara[6], A. Saito[7], H. Baba[7], J.H. Lee[8], J.Y. Moon[8], C.S. Lee[8], H. Ishiyama[9], Y.X. Watanabe[9], T. Hashimoto[9], T. Ishikawa[9], M.H. Tanaka[9], H. Miyatake[9], V. Guimarães[10], R.F. Lihitenthaler[10], Zs. Fülöp[11], K. Sato[12], T. Kawamura[12] and S. Kato[12]

[1] *Center for Nuclear Study (CNS), University of Tokyo, Japan*
[2] *The Institute of Physical and Chemical Research (RIKEN), Japan*
[3] *Department of Physics, University of Tokyo, Japan*
[4] *Tokyo Institute of Technology, Japan*
[5] *Department of Physics, Kyushu University, Japan*
[6] *Nishi-nippon Institute of Technology, Japan*
[7] *Department of Physics, Rikkyo University, Japan*
[9] *Chun-Ang University, Korea*
[10] *IPNS, KEK, Japan*
[11] *Institute of Nuclear Research of the Hungarian Academy of Sciences (ATOMKI), Hungary*
[12] *Department of Physics, Yamagata University, Japan*

Low-energy radioactive-ion beams of around 5 MeV/nucleon were developed by using an in-flight magnetic separator constructed in the RIKEN-CNS Facility. Radioactive nuclides were produced by nuclear reactions with low-energy heavy-ion primary beams bombarding targets of light elements. For example, an ^{14}O beam was produced by using the ^{14}N(p,n)^{14}O reaction in inverse kinematics. Due to high-intensity primary beams available at RIKEN and a large acceptance of the in-flight separator, secondary-beam intensities of about 10^6 particles/sec were achieved for some radioactive nuclides.

Recently, these radioactive beams are used to study resonances in elastic scattering of proton on unstable nuclei. New experimental information on such resonances is useful for nuclear structure study and also helps understand resonance contributions to stellar (p,γ) reactions. In an experiment, a low-energy radioactive beam bombards a thick proton target. Energies of recoil protons are measured to deduce an excitation function of the elastic scattering. The experimental goal is to obtain new information on E_x, J^π, and Γ of the resonances from the resonance interference patterns seen in the excitation function. We will show experimental results of ^{23}Mg+p, ^{11}C+p and some others.

Excited States in Exotic Nuclei via Direct Reactions of RI Beams

S. Shimoura

Center for Nuclear Study (CNS), University of Tokyo,
2-1, Hirosawa, Wako, Saitama 351-0198, Japan

Email: shimoura@cns.s.u-tokyo.ac.jp

Direct reactions of exotic nuclear beams populating their excited states are discussed from the aspects of the inverse kinematics by measuring in-flight decay of the beam-like nucleus and the selectivity of the reactions. Emphasis is made for inelastic scattering and nucleon transfer reactions of α using a liquid helium target.

For studies of unbound excited states, characteristics of the invariant mass spectroscopy where the momenta of all the decaying particles are measured is discussed. For bound state, in-beam γ-ray spectroscopy of fast moving exotic nuclei gives interesting information of excitation spectra.

Angular distributions of the direct reactions and angular correlations in the decaying process are discussed with the experimental data and the DWBA analyses.

Recent experimental results of resonances in ^{12}Be and ^{14}O excited by the (α, α') reactions and γ-ray spectroscopy of ^{13}B* and ^{23}F* populated by the proton-transfer reaction (α,t) are presented relating to the magicities of $N = 8$ and $Z = 8$ in light unstable nuclei.

Ceramic Plutonium Target Development for the MASHA Separator

P. A. Wilk, D. A. Shaughnessy, K. J. Moody, J. M. Kenneally, J. F. Wild,
M. A. Stoyer, R. W. Lougheed, J. B. Patin, B. Ebbinghaus, and R. Landingham
University of California, Lawrence Livermore National Laboratory
Livermore, CA 94550 USA

A. V. Yeremin and Yu. Ts. Oganessian
Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research
RU-141980 Dubna, Moscow Region, Russia

A solid plutonium ceramic target is under development for use in the MASHA [1] on-line mass separator in Dubna. This target, along with recent upgrades of the U400 Cyclotron, will increase at least a ten-fold the production and detection rate of element 114 with MASHA. In addition, it will be possible to measure the weights of the element 114 atoms produced very precisely. The target that is under development for the MASHA separator will consist of a thick plutonium ceramic target capable of tolerating temperatures of around 2000 °C without vaporizing the actinide target material. Promising candidates for the ceramic target include plutonium oxides and carbides, although more research into the thermodynamic properties of these compounds is required and is currently being under taken. Reaction products will diffuse out of the target and drift to an ECR ion source. After being accelerated by the ECR ion source, they will be transported through the separator and implanted into a position-sensitive focal-plane detector array. Furthermore, the operation of the MASHA hot target and ion source combination will provide chemical volatility information that will support our assignment of an atomic number of 114 to these nuclei. All the data that are taken together from these experiments on MASHA with the ceramic plutonium targets will allow us to make measurements that will identify decisively the element 114 isotopes that are produced and provide the basis for future experiments in which the chemical properties of the heaviest elements are studied.

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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Neutron-rich nuclei studied in high-energy Coulomb breakup of secondary beams

Hans Emling

Gesellschaft für Schwerionenforschung (GSI), Darmstadt, Germany

Secondary beams of unstable nuclei with kinetic energies of several hundred MeV per nucleon are produced at GSI in fragmentation and fission reactions followed by in-flight isotope separation. Here, results of studies of neutron-rich nuclei at the LAND detector setup are discussed. Interaction of the projectiles with lead targets leads to Coulomb breakup mediated through dipole excitations into the continuum. Non-resonant excitations near the neutron separation threshold deliver information on ground-state properties [1,2]; resonant excitation of the giant dipole resonance is observed as well. Coulomb breakup measurements were performed for a number of light (halo) nuclei and, more recently, for ^{132}Sn and neighboring isotopes. Other reactions channels such as diffractive dissociation and knockout are measured simultaneously

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Spectroscopy of the odd transfermium isotopes ^{251}Md and ^{255}Lr

Ch. Theisen *et al.*
CEA Saclay, DAPNIA/SPhN, France.
Saclay, Jyväskylä, Liverpool, Ganil, LPC Caen, CSNSM Orsay, Dubna, Strasbourg and GSI collaboration.

Mendelevium (Z=101) and Lawrencium (Z=103) isotopes have been discovered nearly 50 years ago at Berkeley and Dubna. However, very scarce information on their structure has been obtained up to now. For instance, the ground state spin and parity of Md and Lr isotopes remains uncertain. The properties of Transfermium elements is however of great interest for the structure of the heaviest elements. They are entirely stabilised by shell effects; they are deformed and some of their orbitals are also involved in the structure of spherical super-heavy elements. Detailed spectroscopy is therefore essential to move toward a better understanding of the limits of stability. Odd nuclei are crucial, since they provide information on the single particle structure of the Transfermium elements.
A large collaboration involving Saclay, Jyväskylä, Liverpool, Ganil, LPC Caen, CSNSM Orsay, Dubna, Strasbourg and GSI has focused on the study of ^{251}Md and ^{255}Lr isotopes using various techniques.
Prompt gamma and electron spectroscopy was performed at Jyväskylä using the Jurogam and Sacred arrays coupled to the RITU separator. Collective properties (rotation) have been deduced. For the first time, at least 3 rotational bands have been observed in an odd Transfermium isotope as shown in figure 1. Since collective properties alone can hardly disentangle single particle properties, complementary decay experiments have been performed. Gamma and electron spectroscopy after alpha decay of ^{255}Lr has been studied at Jyväskylä and Ganil in order to assign the single particle states.
The experimental results will be presented and compared to theoretical HFB calculations. Single particle as well as collective properties of ^{251}Md and ^{255}Lr will be presented.
Future perspectives of gamma-ray spectroscopy using the VAMOS spectrometer and the EXOGAM array will be also discussed.

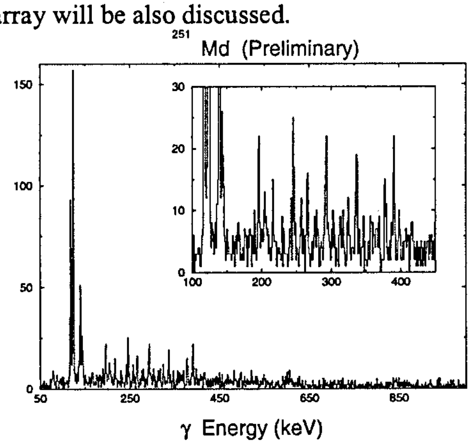

Figure 1: Gamma-ray spectrum of ^{251}Md obtained at Jyväskylä using Jurogam and RITU.

NEW LINES OF RESEARCH WITH THE MAGNEX LARGE-ACCEPTANCE SPECTROMETER

A.Cunsolo[a,b], F.Cappuzzello[a], A.Foti[b,c], A.Lazzaro[a,b], S.Orrigo[a,b], C.Nociforo[a], J.S.Winfield[a],

a. INFN - Laboratori Nazionali del Sud, Catania, Italy
b. Dipartimento di Fisica e Astronomia, Università di Catania, Catania, Italy
c. INFN - Sezione di Catania, Catania, Italy

A new design of magnetic spectrometer, MAGNEX [1], is under construction for the INFN-LNS, Catania. It is primarily intended for use with the Tandem-accelerated radioactive beams from the EXCYT facility [2]. Both projects are expected to be completed by the half of 2004.

The unique features of MAGNEX are its solid angle of acceptance (51 msr), momentum acceptance (10%), overall momentum resolution of 1/2000 and mass resolution of 1/200, together with a focal plane detector having a low detection threshold (0.5 MeV/A). The spectrometer is based on a 55° bend angle dipole magnet with mean radius of 1.6 m. It is designed for a maximum rigidity of 1.8 Tm. Despite the large acceptance, a good momentum resolution is achieved by a combination of careful ion-optical design [3] and software ray-reconstruction. The latter depends on three things: the availability of detailed field maps, the precise measurement of position and angle by the detection system, and the solution to high order of the equation of motion based on, in our case, the program COSY INFINITY of Berz [4].

The MAGNEX spectrometer will provide new opportunities for, e.g., studies of weakly-bound as well as heavy shell-stabilized nuclei via direct reactions, nuclear reactions with large isospin numbers, and nuclear astrophysics with both stable and radioactive beams.

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On-line Production of Rb and Cs isotopes from Uranium Carbide Targets

A.E. Barzakh, D.V. Fedorov, A.M. Ionan, V.S. Ivanov, K.A. Mezilev, F.V. Moroz, S.Yu. Orlov, V.N. Panteleev, Yu.M. Volkov
188350, Petersburg Nuclear Physics Institute RAS, Leningrad district, Russia

A. Andrighetto, G. Lhersonneau, L. Stroe, L.B. Tecchio, X.F. Wang
INFN, Laboratori Nationali di Legnaro, Viale dell' Universita 2, 35020 Legnaro (Padova), Italy

L.Renan, A.Villari
GANIL (Grand Accelerateur National d'Ions Lourds), Boulevard Henri Becquerel, BP 55027, F-14076 Caen Cedex5, France

A series of on-line mass separation experiments have been performed at the IRIS facility to measure the yield and release of Rb and Cs neutron-rich isotopes produced by fission reaction of ^{238}U. A 1 GeV proton beam was used to bombard uranium carbide targets with the densities of 11 g/cm^3 and 1.5 g/cm^3 held at temperatures in the range of 2000 – 2230 °C. The release curves of Rb and Cs long-lived isotopes were measured from both kinds of targets. The overall production efficiency was determined making use of experimentally measured cross-sections of that isotope production. Comparison of the experimental yields of Rb and Cs isotopes with the calculated ones after corrections for losses due to finite release times suggests that the diffusion is the dominating process reducing the efficiency for short-lived isotopes. When normalized to the same thickness, a yield enhancement is observed for the high-density rod target. It is possibly explained by the reactions induced by secondary neutrons. A large odd-even effect with higher yields of Cs even neutron isotopes has been observed, confirming similar effect obtained in earlier experiments.

NUSTAR, Nuclear structure research within the GSI project objectives and organization"

Gottfried Münzenberg
Gesellschaft für Schwerionenforschung (GSI) mbH,
Planckstr. 1, 64291 Darmstadt, Germany
and Johannes Gutenberg - Universität Mainz,
55128 Mainz,Germany
Tel.: +49 6159 71 2733, G.Muenzenberg@gsi.de

The new GSI accelerator complex will extend nuclear structure research into new regions. Experimental developments to enhance sensitivity and resolution and to apply new probes will give new insights in the structure of the atomic nucleus.

New developments for structure research include a large acceptance fragment separator, detection systems for precision spectroscopy such as gamma arrays with tracking capability, a low energy branch, a setup for reaction studies in reversed kinematics, and a storage ring complex for precision reaction studies with unstable nuclei such as proton and electron scattering.

In this contribution the challenges and opportunities for structure research with the new facility will be outlined. The organization of nuclear structure research at GSI on an international basis within NUSTAR will be addressed.

Precision Experiments with Exotic Atoms and Exotic Nuclides with the Present and the Next Generation International Facilities at GSI

Hans Geissel

GSI, Planckstr.1, D-64291 Darmstadt, Germany

Atoms are unique traps for negative particles and normally carry electrons. Exotic atoms can be created in experiments by replacing bound electrons by other negative particles like mesons or antiprotons. In pioneer experiments at the fragment separator FRS at GSI deeply bound pionic heavy atoms were created and investigated. Pionic states in lead and tin atoms in the 1s level have given new information on the strong interaction and the in-medium mass modification of the pions.

Exotic nuclei have been produced and separated with the FRS at relativistic energies. At these high velocities the exotic nuclei are bare and thus provide unique possibilities to measure their decay properties in the storage ring ESR under conditions which prevail in hot stellar matter. We observed that the absence of atomic electrons can change the nuclear decay properties quite significantly and can even open new decay channels like the recently discovered beta decay into bound states. For the first the branching of bound and continuous beta decay have been measured for ^{207}Tl fragments.

Precision experiments normally require a small phase space occupation and a long observation time, conditions which are extremely difficult to achieve with rare isotopes. Special cooling techniques in storage rings and ion-optical measures solve these problems. New results from such precision experiments with stored exotic nuclei at relativistic energies at the FRS-ESR will be presented in this contribution.

The small intensities for exotic nuclides are still the main limitations to reach the neutron dripline for elements heavier than oxygen. A new dimension in research can be opened with the planned international next-generation facility presently discussed at GSI. For the first time nuclei along the nucleosynthesis path of the rapid-neutron (r) process can than be investigated on a larger scale and new structure and shell effects are waiting to be discovered with the planned Super-FRS facility.

Perspective of RI beam based research at RIKEN

Tohru Motobayashi
RIKEN (The Institute of Physical and Chemical Research), 2-1, Hirosawa, Wako, Saitama 351-0198, Japan

The RIKEN Accelerator Research Facility has provided variety of fast radio-isotope (RI) beams. Their intensities are highest in the world for many light unstable nuclei. Many kind of studies have been made and are in progress using these exotic beams. By nuclear reaction studies in reversed kinematics at several tens MeV/nucleon energies, many interesting features of neutron-rich nuclei, such as neutron halo, magicity loss of N=8, 20, have been found. Nuclear astrophysics studies have also made with direct and indirect methods for nuclear burning processes involving unstable nuclei.

Direct reactions are useful for nuclear spectroscopy. However, development of new methods was necessary because of difficulties due to the reversed kinematics, the poor beam-energy resolution, and the low beam intensity. We have developed the following two methods to overcome the difficulties. One is to measure the invariant mass if the excited state of interest is particle unbound. For bound states, deexcitation γ rays are measured to identify the excited levels.

In the invariant mass method, particles decaying in flight is measured. The excitation energy of their parent nucleus is obtained from the invariant mass measured by their momentum vectors. The energy resolution is almost free from the energy spread of secondary beams. We have been studying, by this method, astrophysical (p,γ) processes with the Coulomb dissociation method. The processes with p-shell nuclei, such as ^{8}B$\rightarrow^{7}$Be+p, ^{9}C$\rightarrow^{8}$B+p, and ^{14}O$\rightarrow^{13}$N+p have been measured with Pb targets. Recently we extended the Coulomb dissociation study to a few rp-process nuclei as ^{22}Mg$\rightarrow^{23}$Al. Another application of the Coulomb dissociation is to measure the E1 strength function of very neutron-rich nuclei. Coulomb dissociation experiments with ^{11}Be and ^{26}Ne beams are such examples.

Coulomb excitation to particle-bound states has also been studied for various unstable nuclei. Comparing the yield of deexcitation γ rays and theoretical prediction of the Coulomb excitation cross section, the transition probability of the relevant state can be extracted. We built arrays of NaI(Tl) scintillators called DALI and DALI-2, and measured the probabilities of the 2^{+}-0^{+} transitions in ^{32}Mg, ^{34}Mg, ^{56}Ni, etc, and the E1 transitions in ^{11}Be, ^{12}Be and ^{15}O. The same method was extended recently to (p,p') and (d,d') reactions. Efficient measurements were realized by using a liquid hydrogen target. The location of the first 2^{+} state in ^{30}Ne, the most proton deficient N=20 even-even nucleus, has been determined for the first time by a (p,p') experiment. Recently, we have performed another (p,p') experiment, and found two bound excited states in ^{27}F, which are not expected in any of recent theoretical calculations.

One of the recent highlights is the 2^{+}-0^{+} transition in ^{16}C. A lifetime measurement and a ^{16}C+Pb inelastic scattering experiment point to a surprising nature of the transition: very much hindered E2 and enhanced neutron excitation. This indicates almost complete decoupling of proton- and neutron-motions in this nucleus.

In order to extend studies to more exotic and heavier nuclei, the RIKEN RI Beam Factory is now being build. It is expected to come into operation during the year 2006 and first experiments will start in 2007. The outline of the new facility together with planned experimental devices will be presented.

First beams of the Radioactive Ions Beam Facility in Brazil (RIBRAS)

R. Lichtenthäler[1], A. Lépine-Szily[1], V. Guimarães[1], M.S. Hussein[1], C. Perego[1], V. Pacco[1], O. Camargo Jr.[1], R. Denke[1], P.N. de Faria[1], E.A. Benjamim[1], R.Y.R. Kuramoto[1], N. Added[1] G.F. Lima[1], J. Kolata[2], A. Arazi[3]

[1] Institute of Physics of the University of São Paulo, 05508-900, São Paulo, Brazil
[2] Physics Department, University of Notre Dame, Notre Dame, Indiana 46556- USA
[3] Comision Nacional de Energia Atomica- Laboratorio Tandar - RA 1429 Buenos Aires, Argentina

rubens@if.usp.br

A system consisting of two superconducting solenoids (RIBRAS)[1] for the production of secondary light exotic beams was recently installed at the Pelletron Laboratory of the University of São Paulo, Brazil. The two solenoids are presently installed at one of the beam lines of the 8 MV, Tandem accelerator and, in a later stage, they will be moved to the LINAC pos-accelerator of $10A.MeV$, when operational. The RIBRAS system is similar to the UND-TWINSOL system, with a larger field integral ($5T.m$) and a larger maximum central field ($6.5T$) in order to operate using the higher mass and energy primary beams delivered by the LINAC.

Secondary beams of ^8Li (E_{lab}=26 MeV) and ^6He (E_{lab}=23 MeV) using a (E = 30MeV, $200nA$) ^7Li primary beam and a ^9Be primary target have been produced with intensities of $10^5 part/s$ of ^8Li and $10^4 part/s$ of ^6He. We performed measurements of elastic scattering angular distributions of ^8Li and ^6He on ^{51}V and gold targets.

Details of the project, future perspectives and the new data will be presented.

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Decade of research on the K=130 cyclotron in Jyväskylä

W. H. Trzaska

University of Jyväskylä, Dept. of Physics
FIN-40014 Jyväskylä, Finland
E-mail: trzaska@phys.jyu.fi

Ten years ago the K=130 cyclotron became fully operational delivering for the first time 4000 hours of beam on target. During the next 2 years that number has climbed to the unprecedented 7000 hours of beam on target per year and has remained on that level till now. The delivered beams are not only excellent in quality but also in variety: from protons to Xe ions including the exotic ^{48}Ca. Even more astonishing are the scope and sophistication of the experiments carried out in Jyväskylä, mostly with the help and contribution from our outside collaborators including many physicists from Russia (mostly from Dubna, Kurchatov, Radium Institutes and MEPhI). In my talk I shall present highlights of these joint achievements of the past decade and reveal some of our future plans.

A universal slow RI-beam facility (SLOWRI) at RIKEN RI-beam factory

Michiharu Wada

Atomic Physics Laboratory, RIKEN, 2-1, Hirosawa, Wako, Saitama, 351-0198 Japan
mw@riken.go.jp

A universal slow radioactive beam facility (SLOWRI) is being developed as part of the RIKEN RI-beam factory (RIBF). This factory consists of a linear accelerator, a series of four cyclotrons and a projectile fragment separator that provides a wide variety of energetic RI-beams. SLOWRI aims to provide low-energy RI-beams of high purity and small emittance with less restricted to the chemical property of the nuclides by utilizing a universal slowing down and cooling schemes, *rf ion guide* [1].

In SLOWRI the energetic RI-beam that leaves the fragment separator ($> 100A$ MeV) is first passed through a degrader and then stopped and thermalized in a catcher gas cell filled with a He gas of ~100 Torr. The high ionization potential of He ensures that most radioactive ions end up in the singly charged ions that can be manipulated by applied electric fields. Using dc and rf electric fields that guide the ions to a small exit nozzle the ions are extracted from the gas cell and entered into a rf six-pole ion beam guide (SPIG) [2]. The beam guide separates the ions from residual He buffer gas and delivers them to a high vacuum region.

In an on-line test using a $\sim 100A$ MeV ^{8}Li beam from the RIKEN projectile fragment separator RIPS we obtained an overall efficiency of 4% when the injected beam intensity of ^{8}Li was $\sim 10^3$ s^{-1}. This value corresponds to an ion guide efficiency of 33%, since only 12% of the incoming ^{8}Li beam from RIPS is estimated to be stopped in the gas cell while others are stopped in the degrader upstream and an end-plate downstream from the cell. This efficiency decreases, however, for higher beam intensities due to space-charge effect [3].

In the symposium, technical bases of rf ion guide and the present performance of the on-line tests will be reported. In addition, planned experiments at SLOWRI will be discussed.

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EXCYT: a new heavy-ion facility ready to start

M. Menna, G. Cuttone, M. Re, F. Chines, E. Messina

The EXCYT facility (EXotics with CYclotron and Tandem) at the INFN-LNS, Catania, Italy is based on a K-800 Superconducting Cyclotron injecting stable heavy-ion beams (up to 80 MeV/amu, 1 eμA) into a target-ion source assembly to produce the required nuclear species via the ISOL method, and on a 15 MV Tandem for post-accelerating the radioactive beams. After thermal ANSYS simulations, during May 2003 the Target-Ion Source assembly (TIS) was successfully tested at GANIL under the same operational conditions that will be initially used at EXCYT. Yields and production efficiencies for ^{8,9}Li were compatible with the ones obtained at SPIRAL.

Following suggestions by the Referees and the LNS Research Division, we decided to deliver ^{8}Li as the first EXCYT radioactive beam (primary beam ^{13}C). This choice also takes in account the availability of the MAGNEX detector in 2004 as well as the requests and the first results obtained by the Big Bang collaboration. The commissioning of the EXCYT facility is foreseen by the end of 2004 together with the start of the nuclear experiments programme. In this talk we also report prospective ion beams currently in development as well as results of collaborations on new types of targets.

Present status of the KEK-JAERI joint RNB project

H. Miyatake*

Institute of Particle and Nuclear Studies (IPNS), High Energy Accelerator Research Organization (KEK), Oho 1-1, Tsukuba, Ibaraki 305-0801, JAPAN

High Energy Accelerator Research Organization (KEK) and Japan Atomic Energy Research Institute (JAERI) are jointly constructing the Tokai Radioactive Ion Accelerator Complex (TRIAC) facility at Tokai site of JAERI[1]. This facility consists of the 20 MV Tandem accelerator, Isotope Separator On-Line (ISOL), charge-breeding ECR (CB-ECRIS), split-coaxial RFQ (SCRFQ-) linac, interdigital-H type (IH-) linac, pre-booster linac, three Bunchers, and superconducting (SC-) linac. The output RNB energy is variable between 0.1 to 8 MeV/u. The TRIAC facility will become partly operational later this year. The heavy neutron-rich RNB as well as light RNB having their energy up to 1.1 MeV/u will be supplied from IH-linac at this early stage of the facility. We will report the present status of this facility together with typical research programs at the TRIAC.

So far, various kinds of neutron rich radioactive nuclei produced by the proton induced fission and by the heavy-ion transfer reaction have been successfully ionized in R&D works at Tokai site. Based on these results, the intensity of mass-separated ^{144}Cs-RNB, for example, is expected to be 5×10^5 pps for the 30 MeV and 3 μA proton beam. The charge-breeding efficiency of 18 GHz CB-ECRIS for the externally injected 1^+-ions was measured at KEK-test bench. The highest efficiencies reached 13.5% for Ar^{9+}, 10.4% for Kr^{12+}, and 6.8% for Xe^{20+}, respectively. These high charge states fulfill the acceleration condition (A/q<7) of the linac complex.

Some pilot experiments with low-energy RNB have been performed. The RNB is obtained by utilizing the inverse transfer reaction and the recoil mass separator in Tandem facility. One of these experiments is for a direct measurement of the astrophysical ^{8}Li(α, n) reaction, which is a key reaction for the heavy element synthesis in going across the stability gap of A=8 under the explosive stellar condition. The obtained result has ten times better statistics compared to the previous exclusive measurement. Another experiment is for a non-destructive measurement of the thermal diffusion constant of Li-ions in LiAl intermetallic compound. A very clear diffusion effect of implanted ^{8}Li has been observed at first. These results and future experiments at the TRIAC will be discussed.

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* This paper is a group report made on behalf of about 50 scientists, engineers, technicians of High Energy Accelerator Research Organization (KEK) and Japan Atomic Energy Research Institute (JAERI).

The detection system of the Dubna Gas-filled Separator for SHE's search.

V.G.Subbotin, S.N.Iliev, A.M.Sukhov,
Yu.S.Tsyganov, A.N.Polyakov and A.A.Voinov

Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, Russia

The system of the compound nuclei α-decays sequences and spontaneous fission events detection, amplifying, measurement, readout and data accumulation is described. Represented system was successfully applied in our recent experiments aimed to synthesize superheavy elements and to reach "island of stability" nearly predicted spherical shell with $Z \geq 114$ and $N=178\text{-}184$. The questions of "dead time" decreasing and system up grade for present experiments are discussed.

UC_x fission targets design for the Spiral 2 project and the Alto project

O. BAJEAT[1], S. ESSABAA[1], J.M. GAUTIER[4], Y. HUGUET[2], F. IBRAHIM[1], P. JARDIN[2], C. LAU[1], N. LECESNE[2], R. LEROY[2], M. MIREA[5], F. NIZERY[3], F. PELLEMOINE[2], C. PHAN VIET[6], D. RIDIKAS[3], M.G. SAINT-LAURENT[2]

1) Institut de Physique Nucléaire, 91406 Orsay, France
2) GANIL, Bd H. Becquerel 14076 Caen cedex 5, France
3) DAPNIA, CEA Saclay, 91191 Gif sur Yvette, France
4) LPC, 6, Bd du Maréchal Juin, 14050 Caen cedex, France
5) NIPNE, P.O. Box, MG-6, Bucharest, Romania
6) Institute of Physics, Centre of Nuclear Physics, P.O.Box 429 BOHO, Hanoi 10.000 Vietnam

Two ways of production of radioactive beams using uranium carbide targets are taken into consideration: fission induced by fast neutrons and by bremsstrahlung radiation. For the SPIRAL 2 project, the fission of ^{238}U in uranium carbide target will be induced by a neutron flow created by bombarding a carbon converter with a 40 MeV high intensity deuteron beam. Calculations and design of the target in order to reach 10^{13} fissions/s with good release have been done. The second way is the photofission using an electron beam. In 2005 the ALTO project (Accélérateur Linéaire Auprès du Tandem d'Orsay) will give a 50 MeV/10μA electron beam. This facility will allow more than 10^{11} fissions/s. In this case, the electron beam hits the target without converter. Calculations realised in order to estimate the production are used to choose the best target shape. For the two cases some R&D under way will be described.

MULTICHANNEL ELECTRONICS SETUP FOR COMBAS SEPARATOR

A.G. Artukh, S.A. Klygin[@], O.V. Semchenkova, Yu.M. Sereda[*], Yu.G. Teterev and A.N. Vorontsov[*]

Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, 141980, Dubna, Russia;

A. Budzanowski, G. Kaminski and J. Szmider

The Henryk Niewodniczanski Institute of Nuclear Physics, Radzikowskiego str., 152, 31-342, Krakow, Poland;

N.I. Zamiatin, D.A. Smolin and N.V. Gorbunov

Laboratory of Particle Physics, Institute for Nuclear Research, 141980, Dubna, Russia;

To investigate properties of exotic nuclei, it is necessary to perform complete kinematic measurements of all products in the exit channel. The COMBAS separator multiparameter registration system services both trajectory and time-of-flight measurements of radioactive nuclear beams and detecting systems measuring kinematic characteristics and multiplicity of the products of nuclear reactions in correlation experiments [1].

The whole registration system has a hierarchic multifunctional structure. The top level of this system includes trajectory and time-of-flight measurements of radioactive beams transported by the separator to the focal plane correlation chamber. This level is based on two-coordinate avalanche counters, which perform, together with the magnetic rigidity measurements, precise determination of the energy and mass identification of separated nuclei by the time-of-flight method (TOF). Moreover, physical trigger for the startup of multichannel electronics in the correlation experiments is generated on this level.

The low level of the registration system services detector system for correlation measurements. This subsystem consists of several lines of multichannel electronics for 32-strip Si detectors and ionization chambers used as thin ΔE detectors for measurement and identification of short-range nuclear reaction products or nuclear decays. An electronic line for a 32-strip detector includes three 32-channel modules: a preamplifier (PA), a spectrometric shaping amplifier (SA), a multiplexer (MUX) and a single channel Analog-to-Digital Converter (ADC). The detector with the preamplifier is mounted in a vacuum correlation chamber. The other three modules (SA, MUX and ADC) are implemented in CAMAC standard and placed outside the vacuum chamber.

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Improvement of the SHIP Target Wheel

H.J. Schött[1], B. Kindler[1], B. Lommel[1], R. Mann[1], D. Ackermann[1,2], S. Antalic[3], H.G. Burkhard[1], P. Cagarda[3], F.P. Heßberger[1], S. Hofmann[1,4], J. Kojouharova[1], P. Kuusiniemi[5], M. Leino[5], O.N. Malyshev[6], G. Münzenberg[1], A.G. Popeko[6], S. Saro[3], B. Streicher[3], B. Sulignano[1], J. Uusitalo[5], A.V. Yeremin[6]

[1]GSI Darmstadt, Germany, [2]Johannes Gutenberg-Universität, Mainz, Germany,
[3]Comenius University, Bratislava, Slovakia, [4]J.W. Goethe-Universität, Frankfurt, Germany,
[5]University of Jyväskylä, Finland, [6]JINR Dubna, Russia

The use of metallic lead or bismuth targets is limited at high beam currents due to their low melting point. In order to increase the intensity for irradiation in heavy element experiments, we investigated possibilities to improve the presently used wheel technology. In detail we will report on

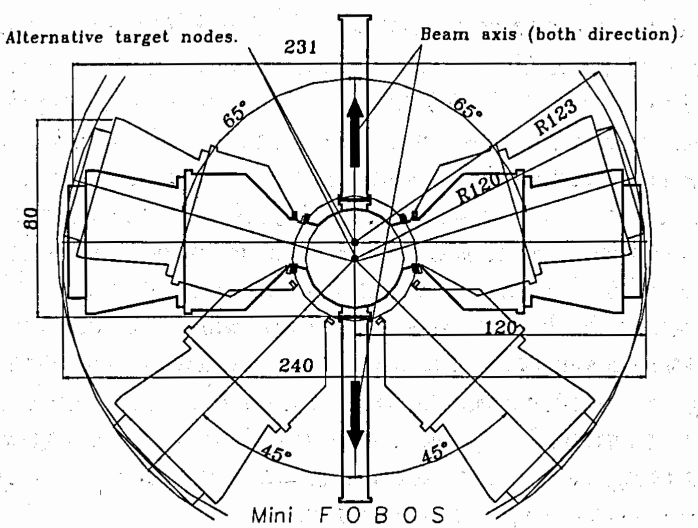
a) the optimization of the beam profile using octupole magnets,
b) the use of chemical compounds with high melting point,
c) the cooling of the target in a He atmosphere, and
d) the on-line control of the target using the scattering of 20 keV electrons.

The application of these methods was already tested in experiments, the results will be presented.

The Modified Mini-FOBOS setup.

S.V. Mitrofanov[1], D. V. Kamanin[1], A.A. Aleksandrov[1], I.A. Aleksandrova[1], E.A.Kuznetsova[1], Yu.V. Pyatkov[2,1], V.G.Tischenko[1], V.M. Vasko[1], V.E. Zhuchko[1]
[1] *Joint Institute for Nuclear Research, Dubna, Russia*
[2] *Moscow Engineering Physics Institute, Moscow, Russia*

The present paper is devoted to the new mobile double-arm TOF-E-Z spectrometer of the charged fragments named the Modified Mini-FOBOS setup (MMF) turned into operation this year. It inherits the modular structure and the standard detector modules of the 4π spectrometer of charged particles FOBOS [1]. The main feature of the FOBOS detector modules is the independent measurement of the velocity vector, mass and charge for each fragment without any kinematical assumptions on the reaction mechanism. This makes possible precise study of the reactions in the most general case – non-binary processes with some missing mass. These excellent capabilities in registering charged products of nuclear reactions have been confirmed in different experiments dedicated to the study of multi-body decays both with HI beams [2] and with the spontaneously fissile sources [3].



The general idea of the MMF consists in using a small reaction chamber, which might be unique for each experiment and the basic universal system maintaining the detectors. The FOBOS-modules are fit to the reaction chamber by means of the adapting cones. Our spectrometer is currently provided by the universal reaction chamber of 44 cm in the diameter with the available arm-angles of 65°, 90° and 135° in the reaction plane for both detector modules (see fig.). The direction of the beam can be reversed increasing thus the number of possible angles between the detectors. The flight-path in this configuration amounts to 50 cm, i.e. the same as at the FOBOS setup. Hence, we keep the resolution parameters specific for FOBOS. Such a configuration of the spectrometer is well suited for study of heavy-ion induced reactions and for spontaneous fission as well.

Thus, all the advantages of the FOBOS spectrometer (except of the declared geometrical efficiency closed to 4π) have been adopted entirely by the Mini-FOBOS spectrometer. Depending on demands of the particular experiments the additional detectors can easily be installed (gamma-detectors, neutron-detectors, forward-angle arrays, etc.). In particular, the high-efficiency neutron counter has been coupled to the spectrometer during the last experiment on the search for the collinear cluster tripartition [4,5]. Besides this, modifications have concerned the start detector, the electronics and the data acquisition system. Also the completely new independent gas-supplying system has been developed.

We are planning to exploit the advantages of the MMF setup in forthcoming experiments dedicated to the study of collinear cluster tripartition in the different reactions with light particle beams.

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SYSTEM FOR FEEDING HYDROGEN ISOTOPE GASES INTO A CYCLOTRON ION SOURCE

A.A. Yukhimchuk, V.V. Antilopov, V.A. Apasov, Yu.I.Vinogradov, A.N. Golubkov, Ye.V. Gornostaev, S.K. Grishechkin, A.M. Demin, S.V. Zlatoustovski, V.G. Klevtsov, A.V. Kuryakin, I.N. Malkov, R.K. Musyaev, V.I. Pustovoi, S.V. Filchagin

Russian Federal Nuclear Centre – All-Russia Scientific Research Institute of Experimental Physics (RFNC-VNIIEF), 607188 Sarov, Nizhniy Novgorod Reg., Russia

V.V. Bekhterev, S.L. Bogomolov, G.G. Gulbekian, A.A. Yefremov, A. Zelenak, M. Leporis, V.N. Loginov, S.V. Pashchenko, A.M. Rodin, Yu.I. Smirnov, N.Yu. Yazvitski

Joint Institute for Nuclear Research, 141980 Dubna, Moscow Reg., Russia.

Transfer reactions observed with the use of tritium beams present a good way for the study of light nuclei at the neutron stability boundary. Experiments employing a triton beam produced by the U-400M cyclotron yielded new data on the resonance states of ^4H and ^5H nuclei produced in the $t+t\rightarrow{}^5H+p$, $t+t\rightarrow{}^4H+d$ and $t+d\rightarrow{}^4H+p$ reactions. The cyclotron was tuned to accelerate singly charged DT^{1+} ions to energy of 19.4×A MeV. A 58.2 MeV triton beam was extracted from the cyclotron chamber by stripping the molecular ions on a thin graphite foil installed at the maximum radius orbit. A RF ion source produced the DT^+ beam for the axial injection line of the cyclotron. An automated system was created for feeding the DT gas into the source. The molecules of hydrogen isotopes were delivered to the ion source with the preset ratios of their flows and concentrations. The isotopes of hydrogen, including tritium, were stored in ^{238}U in chemically bound states. Diffusion through the heated nickel capillary walls was employed to provide for fine tuning of gas flows in the ion source. The allowed flow regulation was within the limits of $5\cdot10^{-3}$-5 cm^3/h. The feeding system implemented the remote control of such processes as (1) the conversion of hydrogen isotopes from the bound state into gas phase, (2) the adjustment and maintenance of the gas flows coming to the ion source, (3) the graphical and digital representation of the controlled processes, (4) the experiment logging.

Two channels of gas feeding worked in the experiments. One channel tuned the flow of a deuterium-tritium gas mixture, containing 1% of tritium, coming to the ion source. The main flow coming into the source through the second feeding channel was the deuterium gas. The value of this flow was tuned for a normal maintenance of the source plasma. The deuterium and deuterium-tritium flows amounted to 1.7 and 0.06–0.10 cm^3/h, respectively. As a result, the main components of the ion current coming out from the source were the D_2^+; D_3^+ and D^+ ions with typical currents of 30, 10 and 6 μ A, respectively. The total current of the DT^+ and D_2H^+ ions was about 100 nA. At long-time operation, a 10-nA current was obtained for a 58.2-MeV triton beam extracted from the cyclotron by stripping on a thin graphite foil.

THE SET-UP ON MAGNETIC SPECTROMETER Q3D –MULTI AT THE U-400M

R.A.Astabatyan[1,2], R.L.Kavalov[1], E.R.Markaryan[1,2],
Yu.E.Penionzhkevich[2], Yu.G.Sobolev[2], A.V.Tikhomirov[2]
1 Yerevan Physical Institute, Yerevan, Armenia
2 Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia

The set-up is intended for experiments on studying elastic and inelastic scattering to carry out inclusive measurements as well as to distinguish the correlated reaction products and measure the angle between them.

For this purpose magnetic spectrometer Q3D [1] with combination of the detecting elements of MULTI set-up [2] are used. The essential characteristics of Q3D are the following: maximal magnetic rigidity is 3,2 Tm; solid angle is 3.0 msr; momentum acceptance-7 %; angle of deflection is 91.6°. Apart from the magnetic spectrometer Q3D, the detecting system will be included three main parts:

1. The multiwire proportional chambers (MWPCs) for the incident beam, installed on the focal plane of the beam channel and just before the physical target. This part of detecting system is intended in order to correct magnetic rigidity $B\rho$ [3], to form a narrow beam onto the target, to generally monitor the beam. Time-of-flight measurements are also intended in order to carry out spectroscopy of incident beam. The counting ability of this system is ~5 10^5 1/s per wire.

2. For trajectory reconstruction and identification of the reaction particles and the total energy determination the MWPCs and ΔE-chambers are used. They are placed at the focal plane and just behind of the focal plane of the magnetic spectrometer Q3D. Angular resolution is determined by cell (X,Y) dimensions (1 x 1), (2 x 2) mm^2 and chambers geometry. Time-of flight measurement by using of "fast OR" MWPCs signal is also intended.

3. Correlation measurements are also of interest for studying the structure of exotic nuclei and in some other experiments. In this case, the third part of detectors will be placed outside of magnetic spectrometer at some angle with the beam axis. This part is consisted of coordinate MWPCs, ΔE ionization detector and total absorption CsI-hodoscope for trajectory reconstruction, identification and measure the total energy of correlated particles.

Using the presented set-up enables to carry out elastic and inelastic scattering measurements in wide angular range including the forward and backward direction [4].

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Pulse height defect of ^{48}Ca ions in ion-implanted silicon detector

[a]Kushniruk V.F., [b]Bialkowsky E., [a]Penionzhkevich Yu.E., [b]Skwirczynska I., [a]Sobolev Yu.G., [a]Ugryumov V.Yu.

[a] Joint Institute for Nuclear Research, Dubna, Russia
[b] H.Newodniczanski Institute of Nuclear Physics, Krakow, Poland

The pulse height defect (PHD) of ^{48}Ca ions in ion- implanted silicon detector has been studied in the energy range from 110 to 223 MeV. The energy dependences of the total PHD, of the recombination component of PHD and of the relative recombination energy losses were obtained. Furthermore, the dependences of measured ion energies and of PHD on the electric field intensity were obtained. The results are discussed on the basis of recombination model taking into account the spreading of nonequilibrium current carriers by ambipolar diffusion during the plasma time.

The investigation has been performed at the Flerov Laboratory of Nuclear Reactions, JINR.

Reaction Dynamics with Radioactive Beams and the Equation of State of Asymmetric Nuclear Matter

Massimo Di Toro

Laboratori Nazionali del Sud INFN, Via S. Sofia 44, I-95123 Catania, Italy and Dipartimento di Fisica e Astronomia, Universita' di Catania.

Our present knowledge of the isovector part of the nuclear effective interaction, with the related isospin dependent transport effects in Heavy Ion Collisions, is analysed. The discussion will be based on non-relativistic and relativistic mean field theories.
A selection of *Observables* from reaction dynamics with charge asymmetric ions, from low to relativistic energies, is finally presented, that we expect particularly sensitive to the isovector channel, i.e. to the symmetry energy and its "fine structure":

i) Isospin Distillation in Multifragmentation: new instabilities in dilute asymmetric matter.

ii) Isospin Diffusion in semicentral collisions at the Fermi energies.

iii) Isospin content of Neck-Fragments. Isoscaling.

iv) Testing the Lorentz structure of the symmetry term: Isospin in collective flows.

v) Isospin Transparency for central collisions at relativistic energies.

vi) Isospin in particle production: nucleon effective mass splitting and threshold effects.

vii) Early transition to a deconfined phase at high isospin density.

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Search for exotic fission modes

W.H.Trzaska, S.Iamaletdinov, V.Lyapin and Yu.Pyatkov
(for HENDES collaboration)

University of Jyväskylä, Dept. of Physics
FIN-40014 Jyväskylä, Finland
E-mail: trzaska@phys.jyu.fi

Modern experimental techniques allow for a new approach to some of the unanswered fundamental questions of nuclear physics. For instance, the search for the true ternary fission in which the nucleus would decay into 3 fragments of comparable mass. Such decays were observed from excited nuclei but never at low excitations or in spontaneous fission. The first results obtained recently at Dubna with FOBOS spectrometer were highly encouraging. Among the 2 million of ^{252}Cf (sf) events there were about 20 with anomalous properties consistent with the hypothesis of collinear cluster tripartion (CCT). These events suggested a new decay mode producing 3 heavy fragments with masses in the 68 – 85 range, two of which were accelerated to the energies comparable to normal, binary fragments while the third was assumed to remain nearly at rest in the center of mass system. Additional credibility for this exotic hypothesis came from the fact that the suspected CCT events were visibly correlated. The masses of the 2 registered fragments belonging to the 20 suspected CCT events formed a clear rectangle in the mass-mass plot. The sides of the rectangle were around masses 68 and 85 in otherwise background-free area. In the talk the results from the follow up experiment will be presented. It was designed to verify the existence of CCT in ^{252}Cf(sf) at the level of about 10 per million as suggested by FOBOS data. In particular, the aim was to exclude the possibility of fragment scattering (and loosing energy) on the wire grids of the gas detectors. Instead of gas detectors 4 micro channel plate detectors (MCP) and 2 PIN diodes with time pick-off were used replacing the standard 2 x TOF + 2 x Energy detection scheme with 6 x Time + 2 x Energy. With so many extra parameters additional crosschecks for data consistency were made possible. If scattering on the detector grid were the source of the CCT events at FOBOS, the Jyväskylä experiment will be able to show it. If on the other hand the effect will persist it will be the needed independent confirmation of the new decay mode that will force us to change our understanding of fission process. The experiment is still running (March 2004) but it has already collected 0.7 million events – sufficient to provide a clear answer either for or against CCT. The final results are expected in time for EXON 2004.

Complex Nuclear-Structure Phenomena Revealed from the Nuclide Production in Fragmentation Reactions

M. V. Ricciardi[(a)], *A. V. Ignatyuk*[(b)], *A. Kelić*[(c)], *P. Napolitani*[(a,c)], *F. Rejmund*[(c)], *K.-H. Schmidt*[(a)], *O. Yordanov*[(a)]

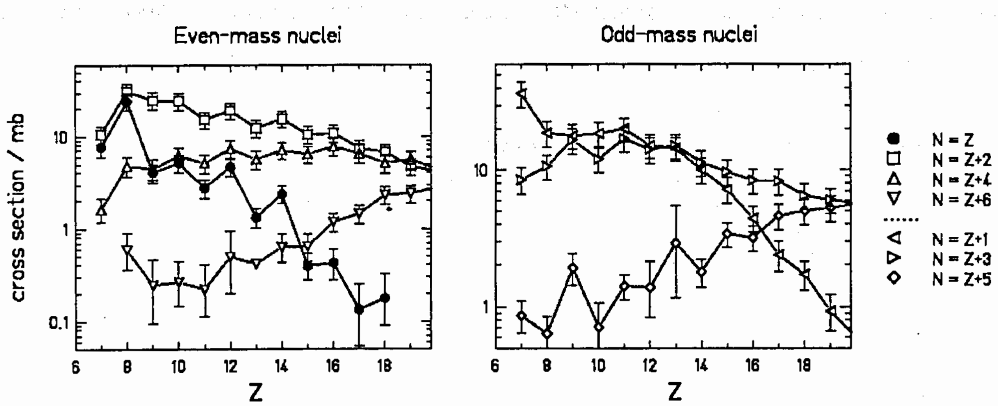
(a) GSI, Planckstr. 1, 64291, Darmstadt, Germany
(b) IPPE, Bondarenko Squ. 1, 249020, Obninsk, Russia
(c) IPN, 91406, Orsay, France

A pronounced nuclear-structure phenomenon is observed in the experimental production cross-section for the reactions $^{238}U + {}^{1}H$ and ^{238}U + Ti at 1 *A* GeV. The experiments were performed at the Fragment Separator (FRS), GSI, Darmstadt, Germany. The cross sections of fragmentation residues, fully identified in mass and atomic number, and cinematically separated to exclude fission events, are modulated by a complex and very strong even-odd structure (see figure). It partly amounts to a magnitude of 50 %, which is comparable to even-odd effects found in low-energy fission.

The origin of this effect was explained on the basis of the statistical model of nuclear reaction. The observed structure was reproduced to a high degree by carefully considering the appropriate nuclear-structure effects in binding energies and level densities. Still some interesting deviations for multiples of alpha particles (even-even N=Z nuclei) remain as a possible signature for alpha clustering.

Besides the information on nuclear-structure itself, these data are also highly relevant for astrophysical question on the production of specific light nuclides in the universe.

This work was recently published in Nucl. Phys. A 733 (2004) 299-318 / arXiv nucl-ex/0312002.



Experimental fragmentation cross-sections for the products of ^{238}U, impinging on a titanium target at 1 GeV per nucleon. The experiment was performed at the FRS at GSI, Darmstadt, Germany. The data reveal a complex structural phenomenon.

Proton halos in light proton-rich nuclei and elastic electron scattering

Zhongzhou Ren[1,2,*] and Zaijun Wang[1]

[1]*Department of Physics, Nanjing University, Nanjing 210008, China*

[2]*Center of Theoretical Nuclear Physics,*

National Laboratory of Heavy-Ion Accelerator at Lanzhou, Lanzhou 730000, China

Abstract

Recent experiments show that there are proton halos in exotic light proton-rich nuclei. We investigate the effect of proton halos on the cross sections and form factors of elastic electron scattering from the exotic proton-rich nuclei ^{28}S and ^{12}O. With the charge density distributions from the self-consistent relativistic mean field model we calculate cross sections and form factors of the elastic electron scattering in the plane wave Born approximation where the main effect of the Coulomb distortions (distorted wave Born-approximation) has been incorporated in numerical calculations. The numerical results are compared with the available data of the stable nuclei ^{32}S and ^{16}O. The results show that the form factors and cross sections of elastic electron scattering at intermediate-momentum transfers are very sensitive to the alterations of the charge density distributions of the last protons in exotic nuclei ^{28}S and ^{12}O. This is an interesting combination of the reliable relativistic mean-field model with the model of electron-nucleus scattering and it can be useful for future experiments.

Keywords: Proton halos; Relativistic mean field model; Elastic electron scattering; Cross section; Form factor.

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*Electronic address: zren@nju.edu.cn;zren99@yahoo.com.

Subbarrier fusion processes with weakly-bound nuclei: the role of the break-up channel and the effect of the continuum-continuum coupling

C.H. Dasso[1] and A. Vitturi[2]

[1] Departamento de Fìsica Atòmica, Molecular y Nuclear, Sevilla, Spain
[2] Dipartimento di Fisica ``G.Galilei" and INFN, Padova, Italy

Large attention has been devoted to the problem of subbarrier fusion processes involving very neutron rich, weakly-bound nuclei. Besides the purely static effects arising from the progressive lowering of the effective height of the potential barrier due to the neutron excess, one also expects others of a dynamical nature, associated with the multidimensional character of the problem. In particular one expects large effects from the strongly coupled break-up channels, due to the vicinity of the continuum threshold. This is an interesting topic because there has existed for quite a while some disagreement insofar as whether it enhances or de-enhances the observable fusion cross sections. Discussions have in particularly focused on the importance of including continuum-continuum couplings in the formalisms used to investigate theoretically these processes. In fact, while microscopic calculations for the bound-continuum inelastic formfactors lead to the conclusion that the nuclear excitation mechanism plays a role comparable to that of the Coulomb excitation, calculations that incorporated the continuum-continuum couplings showed a tendency to reduce (or even cancel) the effect of the nuclear excitation mechanism (1).

In this contribution we will discuss the role of continuum-continuum coupling in the barrier penetration problem within a schematic model involving a reduced number of ``continuum'' channels. The model retains the important features of the problem, avoiding in the same time the large complexity of current coupled discretized continuum channel (CDCC) calculations. We will in particular discuss whether the discretization prescriptions to handle the continuum may be appropriate when extended to truly unbounded integrands.

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Level density effect in fusion reaction

Ajay Kumar[1], A. Kumar[1], G. Singh[1], Hardev Singh[1], B.K. Yogi[2], R.P. Singh[2], Rakesh Kumar[2], K.S. Golda[2], S.K. Datta[2] and I.M. Govil[1]

[1]*Department of Physics, Panjab University, Chandigarh-160014, India*

[2]*Nuclear Science Centre, New Delhi-110067, India*

Residues from fusion reactions ($^{12}C+^{46}Ti$) and ($^{31}P+^{27}Al$) at different energies were identified by their characteristic γ rays. Coincident neutron energy spectra were measured at four angles for transitions in ^{53}Fe and ^{56}Co. The measured energy spectra of evaporated neutrons were compared to statistical-model calculations. In case of symmetric system($^{31}P+^{27}Al$), it was found that a constant excitation energy independent level density parameter is not able to reproduce these spectra and found that the results in this case require an excitation energy dependent level density parameter, while in case of asymmetric system ($^{12}C+^{46}Ti$)the neutron spectra is well defined by the statistical model calculation without any change in level density parameter.

"ABNORMAL NUCLEAR DISPERSION" IN HEAVY-ION SCATTERING: MANIFESTATION OF EXOTIC NUCLEAR EXCITATION?

A.S.Demyanova[1], Yu.A.Glukhov[1], S.A.Goncharov[2], A.A.Ogloblin[1], W.H.Trzaska[3]

At the analysis of the rainbow elastic scattering of some light heavy ions (^6Li + ^{12}C, ^{12}C + ^{12}C, ^{16}O + ^{12}C) [1] unusual behavior of the energy dependence of volume integrals, the basic values describing absorbing and refractive abilities of nucleus-nucleus potentials, was observed. The volume integrals from the imaginary part of potential J_W exhibit a weak wide maximum at the energies 15 - 20 MeV/nucleon. Its position correlates with a non-monotonous course of the energy dependence of the volume integrals from the real part of potential J_V, which is well reproduced by the dispersion relation. Such behavior of J_W and J_V is similar to optical abnormal dispersion (sharp change of the refraction index at the presence of an absorption line). In nuclear physics similar correlation between J_W and J_V was observed closely to the Coulomb barrier (threshold anomaly).

J_W's maxima become considerably more pronounced if one considers their dependence not from the energy but from the relative velocity of the colliding nuclei. The values of J_W's for the ^{12}C + ^{12}C and ^{16}O + ^{12}C systems are very close at the identical velocities. The very fact of the presence of the resonance velocity dependence denotes to affinity of the interaction time to a certain characteristic period of internuclear movement. The only known type of nuclear excitations adequate to the specified condition, are giant resonances. However, the simple explanation does not pass, since, the excitation of giant dipole resonances is forbidden due to the isospin conservation, and besides, the effect is absent in the ^{16}O + ^{16}O scattering [2].

Thus, for some projectile-target combinations there exist some additional resonant absorption at 15 - 20 MэB*A, which physical nature is not clear. The observation of the effect in rainbow scattering, i.e. under conditions of strong mutual penetration of the colliding nuclei, provides some arguments in favor of the assumption that it can be connected with nuclear matter compression in zone of interaction. Some hypotheses (collective movement of alpha particles, possible manifestation of isoscalar giant dipole resonance) and possible ways of experimental testing are discussed.

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Statical and statistical properties of heated rotating nuclei in the temperature-dependent finite-range model

E.G. Ryabov and G.D. Adeev

Department of Theoretical Physics, Omsk State University, Omsk, Russia

There exists three approaches to the problem of calculation of the various properties of the atomic nucleus: microscopic (Hartrey-Fock method), Strutinsky macro-microscopic method and macroscopic one. Certainly, the straight and general microscopic way should lead to good agreement, quantitatively and qualitatively, with experimental data. But this method is hard enough to implement in extensive calculations and it still requires some kind of approximation to real physical picture. As the temperature and angular momentum of the nucleus increases - the microscopic effects' role gets smaller. Therefore, considering a hot rotating nucleus, we can use a macroscopic liquid drop approach, whose results are practically identical to microscopic ones at temperatures $T \geq 1.5 - 2MeV$. But there exists some uncertainty, because vastly and rather successfully employed in theoretical calculations finite-range liquid-drop model (LDM) [1] doesn't take into account for temperature dependence of its parameters. This restricts us to assume all nuclear properties within this model to be temperature independent. A few years ago the finite-range LDM based on the Yukawa-plus-exponential potential [2] has been generalized by Krappe [3] to describe temperature dependence of nuclear free energy. This generalization also allows us to calculate level density parameter a within the same model. The importance of such consistency was already shown in our previous work [4].

In the present work the generalized finite-range LDM was applied to calculate various statical and statistical properties of the hot rotating nuclei (e.g. barrier height B_f and critical angular momenta L_{crit}, saddle configuration, ratio a_f/a_n - level densities at barrier and in ground state, effective moment of inertia J_{eff} and Z^2/A_{crit} parameter, stiffness to mass-asymmetric deformations and Businaro-Galone (BG) point position). The concurrent influence of temperature and angular momentum on these characteristics has been investigated. The results manifest much more importance of rotating excitation of nucleus in most of cases, but none of the competing factors can be neglected. For example, we found that Z^2/A_{crit} parameter changes from 44.5 to 40.5 and BG point moves towards lighter nuclei from $Z^2/A = 21$ to $Z^2/A = 20$, as temperature ranges from $T = 0$ to $T = 4MeV$ and angular momentum sets to zero. To see the difference in magnitudes of the influence one should consider the following: BG point moves from above mentioned $Z^2/A = 21$ at $L = 0\hbar$ to $Z^2/A = 15$ at $L = 60\hbar$, when temperature remains unchanged at zero.

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TIME-DEPENDENT QUANTUM ANALYSIS OF NEUTRON TRANSFER IN HEAVY ION FUSION REACTIONS

V.V. Samarin and V.I. Zagrebaev

Neutron degrees of freedom should play an important role in near-barrier fusion reactions of heavy ions. However, we are still far from good understanding of the subject. Moreover, there is no consensus on the extend to which the intermediate neutron transfer is important in fusion reactions. In Fig. 1 experimental cross sections are shown for the ^{40}Ca+^{90}Zr and ^{40}Ca+^{96}Zr fusion reactions [1] (open and filled circles) along with theoretical analysis of them performed with and without vibration excitations of the nuclei (dashed and dotted curves) [2]. The solid curve shows the effect of intermediate neutron transfer with positive Q-values obtained within the semi-empirical model of "sequential fusion" proposed in [2].

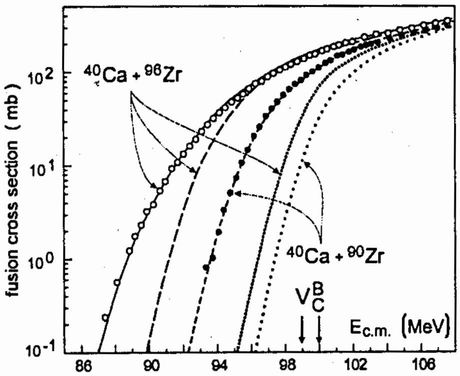

Fig. 1

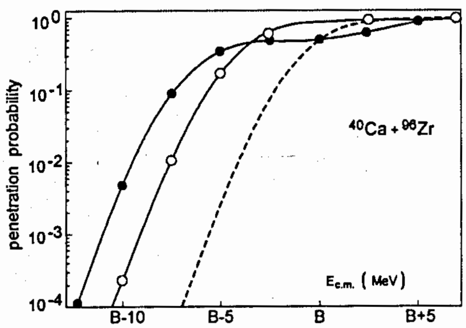

Fig. 2

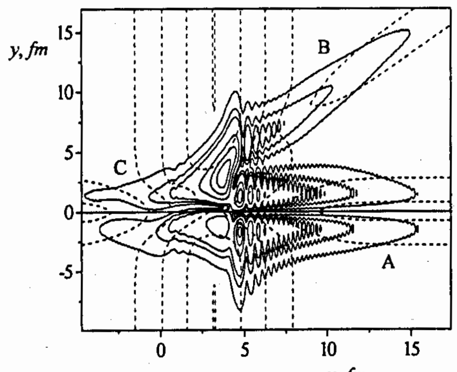

Fig. 3

To clarify more a role of neutron degrees of freedom in heavy ion fusion reactions we developed a new approach based on solution of time dependent Schrödinger equation for the three body quantum system: two nuclear cores and a valence neutron. In the simplest case of head-on collision we need to solve a two-dimensional time dependent quantum problem. The barrier penetration probabilities calculated within this model for the ^{40}Ca+^{96}Zr fusion reaction are shown in Fig. 2. They qualitatively agree with experiment. The curve with the filled circles in this figure corresponds to the neutron intermediate transfer from 2d5/2 single particle state of ^{96}Zr to 1f7/2 state of $^{40+n}$Ca, whereas the curve with open circles shows a role of neutron transfer from 1g9/2 state in 96Zr into 1f7/2 state of calcium. The dashed curve shows the one-dimensional penetration probability calculated without neutron degrees of freedom. The density of valence neutron distribution $|\Psi(x,y,t)|^2$ and the topographical landscape of two-dimensional potential energy surface $U(x,y)$ are shown in Fig.3 for a definite time moment of the ^{40}Ca+^{96}Zr collision. Here x is the distance between nuclei and y is the neutron coordinate on the axis passing through the two nuclei. The neutron transfer from 2d5/2 state of ^{96}Zr (region A) into the 1f7/2 state of calcium (region B) is shown.

Neutron neck formation, polarization potential, and three dimensional neutron motion were also analyzed within the model along with a role played by the Q-value of intermediate neutron transfer (positive, zero, and negative).

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Energy relaxation condition in heavy ion reactions

D.V. Vanin[1)], P. N. Nadtochy[2)], A. V. Karpov[2)], and G. D. Adeev[2)]

[1)]*Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, Dubna, Russia*

[2)]*Department of Theoretical Physics, Omsk State University, Omsk, Russia*

The theoretical approach based on three-dimensional Langevin equations was applied to describe the dynamics of fusion-fission reactions with heavy ions. There were investigated some conditions for relaxation of initial collision kinetic energy. One of the condition is the separating fission events by rotation of di-nuclei system. For experimentalists it is rather difficult to separate "pure" fission (fission of compound nucleus) from quasi-fission if the combined system has rotated more than one cycle. We tried to simulate fusion-fission process and cut off the quasi-fission events. The obtained results are discussed.

ON THE FORMATION MECHANISM OF FORWARD-ANGLE PRODUCTS IN THE REACTIONS ^{18}O(35 MeV/u) + ^{181}Ta(^{9}Be)

V.P. Aleshin[1], A.G. Artukh*[,2] and Yu.M. Sereda[2]

[1]*Institute for Nuclear Research, Kiev, Ukraine,*
[2]*Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, 141980, Dubna, Russia*

In order to study the production mechanisms of exotic nuclei in the Fermi-energy domain, the forward-angle (0°-2.5°) yields of $2 < Z < 11$ isotopes produced in the reactions ^{18}O(35 MeV/u) + ^{181}Ta(^{9}Be) were measured in[1, 2] using the in-flight separator COMBAS[3] in a spectrometry mode. The velocity, isotopic, and element distributions were obtained. The most striking feature of the velocity spectra $\sigma^{(Z,N)}(V,0^{\circ})$ with $6 \leq Z+N < 18$, is that all they have a maximum at the projectile velocity $V=V_p$, which broadens with increasing number of removed nucleons. For ejectiles close to ^{18}O and for neutron drip line isotopes, the velocity spectra are approximately symmetric with respect to $V=V_p$, while for $Z \approx N$ and for proton-rich products the low-velocity part ($V<V_p$) of the spectra is much broader than the high-velocity one ($V>V_p$).

These properties of $\sigma^{(Z,N)}(V,0^{\circ})$ suggest an idea that zero-angle products lighter than projectile, emerge in multi-nucleon removals from ^{18}O. To verify this hypothesis, we designed a computer code MNR+FD, whose first part (MNR) simulates the removal of nucleons from *s*-, *p*-, *d*-shells of ^{18}O, while the second one (FD) deals, within the Fermi's statistical model[4], with the disintegration of those primary products which have got the *s*- and/or *p*-holes in their ground-state shell-model configurations. The nucleon removal probabilities are calculated in the framework of the semiclassical procedure[5, 6] in which the rate of removal per unit time is identified with $2|W|/\hbar$, where W is the imaginary part of the nucleon-target optical potential. Despite its simplicity, the MNR+FD code reasonably reproduces experimental zero-angle velocity distributions in the reactions of study as well as the relative yields of zero-angle products, including those near the neutron drip line.

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* Corresponding author, E-mail address: artukh@jinr.ru

REFRAKTIVE BEHAVIOUR OF $^{16}O+^{14}C$ SCATTERING

A.C.Demyanova[1], G.Bohlen[2], Yu.A.Glukhov[1], S.A.Goncharov[3], A.Izadpanah[3], V.A.Маслов[4], A.A.Ogloblin[1], Yu.E.Penionzhkevich[4], M.V.Rozhkov[1], Yu.G.Sobolev[4], W.Trzaska[5], G.P.Tjorin[6], S. V.Khlebnikov[6], W. fon Oertzen[2]

[1] FSF RRC "Kurchatov institute ", Moscow, Russia
[2] Hahn - Meitner Institute, Berlin, Germany
[3] SINF Moscow State University, Moscow, Russia
[4] JINR, Dubna, Moscow region, Russia
[5] University of Jyvaskyla, Jyvaskyla, Finland
[6] V.G.Khlopin Radium institute, S.-Petersburg, Russia

Study of the $^{16}O + ^{12}C$ elastic scattering demonstrated serious advantages of asymmetrical combinations of colliding nuclei for research of rainbow processes, comparatively to symmetric systems $^{16}O + ^{16}O$ and $^{12}C + ^{12}C$. We have undertaken investigation of another asymmetrical system $^{16}O+^{14}C$ [1]. The measurements were taken at the ^{16}O energy 132 and 281 MeV and the ^{14}C energy 334.4 MeV (the latter is equivalent to ^{16}O energy 382 MeV). Contrary to what was expected, the scattering carried the refractive character at all three energies, and at the energy 132 MeV the typical nuclear rainbow structure was observed. The $^{16}O + ^{14}C$ angular distribution at the energy 281 MeV has been earlier measured up to 60°. It exhibited only a minor bending closely to the angle $\theta = 40°$, which can be attributed to a secondary rainbow minimum analogously to $^{16}O + ^{12}C$. At the same time the calculations fitted to these data predicted the main rainbow minimum at about 70°, being even more intensive than in the case of $^{16}O + ^{12}C$. To check this assumption we carried out new measurements in the large angles interval at the energy 281 MeV at the Jyvaskyla University cyclotron. The reaction products were measured by kinematical coincidences using multidetector system, what allowed getting sufficient statistics for reasonable time. In addition the new measurements with magnetic spectrometer have been carried out at the cyclotron of Hahn - Meitner Institute in Berlin in order to get reliable normalization of the data at the smallest angles.

The results of the experiment showed that clear rainbow structure in $^{16}O + ^{14}C$ scattering at 281 MeV really takes place. However the main rainbow minimum is located at ~ 57°, instead of 70° as it was predicted. The observed position of the minimum fits well to the empirical systematization "angle – inverse energy", obtained for the system $^{16}O + ^{12}C$ [1]. Characteristics of rainbow scattering of ^{16}O nuclei on the neighbor targets ^{12}C, ^{14}C and ^{16}O are discussed.

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Beta decay in medium-heavy nuclei and its application to nuclear astrophysics

Koji Higashiyama and Naotaka Yoshinaga
Department of Physics, Saitama University

The accurate prediction of beta-decay rates requires a detailed knowledge of nuclear structure properties of both the initial and final nuclear states. Moreover, the beta-decay rates provide us important information for predicting the abundance of nuclei in neutron capture reactions by the rapid neutron capture r process in super-nova explosions. Therefore, it is of great interest to study the beta-decay rates in terms of a microscopic framework, where the neutron and proton degrees of freedom are explicitly taken into account.

The nuclear shell model remains one of the most fundamental approaches for a microscopic description of nuclear structure. Although its applications to light nuclei were very successful, the model cannot be applied to medium and heavy nuclei except a few nuclei lying near a shell closure. The main difficulty is the uncontrollable problem of dimension explosion. In order to avoid this problem, some kinds of truncation schemes are necessary. As such an approach, we propose the pair-truncated shell model (PTSM). In the simplest version of the model, low-lying states of even-even nuclei are represented by collective nucleon pairs with angular momenta zero (S) and two (D). For the description of odd-mass and odd-odd nuclei, the PTSM is extended by including an unpaired neutron and/or proton in addition to SD pair states. Studies of the nuclei in the $A \sim 130$ region were carried out in the context of the PTSM 0, and energy spectra as well as electromagnetic transitions were successfully described.

Recently, we applied the PTSM to the even-even and odd-mass nuclei in the $A \sim 100$ region, and our calculation reproduced energy levels and $E2$ transition rates very well. Using this result, we calculate beta-decay rates, and discuss the internal structure of both the initial and final nuclear states. The results of this calculation will be presented and discussed in detail in this conference.

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INTERACTION OF ^{4}He – PARTICLES WITH STABLE NUCLEI AND EFFECTIVE NUCLEON-NUCLEON FORCES

K.A. Kuterbekov[1], T.K. Zholdybayev[1], Yu.E. Penionzhkevich[2], I.N. Kukhtina[2], A. Muchamedzhan[1]

[1]Institute of Nuclear Physics NNC RK, Almaty, Kazakhstan
[2]Joint Institute for Nuclear Research, Dubna, Russia

The most popular method for join analysis of experimental angular distributions (AD) and total cross sections (TCS) at low and moderate energies is semimicroscopic folding model (SFM) [1]. Since ^{4}He-particle is a core of exotic nuclei ^{6,8}He, it is topical to continue systematic investigations at various effective nucleon-nucleon forces.

In [2] we investigated for the first time energy and mass dependencies of the parameters SFM at low and moderate energies. At that, as effective forces between nucleons of the colliding nuclei were used total M3Y-interaction [3] and nucleon densities calculated by the method of density functional [4].

In the present work based on SFM there were investigated influences of the density dependence factor in effective nucleon-nucleon forces (4 force options considered) on calculation of ADs and TCSs at interaction of ^{4}He-particles with stable nuclei ($A = 12 - 208$) at α-particle energies 21 – 141.5 MeV. Corresponding experimental AD and TCS data used for model verification are of high quality with low error both for angular and energy diapason. Therefore, conclusions made in the performed investigation contain important quantitative information and are valuable for consequent comparative analysis of experimental data on interaction of light exotic nuclei with stable nuclei.

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ENERGY DEPENDENCE OF TOTAL REACTION CROSS SECTIONS FOR $^4He + ^{28}Si$ INTERACTION FROM THE COULOMB BARRIER TO 200 MEV

K.A. Kuterbekov[1], T.K. Zholdybayev[1], K.B. Basybekov[1], Yu.E. Penionzhkevich[2], I.N. Kukhtina[2], Yu.G. Sobolev[2], V.Yu. Ugryumov[2], L.I. Slusarenko[3], V.V. Tokarevskii[3]

[1]Institute of Nuclear Physics NNC RK, Almaty, Kazakhstan;
[2]Joint Institute for Nuclear Research, Dubna, Russia;
[3]Institute of Nuclear Research, Kiev, Ukraine

There has been performed systematical analysis of experimental energy dependence for total reaction cross sections (TCS) in $^4He+^{28}Si$ for energy range from the Coulomb barrier (B_c about 6 MeV) up to middle energies (200 MeV). From literature it is known that the reaction $^4He+^{28}Si$ is the only one with well measured excitation function TCS (σ_R) in wide energy range.

TCS experimental data for the range from B_c to 101.2 MeV were obtained at cyclotron facilities U-150M (Institute of Nuclear Physics NNC RK, Kazakhstan) and K-130 (University of Juvaskyla, Finland) [1]. In [2] there was studied the dependence $\sigma_R(E_\alpha)$ at ^{28}Si at middle energies (69.6 – 192.4 MeV.) Data on σ_R at ^{28}Si at E_α = 96 MeV are presented in [3] along with mass-dependence of TCS.

TCS dependence at low energies is determined by the ratio between the Coulomb barrier and energy of a ^4He-particle. When E_α increases, the α-particle wavelength decreases and contribution from nucleon-nucleon interactions becomes considerable what results in decrease of TCS with increase of E_α.

Approximation of the experimental TCS energy dependence for ^{28}Si nuclei is performed using various parameters [4,5,6]. There were studied influences of particular parameter types in particular energy ranges on description of TCS and factors stipulating their discrepancies.

Analysis of experimental angular distributions for elastic scattering of α-particles and tendencies for change in TCS at the nulceus ^{28}Si has been performed in the energy range E_α = (14.47–240) MeV within the optical model and semimicroscopic folding model [7].

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Yield of correlated fragment pairs in the reaction $^{18}O + ^{208}Pb \rightarrow ^{226}Th$ obtained in γ- γ-coincidence method.

A.A.Bogachev[1], A.Astier[3], I.Deloncle[3], O.Dorvaux[2], M.G.Itkis[1], E.M.Kozulin[1], L.Krupa[1,4], M.-G.Porquet[3]

[1]FLNR, Joint Institute for Nuclear Research, 141980, Dubna, Russia
[2]IReS, IN2P3-CNRS/Universite Louis Pasteur de Strasbourg, B.P.28- F-67037 Strasbourg cedex, France
[3]CSNSM, IN2P3-CNRS/Universite Paris-Sud, 91405 Orsay Campus, France
[4] Institute of Physics SASc, 84228 Bratislava, Slovak Republic

It is quite well-known that the region of transitional nuclei from At to U offers a territory of predilection for further explorations of multimodal fission phenomena. In this range of nuclei, one can expect dramatic changes in the fission properties as the nucleonic composition and the excitation energy are varied. The transition from mass-symmetric to mass-asymmetric fission and accompanying changes in the barrier heights and the transition times from saddle to scission for the different fission modes will strongly influence observables such as the fission mass, charge and energy distribution, the fission cross-sections, the angular distributions, the average prescission M_n^{pre} and postscission M_n^{post} neutron and γ-ray multiplicities $<M_\gamma>$. Experimental data on these properties will provide critical testing grounds for theories of both the static and dynamical aspects of the fusion-fission process.

To investigate the fission process of nuclei ^{226}Th, the reaction $^{18}O + ^{208}Pb$ at E_{lab}=85 MeV bombarding energy was measured. The beam was provided by VIVTRON accelerator of IReS (Strasbourg). The γ-rays were detected with EUROBALL IV array coupled with the Inner Ball. The individual identification of each fragment can be achieved from its γ-ray cascades (using the Ge detectors of EUROBALL). The total γ-ray energy and the γ-ray multiplicity obtained from the Inner Ball, in the selected events, can be assigned to particular fragment pairs. The yields of different fragment pairs (charge splits Z_L/Z_H = 44/46, 42/48, 40/50, 38/52, 36/54) have been observed by detecting the coincidences between prompt γ-rays. Multiplicity distributions of prompt neutrons emitted in the five above charge divisions of ^{226}Th and also mass and excitation energy distributions of primary fragments were extracted. The γ-ray multiplicity which is extremely sensitive to symmetric and asymmetric fission modes could provide the very important information on the shape of the fissioning nucleus at scission point.

Spallation reactions with neutron-rich nuclei

J. Cugnon

University of Liège, Allée du 6 Août 17, Bât.B5, B-4000 Liège 1, Belgium

Spallation reactions have been studied for a long time with proton beams in direct kinematics. A renewed interest, due to the advent of ADS projects for transmutation of nuclear wastes, has led to more systematic and more precise measurements. Furthermore, a real improvement of the theoretical tools has taken place, especially in the frame of the EU project HINDAS [1]. These efforts have contributed to a more complete understanding of the spallation processes. In particular, it appeared that one of the best theoretical tools is provided by the Liège intranuclear cascade model INCL4 coupled to the K.-S. Schimdt ABLA evaporation-fission model. This approach, which is basically parameter-free, owing to a "self-consistent" determination of the stopping time, was shown recently to yield particularly good results for a large set of data for incident energies ranging from 200 MeV to a few GeV's [2]. These data include total reaction cross-sections, inclusive light particle production cross-sections, multiplicity distributions and observables whose prediction constitutes crucial tests for the models, such as residue production cross-sections and recoil distributions. Later on, this approach was shown to be largely succesful in the description of spallation reactions at lower incident energy, down to a few tens of MeV, after small changes in the treatment of the Pauli principle [3].

Here, spallation reactions on neutron-rich nuclei will be investigated theoretically within the same approach. The main issue is to know whether there are qualitative differences with spallation reactions on ordinary nuclei. In particular, the following questions will be studied: (*i*) What is the evolution of the neutron multiplicities with the target neutron excess? (*ii*) Does the relative importance of particle average multiplicities ($<n> \gg <p> \gg <d> \gg <t> \quad \cdots$) change drastically with this neutron excess? (*iii*) Is the shape of the residue mass spectra qualitatively modified?

More theoretical issues will also be discussed, such as the distribution of the excitation energy at the end of the cascade stage, the space-time correlations between the neutrons emitted in the cascade stage and the pertinence of the evaporation models for neutron-rich residues.

Finally, calculations will be also presented for observables in reverse kinematics, since such reactions are expected to be experimentally studied in this kinematics. The aim is to provide with guidelines for optimizing various aspects of exerimental set-ups. Preliminary results on proton-rich targets will also be shown.

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COMPETITION BETWEEN FUSION-FISSION AND QUASI-FISSION IN THE REACTIONS WITH HEAVY IONS

E.M. Kozulin, A.A. Bogachev, A.Yu.Chizhov, J.M. Itkis, M.G. Itkis, G.N.Kniajeva, N.A. Kondratiev, L.Krupa, I.V. Pokrovsky, E.V. Prokhorova, R.N.Sagaydak, V.M.Voskressenski
Flerov Laboratory of Nuclear Reaction, Joint Institute for Nuclear Research, Dubna, Russia

A.M. Stefanini, B. R. Behera, L. Corradi, E. Fioretto, A. Gadea, A. Latina, S. Szilner A.M. Vinodkumar
INFN - Laboratori Naziolali di Legnaro, Italy
M. Trotta,
INFN – Sezione di Napoli
S. Beghini, G. Montagnoli, F. Scarlassara
INFN and Universita di Padova, Italy

F.Haas, N. Rowley
Instutut de Recherches Subatomiques, IN2P3-CNRS/Universite Louis Pasteur, Strasbourg, France

W.H.Trzaska, V.Lyapin
Department of Physics, University of Jyväskylä, Finland

D. Ackermann
Gesellschaft für Schwerionenforschung mbH (GSI), Darmstadt, Germany

E. Vardaci
Dipartimento di Scienze Fisiche, Universita di Napoli "Federico II", INFN, Napoli, Italy

The work presents the results of the study of characteristics of the fusion-fission and quasi-fission of heavy nuclei, produced in the reactions with heavy ions. The major part of these experiments has been performed at the U-400 accelerator of the Flerov Laboratory of Nuclear Reactions (JINR, Dubna); at the TANDEM-ALPI accelerator of the LNL (INFN, Legnaro, Italy) and at the Accelerator Laboratory of University of Jyväskylä (JYFL, Finland) using a time-of-flight spectrometer of fission fragments CORSET (CORrelation SET-up), gamma and a neutron detectors. Mass-energy distributions (MED) of the fragment in the reactions with ^{12}C, ^{16}O, $^{40,48}Ca$ projectile on a wide number of targets ($Z = 62 - 92$) at energies near and below the Coulomb barrier (i.e. when the influence of the shell effects on the fusion and characteristics of the decay of the composite system is considerable) have been measured. ^{154}Sm, $^{168,170}Er$, ^{186}W, $^{204,206,208}Pb$, ^{238}U spectrometric layers 120-200 mkg/cm^2 in thicknesses were used as targets. They were deposited on a 20-50 mkg/cm^2,carbon backings. It was found that the quasi-fission dominates as the reaction products in the reactions with the transuranium elements, whereas in the reaction with double-magic ^{208}Pb the contribution of the quasi-fission process into the capture cross-section does not exceed the value of 3-4%. At the same time in the reactions with rare-earths like ^{154}Sm, $^{168,170}Er$, $^{174,176}Yb$ the yield of quasi-fission increases again and its contribution into the capture cross-section reaches the value of ~30-40% [1,2,3].

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The Russian - German Co-operation at GSI an Example of Success and Friendship

Dr. Helmut Zeitträger
GSI, Darmstadt - H.Zeittraeger@gsi.de

Between Russia and Germany a long cultural and scientific tradition existists. For science the correspondence of Peter the Great and Gottfried Wilhelm Leibniz in the framework of building up the Academy of Sciences in St. Petersburg and several visits of Peter the Great in western Europe was very important. The co-operation was interrupted by the breakout of two world wars with big losses in Russia. Thanks to the Russian scientists the co-operation were refurnished e.g. via neutral platforms like CERN. At GSI a close fruitful and friendly co-operation with scientists and engineers from Russia had been formed immediately after GSI's founding in 1969.

In the field of heavy-ion research GSI's interest was very high especially in the production process of superheavy elements in Russian institutes. In the early 1970s the contacts between Dubna and Darmstadt were strengthened. Prof. Flerov presented the Dubna programme at Darmstadt. In 1972, at the GSI a translation series, the so-called 'GSI-translations', was started to get better access to Russian scientific publications in the field of heavy-ion and accelerator research and technology. Mid of the 1980s formal agreements between the governments of the UdSSR and the Federal Republic of Germany were made. GSI and several Russian institutions were integrated in these contracts and co-operations.

After the changes in the political landscape, in the former UdSSR, new agreements and contacts became even easier and also former contracts between the JINR and the GDR, had been transformed and continued. Also in the field of supplying GSI with research instrumentation like electron coolers, detectors, etc. a new field of cooperation was opened.

TRANSFORM, INTAS, and many other programs have opened up new possibilities to strengthen the co-operation between Russian and German scientists and engineers. This co-operation, together with several MOU's on new topics like the development of new types of magnets etc. will be an important contribution for GSI's Future Project FAIR, Facility for Antiproton and Ion Research at Darmstadt, enriching the successful co-operation to a density never achieved before.

PUBLIC AWARENESS OF NUCLEAR SCIENCE IN EUROPE

A.KUGLER
FOR BOARD OF NUCLEAR PHYSICS DIVISION OF EUROPEAN PHYSICAL SOCIETY

Nuclear Physics Institute AS CR, Czech Republic, kugler@ujf.cas.cz

PANS originated from the idea that it is important to convey to the general public important issues associated with Nuclear Science. The assumption is that an informed public is better able to come to sensible judgements based on knowledge instead of prejudice. The image of anything "nuclear" is presently viewed in Europe with suspicion mainly due to the public perception being influenced by sensational negative media coverage rather than a balance view across the whole field. If nuclear science is to have a healthy future, then it is important that we initiate activities that can start to bring about a more balanced view.

This is the basic remit of PANS. It is an activity that was started several years ago by two bodies, which represent Nuclear Physics community in Europe, i.e. by the NPB of EPS and NuPECC of ESF. In the framework of PANS projects like BOOK and EXHIBITION were successfully carried out, currently running is NUPEX project aiming for Web-based education, others are still in preparation, like CD-ROM, PANS-WEB etc.

Charged Hadrons and Leptons identification at HADES

A. KUGLER
FOR HADES COLLABORATION

Nuclear Physics Institute AS CR, Czech Republic, kugler@ujf.cas.cz

The HADES spectrometer installed at GSI Darmstadt is devoted to the study of the production of di-lepton pairs from vector meson decays in relativistic nucleus-nucleus collisions, as well as proton- and pion-induced reactions. Extraction of rare lepton pairs in high hadron multiplicity events requires an efficient particle identification (PID). In HADES leptons are identified by a Rich as well as a Shower detector. For all charged particles momentum is measured by a tracking system surrounding the toroidal superconducting magnet, and velocity and energy loss is provided by a TOF detector. The particle identification method has been developed, allowing efficient identification of particles, using full experimental information from all subdetectors. The basis of the method is test of hypothesis, that the reconstructed track can be identified as certain particle specie. Several measured variables from various subdetectors associated to each identified track are used to provide a set of probabilities in individual PID algorithms, which are then merged assuming their statistical independence. For the resulted PID probability calculation the Bayesian approach taking into account the prior abundances of individual particle types, as well as the known detector response, is implemented. The performance of the method – in terms of efficiency and purity - is then evaluated in detailed simulations. To demonstrate the method performance, single particle spectra of charged hadrons and leptons from C+C at 2 A GeV will be presented and compared with results of corresponding simulations. The proton and pion yields and mt and rapidity distributions will be compared with existing data.

LASER SPECTROSCOPY OF TRANSURANIUM ELEMENTS

Yu.P. Gangrsky, D.V. Karaivanov, K.P. Marinova, B.N. Markov, Yu.E. Penionzhkevich, S.G. Zemlyanoi

Joint Institute for Nuclear Research, Dubna, Russia

The perspectives of the study of the transuranium elements nuclear structure by laser spectroscopy methods are considered. These methods alowes to determine the number of important nuclear parameters – charge radii, spins, magnetic dipole and electric quadrupole moments and to refer about single perticle and collective properties of nuclei. The most interesting peculiarities of the transuranium nuclei are the deformed closed shell 152 neutrons and the excited superdeformed states (spontaneously fissioning isomers).

The first experimental results in these region of nuclei are presented: charge radii differences of the Uranium isotopes chain (A = 233 – 238) and the nuclear multiple moments of the odd nuclei (^{233}U, ^{235}U, ^{241}Am, ^{243}Am). The resonance fluorescence detection in parallel atomic beam was used. The smooch dependence of these values on the neutron number is observed. The comparision of these nuclear parameters with calculated ones using different models is performed. The satisfactory agreement with the droplet model predictions is obtained. The influence of these parameters on the transuranium nuclei stability is considered. The correlation of charge radii odd-even staggering and increasing of stability for the odd proton or neutron nuclei is demonstrated. The plans of the forcoming experiments in region of nuclei near closed shell 152 neutrons are discussed.

On-line Production of Rb and Cs isotopes from Uranium Carbide Targets

A.E. Barzakh, D.V. Fedorov, A.M. Ionan, V.S. Ivanov, K.A. Mezilev, F.V. Moroz, S.Yu. Orlov, V.N. Panteleev, Yu.M. Volkov

188350, Petersburg Nuclear Physics Institute RAS, Leningrad district, Russia

A. Andrighetto, G. Lhersonneau, L. Stroe, L.B. Tecchio, X.F. Wang

INFN, Laboratori Nationali di Legnaro, Viale dell' Universita 2, 35020 Legnaro (Padova), Italy

L.Renan, A.Villari

GANIL (Grand Accelerateur National d'Ions Lourds), Boulevard Henri Becquerel, BP 55027, F-14076 Caen Cedex5, France

A series of on-line mass separation experiments have been performed at the IRIS facility to measure the yield and release of Rb and Cs neutron-rich isotopes produced by fission reaction of ^{238}U. A 1 GeV proton beam was used to bombard uranium carbide targets with the densities of 11 g/cm^3 and 1.5 g/cm^3 held at temperatures in the range of 2000 – 2230 °C. The release curves of Rb and Cs long-lived isotopes were measured from both kinds of targets. The overall production efficiency was determined making use of experimentally measured cross-sections of that isotope production. Comparison of the experimental yields of Rb and Cs isotopes with the calculated ones after corrections for losses due to finite release times suggests that the diffusion is the dominating process reducing the efficiency for short-lived isotopes. When normalized to the same thickness, a yield enhancement is observed for the high-density rod target. It is possibly explained by the reactions induced by secondary neutrons. A large odd-even effect with higher yields of Cs even neutron isotopes has been observed, confirming similar effect obtained in earlier experiments.

Changes in the mean square charge radii of neutron deficient europium isotopes measured by the laser ion source resonance ionization spectroscopy

A.E. Barzakh, D.V. Fedorov, A.M. Ionan, V.S. Ivanov, F.V. Moroz, K.A. Mezilev, S.Yu. Orlov, V.N. Panteleev, Yu.M. Volkov

188300, Petersburg Nuclear Physics Institute RAS, Gatchina, Leningrad district, Russia

Abstract

The laser ion source has been used for the study of the isotope shifts of neutron deficient Eu isotopes. The extension of the region of the applicability of the method by using the γ- and β- radiation detection is reported. We have measured the isotope shifts of the europium optical line 576.520 nm for $^{137-144}$Eu. To increase the laser ion source efficiency an axial magnetic field was applied. Due to the axial magnetic field application the produced ions were extracted more efficiently from the ion source cavity. Nearly twofold rise of europium atom ionization efficiency was observed. By using of the effect of optical ion bunching the increase of selectivity was obtained. The isotope shift data for $^{139-144}$Eu are in keeping with the previously measured isotope shifts for these nuclides. The new data for ^{137}Eu and refined data for ^{138}Eu point to the gradual increase of deformation for these isotopes. Comparison with the microscopic-macroscopic calculations and calculations in the framework of Hartree-Fock model has been made.

LISE++ development: application to low-energy fission of projectiles at relativistic energies

O.B.Tarasov [1,2], D.Bazin [1]

[1] *National Superconducting Cyclotron Laboratory, MSU, East Lansing, MI 48824-1321, USA*
[2] *Flerov Laboratory of Nuclear Reactions, JINR, 141980, Dubna, Moscow region, Russia*

The program LISE++ [1)] is intended to calculate the transmission and yields of fragments produced and collected in a fragment separator at medium-energy and high-energy facilities (fragment- and recoil-separators with electrostatic and/or magnetic selections). The projectile fragmentation and fusion-evaporation [2)] assumed in this program as the production reaction mechanism allows to simulate experiments at beam energies above the Coulomb barrier.

High-energy secondary-beam facilities such as GSI, RIA, and RIBF provide the technical equipment for a new kind of fission experiment [3)]. Fission properties of short-lived nuclei can be investigated in inverse kinematics. A new model of fast analytical calculation of fission fragment transmission through a fragment separator has been developed in the framework of the code LISE++. The electromagnetic excitation cross section calculation procedure (see Figure) is based on work of C.Bertulani [4)] and LisFus evaporation model [2)]. The calculation of nuclide production yields of fissile nuclei have been incorporated from work of J.Benlliure [5)].

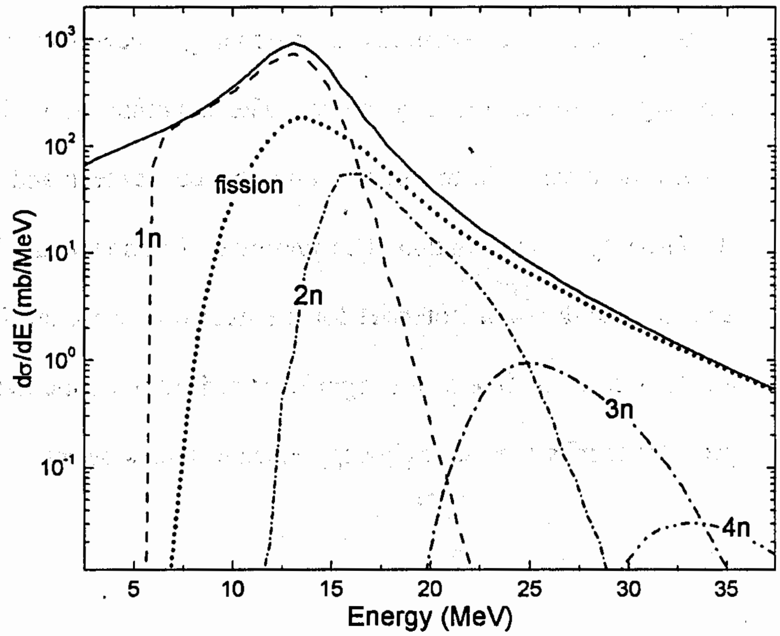

Figure. The differential cross section of electromagnetic excitation in ^{238}U on a lead target at 920 MeV/u (solid curve). Deexcitation channels for excited ^{238}U nuclei as a function of excitation energy are denoted by letters on figure.

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Fulleren-Structure in Superheavies, Nuclei containing Antimatter and Cold Compression

Walter Greiner

Institut für Theoretische Physik,
J. W. Goethe-Universität, Frankfurt am Main,
Germany

Meson field theory predicts the center of the first superheavy island at Z=120, N=184. Such nuclei are semi hollow inside. This suggestes a fulleren - - type structure.

I also discuss the possibility of producing a new kind of nuclear system by putting a few antibaryons inside ordinary nuclei. The structure of such systems is calculated within the relativistic mean-field model assuming that the nucleon and antinucleon potentials are related by the G-parity transformation. The presence of antinucleons leads to decreasing vector potential and increasing scalar potential for the nucleons. As a result, a strongly bound system of high ensity is formed. Due to the significant reduction of the available phase space the annihilation probability might be strongly suppressed in such systems.

Chaotic Surface Quadrupole Oscillations of Nuclei

V.P. Berezovoj, Yu.L.Bolotin, V.A. Cherkaskiy

A.I.Akhiezer Institute for Theoretical Physics
Academicheskaya Str.1, 61108 Kharkov, Ukraine

Quadrupole surface oscillations of atomic nuclei in liquid drop model represent a paradigm for quantum chaos [1-3]. Depending on parameters of the nucleus corresponding potential can have one or several local minima (Fig.1 on the left), corresponding to spherical or deformed shapes of nucleus. In the latter case the mixed case is observed (Fig.1 in the center), which is general situation for multi-well two-dimensional potentials. We investigate the quantum manifestations of classical stochasticity in the energy levels statistics, wave functions structure (Fig.1 on the right) and wave packets dynamics in the mixed state. Role of the mixed state in the chaos-assisted tunnelling from superdeformed to normal deformed states is discussed.

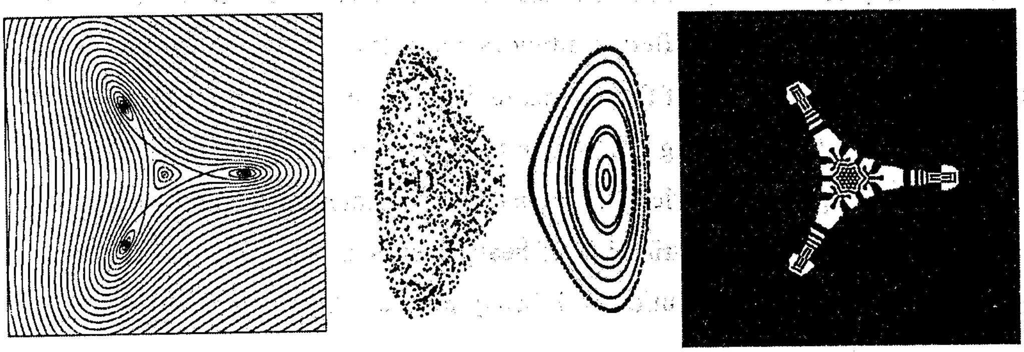

Fig.1 Level lines of the quadupole oscillations potential, corresponding Poincaré surface of section and nodal structure of the stationary wave function.

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Study of Atmospheric Deposition of Heavy Metals Using Active Biomonitoring with Neutron Activation Analysis

Z. Błaszczak, I. Ciszewska, M. V. Frontasyeva*

Faculty of Physics, Adam Mickiewicz University, Poznań, Poland
**Frank Laboratory of Neutron Physics of the Joint Institute for Nuclear Research, Dubna, Russia*

The paper reports preliminary results on the content of heavy metals in the atmospheric air in the city of Poznań. Measurements have been made by the method of active biomonitoring with the use of neutron activation analysis. This method based on the use of moss, has been successfully applied for a few years at the Frank Laboratory of Neutron Physics of the Joint Institute for Nuclear Research, Dubna. It is non-destructive and characterised by high sensitivity of 10^{-10} kg/kg.

Standard samples of living moss distributed at different sites in the city were exposed to the atmospheric air at different altitudes for a few weeks, accumulating the heavy metals from the air. Analysis of the gamma radiation from unstable radioisotopes of different lifetimes formed on exposing the sample to a beam of neutrons from the reactor IBR-2, permitted unambiguous identification of the elements accumulated from the air. The results were used for analysis of distribution of heavy metals in the Poznań atmosphere. Maps illustrating the level of air pollution with heavy metals Cd, Cr, Cu, Hg, Ni, Pb, Zn were made.

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www.jinr.ru/publish/