DREB2018 -- 10th International Conference on Direct Reactions with Exotic Beams

Monday, 4 June 2018 - Friday, 8 June 2018

Matsue

Programme

Table of contents

Monday 04 June 2018

Session 1 **(09:00-10:10)**

opening

time	[id] title
09:00	**[140] Welcome speech** *Presenter: OGATA, Kazuyuki*
09:05	**[141] Welcome speech** *Presenter: YAMADA, Kotaro (Tokyo Institute of Technology)*
09:10	**[142] Keynote talk 1** *Presenter: OBERTELLI, Alexandre*
09:40	**[143] Keynote talk 2** *Presenter: MORO, A. M.*

break - Kunibiki Messe (10:10-10:45)

Session 2 - Kunibiki Messe (10:45-11:57)

time   [id] title

10:45	**[90] Elastic scattering of 6He from polarized proton at 200 A MeV**

Presenter: SAKAGUCHI, Satoshi (Dept. of Physics, Kyushu University)

Spin-dependent interactions play essential roles in nuclear structure and reactions. One of the best known examples is the spin asymmetry found in nucleon elastic scattering, which is a direct manifestation of the spin-orbit interaction. Since the spin-orbit interaction is expected to work in the surface region, it is natural to expect that such interaction could be strongly modified by the characteristic surface structure of neutron-skin or -halo nuclei.

At RIKEN RIBF, we have measured the proton elastic scattering from 6He at 200 A MeV utilizing a spin-polarized proton target specially developed for the RI-beam experiments. Recoil protons were detected with ESPRI Recoil Proton Spectrometer. Scattered particles were analyzed by the SAMURAI spectrometer.

The differential cross sections have been obtained in the highest momentum transfer region among the existing measurement, where the cross sections are dominated by the contribution of an alpha core. The data will be shown and compared with theoretical calculations assuming different radii of the core distribution. Preliminary results of the vector analyzing power will also be presented.

11:03	**[6] Shape coexistence of neutron-rich ^{69,71,73}Co isotopes**

Presenter: LOKOTKO, Taras (The University of Hong Kong)

Observation of high 2^{+} excitation energy in ^{68}Ni (Z = 28, N = 40) had drawn a clear signature of double magic character in this nucleus [1]. And while ^{68}Ni can be described as spherical isotope, 2^{+} excitation energy of ^{66}Fe drops significantly [2], indicating deformed shape of ^{66}Fe. ^{67}Co isotope is in between ^{68}Ni and ^{66}Fe nuclei and found to share coexistence of both spherical and deformed structures in low-lying excited states [3]. This effect can be described as superposition of a proton f$_{7/2}$ hole coupled to neighbouring spherical even-even nickel isotope and a prolate proton-intruder state coupled to the ^{66}Fe isotope [4]. Discovery of shape coexistence in ^{67}Co rose an interesting question about further shape evolution in Co nuclei, namely ^{69,71,73}Co and shell transformation from N = 40 to N = 50.

In-beam gamma experiment was performed at Radioactive Isotope Beam Factory, RIKEN Nishina centre, Japan. Secondary beam of ^{70,72,74}Ni and ^{72}Co isotopes at energy of 260 MeV/μ bombarded liquid hydrogen target (MINOS) to produce ^{69,71,73}Co nuclei via (p, 2p) and (p, pn) reactions. DALI2 NaI(Tl) detector array was used to measure γ-rays. Energy levels were studied using γ-γ coincidence technique. Systematics of excited states of cobalt isotopes was compared with Lenzi-Nowacki-Poves-Sieja (LNPS) model [5] of nuclear interaction using fpgd model space. Experimental results of ^{69,71}Co spectrums show that isotopes share shape coexistence, as spherical structure coexists with deformed band. In case of ^{73}Co nucleus, due to the lack of statistics only spherical band is confirmed.

In this talk the evolution of shell structure in ^{69,71,73}Co isotopes will be discussed together with physics behind the shape coexistence in neutron-rich Co nuclei.

References.
1. R. Broda, B. Fornal, W. Krolas, and T. Pawkat, Phys. Rev. Lett. 74, 868 (1995);
2. S. Lunardi, S. M. Lenzi, F. Della Vedova, Phys. Rev. C, 76, 034303 (2007);
3. F. Recchia et al., Phys. Rev. C 85, 064305 (2012);
4. D. Pauwels et al., Phys. Rev. C 78, 041307(R) 2008;
5. S. M. Lenzi, et. al., Phys. Rev. C 82, 054301 (2010).

11:21 | **[46] Single-particle structure of ^{93,94,95}Sr nuclei**

Presenter: SOUMENDU SEKHAR BHATTACHARJEE, Soumendu (Post Doctoral Fellow at TIGRESS)

The level structure of neutron rich ^{93,94,95}Sr were studied via the \dtsr{94,95,96}, one neutron pickup reactions at TRIUMF. Excited states were populated when ^{94,95,96}Sr beams of 5.5 AMeV bombarded a 0.5 mg/cm^2 CD$_2$ target. The de-exciting γ-rays and outgoing charged particles were detected by using the TIGRESS and SHARC arrays, respectively. The level scheme was contructed by using both E$_x$ vs E$_{\gamma}$ and E$_{\gamma}$ vs E$_{\gamma}$ matrices. Three excited states were observed in ^{93}Sr and ^{95}Sr, respectively. A total of ten excited states were observed in ^{94}Sr of which four states were newly identified in the present experiment. Angular distribution measurements suggest spin and parity assignments for the 1880 (0$^+$), 2294 (0$^+$) and 2415 (3$^+$) keV levels and constrain the other five levels 2615, 2705, 2921, 3077 and 3175 keV in ^{94}Sr. In this work no γ-ray transitions were observed from the 1880 and 2294 keV levels directly to the ground state. This is consistent with spin and parity assignments of the 1880 and 2294 keV levels as 0$^+$. The spectroscopic factors were calculated by fitting DWBA calculations to experimental angular distribution data and taking into consideration γ-decay branching ratios. Shell model calculations were carried out to understand the present experimental observations by using updated interaction and appropriate truncation schemes. The calculation was performed by using an updated NuShellX code and $glek$ interaction. The single-particle energies of the interaction were adjusted in such a way that the calculated and experimentally observed energy levels were in good agreement in the N $\sim$ 56 and Z $\sim$ 38 region. In the present calculations the valence [$1d_{5/2}$], [$2s_{1/2}$], [$1d_{3/2}$] and [$0g_{7/2}$] orbitals were included for neutrons outside the $N = 50$ inert core. The proton degrees of freedom were varied systematically so that the effect of the proton valence space on the calculated levels could be studied. The calculated energy levels and spectroscopic factors that were predicted are in reasonable agreement with the experimental findings. This suggests that the low-energy states are predominantly neutron configurations with minor contributions from excitations between the proton [$1p_{3/2}$] and [$1p_{1/2}$] orbitals.

11:39 | **[100] Single-particle states and collective modes: results from magnetic moment measurement of 75mCu**

Presenter: ICHIKAWA, Yuichi (RIKEN Nishina Center)

The atomic nuclei have dual features, the single-particle shell nature and collective modes, which are competing with each other to express the actual nuclear structure. Here we demonstrate the precision analysis of this competition by focusing on the magnetic moment of an isomeric state of a neutron-rich nucleus 75Cu, where an intriguing shell evolution has been reported.

The experimental magnetic moment measurement was carried out at RIBF, taking advantage of a spin-aligned RI beam obtained in a two-step projectile fragmentation scheme. The 75Cu beam with spin alignment reaching 30% was produced by one-proton removal from a secondary beam of 76Zn. The magnetic moment was determined by means of TDPAD method.

In this presentation, the production of spin alignment in the two-step fragmentation scheme will be introduced and the experimental results will be presented. Discussion on the above competition at the neutron-rich Ci isotopes, analyzed with the Monte-Carlo shell model calculation, will also be given.

Lunch break - Kunibiki Messe (11:57-13:30)

Session 3 - Kunibiki Messe (13:30-14:42)

time [id] title

13:30	**[66] Breakup reactions of one-neutron halo nucleus 31Ne**
	Presenter: TOMAI, Takato (Tokyo Institute of Technology, Department of physics)
	It is well known that N=20 shell gap disappears in the "island of inversion" and thus strong deformation appears.
	The one-neutron halo nucleus 31Ne, located in the island of inversion, has attracted much attention because it is the first example of a deformation-driven halo nucleus.
	Recent experimental studies on 31Ne revealed that it has low separation energy Sn=0.15(+0.16)(-0.10)MeV, and ground-state spin and parity 3/2-.
	These experimental results are consistent with a picture of deformed halo structure.
	However the deformation has not measured directly yet.
	We have performed an invariant-mass spectroscopy of 31Ne in the nuclear breakup reaction with a carbon target at ~230 MeV/u, aiming at observing its rotational band.
	Additionally we also carried out a Coulomb breakup measurement with a lead target at ~230 MeV/u, in order to investigate its ground state properties.
	These experiments have been done using SAMURAI spectrometer at RIBF, RIKEN.
	The experimental results will be discussed in the presentation.
13:48	**[76] First Spectroscopy of 40Mg**
	Presenter: CRAWFORD, Heather (Lawrence Berkeley National Laboratory)
	The study of nuclei far from stability is one of the most active and challenging areas of nuclear structure physics. One of the most exotic neutron-rich nuclei currently accessible to experiment is 40Mg [1], which lies at the intersection of the nucleon magic number N=28 and the dripline, and is expected to have a large prolate deformation similar to that observed in the neighboring lighter isotopes 32-38Mg [2]. In addition, the occupation of the weakly bound p3/2 state may lead to the appearance of an extended neutron halo[3]. Thus 40Mg offers an exciting possibility and a rare opportunity to investigate the coupling of weakly bound valence particles to a deformed core, and the influence of near threshold effects on collective rotational motion.
	We will discuss the results of an experiment carried out at RIBF RIKEN to study low-lying states in 40Mg produced by a 1-proton removal reaction from a ~240 MeV/u 41Al secondary beam. 40Mg and other final products were separated and identified using the Zero Degree Spectrometer, and prompt gamma rays detected using the DALI2 array. The observed excitation spectrum is shown to reveal unexpected properties as compared to both neighboring (more bound) Mg isotopes and theoretical model predictions.
	This work is supported by the U.S. Department of Energy, Office of Nuclear Physics, under contract no DE-AC02-05CH11231.
	[1] H. L. Crawford et al., Phys. Rev. C 89, 041303(R) (2014).
	[2] P. Doornenbal et al., Phys. Rev. Lett. 111, 212502 (2013).
	[3] F. Nowacki and A. Poves, Phys. Rev. C 79, 014310 (2009).

14:06	**[84] Shell structure of 43S studied by one-neutron knockout reaction**
	Presenter: MOMIYAMA, Satoru (Department of Physics, University of Tokyo)

South of 48Ca in the nuclear chart, the erosion of the neutron magic number 28 and the onset of collective behavior have been observed.

Especially the ground-state deformation, the shape coexistence, and the high-K isomerism in 44S have been discussed both experimentally and theoretically.

In this region these phenomena related to the deformation of the nucleus are thought to originate from the interplay of quenching the N = 28 shell gap and quadrupole excitations across Z = 14, 16 sub-shell and N = 28 shell gaps.

The proton configuration of the 44S ground state was investigated previously but the neutron occupation remains unknown prior to this study.

To clarify the reduction of the N = 28 shell gap and the role of the neutron configuration to the deformation in 44S, an in-beam gamma-ray spectroscopic study focused on the one-neutron knockout reaction from 44S was performed.

One-neutron knockout reaction can selectively produce neutron-hole states and is sensitive to the neutron occupation of the ground state of the projectile nucleus.

Also the parallel momentum distribution of the reaction residue is related to the orbital angular momentum of the knocked out neutron, which is helpful to assign the spin-parity to each final state of reaction residue.

The experiment was performed at the NSCL.

A 100-MeV/u secondary beam of 44S was produced by fragmentation of a 48Ca primary beam on a Be production target. The secondary beam impinged on a secondary beryllium target inducing the one-neutron knockout-reaction.

Prompt gamma-rays from excited states in 43S emitted at the target were detected by the GRETINA tracking array.

The one-neutron knockout residues were identified in the S800 spectrograph which also measures the momenta and angles of ejectiles.

In order to deduce the level scheme above the isomeric state at 320 keV in 43S and population to this state for the deduction of the neutron configuration in the fp shell, the IsoTagger which consists of 32 CsI scintillators was placed downstream at the end of the beam line.

The level scheme of 43S deduced via the in-beam gamma-ray spectroscopy of this experiment will be presented combining the analysis on momentum distributions produced by the one-neutron knockout reaction. There also will be the comparison with shell model calculations.

14:24	**[113] Multinucleon transfer and double charge-exchange reactions**
	Presenter: LAY VALERA, José Antonio (Universidad de Sevilla)

There is a renewed interest in single and double charge-exchange reactions due to its connection with the Fermi and Gamow-Teller transitions and double beta decay. It has given origin to different campaigns mainly at RCNP and RIKEN in Japan and at the LNS-INFN Catania in Italy. This last one is focused on the connection of double charge-exchange and the neutrinoless double-beta decay which would help to constrain the possibility of neutrinos to be Majorana particles and eventually the measurement of the mass of the neutrinos.

At the bombarding energies used at the LNS-INFN, different combinations of multinucleon transfer contributes to the final double charge cross section. These contributions are not present in the correspondent beta decay. However, this fact can be of help to further constrain the wavefunction of the nuclei involved since they can also be studied in terms of one and two nucleon transfer cross section which will be measured in the same experiment.

In this contribution, we will evaluate the total cross section for the double charge-exchange reactions 116Cd(20Ne,20O)116Sn and 40Ca(18Ne,18O)40Ar at 15 MeV/nucleon in order to compare with the preliminary experimental data. The double charge exchange will be evaluated as two sequential single charge-exchange processes in 2nd order DWBA. Multinucleon transfer will be added coherently. We will evaluate the possibility of obtaining a full description of the absolute cross section and non-orthogonality terms involved in the 3rd and 4th order DWBA calculations corresponding to the multinucleon transfer processes.

Break+Poster - Kunibiki Messe (14:42-15:15)

Session 4 - Kunibiki Messe (15:15-16:27)

time   [id] title

15:15	**[4] Investigating neutron-proton pairing in sd-shell nuclei via (p,3He) and (3He,p) transfer reactions**

Presenter: LEE, Jenny (The University of Hong Kong)

Pairing correlations, influencing almost every feature of ground and low-lying states in nuclei, lie at the heart of nuclear physics. Understanding the mechanism of neutron-proton (np) pairing in N=Z nuclei has been a long-sought goal in nuclear structure since the early sixties. Despite large efforts in both theoretical and experimental studies, the fundamental nature and the interplay between T=0 and T=1 pairs are still the subject of debate. Cross section measurement of np-pair transfer is considered as a sensitive probe for the insight into T=0 and T=1 np pairing collectivity and its mechanism [1-3].

We therefore carried out systematic np-transfer measurements spanning N=Z sd-shell nuclei using (p,3He) and (3He,p) reactions at RCNP Osaka University. In particular, we study the cross-section ratio of the lowest 0+ and 1+ states as an observable to quantify the interplay between T=0 (isoscalar) and T=1 (isovector) pairing strengths. The experimental results are compared to second-order distorted-wave Born approximation calculations with proton-neutron amplitudes obtained in the shell-model formalism using the universal sd-shell interaction B. Our results suggest underestimation of the nonneglible isoscalar pairing strength in the shell-model descriptions at the expense of the isovector channel. In this talk, we will present this work [4].

References:
[1] R. A. Broglia, O. Hansen and C. Riedel, Adv. Nucl. Phys. Vol 6, 287 (1973).
[2] D.R. Bes et al., Phys. Rep. Vol 34C, 1 (1977).
[3] P. Van Isacker et al., Phys. Rev. Lett. 94, 162502 (2005).
[4] Y. Ayyad, J. Lee et al., Phys. Rev. C 96, 021303(R) (2017).

15:33	**[30] Transfer reactions induced with 56Ni: np pairing and N=28 shell closure**

Presenter: GEORGIADOU, Anastasia (Institut de Physique Nucléaire d'Orsay (IPN))

An efficient way to explore the nuclear structure is the effective use of transfer reactions. Two different physical aspects are being investigated with the use of transfer reactions on 56Ni, which is a N=Z unstable doubly magic nucleus.

(i)To probe the gap of N=28, we study the spectroscopy of the N=29 and N=27 isotones by the (d,t), (p,d) and (d,p) one nucleon transfer reactions on 56Ni (N=28 isotone) and extract information on the single-particle configuration around the Fermi surface.

(ii)To study the np pairing in the self-conjugate nucleus 56Ni, we have measured the two-nucleon transfer reactions 56Ni(p, 3He)54Co [1] and 56Ni(d,α)54Co. In the (p,3He) reaction, the ratio of the population of the T=0 and T=1 states indicates a predominance of T=1 pairing [1]. The selectivity of the (d,α) reaction enables the investigation of the T=0 channel with better precision.

During spring 2014 the experiment aiming to these studies took place at GANIL-Caen, France. The radioactive beam of 56Ni at 30MeV/u was produced by fragmentation of 58Ni and purification. Measurements were performed in inverse kinematics on CH2 and CD2 targets. The experiment included a 4π coverage for the study of the charged projectiles with the MUST2 and TIARA detectors, while 4 clovers of EXOGAM were also used for γ-particle coincidences in order to identify the populated state of the residue. The analysis of the 56Ni(d,t)55Ni and 56Ni(d,p)57Ni reactions yield the differential cross-section for transfer reaction to the ground state and the excited states of 55Ni and 57Ni giving information about the shell closure and depicting the Fermi surface of 56Ni. I will present the angular distribution and compare with the results for the (p,dγ), (d,tγ) and (d,pγ) reactions, as well as with DWBA calculations. The results for the transfer reaction 56Ni(d,α)54Co will be also presented, completing the information about the strength of the isoscalar np pairing in the closure of the fp shell.

[1]Benjamin Le Crom, Thesis: "Etude de l'appariement neutron-proton dans les noyaux instables N=Z par réactions de transfert." Physique Nucléaire Expérimentale [nucl-ex]. Université Paris-Saclay, 2016.

15:51	**[73] Investigating excitation and nucleon correlation in 8He using reactions with a solid hydrogen target**

Presenter: HOLL, Matthias (Saint Mary's University / TRIUMF)

The nucleus 8He is the most neutron-rich nucleus known. Its structure, consisting of a 4He core surrounded by four neutrons makes it an ideal case to study phenomena in highly neutron-proton asymmetric systems and neutron correlations at the nuclear surface.

The effects of the valence neutrons were investigated experimentally using proton elastic and inelastic scattering of 8He at the IRIS facility at ISAC-II at TRIUMF at 8.25 A MeV. The two-neutron transfer from 8He was also measured to gain insight into pairing of the valence neutrons.

The presentation will give an overview of the IRIS reaction spectroscopy facility. It utilizes the novel solid H2 target in combination with a low-pressure ionization chamber to identify the incoming beam particles, and two Delta E-E telescopes to measure the reaction products.

Results of the data analysis will be presented featuring excited states in 8He from inelastic scattering. The elastic scattering cross section will be discussed in comparison to semi-microscopic optical potential calculations. A preliminary comparison of the cross sections for the population of the ground and first excited state in 6He from two-neutron transfer will be discussed as well.

16:09	**[59] Total cross sections of reactions 6,8He+28Si, 9,11Li+28Si and role of neutron rearrangement**

Presenter: SAMARIN, Viacheslav (Joint Institute for Nuclear Research)

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 light nuclei having different external neutron shells. A series of experiments on measurement of total cross sections for reactions 4,6,8He + Si and 6,7,9,11Li + 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 enhancements of total cross sections for 9,11Li + Si reactions as compared with 6,7Li + Si reactions and 6,8He + Si reactions as compared with 4He + Si reaction. 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 effects [2]. These are 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.

References
[1] V. V. Samarin. Description of nucleon-transfer and fusion reactions within time-dependent approaches and coupled-channel method. Phys. At. Nucl. 78 128 (2017).
[2] Yu. E. Penionzhkevich, Yu. G. Sobolev, V. V. Samarin, and M. A. Naumenko. Peculiarities in total cross sections of reactions with weakly bound nuclei 6He, 9Li. Phys. At. Nucl. 80 928 (2017).

Poster Session - Kunibiki Messe (16:30-18:30)

with Coffee

Tuesday 05 June 2018

Session 5 - Kunibiki Messe (09:00-10:30)

time   [id] title

09:00   **[44] Spectroscopic Factors in the Islands of Inversion à la Nilsson ***
Presenter: MACCHIAVELLI, Augusto (Lawrence Berkeley National Laboratory)
Guided by the formalism developed for studies of single-nucleon transfer reactions in deformed nuclei [1], we have analyzed spectroscopic factors data in the Islands of Inversion at N=8 and 20, in the rotational strong-coupling limit.

Based on the fact that intruder deformed configurations dominate the low-lying structure of nuclei within the Islands of Inversion, the Nilsson formalism provides an intuitive and simple approach to obtain important structure information from direct reactions, and a complementary view to shell model calculations.

We will present results for 10,11,12Be and 32,33Mg [2,3], showing good agreement with the experimental data, and discuss some predictions for other regions.

* This work is supported by the U.S. Department of Energy, Office of Nuclear Physics, under contract no DE-AC02-05CH11231.

[1] B. Elbek and P. Tjom, Advances in Nucl. Phys. Vol 3, 259 (1969).
[2] A. O. Macchiavelli, et al. Phys. Rev. C97, 011302 (R) (2018).
[3] A. O. Macchiavelli, et al. Phys. Rev. C96, 054302 (2018).

09:18 **[137] Three-body correlations in direct reactions: Example of 6Be populated in (p, n) reaction**

Presenter: CHUDOBA FOR ACCULINNA COLLABORATION, Vratislav (JINR Dubna, Russia && Silesian University in Opava, Czech Republic)

The 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 6Li 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 1H(6Li,6Be)n collecting very high statistics data (~5x10^6 events) on the three-body alpha+p+p coincidences. 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 6Be excitation spectrum above ~3 MeV is dominated by the novel phenomenon – isovector breed of the soft dipole mode "built" on the 6Li ground state (g.s.). 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.

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.

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.

[1] A. M. Rodin, S. I. Sidorchuk, S. V. Stepantsov, G. M. Ter-Akopian, A. S. Fomichev, R. Wolski, V. B. Galinskiy, G. N. Ivanov, I. B. Ivanova, V. A. Gorshkov, A. Y. Lavrentev, and Y. T. Oganessian, Nuclear Instruments and Methods in Physics Research A 391, 228 (1997)
[2] A. Fomichev, V. Chudoba, I. Egorova, S. Ershov, M. Golovkov, A. Gorshkov, V. Gorshkov, L. Grigorenko, G. Kaminski, S. Krupko, I. Mukha, Y. Parfenova, S. Sidorchuk, R. Slepnev, L. Standylo, S. Stepantsov, G. Ter-Akopian, R. Wolski, and M. Zhukov, Physics Letters B 708, 6 (2012)

09:36 **[16] In-beam gamma-ray spectroscopy near the proton drip line: 25Si and 26P**

Presenter: LONGFELLOW, Brenden (Michigan State University / National Superconducting Cyclotron Laboratory)

The structure of neutron-deficient nuclei plays a vital role in nucleosynthesis via the rp process. Near the proton drip line, the Q values of (p,g) reactions are low and the reaction rates are dominated by single resonances and direct capture. We present here studies of 25Si and 26P produced through one-neutron knockout and charge exchange at the National Superconducting Cyclotron Laboratory at Michigan State University. Energy levels and branching ratios in 25Si and 26P were measured using in-beam gamma-ray spectroscopy with the high-efficiency CsI(Na) array CAESAR and the high-resolution segmented Ge array SeGA. The results are compared with the mirror nuclei to show a significant Thomas-Ehrman shift in this region. Shell-model calculations using the USDB-CDPN interaction with a downward shift of the single-particle energy for the 1S1/2 proton orbital to reproduce the observed Thomas-Ehrman shift are discussed and used with the experimentally measured resonances to calculate the (p,g) reaction rates.

09:54 | **[41] RI-beam-induced charge-exchange reaction studies combined with gamma-ray spectroscopy**

Presenter: NOJI, Shumpei (NSCL/MSU)

Charge-exchange reactions at intermediate beam energies have been a powerful tool for studying spin-isospin responses of nuclei. They become even more powerful when rare isotope beams are utilized or when combined with gamma-ray spectroscopy, as they gain new spin-isospin selectivities that are not possible with conventional reaction probes, or allow for pinning down specific excitations with precise energy determination. They are useful in particular for studying giant resonances and a variety of other astrophysical phenomena such as stellar electron captures. In this presentation, I will discuss some of these instances including our recent results on rare-isotope-beam-induced charge-exchange reactions including (12N,12C), (10Be,10B), and (t,3He) experiments performed at RIBF/RIKEN and NSCL/MSU.

10:12 | **[11] Constraints on the Symmetry Energy from Neutron-Removal Cross Sections**

Presenter: AUMANN, Thomas (Technische Universität Darmstadt, Germany, GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany)

An experimentally constrained equation-of-state (EoS) of neutron-rich matter is one of the fundamental goals in nuclear physics that has not been reached yet.The asymmetry term of the EoS is usually expressed by the symmetry energy, with its parameters representing its value J and slope L at saturation density. To date, in particular the parameter L is still poorly known. One method to bring insight into this open issue is to relate nuclear observables as theoretically predicted using well-calibrated energy-density functionals (EDF) with the corresponding L-value. The challenge is to find observables that are sensitive to L and experimentally accessible. Two appropriate candidates, \textit{i.e.}, the neutron-skin thickness Δr_{np} and the ground-state dipole polarizabillity α_D have been identified in recent years. The accurate experimental determination of these observables, however, remains as a challenging task in particular for neutron-rich nuclei.

Several publications by Roca-Maza \textit{et al.} demonstrate the feasibility of this method on the basis of a large set of EDF. The reachable constraint on L naturally scales with the experimental uncertainty of the measured observable while the model-dependence, \textit{i.e.}, the scatter of theory points sets a hard limit that is in the order of $\pm 10\,$ MeV [1]. The latest analysis [2] limits the symmetry-energy slope parameter to 20-66 MeV by comparing available data for α_D with calculations in the random-phase approximation.

Following the idea described above we have recently proposed a new method to constrain L that might allow to reach the theoretical limit, namely, the measurement of neutron-removal cross sections $\sigma_{\Delta N}$ of neutron-rich nuclei [3]. In our fist systematical study we show the sensitivity of $\sigma_{\Delta N}$ to Δr_{np} and L for the Sn isotopic chain using a parameter-free eikonal reaction-theory and modified versions of the DD2 interaction where L is systematically varied. We conclude that L can be potentially constrained down to $\pm$ 10 MeV, given that both the measured and calculated cross-section are known to a 2\,\% accuracy.
Being aware that this seems to be an ambitious goal, both aspects, \textit{i.e.}, the status and perspectives of the reaction theory as well as the requirements of the experiments proposed to be performed at R^{3}B will be discussed to show that this goal is definitely not out of reach.

References:

[1] X. Roca-Maza, M. Centelles, X. Vi{\~n}as, and M. Warda, Phys. Rev. Lett. \textbf{106}, 252501 (2011)

[2] X. Roca-Maza, X. {Vi{\~n}as}, M. Centelles, B.K. Agrawal, G. Col{\`o}, N. {Paar}, J. {Piekarewicz}, and D. Vretenar, Phys. Rev. C \textbf{92}, 064304, (2015)

[3] T. Aumann, C.A. Bertulani, F. Schindler, and S. Typel, Phys. Rev. Lett. \textbf{119}, 262501 (2017)

Break+Poster - Kunibiki Messe (10:30-11:00)

Session 6 - Kunibiki Messe (11:00-12:30)

time [id] title

11:00	**[109] Evidence for Z=6 subshell closure in neutron-rich carbon isotopes** *Presenter: ONG, Hooi Jin (RCNP, Osaka University)* The nuclear magic numbers, as we know in stable nuclei, consist of two different series of numbers. The first series -- 2, 8, 20 -- is attributed to the harmonic oscillator potential, while the second one -- 28, 50, 82, and 126 -- is due to the spin-orbit (SO) interactions. The spin-orbit interactions are known to be significant and responsible for the large (spin-orbit) splitting of the single-particle states in heavy nuclei. These splittings, however, are expected to diminish in light nuclei due to low orbital angular momenta. This general expectation is supported by the fact that there is an apparent lack of fingerprints for a `magic number' (subshell closure) at 6 or 14 [1], which might have arisen from the widening $1p1/2$-$1p3/2$ and $1d3/2$-$1d5/2$ gaps, respectively, in the stable nuclei. A possible subshell closure at N=6 has been suggested both theoretically [2] and experimentally [3] in the very neutron-rich 8He isotope. For Z=6 and 14, possible subshell closures have been suggested [4] in the semi-magic 14C and 34Si. In this talk, we will present experimental evidence for a prevalent subshell closure at proton number Z=6 in the neutron-rich carbon isotopes. We investigated (i) the point proton density distribution radii, combining our recent data for Be, B and C isotopes measured at RCNP, Osaka University and GSI, Darmstadt, with the available data from Ref. [5]; (ii) the atomic masses [6]; and (iii) the electromagnetic transition strengths [7] for a wide range of isotopes. Our systematic analysis revealed marked regularities which support a prominent proton `magic number' Z=6 in 13-20C. [1] M. G. Mayer, Nobel Lectures in Physics, 20 - 37 (1963). [2] T. Otsuka et al., Phys. Rev. Lett. 87, 082502 (2001). [3] F. Skaza et al., Phys. Rev. C 73, 044301 (2006). [4] I. Angeli and K. P. Marinova, J. Phys. G: Nucl. Part. Phys. 42, 055108 (2015). [5] I. Angeli and K. P. Marinova, At. Data Nucl. Data Tables 99, 69 -95 (2013). [6] M. Wang et al., Chinese Phys. C 41, 030003 (2017). [7] B. Pritychenko et al., At. Data Nucl. Data Tables 107, 1 - 139 (2016).
11:18	**[19] a new measurement of the intruder configuration in 12Be** *Presenter: LOU, Jianling (Peking University)* A new 11Be(d,p)12Be transfer reaction experiment was carried out in inverse kinematics at 26.9 MeV/nucleon, with special efforts devoted to the determination of the deuteron target thickness and of the required optical potentials from the present elastic scattering data. In addition, a direct measurement of the cross section for the 02+ state was realized by applying an isomer-tagging technique. The s-wave spectroscopic factors of 0.20(0.04) and 0.41(0.11) were extracted for the 01+ and 02+ states, respectively, in 12Be. Using these spectroscopic factors, together with the previously reported results for the p-wave components, the single-particle component intensities in the bound 0+ states of 12Be were deduced, allowing a direct comparison with the theoretical predictions. It is evidenced that the ground-state configuration of 12Be is dominated by the d-wave intruder, exhibiting a dramatic evolution of the intruding mechanism from 11Be to 12Be, with a persistence of the N = 8 magic number broken.

11:36 **[31] Nuclear structure study for the neutron-rich cadmium nuclei beyond 132Sn**

Presenter: WANG, He (RIKEN Nishina Center)

Nuclear structure study for exotic nuclei far away the stability is one of major topics in today's nuclear physics research. In particular, the neutron-rich nuclei beyond 132Sn provide a pivot region to explore the exotic nuclear structure because 132Sn is doubly magic and locates far away the stability. In this region, two phenomena in nuclear structure have attracted much attention in recent years: the persistence of N=82 shell gap in the nuclei locating at the south of 132Sn and neutron dominance nature in the 2+ excitation in Te and Sn beyond N=82.

To address these two questions, neutron-rich cadmium isotopes are critical. For N=82 shell gap, mass measurement and spectroscopic studies show contradictory results for 130Cd (Z=48,N=82). While a reduced N=82 shell gap is deduced from the mass measurements on 130,131Cd, spectroscopic study suggests a good N=82 shell closure because the first 2+ state 130Cd is comparable to other N=82 isotones. For the neutron dominance nature, the first 2+ state in 132Cd (Z=48,N=84) is essential to investigate on the role of neutron in low-lying excitation in more neutron-rich system.

Aiming at investigating the exotic nuclear structure beyond 132Sn, we have measured reduced transition possibility B(E2) for the semi-magic nucleus 130Cd and 2+ state in 132Cd at the RI Beam Factory. Coulomb excitation at around 160MeV/u was applied to obtain the B(E2) value in 130Cd and the two-proton removal reaction was used to produce the 2+ state in 132Cd. Gamma rays emitted from the excited states were measured via the DALI2 spectrometer. In the presentation, the newly obtained BE2 value and 2+ state for 130Cd and 132Cd, respectively, will be discussed and experimental details will be given.

11:54 **[62] Robustness of the N=34 shell closure: First spectroscopy of 52Ar**

Presenter: LIU, Hongna (CEA, Saclay)

It is now well known that the magic numbers are not universal across the nuclear landscape and that new shell closures may emerge in nuclei far from stability. In particular, a new subshell closure at N=34 has been reported in 54Ca. While the systematics of the E(2+) of the Ti isotopes does not show any evidence for the existence of the N=34 subshell closure, the significant 2+ excitation energy in 54Ca was a sign of its doubly magic character. For 52Ar, no spectroscopic information has been measured, however, its E(2+) was predicted to be the highest among Ar isotopes with N > 20, suggesting a robust N=34 shell gap. The spectroscopy of 52Ar thus offers a unique chance to explore the robustness of the N = 34 subshell closure and pin down the mechanism at the origin of its emergence.

The measurement of 52Ar was performed at RIBF at RIKEN using the spectrometers of BigRIPS and SAMURAI. The low-lying states of 52Ar were populated via 53K(p, 2p) and 54Ca(p, 3p) reactions at ~240 MeV/u. The selectivity of the (p, 2p) and (p, 3p) channels is used to build the level scheme of 52Ar. The challenge posed by the low secondary beam intensity was tackled by the combination the MINOS device with a 150-mm thick liquid hydrogen target and the recent upgraded high efficiency DALI2+ gamma detector array. In the presentation, we will report on the first in-beam gamma spectroscopy of low-lying states of 52Ar, and discuss the robustness of the N=34 shell closure in light of shell model and ab initio calculations.

12:12 **[111] Structure and reactions of N=7 isotones: the role of core degrees of freedom**

Presenter: VIGEZZI, Enrico (INFN Milano)

The explicit consideration of core degrees of freedom is crucial
in order to obtain an accurate description of the structure and
reactions of light exotic nuclei. In particular, it is important
to consider the role of ground state correlations, respecting
the Pauli principle, and including at the same time the continuum in the calculations (1).
This is possible in the framework of Nuclear Field Theory,
taking the coupling of valence particles and core vibrations in a consistent
way. I will present calculations of the spectrum and of direct reactions on N=7 isotones,
going from the halo nuclei 10Li and 11Be to the more bound systems 12B and 13C.

(1) F. Barranco, G. Potel, R.A. Broglia and E. Vigezzi, Phys. Rev. Lett. 119 (2017) 082501

Lunch break - Kunibiki Messe (12:30-14:00)

Session 7 - Kunibiki Messe (14:00-15:30)

time   [id] title

14:00	**[7] LINKING NUCLEAR REACTIONS AND NUCLEAR STRUCTURE ON THE WAY TO THE DRIP LINES** *Presenter: DICKHOFF, Willem (Department of Physics, Washington University in St. Louis)* The dispersive optical model (DOM), originally conceived by Claude Mahaux [1], provides a unified description of both elastic nucleon scattering and structure information related to single-particle properties below the Fermi energy [2]. Extensions of this framework have introduced a fully non-local implementation for 40-Ca [3,4]. For the first time properties below the Fermi energy like the charge density and the presence of high-momentum nucleons can be included in the DOM description while elastic cross section data can be represented as accurately as in the local DOM implementation. Application of the non-local DOM to 48-Ca incorporates the effect of the 8 additional neutrons and allows for an excellent description of elastic scattering data of both protons and neutrons [5]. The corresponding neutron distribution constrained by all available data generates a prediction for the neutron skin of 0.249 +/- 0.023 fm for this nucleus [5] which is larger than most mean-field and available ab initio results. We report on the most recent developments including a non-local DOM analysis for 208-Pb, an extension to heavier Ca isotopes, an analysis of the energy density in comparison with ab initio nuclear matter calculations, applications to (d,p) and (p,d) transfer reactions with DOM ingredients, and a reanalysis of (e,e'p) data to determine if experimental data can constrain the magnitude of absolute spectroscopic factors. [1] C.Mahaux and R.Sartor, Adv.Nucl. Phys. 20, 1 (1991). [2] W.H.Dickhoff, R.J.Charity, and M.H.Mahzoon, J. Phys. G: Nucl. Part. Phys. 44, 033001 (2017). [3] M.H.Mahzoon et al., Phys. Rev. Lett. 112, 162503 (2014). [4] H.Dussan et al., Phys. Rev. C 90, 061603(R) (2014). [5] M.H.Mahzoon et al., Phys. Rev. Lett. 119, 222503 (2017).
14:18	**[5] Microscopic optical potential for proton elastic scattering off light exotic nuclei** *Presenter: VORABBI, Matteo (TRIUMF Canada's particle accelerator centre)* A microscopic optical potential for intermediate energies is derived using ab initio translationally invariant nonlocal one-body nuclear densities computed within the no-core shell model approach utilizing two- and three-nucleon chiral interactions. The optical potential is obtained at first-order within the spectator expansion of the non-relativistic multiple scattering theory by adopting the impulse approximation. The nuclear density and the nucleon-nucleon t matrix are the two basic ingredients underlying the computation of the optical potential and are both obtained using the same chiral interaction, that represents the only input of our calculations. The ground state local and nonlocal densities of several unstable nuclei are calculated and applied to optical potential construction. The differential cross sections and the analyzing powers for the elastic proton scattering off these nuclei are then calculated for different values of the incident proton energy. The model is first tested on 4He, 12C, and 16O, and then is used to compute and compare the results for the scattering observables with the existing experimental data for 6He and 8He halo nuclei. Finally, predictions for the same observables will be also presented for proton elastic scattering off other unstable nuclei like 10Be, 10C, 14C, and 14O.
14:36	**[17] Microscopic description of global optical potential toward unstable nucleus** *Presenter: FURUMOTO, Takenori (Yokohama National University)* The optical model potential has an aspect of useful tool to analyze the nuclear reaction data of the non-elastic scattering. Therefore, the construction of the optical model potential is developed. Nowadays, the microscopic description based on the realistic nucleon-nucleon interaction is advanced to construct the optical model potential. The microscopic optical potential is success to describe not only the elastic scattering but also inelastic scattering and transfer reaction and so on. In this talk, we will introduce the microscopic global optical potential for the nucleon-nucleus systems. The microscopic global optical potential is based on the single-folding model with the complex G-matrix interaction. The microscopic global optical potential is designed for the nucleon-nucleus systems including the unstable nucleus at E = 50-400 MeV.

14:54 **[110] From ab initio structure predictions to reaction calculations via effective field theory**

Presenter: CAPEL, Pierre (Johannes Gutenberg Universität Mainz)

Halo nuclei exhibit an uncommon nuclear structure with a larger matter radius compared to stable nuclei [1]. This large size is qualitatively understood as due to the loose binding of one or two valence neutrons, which have then a high probability of presence at a large distance from the other nucleons. They thus form a sort of halo around the compact core of the nucleus. The best known examples are 11Be, with a one-neutron halo, and 11Li, with a two-neutron halo. Due to their short lifetime, these nuclei are mostly studied through reactions like breakup [2]. In order to extract valuable structure information from measured cross sections, a precise model of the reaction coupled to a reliable description of the projectile is needed. Many such models have been developed (see Ref. [3] for a recent review). However, they mostly rely on a simple two- or three-body description of the nucleus. Recently, some of these exotic nuclei have become accessible to ab initio calculations [4]. Unfortunately, such A-body descriptions are too computationally demanding to be directly included within existing reaction models. In the present work, we use the outputs of an ab initio calculations of 11Be as inputs to the description
of that nucleus within a reliable breakup model [5]. That description is inspired by an effective field theory treatment of 11Be [6] (see Ref. [7] for a recent review). Our calculations of the breakup of 11Be on Pb and C at about 70AMeV are in very good agreement with experimental measurements [2]. These excellent results prove the feasibility of incorporating results from ab initio calculations in reaction theory in this way. More importantly, they confirm the results for important aspects of 11Be obtained by the calculations of Calci et al. [4], hence improving our understanding of the nuclear structure far from stability.

References
[1] I. Tanihata J. Phys. G 22 157 (1996)
[2] N. Fukuda et al. Phys. Rev. C 70 054606 (2004)
[3] D. Baye and P. Capel Clusters in Nuclei, Vol. 2 vol 848 ed Beck C (2012, Springer, Heidelberg)
[4] A. Calci, P. Navratil, R. Roth, J. Dohet-Eraly, S. Quaglioni and G. Hupin Phys. Rev. Lett. 117 242501 (2016)
[5] D. Baye, P. Capel and G. Goldstein Phys. Rev. Lett. 95 082502 (2005)
[6] C. Bertulani, H.-W. Hammer and U. van Kolck Nucl. Phys. A 712 37-58 (2002)
[7] H.-W. Hammer, C. Ji and D. R. Phillips J. Phys. G 44 103002 (2017)

15:12 **[10] Corrections to the eikonal description of elastic scattering and breakup of halo nuclei**

Presenter: HEBBORN, Chloë (Université libre de Bruxelles)

In the mid-80s, the development of Radioactive-Ion Beam (RIB) has enabled the study of nuclei away from stability. Indeed, these very short-lived nuclei cannot be studied through usual spectroscopic techniques but information about their structure can be deduced from reaction measurements. To conduct a precise analysis, an accurate reaction model coupled to a realistic description of the nuclei are required. The eikonal model provides reliable results at high enough energies, i.e. above 60A MeV, while having a short computational time. Since facilities, such as HIE-ISOLDE at CERN and ReA12 at MSU, aim to accelerate RIBs up to 10A MeV, extending the range of validity of the eikonal model to these energies would be of great interest. In this work, we study two corrections to the eikonal model in the framework of elastic scattering and breakup reactions of halo nuclei. These corrections improve the treatment of the Coulomb and nuclear interactions during the collision. The first is based on a semi-classical approach [1,2] while the second combines the partial-wave expansion and the eikonal model [3]. Considering the case of the one-neutron halo projectile 11Be impinging on a 12C target at 10A MeV, we show that both corrections lead to elastic scattering cross sections in excellent agreement with full CDCC calculations. The extension of these corrections to breakup observables seems, however, less successful. By showing the success and limitations of these corrections, we pinpoint more precisely the flaws of the eikonal approximation at low energy. This will hopefully pave the way towards a more efficient correction to the eikonal model at such energies.

[1] C. E. Aguiar, F. Zardi, and A. Vitturi, Phys. Rev. C 56, 1511 (1997).
[2] C. Hebborn and P. Capel, Phys. Rev. C 96, 054607 (2017).
[3] J. M. Brooke, J. S. Al-Khalili, and J. A. Tostevin, Phys. Rev. C 59, 1560 (1999).

Break+Poster - Kunibiki Messe (15:30-16:00)

Session 8 - Kunibiki Messe (16:00-17:30)

time   [id] title

16:00   **[14] From Nuclei to Neutron Stars with a Microscopic Approach**

Presenter: SAMMARRUCA, Francesca (University of Idaho)

Neutron-rich systems are associated with a variety of important and still open questions such as: the location of neutron drip lines, the thickness of neutron skins, and the structure of neutron stars. Common to these diverse situations is the equation of state (EoS) of neutron-rich matter, namely the energy per particle in isospin-asymmetric matter as a function of density (and other thermodynamic quantities as appropriate, such as temperature). In the presence of different neutron and proton concentrations, the symmetry energy emerges as an important component of the EoS and plays an outstanding role in the physics of neutron-rich systems.

Our predictions of the EoS are based on microscopic high-precision nuclear interactions derived from chiral Effective Field Theory (EFT) [1]. In recent years, chiral EFT has evolved into the authoritative approach to construct nuclear two- and many-body forces in a systematic manner [1, 2].
We apply the microscopic EoS of symmetric nuclear matter and the ones of pure neutron matter as derived in Ref. [3]. The derivation is based on high-precision chiral nucleon-nucleon potentials at next-to-next-to-next-to-leading order (N3LO) of chiral perturbation theory [1, 4]. The leading three-nucleon force, which is treated as an effective density-dependent force [5], is included.

It is well known that the available information on neutron radii and neutron skins is scarce and carry considerable uncertainty. Although future experiments are anticipated which should provide reliable information on the weak charge density in 208Pb and 48Ca, the identification of other "observables" whose knowledge may give complementary information on neutron skins would be most welcome. An issue of current interest is whether information on the neutron skin can be obtained through the knowledge of proton radii alone, specifically those of mirror nuclei. In particular, the difference between the charge radii of mirror nuclei in relation to the slope of the symmetry energy, and, in turn, to the neutron skin, was nvestigated in Ref. [6]. Although phenomenological analyses are a useful exploratory tool to gain some preliminary insight into sensitivities and interdependences among nuclear properties, only through microscopic predictions can we understand a result in terms of the physical input. We will explore, from the microscopic point of view in contrast to the phenomenological one, the relation between the neutron skin of a nucleus, on the one hand, and the difference between the proton radii of the mirror pair with the same mass, on the other.

Moving on to a dramatically different scale, it is remarkable that the relation between the mass and the radius of neutron stars is uniquely determined by the EoS together with their self-gravity. In fact, these compact systems are intriguing testing grounds for nuclear physics. Most recently, the detection by LIGO of gravitational waves from two neutron stars spiraling inward and merging has generated even more interest and excitement around these exotic systems. In fact, the LIGO/Virgo [7] detection of gravitational waves originating from the neutron star merger GW170817 has provided new and more stringent constraints on the maximum radius of a 1.4 M☐ neutron star, based on the tidal deformabilities of the colliding stars [8]. We will present and discuss predictions of neutron star masses and radii based, as far as possible, on state-of-the-art nuclear forces. The focal point is the radius of a star with mass equal to 1.4 M☐ (the most probable mass of a neutron star), which we wish to predict with appropriate quantification of the theoretical error.

[1] R. Machleidt and D.R. Entem, Physics Report 503, 1 (2011).
[2] E. Epelbaum, H.-W. Hammer, and U.-G. Meissner, Rev. Mod. Phys. 81, 1773 (2009).
[3] F. Sammarruca, L. Coraggio, J.W. Holt, N. Itaco, R. Machleidt, and L.E. Marcucci, Phys. Rev. C 91, 054311 (2015).
[4] D.R. Entem and R. Machleidt, Phys. Rev. C 68, 041001 (2003).
[5] J.W. Holt, N. Kaiser, and W. Weise, Phys. Rev. C 79, 054331 (2009);
[6] B.A. Brown, Phys. Rev. Lett. 119, 122502 (2017).
[7] B.P. Abbott et al. [LIGO Scientific and Virgo Collaborations], Phys. Rev. Lett. 119, 161101 (2017).
[8] Eemeli Annala, Tyler Gorda, Aleksi Kurkela, and Aleksi Vuorinen, arXiv:1711.02644 [astro-ph.HE]; and references therein.

16:18   **[8] A POSSIBLE NUCLEAR SOLUTION TO THE 18F DEFICIENCY IN NOVAE**

Presenter: LA COGNATA, marco (infn-lns)

A POSSIBLE NUCLEAR SOLUTION TO THE 18F DEFICIENCY IN NOVAE

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Crucial information on nova nucleosynthesis can be potentially inferred from γ-ray signals powered by 18F decay [1]. Therefore, the reaction network producing and destroying this radioactive isotope has been extensively studied in the last years. Among those reactions, the 18F(p,α)15O cross-section has been measured by means of several dedicated experiments, both using direct and indirect methods. The presence of interfering resonances in the energy region of astrophysical interest has been reported by many authors including the recent applications of the Trojan Horse Method (THM). The THM is an indirect method using direct reactions to populate 19Ne states of astrophysical importance, with no suppression by the Coulomb and centrifugal barriers. In this work, we evaluate what changes are introduced by the Trojan Horse data [2-4] in the 18F(p,α)15O astrophysical factor recommended in a recent R-matrix analysis, accounting for existing direct and indirect measurements [5]. We will particularly focus on the role of the THM experiment, since it allowed us to cover the 0-1 MeV energy range with experimental data, with no need of extrapolation and with unprecedented accuracy. Then, the updated reaction rate is calculated and parameterized and implications of the new results on nova nucleosynthesis are thoroughly discussed. In particular, while no change on the dynamical properties of the explosion is found due to the revised reaction rate, important differences in the chemical composition of the ejected matter is observed, with a net reduction in the mean 18F content by a factor of 2 and a corresponding increase in the detectability distance [4].

[1] J. José, Stellar Explosions: Hydrodynamics and Nucleosynthesis (Boca Raton, FL, London: CRC/Taylor and Francis, 2016)
[2] R. G. Pizzone et al., Eur. Phys. J. A, 52 (2016) 24
[3] S. Cherubini et al., Physical Review C, 92 (2015) 015805
[4] M. La Cognata et al., The Astrophysical Journal, 846 (2017) 65
[5] D. W. Bardayan et al. 2015, Phys. Lett. B, 751, (2015) 311

16:36   **[29] X-ray bursts: Indirect measurement of the astrophysical 23Al(p,γ) reaction**

Presenter: MOUKADDAM, Mohamad (University of Surrey)

X-ray bursts are the most frequent stellar explosions to occur throughout the cosmos and as such, represent key research environments for the field of nuclear astrophysics. These cataclysmic binary systems are known to exhibit distinctive light curves, which have now been observed with unprecedented sensitivity, that provide a detailed reflection of the underlying nuclear physics processes involved. Consequently, an accurate understanding of the observed light curves may hold the key to the unraveling of the burst mechanism, as well as the companion neutron star properties.

Recently, an in-depth study of the dependence of X-ray burst models on nuclear reaction rates has highlighted the 23Al(p,γ)24Si as being of particular significance in determining the shape of the X-ray burst light curve [1]. A direct investigation of this reaction is presently unfeasible due to the current low intensities of radioactive 23Al beams. As such, an innovative indirect approach is required.

In this talk, I will present the first ever study of the 23Ne(d,p)24Ne transfer reaction, which was recently performed at the ISAC-II facility at TRIUMF using a radioactive beam of 23Ne. Here, the high-granularity TIGRESS γ-ray array was used in conjunction with the SHARC silicon detection system to extract spectroscopic information on excited states in 24Ne. These states represent key isobaric analogs of resonances in 24Si and therefore, by measuring their spectroscopic strengths and employing mirror symmetry, it is possible to indirectly determine the 23Al(p,γ) stellar reaction rate. Such investigations have been extremely successful in recent years in constraining astrophysical reactions that lie outside the reach of direct measurements [2,3].

[1] R.H. Cyburt et al., Astrophys. J. 830, 55 (2016).
[2] V. Margerin, G. Lotay et al., Phys. Rev. Lett. 115, 062701 (2015).
[3] S.D. Pain et al., Phys. Rev. Lett. 114, 212501 (2015).

16:54	**[82] Direct Measurement of Resonances in ^{7}Be$(\alpha,\gamma)^{11}$C With DRAGON**
	Presenter: CONNOLLY, Devin (TRIUMF)
	Nucleosynthesis of the *p*-nuclei is one of the remaining unsolved puzzles in nuclear astrophysics. One possible mechanism for production of *p*-nuclei is the *vp*-process, which is thought to occur in the ejecta of core-collapse supernovae. A recent study found that the *p-p* chain breakout reaction ^{7}Be$(\alpha,\gamma)^{11}$C significantly influences nuclear flow in the *vp*-process. However, the ^{7}Be$(\alpha,\gamma)^{11}$C reaction rate is poorly known over the temperature range of interest (*T*=1.5−3 GK). In this temperature range, the astrophysical reaction rate is dominated by resonant capture to states in ^{11}C within the Gamow window, three of which have unknown resonance strengths. A new direct measurement of ^{7}Be$(\alpha,\gamma)^{11}$C was performed at TRIUMF's DRAGON recoil separator in order to measure the strengths and energies of these resonances. Experimental methods and preliminary results will be discussed.
17:12	**[105] Study of 19Ne using the 15O + alpha experiment**
	Presenter: KIM, Dahee (Department of Physics, Ewha Womans University, Seoul, Korea)
	Classical novae are one of the most energetic stellar events in the Universe. In this site, intense y-rays due to the beta decay of 18F produced are emitted by the HCNO cycle. The amount of 18F is determined by two destructive channels 18F(p,α)15O and 18F(p,y)19Ne[1]. The reaction rates of the two destructive channels affect to the novae calculation model[2,3]. For this reason, many experiments and theoretical works have been reported on the resonances of 19Ne near and above the proton threshold, which can contribute to the reaction rate. However, many relevant parameters are still not measured.[4,5] We performed alpha elastic scattering experiment with the radioactive 15O beam for investigating the resonance parameters near the proton threshold using the thick target method at CRIB of the Center for Nuclear Study. The excitation function of 19Ne was obtained between Ex=3.53 MeV and Ex=11.13 MeV. The experimental details and results on the structure of 19Ne will be presented. [1] M. Hernanz et al., Astrophys. J. 526, L97 (1999). [2] S. Utku et al., Phys. Rev. C 58, 1354(E) (1998). [3] A. Coc et al.,Astron. Astrophys. 357, 561(2000). [4] A. St. J. Murphy et al., Phys. Rev. C 79, 058801 (2009). [5] A. M. Laird et al., Phys. Rev. Lett. 110, 032502 (2013).

Wednesday 06 June 2018

Session 9 - Kunibiki Messe (09:00-10:12)

time [id] title

09:00	**[23] Assessing the foundation of the Trojan Horse Method** *Presenter: CARLOS BERTULANI, Carlos (Texas A&M University-Commerce)* I will discuss the foundation of the Trojan Horse Method (THM) within the Inclusive Non-Elastic Breakup (INEB) theory. This work demonstrates that the direct part of the INEB cross section, which is of two-step character, becomes, in the DWBA limit of the three-body theory with appropriate approximations and redefinitions, similar in structure to the one-step THM cross section. I will also discuss the connection of the THM to the Surrogate Method (SM), which is a genuine two-step process.
09:18	**[40] Benchmarking reaction theories for nucleon knockout reactions** *Presenter: YOSHIDA, Kazuki (RCNP, Osaka University)* Recently, proton-induced nucleon knockout reactions, (p,pN), have been utilized for the nucleon spectroscopy of nuclei, for unstable nuclei in the inverse kinematics in particular. In this study the benchmarking of the three reaction theories for describing the (p,pN) reaction has been done. The momentum distributions calculated with the distorted wave impulse approximation (DWIA) and the transfer-to-the-continuum model (TC) for the $15C(p,pn)14C$ reaction at 420 MeV/u have been compared with the already published results of the Faddeev/AGS (FAGS) method. The same inputs are adopted to three reaction calculations as much as possible. As a result, a very good agreement has been found between DWIA, TC and FAGS. Within the DWIA framework, the energy dependence of the distorting potentials, which is difficult to be taken into account in the TC and FAGS frameworks, is found to affect in a modest way on the shape and magnitude of the momentum distributions. However, it is found that the inclusion of relativistic corrections increases the knockout cross section by about 30%, which shows the importance of that treatment for deducing the spectroscopic information from the (p, pN) cross sections.
09:36	**[21] Study of N=34 sub-shell closure in 54Ca from knock-out reaction** *Presenter: CHEN, Sidong (Peking University)* The structure of neutron-rich Ca isotopes have attracted interest from both experimental and theoretical side for a decade. The N=32 sub-shell gap is found to be well established from the measured 2+ energy in 52Ca[1]. Recently, with the availability of intense radioactive beam, the N=34 sub-shell closure was also found experimentally in 54Ca[2]. To quantitatively study the nature of N=34 sub-shell closure, the spectroscopic factor of 54Ca(p,pn) reaction is a useful index. Besides, the 53Ca nucleus, located in between 52Ca and 54Ca, its single-particle properties of low-lying states are of importance to the study of structures for very neutron-rich Ca isotopes above 54Ca and shell evolution towards the potential sub-shell closure nucleus 60Ca. We therefore performed 54Ca(p,pn) experiment at the RIBF facility of the RIKEN Nishina Center. In this experiment, proton induced neutron knock-out cross sections from 54Ca ground state to individual final states of 53Ca have been investigated. The in-beam gamma-ray spectroscopy technique has been employed to tag the final states in 53Ca. The exclusive cross section as well as the residues momentum distribution to individual final states have been measured. The spectroscopic factors deduced from the experimental knock-out cross sections and momentum distribution of the residues to individual final state will be compared to the reaction theory for quantitative structure study. In this report, the experimental setup as well as the preliminary result of data analysis will be presented. [1] A. Gade et al., Phys. Rev. C 74,021302 (R) (2006) [2] D. Steppenbeck et al., Nature, 502, 207-210, (2013)
09:54	**[20] Manifestation of α-clustering in 10Be via α-knockout reaction** *Presenter: LYU, Mengjiao (RCNP, Osaka University)* Despite the remarkable successes obtained by the cluster models, the physical observables that are directly related to the cluster degree of freedom is not available until very recent studies of α-transfer reactions and α-knockout reactions. We introduce the microscopic structure models into the theoretical frameworks for α-knock out reactions to probe the α-clustering in 10Be nucleus. In this work, we integrate the THSR wave function and the distorted wave impulse approximation (DWIA) framework, and make calculation for the 10Be(p,pα)6He reaction at 250MeV. We predict the triple differential cross sections (TDX). We further construct artificial states with extreme shell-model like or gas like states for the target nucleus 10Be, and find the strong dependence of the TDX on the α-clustering structure. With this new framework, we may directly relate the microscopic description of α-clustering structure to the reaction observables in the (p,pα) knockout reaction, and provide sensitive manifestation of α-clustering in the 10Be nucleus. We are further extending this framework to the α-knockout reaction for the 12Be nucleus.

Thursday 07 June 2018

Session 11 - **Kunibiki Messe (09:00-10:30)**

time [id] title

09:00	**[138] Exploring the most neutron-rich isotopes of carbon and nitrogen**

Presenter: ORR, Nigel (LPC-Caen)

Exploring and understanding the structure of nuclei far from stability is one of the central themes of present day nuclear physics, as evidenced by this workshop. In this presentation, work investigating the structure of the most neutron-rich isotopes of carbon and nitrogen employing high-energy nucleon removal (or "knockout") will be discussed. These nuclei are of particular interest as they encompass the N=14 and 16 sub-shell closures and lie below doubly magic 22,24O. Following a brief résumé of the motivation for this work and the tools employed, the results obtained for the unbound system 21C will be presented together with the prospects for probing the continuum states of 22C, including the search for the first 2+ state. The first observation of 24N will also be presented together with evidence for the existence of 25N as a resonance.

09:18	**[102] Study of spin-isospin responses of light nuclei near and along the drip line with PANDORA**

Presenter: STUHL, Laszlo (Center for Nuclear Study, University of Tokyo)

The charge-exchange (p,n) reactions at intermediate beam energies and small angles, can selectively excite Gamow-Teller (GT) states up to high excitation energies in the final nucleus. Therefore, (p,n) reactions in inverse kinematics applying the missing mass reconstruction[1,2] provide the best and efficient tool to study the B(GT) strengths values of unstable isotopes in a wide excitation energy region, without Q-value limitation.

An experimental program aiming to study the spin-isospin responses of light nuclei along the drip line was started at RIKEN RIBF. A measurement [3], SAMURAI-30, with 5 days of beam time was approved to investigate 8He, 11Li and 14Be nuclei. In a pilot measurement of the mentioned experiment at HIMAC facility in Chiba, we studied the Gamow-Teller transitions of 6He in inverse kinematical (p,n) reactions at 123 MeV/nucleon incident energy using polyethylene target. Our new neutron detector, PANDORA [4], with digital readout was also commissioned.

In this talk, details of experiment and the results of B(GT) strengths distribution of 6He will be reported as well as a brief overview of the whole program will be presented.

[1] M. Sasano et al., Phys. Rev. Lett. 107, 202501 (2011).
[2] M. Sasano et al., Phys. Rev. C 86, 034324 (2012).
[3] L. Stuhl et al., RIKEN Accelerator Progress Report 48, 54 (2015).
[4] L. Stuhl et al., Nucl. Instr. Meth. A 866, 164 (2017).

09:36	**[130] Study of 19C using single-neutron knockout**

Presenter: HWANG, Jongwon (Center for Nuclear Study, University of Tokyo)

The evolution of shell structure toward the driplines is a subject of importance in nuclear physics. For a half decade the p-sd-shell nuclei have been a useful tool for expanding our understanding of shell evolution. 19C is one of those nuclei, well known as the s-wave halo ground state. While the low-lying excited states with 3/2+ and 5/2+ were identified by experimental studies, there exists an argument of bound nature of 5/2+1. From a theoretical point of view, shell model calculations with different interactions show discrepancy in location and ordering of levels.

We investigated the neutron-unbound states of 19C using the one-neutron knockout reaction with SAMURAI spectrometer at RIBF, RIKEN. The 20C beam impinged on a carbon target to produce 19C. The decay products, 18C and a neutron, were detected using SAMURAI and NEBULA neutron array.

In this talk, the observation of populated states and the discussion in the context of shell-model calculations will be reported.

09:54 **[36] Pairing collectivity in the ground state of Borromean nuclei and unbound 2n-systems: 22C and 26O**

Presenter: SINGH, JAGJIT (Nuclear Reaction Data Center, Faculty of Science, Hokkaido University, Sapporo 060-0810, Japan)

In recent years, there has been rapidly increasing interest in the study of the Borromean nuclei sitting right on the top of neutron driplines and two-neutron decays of unbound systems beyond the neutron dripline. These systems demands a three-body description with proper treatment of continuum, the conventional shell-model assumptions being insufficient. Very recently a high

precision measurement of interaction cross-section for 22C was made on a carbon target at 235 MeV/nucleon [1] and also the unbound nucleus 26O has been investigated, using invariant-mass spectroscopy [2] at RIKEN Radioactive Isotope Beam Factory. These high precision measurements, are the motivation for selecting these systems for the present study. We have studied the pairing

collectivity in the ground state of Borromean nuclei 22C and in the 2n- unbound system 26O. For this study we have used our recently implemented 3 - body (core+n+n) structure model for ground and continuum states of the Borromean nuclei [3, 4].

We will present the ground state properties of 22C and 26O systems and transitions to the continuum that might be of help in disentangling the still poorly known low-energy resonances and predicting new resonances of these nuclei. We compare our findings with the more recent experimental works and the scarce theoretical work that has been done in the recent past on these

systems.

The neutron single-particle unbound spdf- continuum states of the 21C and 25O system are calculated in a simple shell model picture for different continuum energy cut-off's of 5, 10 and 15 MeV by using a Dirac delta normalization and are checked with a more refined phase-shift analysis. The sensitivity of the (core+n) potential has been explored for the emergence of different dominant configurations in the ground state of 22C and 26O. After fixing convergence with the continuum energy cuts and bining size, a reasonable energy cut of 5 MeV and bin size of 0.1 MeV is used for present study. These (core+n) continuum wavefunctions are used to construct the two-particle 22C and 26O states by proper angular momentum couplings and taking contribution

from different configurations. We have explored the role of different pairing interactions such as density independent (DI) contact-delta pairing interaction and density dependent (DD) contact-delta pairing interaction in the structure of these systems. We have shown how the ground state

displays a collective nature, taking contribution from many different oscillating continuum states that coherently sum up to give an exponentially decaying bound wavefunction in 22C and an oscillating unbound wavefunction in case of 26O.

[1] Y. Togano et al., Phys. Lett. B761, 412-418 (2016).
[2] Y. Kondo et al., Phys. Rev. Lett. 116, 102503 (2016).
[3] L.Fortunato, R.Chatterjee, Jagjit Singh and A.Vitturi, Phys. Rev. 90, 064301 (2014).
[4] Jagjit Singh, L.Fortunato, A.Vitturi and R.Chatterjee, Eur. Phys. J. A 52 209 (2016).

10:12 **[47] Study of the unbound nuclei 27O and 28O using proton removal reactions**

Presenter: KONDO, Yosuke (Tokyo Institute of Technology)

The sudden change of the neutron dripline from 24O (N=16) to 31F (N=22), called oxygen anomaly, is one of the exotic phenomena. Recent theoretical studies suggest importance of three nucleon forces on the binding energies of the oxygen isotopes, especially for N>16, while available experimental data are limited because the measurement requires production of extremely neutron rich nuclei.

The region of the oxygen anomaly is also interesting in terms of the shell evolution. It is well known that the shell closure of the N=20 nuclei disappears in the island of inversion. Recent in-beam gamma-ray spectroscopy suggests that the N=20 shell gap is quenched at 29F. The experimental study of 28O is strongly desired to clarify the shell evolution along N=20 isotonic chain down to Z=8.

The SAMURAI21 collaboration studied 27O and 28O with SAMURAI spectrometer at RIKEN-RIBF. These unbound nuclei are produced by two- and one-proton removal reaction on a liquid hydrogen target from 29Ne and 29F, respectively. Decay products, 24O and neutrons, are detected in coincidence to reconstruct the invariant mass of the 27O and 28O. The experimental results will be discussed in the presentation.

break - Kunibiki Messe (10:30-11:00)

Session 12 - Kunibiki Messe (11:00-12:30)

time [id] title

11:00 **[63] Status report of Beijing Radioactive Ion-beam Facility (BRIF)**
Presenter: WANG, Youbao (China Institute of Atomic Energy)
The Beijing Radioactive Ion-beam Facility (BRIF) is a large-scale scientific infrastructure, which was commissioned as the national first RIB facility based on the Isotope Separator On Line (ISOL) technique in October, 2016. BRIF is comprised of a high-intensity proton cyclotron, thick-target and ion source system, isotope separator on line and the HI-13 tandem as the post accelerator. The radioactive nuclides are produced by intense proton beam of 100 MeV bombarding a thick-target, the reaction products diffusing out of the target are ionized by an ion source, and separated by the online mass separator.
In this talk, the recent progress on the development of 20-25Na ISOL beams is reported, together with the preliminary results from a trial measurement of the exotic decay of 20Na.

11:18 **[26] Study of spectroscopic factors at N=29 using isobaric analog resonances in inverse kinematics**
Presenter: BAZIN, Daniel (Michigan State University)
A measurement was recently performed at the National Superconducting Cyclotron Laboratory on resonant proton scattering of 46Ar in inverse kinematics in the region of isobaric analog states of 47Ar. The experiment was performed using a re-accelerated 46Ar radioactive beam at 4.6 MeV/u from the ReA3 linac after production via the projectile fragmentation of a 48Ca primary beam from the Coupled Cyclotron Facility. This beam was injected into the Active Target Time Projection Chamber where the reaction took place on an isobutane target and the scattered protons were detected. Four candidate resonances were observed, two of which corresponding to the isobaric analogs of 47Ar ground and first excited states. Spectroscopic factors were deduced from the strength of these resonances and compared to values in the literature. This novel experimental method to extract spectroscopic information from proton elastic scattering on radioactive nuclei will be presented, as well as the analysis methods used to extract results from the data.

11:36 **[56] Production of neutron-rich nuclei via two-proton knockout reaction with deuterium target**
Presenter: MIWA, Midori (Department of Physics, Toho University)
Production of neutron-rich nuclei through one-nucleon knockout (p,2p) reactions has been successfully demonstrated with the MINOS at RIBF. In future RIBF experiments, a method to remove more than one protons with a reasonable rate will be required for production of more neutron-rich nuclei. At present there is no consensus on what is the best reaction for two-proton removal. In this presentation, a performance of the (d, 3pn) reaction with the MINOS as a candidate of the two-proton knockout driver in future RIBF experiments is discussed. The experiment was carried out using the SAMURAI spectrometer. A secondary cocktail beam including 58Ti was produced with projectile fragmentation reactions of a primary 70Zn beam at 345 MeV/u impinging on a beryllium target. The liquid hydrogen and deuterium with thicknesses of 1.1 g/cm2 and 2.6 g/cm2, respectively, were used as the secondary targets. The cross sections were derived by counting the numbers of particles before and after the target, considering an effective beam intensity. The secondary beam and fragments were identified event by event using the ΔE–TOF–Bρ method. It was found that cross section for two-proton removal with a deuteron target is larger by a factor of ~3 than that with a proton target. This fact may imply possible advantages of a deuteron target to produce neutron-rich nuclei via two-proton knockout.

11:54 **[74] Study of Charge-Exchange Reactions for constraining Stellar Electron-Capture Rates**
Presenter: ZAMORA, J. C. (National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, USA)
Charge-exchange (CE) reactions at intermediary energies serve as a direct method for the extraction of the Gamow-Teller (GT) transition strengths, which are of importance for the estimation of weak-reaction rates for a variety of astrophysical phenomena such as core-collapse supernovae (CCSN) and the crustal heating of neutron
stars. In particular, CE reactions in the β^+ direction, like $(t,{}^{3}\text{He})$ and $(d,{}^{2}\text{He})$, are essential to determine the electron-capture (EC) rates that play a significant role in the above-mentioned scenarios.\\
Recently, a ${}^{88}\text{Sr}(t,{}^{3}\text{He}+\gamma){}^{88}\text{Rb}$ experiment was performed at NSCL using the S800 spectrometer in coincidence with the gamma-ray detector array GRETINA. Experimental results provide a constrain of the EC rates on neutron-rich nuclei, around the $N=50$ line, which
are of importance for understanding the late stages of CCSN.\\
In the future, $(d,{}^{2}\text{He})$ experiments in inverse kinematics will open up the opportunity to investigate CE reactions of far-from-stability nuclei. The AT-TPC, a detector based on time
projection chamber, provides a unique technique for achieving such experiments. Simulation results show a very good reconstruction of the $(d,{}^{2}\text{He})$ kinematics and
also indicate that this technique might be feasible for upcoming experiments.\\
Results of the data analysis and perspectives for $(d,{}^{2}\text{He})$ experiments will be discussed.

12:12 **[114] Measurement of ^{77,79}Se(d,p) reactions in inverse kinematics at OEDO**

Presenter: IMAI, Nobuaki (CNS, Univ. of Tokyo)

A new beam line named OEDO which can degrade the beam energy and squeeze the spatial distribution was installed at RIBF. As the first campaign of the experiments, ^{77,79}Se(d,p)^{X}Se reactions were measured as a surrogate of the ^{79}Se(n, γ)^{80}Se* reaction for the nuclear mutation of the radioactive waste of ^{79}Se. The γ transition probabilities from the unbound states of ^{78,80}Se were determined by directly measuring the outgoing particles instead of detecting the γ rays. In this talk, we will explain the experimental setup and the preliminary result on the (n,γ) cross sections.

Lunch - Kunibiki Messe (12:30-14:00)

Session 13 - Kunibiki Messe (14:00-15:30)

time   [id] title

14:00	**[139] Resonance scattering with exotic beams - past, present and future** *Presenter: ROGACHEV, Grigory (Texas A&M University)* Experiments employing resonance scattering reactions with radioactive beams have been performed since mid-90s, and originally they were primarily targeting structure of light weakly bound or unbound proton rich nuclei [1]. Strong scientific potential of resonance reactions as an experimental tool has been immediately recognized for physics of exotic proton rich nuclei. Unlike for stable nuclei, for weakly bound or unbound nuclei resonance reactions provide access to states with small or zero excitation energy. Typically low level density at small excitation energies allow for detailed and often unambiguous analysis. These features, combined with application of thick target inverse kinematics approach that allowed high efficiency and excellent energy resolution with relatively simple experimental setup, made resonance scattering experiments popular. Many successful experiments have been performed, including those in which ground states of exotic nuclei were observed for the first time (10N is the latest example [2]). More recently resonance reactions have been applied to study clustering phenomena in neutron and proton rich nuclei [3, 4] and also the structure of neutron rich nuclei through isobaric analog states [5]. Significant improvements of experimental techniques, such as active target systems, open up new exciting opportunities. The goal of this talk is to provide a brief highlight of the most interesting past results, overview the current directions and discuss the outlook and future perspectives. References [1] L. Axelsson, et al., Phys. Rev. C, 54, R1511 (1996). [2] J. Hooker, et al., Phys. Lett. B, 769, 62 (2017). [3] C. Fu, et al., Phys. Rev. C, 77, 064314 (2008). [4] D. Suzuki, et al., Phys. Rev. C, 87, 054301 (2013). [5] E. Uberseder, et al., Phys. Lett. B, 754, 323 (2016).
14:18	**[115] Structure of 9C via proton elastic scattering** *Presenter: HOOKER, Joshua (Texas A&M University - Cyclotron Institute)* The structure of ^{9}C was studied using ^{8}B+p resonance scattering with the newly commissioned Texas Active Target (TexAT) detector system. Recent theoretical developments allow for robust predictions of level structure of light nuclei, including continuum effects, starting from nucleon-nucleon and three-nucleon interactions [1, 2, 3]. High quality experimental data are necessary to benchmark these predictions. Experimental data on ^{9}C is limited - only two excited states in ^{9}C have been observed. The goal of this work was two-fold. First, the ^{8}B+p resonance scattering was used as the first commissioning experiment for the active target detector system TexAT. This reaction was chosen because the experimental data on ^{8}B+p elastic scattering excitation function at low energy are available [4]. The second goal was to search for positive parity states in ^{9}C (non are known). For that we extended the ^{8}B+p elastic scattering excitation function to higher excitation energy, improved statistics and quality of the existing low energy data, measured angular distribution, and also searched for the ^{8}B(p,2p) reaction channel. Preliminary results of this run will be discussed. [1] N. Mihel, W. Nazarewiz, M. Ploszajzak, and J. Okolowiz, PRC 67, 054311 (2003). [2] A. Volya and V. Zelevinsky, PRL 94, 052501 (2005). [3] S. Baroni, P. Navratil, S. Quaglioni, PRC 87, 034326 (2013). [4] G. Rogachev, et al., PRC 75, 014603 (2007).

14:36 | **[119] Study of the A=9 T=3/2 isobaric quartet through R-Matrix analysis of resonance scattering of analogue states.**

Presenter: HUNT, Curtis (Texas A&M University - Physics and Astronomy)

Studies of the structure of neutron rich nuclei are important for exploring shell evolution and the development of theoretical models. While transfer reactions are currently the primary method of studying neutron rich nuclei it is suggested that study of isobaric analogue states through resonance proton scattering could be used as well [1]. We've performed a benchmark study of the A=9, T=3/2 isobaric quartet, populating T=3/2 states in 9Be using 8Li+p resonance scattering. R-matrix analysis combined with the optical model has been applied for analysis of the 8Li+p excitation function to extract the parameters of the isobaric analog states in 9Be. We compare the results of this experiment to the available data on 9Be T=3/2 states and on the other members of the A=9, T=3/2 isobaric quartet - 9Li [2] and 9C [3]. We show that proton resonance scattering can be a useful complimentary tool for spectroscopy studies of neutron rich nuclei with radioactive beams, provided that robust procedure can be established to fix the parameters of the optical model potentials. The radioactive beam of 8Li was delivered by RESOLUT facility at the John D. Fox superconducting linear accelerator facility at Florida State University and also by MARS facility at the Cyclotron Institute at Texas A&M University. The 8Li+p excitation function was measured using modified thick target approach and also with active target detector - Texas Active Target (TexAT), as part of TexAT's commissioning run.

[1] V. Z. Goldberg, AIP Conference Proceeding 455 319 (1998)
[2] A.H. Wuosmaa, et al., Phys. Rev. Lett. 94 082502 (2005)
[3] G. V. Rogachev et al., Phys. Rev. C 75 014603 (2007)

14:54 | **[124] Studying clustering in O-14 and Be-7 nuclei using resonant scattering and Coulomb excitation**

Presenter: AHN, Tan (University of Notre Dame)

Clustering in light nuclei is a prominent feature that manifests itself through various physical observables, which serve as a guide and constraint for nuclear theory. More precise data on these observables, especially for unstable nuclei, are needed to better constrain nuclear theory and thus give us a more fundamental understanding of what causes nuclei to cluster. In order to obtain more data on cluster states in light nuclei, we performed an experiment using resonant alpha scattering with a C-10 radioactive beam to search for cluster states in the proton-rich nucleus O-14 where the structure and properties of levels above the alpha threshold are not well known. Scattering cross sections for the C-10 + alpha resonant scattering were measured with the Prototype Active-Target Time-Projection Chamber. Preliminary results for the analysis of this experiment will be presented. A second experiment using Coulomb excitation with a radioactive beam of Be-7 will be presented. The electromagnetic transition strength to the first excited state was measured and the current results will be compared to various ab-initio nuclear model predictions. These predictions show that clustering and thus the inclusion of continuum states is important for reproducing several electromagnetic observables.

15:12 | **[86] Search for T=5 isobaric analog states in 48Ca**

Presenter: UPADHYAYULA, Sriteja (Cyclotron Institute - Texas A&M University)

Particle-hole excitations near closed shells carry information on single-particle energies and on two-body interactions. The particle-hole excitations near the doubly magic nuclei are of special interest. Information on the charge-changing particle-hole excitations (T= 5 negative parity states) in ^{48} Ca is not available. We performed an experiment to establish the level scheme of the low-lying negative parity T= 5 states in ^{48} Ca. Excitation functions for the ^{1} H (^{47} K, p) ^{47} K (gs) and ^{1} H (^{47} K, p) ^{47} K (3/2$^+$) reactions in the cm energy range from 1 MeV to 4.5 MeV were measured. The T= 5 states are expected to show up in the p+ ^{47} K excitation function as narrow resonances. This experiment was performed at NSCL using the ReA3 beam of ^{47} K at energy of 4.6 MeV/u. ANASEN, set in active target mode, was used for this experiment. Experimental results from this experiment will be presented.

Break - Kunibiki Messe (15:30-16:00)

Session 14 - Kunibiki Messe (16:00-17:30)

time [id] title

16:00 **[32] Mirror energy differences and neutron skin**

Presenter: LENZI, Silvia M. (University of Padova and INFN)

Isospin symmetry is one of the basic concepts in nuclear physics. One of its consequences is that the level scheme of mirror nuclei, i.e. nuclei with the same number of nucleons but interchanged number of protons and neutrons should be identical. The Coulomb excitation breaks this degeneracy to some extent. It is also known that at the strong interaction level, the symmetry is also broken and manifested in the difference in mass of protons and neutrons and in the nucleon-nucleon scattering phase shifts.

New developments in the study of the mirror energy differences in the sd shell suggest that these observables can give information on the nuclear skin as a function of excitation energy. The calculations are performed in the shell model framework using state-of-the-art charge-dependent nucleon-nucleon potentials.

In the presentation some new data together with the calculations will be shown and discussed.

16:18 **[38] Pygmy dipole states in deformed nuclei**

Presenter: LANZA, Edoardo G. (INFN - Sezione di Catania)

In the last years special attention has been devoted to the study of the dipole strength at low excitation energy in neutron-rich nuclei, the so called Pygmy Dipole Resonance (PDR). This mode carries few per cent of the isovector EWSR, and it is present in many stable and unstable isotopes with a consistent neutron excess.

It is possible to study these low lying dipole states by using an isoscalar probe in addition to the conventional isovector one due to the fact that their transition densities show a strong mixing of their isoscalar and isovector components. Indeed, the combined use of real and virtual phonons and experiments employing (α,α γ) as well as (17O, 17O' γ), for the investigation of the PDR states has unveiled a new feature of these states. Namely, the peak of these low-lying dipole states can be separated in two parts: the part lying at low energy is excited by both the isoscalar and isovector interactions while the high energy part is populated only by the electromagnetic probes.

Recently, the interest has moved on deformed nuclei. In these nuclei the Giant Dipole Resonance (GDR) peak is separated in two parts. Each of them corresponds, in the hydro-dynamical model, to an out-of-phase oscillation of neutron against protons along the symmetry and its perpendicular axes. These modes are characterized by two quantum number K = 0− and K = 1− that give rise to two separated bands in the laboratory frame. If it is true that the pygmy states are generated by the out-of-phase oscillation of the neutron excess against a proton plus neutron core, then the same mechanism producing the splitting of the GDR should be valid also for the low lying dipole states. Therefore one should expect as well to observe a separation of the pygmy dipole peak in two bumps.

Calculations done within a simple macroscopic model show that the transition densities of the low lying dipole states have the same typical behaviour of the non- deformed nuclei namely a strong isoscalar-isovector mixing at the nuclear surface. These results are corroborated by some microscopic calculations performed by using a relativistic Hartee-Bogoliubov mean field plus a relativistic quasi-particle random phase approximation.

Therefore a suitable way to investigate the pygmy states in deformed prolate nuclei is through the use of isoscalar probes. Measurement of the pygmy dipole states excitations along an isotope chain with increasing deformation may enlighten and give new perspectives about these novel excitation modes.

16:36 **[103] E1 responses of neutron-rich Ca isotopes 50Ca and 52Ca**

Presenter: TOGANO, Yasuhiro (Tokyo Institute of Technology)

The density dependence of the symmetry energy is one of the keys for understanding the bulk properties of neutron-rich nuclei and astrophysical events, such as supernovae and neutron stars.

Recent theoretical works show that the E1 response of nuclei is well correlated to the density dependence of the symmetry energy close to the saturation density. The dipole polarizability, the inversely energy weighted sum of E1 strength, is pointed out as less model-dependent observable to constrain the density dependence of the symmetry energy. In addition, it is indicated that the low-energy E1 strength up to 10 MeV in 52Ca is well correlated to the density dependence of the symmetry energy. To constrain the symmetry energy with these correlations, the E1 response of 50Ca and 52Ca have been measured by using the relativistic Coulomb excitation.

The experiment was performed using the SAMURAI spectrometer at RIKEN RIBF. The 50Ca and 52Ca beams were impinged on Pb and C targets. The outgoing charged particles and neutrons were measured by SAMURAI spectrometer and the neutron detectors NEBULA and the NeuLAND demonstrator, respectively. The de-excitation gamma-ray from the reaction residue was measured by the gamma-ray detector CATANA.

In this talk, we will report the results obtained for the bound excited states and one-neutron decay channel of 52Ca.

16:54 **[107] Study of breakup channels for the 6He+64Zn reaction at energies around the Coulomb barrier.**
Presenter: FERNÁNDEZ-GARCÍA, Juan Pablo (University of Seville)

Reactions induced by neutron halo nuclei have been intensively studied in the last years. The neutron halo structure can affect the dynamic of reactions at energies around the Coulomb barrier producing a significant reduction of the elastic scattering cross section with respect to the Rutherford prediction. This effect can be associated with couplings to breakup channels, since the continuum of such nuclei is close to the ground state. The breakup channel can be split into two parts; the elastic breakup and non-elastic breakup.

The halo nucleus 6He is composed by an alpha core and two weakly bound neutron (S=0.97 MeV). These two neutrons have a large probability to be far away from the alpha core, producing the so-called nuclear halo.
New experimental elastic cross sections for the reaction 6He+64Zn at energies around the Coulomb barrier have been measured and compared with CRC and CDCC calculations. CDCC calculations are based on the elastic breakup of the projectile, while the CRC calculations consider the transfer of one/two-neutron to the bound and unbound states of the target, which is part of the non-elastic breakup. To compute the total non-elastic breakup, the formalism reported in [Phys. Rev. C 95, 044605 (2017)] has been performed. The results show the angular and energy distributions of the breakup fragment coming from 6He+64Zn reaction are well reproduced by the one/two-neutron transfer mechanism, indicating the importance of the non-elastic breakup.

17:12 **[9] Reaction mechanisms of 17F+58Ni at energies around the Coulomb barrier**
Presenter: YANG, Lei (Center for nulcear study, the University of Tokyo)

With the radioactive ion beam 17F provided by CRIB (Center for Nuclear Study Radioactive Ion Beam separator), the reactions on the proton-shell closed 58Ni target were measured at four energies around the Coulomb barrier: 46.0, 49.8, 57.9 and 65.1 MeV. A specially designed detector array, which consists of ionization chambers and silicon detectors, was used to identify the heavy and light reaction products simultaneously. The angular distributions of the quasi-elastic scattering and inclusive breakup were obtained. The quasi-elastic data were analyzed with the framework of the optical model to deduce the total reaction cross section. The breakup angular distribution can be reproduced reasonably by the continuum-discretized coupled-channels (CDCC) and IAV (Ichimura, Austern, Vincent) model calculations, hence the cross sections of breakup reactions can be derived. Meanwhile, the fusion cross section can be determined by measuring the fusion-evaporation proton and alpha. The resulting fusion excitation function shows an enhancement at energies below the Coulomb barrier, and some suppression above the barrier.

Friday 08 June 2018

Session 15 - Kunibiki Messe (09:00-10:12)

time [id] title

09:00	**[75] Exotic light nuclei from ab initio theory** *Presenter: NAVRATIL, Petr (TRIUMF)* One of the recently developed approaches capable of describing both bound and scattering states in light nuclei simultaneously is the No-Core Shell Model with Continuum (NCSMC). I will present recent NCSMC calculations of weakly bound states and resonances of exotic halo nuclei 6He and 11Be. I will also discuss the 11Be mirror 11N, an unbound 10C+p system, and highlight the role of chiral NN and 3N interactions in the description of the 10C(p,p) scattering measured recently at TRIUMF. Finally, I will discuss our new calculations of the structure of the unbound 9He nucleus as well as our ongoing calculations of the 11C(p,p) scattering and 11C(p,gamma)12N capture.
09:18	**[95] Probing three-nucleon-force effects via knockout reactions** *Presenter: MINOMO, Kosho (Research Center for Nuclear Physics, Osaka University)* Understanding of the roles of three-nucleon forces (3NFs) in nuclear few- and many-body systems is one of the fundamental subjects in nuclear physics. Recently, 3NFs are constructed with chiral effective field theory in which two-, three-, and many-nucleon forces are treated consistently and systematically. The chiral 3NF effects have been analyzed in few-body systems and nuclear matter, and the binding energies of light nuclei and the saturation property in symmetric nuclear matter were well reproduced. Furthermore, it was found that the chiral 3NF effects improve the agreement between theoretical and measured cross sections for nucleus-nucleus elastic scattering. In this talk, we propose to use proton knockout reactions (p,2p) at intermediats and high energies, which can be regarded as a two-proton quasielastic scattering, as a new probe into chiral 3NF effects on reaction observables. In a many-body system, 3NF effects can be represented by the density-dependence of nucleon-nucleon effective interaction. Proton knockout reactions from a deeply bound orbit should be suitable for probing 3NF effects since such reactions occur mainly in the internal region of the target nucleus in which the density is high. We clarify the roles of chiral 3NF for knockout reactions based on the distorted-wave impulse approximation with a nucleon-nucleon g-matrix interaction including the 3NF effects. The chiral 3NF effects significantly change the peak height of the triple differential cross section of (p,2p) reactions.
09:36	**[98] Complete Glauber calculations for high-energy inelastic processes** *Presenter: HORIUCHI, Wataru (Hokkaido University)* The Glauber theory is a powerful and widely used method to describe high energy nuclear collisions. Since the complete evaluation of the so-called Glauber amplitude is much involved, approximate treatment has often been made. In this contribution, we present our recent developments of the Glauber model calculations for nuclear inelastic processes. The Monte Carlo and the factorization methods are employed in order to evaluate the Glauber amplitude which involves a multi-dimensional integral. The power of the complete Glauber calculations is demonstrated by showing some examples: The total reaction cross sections of 22C [1], and the inelastic cross sections involving deformed nuclei [2]. [1] T. Nagahisa and W. Horiuchi, in preparation. [2] S. Hatakeyama and W. Horiuchi, in preparation.

09:54   **[68] Effect of two-particle two-hole excitations in target nuclei on inelastic differential cross sections**

Presenter: MINATO, Futoshi (Japan Atomic Energy Agency)

A basic picture of nuclear excited states can be described by one-particle one-hole (1p1h) excitation. Experimental data of inelastic scatterings of nucleon-nucleus reaction are reasonably reproduced theoretically in this picture. However, it is known that higher-order configurations are important for a better understanding of the excited states. This may apply to the inelastic scattering. However, the relation between higher-order configuration and inelastic scattering is still not clear. To clarify the relation between higher-order configuration and inelastic scattering, we consider two-particle two-hole (2p2h) excitation of target nuclei and pay attention to the angular differential cross sections. The 2p2h stats of target nuclei are calculated by Second RPA, and the reaction process is calculated by DWBA. As reaction channels, inelastic scattering and (p,n) reaction are chosen. Our approach reproduces experimental data reasonably. However, it turned out that the diffraction patterns of the angular differential cross section considering 2p2h excitation were not significantly different from those considering 1p1h excitation although the absolute values were smaller than 1p1h calculation if the same nucleon-nucleon force is used for 1p1h and 2p2h calculations. This indicates that the effect of 2p2h contribution cannot be seen in the inelastic channels. We discuss it in more detail from the nuclear structural point of view.

break - Kunibiki Messe (10:12-10:45)

Session 16 - Kunibiki Messe (10:45-11:57)

time [id] title

10:45 **[67] Analysis of isospin dependence of "quenching factors" for (p,pn) and (p,2p) reactions via the Transfer to the Continuum formalism**
Presenter: GÓMEZ RAMOS, Mario (Universidad de Sevilla)
Nucleon removal (p,pn) and (p,2p) reactions at intermediate energies have gained renewed attention in recent years as a tool to extract information from exotic nuclei, thanks to the availability of exotic beams with which to perform these reactions in inverse kinematics. The information obtained from these experiments is complementary to that obtained from nucleon removal experiments with heavier targets (knockout), but is expected to be sensitive to deeper portions of the wave function of the removed nucleon.

Recently, two sets of (p,pn) and (p,2p) data on oxygen and nitrogen isotopes have been obtained by the R3B collaboration [1,2] and have been analysed in terms of the eikonal DWIA [1] and Faddeev/AGS [2] formalisms. Both analyses obtain a reduction in the spectroscopic strength but predict a different magnitude for this reduction and different isospin dependence. Also, it must be noted that the analysis of [1] was restricted to five selected oxygen isotopes, which were deemed to be more suitably described by the Independent Particle Model (IPM).

In this contribution we present a joint analysis of both sets of data, including all measured isotopes, using a common reaction framework, the recently developed Transfer to the Continuum [3] formalism, with consistent potentials and structure inputs. Our analysis shows an almost constant reduction factor with a very small, nearly absent, isospin dependence. This result is in accord with recent transfer experiments [4], but at odds with the marked asymmetry obtained from the systematic analysis of nucleon knockout reactions at intermediate energies [5]. The effect of the distorting potentials on these results is explored by using two different sets of potentials. It is found that the small asymmetry is maintained with both sets even if the reduction factors for the specific reactions may be significantly different.

[1] L. Atar et al, Phys. Rev. Lett. 120, 052501 (2018)
[2] P. Díaz-Fernández et al, To be published in Phys. Rev. C
[3] A.M. Moro, Phys. Rev. C 92, 044605 (2015)
[4] F. Flavigny et al, Phys. Rev. Lett. 110, 122503 (2013)
[5] J. A. Tostevin and A. Gade, Phys. Rev. C 90, 057602 (2014)

11:03 **[106] Inclusive Quasifree Scattering Cross Sections from Medium-Mass Neutron-Rich Nuclei**
Presenter: PAUL, Nancy (CEA Saclay)
Direct nucleon removal has become a tool of choice to study structure and reactions in exotic nuclei [1,2,3]. Despite the pervasiveness of this method, theoretical approaches to describe these reactions remain incomplete. To remedy this, part of the community has focused on experiments with pure proton targets at intermediate energies where the quasifree scattering paradigm may be invoked and the reaction mechanism simplified [3,4]. However, to date, little data exists for exotic nuclei.
At the Radioactive Isotope Beam Factory, we have measured 77 single proton and neutron removal inclusive cross sections from neutron-rich exotic nuclei from Cr (Z=24) to Tc (Z=43). Obtained on a 10 cm thick liquid hydrogen target [5] at ~250 MeV/U, consistent with quasifree scattering, these results provide a systematic exploration of direct reaction cross sections with isospin and across the N=50 shell closure. The evolution of the cross sections with mass and separation energy will be presented, and the results compared to state-of-the-art Intranuclear Cascade Model and Distorted Wave Eikonal calculations.

[1] T. Wakasa, K. Ogata, T. Noro, Proton-induced knockout reactions with polarized and unpolarized beams, Progress in Particle and Nuclear Physics 96, 32 (2017).
[2] V. Panin et al, Exclusive measurements of quasi-free proton scattering reactions in inverse and complete kinematics, Physics Letters B 753, 204 (2016).
[3] T. Aumann, C. A. Bertulani, J. Ryckebusch, Quasifree (p,2p) and (p,pn) reactions with unstable nuclei, Phys. Rev. C 88, 06461010 (2013).
[4] A. Obertelli and T. Uesaka, Hydrogen targets for exotic-nuclei studies developed over the past 10 years. Eur. Phys. J. A 47: 105 (2011).
[5] A. Obertelli et al, MINOS: A vertex tracker coupled to a thick liquid-hydrogen target for in-beam spectroscopy of exotic nuclei. Eur. Phys. J. A 50: 8 (2014).

11:21	**[101] Persistence of nuclear shell closures far from stability: in-beam γ spectroscopy of 79Cu after proton knockout**

Presenter: FRANCHOO, Serge (IPN Orsay)

The shell model remains one of the main building blocks of nuclear structure. Its robustness is well proven for nuclei close to stability, where it successfully explains the occurence of magic numbers. However, these magic numbers are not universal throughout the nuclear chart and their evolution away from stability, observed experimentally over the last decades, has generated much interest. To probe the possible erosion of the Z=28 shell gap in 78Ni, in-beam γ-ray spectroscopy of 79Cu was performed at the Radioactive Isotope Beam Factory of Riken in Japan. The incoming isotopes were identified in the Bigrips spectrometer. The knockout reaction from the selected 80Zn beam at 270 MeV/n took place in the Minos liquid-hydrogen target, surrounded by a TPC for proton tracking. The outgoing nuclei were identified in the Zerodegree spectrometer. The Dali2 scintillator array was installed around Minos for gamma-ray detection. We built the first level scheme of 79Cu up to 4.6 MeV of excitation energy, at the limit of gamma-ray spectroscopy. The results were compared to Monte-Carlo shell-model calculations and show that the 79Cu nucleus can be described in terms of a valence proton outside a 78Ni core, providing indirect evidence of the magic character of the latter. Cross sections were extracted and compared to recent DWIA calculations, from which we find more fragmentation of the single-particle strengths than expected.
New data was also obtained on the 83Ga and 85Ga isotopes beyond N=50, which is presently under analysis and includes a fresh level scheme for 83Ga.

11:39	**[64] In-beam gamma-ray spectroscopy of 51K and 53K**

Presenter: SUN, Yelei (CEA Saclay)

One of the major focus of modern nuclear physics is to explore which part of the nuclear interaction gives rise to significant shell modifications. Recently, the evolution of the 2s1/2+ and 1d3/2+ single-particle states in odd-A K isotopes attract particular interests. The energy gap between these two states decrease continuously when neutrons fill f7/2 orbit. Inversion of the ordering of the 2s1/2 and 1d3/2 orbits has been observed in 47K (N=28) and 49K(N=30). As the neutrons continue filling the orbits beyond the N = 28 shell, reinversion was observed for the first time in 51K using laser spectroscopy. Such reinversion is consistent with the shell model calculations using different effective interactions and was revealed to be mainly driven by the central term of the monopole interaction. However, different interactions predict very different energy gaps between 2s1/2 and 1d3/2 in 51K. In addition, the shell model calculation and the recently available ab initio calculation also predict the reversion in 53K but also with very different energy gaps. The experimental spectroscopy of the excited states in 51K and 53K are thus crucial to benchmark the shell model and ab initio calculations and improve our understanding on the shell evolution mechanisms.

The in-beam gamma-ray spectroscopy measurement of 51K and 53K was carried out at RIBF at RIKEN, as part of the third campaign of the SEASTAR program. The low-lying states of 51K and 53K were populated via 52Ca(p, 2p) and 54Ca(p, 2p), respectively. In the presentation, I will report on the energy level scheme of 51,53K, exclusive cross sections and the individual parallel momentum distributions.

Lunch - Kunibiki Messe (11:57-13:30)

Session 17 - Kunibiki Messe (13:30-14:42)

time [id] title

13:30 **[39] Halo-induced large enhancement of soft dipole excitation of 11Li observed via proton inelastic scattering**
Presenter: TANAKA, Junki (TU Darmstadt)
Proton inelastic scattering off a neutron halo nucleus, 11Li, has been studied in inverse kinematics at the IRIS facility at TRIUMF. The aim was to establish a soft dipole resonance and to obtain its dipole strength. Using a high quality 66 MeV 11Li beam, a strongly populated excited state in 11Li was observed at Ex=0.80 ± 0.02 MeV with a width of Γ = 1.15 ± 0.06 MeV. A DWBA (distorted-wave Born approximation) analysis of the measured differential cross section with isoscalar macroscopic form factors leads us to conclude that this observed state is excited in an electric dipole (E1) transition. Under the assumption of isoscalar E1 transitions, the strength is evaluated to be extremely large amounting to 30□296 Weisskopf units, exhausting 2.2%□21% of the isoscalar E1 energy-weighted sum rule (EWSR) value. The large observed strength originates from the halo and is consistent with the simple di-neutron model of 11Li halo.

13:48 **[79] Borromean Feshbach resonance in 11Li studied via 11Li(p,p')**
Presenter: MATSUMOTO, Takuma (Kyushu University)
We analyzed the 11Li(p,p') reaction at 6 MeV/nucleon by using a microscopic continuum-discretized coupled-channels method, in which 11Li is described by a 9Li + n + n three-body model. In this analysis, we found a dipole resonance of 11Li, and the resonance can be interpreted as a bound state in the 10Li + n system, that is , a Feshbach resonance in the 9Li + n + n system. For 11Li, the 10Li + n threshold is open above 9Li + n + n one, which reflects a distinctive property of the Borromean system. Thus we refer to this resonance as a Borromean Feshbach resonance. The calculated cross sections by taking into account the resonance and nonresonant continuum reproduce the experimental data recently observed. In this conference, we will show the results and discuss properties of the Borromean Feshbach resonance.

14:06 **[15] Linking structure and dynamics in (p,pN) reactions induced by Borromean nuclei**
Presenter: CASAL, Jesús (ECT)*
One-nucleon removal (p,pN) reactions in inverse kinematics, performed at intermediate energies to increase the mean free path of the proton inside the nucleus, can provide quite clean spectroscopic information on exotic nuclei. The Transfer to the Continuum framework, originally developed for the case of two-body projectiles [1], has been recently extended to describe (p,pN) reactions induced by Borromean (core+N+N) nuclei [2]. In this method, the relative energy distribution of the residual unbound two-body subsystem, which is assumed to retain information on the structure of the initial three-body projectile, is computed by evaluating the transition amplitude for different neutron-core final states in the continuum. These transition amplitudes depend on the overlaps between the original three-body ground-state wave function and the two-body continuum states populated in the reaction, thus ensuring a consistent description of the incident and final nuclei.

We applied the method to the 11Li(p,pn)10Li reaction at 280 MeV/u, obtaining a very good agreement with GSI data [3]. In order to describe the 14Be(p,pn)13Be reaction, in which gamma coincidences from the decay of 12Be provide additional information [4], the effect of core excitations has been incorporated in the structure description. Preliminary results show the sensitivity of the cross sections to the structure input. Other cases of interest include 8He(p,pn)7He, 17Ne(p,2p)16F, or 22C(p,pn)21C.

[1] A. M. Moro, PRC 92 (2015) 044605.
[2] M. Gómez-Ramos, J. Casal, and A. M. Moro, PLB 772 (2017) 115.
[3] Y. Aksyutina et al., PLB 666 (2008) 430.
[4] Y. Kondo et al., PLB 690 (2010) 245.

14:24 **[92] Study of neutron-neutron correlation in Borromean nucleus 11Li via the quasi-free (p,pn) reaction**

Presenter: KUBOTA, Yuki (RIKEN Nishina Center)

Dineutron correlation is one of the phenomena expected to appear in neutron drip-line nuclei. It has been studied using different approaches, such as the transfer reaction and the break up reaction. However, currently available data seem to be insufficient to study the neutron-neutron correlation in terms of (i) the decomposition of high-angular-momentum components, (ii) the extraction of a core excitation, (iii) and the effect of final state interactions (FSIs)[1]. In the present study, (i) the MINOS[2] was used for higher luminosity, (ii) γ rays were detected to tag the core excitation, (iii) and the quasi-free (p,pn) reaction was employed to minimize the FSI. In order to determine the neutron momentum distribution, the kinematically complete measurement was performed. The opening angle between the two neutrons was reconstructed from the measured momentum vectors of all the particles involved in the reaction.

The experiment was carried out by using the SAMURAI spectrometer[3] combined with the liquid hydrogen target system MINOS. Momentum vectors of a knocked-out neutron and a recoil proton were respectively determined by the neutron detector WINDS and a recoil proton detector setup, developed for this project. Decay neutrons and heavy fragments were momentum analyzed by the neutron detector NEBULA and the SAMURAI spectrometer, respectively.

The results on 11Li will be presented in this talk.

References
[1] Y. Kikuchi et al., Phys. Rev. C 87, 034606 (2013).
[2] A. Obertelli et al., Eur. Phys. Jour. A 50, 8 (2014).
[3] T. Kobayashi et al., Nucl. Instr. Meth. B 317, 294(2013).

Break - Kunibiki Messe (14:42-15:15)

Session 18 - Kunibiki Messe (15:15-16:15)

time   [id] title

15:15	**[144] Concluding remark** *Presenter: TANIHATA, Isao*
15:45	**[145] Prize and Closing** *Presenters: NAKAMURA, Takashi (Tokyo Institute of Technology), KONDO, Yosuke*