Zakopane Conference on Nuclear Physics

"Extremes of the Nuclear Landscape"

August 26– September 2, 2018
Zakopane, Poland

Organized by:

The Henryk Niewodniczański Institute of Nuclear Physics PAN
Fundacja dla AGH
Committee of Physics of the Polish Academy of Sciences

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About the conference

The Zakopane Conference on Nuclear Physics, for historical reasons called School, has been organized since 1963 by the Henryk Niewodniczanski Institute of Nuclear Physics of the Polish Academy of Sciences and the Marian Smoluchowski Institute of Physics of the Jagiellonian University. Over the years the School became famous worldwide conference. Nowadays, the Zakopane Conference on Nuclear Physics has a character of a biennial international congress and is one of the major events in Poland related to the low energy nuclear physics.

During the construction of the scientific program special attention has always been paid to offering the enthusiastic and pedagogical overviews of the most recent research subjects in nuclear physics from both the theoretical and the experimental points of view. Young participants have also opportunity to present results of their research in short talks or on posters.

Currently, the conference theme is “Extremes of the Nuclear Landscape” and it is a forum for reviewing progress in theory and experiment at the forefront of nuclear research, especially in what concerns the structure of exotic, unstable nuclei. Furthermore, the conference gives an occasion to discuss the role of the modern nuclear physics in understanding of astrophysical processes and its influence on other disciplines. The aim of the Conference is also to increase the mutual communication of physicists representing various areas of nuclear physics and to create opportunities for intense interaction between graduate students, young researchers and senior scientists.

The 2018 Zakopane Conference on Nuclear Physics is organized by the Henryk Niewodniczański Institute of Nuclear Physics of the Polish Academy of Sciences and AGH UST Foundation and it is cofinanced by the Polish Academy of Sciences. This year the Conference is supported by NuPPEC and CAEN.

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Welcome Address

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Nuclear structure theory: a brief and personal view on status and perspectives

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Monday, August 27th

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Chiral forces for atomic nuclei

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Super asymmetric fission in super heavy nuclei and cluster radioactivity

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Reactions timescales in heavy element synthesis

9:30 **Vyacheslav Saiko, JINR, Dubna,**
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12:15 **David Boiley, GANIL, Caen,**
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16:15 **Remy Thoer, CSNSM, Orsay,**
PolarEx, a future facility for on line nuclear orientation

16:30 **Cory Binnersley, University of Manchester,**
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16:45 **Felix Sommer,TU, Darmstadt,**
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17:00 **Obed Shirinda, iThemba LABS, Cape Town,**
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Friday, August 31st

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Saturday, September 1st

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Exotic isomers explored at the new generation in-flight-separator facility RIBF

9:00 **James J. Caroll, ARL, Maryland,**
Isomer depletion research by the Army Research Laboratory

9:30 **Maxime Mougeot, CSNSM, Orsay,**
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9:45 **Luca Marmugi, University College London,**
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10:00 **Mattias Rudigier, University of Surrey, Guildford,**
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11:30 **Jerzy Dudek, IPHC Strasbourg, and UMCS, Lublin,**
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Special Talk and Closing of the Conference

12:00 **Ewa Gudowska – Nowak, Jagiellonian University, Kraków,**
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a century of inspiration

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19:00 **Conference Banquet**

Sunday, September 2nd

7:30 Breakfast

9:00 – 10:00 Departure to Kraków

Sunday

August 26th

NUCLEAR STRUCTURE THEORY: A BRIEF AND PERSONAL VIEW ON STATUS AND PERSPECTIVES

Gianluca Colo, Dipartimento di Fisica, Universita degli Studi di Milano and INFN, Sezione di Milano, via Celoria 16, 20133 Milano (Italy)

Atomic nuclei constitute a formidable intellectual challenge for scientists who are still striving to answer the fundamental question:
how do the complex nuclear phenomena emerge from the interactions between the neutrons and protons?
The nuclear many-body problem has many similarities with the electronic many-body problem, as recognised already long ago.

In this talk, I will attempt a brief survey of the current status and challenges for nuclear structure theory. I will mention the importance of giving stronger microscopic foundations to nuclear models, namely of rooting them in the theory that describes nucleons, i.e. Quantum Chromo Dynamics (QCD). At the same time, including some phenomenological input seems currently to be unavoidable if one wishes to capture nuclear correlations. Among the available models, I will emphasise that Density Functional Theory (DFT) has the interesting feature of being the framework in which the mutual cross-fertilization between nuclear physics and physics of matter, or chemistry, may work at best.

I will provide examples related to nuclear ground-state properties and I will then focus on nuclear collective excitations. The concept of symmetry breaking and restoration will be briefly alluded to. I will stress the connections with the so-called nuclear equation of state (EoS), that is, the relationship between pressure and density in nuclear matter. This, in turn, sets a link with the macroscopic scale of those "nuclei" that have dimensions of km, namely neutron stars.

EXPERIMENTAL NUCLEAR PHYSICS IN EUROPE RECENT ACHIVEMENTS AND FUTURE PLANS

Marek Lewitowicz, Grand Accélérateur d'Ions Lourds (GANIL), Caen, France

The presentation will focus on recent achievements and future plans of European nuclear physics. The physics of the nucleus and its numerous applications in astrophysics, interdisciplinary research, medicine and industry is a dynamically developing domain of science. In particular, physics with Radioactive Ion Beams (RIB) is entering a new area thanks to next generation RIB facilities, already in operation or under construction in Asia, North America and Europe. The best illustration of this tendency in Europe are recent results obtained at ISOLDE-CERN, GANIL, FLNR Dubna and JYFL and new projects aiming in a spectacular increase of the RIB intensities like FAIR [1] and EURISOL-Distributed Facility [2].

A content and importance of the recent NuPECC Long Range Plan [3] and of integrating activities of the European nuclear physics communities like ENSAR2 will be emphasized.

REFERENCES

[1] https://www.gsi.de/en/researchaccelerators/fair.htm
[2] http://www.eurisol.org/eurisol_df/
[3] http://www.nupecc.org/lrp2016/Documents/lrp2017.pdf

Monday

August 27th

NUCLEAR PHYSICS AND ASTROPHYSICS IN THE MULTIMESSENGER ERA: A PARTNERSHIP MADE IN HEAVEN

J. Piekarewicz, Department of Physics, Florida State University 32306-4350 Tallahassee United States

Neutron stars are unique cosmic laboratories for the exploration of matter under extreme conditions of density and neutron-proton asymmetry. The historical first detection of the binary neutron star merger GW170817 by the LIGO-Virgo collaboration is providing fundamental new insights into the astrophysical site for the r-process and on the nature of dense matter. Limits inferred from the gravitational wave signal seem to suggest that neutron stars are fairly compact—implying that the symmetry energy is relatively soft.

In turn, these limits translate into an upper limit on the neutron-skin thickness of ^{208}Pb that is significantly lower than the central value reported by the PREX collaboration. This suggests an intriguing possibility. If the upcoming PREX-II experiment confirms that the neutron-skin thickness of ^{208}Pb is large, this may be evidence in favor of a softening of the symmetry energy at the higher densities probed by GW170817—likely indicative of a phase transition in the stellar core.

FROM NUCLEAR FORCES AND EFFECTIVE FIELD THEORY TO NUCLEAR STRUCTURE AND REACTIONS

Dean Lee, Michigan State University, 640 South Shaw Lane 48824 East Lansing United States

The first part of the talk is a review of recent progress by several research groups in applying chiral effective field theory to first principles nuclear structure calculations. In the second part of the talk, I focus on new results obtained using lattice effective field theory.

CHIRAL FORCES FOR ATOMIC NUCLEI

Andreas Ekström, Chalmers University of Technology, Gothenburg, Sweden

Chiral nuclear interactions such as the Idaho-N3LO [1] or the more recent interaction NNLOsat [2] are nowadays routinely employed in ab initio calculations for analyzing low-energy nuclear structure observables in terms of strongly interacting protons and neutrons. The continuous development of ab initio methods that scale polynomially with the number of nucleons and a piecewise-improved understanding of the nuclear Hamiltonian has enabled realistic descriptions of several bulk and low-energy structure observables in medium-mass nuclei; ranging from oxygen [3] to calcium [4] to tin [5]. However, most calculations employ different chiral interactions. In addition, the prospective advantages of chiral effective field theory (EFT) [6,7,8], such as tracing the expected convergence using order-by-order calculations [9,10], and quantifying the systematic uncertainties [11] as well as the statistical uncertainties [12], have until now rarely been explored. Work in this direction is pivotal for answering one of the forefront questions in nuclear theory; to which extent can atomic nuclei be described in EFTs of quantum chromodynamics (QCD)? In this talk I will discuss some of the challenges that we need overcome to construct an EFT description of the nuclear interaction, with quantified theoretical uncertainties, and thereby achieving a link between nuclear structure theory and QCD.

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[2] A. Ekström et al. Phys. Rev. C 91, 051301(R) (2015)
[3] T. Otsuka et al. Phys. Rev. Lett. 105, 032501 (2010)
[4] G. Hagen et al. Nat. Phys. 12, 186 (2016)
[5] T. D. Morris et al. Phys. Rev. Lett. 120, 152503 (2018)
[6] P. F. Bedaque and U. van Kolck Ann. Rev. Nucl. Part. Sci. 52, 339 (2002)
[7] E. Epelbaum, H.-W. Hammer, and U.-G. Meissner Rev. Mod. Phys. 81, 1771 (2009)
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[9] S. Binder et al. Phys. Rev. C 93, 044002 (2016)
[10] A. Ekström et al. Phys. Rev. C 97, 024332 (2018)
[11] R. J. Furnstahl Phys. Rev. C 92, 024005 (2015)
[12] B. D. Carlsson et al. Phys. Rev. X 6, 011019 (2016)

SUPER ASYMMETRIC FISSION IN SUPER HEAVY NUCLEI AND CLUSTER RADIOACTIVITY

Michał Warda, Maria Curie-Skłodowska University, Lublin, Poland

M. Warda[1], A. Zdeb[1,2,3], L. M. Robledo[2],

1 Maria Curie-Skłodowska University, Lublin, Poland
2 Universidad Autónoma de Madrid, Spain
3 CEA, Bruyères-le-Châtel, France

The most of heavy and super heavy nuclei decay through fission or alpha emission but other decay modes are also possible. In the 1980's an exotic decay of cluster radioactivity was observed in actinides [1, 2, 3]. In this type of process, a light nucleus, but heavier then alpha particle, is emitted. The heavy mass residue is a doubly magic ^{208}Pb in all observed decays of this type. Theoretical description of this process as a very asymmetric fission have been successfully performed in HFB model [4]. The fission valley on the potential energy surface has been found and fission fragments have been identified as cluster radioactivity products.

The super asymmetric fission valley has been also found in super heavy nuclei [5]. It has been shown that it directly corresponds to cluster radioactivity valley in actinides, with lead as the heavy fragment [6]. Moreover, this process plays non-negligible role in this region. In some super heavy isotopes, it may be the dominant decay channel.

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[1] H. J. Rose and G. A. Jones, Nature (London) 307, 245 (1984).
[2] A. Sandulescu, D. N. Poenaru, and W. Greiner, Sov. J. Part. Nucl. 11, 528 (1980).
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ELECTROMAGNETIC RESPONSE OF NUCLEI: FROM FEW- TO MANY-BODY SYSTEMS

Sonia Bacca, Institut für Kernphysik, Johannes-Gutenberg Universität, Mainz, Germany

The electromagnetic response of nuclei is a fundamental quantity to calculate, since due to its perturbative nature a clean comparison with experimental data can be performed. First principles computations are key to bridge nuclear physics with the underlying QCD regime [1]. Nowadays this valuable information is not only accessible for the lightest nuclei, but novel theoretical approaches are being developed to tackle nuclei with a larger number of nucleons.

Combining the Lorentz integral transform with the coupled-cluster method recently allowed us to perform ab initio calculations of response functions and related sum rules for light and medium-mass nuclei [2,3]. I will present recent highlights on neutron skins and polarizabilities and discussed them in the context of recent and future experiments [4,5]. Finally, I will show how the inclusion of higher order correlations in coupled-cluster theory can reconcile the agreement with experimental data on the polarizability of ^{48}Ca [6].

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TIME-DEPENDENT DFT APPLICATIONS TO NUCLEAR VIBRATIONS AND HEAVY-ION COLLISIONS

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INVITED

Monday 11:30

Time-dependent nuclear density functional theory (TDDFT) is a well-suited tool to describe heavy ion collisions and nuclear vibrations. Here we present a study of nuclear reactions focusing on the aspect of nucleonic clustering in the intermediate states. To visualize emergent clusters, we use the nucleonic localization function, which is based on the probability of finding two nucleons with same spin and isospin in the vicinity of each other. This measure was originally introduced for electronic structure calculations and was proven to be an excellent indicator for clustering in time-independent nuclear DFT calculations.

We demonstrate that the localization function for the TDDFT solutions of collisions of light and intermediate nuclei reveals a variety of time-dependent modes involving nuclear cluster structures. For instance, the ^{16}O + ^{16}O collision results in a vibrational mode of a quasi-molecular ^{4}He - ^{12}C - ^{12}C - ^{4}He state. For heavier ions, a variety of cluster configurations are predicted.

We conclude that the nucleonic localization is also an excellent measure of clustering in time-dependent simulations and gives important insights into the reaction mechanism. It reveals the presence of collective vibrations involving cluster structures, which dominate the initial dynamics of the fusing system.

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PROTON-NEUTRON STRUCTURE OF FIRST AND SECOND QUADRUPOLE EXCITATIONS OF ^{132,134,136}Te

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Low-lying quadrupole isovector excitations of the valence shell of heavy nuclei represent a unique laboratory for studying the balance between collectivity, shell structure, and the isospin degree of freedom. These excitations, so-called mixed-symmetry (MS) states, have been predicted in the proton-neutron (pn) version of the interacting boson model (IBM-2) [1]. The unbalanced pn-content of the wave functions can be interpreted as configurational isospin polarization (CIP) which denotes varying contributions to the 2^+ states by the active proton and neutron configurations due to subshell structure [2]. M1 transitions between low-energy quadrupole excitations of the valence shell are often used as signature for states of MS-character.

Our tool is based on the quasiparticle random phase approximation (QRPA) with the Skyrme force f_- in the p-h channel and the density-dependent pairing interaction in a separable approximation for residual interaction [3]. The coupling between one- and two-phonon terms in the wave functions of excited states is taken into account. The previously reported [4,5] measured reduction of the B(E2) value of the first 2^+ state of ^{136}Te with respect to ^{132}Te by a factor 1.77 has been reproduced [6] with the Skyrme force f_- in the p-h channel and using the volume zero-range pairing interaction. Based on these calculations we have identified the 2_2^+ state of ^{132}Te as a one-phonon MS state in agreement with experiment. The same calculations indicated the 2_2^+ state of ^{136}Te as a proton-dominated state, corresponding to a MS state with substantial CIP [6]. Recently, available experimental data [4,5] was reanalyzed.

For ^{136}Te, the new experimental $B(E2;0_{gs}^+\rightarrow 2_1^+)$ value of 1810±150 e^2fm^4 [7] is significantly larger than the previous one of 1220±180 e^2fm^4, which had at the time misled us to favor the absence of the density-dependent term in the zero-range pairing interaction. The new data leaves the 2_3^+ state of ^{136}Te as the better MS candidate, as predicted in Ref. [8]; more experimental data are needed to clarify this point. Since our previous calculation had been optimized to also reproduce the erroneous previous data, it is no surprise that the new B (E2) limits on the 2_2^+ state of ^{136}Te are inconsistent with our previous prediction of it being the MS state [6]. We have done a new calculation with the same f_- Skyrme interaction and only adjusting now the density-dependent term of the pairing interaction to the new data [7]. Our new results [9] are in reasonable agreement with the new data.

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NOVEL ENERGY DENSITY FUNCTIONAL FOR BEYOND-MEAN-FIELD CALCULATIONS WITH PAIRING AND DEFORMATION

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To build an energy density functional (EDF) for beyond-mean-field calculations with high predictive power, novel approaches are required. Even if the standard Skyrme or Gogny EDFs have been proven to be quite successful, their shortcomings have also become apparent, and the limits of applicability of the current EDFs have been apparently reached. To reproduce properties of homogeneous nuclear matter, one often utilizes two-body density-dependent functional generators, which give rise to complications in beyond-mean-field calculations [1]. In addition, recent analyses point out to the fact that statistical errors cannot explain the residuals between theoretical and experimental results, which indicates a lack of some important physics in the present models [2].

To gain progress in this field of research, a novel formalism was developed in Refs. [3-5], in which contact and regularized higher-order pseudo-potentials were used to generate EDFs. Their parameters must be determined by fitting the model results on experimental data. Earlier parameterizations were generated by using experimental data of spherical nuclei [3]. In this work, we attempt to move towards deformed nuclei by selecting experimental data that may better pin down properties of the novel EDFs.

In my presentation, I focus on the optimization of novel pseudo-potential-based EDFs treated at the deformed-HFB level, by utilizing state-of-the-art algorithm. After arguing for the need to employ novel EDFs, I will discuss the selection of experimental data, optimization procedures, and preliminary results. I will also present impact of the used model-space sizes on the optimization process and obtained results.

ACKNOWLEDGEMENTS

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ON THE CHARACTER OF ISOSPIN-SYMMETRY-BREAKING EFFECTS IN ATOMIC NUCLEI

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Modelling of isospin-symmetry-breaking (ISB) effects in atomic nuclei is a long-standing problem first tackled by Nolen and Schiffer in 1969. Since then, the interplay of electro- magnetic and strong-force-rooted effects has been studied in many models, see, e.g., recent studies performed within the shell model [1,2], Green Function Monte Carlo [3], and density functional theory (DFT) [4,5]. The latter approach turned out to be very successful in reproducing mirror and triplet displacement energies in a broad range of masses (A=10-75) [4]. This encouraged us to extend the model by including second-order (gradient) terms, which leads to even better agreement between calculations and experimental data and enables us to treat the isospin multiplets as light as A=6.

The fundamental question that arises in the context of our calculations relates to the physical nature of the introduced ISB short-range forces. It is a priori not obvious whether these forces model the strong-force-rooted effects, higher-order Coulomb correlations, or both. In this contribution, we shall address this question by comparing our results on the Isobaric Multiplet Mass Equation (IMME) with those obtained within the *ab initio* approach [2]. An analysis of the IMME coefficients leads us to the following conclusions: (i) the influence of the Coulomb interaction on the coefficients is similar in both models [5] (ii) the inclusion of gradient terms improves the agreement of the short-range contributions between the models. Based on these observations we argue that our model properly takes into account the contribution of the Coulomb interaction and that the strong-force-rooted effects can be accounted for order by order.

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DETERMINATION OF STRENGTH OF ISOSCALAR PAIRING INTERACTION BY A MATHEMATICAL IDENTITY IN QRPA

Jun Terasaki, Institute of Experimental and Applied Physics, Czech Technical University in Prague, Prague, Czech Republic

The proton-neutron pairing correlations are one of the major many-body correlations of nuclei and has been studied since many years ago. However, its nature is not as well-known as the like-particle pairing correlations. No experimental evidence is found of the proton-neutron pairing gap, and no alternative physical quantity is established that exclusively reflects on the proton-neutron pairing correlations. This situation causes a problem for determining the strength of the proton-neutron pairing interaction, particularly the isoscalar one. It would be very useful if there is a theoretical method to determine that interaction strength.

In my talk, I will present the theoretical method to determine the isoscalar (proton-neutron) pairing interaction using an identity derived in a study of the neutrinoless double-β decay [1]. The nuclear matrix element of this decay can be calculated, under an approximation, by a two-body operator which changes two neutrons to two protons. By inserting a projection operator of the intermediate states obtained by the proton-neutron quasiparticle random-phase approximation (QRPA), an approximate equation of the nuclear matrix element is obtained. In the similar way, it is possible to obtain an alternative equation by anti-commutating a neutron annihilation operator and proton creation operator and inserting the projection operator of the states of the like-particle QRPA. This is possible because the solutions of the like-particle QRPA include states obtained by two-particle addition and removal. The like-particle QRPA does not depend on the proton-neutron pairing interaction, as long as the Hartree-Fock-Bogoliubov ground state does not have the proton-neutron pairing gap. On the other hand, the proton-neutron QRPA depends on that interaction. The equation expressing the same nuclear matrix element using the two QRPAs implies a constraint on the isoscalar pairing interaction. The strength of the isovector proton-neutron pairing interaction can be determined assuming the isospin invariance of the system approximately.

So far the combination of the strength of the isoscalar pairing interaction and the effective axial-vector current coupling has had an arbitrarity in the QRPA approach to the nuclear matrix element of the neutrinoless double-β decay. Now that the arbitrarity has been removed, and all necessary parameters can be determined; this is a significant progress. It will be shown in my talk how the isoscalar pairing interaction is used in the calculation of the nuclear matrix elements.

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SYSTEMATIC STUDIES OF FISSION FRAGMENT DE-EXCITATION BY PROMPT γ-RAY EMISSION

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Nuclear fission is a complex process, which – after almost 80 years since its discovery – is still not fully understood. One field of research is for instance studies of the de-excitation process of fission fragments, which in the early stages, i.e. within a few nanoseconds after scission, takes place through the successive emission of prompt neutrons and gamma rays. For nuclear applications, information about the prompt neutrons is crucial for calculating the reactivity in reactors, while precise knowledge about the prompt gamma rays is important for the assessment of the prompt heat released in the reactor core. Concerning the latter we have contributed in the past years with a number of precise measurements of prompt γ-ray spectra from spontaneous as well as thermal and fast neutron-induced fission of various compound systems. From those we determined average characteristics like multiplicity, mean energy per photon and total gamma-ray energy released in fission.

The obtained results were investigated for their dependences of mass and atomic numbers of the fissioning system as well as the dissipated excitation energy. The purpose of this endeavour was to find a description that allows predicting prompt gamma-ray spectra characteristics for cases that cannot be studied experimentally.

In this talk we will give an overview on the latest measurements of prompt fission gamma ray spectra. We will also present first results from a recent angular correlation measurement between these gamma rays and fission fragments from the spontaneous fission of ^{252}Cf and infer what can be learned from the observed angular distributions. For instance, the relative contributions of dipole and quadrupole photons were deduced and compared to results of very recent calculations with the Monte Carlo Hauser-Feshbach code FIFRELIN, developed at CEA Cadarache.

VALENCE PARTICLE/HOLE CORE COUPLINGS IN NEUTRON-RICH, EXOTIC NUCLEI

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SEMINAR

Monday 19:30

The couplings between single-particle/hole degrees of freedom and collective and non-collective excitations are of primary importance in nuclear physics, as they are responsible for many phenomena observed in atomic nuclei, from the damping of giant resonances, to the quenching of spectroscopic factors and the anharmonicity of vibrational spectra.

While such properties have been investigated in the past in a limited number of stable nuclei, it is still under discussion whether neutron rich, exotic nuclei display similar features and how couplings with core excitations are influenced by the proton-to-neutron ratio and shell evolution.

To answer these questions, we present recent experimental results in the medium-heavy mass regions around the doubly-magic, neutron-rich ^{48}Ca and ^{132}Sn nuclei. In particular, we discuss new spectroscopic information on the ^{47}Ca, ^{49}Ca, ^{133}Sb and ^{131}Sn isotopes, obtained in different experimental campaigns, at ILL (Grenoble) [1-2] and LNL (Italy) [3], by using large g-ray setups based on HpGe Detectors.

Experimental results are interpreted by a new microscopic theoretical model, the Hybrid Configuration Mixing Model [4,5], specifically designed to describe the structure of nuclear systems with one valence particle/hole outside a doubly-closed core. The model includes couplings between valence nucleons and core excitations, by means of Hartree-Fock (HF) and Random Phase Approximation (RPA) calculations using the Skyrme effective interaction, and it accounts for both collective phonons and non-collective p-h configurations.

The agreement between experimental and theoretical energies, electromagnetic transition probabilities and spectroscopic factors will be outlined, showing the relevance of the new approach, as compared to traditional shell model calculations with a frozen core. Recent improvements of the model and possible future experimental developments with radioactive beams will be discussed.

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NUCLEAR STRUCTURE EFFECTS ON FISSION FRAGMENT MASS DISTRIBUTION IN $^{12}C+^{169}Tm$ SYSTEM

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The formation of super-heavy elements through fusion is influenced by the survival of equilibrated compound nucleus against its fission. In macroscopic models of heavy-ion collisions, the multi-dimensional potential 'energy landscape' sways the dynamics of fusion process from touching configuration to the formation of compound nucleus [1]. Over the last few decades, the phenomenon of nuclear fusion-fission with heavy-ions has been prodigiously investigated for a wide range of fissility, excitation energy, and target deformation [2-4]. It has been observed that the variances (s_m^2) of fission fragments mass distribution in fusion-fission reactions is strongly dependent on target deformation. For spherical targets the variance is rather narrow, and varies smoothly with the excitation energy (E^*) while for deformed targets, particularly above the Coulomb barrier, the s_m^2 is broader, and increases monotonically with E^* [4].

Although a large amount of cross-section data has been generated in light and heavy-ion induced reactions on highly fissile actinide targets yet there is a dearth of comprehensive understanding of underlying dynamics in the pre- actinide region. With the spur to study the effect of target deformation on fusion-fission dynamics in the latter region, we have performed the experiments with beams of ^{12}C (E^*= 57, 63, and 69 MeV) on deformed ^{169}Tm target using the pelletron accelerator facilities at Inter-University Accelerator Center (IUAC), New Delhi, India [5]. The recoil-catcher activation technique followed by offline g spectrocopy has been used to measure the production cross-sections for fission-like nuclei that are isomeric, electron caputred and b^- decaying. These nuclei are identfied by their characteristic g-rays and vetted by decay curve analysis. The mass variance has been found to increase with the excitation energy at above the Coulomb barrier. Details of the experimental techniques and results of the investigations will be delineated and discussed in the conference.

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NEUTRON INDUCED REACTIONS γ SPECTROSCOPY BY THE ν-BALL SPECTROMETER

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The ν-ball is high efficiency hybrid spectrometer with Ge and $LaBr_3$ detectors. It is consist 24 clover Ge detectors and 10 coaxial Ge detector (with BGO shield) as well as up to 20 LaBr3 detectors. This configuration of spectrometer provides excellent energy and timing resolution. The ν-ball geometry allows coupling with the LICORN directional neutron source on the ALTO facility at the IPN, Orsay [1]. That possibility for precision spectroscopy of neutron induced reactions was used for two experiments:

1. Spectroscopy of the neutron-rich fission fragments produced in the ^{238}U(n,f) and ^{232}Th(n,f) reactions [2],
2. Spectroscopy above the shape isomer in ^{238}U.

In ^{238}U(n,f) and ^{232}Th(n,f) reactions will be produced hundreds of neutron-rich nuclei which will give possibility for analysis of many different physics cases. The main goal of the spectroscopy above the shape isomer in ^{238}U is the measurement of population and decay of fission shape isomer as well as determination of level scheme above the super-deformed minimum. The shape isomer will be populated by ^{238}U(n,n') reaction. The preliminary results from those two experiments will be presented.

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SEMINAR

Monday 20:15

PRECISE STUDY OF EVAPORATION DECAY OF LIGHT NUCLEI FORMED IN FUSION-LIKE REACTION

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Since several years, the INFN Nucl-ex collaboration is performing accurate experiments on fusion-like reactions among light nuclei. The peculiarity of these studies is related to the wide acceptance of the GARFIELD-RCo [1] detector at LNL (INFN, Legnaro). It measures charged products from light particles to Evaporation Residues and allows to precisely select fusion-like events, complete in nuclear charge, corresponding to different decay channels. In this contribution we will show the quality of this method and some results on fusion reactions like $^{12}C+^{12,13}C$ at around 90MeV or $^{16}O+^{12}C$ from 90 to 130 MeV. After a brief remind of the performance of the apparatus, we show here evidences for slight deviations of the properties of some evaporation chains from a fully statistical "Hauser-Feshbach" description, especially in decay paths including alpha particles [2-5]. This could indicate some role of alpha-cluster structures, which somehow characterise the states of N=Z nuclei [6] or some dynamical alpha precompound effect as recently suggested in modern version of TDHF calculations [7].

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ACCULINNA-2: A NEW PERSPECTIVES FOR STUDIES WITH LIGHT RADIOACTIVE ION BEAMS AT DUBNA

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In 2017 the first set of radioactive ion beams (RIBs) was obtained from the new in-flight fragment separator ACCULINNA-2 [1] operating at the primary beam line of the U-400M cyclotron. Observed RIB characteristics (intensity, purity, beam spots in all focal planes) were in agreement with estimations. The new separator provides high quality secondary beams and it opens new opportunities for experiments with RIBs in the intermediate energy range 10÷50 AMeV [2].

The ^{6}He + d experiment, aimed at the study of elastic and inelastic scattering in a wide angular range, was chosen for the first run. The data obtained on the ^{6}He + d scattering, and in the subsequent measurements of the ^{8}He + d scattering, are necessary to complete MC simulation of the flagship experiment: search of the enigmatic nucleus ^{7}H in the reactions $d(^{8}\mathrm{He},^{3}\mathrm{He})^{7}\mathrm{H}$ and $p(^{8}\mathrm{He},pp)^{7}\mathrm{H}$.

Opportunities of day-two experiments with RIBs using additional heavy equipment (radio frequency filter, zero angle spectrometer, cryogenic tritium target) will be also reported. In particular, the study of several exotic nuclei ^{16}Be, ^{24}O, ^{17}Ne, ^{26}S and its decay schemes are foreseen.

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WHAT SHALL WE DO WITH THE SPECTATOR SYSTEM IN ULTRARELATIVISTIC HEAVY ION COLLISIONS ?

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The recent exploratory work by K. Mazurek et al. [1] potentially opens new ways for studying the space-time evolution of the nuclear remnant (spectator system) produced in ultrarelativistic heavy ion collisions at CERN SPS energies. The application of several possible scenarios for the initial conditions of the spectator system (a geometrical picture based on the Liquid Drop Model LDM, the abrasion model ABRA of Gaimard and Schmidt [2], and the microscopic theory of Glauber [3]) bring very different predictions for the spectator initial energy as a function of the Pb+Pb collision impact parameter at 158 GeV/nucleon beam energy. The subsequent use of multidimensional stochastic Langevin equation allows the authors to describe the corresponding fate(s) and time evolution scale(s) of the spectator break-up. Some of the corresponding predictions are quite opposed to the ``folklore'' expectations present in the high energy heavy ion community.

The IFJ PAN group in the NA61/SHINE experiment aims at studying the spectator-induced electromagnetic (EM) effects induced by the spectator remnant on spectra of charged particles produced in the course of the collision from the system of hot and dense matter (possibly quark-gluon plasma) created therein [4-6]. These effects are known to be sensitive to the space-time evolution of the spectator system. In the context of [1] it seems that a properly precise measurement of EM distortions on charged particle spectra would make it possible to test the predictions formulated in [1], and probably also to discriminate between the different scenarios applied therein.

The NA61/SHINE collaboration prepared a proposal to the CERN SPSC [7] for new, high statistics measurements of Pb+Pb collisions to be performed after 2020. This includes using the EM effects as a new source of information on the space-time evolution of the spectator system. The aim of the present paper is to give a review of this problematics, including a first comparison of nuclear remnant excitation energy from theoretical calculations [1] to that estimated from spectator-induced EM effects on charged pion spectra [8]. The hope is that the expertise gathered by the nuclear physics community will help the IFJ PAN NA61/SHINE group to clarify the numerous questions opened by the work [1].

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Tuesday

August 28th

MARA, A RECENTLY COMMISSIONED IN-FLIGHT SEPARATOR FOR NUCLEAR SPECTROSCOPY STUDIES AT JYFL-ACCLAB

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Nuclear Spectroscopy Group

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A new separator, **MARA** (**M**ass **A**nalyzing **R**ecoil **A**pparatus) [1], has recently been constructed at Jyväskylä University ACCLAB. MARA is a vacuum-mode double focusing in-flight mass separator. The ion-optical configuration is $QQQD_ED_M$. MARA went through an extensive commissioning program during 2016 and already during 2017 and 2018 MARA was used in spectroscopic studies at and beyond the proton drip line. In these studies, for example, five new isotopes have been identified which is a strong proof itself that MARA fulfills the needed performance.

MARA will be a great addition to the existing apparatus used by the Nuclear Spectroscopy Group. MARA is a complementary device to the existing gas-gilled recoil separator RITU (in use since 1994). and together they give a freedom to extend substantially the experimental program performed by the Nuclear Spectroscopy Group.

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THE ADVANCED GAMMA TRACKING ARRAY (AGATA)

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On behalf of the AGATA Collaboration

The AGATA array [1], is the European forefront instrument based on semiconductor Germanium detectors, for high-resolution γ-ray spectroscopy. Early implementations are being used in the nuclear research facilities operating presently in Europe but it has been conceived for the experimental conditions at the future facilities for intense radioactive and high-intensity stable ions.

AGATA is the result of the early European Commission financed initiative, the TMR network 'Development of γ-ray tracking detectors' [2], that between 1996 and 2001 encouraged the development of the highly segmented position sensitive Germanium detector technology.

The inception of such technology has opened the possibility to build arrays of detectors based on the γ-ray tracking concept, providing an unprecedented level of sensitivity and efficiency. Only two arrays with such technology are being built in the world, the European implementation of the tracking array is realized in the AGATA project. The second one, as well under construction at U.S., is the GRETA array [3].

In this contribution the AGATA project will be presented, emphasising the technical developments and the characteristics and performance figures relevant for the present and future European facilities.

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HIGH-RESOLUTION γ-RAY SPECTROSCOPY WITH ELIADE AT THE EXTREME LIGHT INFRASTRUCTURE

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The Extreme Light Infrastructure is a major European undertaking with the aim of constructing a set of facilities that can produce the worlds highest intensity laser beams as well as unique high-brilliance, narrow-bandwidth gamma-ray beams using laser-based inverse Compton scattering. The latter will be one of the unique features of the facility in Bucharest-Magurele, Romania, where the scientific focus will be towards nuclear physics and nuclear photonics both with high intensity lasers and gamma beams individually, as well as combined.

The gamma-beam system [1] will provide a high luminosity of gamma rays with energies between 200 keV and 19.5 MeV of a relative bandwidth less than 0.5% and a spectral density higher than 5000 photons/s/eV. This beam will be provided by an electron accelerator with a final energy of the electrons up to 720 MeV that interact with a 515 nm Yb:YAG laser, giving a repetition rate of 10 ms between macropulses of the beam. The unique features of this system will open the door to a wide variety of nuclear photonics experiments ranging from astrophysical reactions of light nuclei to fission properties of heavy nuclei, as well as being used for applications and radioactive-ion beam production via the ISOL technique.

One of the main instruments being constructed for the nuclear physics and applications with high-brilliance gamma-beams research activity is the ELIADE detector array [2]. This array consist of eight segmented HPGe clover detectors as well as large-volume $LaBr_3$ detectors. Using the nuclear resonance fluorescence technique this setup will provide us with direct access to several nuclear observables [2], as well as providing a high-resolution tool for both for applied research [3] and diagnostics of more advanced gamma-beam delivery including, for example, beam-polarization measurements for other experimental undertakings [1]. The nuclear physics topics are expected to cover a large range including, but not limited to, properties of pygmy resonance and collective scissors mode excitations, parity violation in nuclear excitations, and matrix elements for neutrinoless double-beta decay.

However, the uniqueness of the environment in which ELIADE will operate presents several challenges in the design and construction of the array. In this presentation we will discuss some of these challenges and how we plan to overcome them, as well as the current status of implementation

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C^7LYC: A NEW SCINTILLATOR FOR FAST NEUTRON SPECTROSCOPY

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The scintillator Cs_2LiYCl_6 (CLYC) has emerged as a versatile detector for both gammas and neutrons, with excellent pulse shape discrimination. Originally developed as a thermal neutron counter via the ^{6}Li(n,α)^{3}H reaction, the discovery of its unexpected and unprecedented ~10% pulse height resolution for fast neutrons in the < 8 MeV range via the ^{35}Cl(n,p)^{35}S reaction [1] has prompted studies to benchmark its use in low energy nuclear science and applications. A key goal is to evaluate how the comparatively low intrinsic efficiency of C^7LYC for fast neutrons can be effectively offset by the solid angle gained in positioning the detectors very near the source/target, since the typical long time-of-flight arms are not needed for achieving good energy resolution. We have constructed a 16-element array of 1" x 1" (largest available at the time) ^{7}Li-enriched C^7LYC crystals, to eliminate the dominant thermal neutron peak from ^{6}Li at a gamma-equivalent energy of ~3.5 MeV, leaving the energy region above 3 MeV with a clean baseline for fast neutron spectroscopy. We have also procured the first ever 3” x 3” C^7LYC crystal.

The talk will focus on our characterization and test experiments with C^7LYC, which include elastic and inelastic neutron scattering cross-sections at Los Alamos with a pulsed white neutron source, as well as measurements using mono-energetic proton and deuteron beams from the 5 MV Van de Graaff accelerator at UMass Lowell. Tests of beta-delayed neutron spectroscopy are planned and being initiated at the NSCL cyclotron at Michigan State University and the CARIBU facility at Argonne, to evaluate C^7LYC as a possible candidate for auxiliary scintillator arrays for stopped beam physics at next generation rare isotope accelerator facilities.

The work is supported by the U.S. Dept. of Energy under NNSA-SSAP Grant DE-NA0002932 and the Office of Science under Grant DE-FG02-94ER40848.

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NUCLEAR PHYSICS FOR NUCLEAR ENERGY

Sylvie Leray, CEA Saclay, France

The development of nuclear energy is driven by the necessity to meet the increasing demand for energy, in particular from developing countries, together with the need to reduce carbon emission. After a brief panorama of the status of nuclear energy in the world, I will discuss the main issues to which nuclear energy has to face up. I will show that there are still important needs for nuclear data measurements and for a better understanding and modeling of nuclear reactions and will present the work done in Europe with a focus on recent achievements.

SEPARATION OF SCANDIUM FROM SOLID TARGETS FOR PET PRINCIPLES AND EXPERIENCE

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Due to specific properties, interest in the positron-emitting scandium isotopes as supplementary PET isotopes has been recently observed. ^{43}Sc ($t_{1/2}$=3,89h, branching ratio β^+:88%) and ^{44}Sc ($t_{1/2}$=3,93h, branching ratio β^+:94.3%) are good alternatives to ^{68}Ga, as they use similar complexing mechanisms. However their half-lives are almost four times longer, which promote the applications for imaging processes, having slower pharmacokinetcs profiles. Especially imaging of neuroendocrine tumors, showing overexpression of somatostatin receptor type 2 was promisingly demonstrated in some preclinical studies with somatostatine analogues: DOTATATE, DOTATOC.

The reason for the rapid increase of scandium applications was the development of the new efficient production routes for radioisotopes in cyclotrons by α and proton irradiations. Especially methods where $^{nat}CaCO_3$ was used as a target material gained the special attention due to low cost of production. Effective irradiation via $^{40}Ca(\alpha,p)^{43}Sc$ was presented but the number of cyclotrons, providing regular and intensive α beam is limited. Thus the proton irradiation on standard medical cyclotrons of ^{44}Ca at its natural abundance (2.09%) in $CaCO_3$ or CaO can provide adequate activity and be cost-effective for research and preclinical studies. Introduction of enriched ^{44}Ca should be sufficient for clinical studies and further regular applications, but due to relatively high costs of $^{44}CaCO_3$, the target material needs to be recovered.

For all cases, it requires post-irradiation separation and preconcentration of radioactive scandium from calcium matrix to give the pure final product in a relatively small volume. Although calcium is non-toxic and is approved in radiopharmaceutical preparations, its excess could influence negatively the radiolabeling yield and, especially in case of ^{44}Ca, should be recovered for further use. Therefore, methods that allow effective scandium capture for labeling with the simultaneous release of possibly not contaminated calcium for further processing are used most often. For this purpose filtration and solid phase extraction methods have been used. In the first approach target dissolved in acid is neutralized to neutral or slightly alkaline conditions and scandium is separated as $Sc(OH)_3$ precipitate on the 0.22 μm filter while calcium passes for further processing. As the chemical purity of the Sc product is important, since the presence of other metals (Fe^{3+}, Al^{3+}, Zn^{2+}) which forms strong complexes with DOTA and reduce the labeling yield, solid phase extraction on selective chelating or extracting sorbents was used. Ion exchange resin Chelex 100, N,N,N',N'-tetra-n-octyldiglicolamide (DGA) resin or Uranium and Tetravalent Actinides (UTEVA) extraction resin were used for minimizing metal impurities coming from processing the target or recovered material.

This work presents the experimental evaluation of effective separation of ^{43} and ^{44}Sc from calcium carbonate targets. Particular attention was paid to the reduction of calcium matrix, presence of metallic impurities, robustness and simple automation.

Acknowledgments

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APPLICATIONS OF PHYSICS OF RADIOACTIVE NUCLEI TO MATERIAL SCIENCE AND MEDICINE

Karl Johnston, ISOLDE/CERN, Geneva, Switzerland

The application of radioactivity to areas beyond pure nuclear physics encompasses a very broad area including solid state physics in its many forms and other fields such as nuclear medicine where the use of radioisotopes has become routine.

At ISOLDE/CERN – in addition to pure nuclear physics – the science programme has long had at its core a dedicated allocation devoted to the applications of radioactive ions in other fields. This has allowed exotic and innovative isotopes to be utilized for scientific studies such as the probing of novel materials and for imaging and therapeutic uses in nuclear medicine.

This talk will detail the use of specific isotopes currently only available at ISOLDE – but which will be readily available at the next generation of radioactive ion beam facilities worldwide – and their uses in materials science and medicine. In addition to a presentation of the current state of the art – including the application of radioactive ions to novel materials such as two-dimensional materials such as graphene and multi-layered solar cells along with recent advances in exotic isotopes for nuclear medicine – recent results and challenges will be presented along with perspectives for the forthcoming facilities currently under construction worldwide.

NUCLEAR PHYSICS AND PROTON RADIOTHERAPY AT CYCLOTRON CENTRE BRONOWICE

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Renata Kopeć and Konrad Guguła

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The Cyclotron Centre Bronowice is one of the few proton therapy centres with experimental room dedicated for nuclear physic programme. In Cyclotron Centre Bronowice IFJ PAN Krakow the dedicated to medicine Proteus C-235 cyclotron is used to produce proton beams in energy range from 70 to 230 MeV and for currents up to 500 nA. The coexistence of medical activities and nuclear physics experimental programme is possible under several limitations. The treatment unit needs the beam for the time of a few minutes, during which the patient irradiation can be completed. For most of the nuclear physics experiments a stable proton beam is requested for the relatively long period of time, in range of hours. In August 2018 a new type of deflector has been installed in Proteus which can potentially improve the cyclotron operation for the long exposures.

EVALUATION OF USEFULNESS OF DUAL-ENERGY CT IN RADIOTHERAPY PLANNING FOR PATIENTS WITH HIP ENDOPROSTHESIS

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Centre of Oncology, Maria Sklodowska-Curie Memorial Institute, Krakow Branch, Poland

Computed tomography is an indispensable element of modern radiotherapy. Based on scans of the interior of a patient's body it is possible to precisely locate Planning Target Volume (PTV) and Organs at Risk (OARs) and then plan radiotherapy. Constant development of this kind of imaging technique has led to the emergence of dual-energy CT, which in conjunction with Metal Artifact Reduction software (MARs) allows to restore the structures and compensate the disorders resulting from the presence of metallic implants in the patient's body. Such implants cause artifacts in the CT image which carry false information about the area surrounding endoprosthesis. The Treatment Planning System (TPS) is working on the basis of Hounsfield's Unit (HU). In the place where the artifact occurs, it recognizes the value of HU for air. From the anatomical point of view, it is known that in these locations, soft tissues or bones are located; therefore, these kinds of artifacts should be eliminated for treatment planning purposes. The aim of this paper is evaluation of usefulness of dual-energy computed tomography in radiotherapy planning purposes for patients with hip endoprosthetis in comparison to manual method of artifacts reduction. Multienergetic GE Discovery HD CT scanner was used for investigation. Manual reconstruction of artifacts relies heavily on estimating where a given tissue passes into another and inflicting one average HU value for the artifact site, based on the HU measurement for several neighboring tissues.

In order to make this evaluation, therapeutic dose distribution determined in treatment planning process on three different sets of CT scans were compared with one to another. Those sets consisted of reference scans, containing metallic artifacts, scans on which metallic artifacts have been manually reconstructed and scans on which the algorithm for metallic artifacts reduction MARs was used.

The comparison was made for three different patients. Treatment plans were created using TPS Varian Eclipse with AAA algorithm and the VMAT: RapidArc technique. Calculated dose distributions were imported into the Sun Nuclear application and subjected to gamma analysis. The acceptance criteria $\Delta D_{max} = 0.5\%$ and DTA = 0.1 mm were chosen for the analysis.

Statistical tests carried out confirmed the lack of compatibility between the dose distributions on all three sets of scans. Differences in dose distributions are statistically significant; therefore it is necessary to create a calibration curve separate for the MARs algorithm (HU vs. density [g/cm^3] and HU vs. relative electron density) for the treatment planning purposes.

It can be concluded that the MARs algorithm is very useful for treatment planning, but it should be used with at most care. Algorithm changes the values of Hounsfield units also in non-disturbed by metal artifacts areas (up to 30 % in range 10-30 HU). It is noticed that images reconstructed by MARs algorithm are filtered and averaged. This conclusion is significant especially during radiotherapy treatment planning. Thanks to MARs algorithm all anatomical structures are easier recognizable, but on the other hand it requires specially prepared calibration curve as an input to TPS.

THE QUEST FOR NEW DATA ON THE SPACE STAR ANOMALY IN pd BREAKUP

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SEMINAR

Tuesday 15:30

Even though the development of the theories providing a precise description of few-nucleon interactions is well advanced, certain inconsistencies between experimental data and theoretical predictions are still to be resolved. One of the most intriguing discrepancies observed in the proton-deuteron breakup reaction is known as the Space Star Anomaly [1]. It concerns a very special geometrical configuration, where the momentum vectors of the reaction products are of the same length. What is interesting, the experimental evidence shows that the effect marks its presence at low energies (7.5-13 MeV/nucleon) [2], to the contrary to the inconsistencies attributed to the so-called three-nucleon force.

It was not possible to draw clear conclusions about the source of the effect due to a poor coverage of the energy range over 19 MeV, for the highest energies ever analysed with this respect were 19 MeV [3] and 65 MeV [4]. The measurement and the calculations at 65 MeV show lack of the Space Star Anomaly at this energy and, on the other hand, enhanced sensitivity to relativistic effects [5]. The systematic studies in the domain of energy and for various orientations of the star relatively to the beam direction are important for better understanding of the process dynamics. The Big Instrument for Nuclear-polarization Analysis (BINA) [6,7] is one of the detectors well suited for such measurements. The research programme of the experiment aims i.a. at providing additional data on the Space Star cross-sections.

In this contribution, a thorough description of the Space Star Anomaly effect will be presented. The latest theoretical predictions based upon Refs. [8,9] will be compared with each other and with the preliminary data points for the star configuration obtained with the BINA experimental setup for beam energies >=50 MeV/nucleon, as the next step in the research programme started recently.

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SEMINAR

Tuesday 15:45

MEASUREMENT OF THE DIFFERENTIAL CROSS SECTION FOR PROTON INDUCED DEUTERON BREAKUP AT 108 MeV

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Research in the domain of few-nucleon systems is the basis for understanding of nuclear interactions and properties of nuclei.

The precision theoretical calculations for three nucleon systems should be confronted with a rich set of systematic experimental data. For this purpose a series of measurements of deuteron breakup in collision with proton was conducted in KVI Groningen and FZ-Julich. These studies confirmed the important role of the Three-Nucleon Force (3NF) and huge influence of Coulomb interaction between protons [1-3]. However, some discrepancies persist, indicating that our present understanding of the problem is not yet perfect [4-6].

Continuation of the studies in a wide range of energies, at the regions of the maximum visibility of the certain effects are necessary. For this purpose, the BINA (Big Instrument for Nuclear-polarization Analysis) detection system has been installed at CCB (Cyclotron Center Bronowice).

The BINA detection setup is especially dedicated to study various aspects of the dynamics in three nucleon system at intermediate energies. Moreover, allows to register coincidences of two-charged particles in nearly 4π solid angle, making it possible to study almost full phase-space of breakup and elastic reactions [1][7].

The data analysis and preliminary results of the measurement of proton-induced deuteron breakup at beam energy of 108 MeV performed at Cyclotron Center Bronowice PAS in Cracow will be presented.

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THEORETICAL UNCERTAINTIES IN THE DESCRIPTION OF THE NUCLEON-DEUTERON ELASTIC SCATTERING UP TO 200 MEV

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An estimation of the theoretical uncertainties present in the nuclear physics is an interesting issue. The necessity of reliable estimation of theoretical errors origins in a growing precision of experimental data as well as in the fact that currently, we are often in the position to study details of underlying physics. A study of the nuclear interaction within the elastic nucleon-deuteron (Nd) scattering can be a good example: while the two -nucleon potential is well known, the details of the three-nucleon force are still not clear. The elastic Nd scattering at energies up to 200 MeV can be used to study the three-nucleon interaction but to draw final conclusions based on the comparison of theoretical predictions and data estimation of theoretical uncertainties is necessary.

There are different types of theoretical uncertainties of the elastic Nd scattering observables. We are interested here in (a) the statistical errors arising from a propagation of uncertainties of parameters of two-nucleon interaction to three-nucleon system, (b) the truncation errors present for chiral interactions, (c) the regulator dependence also connected to chiral forces, (d) the numerical uncertainties as well as the uncertainties bound with the computational scheme used, and last but not least, in (e) the uncertainties arising from using the various models of nuclear interaction. It will be shown that the latter ones are a dominant source of uncertainties of modern predictions for the three-nucleon scattering observables.

To perform above studies we employ mainly the One-Pion-Exchange Gaussian (OPE-Gaussian) nucleon-nucleon potential [1], for which the covariance matrix of its parameters are known. In addition, we use also the newest chiral interaction with the semilocal regularization [2] for which estimation of statistical uncertainties is also possible. We compare these results with predictions based on the chiral forces at the fifth order of chiral expansion (N4LO) by the Moscow(Idaho)-Salamanca [3] and the Bochum -Bonn [4] groups. We use the Faddeev approach [5] to obtain the elastic Nd scattering cross section and various polarization observables.

A comparison of the various theoretical uncertainties and their dependence on the reaction energy as well as a comparison of the predictions with data will be discussed.

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FEW NUCLEON SYSTEMS WITHOUT PARTIAL WAVE DECOMPOSITION

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An overview of the so called "three dimensional" (3D) formalism used to perform few- (two-, three-) nucleon calculations will be presented. In this formalism, states and observables related to few-nucleon systems are calculated without resorting to the partial decomposition of the relevant operators. Instead, the calculations directly rely on the *three dimensional* momentum degrees of freedom of the nucleons. Avoiding the angular momentum decomposition procedure for new models of few-nucleon interactions allows for easier and more flexible tests of these new models.

Recent progress in the development of general forms for two- and three- nucleon operators [1-3] that satisfy appropriate symmetries opens possibilities of new applications of the 3D formalism. A summary of these advances will be presented with an emphasis on three-nucleon scattering. Extending the 3D formalism to describe nucleon – deuteron scattering observables might provide valuable insight into the physics of new models of two- and three- nucleon forces.

Additionally, preliminary results related to the ^{3}H and ^{3}He bound states calculated using potentials derived from chiral effective field theory will be shown along with a discussion of the numerical performance of these 3D calculations. Especially interesting is the relatively straightforward treatment of the Coulomb interaction in this formalism and the possibility to calculate observables related to the triton beta decay.

THREE-BODY CORRELATIONS IN DIRECT REACTIONS: EXAMPLE OF ^{6}Be POPULATED IN (p, n) REACTION

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Nuclear driplines are defined by instability with respect to particle emission, and therefore the entire spectra of the systems beyond the driplines are continuous. The first emission threshold in the light even systems is often, due to pairing interaction, the threshold for two-neutron or two-proton emission, and therefore one has to deal with three-body continuum. Such continuum provides rich information about nuclear structure of ground state and continuum excitations, which is, however, often tightly intertwined with contributions of reaction mechanism. The way to extract this information is to explore the world of various correlations in fragment motions and to look for methods to disentangle contributions of a reaction mechanisms.

The 47 AMeV ^{6}Li beam was produced by the cyclotron U-400M and injected into ACCULINNA facility [1]. The 6Be continuum states were populated in the charge-exchange reaction ^{1}H(^{6}Li,^{6}Be)n and very high statistics data (~5x106 events) on the three-body α+p+p coincidences was collected. The first results of the experiment studying the α+p+p correlations in decays of the 6Be states populated in the (p, n) charge-exchange reaction were published in Ref. [2]. The paper was focused on the proof that the observed ^{6}Be excitation spectrum above ~3 MeV is dominated by the novel phenomenon – isovector breed of the soft dipole mode “built” on the ^{6}Li ground state (g.s.).

A general quantum-mechanical formal issue and important practical task of data interpretation is the extraction of the most complete quantum-mechanical information from the accessible observables. Important but very rare case when extraction of the complete quantum-mechanical information from data is possible is elastic scattering: from angular distributions one can, in principle, extract set of phase shifts which contains all possible information about this process. For the majority of other classes of experimental data, extraction of complete quantum-mechanical information is not possible. For certain classes of reactions the most complete quantum-mechanical information which can be extracted is contained in the density matrix. Because of internal symmetries the density matrix could provide very compact form of data representation depending just on very few parameters.

The correlations in the decay of 6Be states with excitation energy below ~3 MeV, where the data are dominated by the contributions of the known and well-understood 0+ and 2+ states of 6Be, are presented. We demonstrate that basing on the known level scheme it is possible to extract the maximal possible quantum mechanical information about reaction mechanism (e.g. the density-matrix parameters) from the three-body correlations. It is demonstrated how the high-statistics few-body correlation data can be used to extract detailed information on the reaction mechanism. The suggested method of analysis allows for identification of such fine effects like the ratio of the populated states, interference between them and alignment of the states with J>1/2 for other nuclei, and it may be regarded as a general tool for different tasks on radioactive beams.

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SEMINAR

Tuesday 16:45

STUDIES IN NUCLEAR STRUCTURE & BIG BANG NUCLEOSYNTHESIS USING PROTON BEAM

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Proton induced reactions, namely, elastic and quasi-elastic scattering and capture processes continue to have great significance in nuclear physics. We have carried out two different measurements using proton beams to address problems in nuclear structure and nuclear astrophysics. The measurements are a) low energy radiative capture of proton on deuteron and b) inelastic scattering of protons off ^{12}C target.
The radiative capture of proton on deuteron d(p,γ)^{3}He is a reaction of great significance both for nuclear astrophysics and few-body nuclear physics. As far as the nucleosynthesis of ^{3}He is concerned the relevant beam energy varies from few keV to few hundred keV. Broadly, one can consider three scenarios for the production of ^{3}He (or depletion of deuteron) from d(p,γ)^{3}He reaction, namely, the Big Bang Nucleosyntheis (BBN), production in low-mass protostars, and production in low to medium mass stars like sun. In BBN the prevalent temperature at which the d(p,γ)^{3}He reaction takes places is at around 10^9 K (T9). This temperature translates to a beam energy of around few hundred keV. This particular reaction leads to the depletion of deuteron with the reaction rates governing the D/H ratios.

We have measured the cross sections and astrophysical S factors at three new energies which are important to understand the production of ^{3}He during Big Bang Nucleosynthesis (BBN). Our measured values for both σ and S-factor are in good agreement with the existing global data set for other energies. We have also compared our measured values with the recent calculations of Marcucci *et al.* Our measured values fall within the band predicted by Marcucci *et al.* [1] The importance of the precise measurements of d(p,γ)^{3}He cross sections will be discussed in the talk.

The α-cluster structure of ^{12}C nucleus, including the Hoyle state continues to be a very challenging problem in nuclear structure. Understanding the cluster structure of ^{12}C and its evolution with excitation energy paves the way for understanding similar α-cluster structure in heavier nuclei. We have carried out exhaustive measurements of ^{12}C (p,p'γ)^{12}C reaction for beam energies ranging from 8 to 22 MeV for four excited states (4.43, 9.63, 12.71 and 15.11 MeV) of ^{12}C. Angular distribution of the gamma rays have been measured for each beam energy. Total cross sections for the ^{12}C(p,p'γ)^{12}C process were extracted from the differential cross sections. The gamma rays were measured using large volume Lanthanum Bromide detectors [2]. Detailed theoretical calculations and optical model analysis were carried out to reproduce the experimental cross sections. We will be reporting, for the first time the cross section and branching ratio of the 9.6 MeV state of ^{12}C using ^{12}C(p,p'γ)^{12}C reaction.

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THE NEUTRINO SELF-INTERACTION AND MSW EFFECTS ON THE NEUTRINO-PROCESS FOR SUPERNOVAE

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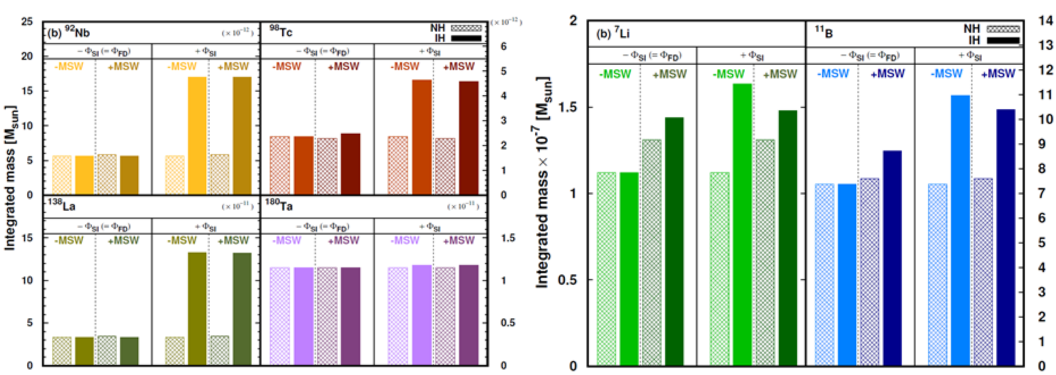
We investigate the neutrino oscillation effects by the neutrino self-interaction near to the neutrino sphere and the MSW effect far from the sphere on the element abundances. The representative synthesized elements by neutrino from supernova explosion are known as ^{7}Li, ^{11}B, ^{92}Nb, ^{98}Tc, ^{138}La, and ^{180}Ta. Near to the neutrino sphere, the neutrino density is about 10^{32} / cm^{3}, whose number is high enough to consider the neutrino self-interaction.

Their effects on the neutrino flux are estimated in the Boltzmann equation with a collision term for the neutrino density under the mean field approximation. Due to the propagation of the shock wave we also have to take the neutrino propagation in matter, i.e. MSW effects. One of the important MSW regions is the O/Ne/Mg layer given by the progenitor and the hydrodynamics models.

In this work, we discuss how the neutrino self-interaction and the MSW effects influence on the element production by using the modified neutrino spectra and the neutrino-nucleus interactions calculated by QRPA. Our results show that the neutrino-process element abundances are increased by the self-interaction rather than the MSW effect. Dependence on the mass hierarchy is also discussed as shown in the following figure.



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SEMINAR

Tuesday 17:15

THE ROLE OF ^{20}Ne STATES IN THE ASTROPHYSICAL IMPORTANT ^{19}F(p,α)^{16}O REACTION AT LOW ENERGY

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The ^{19}F(p,α)^{16}O reaction has a twofold importance: it allows to investigate the spectroscopy of low angular momentum high-energy states in the self-conjugate ^{20}Ne compound nucleus and, at low energy, it is involved in astrophysical models aiming at describing the fluorine nucleosynthesis in stars.

Despite its importance, fragmentary (and often contrasting) experimental data on its absolute reaction cross section were reported in the literature. Recent direct experiments [1,2] triggered by prediction based on indirect techniques [3] led to a better understanding of the low energy behavior of the *S*-factor for the α_0 channel, and pointed out the contribution due broad states in ^{20}Ne. Furthermore, a comprehensive and careful revision of all the data available in the literature has been recently performed [4]; this constitutes an excellent starting point for a general re-analysis on the spectroscopy of high-energy natural-parity states in ^{20}Ne.

In this talk we will discuss preliminary results of a detailed *R*-matrix analysis of ^{19}F(p,α_0)^{16}O and ^{19}F(p,α_π)^{16}O cross section data, and the consequent implications on the reaction rate played by the states contributing to both these reaction channels.

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STUDIES ON THE TWO-PROTON EMISSION FROM THE IAS STATES OF ^{22}Mg

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The β-delayed two-proton emission from ^{22}Al was investigated experimentally through the implantation-decay method at the RIBLL1 facility in Lanzhou, China. The excited states of ^{22}Mg were populated through the β-decay of ^{22}Al. Two-proton emissions from the Isobaric Analogue State (IAS) of ^{22}Mg were identified based on the coincidence of the charged particle and γ-ray signals. The momentum and emission angle of the two protons were measured by silicon detector arrays, from which the relative momentum and opening angle distributions between the two emitted protons could be obtained. A strong peak in the relative momentum around 20 MeV/c, as well as a peak at small opening angle between the two emitted protons was observed clearly. It is determined by fitting the experimental data with the Monte Carlo simulations that the probability of ^{2}He emission from the IAS of ^{22}Mg to the first excited state in ^{20}Ne was 29(13)%.

SEMINAR

Tuesday 15:45

TWO-PROTON RADIOACTIVITY OF ^{67}Kr

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The decay modes of proton-rich nuclei are dominated by β^+ radioactivity. For these nuclei, the one and two proton separation energies are positive, thus the emission of one or two protons from ground state is energetically prohibited. Beyond the proton drip line, the proton separation energy becomes negative, allowing the one- and two-proton emission to compete with β^+ decay.

Observed for even proton number nuclei because of the pairing effect, two-proton radioactivity reveals as a tool to study the nuclear structure near the drip line. This decay was discovered in 2002 with the observation of ^{45}Fe at GANIL and GSI. Then followed the observation of the medium-mass emitters ^{48}Ni and ^{54}Zn. These observations were completed with experiments using time projection chambers, allowing to estimate the angular and energy correlations and explore nuclear structure. In the higher mass domain, the candidates according to local-mass models are ^{59}Ge, ^{63}Se and ^{67}Kr.

In a ^{78}Kr fragmentation experiment at 345 MeV/A performed at the BigRIPS facility in 2015, ^{59}Ge was observed with an unprecedented count rate, ^{63}Se and ^{67}Kr were produced and identified for the first time [1]. The nuclei were implanted in the DSSSDs of WAS3A-Bi, surrounded by the EURICA cluster array. The two-proton radioactivity of ^{67}Kr was unambiguously identified with a decay energy of 1690(17) keV. Its lifetime is 7.4(30) ms and its branching ratio 37(14) % [2]. No evidence of two-proton emission could be pointed out for ^{59}Ge and ^{63}Se. This discovery opens the way to a more detailed study by the use of a time projection chamber.

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TOWARDS THE LIMITS OF NUCLEAR STRUCTURE ALONG THE PROTON-UNBOUND ARGON AND CHLORINE ISOTOPES

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In order to understand of the limits of nuclear structure existence, one can take a closer look at the nuclear systems located far beyond the driplines. The recent investigations of the argon and chlorine isotopes located by two and three mass units beyond the proton drip line will be reviewed. These isotopes were detected by measuring the trajectories of their decay-in-flight products by the means of tracking technique with micro-strip detectors [1]. The experiment has been performed at the FRS fragment separator in GSI, Germany in 2012. The data have been obtained as a by-product of the main objective, ^{30}Ar [2]. The emission of proton (1p) or two-proton (2p) was detected in double or triple correlations with residual heavy ion (HI), i.e. HI+p and HI+p+p, respectively. This technique allowed for the first-time observation of the ^{30}Cl and ^{28}Cl isotopes by measuring their 1*p*-separation energies S_p of -0.48(2) and -1.60(8) MeV, respectively. The first-time observed excited states of ^{31}Ar demonstrated a very high level of isobaric symmetry with respect to its mirror ^{31}Al, which allowed to derive the 2p-separation energy S_{2p} of 6(34) keV for the ^{31}Ar ground state. The state in ^{29}Ar with S_{2p} = -5.50(18) MeV was also observed for the first time.

In particular, the Monte-Carlo simulations performed in order to interpret and precisely identify the 1p and 2p decay energies, as well as the spectroscopy of the previously-unobserved ^{29}Ar, ^{28,30}Cl isotopes will be presented in detail.

On the basis of the obtained data, the limits of nuclear structure existence are predicted for ^{26}Ar and ^{25}Cl in the respective isotopic chains [3].

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SEMINAR

Tuesday 16:00

SHAPE COEXISTENCE IN ^{66}Ni PROBED THROUGH β DECAY

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^{66}Ni is subject of interest from both, theoretical and experimental, point of view. Recent studies [1,2] show that this isotope exhibit properties associated with shape coexistence. The analysis of the ^{66}Co β^- decay allowed us to study this nucleus by determining the γ-ray intensities and the β-decay branching ratios, including the direct feeding to the ground state.

The experiment was performed at ISOLDE facility at CERN. A beam of ^{66}Mn was produced by the proton-induced-fission of uranium and then purified by means of laser resonance ionization and mass separation. The detection setup consisted of two MiniBall High Purity Germanium detectors and three plastic ΔE scintillators. The decays of Mn and the daughter activities of Fe and Co were registered by the digital acquisition system based on XIA-DGF4C modules.

We observed a selective population of the first and third 0^+ and 2^+ states in ^{66}Ni, which can be explained by analyzing the wave functions of the ^{66}Ni states calculated in Monte Carlo Shell Model calculations [3,4]. The significant differences between states configurations, which lead to the shape coexistence, reveal a crucial role of the νg9/2 shell and proton excitation across Z=28 gap.

The presented results are a part of the global analysis of the ^{66}Mn decay, which shows the onset of deformation in the A=66 chain from the nuclei in the Island of Inversion around ^{64}Cr [5] to the spherical isotopes of Ni [1].

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GROUND STATE STRUCTURE OF ^{52}K FROM COLLINEAR RESONANCE IONIZATION SPECTROSCOPY

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The Collinear Resonance Ionization Spectroscopy (CRIS) experiment at CERN-ISOLDE aims to measure the spin, electromagnetic moments and changes in the root-mean-square charge radii of exotic nuclei in a model independent way. The technique combines the high efficiency of resonance ionization with the high resolution of collinear laser spectroscopy [1-2]. Recent developments enabled the measurement of the ground state properties of lighter nuclei with high resolution and high precision, therefore becoming a powerful tool to test state-of-the-art nuclear theory calculation in the Ca region far from stability.

In this contribution, preliminary results of the ^{52}K experiments will be presented. Having one proton hole in the Z=20 shell and 33 neutrons, ^{52}K is an excellent laboratory to study the proposed shell closer at N=32 in the Ca region [3-5]. The ground state propoerties of this key isotope combined with the changes in the root-mean-square charge radii of lighter potassium isotopes give an additional insight into the evolution of nuclear stucture around N=32.

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ISOSPIN SYMMETRY IN THE LOWER sd SHELL: COULOMB EXCITATION STUDY OF ^{21}Mg

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Nuclei around the N = Z line serve as a way to investigate the level to which isospin symmetry is conserved in nature. Traditionally isospin symmetry and its breaking have been investigated by studying mirror displacement energies and mirror energy differences (MED). To further the understanding of isospin symmetry breaking effects and scrutinize theoretical nuclear models, a range of spectroscopic data is required, including B(E2) values, in addition to level energies and nuclear masses.

A shell-model calculation based on the modified USD interaction [1] has been successful in the lower *sd* shell reproducing MED and the B(E2) values of T=1,2,3/2 and T=1,2 nuclei, respectively [2]. However, the available information on the experimental B(E2) values of the neutron- deficient T_z=−3/2 systems is limited to only one value of ^{33}Ar [1]. The present work provides a second data point for the T_z=−3/2, B(E2) systematics at mass A=21, where a large deviation in the B(E2) values between the mirror partners has been predicted.

The B(E2;1/2+ → 5/2+) value in the T_z=−3/2 nucleus ^{21}Mg was recently measured using Coulomb excitation (Coulex) at TRIUMF-ISAC II. The first direct observation of the γ-ray transition de-exciting the first excited $1/2^+$ state in ^{21}Mg was achieved with the TIGRESS Ge array. Scattered particles were detected with the BAMBINO Si array. In addition, a new excited state in ^{21}Mg was observed for the first time. This state is analogous to the known ($7/2^+$, $9/2^+$) state in mirror nucleus ^{21}F.

Digital sampling of Ge and Si detector waveforms allowed the half-life of the $1/2^+$ state to be measured. The B(E2) values extracted from the measured half-life and Coulex cross-section analysis are in very good agreement. To our knowledge this work demonstrates for the first time two independent measurements of a B(E2) value in a single experiment based on electronic timing and Coulex cross-section analysis. The newly obtained experimental B(E2) data in ^{21}Mg will be compared to the phenomenological shell-model calculations employing the modified USD and USDB interactions in addition to the modern *ab initio* calculations utilizing the in-medium similarity renormalization group (IM-SRG), the coupled-cluster effective interaction (CCEI) and the symmetry-adapted no core shell model (SA-NCSM) approaches.

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COULOMB EXCITATION OF ^{45}Sc

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^{45}Sc is an odd-even stable nucleus, situated in the nuclear chart above the doubly magic ^{40}Ca. For many years, this mass region has been a subject of numerous theoretical and experimental studies. They demonstrated that the properties of the ground-state band can be well described by the spherical shell model, while particle-hole excitations across the doubly-magic shell gap result in appearance of superdeformed structures as it was first reported in ^{40}Ca [1], and further investigated via Coulomb excitation in ^{42}Ca [2].

This medium light ^{45}Sc nucleus has one additional proton and 4 neutrons beyond the Z=N=20 shell closure. The number of active particles and the $p_{3/2}f_{7/2}$ configuration space are large enough to allow for the collective motions of nucleons. The negative-parity states built on the $7/2^-$ ground state have a spherical character, while a well -deformed rotational-like band is formed upon the $3/2^+$, 12.4 keV intruder level in ^{45}Sc [3,4]. To study the electromagnetic properties of low-lying excited states in ^{45}Sc, Coulomb excitation experiment was performed in November 2017 using the Inter-University Accelerator Centre - New Delhi facility. The γ-rays depopulating Coulomb excited states in the nuclei of interest were detected by the Clover detectors in coincidence with forward scattered ions detected in PPAC. A complementary thick target measurement was performed at the HIL, University of Warsaw. Collected data are analyzed using the coupled-channel, least-squares search code GOSIA [5] with the aim of determining matrix elements between low-lying excited states. The measured γ -ray intensities will enable us also to evaluate the B(E3) transition probabilities, in particular: the excitation probability from the ground state to the first excited isomeric state: B(E3, $7/2^-_{g.s.} \rightarrow 3/2^+_1$) so far only upper limit is known [6], while the B(E3, $7/2^-_{g.s.} \rightarrow 5/2^+_1$) is unknown. In this contribution, the recently performed measurements will be described and the results of common analysis will be presented.

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^{120}Te – COLLAPSE OF THE VIBRATIONAL PICTURE

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The nuclear structure study of semi-magic nuclei or of nuclei close to a closed shell is of great importance for a deep understanding of the nuclear interaction. Information on the single-particle energies and two-body residual interactions can be derived from the experimental observables, such as energies of the excited states, reduced transition probabilities, and it can be used to estimate the nuclear structure of more complex configurations.

The Te nuclei with Z = 52, is two protons away from the well-studied tin isotopic chain. For the mid-shell ^{120,122,124}Te nuclei the partial level scheme show the expected vibrational-like structure with equal energy spacing between the phonon states. In our previous Coulomb excitation experiment [1] at IUAC, New Delhi. The B(E2; $0^+ \rightarrow 2^+$) value in ^{120}Te was re-measured with a much higher precision to allow a comparison with the predictions of the large scale shell model calculations (LSSM). Based on all experimental findings, including the excitation of higher excited states for ^{120,122,124}Te, one obtained the best agreement with an asymmetric rotor behavior.

The most sensitive probe to characterize a nuclear excitation is via a measurement of quadrupole moments. Therefore, to investigate the second-order effects in Coulomb excitation and to find an experimental proof of the deformation in ^{120}Te, a Coulomb excitation experiment was performed at Heavy Ion Laboratory (HIL), Warsaw using the EAGLE array. The resulting E2 transitional and diagonal matrix elements were extracted using the least square Coulomb Excitation search code - GOSIA [2]. The measured value for Q(2^+) provides first experimental proof of the prolate-like shape of the ^{120}Te nucleus in the 2^+ state. The set of reduced E2 matrix elements was analysed to obtain, using the quadrupole sum rules approach, quadrupole deformation parameters in the 0^+ (ground state). The experimental results are compared with the predictions of the general Bohr Hamiltonian (GBH) model [3]. The theoretical calculations were performed using two variants of the Skyrme effective interaction, well known and widely used SLy4 and the recently proposed UNEDF0 [4] energy functional. The experimental results are compared with the predictions of the general Bohr Hamiltonian (GBH) model performed using the Skyrme interaction (SLy4) and UNEDF0 energy functional. Final results and interpretations will be presented at the conference.

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Wednesday

August 29th

INVITED

EMERGENCE OF COLLECTIVE EXCITATIONS AND DEFORMED SHAPES IN HEAVY NEUTRON-DEFICIENT (N~90) NUCLEI

David Joss, Oliver Lodge Laboratory, University of Liverpool, Liverpool, UK

The systematic variation of nuclear properties across complete shells can reveal the evolution of collective excitations arising from correlated nucleon motion. The $82 < N < 126$ shell is the largest open shell that can be accessed with current experimental techniques although spectroscopic investigations in the transitional nuclei at the extremes of the shell are challenging. However, considerable progress has been made towards identifying excited states and measuring reduced transition probabilities in the heavy neutron-deficient nuclei above N=82.

This paper reviews recent experiments probing the structure of the W and Os (N~90) nuclides using large γ-ray spectrometer arrays in conjunction with selective tagging techniques. These nuclei occupy a gamma-soft transitional region where the nuclear shape and associated collective excitations are particularly sensitive to the underlying single-particle structure. New features emerging from these experiments are discussed.

INTERPRETATION OF HIGH-SPIN BANDS WITHIN THE CRANKED NILSSON-STRUTINSKY FORMALISM

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High-spin bands in different mass regions are analyzed using the cranked Nilsson-Strutinsky formalism with [1,2] and without [3,4] inclusion of pairing. Phenomena which will be discussed include

- The continuous evolution with spin of high-spin bands in ^{62}Zn from terminating bands over non-terminating configurations to collective superdeformed bands [5].
- The crossing bands in ^{76}Rb, where it is possible to identify smooth undisturbed bands which are well described in an unpaired formalism [6].
- The high-spin linked bands in ^{125,126}Xe which appear rather similar but where the bands in the two nuclei turn out to have very different excitation energies in the I =55 spin range.
- The ^{156}Dy high-spin bands [6] where a `full understanding' can be achieved only if a distinction is made between N_{osc}=4 dg ($d_{5/2}g_{7/2}$) and sd ($s_{1/2}d_{3/2}$) pseudospin partners.
- A critical evaluation [8] of the experimental fingerprints for large deformation in the so called TSD (triaxial strongly deformed) bands in the A =165 region and a reinterpretation of some of these bands.

The analyses suggests that in the high-spin region where pairing is severely quenched, angular momentum is built from small contribution of most of the valence particles and it is not meaningful to refer to specific orbitals as aligned. Thus, the high-spin configurations are preferably defined from the filling of the orbitals at the Fermi surface where these orbitals can generally be assigned as belonging to the high-*j* or low-*j* shells.

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THE ν-BALL CAMPAIGN AT ALTO

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From November 2017 to June 2018, the ALTO facility hosted the ν-ball high efficiency hybrid spectrometer. It is made of Ge (24 clover Ge detectors and 10 coaxial Ge) and 20 $LaBr_3$ detectors to combine the excellent energy resolution of HPGe with excellent time resolution of $LaBr_3$ scintillators. All Ge detectors have their BGO shield for Compton suppression. This configuration provide excellent characteristics for a gamma spectrometer such as high photopeak efficiency (~7.5%) and peak-to-total ratio (~50 %). In addition, the ν-ball geometry allows coupling with the LICORNE directional fast neutron source at the ALTO facility on the Orsay campus. That gives possibility for precision spectroscopy of neutron induced reactions. The beam pulsing capability of the tandem also opens the possibility of precise timing measurements.

As mentioned the experimental campaign on ν-ball project was held from November 2017 up to June 2018. More than 2800 hours of beam time were provided to ten different experiments which range from fusion-evaporation reaction to fast neutron induced fission of ^{232}Th to populate high spin states in neutron rich nuclei.

In this talk, coupled to a short presentation of the ALTO facility, all the main characteristics of the ν-ball array will be presented. A brief overview of all the experiment performed during the campaign will be given. However, more focus will be given to two experiments on fission of ^{232}Th and fission isomer studies of ^{238}U. The most recent analysis results for these will be presented.

SEARCH OF TWO-PHONON-OCTUPOLE STATE IN THE VICINITY OF ^{208}Pb

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^{147}Gd with one neutron more than the neutron close shell (N=82) and proton sub-shell closure (Z=64), was the first nucleus for which a nuclear double-phonon-octupole state was found [1]. In the doubly magic ^{208}Pb, the first excited state is found to have a spin and parity 3^-. This state is strongly collective (33 w.u. [2]) and therefore associated to the first phonon state in ^{208}Pb. Nevertheless, the search of the two-phonon state in ^{208}Pb was so far not conclusive [3]. Recently, additional effort on search of phonon states around ^{208}Pb was conducted [4] and the octupole character of four E3 transitions was proved for the first time. For example, the octupole character of $19/2^-$ to $13/2^+$ transition in ^{207}Pb was confirmed by gamma-ray angular distribution measurements. The $13/2^+$ isomeric state in ^{207}Pb is interpreted [5] as a neutron-hole ($i_{13/2}$) couple to the 3^- one-phonon-octupole state of ^{208}Pb. The $19/2^-$ state is therefore a good candidate for a two-phonon-octupole state.

The presentation will report on a recent measurement performed with AGATA [6] +VAMOS [7] at GANIL in which the lifetime of the $19/2^-$ state was measured. The result will be presented and the possibility to have a two-phonon-octupole state will be discussed.

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PROPERTIES OF γ-DECAYING ISOMERS IN THE ^{100}Sn REGION REVISITED

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Extending Single Reference Density Functional Theory (DFT) into a multireference (MRDFT) scheme by means of projection techniques allows one to restore symmetries and, in turn, to calculate transition rates for various nuclear reactions [1]. The scheme can be further generalized to include correlations from relevant (multi) particle-(multi)hole excitations by performing configuration-interaction (CI) calculations.

The aim of this presentation is to introduce the MRDFT model involving angular momentum and isospin projections and its extension to the no-core CI (NCCI) scheme developed by our group [2]. We shall present applications of the MRDFT and NCCI models to the structure of selected nuclei focusing on their capability to investigate Gamow-Teller (GT) beta decay channel in N ≈ Z nuclei ranging from A = 6 up to A = 100.

In particular, we shall discuss the following issues: 1) influence of core polarization on the quenching of GT matrix elements [3] by comparing our results to the state-of-the-art shell model calculations, 2) spin-orbit dependence of the GT matrix elements [3], and 3) the GT strength distribution for the ^{24}Al → ^{24}Mg decay. Special attention will be paid to study the influence of isospin symmetry breaking correlations (ISB) on the GT transitions. It will be shown, that the calculated differences between GT matrix elements corresponding to the mirror transitions in N ≈ Z, T=1 nuclei in *p*- and *sd*- shells are in a very good agreement with the experimental values [4,5] in a handful of cases where such data are available. To the best of our knowledge, this is the very first study of the effect of ISB correlations on the spin-isospin channel of an axial-current-mediated beta decay.

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STUDY OF ISOSPIN SYMMETRY IN THE A=50 ISOBARIC TRIPLET - ^{50}Fe, ^{50}Mn, ^{50}Cr

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Nuclei along the N=Z line serve as good candidates to study isospin-symmetry breaking (ISB) through the slight differences between isobaric nuclei in the observed analogue level energies and electromagnetic transition ((EM)) rates [1]. The level of isospin mixing is expected to increase quadratically with proton number [2, 3]. Consequently, higher Z nuclei should, in general, be better candidates to study ISB. Due to the appearance of the shape coexistence phenomena in the A~70 region, nuclei with A~50 and N=Z may well be the best candidates to study ISB [4]. Despite such strong interest, low-production rates limit such experiments. For example, in the A~50 region, only one experiment has been performed to date to measure EM rates in the A = 46 isobaric triplet [5-9]. In this talk, results from our measurements of the lifetimes of the isobaric analogue T =1, $I^{\pi}=2^{+}$ states in ^{50}Mn and ^{50}Cr will be presented. A plunger device [10] was employed at the at the FN Tandem ac facility of the University of Cologne in order to measure the lifetime of the states produced in a ^{12}C+^{40}Ca fusion evaporation reaction. The deduced B(E2) values together with the available data of ^{50}Cr [5-7] and ^{50}Fe [11] nuclei will be compared with our shell model calculations to investigate isospin symmetry in this A=50 isobaric triplet through the variation of the M (E2) matrix element as a function of T_Z=(N-Z)/2.

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GAMMA DECAY FROM ELECTRIC DIPOLE EXCITATIONS

Angela Bracco, Dipartimento di Fisica Università di Milano and INFN Milano

The presentation will start with a short overview of relevant results and directions for the study of the gamma decay from dipole states in nuclei at zero and finite temperature.

The latest efforts for the study of pygmy states will be the core of the presentation. In particular the isospin character of the PDR states will be discussed. For this purpose comparisons will be made with data from (^{17}O, ^{17}O'), the (α,α'γ) and the (p,p'γ) reactions (mainly isoscalar character, better sensitivity to the inner transition density), and data from (γ,γ') (isovector character). Preliminary results of the very recent study of the low-energy part of the E1 response in ^{90,94}Zr nuclei will be discussed. They are related to the (p,p'g) and (α,α'γ) inelastic scattering measurements at energies $E_{beam,p}$= 80 MeV and $E_{beam\alpha}$=130 MeV respectively. The inelastically scattered particles were measured by the high-resolution spectrometer Grand Raiden at RCNP, Osaka University. The γ-rays emitted following the de-excitation of the Zr target nuclei were detected using both the clover type HPGe detectors of the CAGRA array and the large volume $LaBr_3$:Ce scintillation detectors from the HECTOR+ array.

RECENT STUDIES OF THE MONOPOLE AND DIPOLE RESPONSE IN NUCLEI

M.N. Harakeh, KVI-CART, University of Groningen, the Netherlands

INVITED

Wednesday 11:30

During the last decade, new techniques have been developed in connection with study of giant resonances in exotic nuclei. This involved the deployment of active targets in experiments wherein the isoscalar giant resonances, in particular the isoscalar giant monopole (ISGMR) and dipole (ISGDR) resonances, were studied by inelastic alpha scattering in inverse kinematics. Furthermore, at the Experimental Storage Ring (ESR) at GSI a pioneering experiment was performed with a circulating stable ^{58}Ni beam as a proof-of-principle method for studying excitation of ISGMR and ISGDR in exotic nuclei by scattering circulating radioactive ions from ^{4}He gas target.

These techniques together with techniques for investigation of isovector dipole response of radioactive ions scattered in inverse kinematics from heavy targets will be presented. Very recent studies of excitation of the isovector giant dipole resonance (IVGDR) and pygmy dipole resonance (PDR) in inelastic proton scattering at intermediate energies and of PDR in inelastic alpha scattering in coincidence with gamma decay will be briefly presented.

FINE STRUCTURE OF GIANT RESONANCES – WHAT CAN BE LEARNED

Peter von Neumann-Cosel, Institut für Kernphysik, Technische Universität Darmstadt, 64289 Darmstadt, Germany

I will discuss two methods for a quantitative analysis of the fine structure of giant resonances observed in high-resolution (p,p') experiments at RCNP and iThemba LABS and (e,e') experiments at the S-DALINAC. Wavelet analysis allows the extraction of scales characterizing the fine structure [1]. By comparison with scales derived from microscopic RPA-based models including the coupling to 2p-2h states it is possible to investigate the role of different mechanisms contributing to the decay widths of the giant resonances [2-8]. The phase relations of experimental and theoretical wavelet coefficients reveal information on K splitting of giant resonances in deformed nuclei [9]. The magnitude of the observed fluctuations is related to the average level spacing and one can extract spin-parity-selective level densities at excitation energies well above the neutron threshold, where level density data are almost non-existing [10-13]. Combining results from different electric and magnetic resonances one can test the parity and spin dependence of level densities [14].

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MAPPING THE GDR QUENCHING IN NUCLEI OF MASS REGION A = 120-132

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The evolution of the Giant Dipole Resonance properties in nuclei of mass A = 120÷132 has been investigated using ^{116}Sn beams at 17*A* and 23*A* MeV delivered by the cyclotron of the Laboratori Nazionali del Sud impinging on ^{12}C and ^{24}Mg targets [1,2]. Hot nuclei in an excitation energy range between 150 and 330 MeV were populated through complete and nearly complete fusion reactions. Gamma-rays and light charged particles were detected using MEDEA in coincidence with evaporation residues detected in MACISTE. The analysis of the light charged particle energy spectra together with the residue selection in ToF allowed for a proper determination of the excitation energy of the hot systems populated in the ractions after the pre-equilibirium stage.

A detailed analysis of the gamma-ray spectra and their comparison with statistical model calculations will be shown. Evidence of a quenching of the GDR gamma yield was found in the analysis of the gamma spectra at 270 MeV and 330 MeV excitation energies . The quenching effect becomes progressively more important with increasing excitation energy [1]. A limiting excitation energy for the collective motion of about 230 MeV can be extracted from the full data set. The transition towards the disappearance of the dipole strength appears to be remarkably sharp. Current phenomenological models describing the GDR disappearance at high excitation either as a progressive width broadening [3] or as a real yield suppression [4] give qualitative explanations for the quenching but cannot reproduce its detailed features [2]. A detailed comparison between the full data set and model predictions will be presented.

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INVITED

STUDY OF IVSM GIANT RESONANCE VIA THE EXOTHERMIC REACTION

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On behalf of SHARAQ Collaboration

An IsoVector Spin Monopole (IVSM) giant resonance (GR) induced by an operator $st\times r^2$ is one of a representative mode of collective excitations of the nucleus. It is characterized by the quantum numbers having T=1, L=0, S=1, J=1. The IVSM GR is considered as a breathing mode (2hw) with spin degrees of freedom. The IVSM GR can be excited by charge-exchange reactions such as (p,n)/(n.p) or (^{3}He,t)/(t,^{3}He) for the b^-/b^+ directions. However, the b^- IVSM GR appears in highly excited region around E_x=20-40 MeV and it inevitably couples with the Gamow-Teller state which has the same quantum numbers T=1, L=0, S=1, J=1 (0hw). Those features make it difficult to extract an IVSM strength from an experimental spectrum.

Since the transition density of IVSM is expected to have a node near surface due to the 2hw excitation character, a heavy ion probe which gets absorbed at the surface seems to be an excellent tool to enhance the IVSM yield.

We studied the b^-IVSM GR with the heavy ion charge exchange reaction ^{90}Zr(^{12}N,^{12}C) at 175 MeV/u at RIBF of RIKEN Nishina Center [1]. Some characteristic features of this experiment are:

The (^{12}N,^{12}C) reaction has an excellent spin-isospin selectivity. It exclusively excites DT=1 and DS=1 states. Note that ^{12}N is a radioactive secondary beam.

It is an exothermic reaction due to the large positive reaction Q-value (+11.2 MeV). This enables us to excite IVSM with less momentum transfer (q<w) compared to stable beams (q>w).

The magnetic spectrometer SHARAQ designed for the radioactive secondary beam experiments was employed for the measurement.

In this talk, after a short introduction on the exothermic reaction and the IVSM GR, the experiment and results are presented together with the b^+ IVSM GR study by the (t,^{3}He) reaction [2].

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Wednesday 19:00

EVOLUTION OF THE IVGDR AND ITS FINE STRUCTURE FROM DOUBLY-MAGIC ^{40}Ca TO NEUTRON RICH ^{48}Ca PROBED USING (p,p')

Iyabo T. Usman, University of the Witwatersrand, Johannesburg, South Africa

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Experiments investigating the fine structure of the Isovector Giant Dipole Resonances (IVGDR) have been carried out on target nuclei ^{40,42,44,48}Ca with 200 MeV proton inelastic scattering reactions using the high energy-resolution capability and the zero-degree set-up at the K600 magnetic spectrometer of iThemba LABS, Cape Town, South Africa. Quasi-free scattering background contributions in the experimental data has been removed by applying a novel method of Discrete Wavelet Transform (DWT) analysis. Energy scales extracted are compared with the state-of-the-art theoretical calculations within the framework of the Quasiparticle-RPA and Relativistic Quasiparticle Time Blocking Approximation (RQTBA). For ^{40,48}Ca, these calculations consider all major processes (Landau damping, escape width, spreading width) contributing to the damping of the IVGDR.

SEMINAR

FIRST MEASUREMENTS OF COLLECTIVE EXCITATIONS IN ^{208}Pb INDUCED BY PROTON BEAM AT CCB KRAKOW

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Wednesday 19:50

A new proton beam facility at the Institute of Nuclear Physics Polish Academy of Sciences, the Cyclotron Center Bronowice (CCB) has been operating since few years. Alongside the proton-therapy, it runs a challenging scientific program. The first experiment studying the nuclear structure by proton-induced collective excitations in ^{208}Pb was performed in March 2017.

In the focus of the experiment was study of the γ-decay from high-energy excitations populated by inelastic proton scattering. To achieve the goal of the experiment, a set-up that enabled a coincidence measurement of high-energy γ rays and scattered protons was prepared. To measure high-energy γ rays with high efficiency, the HECTOR array [1] consisting of 8 big BaF2 detectors was used along with a cluster of PARIS type *phoswiches* (4 $LaBr_3$:Ce-NaI:Tl and 5 $CeBr_3$-NaI:Tl crystals) [2] and a large volume $LaBr_3$:Ce scintillator.

The angle and energy of the scattered protons was measured with the use of the KRATTA array [3] – a set of 24 triple telescopes made of three photodiodes and two CsI:Tl crystals. On the front of the KRATTA array, plastic scintillators were mounted to allow generation of a trigger with precisely time-defined condition.
The results show the γ-decay of Giant Resonances – giant quadrupole resonance (GQR) and giant dipole resonance (GDR). In the region below the particle binding energy, γ-decay from the pygmy states (PDR) was observed, as well.

The talk will present the setup and show the obtained experimental results, followed by the comparison with the theoretical predictions. The outlook for future studies at CCB will be mentioned, as well.

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STUDY OF DIPOLE EXCITATIONS IN ^{124}Sn VIA INELASTIC PROTON SCATTERING

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In the energy region below the neutron separation energy, the collective E1 behaviour can be separated into the low-energy tail of the giant dipole resonance (GDR) and the pygmy dipole resonance (PDR) [1,2]. Additionally, 1^- states formed by the quadrupole-octupole coupling $[2^+ \otimes 3^-]_{1-}$ of a low-energy 2^+ and 3^- state contribute at energies below the PDR. In a microscopic picture, the PDR corresponds to an oscillation of a neutron skin against the isospin saturated core whereas the GDR can be imagined as an oscillation of all neutrons against all protons.

As the study of the E1 strength of the N=82 isotones ^{138}Ba [3,4], ^{140}Ce [3,4,5] and ^{124}Sn [6,7] indicates, a deviation in the observation of 1^- states occurs when comparing the E1 excitation behaviour of (γ,γ') with (α,α'γ) experiments performed at high particle energies. Two accumulations of 1^- states can be found where the low-energy part is excited by both probes and can be assigned to the isoscalar PDR. The higher lying 1^- states are only excited with the nuclear resonance fluorescence method [4,7] and can be assigned to the isovector tail of the GDR. This phenomenon is called isospin splitting.
To complement this picture in ^{124}Sn, a (p,p'γ) experiment was performed at the SONIC@HORUS setup with a proton beam of 15 MeV provided by the 10 MV FN Tandem accelerator in Cologne.

The aim was to investigate the response of ^{124}Sn in inelastic proton scattering and determine branching ratios. The latter are important observables that probe the overlap of the wave functions of the involved states and furthermore can be used to correct the E1 strength obtained by (γ,γ') experiments using bremsstrahlung.

In this contribution, preliminary results of the ^{124}Sn(p,p'γ) experiment on these quantities will be presented.

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INVITED

JACOBI SHAPE AND CLUSTERING EFFECTS IN LIGHT NUCLEI

Balaram Dey, Saha Institute of Nuclear Physics, Kolkata, India

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The Jacobi shape transition has become an important subject of investigation in nuclear physics research. It is an abrupt change of shape from non-collective oblate to collective triaxial or prolate shape above a critical spin. While this was initially thought of in connection with rotating gravitational objects, it is also expected to occur in a nucleus due to its liquid drop behavior at high excitation energy. These type shape transition have been observed earlier in ^{45}Sc [1], ^{46}Ti [2,3], ^{47}V [4] nuclei etc. Recently, for the first time, we observed the Jacobi shape transition in very light mass nucleus ^{31}P using high energy gamma rays from the decay of giant dipole resonance (GDR) as a probe [5].

The measured GDR spectrum in the decay of ^{31}P shows a distinct low energy component around 10 MeV [5], which is a clear signature of Coriolis splitting in a highly deformed rotating nucleus. In addition, a self-conjugate α-cluster nucleus ^{28}Si was populated at similar initial excitation energy and angular momentum, which exhibits a vastly different GDR lineshape [5]. Even though the angular momentum of the compound nucleus ^{28}Si is higher than the critical angular momentum required for the Jacobi shape transition, its GDR lineshape is akin to a prolate deformed nucleus.

Considering the present results for ^{28}Si [5] and similar observation recently reported in ^{32}S [4,6], it is proposed that the nuclear orbiting phenomenon exhibited by α-cluster nuclei hinders the Jacobi shape transition. The present experimental results suggest a possibility to investigate the nuclear orbiting phenomenon using high energy gamma rays as a probe.

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Wednesday 20:20

SEMINAR

ISOSPIN SYMMETRY BREAKING IN THE NUCLEUS ^{60}Zn

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Symmetries in a quantum system are strongly related to conservation laws, which, in turns, link to conservation of quantum numbers. The isospin symmetry is one of the fundamental symmetries identified in atomic nuclei. This symmetry is based on the assumption that the nuclear interaction is charge symmetric and charge independent. In the isospin formalism, neutrons and protons are considered as two quantum states of the same system, the nucleon. The presence of the Coulomb interaction between protons in the nucleus breaks this symmetry introducing isospin impurities in the wave function.

This phenomenon is called isospin mixing and it is the topic of this contribution. The knowledge of the isospin mixing is important because it affects the properties of the Isobaric Analog States (IAS) and the Fermi decay transition rates and thus, it has implications on the Cabibbo-Kobayashi-Maskawa matrix. The breaking of isospin symmetry can be observed through decays which would be forbidden by selection rules. This is the case of the E1 decay from self-conjugate nuclei in a I=0 configuration. To fully exploit this property, one should go in the region of the Giant Dipole Resonance (GDR), where most of the E1 strength is concentrated. This approach has been employed to measure the isospin mixing in nuclei at finite temperature T, formed in fusion evaporation reactions. In this type of experiments, the use of self-conjugate projectile and target nuclei ensures the population of a compound nucleus (CN) with I=0. The hindrance of the GDR gamma decay can be measured and thus the mixing amplitude deduced. A partial restoration of the isospin symmetry is expected at high temperature due to the decreasing of CN lifetime for particle decay.

In the present case, the isospin mixing was measured in the hot CN ^{60}Zn at two different nuclear temperatures, 2.1 and 2.4 MeV. The experimental method is based on the analysis of the GDR gamma-ray emission in the fusion reactions ^{32}S+^{28}Si at two different beam energies (86 and 110 MeV). The goal of the experiment is to measure the temperature dependence of the isospin-mixing mechanism. The experiment was performed in Laboratori Nazionali di Legnaro using an array of ten $LaBr_3$:Ce coupled with: an array of HPGe detectors (GALILEO), an array of silicon detectors in a telescope configuration (EUCLIDES) and an array of liquid BC501 scintillation detectors (Neutron Wall).
The status of the analysis will be presented.

Wednesday 20:45

PHOTONEUTRON CROSS SECTION MEASUREMENTS FOR ^{165}Ho BY DIRECT NEUTRON-MULTIPLICITY SORTING AT NEWSUBARU

Mateusz Krzysiek, Institute of Nuclear Physics, Krakow, Poland

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The Coordinated Research Project of the International Atomic Energy Agency (IAEACRP F41032) was launched with a goal to publish two compilations of an updated photonuclear data library and a reference database of photon strength functions. The PHOENIX (PHOto-Excitation and Neutron emIssion cross [X] sections) Collaboration has been established for the IAEA-CRP in the γ-ray beam line GACKO (Gamma Collaboration hutch of KOnan university) of the NewSUBARU synchrotron radiation facility in Japan. The collaboration provides (γ,xn) cross section data to resolve the long-standing discrepancy between the Livermore and Saclay data of partial photoneutron cross sections.

For the IAEA-CRP a flat-efficiency neutron detector (FED) for (γ,xn) cross section measurements was developed. The detector consists of three concentric rings of 4, 9, and 18 ^{3}He counters embedded in a 46 cm (horizontally) x 46 cm (vertically) x 50 cm (along the beam axis) polyethylene moderator at the distances of 5.5, 13.0 and 16.0 cm from the γ-ray beam axis, respectively. Due to the fact, that the efficiency of the detector is constant for the neutron energies up to several MeV, it is possible to determine the partial cross sections using direct neutron-multiplicity sorting technique.

The presentation will give details of the experimental setup and data analysis. Results of (γ,xn) cross sections (x = 1-4) for ^{165}Ho will be presented. Future research plans, including the application of similar technique at the gamma-beam facility of the Extreme Light Infrastructure – Nuclear Physics (ELI-NP) will be discussed.

Thursday

August 30th

INVITED

RARE ISOTOPE SCIENCE PROJECT IN KOREA

Sunchan Jeong, Rare Isotope Science Project (RISP), Institute for Basic Science (IBS), Daejeon, Republic of Korea

The use of rare isotopes existing in the world only at a very short moment (radioactivity with short lifetime) is increasing nowadays in various research fields, not only for basic researches in nuclear physics investigating origin of matter, synthesis of new atomic elements, and exotic nuclear structure of rare isotopes but also for applied researches in medical-bio-life science, materials and nuclear sciences.

In Korea, a new heavy-ion (HI) accelerator complex, RAON (Rare isotope Accelerator complex for on-line experiments), is under construction at Daejeon. Fully utilizing the conventional diversity of HI beams, in addition to the new availability of rare isotope (RI) beams, RAON is intended to become one of the world-leading HI beam facilities. RAON could provide new research opportunities in rare isotope science, which is recently attracting many interdisciplinary scientists, manifesting itself in the form of a second renaissance in heavy ion science.

Powered by a 400-kW superconducting heavy ion linear accelerator, RAON is intended to establish the In-flight Fragment (IF) and Isotope Separation On-Line (ISOL) facilities. The ISOL facility derived by a 70-MeV cyclotron could induce U-fission with a rate of 1014 fissions/s in maximum. The fission-product (FP) beam isolated by the ISOL will be post-accelerated by a superconducting linear accelerator SCL3 for low energy experiments (up to 18.5MeV/u for the beam of A/q~7). The IF facility will be derived by a 400kW superconducting linear accelerator system, SCL1 and SCL2, where U beam could be accelerated up to 200MeV/u. The post-accelerated FP beams can be injected to the SCL2 for further acceleration, e.g. up to about 250MeV/u for ^{132}Sn, and then can derive the IF facility for producing more exotic rare isotope beams. The combined operation of the ISOL and IF facilities is unique feature of RAON, allowing to reach more than 80% of the unexplored region in the chart of nuclide.

Prototyping major accelerator components has been almost complete, and the fabrication of some major components are underway. Especially putting the highest priority for early completion of the low-energy facility by the end of 2020, the mass production of major components of the SCL3, i.e. superconducting cavities of QWR and HWR structure, cryomodules, tuners, and power coupler will start soon. The low-energy facility consisting of the cyclotron, ISOL and SCL3 will deliver various stable and RI beams with variable energy from around 500keV/u (RFQ linac energy) to the energies in maximum around between 18.5 MeV/u (U) and 90 MeV (p) according to their A/q values, to the very low- and low-energy experimental halls. This facility, though part of the full facility, is supposed to be unique and hence highly competitive machine in terms of available beam energy and variety of beam.
Following a brief overview of the project and facility RAON, the present status of the project will be presented.

ACCELERATOR FACILITIES AND ACCELERATOR TECHNOLOGIES IN JINR

Boris Sharkov, Joint Institute for Nuclear Research, Dubna, Russia

This presentation outlines the development of heavy ion accelerators in JINR for research into heavy ion nuclear physics. Considerations are focused on new largest heavy ion drivers - mega-science projects NICA and SHE-factory being under construction now. Both facilities will provide worldwide unique accelerated beams and experimental capabilities allowing for a large variety of unprecedented fore-front research in low energy as well as relativistic nuclear physics.

Manifested facilities goals is pushing the "intensity" and the "precision frontiers" to the extremes when accelerating full range of ion beam species from p+ to U to highest beam intensities and luminosities.

Generation of "Precision beams", sophisticated beam manipulation methods-stochastic and electron cooling of ion beams, also applicable to the secondary radioactive beams of exotic nuclei is under discussion.

Construction of new generation of heavy ion accelerator facilities is progressing well and forefront accelerator technologies are under development in JINR

ACCELERATOR-DRIVEN FUSION AND TRANSMUTATOR TRIGGERED BY ACCELERATOR-DRIVEN FUSION

Ales Necas, TAE Technologies, 19631 Pauling, 92610 Foothill Ranch, United State

Toshiki Tajima, Michl Binderbauer, Sydney Gales, Gerard Mourou, Maurice Leroy

At TAE Technologies founded by Norman Rostoker in 1998 (with Glenn Seaborg as the first Chairman of the Board), a fusion reactor using aneutronic pB11 fuel is pursued through accelerator-driven plasma. Its latest fifth generation machine - Norman - has been operated as the major magnetic fusion experimental machine in US among all venues (including governmental and private funded). We have demonstrated [1] that the accelerator drive allows both the easy access to high temperatures of the advanced fuel as well as the beam-assisted robust stability and confinement. Taking advantage of the unique window of the nuclear physics cross-sections, we employ the accelerator-driven fusion as an ignition of transmutation process for incinerating nuclear spent fuel waste of minor actinides (MA). Beam-driven neutrons are injected into liquid phased transmutator filled with MAs and molten salt amplifying fission neutrons subcritical fashion monitored and controlled in real-time through the transparent solution. Simulation using the MCNP code of the startup phase as well as MA burnup rate and fission product removal are presented.

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SAIF (SOUTH AFRICAN ISOTOPES FACILITY): OPENING NEW FRONTIERS IN NUCLEAR SCIENCE AND APPLICATIONS

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The iThemba Laboratory for Accelerator Based Sciences (iThemba LABS) is a National Research Facility. It is also the premier atomic particle accelerator laboratory on the African continent and the only facility of its kind in the southern hemisphere. The facility contributes to the National System of Innovation (NSI) through the provision of unique research infrastructure platforms supported by highly skilled scientists, and operations staff. The research agenda of the facility is based largely on the Separated Sector Cyclotron (SSC), a particle accelerator which produces particle beams for research.

iThemba LABS plays a pivotal role in the National System of Innovation through its collaboration network with South African Universities and Institutions. The facility also enjoys a prominent global position and plays a critical role in co-ordinating the African contribution in collaborative initiatives with prestigious institutions like the European Organisation for Nuclear Research (CERN), the Facility for Antiprotons and Ions Research FAIR and the joint Institute for Nuclear research (JINR) in Russia. The research and production of accelerator-based radioisotopes is a demonstration of basic and applied research being translated into innovative real world solutions.

The talk will highlight and describe how the Long Range Plan of iThemba LABS will create the South African Isotope Facility (SAIF) which will put South Africa in a prominent position in the future to address the new challenges both in research and training within the subatomic field and beyond.

Friday

August 31st

HEAVY-ION REACTION AND FISSION STUDIES AT JAEA TANDEM ACCELERATOR FACILITY

Katsuhisa Nishio, Advanced Science Research Centre, Japan Atomic Energy Agency, Tokai, Ibaraki, Japan

Heavy-ion reaction studies at the JAEA tandem accelerator facility will be discussed. In order to predict cross sections to produce super-heavy nuclei in fusion-evaporation reactions, it is essential to determine fusion probability, i.e. the probability to produce compound nucleus after a system overcome and/or penetrate the Coulomb barrier. Our attempt to determine fusion probability from the measurement of fission fragments mass distribution and evaporation residue cross sections will be presented, particularly placing emphasis on the effects of static deformation of the target nucleus ^{238}U on fusion, using various projectile ^{16}O - ^{48}Ca [1-4].

Recently, we are promoting a program of fission/reaction studies in multi-nucleon transfer (MNT) reactions using various actinide target nuclei [5,6]. The MNT reaction allows us to produce neutron-rich actinide nuclei, which cannot be populated by particle capture reactions. The MNT reactions were used to measure fission properties and fission barrier height for various nuclei. The fission-fragment mass distributions (FFMDs) and their evolution with initial excitation energies were explained only by invoking a concept of multi-chance fission, i.e. neutron-evaporation before fission [7]. The obtained data set was used to improve the Langevin model to describe low-energy fission [8], which derives a clear explanation of the transition from the mass-asymmetric fission to the sharp symmetric fission observed in fermium isotopes.

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REACTIONS TIMESCALES IN HEAVY ELEMENT SYNTHESIS

David J. Hinde, Department of Nuclear Physics, RSPE, Australian National University, Canberra, Australia

INVITED

Heavy ion reactions used in the synthesis of heavy and superheavy elements show a wide variety of largely non-equilibrium outcomes, which compete with the desired process of fusion forming an equilibrated compound nucleus.

These competing processes range from fast mechanisms occurring in a few zeptoseconds, namely deep-inelastic and fast quasi-fission reactions, to much slower quasifission processes taking tens of zeptoseconds, and a three-body process involving sequential fission of the heavy target-like nucleus. Insights into the probabilities and timescales of these processes can be obtained from measurements of mass-angle distributions [1] (MAD), where the mass-split $MR=M_1/(M_1+M_2)$ is measured over as wide an angular range as achievable.

An extensive program of MAD measurements is being pursued at the Australian National University (ANU). Target nuclei have ranged from ^{144}Sm to ^{249}Cf, and projectile nuclei from ^{9}Be to ^{64}Ni. Measurements were made using the CUBE MWPC detectors, the Heavy Ion Accelerator Facility at the ANU, and radioactive actinide targets made through a collaboration with the University of Mainz and GSI. The combination of the 15MV tandem accelerator and the superconducting linear accelerator has allowed above-barrier measurements up to the reaction ^{64}Ni+^{249}Cf. In recent measurements, almost complete MAD have been measured, with MR covering the range 0.1 to 0.9, and an angular coverage from 20^{o} to 160^{o}.

At beam energies well above-barrier (~10%), it has been shown [2] that reaction outcomes have a smooth dependence on macroscopic parameters, namely the entrance channel and compound nucleus fissility. At near-barrier energies, there is a strong dependence on nuclear structure, both spherical closed shells [3] and static deformation [4,5] playing a significant role.

Recent insights [6,7,8] into the dependence of reaction dynamics and timescales on the nuclear structure of the colliding nuclei will be discussed.

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ORIENTATIONAL EFFECTS IN LOW-ENERGY COLLISIONS OF HEAVY STATICALLY DEFORMED NUCLEI

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A multinucleon transfer processes is occurred in quasifission and deep inelastic (damped) collisions of heavy ions. This particular feature makes the low-energy collisions of heavy ions to be a promising method of production of heavy neutron-enriched nuclei hardly achievable by other methods (fusion, fragmentation).
Dynamical models based on Langevin equations give a rather complete description of the main features of the collisions of heavy ions [1,2]. In our previous work [2] some of promising combinations of colliding heavy nuclei having spherical shapes were investigated within a multidimensional dynamical model based on Langevin equations.

In the present work collision dynamics of heavy nuclei deformed at their ground states is analyzed within the developed model. The orientation effects were investigated on the ^{160}Gd + ^{186}W, ^{154}Sm + ^{154}Sm, ^{238}U + ^{238}U/^{248}Cm reactions.

Initial mutual orientations of colliding nuclei influence the distributions of reaction products at near-barrier energies. Particularly, the orientation effects should be taken into account when such combinations are used for production of new heavy nuclei in multinucleon transfer reactions.

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STUDY OF MULTI-NUCLEON TRANSFER REACTIONS IN COLLISIONS OF ^{197}Au + ^{197}Au SYSTEM AT ENERGY OF 23 AMeV

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Multi-nucleon transfer reactions have been studied in collisions of the ^{197}Au + ^{197}Au system at an energy of 23 AMeV. The experiment was performed at the INFN Laboratori Nazionali del Sud (LNS) in Catania. For detection and identification of the reaction products the Charged Heavy Ion Mass and Energy Resolving Array (CHIMERA) was used. The unique construction of the detecting system, which is made up of 1192 ΔE-E telescopes arranged in 4π geometry, allowed a detailed study of kinematic and angular correlations between all reaction products.

Analysis is concentrated on a class of kinematically complete events in which one observes two, three or four heavy fragments with a total mass close to the mass of the colliding system. It will be demonstrated that the formation of multiple massive fragments in the exit channel can proceed in both sequential and simultaneous processes. Sequential divisions proceed in two stages. In the first stage, a large portion of the kinetic energy is dissipated and an excited projectile-like fragment (PLF) and excited target-like fragment (TLF) are formed as result of the exchange of many nucleons between the target and the projectile. In the second stage of the reaction, either the PLF or TLF or both fragments undergo further divisions. In the case of simultaneous breakup of the interacting system into more than two heavy fragments one observes a process that shows the characteristics of prompt emission of "intermediate mass fragments"' from the projectile-target interaction zone (neck). The mass numbers of fragments emitted from the neck side cover a much wider range than in typical neck-fragmentation reactions at intermediate energies, indicating that the decaying system evidently keeps a memory of the neck configuration even when the PLF and TLF are no longer in close proximity.

Data will be interpreted in terms of a dynamical model of deep inelastic collisions. Special attention will be given to analysis of multi-nucleon transfers between projectile and target nuclei as a function of impact parameter and kinetic energy dissipation. The impact of nucleon exchange on observed reaction mechanisms will be also presented. Possible use of multi-nucleon transfer reactions in ^{197}Au+^{197}Au collisions to study yet unexplored heavy neutron rich nuclei of Z<82 located along the closed neutron shell N=126 will be discussed.

DECAY SPECTROSCOPY IN THE RUTHERFORDIUM REGION (Z=104) AT SHIP

S. Antalic, Comenius University in Bratislava, 84248 Bratislava, Slovakia

S. Antalic[1], F.P. Heßberger [2,3], B. Andel[1], D. Ackermann[2], M. Block [2,3,4], S. Heinz[2], S. Hofmann[2], Z. Kalaninová[1],†, B. Kindler[2], J. Khuyagbaatar [2,3], M. Laatiaoui[4], B. Lommel[2], A. K. Mistry [2,3], P. Mošať[1], J. Piot[5], and M. Vostinar[5],*

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The knowledge of the single-particle level structure is essential for the estimation of decay properties for the heaviest nuclei and explanation of their isomeric states. There are several theoretical models predicting low-lying single-particle states for isotopes above fermium (Z > 100) (see for example [1 - 3]). However, experimental data remains rather limited in this region and every experimental result serves as an important test of theoretical predictions. The application of sensitive α, γ and conversion electron (CE) spectroscopy methods allowed the investigation of the structure for heaviest nuclei (A > 250) in the recent years.

We performed an extensive program aimed at nuclear structure studies of isotopes of trans-fermium elements using α-CE, α-γ and CE-γ spectroscopy at the velocity filter SHIP at GSI Darmstadt. In these studies we obtained enhanced data of the nuclear structure for several isotopes with Z > 100. These results helped to extend and improve the single particle level systematics for N = 149, 151 and 153 isotones. Besides the study via α decay we performed also first β-decay studies.

This series of experiments at SHIP provided a substantial body of new data. The most recent results for selected isotopes in the rutherfordium region (Z = 104) will be presented and discussed within different theoretical frameworks. In particular the new isomeric states observed in 259Sg and 255Rf [4, 5] will be discussed. Additionally, first preliminary data for the EC decay of 254Md will be presented, and opened problems related to decay systematics of odd-Z isotopes will be discussed, too.

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β-DELAYED FISSION OF ^{188m1,m2}Bi INVESTIGATED WITH LASER-IONIZED ISOMERIC BEAMS

Boris Andel, Comenius University in Bratislava, Bratislava, Slovakia

On behalf of WM-RILIS-IDS-York-Bratislava-Leuven collaboration

Beta-delayed fission (βDF) allows us to study the fission of isotopes, which do not fission from the ground state and for which induced fission would be extremely difficult or impossible to study with current experimental facilities. It makes possible to extend fission studies to very exotic isotopes. The process of βDF consists of two steps. Mother nucleus first undergoes β decay to excited state in the daughter nucleus with the energy comparable to or higher than the fission barrier and then the daughter isotope fissions. Since the excitation energy may reach only up to several MeV, βDF belongs to so called "low-energy" fission, which is still sensitive to microscopic effects and thus to underlying structure of the nucleus. Investigations of this process already established a new region (and a new type) of asymmetric fission [1,2] and revealed fission properties of many exotic isotopes [2].

Previously, βDF of ^{188}Bi was studied in JINR Dubna [3] and at SHIP (GSI Darmstadt) [4], but without a possibility to assign the fission to specific isomer in ^{188}Bi or to deduce the total kinetic energy (TKE). In this contribution, we report on the recent βDF investigations of ^{188}Bi performed at the ISOLDE facility (CERN). As there are two isomers in this isotope, we employed combined selective power of laser ionization (RILIS) and precise mass separation (ISOLDE separators). In one part of our measurement, we used high resolution mode of RILIS to obtain pure isomeric beams of the two isomers and thus to evaluate partial half-lives of βDF for each of them separately. During the rest of the experiment, combined ionization of both isomers was used to increase collected statistics of fission events. Preliminary results of these investigations will be presented, including partial half-lives of βDF for each isomer, TKE and mass distributions for longer-lived isomer.

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FROM DINUCLEAR SYSTEMS TO CLOSE BINARY STARS: APPLICATION TO MASS TRANSFER

G.G. Adamian, Joint Institute for Nuclear Research, 141980 Dubna, Russia

Applying the microscopic nuclear physics ideas to macroscopic stellar systems, we study the evolution of the compact di-stars in mass asymmetry (transfer) coordinate. Depending on the internal structure of constituent stars, the initial mass asymmetry, total mass, and orbital angular momentum, the close di-star system can either exist in symmetric configuration or fuse into mono-star. The limitations for the formation of stable symmetric binary stars are analyzed.

BASIC NUCLEAR STRUCTURE FEATURES OF SHN AND PERSPECTIVES AT S3

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INVITED

The synthesis of new elements has reached up to Z = 118 with IUPAC recently assigning the naming rights for the elements 113, 115, 117 and 118 to groups at the FLNR and at RIKEN [1–4]. Nuclei beyond fermium-rutherfordium owe their existence solely to quantum mechanics effects what makes them an ideal laboratory to study the strong nuclear interaction by in-beam methods as well as decay spectroscopy after separation [5].

While in-beam spectroscopy gives access to nuclear structure at higher spins like e.g. rotational bands [6], decay spectroscopy after separation (DSAS) of these deformed nuclei in the region Z=100-112 and N=152-162 provides direct links to the next heavier spherical closed shell nuclei, by investigating single particle levels [7]. Particularly interesting features are meta-stable states due to nuclear deformation, so-called K isomers, can be used to trace the spherical superheavy nuclei (SHN) and to locate the island of stability [8]. In the region of fermium isotopes and beyond, cases have been discovered mainly for isotopes of all even-Z elements up to darmstadtium (Z=110) apart from seaborgium (Z=106), but also for some even-odd and odd nuclei.

High intensity accelerators, efficient in-flight separators and spectrometers, and highly efficient detectors with fast electronics are the essential ingredients for the success of the field. The new SPIRAL2 facility and, in particular, the separator-spectrometer setup S^3 [9] presently under construction at the accelerator laboratory GANIL in Caen, France, will offer great perspectives for the field [8]. At this facility a number of ground braking experiments are envisaged, including DSAS examining features like the single particle structure, deformation and the search for K-isomers for those exotic nuclear species. An overview of the recent achievements and future perspectives for the field of SHN research will be given.

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SEMINAR

HINDERED α DECAYS OF HEAVIEST HIGH-K ISOMERS

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In this talk I will present the results of our search for candidates for long-lived high-K isomers in even-even Z=106-112 superheavy nuclei. We study alpha-decay, which is a main decay channel in the region of considered nuclei, of two- and four-quasi-particle configurations at a low excitation. Our analysis is performed within the microscopic-macroscopic approach, based on the deformed Woods-Saxon single-particle potential and the Yukawa-plus-exponential macroscopic energy. Configurations are fixed by a standard blocking procedure and their energy found by a subsequent minimization over deformations. Different excitation energies of a high-K configuration in parent and daughter nucleus seem particularly important for a hindrance of the alpha-decay. A strong hindrance is found for some four-quasi-particle states, particularly $K^{\pi} = 20^{+}$ and/or 19^{+} states in $^{264-270}$Ds.

Friday 12:00

SYNTHESIS OF SUPER-HEAVY-ELEMENTS AND FUSION HINDRANCE

David Boilley, GANIL and Normandie Université, Caen, France

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Describing the complete reaction leading to the synthesis of super-heavy elements is still a challenge. One of the reasons is the so-called fusion hindrance phenomenon that is well understood qualitatively but not quantitatively. There are large discrepancies spanning few orders of magnitude in the predictions of various models. Some differences come from the parameters and some from the models.

Parameters can be assessed and constrained by an uncertainty analysis. With the current state of the art models, we will show that it is not possible to do predictions with accuracy better than one order of magnitude.

Moreover, no consensus has been reached yet regarding the models calculating the formation probability from the contact point of the two colliding nuclei to the compound shape that is responsible of the fusion hindrance. In this presentation, we shall show a new mechanism contributing to the fusion hindrance.

POPULATION OF ISOMERIC STATES IN FUSION AND TRANSFER REACTIONS IN BEAMS OF RADIOACTIVE AND LOOSELY BOUND NUCLEI

Nikolay Skobelev, Joint Institute for Nuclear Research, Dubna, Russia

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In recent years, mechanisms of fusion and transfer reactions at low energies have been of growing interest due to problems in synthesis of superheavy transuranic elements and other nuclei near the border of the nuclear stability. The purpose of this report is to obtain, analyze, and summarize experimental data on cross sections of such reaction channels using beams of radioactive nuclei with halo structure and loosely bound cluster and stable light nuclei. Their interrelation with excitation of collective and single-particle states in nuclei formed as reaction products is also to be investigated.

The influence of the mechanisms of nuclear reactions on the population of ^{44m}Sc (6+), ^{196m}Au and ^{198m}Au (12−), ^{195m}Hg and ^{197m}Hg (13/2+), and ^{198m}Tl and ^{196m}Tl (7+) isomeric nuclear states obtained in reactions induced by beams of weakly bound ^{3}He, ^{6}Li and radioactive ^{6}He nuclei is studied.

The analysis of the results and their comparison with data obtained earlier leads to the following conclusions. The behavior of excitation functions and high values of isomeric ratios (σ_m/σ_g) for products of nuclear reactions proceeding through a compound nucleus and involving neutron evaporation are explained within statistical models. One should also take into account structural features of nuclei (^{6}He and ^{6}Li etc) and coupling with other reaction channels. Reactions in which the emission of charged particles occurs have various isomeric ratios depending on the reaction type. The isomeric ratio is lower in direct transfer reactions involving cluster capture than in reactions where the fusion evaporation of charged particles occurs. In the case of charge-exchange reactions in beams of loosely bound nuclei, the isomeric ratios change only slightly.

Neutron transfer is observed with high probability in interactions between all weakly bound nuclei and light and heavy stable target nuclei, when the reaction Q-value being positive. Cross sections of reaction channels and their isomeric ratios differ drastically for stripping and pickup nucleon reaction channels owning to difference in population of excited collective and single-particle states.

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ON PROPERIES OF EVEN-EVEN SUPER-HEAVY NUCLEI

Krzysztof Pomorski, Department of Theoretical Physics, MCS University, Lublin, Poland

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SEMINAR

Friday 12:45

The potential-energy surfaces of superheavy even-even nuclei with are evaluated using the Fourier shape parametrization [1]. The calculations are performed in a four-dimensional deformation space, defined by nonaxiality, quadrupole, octupole, and hexadecapole degrees of freedom. Nuclear deformation energies are evaluated in the macroscopic-microscopic model using the Lublin-Strasbourg drop and a Yukawa-folded mean-field potential. The ground-state equilibrium shape and possible isomeric states) are studied in a wide isospin range ($40 \leq N-Z \leq 74$). The alpha Q-values and the decay half-lives, as well as fission-barrier heights, are estimated. Good agreement is found with experimental data wherever available. The population of different fission modes for these nuclei are also studied.

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ISOSPIN-SYMMETRY-BREAKING CORRECTIONS TO β-DECAY TRANSITIONS BETWEEN T=1/2 MIRROR NUCLEI

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2 Helsinki Institute of Physics, University of Helsinki, Finland

High-precision tests of the unitarity condition of the Cabbibo-Kobayashi-Maskawa quark-mixing matrix may provide an essential information about the primary building-blocks of nature. The accuracy of the test relies on the value of the dominant V_{ud} element. Its most precise determination comes from the studies of $0^+ \rightarrow 0^+$ superallowed Fermi beta decay [1,3]. An alternative source of information about the V_{ud} matrix element is offered by beta-decay transitions between T=1/2 mirror nuclei [2]. Both the methods depend on many-body corrections related to isospin-symmetry-breaking (ISB) effect in atomic nuclei. The ISB corrections can be evaluated within Density Functional Theory (DFT) that naturally accounts for long-range polarization effects due to the Coulomb interaction [3,4].

Recently, we have developed the extended single-reference DFT formalism capable of reproducing the experimental data on Mirror (MDE) and Triplet (TDE) Displacement Energies in isospin doublets and triplets globally, irrespectively on A [5]. The extended energy density functional (EDF) involves the isoscalar Skyrme interaction, Coulomb interaction and the leading-order isovector and isotensor zero-range interactions.

In this work we shall present the first applications of the extended EDF within the angular-momentum and isospin-projected multi-reference DFT and the so-called DFT-rooted No-Core Configuration-Interaction model [6]. We shall focus on the calculation of ISB corrections to the beta-decay transitions between T=1/2 mirror nuclei. In particular, We shall discuss the influence of the isovector short-range force on the isospin mixing and the ISB corrections and address the necessity to involve configuration mixing. The results will be compared to shell-model calculations.

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EVOLUTION OF TRIAXIAL SHAPES ALONG THE Z = 120 ISOTOPIC CHAIN

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Using the constrained Hartree-Fock-Bogoliubov framework based on the Skyrme SkM* energy density functional (for details see Ref. [1]), we examine evolution of ground-state shapes and effects of triaxiality on heights of inner and outer fission barriers in the even-even isotopes $Z = 120$ with number of neutrons $N = 160$ - 196.

Our results show, that the isotopes with number of neutrons from $N = 160$ to 166 are super-oblate-deformed nuclei with the axial minimum at $Q_{20} \simeq -50$ b. The isotopes with $N = 168$ to 178 form the group of gamma-soft nuclei with two axial minima, the ground state minimum in the region of $Q_{20} \simeq -25$ b and the second one in the region of $Q_{20} \simeq +25$ b. The barrier between these minima disappears for isotope $Z = 120$ with $N = 180$ neutrons. This flat-bottom spherical potential allows the mixture of oblate, spherical, and prolate shapes at the ground-state, and can be viewed as the E(5) critical point solution in the interacting boson approximation [2,3]. The $Z = 120$ isotopes with $N = 182$ to 190 are spherical, however, the ground-state axial quadrupole moment becomes again non-zero for $N > 190$ and reaches value of $Q_{20} \simeq -65$ b at $N = 196$.

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SEMINAR

EFFECTIVE BASIS TRUNCATION IN THE SYMMETRY-ADAPTED NO-CORE SHELL MODEL

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We apply, for the first time, the importance-truncation (IT) procedure based on the many-body perturbation theory [1] for the multi-shell SU(3) scheme basis of the *ab initio* symmetry-adapted no-core shell model (SA-NCSM) [2]. It will be shown that the IT method can yield a quantitative justification for the symmetry based truncation of the SA-NCSM approach. Furthermore, we will demonstrate that the IT algorithm can be applied in a symmetry-truncated model space and it leads to even more dramatic reduction in dimensionality of the nuclear eigenvalue problem. Fast convergence of energies, B(E2) values and radii in ^{6}Li and ^{20}Ne calculated with realistic JISP16 potential shows potential of combined IT and symmetry-based basis truncation approach in the no-core shell model.

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Friday 16:00

STRUCTURE OF CONTINUUM STATES OF THE A=5 MIRROR NUCLEI IN THE COMPLEX SCALING METHOD

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A virtual state plays an important role in reaction cross sections just above the breakup threshold energy [1, 2]. However, the virtual state in the complex scaling method (CSM) [3, 4] cannot be directly solved as an isolated pole solution since the scaling angle in the CSM does not cover the position of the virtual state pole on the negative imaginary axis of the complex momentum plane. Therefore, it has been desired to find a new approach for the CSM to describe the virtual state.

In 2015, we studied the $1/2^+$ state of ^{9}Be and the photodisintegration cross section applying the CSM to the α+α+n three-cluster model [1]. The results indicate that there is no sharp resonant state corresponding to the distinct peak observed just above the ^{8}Be+n threshold in the photodisintegration cross section of ^{9}Be. We concluded that the first excited $1/2^+$ state in ^{9}Be is a ^{8}Be+n virtual state but not resonant one. Recently, we proposed a useful approach to find the pole position of the virtual state using the continuum level density, the scattering phase shift and scattering length calculated in the CSM [5, 6].

In addition, we investigated the structure of higher excited states of ^{9}Be by using the $\alpha+\alpha+n$ three-body model and the CSM [2] and we find that the dipole strength is dominated by the transitions into the non-resonant continuum states of $3/2^+$ and $5/2^+$. To understand the origin of the dipole strength, the decomposed photodisintegration cross section into each nonresonant continuum state is calculated by the use of the energy eigenvalue distribution in the CSM. From the decomposed cross section, it is shown that the strength mainly comes from the transitions into the nonresonant continuum states. Above mentioned facts indicate that investigation of continuum states are important for structure of light nuclei.

In this report, we present our recent results of the mirror nuclei ^{5}He and ^{5}Li obtained by analyzing structure of continuum states in the complex scaled $\alpha+N$ two-body model. Decomposed scattering phase shifts and continuum level density of $\alpha+N$ system are discussed.

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GAMOW-TELLER EXCITATIONS IN OPEN-SHELL NUCLEI AT FINITE TEMPERATURES

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Spin-isospin excitations are known as fundamental modes of excitation in nuclei that gained considerable attention with the advances in experimental facilities and progress in theoretical models [1-4]. The detailed knowledge about their structure is important, not only for nuclear physics but also for the nuclear astrophysics [1, 2]. Especially, in the calculation of nuclear weak interaction processes (beta decay, electron capture, neutrino-nucleus scattering etc.), accurate knowledge on the spin-isospin excitations is necessary. The proton-neutron quasiparticle random phase approximation (PNQRPA) based on the relativistic energy density functionals provides a consistent and reliable approach for the description of the spin-isospin excitations over the nuclide map [3-5].

On the other hand, it is known that the nuclear weak interaction processes in stellar environments mainly take place at finite temperatures ranging from several hundreds of keV to MeV. Recently, the effect of the temperature on the electron capture cross sections and rates was studied with the finite temperature proton-neutron random phase approximation, using the relativistic [4] and non-relativistic functionals [6]. However, the calculations were limited because the pairing correlations were not taken into account. Therefore, for a complete understanding of the nuclear weak interaction processes at finite temperatures, it is necessary to extend the current theoretical models to include both the temperature and pairing effects in the calculations of the spin-isospin excitations for open-shell nuclei.

In this work, we established the finite temperature proton-neutron QRPA based on the relativistic nuclear energy density functional with density dependent meson-nucleon couplings, and pairing correlations are taken into account in the BCS scheme. Within this framework, we have performed calculations for the Gamow-Teller excitations in open-shell nuclei using the DD-ME2 functional. The effect of the temperature on the strength functions and excitation energies of the Gamow-Teller excitations is investigated for the selected open-shell nuclei. In addition, the interplay between the temperature and pairing effects is discussed at low temperatures, where both effects are relevant.

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EVOLUTION OF NUCLEAR SHAPES AND STRUCTURE IN TELLURIUM, XENON, BARIUM AND CERIUM ISOTOPES

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The mass region above the doubly closed ^{132}Sn towards the neutron drip-line represents a challenging subject for both experimental and theoretical nuclear structure research. New experimental radioactive beam facilities at ORNL, RIKEN or GANIL together with highly efficient arrays of HPGe detectors at neutron beam facilities (EXILL campaign at ILL) made this region accessible for spectroscopic studies [1-3]. Chains of Te, Xe, Ba and Ce isotopes beyond $N = 82$ are of particular interest because they provide a natural laboratory to study shape and structural changes with gradually increasing number of nucleons outside doubly closed shells.

From the theoretical point of view the evolution of nuclear shapes and structural changes can be studied within algebraic models (IBM, algebraic collective model [4]) or in a more fundamental microscopic approach (mean field or shell model [5]). In the contribution we present microscopic calculations based on the axial Skyrme-Hartree-Fock model [6]. We test 18 different Skyrme functional parameterizations [7] and investigate potential energy curves obtained from constrained (β_2, β_3 and β_4) calculations for Te, Xe, Ba and Ce isotopes for $N > 82$. For the parameterization, which best fits the experimental binding energy, Skyrme QRPA calculations [8] are performed and positions of the lowest quadrupole and octupole vibrational states calculated. For deformed nuclei positions of the lowest 2^+ rotational states are obtained from the spurious rotation correction in Skyrme QRPA [9]. The results are compared to existing experimental data.

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PARTIAL DYNAMICAL SYMMETRY AND THE PHONON STRUCTURE OF CADMIUM ISOTOPES

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The Cd isotopes have been traditionally considered to be a prime example of spherical vibrators. Recently, advanced experimental studies have reported significant deviations from this behavior in selected two- and three-phonon states, along the Cd chain (A=108-126) [1-3]. Attempts to explain these deviations in terms of strong mixing between the normal spherical [U(5)-like] states and coexisting intruder deformed [O(6)-like] states, have been shown to be unsatisfactory. These observations have led to claims for the ``breakdown of the vibrational motion" in these isotopes and the need for a paradigm shift [1,2]. In the present contribution, we examine an alternative explanation for the structure of the Cd isotopes, in terms of U(5) partial dynamical symmetry (PDS) [4].

PDS corresponds to a situation for which the properties of a dynamical symmetry, i.e., complete solvability and good quantum numbers, are fulfilled by only a subset of states. Such intermediate symmetries are known to be relevant to various aspects of nuclear spectroscopy, including band-structure and shape-coexistence [4-8]. In the present contribution, we present an Hamiltonian with U(5)-PDS, in the framework of the interacting boson model of nuclei (IBM). The Hamiltonian retains good U(5) symmetry for a segment of the spectrum and gives rise to strong mixing for other states. In this manner, most of the normal states maintain the vibrational character, and only specific non-yrast states exhibit a departure from this behavior, in line with the empirical data.

The PDS-based mixing mechanism is induced by particular cubic terms in the Hamiltonian, which act only in the sector of particular non-yrast normal states. The small effect of the coexisting intruder states is taken care of within the IBM with configuration mixing.

This work was done in collaboration with J.E. Garcia-Ramos (Huelva) and P. Van Isacker (GANIL) and is supported by the Israel Science Foundation.

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SELF-CONSISTENT COLLECTIVE PATH AND TWO-BODY DISSIPATION EFFECT IN NUCLEAR FUSION REACTIONS

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I will present results of numerical simulations of nuclear fusion at low energies. Our studies are from theoretical perspective and based on two different methodologies.

First, I will talk about an adiabatic method to study large amplitude collective motion, this method provides the collective reaction path for the fusion process at sub-barrier energies [1, 2]. We focus on the reactions of N = Z stable nuclei, α + α, α + ^{16}O and ^{16}O + ^{16}O. The reaction paths turn out to deviate from those obtained with standard mean-field calculations with constraints on quadrupole and octupole moments.

Then, I will discuss time-dependent simulation based on the time-dependent density matrix (TDDM) model [3], which goes beyond the standard mean-field approximation and takes into account the effect of two-body correlations, this study aims at providing a more realistic description for the dissipation process in nuclear fusion/ fission reactions.

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A FAST IONIZATION CHAMBER FOR THE STUDY OF FUSION REACTIONS INDUCED BY LOW-INTENSITY RADIOACTIVE BEAMS

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Heavy-ion fusion at near-barrier energies is a complex phenomenon which study involves significant experimental and theoretical efforts. The availability of radioactive beams has opened new possibilities to investigate these reactions, despite the low intensity of the beams available so far.

The availability of the very neutron-rich beams of the SPES facility [1] at relatively low intensities is very tempting to extend the study of near- and sub-barrier fusion to exotic systems. However, the use of RIBs is often very challenging because of the low available intensities and the forward focusing of the fusion evaporation residues (ER). Thus, applications of radioactive beams require detection systems with very high efficiency and detectors that avoid unnecessary energy straggling and angular dispersion and assure fast response.

A new set-up for fusion cross section measurements, especially designed for the low intensity beams which will be delivered by the SPES facility, has been developed and installed and it is presently in use at the National Laboratories of Legnaro (LNL), in its initial operation phase. The set-up is inspired on a similar one built at Oak Ridge [2] some years ago, with a significant improvement due to the use of a very fast ionization chamber (IC). This new fast IC is designed to ensure a high counting rate particle identification for fusion studies involving exotic beams up to 10^5 pps. Indeed, the IC will be placed at 0° with respect to the beam direction without filtering out the beam ions in any way. To reduce the response time of the ionization chamber, a design using a series of tilted electrodes has been adopted [3]. The aim is to be able to detect and identify fusion events within a total counting rate up to 100-200 kHz.

The set-up already existing at LNL for fusion measurements (based on the electrostatic beam deflector) has been upgraded by using the new IC, and will remain in use for experiments with high-intensity stable (and upcoming exotic) beams. Several tests with stable beams have been performed to optimize the performance of the IC. The fundamental concepts and receipt how to build a IC with fast response will be presented, the results of the in-beam tests performed so far will be showed in this contribution.

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DEDICATED ΔE-E DETECTOR SYSTEM FOR SEARCHING LONG LIVED HEAVIEST NUCLEI IN IRRADIATED SCINTILLATORS

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We present a dedicated experimental set-up that has been built and is used to search for long lived super heavy elements deposited in an active catcher material. The reaction products between ^{197}Au (7.5 A.MeV) and ^{232}Th heavy nuclei have been deposited in a thin scintillator during our experiment conducted in 2015 at the Cyclotron Institute, Texas A & M [1]. The built-in innovative measuring set consists of ΔE-E detectors arranged in a special configuration. The purpose of the detectors is the registration and identification a/spontaneous fission decays of SHEs. Their unique feature is that the examined scintillators are at the same time ΔE part of each of ΔE-E detector. The other part, E part, is silicon detector. Another important feature of our detector lies in the fact that with respect to the external sources of radiation such as natural sources from surroundings materials, as well as cosmic rays, the detection set-up works in the reverse mode i.e. E-ΔE. This largely eliminates background events in the region where alpha particles emitted by decaying SHE are expected. Our measurements should be sensitive to search for super heavy elements which are possibly deposited in irradiated scintillators and which have life-time of a year till tens of years. Although we will focus on the commissioning tests of the detector also some preliminary results of the continuous measurement that already lasts 6 months will be presented. Some characteristics of interesting events, selected during measurements will be shown and discussed.

This work is supported by the National Science Center in Poland, contract no. UMO-2012/04/A/ST2/00082, by the U.S. Department of Energy under Grant No. DE-FG03-93ER40773 and by the Robert A. Welch Foundation under Grant A0330.

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THE NEW NEUTRON MULTIPLICITY FILTER NEDA AND ITS FIRST PHYSICAL CAMPAIGN WITH AGATA

Grzegorz Jaworski, LNL INFN, Legnaro, Italy

On behalf of the NEDA collaboration

Contemporary studies of nuclear structure concentrate in regions far from the valley of β stability. Experimentally those regions are accessible via, inter alia, fusion-evaporation reactions in which the nuclei of interest are produced by the emission of a few particles from the compound nucleus. The arrays of HPGe detectors, used for these studies, have to be complemented with ancillary devices, which make possible accurate identification of the reaction products, and thus of the reaction channel. In particular, when approaching very neutron-deficient nuclei the channels with neutron emission lead to the most exotic nuclear structures, which are produced with very small cross sections.

With the purpose of identifying neutron-evaporating reaction channels, large arrays of liquid scintillator detectors like the Neutron Wall [1, 2] and the Neutron Shell [3] were constructed in the past and successfully used in many experiments, aiming at the study of more and more neutron deficient nuclei, especially along and close to the N = Z line, up to the region of the doubly magic ^{100}Sn. The existing devices are rather well suited for the detection of single or maximum two neutrons, achieving efficiencies of ~20% and ~2% in symmetric fusion-evaporation reactions for clean detection of one and two neutrons, respectively. The efficient identification of events with neutron multiplicity two and larger is difficult, since it requires both large granularity of the array and excellent neutron-γ discrimination (NGD) capabilities.

Following years of R&D in the departments of both detectors and electronics, the new neutron multiplicity filter NEDA [4,5] has been currently built as an ancillary detector of the state- of-the-art γ spectrometers to address the above-described demand and make possible the nuclear structure investigations of not-achievable so far exotic neutron-deficient nuclei. The first implementation of NEDA, coupled together with 42 Neutron Wall detectors, is expected to present 30% and 4.5% for clean identification of one and two neutrons emission, respectively. Such a setup has been installed as the complementary detection system to the AGATA [6] spectrometer and runs the first physical campaign addressing the hot topics of the nuclear landscape: the nucleon-nucleon interactions, single particle energies and the core excitations, isoscalar pairing, isospin symmetry and the shape coexistence, octupole and quadrupole correlations, or clusterization.

Within the contribution to the Zakopane Conference the milestones of 11 years of the NEDA project will be presented, the first implementation with AGATA and the highlights from its physical campaign will be shown, finally the future of the project and the fast neutron detection will be discussed.

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POLAREX, A FUTURE FACILITY FOR ON LINE NUCLEAR ORIENTATION

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Low temperature nuclear orientation (LTNO) allows to study polarized exotic nuclei. At very low temperature (~10mK) nuclei can experience a very high polarization in the hyperfine field which exists into a ferromagnetic metal host. The decay products can be observed using proton, alpha or beta-particle detectors fitted within the cryostat and/or external gamma or neutron detectors, providing a very versatile instrument.

Oriented nuclei give access to a wide range of experiments. These include a precise measurement of nuclear moments using the NMR technique and the observation of beta-decay to, and gamma emission from, excited states in the daughter nucleus to study aspects of nuclear structure. As a special feature of LTNO, far-reaching studies of fundamental weak interactions and associated symmetries can be made as well as investigations of parity non conservation.

PolarEx (Polarization of Exotic nuclei) is a facility dedicated to this kind of study through the decay of polarized nuclei that will run on-line at the ALTO facility at Orsay, France. This experimental setup is also designed to give a large access for the detection system: up to eight germanium detectors can be fitted in the plan perpendicular to the orientation axis to study the spatial asymmetry of the gamma radiation.

At PolarEx, long lived nuclei can be studied OFF-line while the direct implantation of the nuclei produced at ALTO into PolarEx will open a wide range of ON-line experiments with exotic nuclei (with typical lifetimes as short as 1 second). In particular, a precise measurement of nuclear moments can be made using the NMR technics. Also, one can reach the level spins in the daughter nucleus, the aspects of nuclear structure based on gamma multi-polarity and the parity non-conservation in nuclear decay. As a special feature of PolarEx, far-reaching studies of fundamental weak interactions and associated symmetries can be done.

In this contribution will be presented the status of Polarex and the on going off-line studies, in particular the new measurements of the multipole mixing ratios in 56Fe.

SEMINAR

COLLINEAR RESONANCE IONISATION SPECTROSCOPY (CRIS) STUDIES OF NEUTRON-RICH INDIUM ISOTOPES

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With a proton hole in the Z = 50 shell closure, the indium isotopic chain (Z = 49) provides a compelling environment to explore the evolution of nuclear-structure properties in the vicinity of the doubly-magic isotopes ^{100}Sn (Z, N = 55) and ^{132}Sn (N = 82). This contribution will focus on recent measurements of neutron-rich indium isotopes, $^{113\text{-}131}$In, at the Collinear Resonance Ionization Spectroscopy (CRIS) experiment, CERN. The CRIS technique combines the high resolution attained using collinear laser spectroscopy with the sensitivity provided by resonance ionization spectroscopy. From the measured hyperfine spectra, the spins, electromagnetic moments, and changes in root-mean-squared charge radii of several ground and isomeric states have been determined for the first time, extending our experimental knowledge up to N = 82.

The recently installed ablation ion-source at the CRIS experiment has enabled rigorous assessment of ionisation schemes used during radioactive beam experiments. Development of this ion-source and results from two stable beam indium experiments will also be discussed.

Friday 16:30

NUCLEAR CHARGE RADII AND MOMENTS THROUGH COLLINEAR LASER SPECTROSCOPY AT ARGONNE NATIONAL LABORATORY

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Collinear Laser Spectroscopy (CLS) is a well-established technique that allows studying nuclear properties of short lived isotopes through measurements of the atomic hyperfine structure. Differences of mean-squared nuclear charge radii along an isotopic chain, nuclear spins, magnetic dipole and electric quadrupole moments can be extracted with high precision and in a nuclear-model independent way [1]. Collinear Laser Spectroscopy is already successfully being utilized at COLLAPS (Geneva), BECOLA (Lansing), IGISOL (Jyväskylä) and TRIUMF (Vancouver). To extend the capabilities of this technique, we are commissioning a CLS beamline at Argonne National Laboratory (ANL) in Chicago. The ATLAS accelerator at ANL provides the opportunity to investigate the charge radius of Boron-8 and thereby confirm its proton halo character. In addition, the new CARIBU Californium fission source opens up a vast area of interesting isotopes for collinear laser spectroscopy. This includes in particular neutron rich refractory metals that have not been studied so far.

In preparation of the Boron-8 experiment, offline laser spectroscopy measurements on atomic Boron-10 and -11 have been conducted in Darmstadt. To determine the difference in mean-squared nuclear charge radii between these isotopes an exact calculation of the atomic five electron system [2] has been used for the first time. We will present the results of these measurements as well as an overview and status of the experimental campaign at Argonne National Laboratory.

This work is supported by the U.S. DOE, Office of Science, Office of Nuclear Physics, under contract DE-AC02-06CH1135, and by the Deutsche Forschungsgemeinschaft through Grant SFB 1245.

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ANGULAR CORRELATION MEASUREMENTS WITH THE ITHEMBA LABS SEGMENTED CLOVER DETECTOR

Obed Shirinda, iThemba LABS, National Research Foundation, South Africa

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iThemba LABS has purchased a segmented clover detector, a detector that uses the latest achievements in the Ge detectors technology. Contrary to the standard Ge detectors the new detector is segmented on the outer contact, resulting in 8 segments per crystals, or 32 segments for the whole detector. The segments can be run as individual detectors, allowing considerably higher event rates to be handled successfully. In addition, utilising segments allows improved accuracy for all direction-sensitive measurements, such as Doppler correction, angular distributions and correlations, g-factor measurements based on recoil in vacuum technique, linear polarization, lifetime measurements based on Doppler effects, etc. The impact of this improvements increases dramatically with the increase of the opening angle of the detector, i.e. at small detector-to-target distances.

In close geometry the face of the detector covers a large opening angle, for instance at 4 cm from the radioactive target the detector subtends a solid angle of approximately 1/8 of 4π. Therefore, it covers the whole range of angles needed for precise angular correlation measurements. Such full coverage in addition to the excellent position sensitivity of the detector (due to its segmentation and its tracking ability) allows very precise spin and parity measurements to be carried out. It should be noted that measurements with such precision cannot be performed at present with the current much larger AFRODITE array. In particular, one would be able to measure (i) high-order multipolarities such as E3, M4, E4, M5, E5, etc, (ii) mixing ratios of M1+E2, M2+E3, etc, (iii) distinguish unstretched dipole from a stretched quadrupole transition, etc. Furthermore, due to the segmentation and the tracking capability, the detector will produce more precise linear polarization results too.

We collected data with several gamma-ray sources to evaluate the performance of the detector in close geometry for angular correlations measurements. A few targets were also irradiated with neutrons in the neutron therapy vault to test the activity that can be produced and the performance of the detector. The data are being analysed, but preliminary results look very promising. The results will be presented and discussed.

THERMAL AND RADIATION HARDNESS OF DIAMOND DETECTORS FOR NEUTRON MEASUREMENTS IN ITER

Jan Dankowski, IFJ PAN, Kraków, Poland

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Hot plasma diagnostics in the next generation large scale thermonuclear devices, such as the International Thermonuclear Experimental Reactor (ITER), requires new technologies and alternative materials. Extremely harsh conditions close to first wall of the reactor define the requirements on the new electronic devices and methods which must be developed for in-situ measurements. At IFJ PAN we have investigated the usability of Chemical Vapor Deposition (CVD) Diamond Detectors for spectrometric neutron measurements in fusion devices.

I will discuss the physical and functional properties of CVD Diamond Detectors relevant for neutron diagnostics measurements such as the energy and time resolution, sensitivity and efficiency to different neutron energies. Next, I will present the results our recent experimental studies of the spectrometric response of diamond detectors to neutrons in the ITER neutron diagnostics regime. In a four months long experimental session at IFJ PAN which included two different ITER–RNC (ITER – Radial Neutron Camera) In–Port heating scenarios we have demonstrated that the spectrometric properties of diamond detectors are maintained and the required level of stable operation can be assured. Collected experimental data confirm the usability of Diamond Detector for ITER diagnostics. At the same time it indicates some key parameters significantly affecting the properties of the detectors which were not considered before.

GALACTIC DARK MATTER SEARCH WITH SABRE, A DUAL-SITE DETECTOR USING ULTRA-PURE NaI(Tl) SCINTILLATOR

Greg Lane, Australian National University, Canberra, Australia

For the SABRE collaboration

The direct detection of dark matter is a key problem in astroparticle physics that generally requires the use of deep-underground laboratories for a low-background environment where the miniscule signals from dark matter interactions can be observed. A dark matter signal from Weakly Interacting Massive Particles (WIMPs) in an Earth-based detector, is expected to modulate yearly due to the change of the Earth's speed relative to the galactic halo reference frame. There is a long-standing result from the DAMA/LIBRA experiment at the Gran Sasso National Laboratory (LNGS) in Italy that used NaI(Tl) scintillator for the detector medium and is consistent with this scenario [1,2,3]. However, the magnitude of the signal is in tension with a number of other direct detection measurements that use different detector technologies [4].

SABRE (Sodium-iodide with Active Background REjection) is a new NaI(Tl) experiment [5] designed to search for galactic dark matter through the annual modulation signature. Arrays of NaI(Tl) detectors with unprecedented radio-purity will be operated inside volumes of active liquid scintillator to veto against both external and internal backgrounds, especially the 3 keV signature from the decay of trace amounts of ^{40}K within the crystals. SABRE will be a dual-site experiment located at both LNGS (Italy) and at the Stawell Underground Physics Laboratory under development in Victoria, Australia. The operation of twin full scale experiments in both the northern and southern hemispheres is an important factor that will strengthen the reliability of a dark matter detection result by discriminating against possible seasonal systematic effects.

SABRE relies on detector materials and measurement techniques from nuclear physics. This presentation will describe the SABRE experiment, plans for the new laboratory in Australia (anticipated to be the first deep underground laboratory operational in the southern hemisphere), and the results from nuclear physics experiments performed at the Australian National University with our 14UD tandem accelerator that support the SABRE detector development effort.

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NUCLEAR STRUCTURE STUDIES USING THE ROSPHERE ARRAY

Nicolae Marginean, "Horia Hulubei" National Institute for Physics and Nuclear Engineering, Bucharest-Magurele, Romania

During the last decade the Tandem Laboratory of IFIN-HH was continuously developed, reaching at present the technical and scientific level expected for the international facilities in the field of low energy nuclear physics. With the construction of ROSPHERE[1], a 4π array with 25 elements that is normally used in mixed configurations with HPGe and $LaBr_3$(Ce) gamma ray detectors, it became possible to exploit with both efficiency and flexibility the ion beams delivered by the 9 MV Tandem accelerator of IFIN-HH. The combined use of fast detectors and the plunger device gives very good sensitivity for lifetime measurements over many orders of magnitude. Consequently, the physics addressed mainly concerns detailed spectroscopy and lifetime measurements in nuclei not very far from stability line, providing complementarity with the nuclear structure studies at the large-scale facilities. The most prolific type of experiments done in the last years with ROSPHERE is the gamma ray spectroscopy in sub-barrier transfer reactions with ions like ^{13}C, ^{18}O or ^{11}B, which allows to observe very interesting aspects of nuclear structure like, for instance, the multiple shapes reflected in the excited 0+ states of ^{66}Ni[2].

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INVITED

Friday 19:30

INVITED

SHAPE COEXISTENCE AND SHAPE ISOMERISM IN THE Ni ISOTOPIC CHAIN

S. Leoni, University of Milan and INFN, Milano, Italy

For the collaboration:
S. Leoni[1] et al.,
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The very peculiar phenomenon of shape isomerism is an extreme manifestation of the coexistence of shapes in the atomic nucleus. Shape isomerism arises from the existence of a high barrier in the nuclear potential energy surface (PES), separating the primary energy minimum from a secondary minimum at large deformation.

In 2016, our collaboration has performed an experiment in Bucharest [1], which led to the identification of a shape-isomer like structure in the ^{66}Ni nucleus. This is the lightest, ever, atomic nucleus exhibiting a photon decay hindered - solely - by a nuclear shape change. Such a rare process, at spin zero, was clearly observed only in actinide nuclei in the 1970's [2]. In Bucharest, ^{66}Ni was populated employing a two-neutron transfer reaction induced by an ^{18}O beam on a ^{64}Ni target, at sub-Coulomb barrier energy. The study was inspired by various mean-field theoretical approaches [3-5] as well as by Monte Carlo Shell Model (MCSM) calculations [1], all pointing to ^{66}Ni as the best, lightest candidate for shape isomerism.

Encouraged by the results on ^{66}Ni, our collaboration has started a comprehensive gamma spectroscopy investigation of the nickel isotopes, focusing, in particular on ^{62}Ni, ^{64}Ni and ^{65}Ni, populated in experiments performed at IFIN-HH (Bucharest), ILL (Grenoble) and IPN Orsay. The aim is to shed light on the shape coexistence phenomenon and on the origin of deformation in neutron-rich Ni isotopes, possibly locating other examples of shape isomerism in this region. Preliminary results on ^{64}Ni and ^{65}Ni will be presented, focusing, in particular, on the population of the states of interest by different reaction mechanism. Comparison with MCSM predictions will be of key importance to interpret the data.

Perspectives in the search for shape isomerism in other mass regions will be also discussed, following very recent calculations [6,7] pointing to Pt, Hg and Pb nuclei (with N≈110) and Pd, Cd and Sn (with N≈66) as best candidates. Such systems could be investigated in transfer reactions with radioactive beams from HIE-ISOLDE and SPES.

Friday 20:00

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LIFETIME MEASUREMENTS OF EXCITED STATES IN NEUTRON-RICH C AND O ISOTOPES

Michał Ciemała, IFJ PAN, Kraków, Poland

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This contribution reports on an experiment performed in GANIL in July 2017 with the AGATA array coupled to PARIS and VAMOS. Aim of the measurement was the determination of the lifetimes of excited states in neutron rich C and O isotopes, in particular in ^{16}C and ^{20}O. For these nuclei, ab-initio calculations predict a strong sensitivity of selected electromagnetic transition probabilities to the details of the nucleon-nucleon interactions, especially to the three-body term. Strong sensitivity is expected, in particular, in the case of the lifetime of the second excited 2^+ state, in each nucleus of interest.

In the talk, the analysis of the data collected with the AGATA, VAMOS and PARIS detectors, for the reaction employing the ^{18}O beam (E_{beam} = 7.0 MeV/A) on a thick (6.7 mg/cm2) ^{181}Ta target, will be shown. The isotopic identification of the reaction products and their velocity vector reconstruction, using the VAMOS spectrometer data, will be presented and applied in the analysis of the AGATA and PARIS data. A novel technique for the determination of state lifetimes in the range of few hundreds femtoseconds, will be introduced: it is based on the analysis of line shape and line centroid shift angular dependence observed in AGATA Doppler corrected gamma-ray energy spectra, in comparison with simulation calculations. Preliminary results for the lifetime of second 2^+ states in ^{20}O will be given.

SEMINAR

SPECTROSCOPY OF NEUTRON-RICH C, O, N AND F ISOTOPES WITH THE AGATA+PARIS+VAMOS SETUP AT GANIL

S. Ziliani, University of Milan and INFN, Milano, Italy

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A unified description of the structure and dynamics of nuclei as many-body systems is a great challenge in nuclear physics, as our knowledge of the nuclear force is still incomplete. Ab initio calculations offer an interesting opportunity to make progress in this description: they predict strong sensitivity of selected electromagnetic transition probabilities and multipolarity to the details of the nucleon-nucleon interaction, especially to the three-body term.

Nuclei lying away of the stability valley, in particular nuclei with large excess of neutrons, are good probes of the nuclear force, as some features of the nucleus-nucleus interaction may be amplified here. There is, however, a shortage of the experimental data on these systems, concerning especially properties of excited states. For this reason, an experiment, aiming at the investigation of state lifetimes and gamma-transition angular distributions for nuclei located "south-east" of ^{18}O, was performed in GANIL in July 2017 with the AGATA and PARIS arrays coupled to VAMOS. To populate the nuclei of interest, we used the multinucleon transfer reaction of a ^{18}O beam (Ebeam = 7.0 MeV/A) on a thick (6.7 mg/cm2) ^{181}Ta target. Identification of the isotopes produced was performed with the VAMOS spectrometer.

The talk will discuss principally the AGATA data analysis, with particular emphasis on the replay process, the energy and time calibrations and the fine-tuning of the gamma-spectra, which are the most crucial aspects of the analysis of the experiment. A survey of preliminary results on nuclear state lifetimes and gamma-transitions angular distributions will be presented for some of the most intensely populated isotopes of O, C, N, F, … representing the starting point for future extended comparison with ab initio calculations.

Friday 20:50

IN FLIGHT AND β-DELAYED γ-SPECTROSCOPY IN THE VICINITY OF ^{78}Ni WITH AGATA AT GANIL AND BEDO AT ALTO

Clément Delafosse, Institut de Physique Nucléaire, Orsay, France

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While the N=50 shell-gap evolution towards ^{78}Ni is presently in the focus of nuclear structure research, experimental information on the neutron effective single particle energy (ESPE) sequence above the ^{78}Ni core remain scarce. Direct nucleon exchange reactions are indeed difficult with presently available post-accelerated radioactive ion beams (especially for high orbital momentum orbitals) in this exotic region. We have studied the evolution of the $\nu g_{7/2}$ ESPE which is the key to understanding the possible evolution of the spin-orbit splitting due to the action of the proton-neutron interaction terms in the ^{78}Ni region by measuring the lifetime of excited states in order to distinguish between collective and single-particle states. The evolution of the ESPE of this orbital, characterized by a high orbital momentum l=4, should indeed be particularly sensitive to tensor effects.

In the continuity of an experiment performed in LNL-Legnaro [1], we performed an experiment at GANIL (Caen, France) with AGATA [2], VAMOS [3] and the Orsay plunger OUPS [4] in order to measure lifetime of Yrast excited states (in peculiar $7/2_1^+$ states) in several N=51 isotones populated by the reaction ^{238}U(^{9}Be,f). We particularly focused our study on ^{83}Ge, the closest N=51 odd isotones to ^{79}Ni for which detailed spectroscopy studies are possible within our experimental conditions. We also performed complementary β-delayed γ spectroscopy of ^{83}Ge with BEDO [5] at the ALTO ISOL photo-fission facility in Orsay to investigate non-Yrast spectroscopy.

Results from both experiments will be presented and discussed.

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Saturday

September 1st

INVITED

EXOTIC ISOMERS EXPLORED AT THE NEW GENERATION IN-FLIGHT-SEPARATOR FACILITY RIBF

Hiroshi Watanabe, Beihang University, Beijing, China / RIKEN Nishina Center, Wako, Japan

Since the late 1980s, when dedicated radioactive isotope (RI) beam facilities started their operation, in-flight fragment separators have played an important role in producing new isotopes, particularly those on the neutron-rich side of the β-stability line [1]. The characteristic features of in-flight separators, i.e., physical separation, fast transportation, and unambiguous identification of fragments, are beneficial also to decay studies of short-lived rare isotopes with highly unbalanced ratios of protons to neutrons, or alternatively exotic nuclei, not only in the ground state but in metastable states (isomers) that are populated in the production process. Gamma rays following the decay of isomeric states with half-lives ranging from several tens of nanoseconds to several hundred microseconds can be observed in delayed coincidence with each individual stopped fragment that is identified in terms of atomic number (Z) and mass-to-charge ratio (A/Q) through the preceding in-flight separator. The detection of such delayed γ rays on an event-by-event basis allows for an unambiguous assignment of isomeric states to specific isotopes. Meanwhile, the identification of long-lived isomers in the millisecond range often relies on the detection of internal-conversion electrons that are emitted in the decay cascades from the isomers. It should be emphasized that for the study of rare isotopes, especially when the nucleus of interest lies at the boundaries of availability for spectroscopic studies, such isomeric-decay measurements are likely to be a powerful instrument to investigate excited levels under the condition of low backgrounds.

A new-generation in-flight-separator facility has come online for the first time at RIKEN Nishina Center in Japan, as the RI-Beam Factory (RIBF) [2], with the installation of the large-acceptance in-flight separator BigRIPS [3]. The advent of the RIBF-BigRIPS facility combined with a highly efficient detector system enables us to explore characteristic isomers in as-yet-unknown exotic nuclei. In this presentation, recent highlights of isomeric-decay spectroscopy carried out at RIBF as the EURICA (EUROBALL-RIKEN Cluster Array) project [4] will be introduced, with particular focus on neutron-rich nuclei in the vicinity of ^{78}Ni, ^{132}Sn, and ^{170}Dy [5].

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Saturday 08:30

ISOMER DEPLETION RESEARCH BY THE ARMY RESEARCH LABORATORY

James J. Carroll, US Army Research Laboratory

Energy storage in chemicals, whether fuels or batteries, forms the basis for the U. S. Army's many energy and power applications. However, these materials are restricted in both energy density and longevity, motivating interest in radioisotopes and nuclear isomers as a means of pushing beyond the "chemical limit". In particular, the potential for long-lived isomers to enable production, accumulation, and storage of energy-dense materials for extended periods is attractive. The ability to utilize isomeric materials for applications will likely depend on mechanisms by which to transfer population from such isomers to shorter-lived states upon demand. This presentation will survey basic research conducted by the Army Research Laboratory on isomer depletion processes, including the first demonstration of nuclear excitation by electron capture (NEEC).

BINDING ENERGY STUDIES AT THE EXTREME OF THE NUCLEAR LANDSCAPE WITH ISOLTRAP

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The modern approach unravelling the complex nuclear many body problem has been to track the evolution of nuclear properties in systems ever closer to the proton or neutron drip-line. Binding energies are among the first observables reaching in yet uncharted regions of the nuclear chart and their trends are sensitive to a wide range of nuclear-structure phenomena. As such, they additionally provide invaluable inputs to all nuclear models.

Over the last years the ISOLTRAP high-precision mass spectrometer [1-2], located at ISOLDE/CERN, was intensively used to probe the region around N=82 below the tin isotopic chain. More precisely, the impact of the N=82 shell closure in neutron-rich Cd isotopes near ^{130}Cd and its implications on the r-process nucleosynthesis has already been studied at ISOLTRAP [3]. Recent results from an extension of this campaign to Cd isotopes beyond N=82 will be presented. Additionally, several odd-even Cd isotopes below N=82 were shown to exhibit long-lived isomeric states [4]. Traditional Penning-trap mass spectrometry techniques already provided direct measurements of the excitation energies of ^{125m,127m}Cd [5] but the energy of the elusive ^{129m}Cd state has yet to be measured. The successfully commissioned phase-imaging ion-cyclotron-resonance technique [6] now completes ISOLTRAP's arsenal of high-resolving power and high-sensitivity mass spectrometry techniques by allowing for isomeric separation within a few hundred milliseconds. Thus, recent results from the application of this technique in ^{127}Cd and ^{129}Cd will be presented as well.

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TOWARDS ULTRA-COLD GASES OF CAESIUM ISOMERS: PROGRESS AND PERSPECTIVES

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University College London and IGISOL have recently commissioned a facility for the production, laser cooling, and trapping of ultra-cold Caesium isotopes and isomers at the Accelerator Laboratory of the University of Jyväskylä (Finland). In this talk, we will report on the design, installation, and test of the experimental facility, and on its latest results. The desired $^{A,Am}Cs$ species is produced by proton-induced fission or fusion-evaporation in the IGISOL-4 facility [1]. $^{A,Am}Cs^{+}$ are electrostatically extracted, accelerated to 30 keV, mass separated, and routed to the "cold" experimental chamber. Here, thin foil implantation allows creation of a stable thermal vapour of neutral $^{A,Am}Cs$ atoms, which are then laser cooled and trapped in a magneto-optical trap at $T \sim 10^{-4}$ K. At the current stage, $^{A,Am}Cs$ is brought from 10^{4} eV to 10^{-8} eV in around 5 s, at full capacity.

The availability of ultra-cold samples of unstable Cs isotopes and isomers opens new perspectives for a deeper insight into the nuclear structure and for the investigation of multi-body physics at the nuclear level. In particular, direct comparison of optical transitions shifts in ^{A}Cs/ ^{Am}Cs pairs provides novel data for investigating the charge radii variations and the nuclear shape. Furthermore, the possibility of selectively trapping and detecting small traces of given Cs isotopes constitutes the building block of a new, highly sensitive approach to nuclear forensics, with applications in environmental control and security. Finally, perspectives on the realisation of an isomeric Bose-Einstein condensate and of the long-awaited experimental demonstration of coherent gamma photons generation will be also presented [2].

ACKNOWLEDGMENTS

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ISOMER SPECTROSCOPY AND SUB-NANOSECOND LIFETIME DETERMINATION IN ^{178}W USING THE ν-BALL ARRAY

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The NuBall array at IPN Orsay is a hybrid HPGe-$LaBr_3$ coincident gamma-ray spectrometer comprising 24 Compton suppressed HPGe Clover detectors, 10 Compton suppressed coaxial HPGe detectors, and 20 $LaBr_3$(Ce) scintillator detectors supplied by the FATIMA collaboration. Compton suppression was achieved by BGO detectors surrounding the Ge crystals. The BGO detectors were not shielded towards the target position, giving the advantage of enhance calorimetry capabilities of the setup. In the first in-beam experiment with NuBall in November 2017, radioactive nuclei were produced by accelerating an ^{18}O ion beam on a ^{164}Dy target. The measurement was taken at three different beam energies, 71, 76, and 80 MeV, using a pulsed beam provided by the tandem accelerator of the ALTO facility. The beam packets were 2 ns long with 400 ns between pulses. The main reaction channel, apart from Coulomb excitation of the target, was the ^{164}Dy(^{18}O,4n)^{178}W fusion evaporation reaction.

In this contribution the performance of the NuBall array in terms of isomer spectroscopy of ^{178}W will be discussed. Especially the capability of the array as a calorimeter will be addressed in terms of reaction channel selection. The $LaBr_3$ detectors allow for the determination of excited states half-lives by means of delayed coincidence fast timing that were previously inaccessible using standard Ge detectors. Sub-nanosecond half-life determination was possible using the centroid shift method. First results of this part of the analysis will be presented. This includes the time walk characteristics of the setup, which featured a fully digital data acquisition system, and the determination of the previously unknown half-life of the first excited 4^+ state of ^{178}W.

SHELL EVOLUTION IN NEUTRON RICH TITANIUM ISOTOPES INVESTIGATED BY ISOMER SPECTROSCOPY

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The description of shell structure has evolved in recent years extending toward the driplines. The role of shell closures has been challenged and modifications of shell structure have been observed in short-lived nuclei with extreme proton-to-neutron ratio. The harmonic oscillator shell gap at N=40 is reduced as protons are removed from Ni to Fe and Cr isotopes. Both ^{66}Fe and ^{64}Cr show a decreased energy of the yrast 2^+ state and increased transition probability B(E2; 2^+ à 0^+). The collective behavior is caused by quadrupole correlations which favor energetically the deformed intruder states involving the neutron $g_{9/2}$ and $d_{5/2}$ orbitals and proton excitations across the Z=28 sub-shell gap. Moreover, the proton-neutron tensor force, and in particular the strongly attractive monopole part, is expected to modify the shell structure in this region. These potential changes in the intrinsic shell structure are of fundamental interest for testing the validity of modern residual interactions and their predict power further from stability. The subtle interplay between such shell-evolution mechanisms provokes the modification of the magic numbers and gives rise to new regions of deformation and shape coexistence phenomena. Previous studies indicate ^{64}Cr as the center of a new region of prolate deformation. As in the case of ^{32}Mg along N = 20, shape coexistence should be expected in this region.

We will present some unpublished results from an experiment performed at the RIKEN Nishina Center for Accelerator-Based Science. A high intensity ^{238}U beam impinging on a Be target was used to produce the nuclides of interest in in-flight fission. In the experiment the EURICA gamma-ray array surrounded the implantation detector AIDA into which the fragments of interest were implanted. The fragments were identified using the BigRIPS separator employing the ΔE-ToF-Bρ method. New gamma transitions de-exciting isomeric states, as well as states populated in the beta decay have been identified . In particular new isomers in neutron-rich Ti isotopes are identified. The proposed spin and parity assignments will be motivated and the implication for the structure of the isotopes will be discussed in comparison to state-of-the-art shell-model calculations.

ON A NEW LIGHT PARTICLE OBSERVED IN HIGH ENERGY NUCLEAR TRANSITIONS

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Dark matter is currently one of the greatest unsolved mysteries in physics. Recently we have observed an anomaly in the internal e^+e^- decay of ^{8}Be [1]. It turned out [2] that this could be a first hint for a 17 MeV X-boson (X17), which may connect our visible world with dark matter. The possible relation of the X17 to the dark matter problem as well as the fact that it might explain the (g-2)μ puzzle, triggered an enormous theoretical and experimental interest in the particle, hadron and atomic physics community. Zhang and Miller discussed in detail any possible explanations with nuclear physics origin without any success [3].

Using a significantly modified and improved experimental setup, recently we reinvestigated the anomaly observed in the e^+e^- angular correlation by using the new tandetron accelerator of our institute. This setup has different efficiency curve as a function of the correlation angle, and different sensitivity to cosmic rays resulting practically independent experimental results. In this experiment, the previous data were reproduced within the error bars. The ^{8}Be anomaly was a strong motivation for further experiments to study possible signals of a new force interacting with nuclei and electrons.

In my talk I am going to discuss the preliminary results of a few follow-up experiments. We obtained new results for high energy transitions in ^{4}He and ^{12}C, which also supports the existence of the X17 particle. The γγ-decay of X17 boson was also studied in order to distinguish between the vector and pseudo scalar scenario suggested recently by theoretical groups in interpreting our experimental results [4,5]. According to the Landau-Yang theorem, the decay of a vector boson is forbidden by double γ-emission, however a pseudoscalar one is allowed. The possibilities of further nuclear physics studies of the X-boson in small laboratories will also be discussed.

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NUCLEAR TETRAHEDRAL AND OCTAHEDRAL SYMMETRIES: EXPERIMENTAL EVIDENCE AND APPLICATIONS IN THE EXOTIC-NUCLEI RESEARCH

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We develop a series of theory-focussed nuclear structure projects which aim at employing the symmetries in order to explore and possibly profit from various forms of hindrance of certain decay processes to increase the chances of observation of certain nuclei which otherwise have too short lifetimes. In particular: Nuclear states involving such symmetries (even if the states themselves are excited) are likely to produce isomers with lifetimes longer or even significantly longer than the lifetimes of the corresponding ground states. The central line of action according to this way of thinking is to examine the possible occurrence of symmetries throughout the Periodic Table. The symmetries which may provide sufficient decay hindrance factors to become of *practical* interest in the large-scale exotic-nuclei research-projects are in the center of interest of the project.

We have been focussing on the geometrical symmetries, tetrahedral and octahedral ones, which we refer to as high-rank symmetries. This nickname has been justified by the fact that the two symmetries, in contrast to all other symmetries in the world of deformed nuclei studied so far, lead to four-fold degenerate single-nucleonic levels in contrast to the double (Kramers) degeneracy of these levels in any other geometry. This mechanism in itself is fascinating in that it leads to unprecedented features such as 16-fold degenerate particle-hole excitations, new selection rules, new magic gaps totally different from has been studied in the nuclear structure before, etc. However there exists yet another feature which is of central interest in the present project: Nuclear states with the high-rank symmetry cannot decay via neither E1 nor E2 collective transitions due to the symmetry hindrance. Thus the most abundant decay modes in nuclear structure physics are forbidden in this case. This provides (potentially) the unique chances to expand the nuclear exotic-nuclei research-programs.

We present shortly an overview of the past research in this domain focussing on the resent results on the high-rank symmetry identification methods which open a way for the new generation of this typeof research. We present the illustrations of what we consider as the first positively identified case in the literature.

The experimental research focussing on this type of physics is, in our opinion, of fundamental importance for various applications in the low energy subatomic physics and astrophysics. Firstly, the nuclei with the discussed properties are expected to produce totally unprecedented in nuclear physics selection rules for the rotational bands; these new features are discussed to a certain detail. Secondly, certain nuclei with the proton and neutron tetrahedral-magic numbers may be so stable that they may play a role of the new waiting point nuclei in the astrophysical processes. As one physicist put it: “it is difficult to overestimate the potential gains in terms of new physics effects and the general interest in the new form of isomerism, with the importance comparable with that of the fission isomers discovered over a half century ago”.

MARIAN SMOLUCHOWSKI'S LEGACY IN CONTEMPORARY PHYSICS: A CENTURY OF INSPIRATION

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The beginning of the 20th century was a tumultuous time in science. The strongholds of physics were shaken at several ends: Einstein's special and later general relativity questioned Newtonian mechanics for particles at high speeds; the discovery of sponta-neous radioactivity by Becquerel and later the successful isolation of radium by the Curies; Rutherford, Geiger, and Marsden's gold foil scattering experiment; and the advent of quantum mechanics pushed by Bohr and Planck. Yet another topic soaring at that time was the quest to understand the stochasticity and fluctuations observed in phenomena like Brownian motion or opalescence – both involving assemblies of particles and pointing to a kinetic picture of matter.

The lecture aims to present influence of Marian Smoluchowski (1872-1917), an outstan-ding Polish physicist on foundations of modern statistical physics, theory of stochastic processes and nonequlibrium thermodynamics.

Throughout his career Smoluchowski worked at the forefront of research at the time, He had the ability to combine mathematical rigour with deep physical insight, a prime example being his work on clarification of the role of ergodic hypothesis of Boltzmann and probabilistic interpretation of the Second Law of thermodynamics. Today Smolu-chowski's heritage in physics is broader than ever and entering various fields – from theory of coagulation, description of diffusive motion and first passage time processes in molecular context to facilitated diffusion, anomalous transport and random search strategies.

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EXPERIMENT

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Multipolarity assignment of $\Delta I = 0$, γ transitions

E-2 **Sergio Bartalucci, INFN, Frascati**
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E-3 **T.A. Berry University of Surrey, Guildford**
Investigating octupole-vibrational states in $^{207}Tl_{126}$

E-4 **R.L. Canavan, University of Surrey, Guildford**
Excited state lifetime studies in the N=100 isotone ^{166}Dy

E-5 **Linda Mdletshe, University of Zululand, KwaDlangezwa**
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E-6 **Pavol Mosat, Comenius University, Bratislava**
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E-7 **Mikhail A. Naumenko, JINR, Dubna**
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E-8 **Deepak Pandit, Variable Energy Cyclotron Centre, Kolkata**
Experimental evidence of collectivity in the nuclear level density

E-9 **K. Słabkowska, Nicolaus Copernicus University, Toruń**
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E-10 **Samiksha Sood, Department of Physics, Panjab University, Chandigarh**
Systematic study of entropy production in asymmetric reactions using transport model

E-11 **Łukasz Syrocki, Nicolaus Copernicus University, Toruń**
Obtaining the dependence of the equilibrium charge state

E-12 **Jakub Wiśniewski, University of Warsaw**
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APPLICATIONS

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Verification of the attenuation factors for γ-rays emitted by commonly used isotropic radiation sources

A-2 **Bartosz Kiełtyka, Jagiellonian University, Krakow**
Verification of the planned dose of ionizing radiation at the border of tissue-hip endocrine centers during radiotherapy

A-3 **Kamil Kisielewicz, Centre of Oncology, Maria Sklodowska-Curie Memorial Institute,**
Exposure burden for patients during a dual-energy contrast-enhanced spectral mammography

A-4 **Kamil Kisielewicz, Centre of Oncology, Maria Sklodowska-Curie Memorial Institute,**
Patient dose evaluation in digital breast tomosynthesis

A-5 **Adam Konefał, University of Silesia, Katowice**
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A-6 **Wioletta Lniak, University of Silesia, Katowice**
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A-7 **Justyna Rostocka, University of Silesia, Katowice**
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A-8 **Aleksandra Sapikowska, Centre of Oncology, Maria Sklodowska-Curie Memorial Institute,**
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I-1 **J. Szerypo, University of Munich, Garching**
Technological Laboratory (LMU Munich) - status

I-2 **Anna Wójcik-Gargula, IFJ PAN, Kraków**
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THEORY

T-1 **Eunja Ha, Soongsil University, Seoul, Korea**
Neutron-proton pairing correlations and deformation for N = Z Nuclei in sd- and pf-shell by the deformed BCS and deformed QRPA

T-2 **Yannen Jaganathen, IFJ PAN, Kraków**
Quantified Gamow Shell Model interaction for psd-shell nuclei

T-3 **Nassurlla Maulen, Institute of Nuclear Physics, Almaty**
Study of the ^{7}Li (d, t)^{6}Li reaction at energy 14.5 MeV

T-4 **David Muir, University of York**
Describing quadrupole collective excitations of nuclei within self-consistent methods

T-5 **A. K. Rhine Kumar, Cochin University of Science and Technology, Kerala**
Giant dipole resonance observables in ^{88}Mo

T-6 **Antonio Márquez Romero, University of York**
Neutron-proton pairing correlations in a single l-shell model with beyond-mean-field techniques

T-7 **A. Saxena, IIT, Roorkee**
No core shell model study for nitrogen isotopes

T-8 **E.O. Sushenok, JINR Dubna**
The pairing-interaction impact on the beta-decay characteristics and multi-neutron emission of the neutron-rich ^{126,128,130,132}Cd

Abstracts of Posters

MULTIPOLARITY ASSIGNMENT OF ΔI = 0, GAMMA TRANSITIONS

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It is well known that the determination of the polarization for the γ transition (Electric or Magnetic) will lead to the unique parity assignments of the decaying nuclear states. The electric and magnetic nature of the γ-rays is actually distinguished by the direction of the electric vector of the emitted radiation with respect to a plane produced by the direction of polarization and the detector axis. The value of the polarization depends on the detector sensitivity as well as the difference between the perpendicular and parallel scattering of the γ radiation due to Compton scattering. This difference is positive for electric type and negative for magnetic type transitions while for mixed transitions it is almost zero. However, for a ΔI = 0 γ transitions the present calculation using the relation in Ref. [1] shows that the difference is positive for magnetic type and negative for electric type of transitions over a large range of mixing. This opposite results of the polarization asymmetry for the ΔI = 0, γ transitions may sometimes leads to improper assignments of the parity of the nuclear states.

In the present work the characteristics of ΔI = 0 transitions are studied in ^{142}Eu and ^{142}Sm nuclei, populated through the fusion evaporation reaction of ^{116}Cd with ^{31}P at an energy of 148 MeV obtained from the Pelletron-Linac facility at TIFR, Mumbai. The de-exciting γ transitions have been detected by the Indian National Gamma Array (INGA) which were consisted of nineteen Compton suppressed clover detectors at the time of experiment. The previous measurement of ^{142}Sm [2] proposed 540-keV ($7^- \rightarrow 7^-$) γ transition as a ΔI = 0, M1 without measuring the linear polarization. In the present experiment linear polarization measurements of the 540-keV transition has been carried out. The large positive value of the polarization [+0.29 (0.11)] is being strongly supported its' ΔI = 0, M1 nature by the present theoretical calculations. Another example of a ΔI = 0 transition is the 283-keV ($8^+ \rightarrow 8^-$) transition in ^{142}Eu. The spin-parity of the 8^+ state has been confirmed by g-factor measurements [3]. Measured linear polarization value for the 283-keV transition is found to be of −0.19(0.08) in agreement with the present calculation considering its ΔI = 0, E1 character. Angular distributions for the 540-keV and 283-keV transitions are carried out using the expression as in Ref. [4]. Mixing ratios are calculated from the χ^2 minimization of the measured angular distribution coefficients using the prescription in Ref. [5] and the obtained values are 0.06(+0.01/-0.01) and 0.28(+0.02/-0.03), respectively. Thus the polarization value for ΔI = 0 transition is positive (negative) for M1 + E2 (E1 + M2) type over a large range of mixing of higher multipolarity transition. Therefore, the present measurements strongly indicate that the sign of the polarization value for the ΔI = 0 transitions are opposite from those of the ΔI = 1 and 2 transitions having same character.

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A SEARCH FOR THE EXISTENCE OF COHERENT CORRELATED STATES IN NUCLEAR PROCESSES AT LOW ENERGY

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The existence of "non-classical" states of light has been demonstrated long ago, giving rise to the remarkable development of Quantum Optics. In other areas, ranging from Condensed Matter physics to Cosmology, such states have been intensively studied, but a clear signature of their existence is still lacking. An experimental programme is described in this paper, aiming at detecting the formation of coherent correlated states (CCS) in crystal lattices, when bombarded by a very low energy proton beam. This may be a clue to various unexplained phenomena, including the strong enhancement of nucler reaction rates reported by several experiments, which cannot be accounted for by electron screening only.

INVESTIGATING OCTUPOLE-VIBRATIONAL STATES IN $^{207}Tl_{126}$

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Few-body systems provide a testing ground for models of the NN interaction, reaction mechanism and for models of nuclei. In a medium energy domain the properties of few-nucleon systems are successfully modeled with the use of the realistic potentials, coupled-channel (CC) calculations with realistic potential including non-nucleonic degrees of freedom or Chiral Perturbation Theory (ChPT). At a certain level of experimental precision, subtle effects can be studied, for example Three Nucleon Force (3NF). The calculations, in order to correctly describe the system dynamics include the model of 3NF (e.g. Tucson Melbourne TM force) and/or the Coulomb force [4]. Recently, also the relativistic treatment of the breakup reaction in 3N system was developed and the approach has been already applied for calculations including 3NF [2]. Depending on the investigated part of the phase space, one can study the influence of these effects separately and also their mutual interplay. All those effects vary with energy and appear with different strength in certain observables, therefore systematic (over beam energies) and precise data are needed to distinguish between, sometimes, very subtle effects.

In a medium energy region the 3NF effects are generally small and hard for experimental study. The data obtained so-far [1,3-5] have not brought any firm conclusions concerning the role of the 3NF in the 3N interaction. The situation can change for heavier systems where sensitivity to the 3NF effects become higher. The simplest ensemble which reveals the complexity of heavier systems, e.g. variety of entrance and exit channels, various total isospin states etc., is the one composed of four nucleons. In expectation of the precise calculations for 4-nucleon systems at medium energies, our experimental group has made a step forward and measured the deuteron-deuteron scattering at 160 MeV [5] with use of the BINA detector at KVI Groningen. The search for the 3NF effects is planned to be continued with the use of the p-^{3}He scattering at medium energies at the new facility - Cyclotron Center Bronowice (CCB) in Poland. The project assumes the measurement of vector analyzing power and differential cross section for protons scattered on a polarized ^{3}He target.

In the poster I will present how, from the experimental point of view, one can trace the different dynamical effects predicted by theory in the 3- and 4-nucleon systems. As the outlook plans of utilizing the polarized ^{3}He target at CCB will be presented.

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EXCITED STATE LIFETIME STUDIES IN THE N=100 ISOTONE ^{166}Dy

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We present analysis from the first in-beam experiment using the NuBALL hybrid HPGe-$LaBr_3$ coincident gamma-ray spectrometer at IPN, Orsay, from an experiment performed in November 2017 to investigate the low-lying state transitions rates in the N=100 nucleus ^{166}Dy. In the configuration during the experiment, the NuBALL spectrometer comprised 24 Compton suppressed four-element HPGe Clover detectors, 10 coaxial HPGe Compton suppressed spectrometers, and 20 single-element $LaBr_3$ detectors supplied by the FATIMA collaboration. These detectors were read out using a fully digital data acquisition system. Excited states in ^{166}Dy were populated via the ^{164}Dy(^{18}O,^{16}O)^{166}Dy two-neutron transfer reaction using a pulsed ^{18}O beam with energies of 71, 76 and 80 MeV provided by the tandem van de Graaff accelerator at IPN Orsay. The aim of this work was to determine excited state lifetimes in the vicinity of the valence maximum nucleus $^{170}Dy_{104}$ [1], using the HPGe-gated, $LaBr_3$-$LaBr_3$ fast-timing time difference technique. The states identified as populated in ^{166}Dy using the (^{18}O,^{16}O) reaction will be compared with results of previous spectroscopic studies of this quadrupole deformed nucleus, studies using deep-inelastic reactions to populate high-spin cascades [2,3], and (t,p) transfer reactions on ^{164}Dy [4] and β^--decay from ^{166}Tb [5] which are more selective for lower-spin states. The array performance during the experiment, methods of channel selection used to enhance the peak-to-total ratio for the ^{166}Dy and discriminate these from the ^{178}W channel populated via the competing fusion-evaporation channel [6,7], and the current progress on analysis of these data to extract B(E2) values of low-lying transitions in ^{166}Dy will be presented. In particular, the effects of total energy-total gamma multiplicity and prompt-delayed coincidence timing will be demonstrated.

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LOW LYING POSITIVE PARITY BANDS IN ^{162}Yb

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The spectroscopy of low lying positive parity bands have been studied at iThemba LABS using the ^{150}Sm(^{16}O, 4n)^{162}Yb fusion evaporation reaction at a beam energy of 85 MeV. The γ-rays emitted from the reaction products were detected using the AFRODITE γ-ray spectrometer equipped with 8 BGO escaped-suppressed HPGe clover detectors. A total of 10 bands have been observed in this work. In particular, positive parity bands built on the first excited $K^{\pi}= 0_2^+$ and $K^{\pi}= 2_\gamma^+$ states have been identified for the first time. DCO and polarization measurements have been instrumental in the assignment of spins and parities for the majority of the newly established levels in ^{162}Yb.

The first excited 0_2^+ band and the even spin members of the γ band exhibit a Landau-Zenner crossing. This crossing demonstrates that the significant signature splitting between the odd and even spin members of the γ band is mainly caused by band mixing. These results are compared with calculations of Shi, Song, Li, Zhang et al. using a five-Dimensional Collective Hamiltonian (5-DCH) based on PC-PK1 Covariant Density Functional Theory (CDFT) [1]. A very impressive agreement is obtained between the experimental and theoretical results.

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SPONTANEOUS FISSION OF RUTHERFORDIUM ISOTOPES - TOTAL KINETIC ENERGIES

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Spontaneous fission (SF) is a decay mode with large impact on the stability of nuclei in the trans-fermium region. These isotopes are stabilized mainly by microscopic effects [1]. Systematic studies of SF properties allow us to understand these effects and to determine the production possibilities for the heaviest nuclei. Theoretical calculations discuss the possibility of bimodal fission for even-even $^{254-260}$Rf isotopes, which should be noticeable on the fragments mass distributions but also on the TKE distributions [2]. Experimental studies already confirmed the concept of bimodal fission in lighter nuclei [3, 4]. Up to now, only a few results with limited statistics of SF events with measured total kinetic energy (TKE) were obtained for rutherfordium (Z = 104) isotopes [3-6]. We collected several hundreds of SF events for ^{255,256,258}Rf produced in the fusion-evaporation reactions ^{50}Ti + ^{207,208}Pb and ^{50}Ti + ^{209}Bi at the velocity filter SHIP in GSI Darmstadt.
The crucial task for the evaluation of TKE using Si detectors is the correction of deficit in measured energies, discussed in previous studies performed at SHIP [7, 8]. This effect have two main sources: a) calibration based on α-decay energies is not valid for fission fragments due to the pulse-height defect (see e.g. [9]), b) dependence of detected TKE on the implantation depth of evaporation residues in the detector. In order to find the energy correction, we performed TKE measurements for ^{252}No with well-known <TKE> [3] at six different implantation depths. Our observations proved the strong non-linear saturation-like dependence of detected TKE on implantation depth [10].
Mean values of corrected TKE distributions for ^{255,256,258}Rf were in a good agreement with the previous results which supports the validity of the correction method. The results of the search for bimodal fission signs in the TKE distributions will be presented as well.

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STUDY OF TOTAL CROSS SECTIONS OF REACTIONS WITH ^{6,7,9,11}Li NUCLEI

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It is well known that neutron rearrangement may play an important role in nuclear reactions. The aim of this work is the investigation of the reactions with Li isotopes having different structure. A series of experiments on measurement of total cross sections for reactions ^{6,7,9,11}Li + ^{28}Si in the beam energy range 5–50 AMeV was performed at Flerov Laboratory of Nuclear Reactions (FLNR), Joint Institute for Nuclear Research (JINR). The interesting results were the unusual enhancement of total cross sections for ^{9}Li + ^{28}Si reactions as compared with ^{6,7}Li + ^{28}Si reactions. The microscopic approach based on the numeric solution of the time-dependent Schrödinger equation [1] for the external neutrons of weakly bound projectile nuclei combined with the optical model is used for description of the observed effect [2]. It is explained by the rearrangement of external neutrons and thus the increase of neutron probability density in the region between the two nuclei depending on the collision energy. The calculated cross sections are in agreement with the experimental data on the total reaction cross sections for the studied nuclei.

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EXPERIMENTAL EVIDENCE OF COLLECTIVITY IN THE NUCLEAR LEVEL DENSITY

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It is now a very well known fact that the density of nuclear states increases rapidly with excitation energy and soon becomes very large [1]. As a result, the nucleus leaves the discrete region and enters the region of quasi-continuum and continuum. Along with the intrinsic excitations, the nucleus also displays collective vibration and rotational motion. These collective excitations have a significant effect on nuclear level density (NLD), in particular, for deformed nuclei and their contribution is defined as the collective enhancement in the NLD. Therefore, the total level density is expressed as $r(E^*,J) = r_{int}(E^*,J) * K_{coll}$, where $r_{int}(E^*,J)$ is the intrinsic single particle level density and K_{coll} is the collective enhancement factor [2]. Although the NLD is indispensable in the study of nuclear decay, the collective enhancement in the NLD is still not well-understood due to the lack of experimental data. The magnitude and exact form of K_{coll} still remains an open question. In order to address this issue, an extensive experiment was carried out at VECC using the alpha beams from the K-130 Cyclotron.

The highly deformed ^{169}Tm (b~0.3 in the ground state) nucleus was populated at 26.1 MeV excitation energy by using the reaction ^{4}He + ^{165}Ho with 28 MeV alpha beams. The high energy GDR g rays were measured at 90^{o} and 125^{o} employing the LAMBDA spectrometer [3]. The 50-element multiplicity filter [4] was split into two blocks of 25 detectors each and was placed on the top and bottom of the scattering chamber at a distance of 4.5 cm from the target to extract the angular momentum of the compound nucleus. The evaporated neutron energy spectra were measured through time of flight technique using two liquid scintillator based neutron detectors [5] placed at the backward angles 120^{o} and 150^{o} at a distance of 150 cm from the target position. The detail of the experimental setup and analysis is given in ref [6]. It was intriguing to find a large yield in both the neutron energy spectrum (beyond 6 MeV) and the GDR γ-ray (around 16 MeV) spectrum. It was also interesting to note that the GDR and the neutron decay explore the same excitation energy region in the daughter nuclei ^{169}Tm and ^{168}Tm, respectively. The enhancement could only be reproduced by including a collective enhancement factor in the Fermi gas model of NLD to explain the neutron and GDR spectra simultaneously [6]. The experimental results show that the relative enhancement factor is of the order of 10 and the fadeout occurs at □14 MeV excitation energy, much before the commonly accepted transition from deformed to spherical shape. These interesting results as well as the collective enhancement signature reflected through the change in the inverse level density parameter [6,7] will be presented during the conference.

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EVALUATION OF THE NEEC RESONANCE WINDOW WIDTHS FOR ^{93m}Mo ISOMER IN THE CASE OF ELECTRON CAPTURE INTO ATOMIC SHELLS FOR THE ASSUMED ELECTRONIC EXCITED CONFIGURATIONS

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The main objective of this study is to determine the optimal conditions for a detailed knowledge of the nuclear excitation by electron capture (NEEC) process for selected nuclear isomers (i.e. metastable exited states of atomic nuclei) of a few elements. The part of these research focuses on the especially interesting and important case of NEEC process for the ^{93m}Mo isomer ($T_{1/2} \sim 6.8$ h), for which the NEEC process has been very recently registered for the first time [1, 2], on the world's most powerful Digital Gammasphere Spectrometer, installed in the linear accelerator (ATLAS) at Argonne National Laboratory in the USA [2].

The evaluation of the NEEC resonance window widths for ^{93m}Mo isomer will mean in practice determining the width of the atomic level for the state obtained after the electron capture to the unfilled shells, using the multiconfiguration Dirac-Fock (MCDF) method [3-8], because the contribution from the nuclear level width is only about 1.3 x 10^{-7} eV. Accordingly to this, it is worth to underline that the resonance should occur if the resonance window is sufficiently wide (i.e. in practice if enough large is the natural width of the atomic state obtained after the electron capture to particular subshells) in the comparison with amount of change of studied ion (of particular element) kinetic energy in single collision.

Obtained in this study knowledge allow to understand the processes occurring in the Universe, and in particular to provide a fundamental information concerning the survival of the nuclei of different isotopes of the elements in stellar environments. The results of this study will be a starting point for applied research, which aim will be to allow the controlled release of energy stored in the nuclear isomer of selected elements. Moreover, these studies will also contribute to the development of the concept of new, unconventional and ultraefficient nuclear batteries.

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SYSTEMATIC STUDY OF ENTROPY PRODUCTION IN ASYMMETRIC REACTIONS USING TRANSPORT MODEL

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The ultimate goal of studying heavy-ion reactions at intermediate energies is to investigate nuclear matter at high density and temperature [1]. Very few observables are available in literature that preserves the signature of the early phase (at which nuclear matter is at high density and temperature) of the reaction. The interesting quantity "entropy" is found to be one of the most famous ones as its value set up in the initial phase of the reaction shows only little change at the latter time of a reaction, thus provides a window to study hot and dense nuclear matter. Entropy is calculated using ratio of lighter mass nuclei [2]. The experiments carried out to study entropy are broadly classified into symmetric and asymmetric reactions. In the former case, the incident energy is stored in the composite system in form of compression energy whereas, in later case, large portion of incident energy is stored as excitation energy. Though, dynamical models have been reported to undergone a tremendous success describing the entropy production in symmetric reactions and Puri and collaborators have performed elaborated systematic studies on entropy production in symmetric reactions [3]. The study of entropy production in asymmetric reactions is never been explored with dynamical model. In the present work, we plan to present the investigation of entropy production in case of asymmetric reactions over a broad range of asymmetry using dynamical model. In particular, we used quantum molecular dynamics model coupled with clusterization algorithm based on spatial constraints [4].

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OBTAINING THE DEPENDENCE OF THE EQUILIBRIUM CHARGE STATE FOR ^{93}Mo IONS FROM THEIR KINETIC ENERGY DURING THE PENETRATION THROUGH DIFFERENT SOLID TARGETS

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The main purpose of this research is to evaluate the optimal conditions for a detailed knowledge of the nuclear excitation by electron capture (NEEC) process for selected nuclear isomers (i.e. metastable exited states of atomic nuclei) of a few elements. The part of these research concentrate on the especially interesting and important case of NEEC process for the ^{93m}Mo isomer (T1/2 ~ 6.8 h), for which the NEEC process has been very recently registered for the first time [1, 2], on the world's most powerful Digital Gammasphere Spectrometer, installed in the linear accelerator (ATLAS) at Argonne National Laboratory in the USA [2].

The dependence of the equilibrium charge state for ^{93}Mo ions from their kinetic energy during the penetration through different solid targets will be performed using formulas proposed by Schiwietz and Grande [3] for gas and solid stopping media, in the wide range of kinetic beam energy of Mo ions (i.e. in a much broader region than region taken into account in our article [1]). The formulas proposed by Schiwietz and Grande reproduce the experimental date quite well, with an accuracy not worse than $\Delta q_{mean}/Zp$~2.5% [3]. The initial kinetic energy of ^{93m}Mo isomer ions will be obtain from the energy distribution of residual nuclei forming in the nuclear reaction (which must exceed energy needed for the NEEC resonance). The resonance energy can be reached during the stopping process of the recoil ^{93}Mo ions penetrating the solid state (or gas) target.

These research are very important from the point of view of the theory describing the structure, formation and evolution of high-spin states of nuclei. The obtained knowledge allow to understand the processes occurring in the Universe, and in particular to provide a fundamental information about the survival of nuclei of different isotopes of the elements in the stellar environments, where it could cause isomers to be excited to shorter-lived states that may reduce the abundance of the isotope after its production. The results of the studies will also contribute to the development of the concept of new, unconventional and ultra-efficient nuclear batteries.

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STUDY OF EXCITED STATES IN ^{87}Br NUCLEUS

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This work is a continuation of our previous works [1 - 6] devoted to studies of neutron-rich nuclei in the "noth-east" of the ^{78}Ni core. The main motivation of those studies is understanding structure of this very exotic nuclei. In particular, it is of great interest to understand the development and evolution of collectivity in the vicinity of ^{78}Ni. Their detailed behavior is driven by the forces acting in nuclear many body systems. Precise modeling of the shell structure has a direct impact on different scenarios for the astrophysical r-processes occurring probably in type-II supernovae.

Excited states of odd-A nuclei in the vicinity of doubly magic nuclei provide valuable information about single particle energies in the region. In our recent work on ^{83}As [7] we have proposed single-particle energy for the $g_{9/2}$ proton orbital, crucial for describing medium-spin levels in the region. It is of high importance to confirm this value, which may be achieved by studying ^{87}Br nuclei. We have studied excited states of ^{87}Br in the neutron-induced fission of ^{235}U performed at cold-neutron facility PF1B of ILL Grenoble, using EXILL spectrometer. [8]. Our preliminary data indicate the presence of $9/2^+$ levels corresponding to the $g_{9/2}$ proton orbital. This, however, requires proper identification of the ground state of ^{87}Br. It was tentatively assigned spin-parity $5/2^-$ in the beta-decay of ^{87}Br study [9]. To firmly establish spin and parity of ground stated we have measured β-decay of ^{87}Se at IGISOL facility [10] at the Accelerator Laboratory of the University of Jyväskylä. We will present new results from the Penning-trap-assisted measurement of β^- decay of the neutron-rich ^{87}Se isotope. Compared to previous β-decay studies in the region, the use of Penning trap allows the reduction of background and removal of isobaric contaminations from the data. Excited levels in ^{87}Br were studied by means of γ spectroscopy. Obtained data allowed to extend β-decay scheme of ^{87}Br, where only few excited levels populated in β^-decay of ^{87}Se were known [11]. Results were interpreted with large scale shell-model calculations.

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VERIFICATION OF THE ATTENUATION FACTORS FOR γ-RAYS EMITTED BY COMMONLY USED ISOTROPIC RADIATION SOURCES

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In the last decade the use of radiation sources spread over various branches of human activity. Presently the radiation sources are applied in industry, medicine and science. The use of the radiation sources is regulated by the Atomic Low. In Poland the Atomic Low is compatible with the directives of Euroatoms. Care of the radiological protection is exercised by inspectors of radiological protection. The significant part of their activity is planning of places of the work. It needs the accurate estimation of a dose absorbed by a worker during workday. This dose is calculated according to the procedure given by Gostkowska in [1]. This procedure is based on the norm PN-86/J-80001. The absorbed dose from the commonly used isotropic sources is estimated by means of the formula in which the significant parameter is the attenuation factor. Values of these factors in a function of a thickness of the shield from gamma-rays are included in the histograms and in the tables shown in [1]. The curves presenting the dependence between the attenuation factors and the shield thickness are not in agreement with the values included in the tables. In the case of thicker shields the discrepancy between the histograms and the tables are unjustified great. In connection of this fact necessity of the accurate determination of the attenuation factors appears. In this work the attenuation factors were determined for the basic shielding materials – concrete with density of 2.3 g/cm3, for the chosen radiation sources – 60Co, 137Cs, 24Na and 198Au. The attenuation factors were determined with the use of the Monte Carlo method basing on the GEANT4 code [2]. Verification of the performed calculations was carried out using thermoluminescence detectors. In general the estimated attenuation factors differ from those presented in the histograms as well as from the values included in the tables provided by Gostkowska. Generally, the attenuation factors estimated in this work depends on the thickness of the shield and the radiation source. The differences between the obtained results and those given in [1] can even reach values of several dozen percent for considered shields and in several cases even much greater. The use of the attenuation factors verified in this study makes it possible to determine the dose at places of the work with the greater accuracy. It certainly ensures the safety of work under conditions of the radiation risk.

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VERIFICATION OF THE PLANNED DOSE OF IONIZING RADIATION AT THE BORDER OF TISSUE-HIP ENDOCRINE CENTERS DURING RADIOTHERAPY

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The success or failure of radiotherapy depends largely on the accuracy with which the dose will be delivered to a specific volume in the patient's body. In many cases, a change in dose by 3-4% may cause failure of the whole therapy. Both national and international guidelines on coherence and accuracy in ionizing radiation dosimetry will focus on homogeneous media (eg water), however, the human body is composed of elements differing in density (bones, lungs, teeth, muscles) [1]. Nowadays, apart from natural heterogeneous structures, there may also be artificial elements, eg hip prostheses, surgical rods, stents and dental fillings.

One of the problems associated with radiotherapy planning for patients with endoprostheses (mainly hip) is the inaccuracy of the algorithm that calculates the dose distribution in the treatment planning system for the area in the immediate vicinity of the border of tissue-prosthesis medium. Due to the use of high-energy ionizing radiation, during the treatment of patients after hip joint prosthesis implantation, the dose delivered during the therapy session may be significantly different compared to the treatment plan. This is related to the change in the amount of energy deposited in the structure of irradiated organs - usually with its reduction. This is due to such phenomena as: beam hardening by a high-density metal element and secondary build-up of the dose at the border of the mediums (secondary build up), resulting in an increase of the dose at the border of the mediums - up to about 20% [2]. Such a large change in energy deposited in the tissues of treated patients may lead to skeletal changes (leading to fractures in the hip joint) or even necrosis and weakening of the fixation of the implant.

To verify the dose of ionizing radiation a phantom filled with water - a good equivalent of soft tissue - was used with the bone elements (imitating hip joint) and metallic and ceramic (hip joint endoprostheses) placed in the stand. On acetabulum surface, thermoluminescent microdosimeters (TLD) based on lithium fluoride (LiF) and Gafchromic EBT were placed. The first irradiation by medical linear accelerator were done. The dosimeters are under readout procedure.

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EXPOSURE BURDEN FOR PATIENTS DURING A DUAL-ENERGY CONTRAST-ENHANCED SPECTRAL MAMMOGRAPHY

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Breast cancer (BC) is one of the most common women malignancies. Nowadays mammography and ultrasound examinations are basic methods used in screening programs. Mammography provides early microcalcification recognition, crucial for further cancer diagnosis.

High progress in the development of new mammography devices e.g. new flat panel detectors, compression paddles, spectral modes (CESM – Contrast Enhanced Spectral Mammography) and new type of X-Ray tubes gives a variety of new diagnostic modules available for clinical use.

The aim of this study was to compare doses given to the patients during conventional mammography with doses obtained from dual-energy contrast-enhanced spectral mammography. The comparison of entrance surface air kerma (ESAK) and mean glandular dose (MGD) values for both options are discussed in the paper, respectively.

In the study 482 women diagnosed with screening mammography between 2011 and 2014 were respectivetly enrolled. The first group of 250 patients was examined using a fully digital mammo unit, GE Senographe Essential. The second group of 232 patients were examined using the same digital mammography device developed by GE Healthcare with the option of dual-energy CESM acquisition (SenoBright®).

For our group of patients and for an average breast thickness of 45mm (43 - 52 mm), median MGD is 6.6 mGy (values of MGD for a low-energy acquisition and high-energy acquisition were equal to 5.1 mGy and 1.5 mGy, respectively) for CESM compared to 1.2 mGy for Full Field Digital Mammography (FFDM). Moving up to 72 mm average breast thickness, MGD for CESM is nearly 7.5 times higher than for FFDM - medians of 12 mGy and 1.6 mGy, respectively.

Our preliminary data show that CESM might be a new diagnostic tool allowing an accurate detection of malignant breast lesions, giving results similar to those received from magnetic resonance imaging (MRI). However due to higher levels of radiation exposure during CESM, one should take risk factor into account.

Each method has its own benefits with respect to specific applications which are further discussed.

PATIENT DOSE EVALUATION IN DIGITAL BREAST TOMOSYNTHESIS

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Breast cancer (BC), a most common women malignancy, is often screened by mammography and ultrasound exams. Mammography provides early micro-calcification recognition, that is important for further cancer diagnosis. The imaging method-of-choice in the case of BC is an X-ray mammography (MG), also with the use of high-resolution digital modality. However, a planar MG has some limitations in terms of its sensitivity, especially in patients with dense and treated breasts. Moreover, MG contributes to the overall radiation burden of patients, and it is known that the risk for breast cancer is correlated with an exposure on ionizing radiation due to medical imaging. Patients, for whom MG study does not give a clear answer or is impossible to interpret, are often further diagnosed by contrast-enhanced breast magnetic resonance imaging (MRI). MRI is currently regarded as the most sensitive BC detection technique. On the other hand, it is limited by higher costs and lower availability and it provides higher rates of false positive cases. Relatively new method applied in breast neoplasms detection is digital tomosynthesis, introduced in 2011.

Classical planar (2D) mammography image characterized by a superposition of all breast structures projected onto the detector plane making difficult to recognize suspected areas. Tomosynthesis is a modality in which a series of breast exposures are performed at different angles (usually 9). Acquired images are subsequently used to reconstruct thin (1 mm) slices, which eliminates the problem of overlapping breast structures. This makes it easier to detect potentially suspicious changes, which can additionally be supported by specialist software such as CAD (Computer Aided Diagnosis).

Image and dosimetry data were used for studies performed in the digital tomosynthesis mode at the Department of Radiology and Imaging Diagnostics. So far, data from 219 patients have been collected and analyzed in a total of 357 CC / MLO projections in tomosynthesis mode. Additionally 70 of the patients had also classic 2D examination used as a reference in terms of dose.

/ of the projection and mammography mode (2D-planar, tomosynthesis), the average glandular dose (AGD) increases with increasing breast thickness. It was observed that the increase of AGD is much faster in patients undergoing tomosynthesis. AGD for thomosynthesis was 30-60% higher depending on breast thickness, comparing with 2D examination (i.e. 1,36 vs 1,75 mGy for 63-72mm compressed breast thickness).

The diagnostic benefits of 3D imaging compensate for the risk associated with increasing the glandular dose in patients, especially in groups where the breast thickness after compression does not exceed 63mm.

MEASUREMENTS AND ANALYSIS OF ENERGY SPECTRA OF γ-RAYS EMITTED BY RADIOISOTOPES INDUCED BY THERAPEUTIC BEAMS FROM THE MEDICAL LINEAR ACCELERATOR ELEKTA

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This paper presents results of the study that is a continuation of our previous work which we refer to as [1]. In this work energy spectra of gamma-rays emitted by radioisotopes induced by high-energy therapeutic beams from the medical linac - Elekta were measured and analyzed.

The high-energy X-ray and electron beams used in radiotherapy can cause photonuclear and electronuclear reactions in which neutrons and radioisotopes are produced [2-6]. These neutrons are also able to induce radioisotopes in nuclear reactions, particularly in the thermal and resonance energy range. The described processes are undesirable in radiotherapy, because the induced radiation is a source of an additional dose to patients as well as to staff.

The purpose of this work was identification of nuclear reactions and radioisotopes produced inside the treatment room and in the accelerator accessories. The measurements were carried out by means of the detection set by ORTEC, assigned for the field spectroscopy. This set was consists of the high-purity germanium detector (HPGe) connected to multichannel analyzer controlled by a laptop with the GammaVision sofware. The isotope tables edited by Firestone [7] were applied in the analysis of the measured spectra.

Eight radioisotopes ^{122}Sb, ^{124}Sb, ^{60}Co, ^{187}W, ^{82}Br, ^{56}Mn, ^{24}Na and ^{38}Cl induced in the simple capture reactions were identified. Almost all identified radioisotopes were observed for other medical linacs i.e. Clinac-2300 [3] and TrueBeam [6] by Varian and Primus by Siemens [2,3]. The exception is ^{60}Co not observed for the mentioned accelerators. The results of this work constitutes the data valuable for the manufacturers of medical linear accelerators and they can also be used in radiological protection of patients and staff.

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THE COMPARISON OF THERAPEUTIC DOSE INCREASE OBTAINED BY PLACING GOLD ATOMS AND NANOPARTICLES IN THE TARGET VOLUME

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In the field of radiotherapy, metal nanoparticles are extensively studied because of their potential application in the enhancement of the received radiation dose [1-3]. The dose enhancement is caused mainly by increase of the photoelectric effect yield in the irradiated medium. The photoelectric effect is the most effective way of energy transfer from radiation to the irradiated medium. The yield of the photoelectric effect increases because the average number of electrons per a unit of the irradiated volume increases when atoms with the high atomic number are used. The details of the dose enhancement mechanism was described in [3]. The aim of this work was a numerical microdosimetry study of the influence of the gold nanoparticle size on the dose enhancement by placing gold atoms and large gold nanoparticles in the target volume in teleradiotherapy for the 6 MV and 20 MV X-ray therapeutic beams from a medical linac. This work was based on the Monte Carlo simulations realized by means of the GEANT4 code. We decided to apply this code because of its validation in the range of electromagnetic interactions [4-6]. The spectrum of the therapeutic 6 MV X-ray beam was taken from [7-9] whereas the one for the 20 MV-rays was copied from [10]. In the case of the irradiated medium with gold atoms as well as of that with the gold nanoparticles the expected dose enhancement appears as the mass concentration of gold increases. The maximum increase in the dose does not exceed 10 % for the medium filled with a mixture of gold and water atoms for both considered beams. In the case of the target volume with the large gold nanoparticles the significant difference in the dose enhancement for the 6 MV and the 20 MV beams is visible. The maximum increase in the dose of 14 % is observed for the 6 MV beam whereas it is equal to 7.5 % for the 20 MV beam. This difference is caused by the fact that the considered gold nanoparticles are massive objects increasing the mean number of electrons as well as absorbing energy of radiation. Thus, they increase the yield of the photoelectric effect in the target volume. However, they contribute also to the absorption of secondary electrons produced in gold atoms as well as in water, in the photoelectric effect and in the Compton scattering. The performed study indicates that the use of the relatively large gold nanoparticles can limit the increase of the absorbed dose.

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TEST OF PRODUCTION OF ^{186}Re AND ^{188}Re USED IN THE NUCLEAR MEDICINE, BY MEANS OF MEDICAL LINEAR ACCELERATORS

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In the last decade, several independent reactor shutdowns and outage extensions significantly disrupted global radioisotope supplies. Therefore, new methods of production of widely used radioisotopes are required. The aim of this work was to test a possibility of ^{186}Re and ^{188}Re production by means of medical linacs used in teleradiotherapy. This work is a continuation of our previous works which we refer to as [1, 2]. Series of measurements with an activation of the natural rhenium foils was performed with the use of Varian medical linear accelerators Clinac-2300 and TrueBeam. The high energy X-rays of the therapeutic beam induce the photonuclear reactions (γ,n) in which radioisotopes as well as neutrons contaminating the therapeutic beam can be produced [3-5]. These neutrons can cause the next reactions producing radioisotopes. In this work the foils were activated with the use of the high energy therapeutic 20 MV X-ray beam and neutrons contaminating the therapeutic beam or the rhenium radioisotopes were produced only in the neutron field. The saturation of activity of ^{186}Re appears after irradiation lasting about 400 hours whereas in the case of ^{188}Re it is observed after about 120 hours. The maximum specific activity of ^{186}Re (2.6 MBq / g) was obtained for the lead - PMMA system increasing the neutron field at the location of the foils i.e. on the surface of the accelerator window. Fundamentally, the specific activities in saturation state obtained without the lead - PMMA system were approximately one order of magnitude less for the foils located outside the therapeutic beam i.e. for the foils activated only in the neutron reactions. In the case of foils located on the surface of the accelerator window the specific activities in saturation state were also less for activation without the lead - PMMA system but only from several to several tens of percents. This difference is also affected by the radiation field size. In the case of ^{188}Re the increase of the activity produced without the lead - PMMA system was also observed. However, the activity increased about 3 - 4 times. The maximum specific activity of ^{188}Re in saturation state was about one order of magnitude less than in the case of ^{186}Re. It is caused by the fact that the radioisotope ^{188}Re can be only originated from the slowed down neutron reactions whereas the radioisotope ^{186}Re can be also produced in photonuclear reactions as well as in the (n,2n) reaction induced by fast neutrons with energy over 7.25 MeV. However, the produced amount of the rhenium radioisotopes is sufficient to make use of these radionuclides in laboratory tests of new drugs for potential clinical applications. It is too small for commercial production. Attempts to increase the induced activity of ^{186}Re and ^{188}Re are in progress.

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USEFULNESS OF DUAL ENERGY COMPUTED TOMOGRAPHY IN DETERMINING THE MINERALOGICAL COMPOSITION OF STONES INSIDE THE ORGANS

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Computed tomography is the most common method of diagnostic radiology. The latest trend in the field of imaging using X-ray is multi-energy tomography, wherein a patient is scanned simultaneously by two energies: high (140 keV) and low (80 keV). In single-energy tomography, image in a given voxel is based on ascribing to that specific voxel value of Hounsfield unit (HU). HU value is obtained from linear absorption coefficient in the patient's body. Hounsfield units may, however, imprecisely reflect the composition of the structure under study, due to the effect of beam hardening. This causes the scanned field, despite its homogeneous structure, to have different CT values for different layers. In addition, it can be observed that in CT images the same HU can be characterized by two materials differing in elemental composition. These inaccuracies appear for substances with similar values of the linear coefficient of radiation absorption. The aim of this study was to evaluate the usefulness of dual-energy CT in determining the mineralogical composition of organs stones using Advantage Workstation GE software. The results obtained from dual energy computed tomography (DECT) were compared with the effective atomic number calculated during the IR measurements.

The research material were 11 kidney stones and 16 gallstones. They were divided into 18 groups. The criterion for the division was the origin of the stones: whether they were kidney stones, gallstones or whether they came from one patient or many. In order to perform tomographic scans, each of the stones was placed in a phantom made of plexiglass. During the test, the phantom was filled with water, which was a simulation of soft tissues. Then, the composition of the stones was analyzed using infrared spectrometry.

For most cases (28 samples) the percentage difference between Z_{eff} calculated on the basis of the tomography(Z_{eff} CT) and Z_{eff} obtained on the basis of the mid-infrared studies (Z_{eff} IR) does not exceed 10%. When cortex and medulla are investigated separately the percentage difference between Z_{eff} CT and Z_{eff} IR significantly exceeds 12,5% up to 42%.

Z_{eff} information determined by DECT gives appropriate knowledge necessary to eliminate the stone from patient body (ultrasound, splitting or resection).

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Technological Laboratory develops and produces thin foils and targets for the needs of both laser and nuclear physics. Its main activity is presently concerned with ultra-thin (nm range) free standing Diamond-Like-Carbon (DLC) foils for laser physics applications. The foils are produced by a cathodic arc deposition technique in a dust-reduced environment. Basic application of such foils is laser-driven charged-particle acceleration. It allows to accelerate electrons, protons and ^{12}C ions to high energies, achievable so far only in big conventional accelerators. Such laser accelerator will be much smaller and cheaper, than the conventional one. Main application of such device would be very precise cancer radiation therapy. The DLC assembly has undergone certain modifications, aiming at improvement of the foil thickness determination and homogeneity. In the Technological Laboratory, also standard thin film deposition by high vacuum evaporation technique is possible.

CHARACTERIZATION OF THE N-TYPE HPGe COAXIAL DETECTOR FOR ACTIVITY MEASUREMENTS OF ITER MATERIALS IRRADIATED IN JET

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Samples of structural materials, which will be used for construction of International Thermonuclear Experimental Reactor (ITER), will be irradiated in the Joint European Torus (JET) during the next D-D (deuterium-deuterium) and D-T (deuterium-tritium) experimental campaigns. This will be done to validate, in fusion-relevant operational conditions, the radiation transport and activation calculation predictions based on state-of-the-art codes and nuclear data used in ITER nuclear analyses [1].

The quality of gamma spectrometry measurements, carried out with HPGe (High-Purity Germanium) detectors, depends on the knowledge of a full-energy photopeak efficiency for a specific source-detector configuration. In case the measured activity is low, positioning of the sample as close as possible to the detector's end-cup window is necessary in order to reduce the counting times. However, the appropriate corrections for the true coincidence summing effect for radionuclides with complex decay schemes are then needed to accurately determine the sample activity. Introducing such correction factors is extremely important especially for n-type HPGe coaxial detector with 0.3 μm boron-implanted contact and thin beryllium entrance window allowing photons of energy down to 3 keV to enter the active volume of the detector. Obtaining equivalent calibration standards that match the samples to be counted (by shape, size, density, chemical composition) can be difficult. Therefore, computational methods such as Monte Carlo techniques can be used to take into account the dimensions of the sample and self-absorption within it.

This work describes a procedure of a theoretical efficiency curve calculation using a MCNP (Monte Carlo N-Particle) transport code. Results obtained with the simulations are compared with efficiency determined experimentally, in order to validate the model. It is shown that the accuracy of the modelled detector response function depends strongly on proper information and assumptions on the detector geometrical parameters such as dead layer thickness and crystal active volume.

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NEUTRON-PROTON PAIRING CORRELATIONS AND DEFORMATION FOR N = Z NUCLEI IN *sd*- AND *pf*-SHELL BY THE DEFORMED BCS AND DEFORMED QRPA

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We investigated neutron-proton pairing correlations effects on the shell evolution of ground state energies by the deformation for N = Z nuclei in sd- and pf-shell, such as ^{24}Mg, ^{28}Si, ^{44}Ti, ^{64}Ge, ^{68}Se, and ^{72}Kr.

We started from a simple shell-filling model constructed by a deformed Woods-Saxon potential with β_2 deformation, and included pairing correlations in the residual interaction. In this work, like-pairing and unlike-pairing correlations decomposed as isoscalar T = 1 and isovector T = 0 components are explicitly taken into account. We estimate ground state energies comprising the mean field energy, the pairing energy and the self-energy due to the pairing correlations, in terms of the deformation. The isoscalar condensation gives oblate deformations for ^{28}Si (Fig.1), ^{72}Kr, and ^{68}Se, whose feature is different from other sd- and pf-shell N = Z nuclei considered in this work [1, 2]. We applied this approach to the Gamow-Teller (GT) transition for another N = Z nucleus, ^{56}Ni (Fig.1), which exhibits explicitly the effects by the deformation (β_2) and the isoscalar condensation (T).

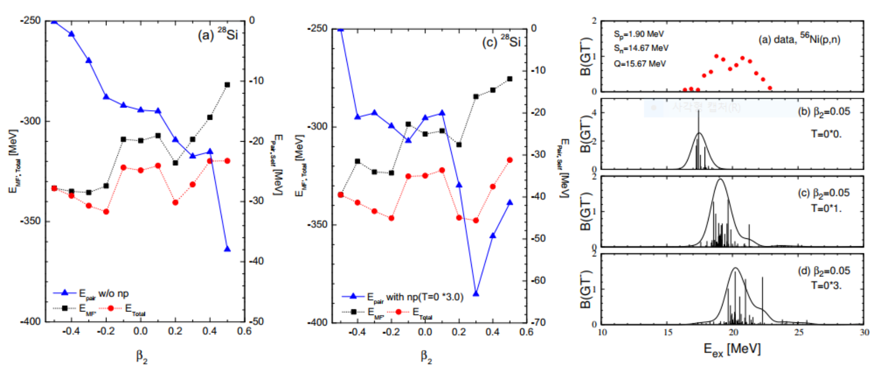

Figure 1: (Color online) Left: Ground state energy for ^{28}Si by the BCS model based on a Woods-Saxon potential. Energies are estimated from the Fermi energy surface by the BCS. $E_{MF'}$ is the mean field energy w.r.t. the Fermi energy. E_{pair} is the pairing energy . Right: The GT strength distribution in terms of the β_2 and T.

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QUANTIFIED GAMOW SHELL MODEL INTERACTION FOR psd-SHELL NUCLEI

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The structure of weakly bound and unbound nuclei close to particle drip lines is one of the major science drivers of nuclear physics. A comprehensive understanding of these systems goes beyond the traditional configuration interactions approach formulated in the Hilbert space of localized states (nuclear shell model) and requires an open quantum system description. The complex-energy Gamow Shell Model (GSM) provides such a framework as it is capable of describing resonant and non-resonant many-body states on equal footing.

To make reliable predictions, quality input is needed that allows for the full uncertainty quantification of theoretical results. In this study, we carry out the optimization of an effective GSM (one-body and two-body) interaction in the psdf shell model space. The resulting interaction is expected to describe nuclei with $5 \leq A \leq 12$ at the p-sd-shell interface.

The chi-square optimization is performed using the Gauss-Newton algorithm augmented by the singular value decomposition technique. The resulting covariance matrix enables quantification of statistical errors within the linear regression approach.
The interaction is adjusted to the bound and unbound ground-state binding energies and selected excited states of the Helium, Lithium, and Beryllium isotopes up to $A = 9$. A very good agreement with experiment was obtained for binding energies. First applications of the optimized interaction include predictions for two-nucleon correlation densities and excitation spectra of light nuclei with quantified uncertainties.

The new interaction will enable comprehensive and fully quantified studies of structure and reactions aspects of nuclei from the psd region of the nuclear chart.

STUDY OF THE ^{7}Li (d, t)^{6}Li REACTION AT ENERGY 14.5 MeV

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As it is well known, attempts to describe the scattering and nucleon transfer reactions between the light nuclei are often failed in the frameworks of the simple optical model and conventional DWBA [1]. The reason is small amount of target nucleons and cluster effects, which become apparent as an anomalous large-angle scattering. The nature of this phenomenon for the lithium nuclei can be stipulated for their pronounced ($\alpha + d$) and ($\alpha + t$) cluster structure [2]. At the same time, the reactions with lithium nuclei are very important as lithium is one of the most important elements of the fuel cycle in the promising projects of the fusion reactors, and in connection with the problem of nucleosynthesis of light nuclei. Such reactions were studied extensively in 70-ies, but consecutive analysis of their mechanisms and obtaining the correct spectroscopic information has been carried out in last decade [1, 3, 4].

This work is intended to trace the energy dependence of the neutron transfer mechanisms in the reaction ^{7}Li(d, t)^{6}Li in totality with [1], where the calculations were made taking into account the cluster exchange and the coupling the reaction channels (CRC method). The angular distributions of the tritons and elastically scattered deuterons have been measured at U-150M cyclotron of INP (Almaty, Kazakhstan) at E_d =14.5 MeV using the ΔE-E method for the particles identification. The differential cross sections (DCS) were measured in the angular range from 10º to 140º with the experimental errors not exceed 8%.

The obtained DCS and the data from [5] have been analyzed at E_d=12 MeV with CRC taking into account the alpha transfer mechanism. The optical model potentials for the entrance and exit channels were taken from [2] and [1] correspondingly, whereas the spectroscopic factor (SF) of ^{6}Li = $\alpha + d$ was used from [6]. As a result, the SFs for $\alpha + t$ and n + ^{6}Li configurations of ^{7}Li have been obtained from the analysis. Also the analysis of the data at the forward hemisphere was carried out using the modified DWBA method as it was made in [3] for obtaining the asymptotical normalization coefficient for the $^{7}Li_{g.s.}$= ^{6}Li+n configuration. The contribution of one-step neutron pick-up to the DCS was evaluated by matching the SFs for this configuration extracted from the ordinary DWBA analysis and CRC method.

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DESCRIBING QUADRUPOLE COLLECTIVE EXCITATIONS OF NUCLEI WITHIN SELF-CONSISTENT METHODS

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Collective excitations (specifically rotations and vibrations) of nuclei are especially key to an accurate description of medium to heavy mass nuclei across the nuclear chart. In this work, we consider describing collective excitations of nuclei using the Bohr Hamiltonian derived from microscopic density functional calculations. The aim of this work is to create a robust and informed procedure for describing such medium to heavy mass nuclei right across the nuclear chart. Following the formalism presented in [1] we perform a systematic sensitivity study of low lying 2^+ states using different Skyrme functionals. This work follows on from previous studies undertaken with the Gogny functional [2] and aims to understand which parameters of various Skyrme functionals have the most impact on the spectra obtained in collective calculations. Based on the outlined study we aim to inform the functional parameters in the initial fitting stage. From [3] we know that the limits of the Skyrme-like family of functionals have been reached. Thus, new novel approaches must be implemented if we wish to explore the use and applicability of this family of functionals in future work.

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GIANT DIPOLE RESONANCE OBSERVABLES IN ^{88}Mo

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Recently, the giant dipole resonance (GDR) γ-rays emitted from the highly excited ^{88}Mo compound nucleus as well as the number of daughter nuclei produced along the decay path of the compound nucleus at different temperatures (T), angular momentum (I) were measured exclusively [1]. In this work, we employ the thermal shape fluctuation model (TSFM) to calculate the GDR observables by considering the probability distributions of different T and I extracted from experimental data. Also the GDR observables are calculated by considering the mean T and mean I obtained from the corresponding probability distributions. Interestingly, both the results are found to be very similar [2]. Our results suggest an increase in the GDR width of ^{88}Mo nucleus with increasing T and I.

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NEUTRON-PROTON PAIRING CORRELATIONS IN A SINGLE L-SHELL MODEL WITH BEYOND-MEAN-FIELD TECHNIQUES

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We revisit the long-standing problem of neutron-proton pairing correlations by employing the Hartree-Fock-Bogoliubov (HFB) formalism with neutron-proton mixing included in both the particle-hole and particle-particle channels. We employ beyond-mean-field methods, namely, projection techniques, to restore all broken symmetries: particle number, spin, and isospin [1, 2], simultaneously. We explore both the projection after variation (PAV) and the variation after projection (VAP) methods using the paired mean-field states given by the Thouless representation. We apply this methodology to a simple pairing model based on the SO(8) algebra [3, 4], where we can compare the results with those obtained within the exact solutions. All analyses are performed in function of the mixing parameter x, which defines the balance between the isoscalar (T=0) and isovector (T=1) pairing strengths. In this way, we can investigate simultaneous presence and coexistence of all four different pairing modes based on the proton-proton, neutron-neutron, and isoscalar and isovector neutron-proton correlations.

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NO CORE SHELL MODEL STUDY FOR NITROGEN ISOTOPES

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At the present time, *ab initio* methods are most powerful techniques to solve many body problem. In the present work, we show no core shell model calculations (NCSM) [1] for Nitrogen isotopes using inside non local outside Yukawa (INOY) [2] *NN* effective interaction at hΩ = 22 MeV. In NCSM all the particles are taken active. We solve the Schrödinger equation for *A*-nucleons nonperturbatively. The starting *A*-dependent intrinsic Hamiltonian:

$$H_A = T_{rel} + V = \frac{1}{A}\sum_{i<j}\frac{\left(\vec{p_i} - \vec{p_j}\right)^2}{2m} + \sum_{i<j}^{A} V_{NN,ij} + \cdots$$

Where, m is the nucleon mass, $V_{NN,ij}$ is the *NN* interaction having nuclear and Columbic part both. We add the center of mass (CM) Hamiltonian to make initial Hamiltonian frequency dependent. The CM Harmonic Oscillator (HO) Hamiltonian can be subtracted out later in the final many body Hamiltonian. Since, the Hamiltonian is translationally invariant, so the CM HO has infect no effect on the intrinsic properties of the system. We use Okubo-Lee-Suzuki unitary transformation [3] to soften the INOY interaction, because when we use INOY *NN* interaction it produces short range correlations which cannot be accommodated in the HO basis. We use the HO basis space truncated by a cutoff parameter N_{max}. The choice of INOY interaction is the non-locality present in it. This interaction gives the effects of three body forces without adding three body forces explicitly. We have reached up to N_{max}= 6 for ^{14}N isotope for positive parity states. The effective dimensions corresponding to N_{max}= 6 and N_{max}= 8 (further working for higher N_{max}) are 2.1×10^7 and 5.4×10^8, respectively (positive parity states). For negative parity states, the dimensions corresponding to N_{max}= 5 and N_{max}= 7 are 3.5×10^6 and 1.1×10^8, respectively. We show how the ground state (g.s.) energy varies with the frequency and model space sizes. We select a HO frequency hΩ = 22 MeV, around which the g.s. is very less dependent on HO frequency. So, we have chosen this frequency to calculate the energy spectrum for ^{14}N isotope. We get 1^+ as a g.s. in the NCSM calculations corresponding to highest model space N_{max}= 6 obtained in the NCSM calculations for ^{14}N. The 0_1^+, 2_1^+ and 3_1^+ state are at 3.177 MeV, 8.669 MeV and 22.293 MeV above from the g.s., respectively. The 3_1^+ state is at very high in energy. In the present work, we show how the excited states vary with the increasing model space size and reaching towards the experimental values. The quadrupole moment of g.s. is +0.50058 eb corresponding to N_{max}= 6 basis space.

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THE PAIRING-INTERACTION IMPACT ON THE β-DECAY CHARACTERISTICS AND MULTI-NEUTRON EMISSION OF THE NEUTRON-RICH ^{126,128,130,132}Cd

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The effects of the residual interaction in the particle-particle channel on β-decay characteristics and the multi-neutron emission probabilities in the β-decay of ^{126,128,130,132}Cd are studied within the quasiparticle random phase approximation with the Skyrme interaction. The coupling between one- and two-phonon terms in the wave functions of the low-energy 1^+ states of the daughter nuclei is taken into account. It is shown that the inclusion of the spin-isospin interaction in the particle-particle channel leads to the reduction of half-lives and the redistribution of one- and two-neutron emission probabilities. The competition of the tensor interaction and the neutron-proton pairing in the β-decay characteristics of the neutron-rich Cd isotopes is discussed.

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