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Report of Abstracts

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A Particle-Rotor Model Description of 29F *

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Recent results from RIKEN/RIBF on the low-lying level structure of 29F, and state of the art Shell Model calculations using the SDPF-M effective interaction [1], suggest the extension of the N=20 Island of Inversion to the Z=9 Fluorine isotopes.

In this work we discuss the low-lying excitation spectrum of 29F in terms of a collective picture [2], with a level structure corresponding to the rotation-aligned coupling limit of the Particle Rotor Model (PRM) [3].

The Coriolis coupling effects on the proton d5/2 Nilsson multiplet give rise to a (favored) decoupled band, with its 5/2+ bandhead naturally emerging as the ground state. The first excited state corresponds to the anti-aligned 1/2+ configuration at an energy that depends directly on the core E(2+). We find a consistent solution at a deformation of ε ~ 0.17, corresponding to an excitation energy of the 2+ in 28O at ~2.4 MeV, in line with the conclusions reached in Ref. [1].

PRM predictions for some spectroscopic observables will also be presented and discussed in the context of a Coulomb Excitation experiment approved at RIKEN [4]. If similar energetics and coupling conditions persist, a πd5/2 x νf7/2 double-decoupled structure in 30F is predicted with a 6- ground state.

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A new scattering chamber for conducting precision experiments on the heavy-ion reaction cross sections at the accelerator DC-60 (Astana, Kazakhstan) at low energies

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Within the framework of the long-term program of cooperation between JINR, ENU and Institute of Nuclear Physics (INP), joint experiments connected with the peculiarities of the interaction of lithium nuclei (6-9,11Li) at energies near the Coulomb barrier will be conducted on the U-400M cyclotron of G.N. Flerov Nuclear Reaction Laboratory (FLNR JINR) and on the DC-60 accelerator (Astana) of the INP. To obtain new experimental information on the properties of weakly bound (cluster and exotic) lithium nuclei (the entire chain of lithium isotopes) and their manifestation in interaction with other nuclei, the features of the angular distributions of elastic and inelastic scattering cross sections, the energy dependences of the total reaction cross sections (σR(E) and cross sections of individual dominant reaction channels; the corresponding reaction mechanisms in the previously unexplored region of energy will be studied.
Experiments in Astana (Kazakhstan) are supposed to be carried out at the DC-60 using a new scattering chamber and corresponding detector systems and nuclear electronics, which was manufactured at the FLNR JINR. The new dispersion chamber for the DC-60 is a completely new modern installation, which includes a new electronic system for collecting and processing experimental information FASTER.
Control experiments using the new camera will be conducted on beams 6,9,11Li at the FLNR JINR and on 7Li nuclei – on the DC-60. These nuclei (6,7,9Li) have a weakly bound cluster structure, and the 11Li nucleus is an exotic nucleus with a very low binding energy (Ebind = 0.3 MeV). In such experiments, we are expected to detect the features of their manifestation in nuclear reactions near the Coulomb barrier: subbarrier fusion, an increase in the cross section for cluster transfer reactions, features in the angular distributions of elastic and inelastic scattering, and features in σR(E. The obtained information is of great importance for fundamental nuclear physics and in other fields of science, for example, for describing the scenario of nucleosynthesis in astrophysics.

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Ab initio translationally invariant nonlocal one-body densities

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Nonlocal nuclear density is derived from the no-core shell model (NCSM) one-body densities by generalizing the local density operator to a nonlocal form. The translational invariance is generated by exactly removing the spurious center of mass (COM) component from the NCSM eigenstates expanded in the harmonic oscillator (HO) basis. The ground state local and nonlocal density of ^{4,6,8}He, ^{12}C and ^{16}O are calculated to display the effects of COM removal on predicted nuclear structure. This enables the ab initio NCSM nuclear structure to be used in intermediate energy nuclear reactions. We include the nonlocal density in calculations of optical potentials and show more accurate theoretical predictions for the differential cross sections of proton scattering off of stable and exotic light nuclei.

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Constraining the ^{30}P(p,γ)^{31}S Reaction Rate, via a Measurement of the ^{32}S(p,d)^{31}S* Reaction

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Accurate modeling of classical nova nucleosynthesis is fundamentally dependent on the thermonuclear reaction rates of the nuclei involved. In particular it has been shown that the ^{30}P(p,γ)^{31}S reaction rate is the largest source of uncertainty in the final abundance of nuclei created in a classical nova, involving an ONe white dwarf. The calculation of the ^{30}P(p,γ)^{31}S reaction rate, at nova temperatures, requires knowledge of the spin and parity assignments and partial widths of the levels in ^{31}S just above the proton threshold. To obtain the relevant nuclear data, a measurement of the ^{32}S(p,d)^{31}S* reaction has been performed at the Texas A&M Cyclotron Institue using a proton beam from the K150 cyclotron and a target consisting of ZnS deposited on a thin carbon backing. The newly commisioned, high-efficiency, particle-gamma array, Hyperion, was used in a configuration with 12 HPGe clover detectors and a dE-E telescope of segmented annular silicon detectors downstream of the target position for the detection of direct reaction products. In addition, a single silicon detector was placed upstream of the target for the detection of decay protons. Initial results from the experiment will be presented.
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Cooled BGO array detector for experiments at JUNA

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Jinping Underground lab for Nuclear Astrophysics (JUNA) is designed to directly measure the cross-sections of crucial reactions during the evolution of hydrostatic stars. The extremely low cross-sections of radiative capture reactions within their relevant Gamow peaks require a gamma detector with high detection efficiency. For this reason, we have constructed a 4π BGO array detector composed of eight crystals with a length of 250 mm and a radial thickness of 63 mm. In order to improve the energy resolution of the BGO array detector, all the crystals are cooled to -20 degrees Celsius. An energy resolution <11% is observed for the 661 keV gamma ray.

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Coulomb shift in two-center mirror nuclei

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The so-called alpha cluster structure appears in the excited states of light nuclear system, and the structures have been extensively investigated in the N=Z systems. Furthermore, the alpha cluster structures are also discussed in neutron-excess (N>Z) systems extensively.

In the present report, we focus on the mirror systems, which are obtained by replacing neutrons to protons in neutron-excess system, and demonstrate that the Coulomb shift of the mirror systems is a new probe to catch the sign of the clustering phenomena. Here we discuss the Coulomb shift of the mirror systems, such as (18O = alpha + 14C) - (18Ne = alpha + 14O).

The interaction potential of alpha and the residual nucleus is derived from the double folding (DF) model with the effective nucleon-nucleon interaction of the density-dependent Michigan 3-range Yukawa. The validity of the DF potential is checked by applying it to the alpha + 14C elastic scattering. The scattering calculation with the DF potential nicely reproduces the observed differential cross sections.

The energy level of these mirror systems are calculated from the orthogonality condition model (OCM), in which the functional space allowed by the Pauli's exclusion principle is exactly constructed. Here we have constructed the Pauli's allowed space by employing the mathematical technique of the SU(3) group representation in nuclei. The resonant 0+ levels and their decay width are identified by imposing the absorbing boundary condition. Above the alpha decay threshold, two resonant 0+ states are obtained, which seem to be consistent to the recent observations of the alpha + 14C elastic scattering and the multi-nucleon transfer reaction.

We have evaluated the energy shift of the 0+ states in the mirror systems of 18O - 18Ne, which arises from the difference of the Coulomb interaction. The OCM calculation predicts that the Coulomb shift for the resonant 0+ states is prominently reduced in comparison to the shift for the low-lying bound states. This reduction of the Coulomb shift for the resonant 0+ state is induced by the development of the alpha clustering. Therefore this result strongly suggests that the Coulomb shift is new probe to identify the cluster degrees of freedom.

In this report, we will discuss the relation of the reduction of the Coulomb shift and the development of the cluster degrees of freedom in detail.

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Decay mode of the linear-chain states in C isotopes

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Recent years have seen many important experimental studies for the linear-chain states (linearly aligned 3α particles) in 14C and 16C.
These new data motivated us to perform an analysis and to summarize the calculated and observed properties of the linear-chain bands in carbone isotopes.
In this presentation, the linear-chain states of 14C and 16C and their decay modes are theoretically investigated by using the antisymmetrized molecular dynamics. It is found that the positive-parity linear-chain states have the molecular orbit configuration and primary decay to the 10,12Be(2+ 1) as well as to the 12Be(g.s.) by the α particle emission.
Moreover, we show that they also have 6He decay widths.
Their α and 6He reduced widths are sufficiently large to be distinguished from other non-cluster states.

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Development of the gaseous Xe scintillation detector for the particle identification of high intensity and heavy RI beams

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For the experiments of unstable nuclei, the cocktail RI beams produced by the fragmentation of HI beams are often used. It is necessary to identify the RI beam event by event RIBF can provide the high intense RI beam, but we cannot fully utilize it due to the radiation damages of the existing detectors for the particle identification. To get enough data efficiently in a limited time, we need new detectors which have a good radiation hardness, a fast timing response, and a good energy and timing resolution.
For this purpose, we have developed a new detector employing the scintillation of the gaseous Xe. Since Xe gas is known to have a small work function,a high energy resolution is expected. However, the scintillation properties of the gaseous Xe from high-energy and –intensity HI particles not fully understood so far.
In order to evaluate the performance of the gaseous Xe scintillation detector, we tested it with a primary beam of 132Xe 290Mev/u and a secondary beam of A/Z ~2.28 at 300MeV/u produced by 132Xe 400MeV/u at Heavy Ion Medical Accelerator in Chiba in Nov.2017. I will report the result of this experiment in this conference.

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Effect of Tensor Force on Proton Shell Evolution in the ”South-West” of 132Sn: Low-Lying -emitting Isomers in 123,125Ag

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The beta-delayed gamma-ray spectroscopy of 123,125Pd are investigated at the Radioactive Isotope Beam Factory of the RIKEN Nishina Center. Neutron-rich nuclei 123,125Pd are produced by in-flight fission of the 238U beam at 345 MeV/nucleon. The 1/2− low-lying beta-emitting isomers in 123,125Ag and gamma transitions feeding into the isomers are constructed for the first time and the results are compared to large-scale shell-model calculations using the state-of-the-art EPQQM effective interaction. The effects of the monopole interaction on the proton shell evolution in the "southwest" of 132Sn are discussed in terms of Vmu interaction.

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Fragmentation of carbon on elemental targets at 400 A MeV

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The total charge-changing reaction cross-sections and the partial cross-sections of projectile fragments(PFs) production for the fragmentation of 12C on C, Al, Cu, Pb and CH2 targets at the highest energy of 400 A MeV are investigated. It is found that the total charge-changing cross-sections and the partial cross-sections of PFs production for the fragmentation are independent of the beam energy, and increase with increase of mass of target for the same beam energy. The total charge-changing reaction cross section is the same as the prediction of Bradt-Peters semi-empirical formula, PHITS and NUCFRG2 models. The partial cross section of PFs production increases with the increase of the mass of target, and it is the same as the prediction of NUCFRG2 model. The average scattering angle of beam particle is less than the mean emission angle of PF, and the width of scattering angle distribution of beam particle is less than that of emission angle distribution of PF. The mean emission angle of PF increases with the mass of target for the same beam energy and charge of PF.

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Investigation of 198,200Hg isotopes

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The observation of a large permanent electric dipole moment (EDM) would represent a clear signal of CP violation from new physics outside the Standard Model. The 199Hg isotope currently provides the most stringent limit on an atomic EDM, which is converted to a limit on the nuclear EDM via a calculation of the Schiff moment, requiring knowledge of the nuclear structure of 199Hg. Ideal information to further develop and constrain the 199Hg Schiff moment nuclear structure theoretical models would be the E3 and E1 strength distributions to the ground state, and E2 transitions amongst excited states. The high level density of 199Hg makes those determinations extremely challenging, however similar information can be obtained from exploring surrounding even-even Hg isotopes. One of the most direct ways of measuring the E3 and E2 matrix elements is through inelastic hadron scattering, and single-nucleon transfer reactions on targets of even-even isotopes of Hg can yield important information on the single-particle nature of 199Hg.

As part of a campaign to study the Hg isotopes, a number of experiments have been performed using the Q3D spectrograph at the Maier-Leibnitz Laboratory, with 22 MeV deuteron beams impinging on enriched Hg32S targets. The first set are inelastic deuteron scattering experiments, 198Hg(d,d')198Hg and 200Hg(d,d')200Hg. Deformation parameters were extracted through coupled-channel calculations with global optical-model potential (OMP) parameter sets for 200Hg. The second set of experiments were single-nucleon transfer reactions, 198Hg(d,p)199Hg and 200Hg(d,t)199Hg, with spin-parity assignments and spectroscopic factors extracted through distorted-wave Born approximation calculations with global OMP sets. Highlights of the results for the four experiments will be presented.

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Investigation on alpha clustering via knockout reaction

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The alpha clustering has been one of the main interest in nuclear physics. In order to probe the alpha clustering through reaction observables, the proton-induced alpha knockout reaction, (p,p alpha), is considered in this study. The purpose of this work is to reveal how the alpha cluster amplitude is probed through the (p,p alpha) reactions.
Within the distorted wave impulse approximation (DWIA) framework, We have newly introduced the "masking function" which defines the probed region of the alpha cluster amplitude through the (p,p alpha) reactions. It has been clearly shown by means of the masking function that the alpha knockout reaction probes the alpha cluster in the nuclear surface, which will be the direct measure of well-developed alpha cluster states. A simplified form of the masking function is also introduced and the incident energy dependence of the masking effect is investigated.
As a conclusion, alpha knockout reaction can be the probe for the alpha cluster amplitude in the nuclear surface owing to the masking effect originated from the absorption of distorting potentials, and is a suitable method to investigate how alpha cluster states are spatially developed.

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Isoscalar monopole and dipole transitions as a probe for cluster states in 24Mg

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In this contribution, we will show that isoscalar monopole and dipole transitions are a good probe for cluster states in 24Mg. The cluster states having significant influence on He- and Carbon-burning processes such as 12C+12C and 4He+20Ne are expected in 24Mg according to Ikeda diagram. However, their existences are still ambiguous due to experimental and theoretical difficulties. In this decade, it was suggested that cluster states can be strongly populated by isoscalar monopole and dipole transitions. This means that unknown cluster states can be accessible by isoscalar monopole and dipole transitions. Therefore, we will present antisymmetrized molecular dynamics calculation results for 24Mg and reveal that relation between isoscalar monopole and dipole transition strengths and cluster states of 24Mg. Furthermore, we discuss the p-, 4He- and 12C-decay widths of the excited states.

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Maris polarization of neutron-rich nuclei

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I will discuss the Maris polarization effect and its application in quasi-free reactions to assess information on the structure of exotic nuclei. The uncertainties in the calculations of triple differential cross sections and of analyzing powers due the choices of various nucleon-nucleon interactions the optical potentials and limitations of the method are the main focus. Theoretical calculations explore a large number of choices for the nucleon-nucleon (NN) interactions and the optical potential for nucleon-nucleus scattering and implies that polarization variables in (p,2p) reactions in inverse kinematics can be an effective probe of single-particle structure of nuclei in radioactive-beam facilities.

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Microscopic analysis of elastic scattering based on chiral g matrix

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We investigated the effects of three-nucleon force (3NF) from chiral effective field theory on nucleon-nucleus (NA) and nucleus-nucleus (AA) elastic scattering by using g-matrix folding model. To clarify the 3NF effects accurately, we constructed new g-matrix, so called chiral g matrix, from chiral two-nucleon force and 3NF by using Bruckner-Hartree-Fock method and localized the g matrix in order to apply g-matrix folding model. In this conference, we will show the microscopic analysis with chiral g matrix reproduces the experimental data without introducing any adjustable parameter.

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Microscopic optical potential obtained from energy-density-functional approach for nucleon-nucleus elastic scattering

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Nucleon-nucleus (NA) optical potentials are microscopically generated from a fully self-consistent framework of the particle-vibration coupling (PVC), in which the nucleon-nucleon (NN) effective interaction of the Skyrme type is consistently used to describe the Hartree-Fock (HF) mean-field, the small amplitude collective motions of the target, and the particle-collective states coupling. For the first time, a systematic calculation of low-energy NA elastic scattering off a series of doubly closed-shell nuclei is carried out without ad hoc adjusted parameters. Angular distributions obtained using the present optical potentials are in good agreement with the experimental data. This will be a major step forward in the applications of the Skyrme energy-density-functional theory to build up the global microscopic optical potentials, which are expected to be a powerful tool for the study of unstable (exotic) nuclei at low incident nucleon energies.

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Microscopic optical potentials for nucleus-nucleus scattering based on the Glauber model

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Recently, study on unstable nuclei near the neutron dripline has been attracted by the development of radioactive ion-beam experiments. The optical potential between a projectile and a target is a basic ingredient to describe the elastic scattering. In the neutron-rich region, it is difficult to determine the phenomenological optical potential due to restrictions on experimental data. Therefore, we need to construct the optical potential microscopically.

The g-matrix folding model has been widely used as a reliable method to obtain the microscopic optical potential. In the previous works, we proposed a double-single folding (DSF) model for 3He and 4He scattering, in which the optical potential between 3,4He and a target is constructed by folding the projectile density with a microscopic nucleon-target optical potential. The DSF model well reproduces the experimental data without any adjustable parameter. However, the same approach does not work well for the case of unstable nuclei, since the DSF model neglects projectile-excitation effects that are important for reactions involving weakly-binding nuclei. The continuum-discretized coupled-channels method (CDCC) can provide the framework to circumvent this shortcoming.

In our research, we propose a method to construct a microscopic optical potential including projectile-excitation effects by combining the DSF model with the Glauber model. In this conference, we will report properties of the obtained potential, and discuss applicability to reactions involving unstable nuclei.

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Neutron-proton Pairing Correlations and Deformation for N = Z Nuclei in sd, pf, gd-shell by the deformed BCS and HFB approach

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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, pf, dg-shell. 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, which give rise to smearing of the Fermi surface revealing interesting evolution of the Fermi energy along the shell evolution. In this work, like-pairing and unlike-pairing correlations decomposed as isoscalar $T = 1$ and isovector $T = 0$ components are explicitly taken into account. Finally, 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.

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Nuclear collective excitation within finite-amplitude method

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Giant resonances provide us important information on nuclear collective properties. For the nuclear density functional theory (DFT), the giant resonance will determine the coupling constants that are not very well constrained from the ground-state properties. In order to assess the giant resonances in a wide region of the nuclear chart, an efficient technique to compute the giant-resonance energy is necessary for constraining the coupling constants in the nuclear energy density functional.
The quasiparticle random-phase approximation (QRPA) is a standard theory for describing various kinds of small-amplitude collective modes including giant resonances based on the nuclear DFT. The

widely used technique for the QRPA problem is, however, based on the matrix diagonalization, and is too demanding to perform repeatedly in medium and heavy systems as the dimension of the two-quasiparticle space become large.
The finite-amplitude method (FAM) technique for the linear-response theory [1] allows us to derive efficient solutions for the QRPA problem within the nuclear DFT. In this presentation, I will show the technique for evaluating the QRPA sum rules using the contour integration of the FAM response function in the complex-energy plane [2]. From the ratio of the sum rule, the giant-resonance peak energy can be evaluated. Typical examples of the giant-resonance energies of doubly magic systems are discussed. Among the sum rules of different energy moments, the energy-weighted and inverse-energy-weighted sum rule are the most important ones. I will extend the Thouless theorem for the energy-weighted sum rule in the case of the generalized nuclear DFT. The Thouless theorem has been conventionally derived from the expectation value of the double commutator of the Hamiltonian, but such a Hamiltonian operator does not exist in the case of the nuclear DFT. I will derive the theorem without using the double commutator of the Hamiltonian, and show the extended version of the theorem for the nuclear DFT [3].

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Nucleosynthesis by the neutrinos in the supernova explosion

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We present recent results of the the neutrino-process in the supernova explosion. In particular, we discuss the neutrino-nucleus reactions by the QRPA formalism. Sensitivity of the reaction on the nucleosynthesis is studied in detail. Also the MSW effects of the neutrino propagation are to be presented for discussions. Finally, other exotic effets on the neutrino propagation, like the neutrino self interaction, will be also discussed with numerical results of the related elements abundances in this talk.

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Peculiarities of interaction of weakly bound lithium nuclei (A=6–11) at low energies: Elastic scattering and Total reaction cross sections

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The review presents the latest experimental data on the total reaction cross sections and angular distributions of differential cross sections for elastic scattering of light weakly bound lithium nuclei 6–9,11Li [1].
A review of papers on the interaction of weakly bound (cluster and exotic) 6-9Li and 11Li nuclei published so far and their analysis shows that there are no experimental data on total reaction cross sections (TRC, σR) and it is necessary to measure it for Li-isotopes at energies from the Coulomb barrier Bc=(3–4) MeV up to (10–40) MeV/nucleon on 28Si, 27Al, 9Be, and 12C nuclei.
For the interacting systems (8,9Li+28Si), there are only two points with a large energy error (about ±10 MeV/nucleon) in Ref. [2] (Warner et al.): for (8Li+28Si)- reaction at 34 and 50 MeV/nucleon, and for reaction (9Li+28Si)- at 37 and 50 MeV/nucleon.
The new data on TRC for reactions (8,9Li+28Si) in the energy range (5–30) MeV/nucleon with their analysis are presented in [3]. In the TRC energy dependence of (9Li+28Si) reaction, a "bump", i.e., a local increase in the cross section in the energy interval (10–30) MeV/nucleon, was first observed. Therefore, this dependence requires further theoretical analysis and experimental study.
In Ref. [2] in the energy range from 25 to 52.5 MeV/nucleon there were only three points for TRC for the system (11Li+28Si) at energies of 29.9, 42.5 and 52.5 MeV/nucleon. The points have large errors both in energy (up to ±7 MeV/nucleon) and in the values of the cross section (±100 mb). In the work of Villari [4] one point at an energy of 25.5 with an error in the TRC value of ±386 mb was obtained. Li Chen [5] presents six points at energies from 25 to 41 MeV/nucleon, however, he does not give errors in cross sections and energy.
Therefore, the measurements of TRC (8,9,11Li+28Si), presented in [5, 3] and planned for 2018 in the previously unexplored energy interval, will fill the gap in the available literature data.
Large TRC values detected in the σR(E) dependence, as well as their rapid increase in a short energy interval in the low-energy region, can lead to a release of a large amount of energy, which is interesting in terms of search for new energy sources of the future.
The obtained new data (the existence of an anomalous increase in the TRC) in a narrow energy range (10-30) MeV/nucleon in the (6He, 9Li)+28Si reactions at barrier energies will enable scientists to explain important questions of nucleosynthesis (nuclear astrophysics).
One of the most important features explaining why light elements are abundant in the universe is the increase in the interaction cross sections in the sub-barrier energy region in nuclear reactions with weakly bound nuclei. This effect is especially strongly manifested for light cluster nuclei 6,9,11Li and nuclei with a neutron halo 6,8He and 11Li. The main channels of interaction of such nuclei are transfer, breakup and complete- fusion reactions.
Such peculiarities of interactions manifested in an increase in the cross section for the transfer of clusters and for complete-fusion reactions near the Coulomb barrier are typical of many weakly bound nuclei.
In the future, this will enable us to predict the trend in the change in the excitation function σR(E) in the interaction of a light weakly bound nucleus with the same target nucleus, in order to obtain the TRC energy dependence at barrier energies. In particular, scientists are very interested in the TRC behavior for such reactions as (11Li+2H), (11Li+9Be) and others at energies near (above and below) the Coulomb barrier.

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Production of isomer beam around 52Fe nucleus via projectile fragmentation

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Nuclear reaction in extreme condition is one of the attractive topics from the point of view of not only the nuclear structure and reaction but also the nucleosynthesis. Although the electron capture rate in supernova explosion is estimated from the charge exchange reaction with the ground state, the charge exchange reaction with the high-excitation energy state may provide the rate in the similar circumstance with the supernova explosion. Fusion reactions with superdeformed nuclei may provide us the high spin limit.

In some nuclei, there are long-lived states with high spins, so called isomers. The 12+ state in 52Fe is a typical high-spin isomer with the lifetime of 46 second. The production of such an isomer beam provides us the opportunities to challenge the reactions with high-temperature and high-spin state. Presently the reported isomer ratio of 52Fe(12+) is below 1% while the isomer ratio of 10% is required for charge exchange reactions. In this study we are aiming at the production of high-isomer-ratio beams by changing the transfer momentum and incident angle.

Experiment (program number H362) was performed at HIMAC in Chiba. The ratios of isomeric states in the beams are measured by using projectile fragmentation from 58Ni and 82Kr, changing momentum transfer, incident angle and incident nucleus.The incident energy was 350 MeV/u, which is similar to the typical incident energy at RIBF. The beam particles implanted the active stopper of plastic scintillator and two germanium detectors were placed beside the stopper in order to measure the gamma rays from the decay of isomeric states. The decay gamma ray from isomer of 52Fe was clearly observed and typical isomer ratio is more than 10 %.

In this talk, we report the detail of experiment and its result, and discuss the isomer production via fragmentation reactions.

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Progress of PANDORA Project

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The PANDORA (Particle Analyzer Neutron Detector Of Real-time Acquisition) system is a neutron detector based on plastic scintillator coupled to digital readout.[1] This system is designed for study of unstable nuclei by (p,n) reaction using inverse kinematics. As it is well known, the detection of low energy neutrons is difficult due to the gamma events background. A new type of scintillation material provides different response to neutrons and gamma rays, so we can select neutron events by analyzing the pulse shape. This pulse shape analyses can be done by a digital data acquisition (DAQ) system so that the gamma background can be greatly suppressed.

Comparing to ref. 1, newer version scintillators with better neutron-gamma discrimination performance are applied. In addition, the DAQ software was modified to suit our configuration and some bugs were fixed. The system was commissioned in a 6He(p,n)6Li reaction experiment and the system shows a good performance on neutron-gamma separation.

In this poster, we will show some results of the neutron-gamma separation and some preliminary results of our (p,n) reaction experiment.

Reference:
[1] L. Stuhl et al., Nucl. Instr. Meth. A 866, 164 (2017).

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Proton- and deuteron-induced reactions on 107Pd and 93Zr at 20 - 30 MeV/u

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Nuclear transmutation of long-lived fission products (LLFPs), which are produced in nuclear reactors, is one of the candidate techniques for the reduction and/or reuse of LLFPs. To design optimum pathways of the transmutation process, several nuclear reactions have been studied by using LLFPs as secondary beams. In this study, we report on the proton- and deuteron-induced reactions on 107Pd and 93Zr at 20 - 30 MeV/u.

The experiment was performed at RIKEN RIBF. The degraded RI beams at 20 - 30 MeV/u were produced by a newly developed beam line, OEDO. To induce the reactions, the high-pressure cooled gas targets (H2 and D2) were used. Reaction residues were analyzed by the SHARAQ spectrometer.

In this talk, we will present the details of the experiments and the obtained results.

This work was funded by ImPACT Program of Council for Science, Technology and Innovation (Cabinet Office, Government of Japan).

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Quasi-free (p, 2p) reactions with 200-MeV protons on 112,124Sn

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Single-particle structure and nucleon-nucleon correlations are a few topics of the R3B (Reactions with Relativistic Radioactive Beams) research program to be carried out at FAIR. CALIFA (CALorimeter for In-Flight detection of gamma rays and high-energy charged pArticles) is one of the detector systems of R3B. Components of the CALIFA Barrel are currently being assembled and tested. At the Bronowice Cyclotron Center in Krakow, a beam of 200-MeV protons was used to induce quasi-free (p, 2p) reactions on various targets such as 12C, 16O, 112Sn, 124Sn, and 208Pb. Light charged fragments and gamma rays were detected with several CALIFA Barrel detector modules consisting of CsI(Tl) crystals. Preliminary results from reactions on the 112Sn and 124Sn targets will be presented, with emphasis on the differences in reaction cross sections to the ground and excited states of the residual isotopes.

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Recent advances and current status of chiral nuclear forces

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During the past two decades, chiral effective field theory has evolved into a powerful tool to derive nuclear two- and many-body forces in a systematic and model-independent way. Nowadays, most ab initio calculations of nuclear structure and reactions (including, in particular, exotic nuclei) are conducted with chiral forces. Therefore, it is of interest to have an overview of the status in the field. Thus, after providing some background, I will summarize the state of the art in the construction of high-quality chiral two-nucleon forces. Furthermore, I will also elaborate on the derivation and application of chiral three-nucleon forces, indispensible for any meaningful microscopic calculation.

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S-matrix analysis of pairing correlation effects on low-energy s-wave scattering in neutron-rich nuclei

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Effects of pairing correlation on s-wave scattering in superfluid nuclei are discussed. In the s-wave, single-particle potential resonance cannot be formed due to no potential barrier, whereas quasi-particle resonance can be formed by the pairing correlation. The quasi-particle resonance is a novel resonance in superfluid nuclei which is predicted by the Hartree-Fock-Bogoliubov (HFB) theory.
In recent progress of the SAMURAI experiments in RIKEN, characteristic s-wave peaks are observed in invariant mass spectroscopy of 21C. We anticipate that the s-wave peaks can be the s-wave quasi-particle resonance.
We analyze in detail how the low-lying s-wave quasi-particle resonance is governed by the pairing correlation in neutron drip-line nuclei. Solving the HFB equation in coordinate space with the scattering boundary condition, we calculate the phase shift, the elastic cross section, and the S-matrix. We find that the pairing correlation influence strongly the phase shift and the elastic cross section, in addition, four poles of S-matrix emerge by the pairing correlation. As a numerical example, we consider the 20C+n(s1/2) system to discuss the low-lying s-wave quasiparticle resonance.
In this presentation, we explain, using the S-matrix analysis, how the s-wave resonance caused by the pairing correlation (the s-wave quasi-particle resonance) emerge in neutron drip-line nuclei.

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Spectroscopy of Neutron-Rich Al Isotopes at the Border of the Island of Inversion

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Neutron-rich Al isotopes (Z=13) lie at the transition point between the classical shell gap N=20 and the Island of Inversion (IoI). Extended spectroscopy of the isotopes 32-35Al was performed at NSCL. Each isotope has been produced via several reaction mechanisms (proton and neutron knockout, fragmentation, charge changing, inelastic scattering) which are sensitive either to the proton or neutron single-particle-like states or to collective states. The reaction products, i.e. fragments and prompt gamma-rays, were detected with the S800 Spectrograph and GRETINA, respectively.

Gamma-gamma coincidence analyses were performed and existing level schemes were updated. The N=20 nucleus 33Al was produced via one- and two-proton and one-neutron knockout. A comparison of the cross sections for the populated states shows clearly states belonging either to the proton or neutron shells. The analysis of the parallel momentum distribution from one-neutron knockout offers complementary information to reported one-proton knockout data.

The preliminary results will be presented and compared to state-of-the-art shell model calculations.

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Study of astrophysical α + 22Ne reaction using alpha transfer in inverse kinematics with TIARA and MDM spectrometer

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In core He burning and C-shell burning of massive stars, the 22Ne(α,n)25Mg reaction is considered to be a dominant neutron source for the weak s process. The reaction also largely contributes to the neutron production for the main s process in asymptotic giant branch (AGB) stars. While a variety of experimental attempts to determine the rate for this reaction at the Gamow window corresponding to s process temperatures have been made either through direct or indirect measurements, uncertainties of some resonance strengths in 26Mg, particularly about two resonances (Ex ~ 11.17 and 11.32 MeV) above neutron separation energy (Sn =11.09 MeV), have remained a long-standing problem. To address this problem, we performed an experiment using the 6Li(22Ne,26Mg)d α-transfer reaction in inverse kinematics at K150 cyclotron of Texas A&M University. A 6LiF target was bombarded with a 7 MeV/u 22Ne beam. Deuterons, γ-rays, and recoil Mg ions were detected in coincidence using a large Si detector array (TIARA), HPGe clover detectors, and an MDM spectrometer backed by an ionization chamber, respectively, to precisely obtain the 26Mg excitation spectrum. Results about the resonances obtained from the experiment will be presented.

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Study of the Molecular States in Oxygen 20

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It is well established that clustering is an essential aspect of nuclear many-body system. In neutron-rich domains, the valence neutrons in nuclei can exist in molecular orbitals, their role is similar to that of electrons in covalent bonds in atomic molecules, which help to stabilize the unstable multi-cluster states. The AMD plus GCM calculation found that the valence neutrons give richer structures for 20O. It suggests that the second 0+ band is a mixture of the 12C+4He+4n and 14C+6He cluster structures, and the third 0+ band and the 0- band have prominent 16C+4He cluster structure, and these two bands are regarded to be parity doublet bands.

Our group has performed an inelastic breakup experiment with a 30MeV/A 20O beam off a plastic target in Lanzhou to study the cluster states in 20O above 16C+α breakup threshold. With both the invariant mass and missing mass methods, we have detected the breakup fragments and the recoiled protons to reconstruct the two interest rotational bands. Thanks to the excellent energy calibration results and particle identification, 7 excited states of Oxygen 20 from this spectrum are in excellent agreement with those published in Bohlen's work. Besides, a new excited state is proposed to exist in Oxygen 20 with excitation energy of 17.16MeV, which decays predominantly in the way of cluster emission rather than neutron emission. And this state has not been observed by previous experiments.

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Study of the deuteron scattering on 7Li nuclei

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New data of the differential cross section of the elastic and inelastic scattering of deuterons has been measured at energies 14.5 MeV on the isochronous cyclotron U-150M (Institute of Nuclear Physics, Almaty). The differential cross sections of the scattering were obtained for the ground state and the following excited states of the 7Li: 1/2- (0.478 MeV), 7/2- (4.68 MeV) in the angular range 180 - 1400 in laboratory system. The angular distribution showed the diffraction structure of the elastically and inelastically scattered deuterons.
The optimal values of the potential parameters were established for the system "d + 7Li" as a function of the energy from the joint analysis of the literature data at the energy range 7 - 25 MeV [1-4] within the framework of the optical model. Previously, the analysis of scattering process was performed at energies 14.7 MeV [3] and 25 MeV [4], while at energy 14.7 MeV [3] the experimental data were obtained at the forward hemisphere.
The analysis of differential cross sections of elastic and inelastic scattering of deuterons on 7Li at energy 14.5 MeV were performed within the framework of the coupled channel method for the negative parity levels that constitute the rotational band on the ground state of the nucleus using the FRESCO program. The value of the quadrupole deformation parameter β2 determined from the analysis of the inelastic scattering and is in agreement with the values established from the analysis of the scattering data for deuterons [4].

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Study on performance of the OEDO beamline

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OEDO (Optimized Energy Degrading Optics for RI beam) is the renovation project of the SHARAQ beamline at RIBF-RIKEN to accommodate a RI beam of with a few tens of MeV/u by energy degrading method. The highly exotic beams with such an energy, which still have been uncharted territory for the existing RI beam facilities, are expected to be achievable by the OEDO beamline. The beamline was designed to produce a well-focused beam of small momentum dispersion from secondary beams separated by BigRIPS with the help of the angle-tunable energy degrader and the RF deflector.

The commissioning experiment of the OEDO beamline as a part of the ImPACT program for nuclear transmutation of long-lived fission products (LLFPs) was carried out after the completion of construction in last year. The 79Se and 107Pd beams at 35 MeV/u (30 MeV/u for 107Pd) were produced from the 180-MeV/u beams. The beamline elements were carefully optimized to obtain a beam of high quality.

In this talk, the evaluation results of the performance of the OEDO beamline together with responses on the beamline elements will be reported.

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TINA - a New Silicon Tracker for Transfer Reactions

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Transfer reactions are powerful tools to study the structure of atomic nuclei. The recently commissioned OEDO beamline of CNS and RIKEN can provide beams with the necessary intensities at low energies (10-20 MeV/u) offering experimental access to regions of the nuclear chart which were hitherto not accessible for transfer studies.

To utilize OEDO for transfer reactions, a detector array called TINA has been built and successfully used in two experiments. TINA is a joint project of CNS, RCNP Osaka and RIKEN Nishina Center. It is designed for the position and energy measurements of the recoiling light particles (protons) from transfer reactions in inverse kinematics.

The first version consists of six deltaE - E telescopes, each consisting of YY1-type silicon strip and CsI detectors. It has been used at Kyushu University Tandem Accelerator and at the OEDO facility. An excellent performance has been achieved in identifying light reaction products and in obtaining kinematics information with both stable and energy-degraded radioactive beams.

TINA is also compact enough to be coupled with 4-Pi gamma-ray detector arrays. An upgrade is ongoing that implements highly granular DSSD detectors to improve the angular resolution. The upgraded TINA will be well-suited for future transfer studies at OEDO and can compete with other world-leading devices.

A general overview, some first results about the performance and a short outlook on future perspectives will be presented.

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The neutron magic number 28 and the structure in neutron-rich nuclei

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The magic number 28 appears in the pf shell because of the spin-orbit interaction. However, in some $N \approx 28$ neutron-rich nuclei, the neutron magic number 28 disappears. This leads to the quadrupole deformation of the ground state, the reduction of the excited energies and so on. In what region of the nuclear chart, does the magic number disappear? This is one of the interesting problems. In particular, in $N = 26$ isotones which have less neutrons than closed nuclei, does the effect appear in the low-lying energy spectra? Then, we apply the antisymmetrized molecular dynamics (AMD) combined with the generator coordinate method (GCM), and study the structure of $N = 26$ isotones.

As a result, we found that 44Ar and 40Si have triaxially deformed shape, and 42S has prolate-deformed shape at the ground states. In addition, we found that several 2^+ states appear at low energies in these nuclei. It suggests that they are unstable against the deformation parameter γ.

Furthermore, we found that the rotational bands appear on the low-lying excited 0^+ states in 44Ar and 40Si. In these bands, 44Ar has prolate-deformed shape and 40Si has oblate-deformed shape. As a result of the analysis of the single particles, we found that around 40% of last neutrons occupy the p orbits in the oblate-deformed states of 40Si.
It suggests the reduction of the energy gap in the neutron magic number 28.

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Theoretical Study of Heavy-ion Charge Exchange Reaction at Intermediate Energies With Eikonal Model

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Heavy-ion charge exchange reactions at intermediate energies have drawn much attention because they have great advantages for determination of spin-isospin strength with better resolution and selectivity than that with nucleon probes such as (p,n) reaction. Such reactions could be used to extract values of GT strengh which is important for electron capture and beta-decay rates, and electron capture results in the deleptonization of the Steller environment. With the development of new facilities, accelerators, and detectors, there are more and more experimental studies of heavy-ion charge exchange reactions. However, in spite of the advantages of heavy-ion charge exchange reaction at intermediate energies, the reaction mechanisms for heavy ion induced charge exchange reactions are more complicated than that for (p,n) or (n,p) reactions. Now, based on Eikonal approximation, a newly developed theoretical instrument could give some results, and the results have been compared with that predicated by FOLD which has been developed based on DWBA.

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Two novel determinations of nuclear density, temperature, symmetry energy

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Nuclear symmetry energy, temperature and density at the time of the intermediate mass fragment formation are determined using two novel methods, i.e., a self-consistent method and a chemical potential method.

(1) In a self-consistent manner, the yields of primary hot fragments are experimentally reconstructed for multifragmentation events in the reaction system ^64Zn + ^112Sn at 40 MeV/nucleon. Using the reconstructed hot isotope yields and an improved method, based on the modified Fisher model, symmetry energy values relative to the apparent temperature, a_sym/T, are extracted. The extracted values are compared with those of the anti-symmetrized molecular dynamics (AMD) simulations, extracted in the same way as that for the experiment, with the Gogny interaction with three different density-dependent symmetry energy terms. a_sym/T values change according to the density-dependent symmetry energy terms used. Using this relation, the density of the fragmenting system is extracted first. Then symmetry energy and apparent temperature are determined in a self consistent manner in the AMD model simulations. Comparing the calculated a_sym/T values and those of the experimental values from the reconstructed yields, \rho /\rho_0 = 0.65 \pm 0.02 , a_sym = 23.1 \pm 0.6 MeV and T= 5.0 \pm 0.4 MeV are evaluated for the fragmenting system experimentally observed in the reaction studied.

(2) In the chemical potential method, ratios of differential chemical potential values relative to the temperature, (\mu_n-\mu_p)/T, extracted from isotope yields of thirteen reaction systems at 40 MeV/nucleon are compared to those of a quantum statistical model to determine the temperature and symmetry energy values of the fragmenting system. The experimental (\mu_n-\mu_p)/T values are extracted based on the Modified Fisher Model. Using the density value of \rho/\rho_0=0.56 from the previous analysis, the temperature and symmetry energy values of T=4.6 \pm 0.4 MeV and a_sym=23.6 \pm 2.1 MeV are extracted in a frame work of a quantum statistical model. These values agree well with those of the previous work, in which a self-consistent method is utilized with AMD simulations.

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Valence particle/hole-core couplings in neutron-rich, exotic nuclei

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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 [1].
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 (France) and LNL (Italy), by using large γ-ray setups based on HpGe Detectors.
Experimental results will be interpreted by a new microscopic theoretical model, the Hybrid Configuration Mixing Model [2-3], specifically designed to describe the structure of nuclear systems with one valence particle/hole outside a core. The model includes couplings between valence nucleons and core excitations in a self-consistent way, 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 configurations.
The agreement between experimental and theoretical energies, electromagnetic transition probabilities and spectroscopic factors will be outlined, especially in the case of ^{133}Sb and ^{49}Ca, 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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cluster structure in 18O

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Alpha particle clustering is an important concept in nuclear physics, and it has been used over the years to explain certain features in nuclei, especially for the study of light N = Z nuclei. It proved to be far more difficult to study clustering phenomena in non-self-conjugate N != Z nuclei because of the addition degrees of freedom from the extra nucleons. However, the extra nucleons may have important and special contribute to the formation of exotic, molecular-type structures, which provide an opportunity to understand the interplay between cluster and nucleon degrees of freedom. 18O is the prime example of a non-self-conjugate nucleus for which clustering is known to play an important role.
A new experiment has been carried out at CIAE in 2017 to investigate the cluster structures of 18O through the multi-nucleon transfer reaction 9Be(13C,14C+alpha)alpha at 13C beam energy of 65MeV. In this experiment, coincidence detection of the 14C and alpha breakup fragments from 18O was done by six sets of silicon detector telescopes. Owing to the extremely large positive reaction Q-value, the interested reaction channel has been identified clearly. Through the missing mass method and invariant mass method, excited states of 18O from 7MeV to ~20MeV were observed. At present, further analysis has been applying to such states to extract the spin and then to search the monopole transition in 18O.