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ABSTRACTS

Decay Spectroscopy of the Proton Rich Isotopes ^{176,177}Tl

M. A. Alaqeel[1,2], B. Andel,[3] S. Antalic,[3] H. Badran,[4] A. Briscoe,[1] T. Calverley,[1,4] D. Cox,[4] U. Forsberg,[4,6,7] T. Grahn,[4] P.T. Greenlees,[4] L.J. Harkness-Brennan,[1] A. Herzan,[1] J. Hilton,[1,4] D.T. Joss,[1] R. Julin,[4] S. Juutinen,[4] J. Konki,[4] M. Labiche,[5] M. Lewis,[1] M. Leino,[4] J. Ojala,[4] R.D. Page,[1] J. Pakarinen,[4] P. Papadakis,[4] J. Partanen,[4] P. Rahkila,[4] P. Ruotsalainen,[4] M. Sandzelius,[4] J. Sarén,[4] C. Scholey,[4] S. Stolze,[4] and J. Uusitalo.[4]

[1] *Department of Physics,Oliver Lodge Laboratory,*
University of Liverpool, Oxford Street, Liverpool L69 7ZE, United Kingdom.

[2] *Department of Physics, Faculty of Science,*
Imam Mohammad Ibn Saud Islamic University, Riyadh, 11623, Saudi Arabia.

[3] *Department of Nuclear Physics and Biophysics,*
Comenius University, 84248 Bratislava, Slovakia.

[4]*Department of Physics, Faculty of Mathematics and Science,*
University of Jyvaskyla, P.O. Box 35, FI-40014, Jyvaskyla, Finland.

[5]*STFC Daresbury Laboratory, Sci-Tech Daresbury, Warrington WA4 4AD, United Kingdom.*

[6]*Department of Nuclear Physics, Faculty of Science,*
Lund University, 22100 Lund, Sweeden.

[7]*Department of Physics, Faculty of Science,*
University of York, Heslington, York, YO10 5DD, United Kingdom.

Measurements of proton-decay properties provide an important source of spectroscopic information at the limits of known nuclei. Spherical proton emitters are important for testing models of proton emission. The most nearly spherical cases are expected to be the Ta nuclei closest to $N = 82$ and the proton-emitting isotopes ^{176,177}Tl that lie just one proton below the $Z = 82$ shell closure. These nuclei are the focus of this study which was performed at the Accelerator Laboratory of the University of Jyväskylä. The ^{176,177}Tl nuclei were produced in fusion-evaporation reactions induced by a beam of ^{78}Kr ions bombarding a ^{102}Pd target at energies of 397 MeV and 376 MeV. The fusion products were separated in flight using the newly commissioned recoil mass separator MARA and implanted into a double-sided silicon strip detector. The proton and alpha decays of the ground and isomeric states of ^{177}Tl were remeasured and found to be consistent with previous studies [1, 2]. In addition, proton emission from the ground state of ^{176}Tl was confirmed [1]. The previously unobserved α decay from this state was identified through correlations with α decays of ^{172}Au. The decays of the isomeric state in ^{176}Tl were also observed for the first time.

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Advanced Implantation Detetector Array (AIDA) for decay measurements of exotic nuclei.

C. J. Appleton[1], P. J. Woods[1], T. Davinson[1], C. G. Bruno[1], A. Estrade-Vaz[1*], C. J. Griffin[1], O. Hall[1], D. Kahl[1], I. Burrows[2], P. J. Coleman-Smith[2], A. Grant[2], M. Kogmitis[2], M. Labiche[2], I. Lazarus[2], S. Letts[2], P. Morall[2], V. F. E. Pucknell[2], J. Simpson[2], J. Strachan[2], L. Harkness-Brennan[3], P. J. Nolan[3], R. D. Page[3], D. Seddon[3].

[1] *University of Edinburgh, School of Physics and Astronomy, Edinburgh EH9 3FD, UK*
[2] *STFC Daresbury Laboratory, Daresbury, Warrington WA4 4AD, UK*
[3] *Department of Physics, University of Liverpool, Liverpool L69 7ZE, UK*
[*] *Currently based at Central Michigan University, Mount Pleasant, MI, USA*

The Advanced Implantation Detector Array (AIDA) [1] is a state of the art Double-Sided Silicon Strip Detector (DSSSD) array designed to study the decays of implanted exotic nuclei. It is now being deployed for such measurements at RIKEN and will also be used in the future FAIR facility.
This talk will give an overview of the design of AIDA, and how it can be combined with ancillary detectors.

We acknowledge support from UK Science and Technology Facilities Council (STFC).

1. https://www2.ph.ed.ac.uk/~td/AIDA/

WISArD: Weak Interaction Studies with ^{32}Ar Decay

V. Araujo-Escalona[1], P. Alfaurt[2], P. Ascher[2], D. Atanasov[1], B. Blank[2], L. Daudin[2], X. Fléchard[3], M. Gerbaux[2], J. Giovinazzo[2], S. Grévy[2], T. Kurtukian Nieto[2], E. Liénard[3], L. Nies[4], G. Quéméner[3], M. Roche[2], N. Severijns[1], S. Vanlangendonck[1], M. Versteegen[2], P. Wagenknecht[1], D. Zakoucky[5].

[1] *KU Leuven, Instituut voor Kern- en Stralingsfysica, Leuven, Belgium.*
[2] *CEN Bordeaux-Gradignan, France.*
[3] *LPC Caen, France.*
[4] *II. Physics Institute, University of Giessen, Germany.*
[5] *Nuclear Physics Institute CAS, Řež, Czech Republic.*

The β decay description in the electroweak sector of the Standard Model (SM) is given by the well known Vector-Axial vector (V-A) theory. Nevertheless, the most general Hamiltonian includes also other possible interaction types, such as scalar (S) and tensor (T) contributions, that are still not discarded experimentally.
The WISArD (Weak Interaction Study with ^{32}Ar Decay) experiment pursues a significant increase in sensitivity for scalar contributions to the weak-interaction through measurements of the β-ν angular correlation coefficient, $a_{\beta\nu}$.

The ^{32}Ar nuclide is of interest as the final state of the superallowed Fermi transition, the Isobaric Analogue State (IAS) in ^{32}Cl, is unbound to proton emission. This allows the measurement of the kinematic shift in the energy of the protons emitted in coincidence with the beta particle. This coincidence measurement is a sensitive probe of the $a_{\beta\nu}$ coefficient.

The experimental set-up is situated at ISOLDE/CERN, where a new detection system was commissioned. In this contribution, the WISArD layout, as well as preliminary results from a proof-of-principle experiment, will be presented.

Proton decay of ^{108}I and its significance for the termination of the astrophysical *rp*-process

K. Auranen[1,a], D. Seweryniak[1], M. Albers[1], A. D. Ayangeakaa[1], S. Bottoni[1], M.P. Carpenter[1], C.J. Chiara[1,2], P. Copp[1,3], H.M. David[1], D.T. Doherty[4], J. Harker[1,2], C.R. Hoffman[1], R.V.F. Janssens[5,6], T.L. Khoo[1], S.A. Kuvin[1,7], T. Lauritsen[1], G. Lotay[8], A.M. Rogers[1], C. Scholey[9], J. Sethi[1,2], R. Talwar[1], W.B. Walters[2], P.J. Woods[4], S. Zhu[1],

[1] *Physics Division, Argonne National Laboratory, 9700 S. Cass ave, Lemont, IL 60439, USA*

[2] *Department of Chemistry and Biochemistry, University of Maryland, College Park, MD 20742, USA*

[3] *Department of Physics and Applied Physics, University of Massachusetts Lowell, Lowell, MA 01854, USA*

[4] *University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom*

[5] *Department of Physics and Astronomy, University of North Carolina at Chapel Hill, Chapel Hill, NC 27599, USA*

[6] *Triangle Universities Nuclear Laboratory, Duke University, Durham, NC 27708, USA*

[7] *Department of Physics, University of Connecticut, Storrs, CT 06269, USA*

[8] *University of Surrey, Guildford GU2 7XH, United Kingdom*

[9] *Department of Physics, University of Jyvaskyla, P.O. Box 35, FI-40014 University of Jyvaskyla, Finland*

In this presentation we report the results of our recent [1] decay-spectroscopy study near ^{100}Sn. In this experiment, by employing fusion-evaporation reaction and the Argonne Fragment Mass Analyzer, we identified a weak proton-decay branch in ^{108}I. The ^{108}I proton-decay rate is consistent with a hindered $l = 2$ emission, suggesting a $d_{\frac{5}{2}}$ origin. Using the extracted ^{108}I proton-decay Q value of 597(13) keV, and the α-decay Q-values of the ^{108}I and ^{107}Te isotopes, a proton-decay Q value of 510(20) keV for ^{104}Sb was extracted. Similarly to the ^{112,113}Cs proton-emitter pair, the $Q_p(^{108}\mathrm{I})$ value is lower than that for the less-exotic neighbor ^{109}I, possibly due to enhanced proton-neutron interactions in $N \approx Z$ nuclei. Surprisingly, the present $Q_p(^{104}\mathrm{Sb})$ value is higher than that of ^{105}Sb, suggesting a weaker interaction energy. For the present $Q_p(^{104}\mathrm{Sb})$ value, network calculations with the one-zone X-ray burst model [2] predict no significant branching into the Sn-Sb-Te cycle at ^{103}Sn.

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[a] Present address: National Nuclear Data Center, Brookhaven National Laboratory, Upton, New York 11973-5000, USA

Triaxiality and residual neutron-proton interaction in proton emitters

P. Arumugam[1], Pooja,[1] S. Modi,[1] M. Patial,[1] E. Maglione[2,3] and L.S. Ferreira[3]

[1] *Department of Physics, Indian Institute of Technology Roorkee, Roorkee 247667, India*
[2] *Dipartimento di Fisica e Astronomia "G. Galilei", and*
Istituto Nazionale di Fisica Nucleare, Via Marzolo 8, I-35131 Padova, Italy
[3] *Centro de Física e Engenharia de Materiais Avançados CeFEMA, and*
Departmento de Física, Instituto Superior Técnico,
Universidade de Lisboa, Avenida Rovisco Pais, P1049-001 Lisbon, Portugal

Proton emission study is an accurate tool to ascertain triaxiality [1,2]. With a nonadiabatic quasiparticle description [3], it has been demonstrated that the residual neutron-proton interaction in odd-odd nuclei could influence the effect of Coriolis interaction and such effects can significantly modify the proton emission half-lives [4]. Recently, we have formulated [5] a modified particle rotor model (MPRM) where the rotation-particle coupling is treated microscopically by coupling the deformed rotor states of the even-even core with the states of the valence particle in order to obtain the matrix elements of the odd-A system. With the inclusion of triaxiality, the MPRM could unambiguously explain the rotational spectra and decay widths of ^{109}I, ^{141}Ho, ^{145}Tm, and ^{147}Tm and yield better agreement with the data when compared to the conventional models. The progress in these studies will be discussed along with the extension of our approach to triaxial odd-odd proton emitters. Preliminary results in the case of recent observation of proton emission from ^{108}I [6] will also be presented.

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Two-proton and β-delayed proton emission from proton-rich nuclei

B. Blank[1]

[1] *CEN Bordeaux-Gradignan, 19 chemin du Solarium, F-33175 Gradigan Cedex, France*

The presentation will review the latest results of proton emission from experiments at Nishina Research Center's BigRIPS facility as well as from new experiments from GANIL.

The results will include data from two-proton emission studies of ^{67}Kr and other nuclei [1], but also β-delayed proton emission from nuclei produced by ^{58}Ni fragmentation [2]. These latter results will be used to determine isospin impurities of the emitting isobaric analogue states in the daughter nuclei [3] as well as masses of the β-emitting nuclei. A comparison with previous results and theoretical predictions will also be included.

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Two-Proton decay in the sd-shell

K. W. Brown[1], R. J. Charity[2], A. Anthony[1], J. Barney[1], J. Chang[1], D. Dell'Aquila[1], J. Elson[2], J. Estee[1], H. Hua[3], Y. Jin[3], Z. Li[3], B. Lynch[1], C. Nui[1], L. Sobotka[2], S. Sweany[1], C. Teh[1], A. Thomas[2], B. Tsang[1], C. Tsang[1], H. Wu[3], K. Zhu[1]

[1] *National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824-1321, USA*

[2] *Department of Chemistry, Washington University in St. Louis 1 Brookings Drive, St. Louis, Missouri 63130*

[3] *Peking University, No. 5 Yiheyuan Road Haidian District, Beijing, China 100871*

The invariant-mass technique has been widely employed to study two-nucleon decaying systems on both the proton-rich and neutron-rich sides of the chart, for example ^{11}Li [1] and ^{26}O [2]. While most lighter, proton-rich systems studied by our group have been measured using the High Resolution Array, for heavier systems the residue does not extend much beyond zero degrees, so a new device must be employed. I will present some details on the new device and show results from the first campaign on the two-proton decay of ^{30}Ar and ^{19}Mg.

This research is supported by the National Science Foundation under Grant No. PHY-1565546, the Department of Energy under Grant No. DE-FG02-87ER-40316 and the National Key R&D Program of China under Contract No. 2018YFA0404403.

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Configuration Interactions Calculations for Two-Proton Decay

B. Alex Brown

Department of Physics and Astronomy, National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824-1321, USA

Two-nucleon transfer amplitudes have been calculated with the configuration-interaction method [1] for all of the measured cases of two-proton decay [2, 3, 4, 5]. I will discuss ways that these can be used to obtain lifetimes. One of these uses the cluster transfer model developed in [6] together with the di-proton R-matrix model of Barker [7]. They can also be combined [8] with the three-body decay half-lives obtained by Grigorenko and co-workers for [9, 10, 11].

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Web Chart

Alex Brown

Department of Physics and Astronomy, National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824-1321, USA

A version of the nuclear chart has been made as a large html table.

`https://people.nscl.msu.edu/~brown/chart/chart-data.html`

The table was generated by a program that uses the NNDC compilation of nuclear data, a compilation of evaluated nuclear masses, and a model for nuclear masses out to the drip lines. Every nucleus with measured properties has a link to a pdf summary of the NNDC energy-level data, binding energy and Q values. The table of energy levels includes horizontal lines that show the position of the 1-p, 2-p, 1-n, 2-n and α-decay separation energies. Each table provides a direct link to the NNDC web site. Some links are provided for other information such as the Wiki pages for the heaviest known elements.

Constraining ^{30}P(p,γ)^{31}S to understand nova nucleosynthesis by measuring β-delayed protons

T. Budner[1,2], M. Friedman[1], C. Wrede[1,2], D. Pérez-Loureiro[1], Y. Ayyad[1], D. Bardayan[3], K. Chae[3], A. A. Chen[4], K. Chipps[5], M. Cortesi[1], B. Glassman[1,2], M. Hall[3], M. Janasik[1,2], J. Liang[4], P. O'Malley[3], E. Pollacco[6], A. Psaltis[4], A. Saastamoinen[7], J. Stomps[1,2], L. J. Sun[1,8], J. Surbrook[1,2], T. Wheeler[1,2]

[1] *NSCL, Michigan State University, East Lansing, MI 48824-1321, USA*
[2] *Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824-1321, USA*
[3] *ISNAP, Notre Dame, South Bend, IN 46637, USA*
[4] *McMaster University, Hamilton, ON L8S 4L8, Canada*
[5] *Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37830-37831, USA*
[6] *CEA, IRFU, Université de Paris Saclay, F-91191 Gif-sur-Yvette, France*
[7] *Cyclotron Institute, Texas A&M University, College Station, TX 77840, USA*
[8] *School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China*

Presolar grains are microscopic crystals found inside primitive meteorites, whose isotopic compositions suggest that, unlike the surrounding rock, they were formed before the early solar system. Classical novae have been proposed as the site of origin for particularly ^{30}Si-enriched grains [1]. However, large uncertainties in the ^{30}P(p,γ)^{31}S reaction rate make modeling the chemical and isotopic abundances of nova ejecta a challenge [2]. The β^+-decay of ^{31}Cl populates an excited state in ^{31}S which corresponds to a potentially dominant resonance for proton capture on ^{30}P [3]. In November 2018, we collected the data for measuring the intensity of resonant protons emitted in the ^{31}Cl(βp)^{30}P decay using the newly developed GADGET system [4] in order to constrain this astrophysically important thermonuclear reaction; analysis is ongoing. Here we present preliminary results from this experiment.

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Proton and Gamma Partial Widths for the Astrophysical ^{30}P(p,γ)^{31}S Reaction

S. Burcher[1], K.A. Chipps[2], R.O. Hughes[3], S. Ahn[4], J.M. Allmond[2], J. Burke[3], H. Clark[4], J.A. Cizewski[5], N. Cooper[6], J. Hooker[4], H. Jayatissa[4], K.L. Jones[1], S. Ota[4], S.D. Pain[2], C. Reingold[6], A. Saastamoinen[4], K. Schmidt[7], A. Simon[6], and S. Upadhyayula[4]

[1] *University of Tennessee, Knoxville TN*
[2] *Oak Ridge National Laboratory, Oak Ridge TN*
[3] *Lawrence Livermore National Laboratory, Livermore CA*
[4] *Texas A&M University, College Station TX*
[5] *Rutgers University, New Brunswick NJ*
[6] *University of Notre Dame, Notre Dame IN*
[7] *Michigan State University, National Superconducting Cyclotron Laboratory, and Joint Institute for Nuclear Astrophysics, East Lansing MI*

The ^{30}P(p,γ)^{31}S reaction rate has been identied as the largest remaining source of uncertainty in the abundances of intermediate-mass nuclei produced in classical nova explosions involving oxygen-neon white dwarfs, and plays an important role in the correct interpretation of several isotopic ratios observed in presolar grains. A direct measurement of the ^{30}P(p,γ)^{31}S cross section has thus far been infeasible, but many indirect measurements have been undertaken with the goal of informing the astrophysical reaction rate. Due to the existence of narrow, isolated resonances in ^{31}S above the proton separation energy, the reaction rate must be calculated from the energies, J^{π} assignments, and resonance strengths or partial widths of these resonances.

We report a measurement of the ^{32}S(p,d)^{31}S* reaction with the goal of populating states above the proton threshold in ^{31}S. The measurement was performed in normal kinematics at the Texas A&M Cyclotron Institute using the Livermore particle-gamma detection array Hyperion. 32 MeV protons from the K150 cyclotron impinged on ZnS targets in the Hyperion target chamber. An annular silicon telescope at forward angles was used to identify reaction products, while an additional annular detector at back angles detected low-energy decay particles in coincidence. The Hyperion HPGe clovers were used to detect decay gammas from excited ^{31}S levels. The measurement allowed for simultaneous observation of protons and gammas from the decay of ^{30}P+p resonances, in addition to angular distributions of reaction deuterons.

The measurement constitutes the first time both decay channels were measured in a single experiment, with the goal of constraining the astrophysically-relevant proton and gamma partial widths through a measurement of their respective branching ratios. Preliminary results, including proton decay and particle-γ coincidence spectra, will be presented.

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Single and two-proton emission from states in ^{11,12}O and ^{10,11,12}N

R.J. Charity[1], T.B. Webb[2], K.W. Brown[3], J.M. Elson[1], D.E.M Hoff[1], C.D. Pruitt[1], L.G. Sobotka[1,2], J. Barney[3], G. Cerizza[3], J. Estee[3], W.G. Lynch[3], J. Manfredi[3], P. Morfouace[3], C. Santamaria[3], S. Sweany[3], M.B. Tsang[3], T. Tsang[3], S.M. Wang[3], Y. Zhang[2], K. Zhu[3], S.A. Kuvin[3], W. Nazarewicz[6],D. McNeel[5], J. Smith[5], A.H. Wuosmaa[5], and Z. Chajecki[6]

[1] *Department of Chemistry, Washington University, St. Louis, Missouri 63130, USA*

[2] *Department of Physics, Washington University, St. Louis, Missouri 63130, USA*

[3] *Department of Physics and Astronomy, National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824-1321, USA*

[4] *FRIB labortory, Michigan State University, East Lansing, Michigan 48824-1321, USA*

[5] *Department of Physics, University of Connecticut, Storrs, Connecticut, 06269, USA*

[5] *Department of Physics, Western Michigan University, Kalamazoo, Michigan 49008*

A study of light oxygen and nitrogen isotopes located beyond the proton drip line was made with a ^{13}O beam and the HiRA array. The isotopes were produced using single and multiple nucleon knockout reactions with a ^{9}Be target and identified from their decay products using the invariant-mass technique. The first identification of ^{11}O was made and new states in ^{12}O were observed as well as clarification of the states in ^{10}N and ^{11}N. Analog states to the observed ^{12}O levels were also found in ^{12}N which also two-proton decay. Evidence is also seen for fission-like decays of high-lying ^{12}O states and their analogs. Momentum correlations for the two-proton decays will also be discussed and comparisons to predictions of the Gamow Coupled-Channel model will be made.

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Proton Decay of the 6.15 MeV Level in ^{18}Ne

K.A. Chipps[1], S.D. Pain[1], P. Thompson[1,2], R. Kozub[3], and the JENSA Collaboration

[1] *Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831*
[2] *Department of Physics and Astronomy, University of Tennessee, Knoxville TN 37996*
[3] *Physics Department, Tennessee Technological University, Cookeville, TN 38505*

Due to its importance as a "trigger" reaction in x-ray bursts, the ^{14}O(α,p)^{17}F reaction rate has been the focus of many experimental studies. The ^{14}O(α,p)^{17}F reaction rate significantly impacts the outcome of the burst light curve and final abundances of the A=29 mass chain, and provides a pathway to alter the ratio of ^{14}O to ^{15}O in the accreted material, affecting the availability of ^{15}O to feed the important ^{15}O(α,γ)^{19}Ne reaction over time. In particular, a $J^{\pi} = 1^{-}$, $\ell_{\alpha} = 1$ resonance in ^{18}Ne above the ^{14}O+α threshold is expected to dominate the astrophysical reaction rate at temperatures relevant to Type I x-ray bursts. However, the adopted literature assignment of this 1^{-} state to the level at $E_x = 6150$ keV in ^{18}Ne was recently questioned based on a combined reanalysis of new and existing data. The relative strengths of the proton branches to the ground and first excited state of ^{17}F from this important ^{18}Ne level, which are critical to the correct calculation of the reaction rate from the time-inverse reaction ^{17}F(p,α)^{14}O, are also not fully constrained, with large variations reported in the literature. In order to address these discrepancies, commissioning data from the Jet Experiments in Nuclear Structure and Astrophysics (JENSA) gas jet target system were examined, utilizing a technique not previously used for astrophysically-important reactions. Due in large part to the low backgrounds and lack of contaminants originating from the jet target, these data were sensitive to both the ℓ transfer and particle decays of the excited levels in ^{18}Ne. The technique and preliminary results will be presented.

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Exotic decay modes of light silicon isotopes

A. A. Ciemny [1], C. Mazzocchi [1], W. Dominik[1], A. Fijałkowska[1,2], J. Hooker[3,4], C. Hunt[3], Ł. Janiak[1,5], H. Jayatissa[3], G. Kamiński[6], Y. Koshchiy[3], M. Pfützner[1], M. Pomorski[1], B. T. Roeder[3], G. Rogachev[3], A. Saastamoinen[3], N. Sokołowska[1], S. Sharma[1]

[1] *Faculty of Physics, University of Warsaw, Warsaw, Poland*
[2] *Department of Physics and Astronomy Rutgers, The State University of New Jersey, USA*
[3] *Texas A&M University, College Station, TX, USA*
[4] *Department of Physics and Astronomy, University of Tennessee, Knoxville, TN, USA*
[5] *National Centre for Nuclear Research, Otwock, Poland*
[6] *Joint Institute for Nuclear Research, Dubna, Russia*

Nuclei lying far to the left from the β-stability path are characterised by high $Q_{\beta+}$-value, leading to population of highly excited states in the daughter nuclei. This, combined with decreasing charged-particle separation energies, opens windows for a variety of decay channels with β-delayed (multi-) particle emission. Once such processes occur, they become very competitive to the deexcitation via gamma radiation. Hence, the study of these decay channels provide a unique tool for gaining an insight and understanding on the nuclear structure in this region. Moreover, decay data of these nuclei can provide an important input for the astrophysical rp-process modeling[1, 2]

The two most neutron-deficient silicon isotopes, ^{22,23}Si, were investigated in an experiment performed using the MARS spectrometer at the Cyclotron Institute of Texas A&M University. The ions of interest were implanted into the Warsaw Optical Time Projection Chamber [3] - a tool characterized by almost 100% detecting efficiency for rare decay modes involving emission of charged particles. The data collected allowed confirmation of all known decay channels for both isotopes (β-delayed proton and two-proton emission), as well as for the extension of the known energy spectra for the delayed protons to lower energies and the identification of new, exotic, decay branches such as β-delayed three-proton and β-delayed proton-alpha emission. The results will be presented and discussed.

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Study of exotic decay of the nuclei around proton drip line at A $\sim$ 115

Ushasi Datta[1], P.Das[1], S.Chakraborty[1,4], A.Rahaman[1,5], J.Ray[1], O.Tengblad[2], A.Becerril[2], A.Bhattacharya[1], P.Bhattacharya[1], M.J.G. Borge[2,3], J.Cederkall[6], A.Gottberg[3,7], B.Jonson[8], M.Kowalska[3], J.Kurcewicz[3], R.Lica[9], S.Mandal[10], I.Marroquin[2], K. Riisager[11], C.Sotty[12], T.Stora[3]

[1]*Saha Institute Of Nuclear Physics, Kolkata, India,* [2]*Inst. de Estructura de la Materia, CSIC, Madrid, Spain,* [3]*ISOLDE, CERN, Geneva, Switzerland,* [4]*University of Engg. Management, Kolkata, India,* [5]*Jalpaiguri Govt. Eng. College, West Bengal, India,* [6]*University of Lund, Sweden,* [7]*Triamf, Canada,* [8]*Chalmers University of Technology, Gteborg, Sweden,* [9]*National Institute for Physics and Nuclear Engineering, Bucharest, Romania,* [10]*University Of New Delhi, India,* [11] *Aarhus University, Denmark,* [12] *KU Leuven, Leuven, Belgium,*

Study of properties of the nuclei near and beyond drip line provides unique information for validating nuclear theory on n-n interactions which may provide the missing link in understanding limits of existence of atomic nuclei. With this aim exotic decay of ^{115}Cs and neighbouring nuclei have been studied at ISOLDE, CERN. ^{115}Cs is lying just beyond the proton drip line (Sp = -100 keV) but due to Coulomb barrier and centrifugal barrier, its life time is 1.4 sec. Theoreticians predicted that Xe, Cs, Ba isotopes in the the mass region A $\sim$ 110-120, are in the island of cluster emitters. Moreover, the effect of the proton-skin thickness on the decays of neutron-deficient nuclei still needs further investigation. The neutron deficient Cs and Ba radioactive ion beam was produced by bombarding a tailored LaC2 target with 1.4 GeV protons. The radioactive ions were extracted, ionized by a hot rhenium surface ion source, and separated using the ISOL method. Efficiencies of extraction and ionization of atomic Cs isotopes exceed the ones for Ba isotopes significantly. Therefore, in-target fluorination was used in order to extract Ba as fluoride molecules on a mass with greatly reduced isobaric contaminations. Ions were separated by GPS and then implanted into a 20 g/cm2 carbon foil located in the middle of the detector set-up. A compact particle detection system consisting of double-sided silicon strip detectors (DSSSD), backed by a thick silicon PAD along with Clover detectors to optimize detection of the rays were placed. According to present literature, ^{115}Cs ($t_{1/2}$ = 1.4 s) mainly decays by electron capture with small fraction (sin 0.07 %) delayed proton. But from present experimental data, first time exotic decay mode of delayed proton-proton and α in addition to delayed proton and electron capture have been observed. Several quasibound resonance states were populated via decay which were decayed by proton(s) and alpha. We shall report these states along with properties of reduced decay widths. The delayed cluster (^{12}C etc.) emission from ^{115}Cs has been predicted theoretically. It is a rare process which was observed in rare-earth region. But several theoretician predicted similar phenomena in this exotic region. An upper limit of this exotic decay mode has been obtained from present data. Unlike, ^{115}Cs, ^{116}Cs is moderately proton bound statem but many interesting features of exotic decay mode has been observed in the present experimental data. Several higher-lying resonance states and cluster states have been populated via decay. We shall present the above mentioned facts along with comparision with theoretical prediction.

Theoretical interpretation of proton radioactivity: current status

Lídia S. Ferreira

Centro de Física e Engenharia de Materiais CeFEMA and Departmento de Física, Instituto Superior Técnico,
Universidade de Lisboa, Av Rovisco Pais, 1049 001, Lisboa, Portugal

A review of the recent developments in the theoretical interpretation of proton emission from drip line nuclei, will be presented.

Low-Background Measurement of Low-Energy ^{23}Al β-delayed Protons as a Probe for ^{22}Na Destruction Rates in Novae

M. Friedman[1], D. Pérez-Loureiro[1,2], T. Budner[1,3], E. Pollacco[4], C. Wrede[1,3], M. Cortesi[1], C. Fry[1,3], B. Glassman[1,3], J. Heideman[2], M. Janasik[1,3], M. Roosa[1,3], J. Stomps[1,3], J. Surbrook[1,3], P. Tiwari[1,3], and J. Yurkon[1]

[1] *National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824-1321, USA*

[2] *Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee , 37996 USA*

[3] *Department of Physics and Astronomy Michigan State University, East Lansing, Michigan 48824-1321, USA*

[4] *IRFU, CEA, Université Paris-Saclay, F-91191, Gif-sur-Yvette, France*

Classical novae are energetic and common thermonuclear astrophysical explosions on the surface of a white dwarf that is accreting hydrogen-rich material from a companion star. Space-based observations of 1275 keV γ-rays from ^{22}Na produced in nova explosions are expected to provide direct constraints on nova models [1]. Previously and currently deployed instruments may have been on the cusp of detecting ^{22}Na and more sensitive future missions are being planned [2].

^{22}Na production in novae is strongly dependent on the rate of the destructive ^{22}Na(p,γ) reaction, and, in particular, on the strength of a single resonance at center-of-mass energy of 204 keV. Two direct measurements of this resonance strength differ by a factor of 3.2 [3, 4]. Another way to determine the strength is to combine measurements of the proton branching ratio Γ_p/Γ of the resonance with its lifetime. This can be done using the ^{23}Al$(\beta^+p)^{22}$Na decay [5]. However, such a measurement is challenging due to the low proton branching ratio from the 204 keV state, and the overwhelming β^+ background at that energy.

The GADGET assembly is a new detection system, comprised of gas-filled charged-particle detector surrounded by the Segmented Germanium Array [6]. The detector is designed to measure protons and heavier charged particles with high efficiency, while maintaining low ionization from β particles. GADGET was recently used to measure the aforementioned branching ratio at NSCL, providing clean and surprising results that will be presented.

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Delayed particle emission from light nuclei

Hans. O.U. FYNBO[1]

[1] *Department of Physics and Astronomy, Aarhus University, Aarhus, Denmark*

In this talk I will discuss recent experiments on delayed particle emission from light nuclei. The experiments are motivated by two themes: nuclear astrophysics and decay properties of halo-nuclei.

For nuclear astrophysics the experimental challenge is to precisely determine properties of resonances with very short lifetimes, or correspondingly very large widths. For the decay of halo nuclei the challenge is to find very weak decay branches corresponding to the decay of either the core or the halo-nucleon.

I will cover experiments performed at the ISOLDE facility at CERN, and facilities in Finland, the Netherlands and the US.

Mass measurements of N=Z nuclei upto ^{100}Sn at the Rare-RI Ring in RIKEN

Zhuang GE[1,2], Tomohiro UESAKA[2], Sarah NAIMI[2], Daisuke NAGAE[2], Yasushi ABE[2], Syunichiro OMIKA[2,3], Fumi SUZAKI[2], Hongfu LI[1,2], Yoshitaka YAMAGUCHI[2], Masanori WAKASUGI[2], Kiyoshi WAKAYAMA[3], Takayuki YAMAGUCHI[3,4], Akira OZAWA[4],Hiroki ARAKAWA[3], Kumi INOMATA[3], Takaaki KOBAYASHI[4],Kunimitsu NISHIMURO[3], Shinji SUZUKI[4], Tetsuaki MORIGUCHI[4], Daiki KAMIOKA[4], Momo MUKAI[3], Masamichi AMANO[4], Atsushi KITAGAWA[5], Shinji SATO[5], Giuseppe LORUSSO[6], Yasushige YANO[2]

[1]*Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, People's Republic of China*

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

[3]*Department of Physics, Saitama University, Shimo-Okubo 255, Sakura-ku Saitama-shi, 338-8570,Japan*

[4]*Institute of Physics, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8571,Japan*

[5]*National Institute of Radiological Sciences, Chiba 263-8555, Japan*

[6]*Department of Physics, University of Surrey, Guildford, Surrey GU2 7XH, United Kingdom*

Strong interest in fast, high-accuracy and high-precision mass measurements for exotic nuclides due to their importance in nuclear astrophysics and nuclear structure studies, has triggered the development of a various of techniques for mass measurement around the world. An isochronous mass spectrometry (IMS) using a newly constructed storage ring named the Rare-RI ring (R3) has been implemented at the RIKEN Nishina Center to determine the masses of short-lived rare nuclei with a relative precision of the order of 10^{-6}[1, 2, 3]. A combination of the High-resolution Achromatic (HA) beam-line (updated to be newly constructed OEDO beam-line in the year 2017), SHARAQ spectrometer, injection-line (IL) of R3, the R3 mass spectrometer to the BigRIPS separator makes the mass measurements by two complementary TOF (Bρ-TOF and IMS) methods possible in one experimental setup. To realize high-resolution and high-accuracy mass measurements by the TOF methods, a position-sensitive timing MCP detector [4, 5] has been developed for R3. We have also developed a new method via IMS for mass measurements for N=Z nuclei at R3 in RIBF. A simulation study of this method have been done to measure the mass of N=Z nuclei including ^{100}Sn. We will use this method and the corresponding setup for the approved experiment at RIBF for mass measurements of N=Z nuclei soon. In this contribution, we will report on the development of the MCP detector and the simulation study of the mass measurements of N=Z nuclei for the coming experiment at RIBF.

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^{73}Sr β-delayed proton emission and the structure of ^{73}Rb

D. E. M. Hoff[1], A. M. Rogers[1], P. C. Bender[1], K. Brandenburg[6], B. A. Brown[2,3], K. Childers[2,4], J. Clark[5], A. C. Dombos[2,3], E. R. Doucet[1], S. Jin[2,3], R. Lewis[2,4], S. N. Liddick[2,4], C. J. Lister,[1], C. M. Morse[1], Z. Meisel[6], H. Schatz[2,3], K. Schmidt[2,3], D. Soltesz[6], S. K. Subedi[6], and S. Waniganeththi[1]

[1] *Department of Physics and Applied Physics, University of Massachussetts Lowell, Lowell, MA 01854*

[2] *National Superconducting Cyclotron Laboratory (NSCL), Michigan State University, East Lansing, Michigan 48824, USA*

[3] *Department of Physics and Astronomy and National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824*

[4] *Department of Chemistry, Michigan State University, East Lansing, Michigan 48824, USA*

[5] *Physics Division, Argonne National Laboratory, Argonne, IL 60439, USA*

[6] *Department of Physics and Astronomy, Ohio University, Athens, OH 45701*

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Properties of proton-emitting nuclei at the limits of nuclear binding, along the proton dripline, impact the rapid proton-capture (rp) process while also revealing interesting nuclear structure. The proton separation energy of the nucleus ^{73}Rb ($T = 1/2$), for example, is important for quantifying the amount by which the ^{72}Kr waiting point is bypassed through $2p$-capture during the rp process. Other properties, such as the branching of ^{73}Rb p decay, can provide information on the extent of deformation in the nearby region of the nuclear chart. To probe the properties of ^{73}Rb, β-delayed protons emitted from a ^{73}Sr precursor were measured via ion implantation-decay correlations at the NSCL using the Beta-Counting Station (BCS) providing the first direct measurement of the ^{73}Sr lifetime in conjunction with protons emitted from previously unobserved states in ^{73}Rb. A low-energy proton peak was observed that is consistent with transistions from ^{73}Rb(g.s.) to ^{72}Kr(g.s.), supported by fp shell model predictions (using the GPFX1A Hamiltonian) for the β feeding from ^{73}Sr. The determined proton separation energy of ^{73}Rb highly suppresses $2p$ capture at the ^{72}Kr rp-process waiting point. β-delayed proton-γ correlations were measured by the Segmented Germanium Array (SeGA) surrounding the BCS, and these correlations suggest that ^{73}Rb*(IAS) and its parent, ^{73}Sr, are highly deformed.

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Fine Structure of Beta-Decay Strength Function $S_\beta(E)$ Anisotropy of Isovector Nuclear Dencity Component Oscillartions in Deformed Nuclei

I. N. Izosimov[1]

[1] *Joint Institute for Nuclear Research,*

Joliot-Curie 6, Dubna 141980, RUSSIA

The strength function $S_\beta(E)$ governs [1, 2, 3] the nuclear energy distribution of elementary charge-exchange excitations and their combinations like proton particle (πp)-neutron hole (νh) coupled into a spin-parity I^π : $[\pi p \otimes \nu h]I^\pi$ and neutron particle (νp)-proton hole (πh) coupled into a spin-parity $I^\pi : [\nu p \otimes \pi h]I^\pi$. The strength function of Fermi-type β-transitions takes into account excitations $[\pi p \otimes \nu h]0^+$ or $[\nu p \otimes \pi h]0^+$. Since isospin is a quite good quantum number, the strength of the Fermi-type transitions is concentrated in the region of the isobar-analogue resonance (IAR). The strength function for β-transitions of the GamowTeller (GT) type describes excitations $[\pi p \otimes \nu h]1^+$ or $[\nu p \otimes \pi h]1^+$. Residual interaction can cause collectivization of these configurations and occurrence of resonances in $S_\beta(E)$.

From the macroscopic point of view, the resonances in the Gamow-Teller (GT) beta-decay strength function $S_\beta(E)$ are connected with the oscillation of the spin-isospin density without change in the shape of the [1, 2]. Modern high-resolution nuclear spectroscopy methods made it possible to identify the splitting of peaks in $S_\beta(E)$ for deformed nuclei [3, 4, 5]. By anology with splitting of the peak of $E1$ giant resonance (GDR) in deformed nuclei, the peaks in $S_\beta(E)$ are split into two components from the axial nuclear deformation [3, 6, 7].

In this report the fine structure of $S_\beta(E)$ is considered. Splitting of the peaks connected with the oscillations of neutrons agaist protons ($E1-GDR$), of proton holes against neutrons (peaks in $S_\beta(E)$ of GT β^+/EC-decay), of protons against neutron holes (peaks in $S_\beta(E)$ of GT β^--decay) and influence of such splitting on delayed particles emission are discussed.

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Shapes, Structures and Radioactive Decay Modes in Heavy Proton-Unbound Nuclei

D. T. Joss[1]

[1] *Oliver Lodge Laboratory, Department of Physics, University of Liverpool, Liverpool, L69 7ZE, United Kingdom*

Proton emission from nuclear ground states is expected to determine the limit of observable proton-rich nuclei for most elements. Considerable progress has been made in the study of proton-unbound nuclei since the advent of selective correlation techniques that have allowed particle and gamma-ray emissions to be identified from excited states. This paper reports recent experimental investigations into nuclear shapes at large neutron deficiency and the search for new proton-emitting states from multiparticle isomers using electromagnetic recoil separators.

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Studies of proton-rich nuclei in the $A \approx 30$ region for nuclear astrophysics

A. Kankainen[1]

[1] *Department of Physics, University of Jyvaskyla,*
P.O. Box 35 (YFL), FI-40014 University of Jyvaskyla, Finland

Proton-rich nuclei in the $A \approx 30$ region play a central role in some of the key reactions for nuclear astrophysics. The amount of cosmic 1809-keV γ-rays, originating from the ground-state beta decay of ^{26}Al ($T_{1/2} \approx 0.7$ My), depends sensitively on the proton-capture rate ^{26}Al$(p,\gamma)^{27}$Si and bypass routes, such as ^{25}Al$(p,\gamma)^{26}$Si$(\beta^+)^{26m}$Al. Another key reaction for nuclear astrophysics is ^{30}P$(p,\gamma)^{31}$S which controls the production of intermediate-mass elements beyond sulphur in novae. The bypass route via ^{30}S$(p,\gamma)^{31}$Cl is hindered due to its low proton-capture Q value. In this contribution, I will give an overview on recent experiments related to these key reactions. In particular, the surrogate reactions ^{26}Al$(d,n)^{27}$Si [1] and ^{30}P$(d,n)^{31}$S [2], studied in inverse kinematics with GRETINA at NSCL, will be discussed, as well as recent mass measurements [3, 4] performed in the region.

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Probing shell evolution and nuclear force at the proton drip-line

R. Kanungo[1,2]

[1] *Saint Marys University, Halifax, Canada*
[2] *TRIUMF, Vancouver, Canada*

The rare isotopes have ushered an exciting era in nuclear science with exotic nuclear forms appearing as nuclear halos and skin. Their existence is tied to changes in conventional nuclear shells. There has been much exploration in the neutron-rich landscape of light nuclei that have unmasked disappearance of traditional magic numbers and appearance of new ones. Do such features also appear in the vicinity of the proton drip-line is a question that will be addressed in this presentation.

The discussion will focus on probing the ground and excited states of proton-rich nuclei using direct reactions both at low- and high-energies. Spectroscopy of the drip-line nucleus 20Mg with different probes and their implications will be presented.

The new features in the rare isotopes challenge our understanding of the nuclear force bringing new insight. It has been a century-long challenge to understand the nuclear force between protons and neutrons forming many-body nuclei, from the fundamental basis of quantum chromodynamics (QCD). The formulation of the chiral effective field theory has paved the closest link with QCD making it possible to predict some observable properties of many-body nuclei. The presentation will show examples of how spectroscopic information compared to *ab initio* predictions provide insight on the nuclear force.

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Investigating N/Z effects in the decay of compound nuclei with mass A = 60

Mandeep Kaur[1,†,*], BirBikram Singh,[1,**] and Manoj K. Sharma[2]

[1] *Department of Physics, Sri Guru Granth Sahib World University, Fatehgarh Sahib-140406, Punjab, India,*

[2] *School of Physics and Materials Science, TIET, Patiala-147004, India.*

[†] *Present address: 2121, 45th street, Unit number 4211, Highland, Indiana-46322, USA*

The quantum mechanical fragmentation theory (QMFT)-based dynamical cluster-decay model (DCM)[1, 2, 3] has been applied to predict the fusion cross section (σ_{fus}) for the compound systems (CS) ^{60}Zn*, ^{60}Ni* and ^{60}Fe* formed, respectively, via ^{4}He+^{56}Ni, ^{4}He+^{56}Fe and ^{4}He+^{56}Cr, reactions, by fixing the only parameter (neck length ΔR_{emp}) of the model, empirically with the available experimental data on σ_{fus} of ^{44,48}Ti* and ^{68}Ge* formed through ^{4}He induced reactions at different laboratory energies, i.e., $E_{lab} \sim 10$, 13, 17 MeV[4, 5]. We have investigated the effect of neutron to proton (N/Z) ratio in the decay of CS under study, i.e., ^{60}Zn*, ^{60}Ni* and ^{60}Fe*[6]. The contributions of light-particles cross section (σ_{LPs}), intermediate mass fragments cross section (σ_{IMFs}) and symmetric mass fragments cross section (σ_{SMFs}) are taken simultaneously to calculate σ_{fus} (= σ_{LPs} + σ_{IMFs} + σ_{SMFs}). The small percentage yield of SMFs is noticed in σ_{fus}, the contributions of LPs and IMFs yields being much more influential, for the decay of all CS under study at different incident energies. We see that the preformation factor (P_0) and penetration probability (P) for SMFs decrease with rising value of N/Z ratio, and hence the symmetric breakup goes-out-of-favor for higher N/Z numbers. In other words, the symmetric mass decay is favored in the case of ^{60}Zn* having N=Z, the LPs, IMFs and SMFs percentage yields increasing with increase in laboratory energy.

This work is dedicated to Late Prof. Raj K. Gupta for his noble contribution to nuclear physics society.

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End of nuclear landscape foreseen for light argon and chlorine isotopes

D. Kostyleva[1,2], I. Mukha,[2] L.V. Grigorenko[3,4,5] and C. Scheidenberger[1,2]

[1] *II. Physikalisches Institut, Justus-Liebig-Universität, 35392 Gießen, Germany*
[2] *GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany*
[3] *Flerov Laboratory of Nuclear Reactions, JINR, 141980 Dubna, Russia*
[4] *National Research Nuclear University "MEPhI", 115409 Moscow, Russia*
[5] *National Research Centre "Kurchatov Institute", Kurchatov sq. 1, 123182 Moscow, Russia*

In order to understand the limits of nuclear structure existence, one can take a closer look at the nuclear systems located far beyond the driplines. Although unbound nuclear systems are unstable, they also exhibit individual quantum states, and can have lifetimes long enough to be seen as quasi-stationary ones. Still, the region of nuclei along this border and beyond remains poorly explored. Here, we report on discovery and phenomena observed in new, extremely neutron-deficient quasi-stationary isotopes of argon and chlorine, which are located far off the valley of stability [1]. The experiment, where spectroscopy of six previously-unobserved proton-unbound isotopes could be achieved, was performed at GSI, Germany, using the state-of-the-art EXPERT tracking technique of all decay products.

The previously-unknown isotopes ^{29,31}Ar and ^{28,30}Cl were found to dissociate via proton radioactivity, namely via emission of one or two protons, and the first spectroscopy of those isotopes has been performed. The first-time observed excited states of ^{31}Ar demonstrated a very high level of isobaric symmetry with respect to its mirror ^{31}Al, which allowed to derive the 2p-separation energy S_{2p} of +6(34) keV for the ^{31}Ar ground state. This result is in agreement with the previous estimate [2] done within β-delayed proton decay studies of this nucleus. The observed systematic trends were used to predict properties in even lighter systems, located up to five mass units beyond the dripline, where ^{26}Ar and ^{25}Cl isotopes are predicted to form the lightest possible nuclei of these chemical elements [3].

This work was carried out in the framework of the Super-FRS Experiment collaboration.

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Charge radii of proton-rich Ca isotopes

J.D. Lantis[1,2], K. Minamisono[2,3], A. Klose[4], D. Garand[2], C.Kujawa[4], Y.Liu[5], B.Maaß[6], P.F. Mantica[2,7], A.J. Miller[2,3], W. Nazarewicz[3,7], W.Nörterhäser[6], S.V. Pineda[4], P.-G. Reinhard[8], D.M. Rossi[6], F. Sommer[6], C. Sumithrarachchi[2], A. Teigelhöfer[9], and J. Watkins[2]

[1] *Department of Chemistry, Michigan State University, East Lansing, MI, USA East Lansing, Michigan 48824-1321, USA*

[2] *National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, MI, USA*

[3] *Department of Physics and Astronomy, Michigan State University, East Lansing, MI, USA*

[4] *Department of Chemistry, Augustana University, Sioux Falls, SD, USA*

[5] *Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN, USA*

[6] *Institut für Kernphysik, Technische Universität Darmstadt, Darmstadt, Germany*

[7] *Facility for Rare Isotope Beams, Michigan State University, East Lansing, MI, USA*

[8] *Institut für Theoretische Physik, Universität Erlangen, Erlangen, Germany*

[9] *TRIUMF, Vancouver, British Columbia, Canada*

The chain of charge radii of Ca isotopes has been a challenge to nuclear theory because of its intricate pattern. The Ca chain contains many interesting features. The radius of ^{48}Ca is about the same size as ^{40}Ca even with eight neutrons added, there is a pronounced odd-even staggering in between, and an unexpected large increase in the charge radius was observed above ^{48}Ca [1], all of which require more advanced approaches to model.

The mean-square charge radii of ^{36,37,38}Ca approaching the proton dripline were determined [2] at the BEam COoler and LAser spectroscopy (BECOLA) facility [3] at NSCL/MSU , using collinear laser spectroscopy technique. Atomic hyperfine spectra were measured to deduce differential mean-square charge radii.

The extracted charge radii are not reproduced by the previous density functional theory with Skyrme or Fayans energy density functionals, which strongly overestimates the present charge radii, introducing a new challenge to theories. It was determined that the weak binding effect of protons in these proton-rich Ca isotopes can explain the discrepancy. The improved model with coupling to the proton continuum successfully reproduces the charge radii. Details of the experimental results and new developments in the theory describing the chain of Ca charge radii will be discussed.

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Isospin Symmetry and Independence Tests in Analog States of Isobaric Multiplets

Silvia M. Lenzi[1,2]

[1] *Department of Physics and Astronomy, University of Padova, Padova, Italy*
[2] *Istituto Nazionale di Fisica Nucleare, Sezione di Padova, Padova, Italy*

In nuclear physics, simmetries play a key role in the understanding of the behaviour of matter. Isospin symmetry and independence is a consequence of the (approximate) charge invariance of nucleon - nucleon forces. Although the symmetry is already broken, to some extent, at the level of strong interaction and - to a much larger extent - by electromagnetic forces, the isospin formalism remains a very powerful tool to relate the properties of corresponding levels in different nuclei, from which complementary information can be derived on the structure of the nuclear wave function. The most important component of the symmetry breaking interaction, i.e., the Coulomb force between protons, is certainly the best known part of the Hamiltonian, and its effects can be calculated as a perturbation series if the structure of unperturbed (charge symmetric) states is assumed to be known.

During the last years the systematic experimental studies of excited states in isobaric multiplets have allowed to probe the validity of isospin symmetry and independence in nuclei of the $f_{7/2}$ shell [1, 2]. More recently these studies have been extended to other mass regions [3, 4, 5]. A review of the recent developments together with new insights on the nuclear structure properties through the energy differences between mirror nuclei and isobaric triplets will be presented and discussed.

Change this line. We acknowledge support from NSF grant PHY-1811855.

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Exotic Decays of Extremely Proton-rich Nuclei in *sd*-shell and Related Topics

C. J. Lin[1,4], X. X. Xu[1,3], L. J. Sun[1,5], J. S. Wang[2], S. Q. Hou[2], et al.
(RIBLL Collaboration)

[1] *Department of Nuclear Physics, China Institute of Atomic Energy, Beijing 102413, China*
[2] *Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China*
[3] *Department of Physics, The University of Hong Kong, Hong Kong, China*
[4] *College of Physics and Technology, Guangxi Normal University, Guilin 541004, China*
[5] *School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China*

A series of experiments have been done at the HIRFL-RIBLL1 facility for studying the exotic decays of extremely proton-rich nuclei. Beta-delayed proton and two-proton decays from ^{20,21}Mg, ^{22,23}Al, ^{22,23,24}Si, ^{26,27}P, ^{27,28,29}S have been measured by the continuous implantation-decay method using silicon array and gamma-ray detectors [1]. With high detection efficiency, low energy threshold and good statistics, numbers of new decays have been observed and rich information on the β-decay spectroscopy (e.g. half-life, decay energy, branching ratio, etc.) has been obtained. Some typical results will be presented in the conference. In particular, two nuclei will be emphasized:

1) ^{22}Si, β-delayed two-proton decay was observed for the first time [2]. The ground-state mass was deduced to be -108(125) keV, indicating it is a very marginal candidate for direct two-proton emission. Combined with ^{20}Mg results [3], related topics, for instance, the isospin asymmetric decays of mirror nuclei and the three-body force will be discussed.

2) ^{27}S, the proton and gamma emissions from the first excited state (1125 keV, 3/2+) of ^{27}P were measured simultaneously for the first time in ^{27}S beta-decays [4]. The key astrophysical reaction rate of ^{26}Si(p,γ) related to the abundance issue of ^{26}Al in the Milky Way will be discussed.

More details will be presented in the conference.

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Spectroscopy and lifetime measurements near the proton drip line: ^{26,27,28}P

B. Longfellow,[1,2] A. Gade,[1,2,3] B. A. Brown,[1,2] D. Bazin,[1,2] P. C. Bender,[1] M. Bowry,[1] P. D. Cottle,[4] B. Elman,[1,2] E. Lunderberg,[1,2] A. Magilligan,[1,2] M. Spieker,[1] D. Weisshaar,[1] and S. J. Williams[1]

[1] *National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, USA*

[2] *Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA*

[3] *The JINA Center for the Evolution of the Elements, Michigan State University, East Lansing, Michigan 48824, USA*

[4] *Department of Physics, Florida State University, Tallahassee, Florida 32306, USA*

The properties of the phosphorus isotopes closest to the proton drip line have prompted a number of experimental and theoretical studies with a focus on both nuclear structure and nuclear astrophysics. We will present results from in-beam γ-ray spectroscopy experiments on ^{26,27,28}P performed at the National Superconducting Cyclotron Laboratory with the high-efficiency CsI(Na) array CAESAR and the high-resolution segmented Ge array SeGA. In ^{26}P, a previously-unobserved level has been identified at 244(3) keV, two new measurements of the astrophysically-important $3/2^+$ resonance in ^{27}P have been performed, γ decays have been assigned to the proton-unbound levels at 2216 keV and 2483 keV in ^{28}P, and the γ-ray lineshape method has been used to make the first determination of the lifetimes of the two lowest-lying excited states in ^{28}P. The expected Thomas-Ehrman shifts were calculated and applied to levels in the mirror nuclei. The resulting level energies from this procedure were then compared with the energies of known states in ^{26,27,28}P.

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Monte Carlo Reaction Rate Uncertainties

R. Longland[1,2]

[1] *Department of Physics, North Carolina State University, Raleigh, NC 27695, USA*
[2] *Triangle Universities Nuclear Laboratory, Durham, NC 27708, USA*

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Nuclear reaction rates must be known to compute nuclear energy generation and nucleosynthesis in stars. Our knowledge of these rates and stellar models give us a good qualitative description of stars. However, in the era of precision astronomy and high performance computing, stellar models have now reached a point in which they can be compared quantitatively with observations of stars and stellar explosions. To make these comparisons nuclear reaction rate uncertainties must be considered before we can identify and remedy any shortcomings in our understanding of stellar structure. In the last decade, Monte Carlo methods have been developed for calculating nuclear reaction rate uncertainties in a statistically rigorous manner, which can now be used as inputs to stellar models. I will present an overview of those techniques, which require carefully assigned nuclear property probabilities that are physically and statistically motivated. A number of recent extensions to our method will be detailed that allow for correlations between the uncertain nuclear inputs to these calculations, and cases where unknown spins and parities affect the reaction cross section. I'll also outline nucleosynthesis modelling techniques for utilizing the Monte Carlo reaction rates. Some examples will be highlighted, including full Monte Carlo stellar model calculations that show the power of these methods.

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Spectroscopic Studies for Explosive Nuclear Astrophysics

G. Lotay[1],

[1] *Department of Physics, University of Surrey, UK.*

Classical novae and astrophysical X-ray bursts are among the most frequent and violent stellar explosions to occur in our Galaxy and as such, play a key role in its evolution. Recently, remarkable advances in astronomy and meteoritics have produced a wealth of observational data on these cataclysmic astronomical events, giving us unprecedented insight into their properties. Unfortunately, a detailed understanding of this latest data is severely hindered by large uncertainties in the underlying nuclear physics processes that govern both the rate of energy release and pathway of nucleosynthesis in explosive astrophysical environments.

In this regard, the properties of proton-unbound states in unstable nuclei play a key role. Specifically, precise knowledge of the location of particle-unbound levels that act as key resonances in astrophysical reactions, together with their corresponding proton partial widths, allows for an accurate determination of (p, γ) stellar reaction rates. In this talk, indirect measurements aimed at determining the properties of astrophysical resonant states in the nuclei ^{34}Ar and ^{24}Si will be discussed.

New Isospin-Breaking "USD" Hamiltonians and their Predictions for Proton-Rich Nuclei in the *sd*-shell

A. Magilligan and B. A. Brown

[1] *Department of Physics and Astronomy, National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824-1321, USA*

Two new "USD" type Hamiltonians [1], USDC and USDC-m, have been developed that directly incorporate Coulomb and other isospin breaking interactions. Starting from *ab initio* Hamiltonians and a Coulomb interaction, linear combinations of two-body matrix elements were constrained by experimental energy levels in *sd*-shell nuclei. With this new method, binding energies and excitation energies of proton-rich nuclei in the shell can be included in the data set.

USDC uses an analytic Coulomb interaction with short range correlations, while USDC-m has a modified Coulomb reaction that can better reproduce the experimental linear coefficients of the Isobaric Mass Multiplet Equation. These Hamiltonians are used to provide new predictions for the proton-dripline, and to examine isospin level mixing and other properties of *sd*-shell nuclei.

We acknowledge support from NSF grant PHY-1811855.

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The Influence of Proton-Rich Nuclei on the Most Neutron-rich Matter in the Universe

Z. Meisel[1]

[1] *Department of Physics and Astronomy & Institute of Nuclear and Particle Physics, Ohio University, Athens, Ohio 45701, USA*

Accreting neutron stars provide unique windows on the behavior of matter at ultrahigh density and relatively low temperature. Observables from these extremely neutron-rich objects are sensitive to the properties of some of the most proton-rich nuclei. In this talk I will demonstrate how specific nuclear properties impact dense matter constraints obtained from type-I X-ray burst model-observation comparisons. I will also discuss recent and ongoing experimental work to remove some of the most influential nuclear physics uncertainties.

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Proton emission in ultra-intense laser fields

Ş. Mişicu[1] and M. Rizea[1]

[1] *Department for Theoretical Physics, National Institute for Nuclear Physics and Engineering, P.O.Box MG-6, RO-077125 Bucharest-Magurele, Romania*

The possibility to modify particle decay rates in strong laser fields is a topic that received only recently expanded interest in nuclear physics, specially due to the entrance in operation of new powerful laser facilities around the globe. Previously we investigated the modification rates of α-decay in ultra-intense optical and X-ray laser fields [1].

Next we moved our inquiry on the proton emission from the ground state of a spherical nucleus (^{171}Au) and the deformed nuclei ^{141}Ho and ^{145}Tm by solving the time-dependent Schrödinger equation in cylindrical coordinates (two dimensions) by the Crank-Nicolson method, a method that allows us to follow the tunneling dynamics in ultra-intense laser fields within a spatial region large compared to the nuclear volume. As time-independent potential we use the Woods-Saxon form of the nuclear potential with parameters adapted for the proton-decay of ^{109}I and the Coulomb potential produced by the uniformly distributed charge of the daughter nucleus inside the nuclear surface.

The proton decay-rate for long or short laser pulses is calculated as a function of intensity and photon frequency. Application of a continuous laser field of Ti:sapphire type of very high intensity or of X-ray type with corresponding lower intensity induces only more or less pronounced oscillations around the field-free decay rate values. On the other hand short laser pulses of rectangular shape with an odd number of half-cycles yield an enhancement of up to three orders of magnitude of the decay rate.

We acknowledge support from Institute of Atomic Physics-IFA, through the national programme PN III 5/5.1/ELI-RO, Project 04-ELI/2016 (”QLASNUC”) .

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Deep Excursion beyond the Proton Drip Line along Argon and Chlorine Isotope Chains

I. Mukha[1]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany*

The location of the driplines (borderlines separating particle-stable and particle-unstable nuclei) is one of the fundamental questions of nuclear science. The unbound isotopes just beyond the driplines can have half-lives which are long enough to be treated as quasistationary states, provided their decay energy is small. States of more remote nuclides usually have larger decay energies and shorter half-lives. This naturally leads us to the question: what are the limits of nuclear structure existence? In other words, how far beyond the driplines the nuclear structure phenomena fade and are completely replaced by the continuum dynamics?

The recent experimental [1] and theoretical [2] studies of the lightest previously-unknown isotopes in the argon and chlorine chains will be reported, and the limits of existence of the corresponding nuclear structure will be discussed. For the issue of existence of nuclear structure, the approach used in Ref. [2] is adopted. Namely, a nuclear configuration has an individual structure with at least one distinctive state, if the orbiting valence protons of the system are reflected from the corresponding nuclear barrier at least one time. Thus nuclear half-life may be used as a criterium here. Two opposite cases may be mentioned. In the first case, the very long-lived particle-emitting states may be considered as *quasistationary.* For example, the half-lives of all known heavy two-proton ($2p$) radioactivity precursors (^{45}Fe, ^{48}Ni, ^{54}Zn *etc*) are a few milliseconds. Their $2p$ decays are so slow that weak transitions become competitive. For such states, modifications of nuclear structure by coupling with continuum are negligible. In the second case of very short-lived unbound ground states, the continuum coupling becomes increasingly important, which can be regarded as a transition to continuum dynamics. For example, the discussion of the tetra-neutron ($4n$) system has demonstrated that the observed $4n$ spectrum is strongly affected both by the mechanism of the $4n$-population reaction and by initial nuclear structure of the reaction participants [3].

Such a limit of existence of nuclear structure investigated in Ref. [2] on the basis of the separation energies of the recently-studied isotopes ^{29,30,31}Ar and ^{28,29,30}Cl isotopes (see Ref. [1]) will be addressed. In particular, the isotopes ^{26}Ar and ^{25}Cl are predicted as the most remote nuclear configurations with a possible ground state.

By extrapolating the obtained predictions to other nuclear systems, one may expect a number of previously-unknown unbound isotopes located within a relatively broad (by 2–5 atomic mass units) area along the proton drip line. For more exotic nuclear systems beyond such a domain, no ground states of isotopes (and therefore no new isotope identification) are expected. Therefore a new borderline indicating the limits of existence of nuclear isotopes in the nuclear chart may be suggested.

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Quantified nuclear density functional theory

W. Nazarewicz[1]

[1] *Department of Physics and Astronomy and Facility for Rare Isotope Beams, Michigan State University, East Lansing, Michigan, USA*

There has been noticeable progress in global modeling of nuclear masses and other nuclear properties. A microscopic approach that is well suited to providing quantified predictions throughout the nuclear chart is nuclear Density Functional Theory (DFT). An effective interaction in DFT is given by the energy density functional, whose coupling constants are adjusted to measured observables. This global approach can be used to assess the uncertainties on calculated observables, both statistical and systematic. Such a capability is essential, especially in the context of making wide-ranging extrapolations into the regions where experiments are impossible. In this presentation, through Bayesian machine learning approaches [1, 2], I assess the predictive power of global mass models towards more unstable nuclei and provide uncertainty quantification of predictions. The proposed robust statistical approach to extrapolation of nuclear model results can be useful for assessing the impact of current and future experiments in the context of model developments.

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^{21}Ne structure in the ^{17}O(α,α) resonance reaction

D.K. Nauruzbayev[1,2], A.K. Nurmukhanbetova[3], V.Z. Goldberg[4], Marco La Cognata[5], Alessia Di Pietro[5], Pierpaolo Figuera[5], M.S. Golovkov[6,7], S. Cherubini[5], M. Gulino[5], L. Lamia[5], R.G. Pizzone[5], R. Spart[5], A. Tumino[5], A. Serikov[6,7] and E.M. Gazeeva[6,7]

[1] *National Laboratory Astana, Nazarbayev University, Astana, 010000, Kazakhstan*
[2] *Saint Petersburg State University, Saint Petersburg, 199034, Russia*
[3] *Nazarbayev University, Astana, 010000, Kazakhstan*
[4] *Cyclotron Institute, Texas A&M University, College station, Texas, USA*
[5] *Istituto Nazionale di Fisica Nucleare,Catania, Italy*
[6] *Joint Institute for Nuclear Research, Dubna, Russia*
[7] *Dubna State University, Dubna 141982, Russia*

Recently [1], the excitation function for the ^{17}O+α elastic scattering was studied for the first time. The R-matrix analysis of the data [1] showed that a developed alpha cluster structure exists in ^{21}Ne, and properties of levels support a weak coupling of the ^{17}O core with the α-cluster, reminding the structure well known in ^{20}Ne. Besides that, a very intense group of α-cluster states were observed close to the high energy limit of the measurements [1]. The high energy results were not interpreted in Ref. [1] due to lack of data at higher excitation energy. We then performed measurements of the ^{17}O(α,α) excitation functions at higher energies using the TTIK method at the INFN-LNS tandem [2]. The ^{17}O beam energy was ~3.5MeV/A and the intensity ~10 nA. Figure 1 shows the excitation function for ^{17}O+α elastic scattering compared with previous data [1] at 180° degree in the c.m. system.

As seen in Fig.1 there are strong groups of resonances up to the excitation energy of 16 MeV in ^{21}Ne, well beyond the former observations. We are performing an R-matrix analysis of the new data at high excitation energy and results will be presented.

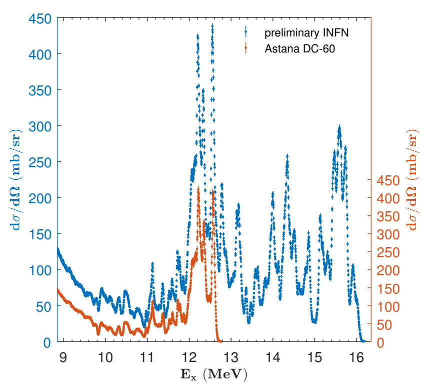

Figure 1: Excitation function for the ^{17}O(α,α)^{17}O elastic scattering at 180° degree reported vs the ^{21}Ne excitation energy. The bold blue line represents the new data multiplied by a factor of two, and the brown line is the previous data [1].

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Proton emission as a tool to invesigate hypernuclei

Tomohiro Oishi[1]

[1] *Department of Physics, Faculty of Science, University of Zagreb, Bijenička c. 32, 10000 Zagreb, Croatia*

Background: inclusion of hyperons in atomic nuclei has been a fascinating topic recently in nuclear physics. One of the famous effects is that the hyperon plays as a gluelike particle: its inclusion leads to an expansion of the proton and neutron drip lines, as well as a new emergence of stable nuclei. This effect is closely linked to the effective strength of the hyperon-nucleon (YN) attraction inside nuclei.

Purpose: my aim is to invoke the interest to utilize the proton emission as a suitable tool to investigate the hypernuclear properties. For this purpose, I demonstrate a simple calculation for the lightest hyper-1p emitter, ${}^{6}_{\Lambda}$Li.

Method: time-dependent calculation for the alpha-proton-Λ^0 three-body system is employed. The proton-Λ^0 interaction is described by the zero-range effective force, which can be linked to the scattering length of the proton-Λ^0 subsystem.

Result: A noticeable sensitivity of the 1p-emission energy and width to the effective strength of the proton-Λ^0 interaction is shown. For the QCD-predicted values of the proton-Λ^0 scattering length, the 1p-resonance width is suggested to be of the order of $0.1 - 0.01$ MeV. By taking the spin-dependence of the proton-Λ^0 interaction into account, a remarkable split of the $J^\pi = 1^-$ and 2^- 1p-resonance states is predicted. From these results, it is concluded that the 1p emission can be a suitable phenomenon to investigate the basic properties of the YN interaction, for which a direct measurement is still difficult.

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Discoveries of new cases of proton emission with sub-microsecond half-lives

R. D. Page[1], J. B. Hilton,[1,2] J. Uusitalo,[2] J. Sarén,[2] D. T. Joss,[1] M. A. M. Al Aqeel,[1,3] A. N. Andreyev,[4] S. Antalic,[5] H. Badran,[2] A. D. Briscoe,[1] T. Calverley,[1,2] D. Cox,[2] T. Grahn,[2] A. Gredley,[1] P.T. Greenlees,[2] R. Harding,[4] A. Herzan,[1,6] E. Higgins,[1] R. Julin,[2] S. Juutinen,[2] J. Konki,[2] M. Labiche,[7] M. Leino,[2] M. C. Lewis,[1] J. Ojala,[2] J. Pakarinen,[2] P. Papadakis,[1,2] J. Partanen,[2] P. Rahkila,[2] P. Ruotsalainen,[2] M. Sandzelius,[2] C. Scholey,[2] J. Sorri,[2,8] L. Sottili,[2] S. Stolze[2] and F. P. Wearing[1]

[1] *Department of Physics, University of Liverpool, Liverpool L69 7ZE, United Kingdom*
[2] *University of Jyvaskyla, Department of Physics, P.O. Box 35, FI-40014 University of Jyvaskyla, Finland*
[3] *Imam Mohammad Ibn Saud Islamic University (IMISU), Riyadh, 11623, Saudi Arabia*
[4] *Department of Physics, University of York, Heslington, York, YO10 5DD, United Kingdom*
[5] *Department of Nuclear Physics and Biophysics, Comenius University, Bratislava, SK-84248, Slovakia*
[6] *Institute of Physics, Slovak Academy of Science, Bratislava, SK-84511, Slovakia*
[7] *STFC Daresbury Laboratory, Sci-Tech Daresbury, Warrington WA4 4AD, United Kingdom*
[8] *Sodankylä Geophysical Observatory, University of Oulu, FI-99600 Sodankylä, Finland*

It is well known that half-lives can be very short for proton-emitting nuclei. Many experiments have been performed over the years in which proton emitters produced in fusion-evaporation reactions were transported to the focal plane of a recoil separator on microsecond timescales. The challenge then is to ensure the detection system responds quickly enough to be sensitive to the proton decays as soon as possible after the proton emitter's arrival. One approach that has proved successful and was employed in this work is to use digital electronics to capture detector output signals that can be analysed offline to extract the proton-decay energies and half-lives. In the present study, the recently commissioned vacuum mode recoil mass separator MARA at the University of Jyväskylä Accelerator Laboratory was used in a search for new cases of proton emission above the N = 82 shell closure. The proton emitters that were discovered in this first MARA experiment were found to have half-lives below 1 μs, demonstrating the capabilities of this new device.

Proton dripline near the doubly magic ^{100}Sn: current status and outlook

J. Park[1], R. Krücken[2,3], D. Lubos[4,5,6], R. Gernhäuser[4], M. Lewitowicz[7] and S. Nishimura[5],
on behalf of the EURICA collaboration

[1] *Department of Physics, Lund University, 22100 Lund, Sweden*
[2] *TRIUMF, 4004 Wesbrook Mall, Vancouver, British Columbia, Canada*
[3] *Department of Physics and Astronomy, University of British Columbia, Vancouver, British Columbia, Canada*
[4] *Physik Department, Technische Universität München, D-85748 Garching, Germany*
[5] *RIKEN Nishina Center, Wako-shi, Saitama 351-0198, Japan*
[6] *Excellence Cluster Universe, Technische Universität München, D-85748 Garching, Germany*
[7] *Grand Accélérateur National d'Ions Lourds (GANIL), CEA/DSM-CNRS/IN2P3, Boulevard H. Becquerel, 14076 Caen, France*

The structure of the doubly magic ^{100}Sn and the neighboring nuclei has been investigated in depth, motivated by their relevance in shell evolution, proton-neutron interactions in the $g_{9/2}$ orbitals, the superallowed Gamow-Teller decay of ^{100}Sn, and the *rp*-process nucleosynthesis. Measurements of the proton dripline, β-delayed proton decay branching ratios and half-lives in this region of nuclides are especially important for *rp*-path calculations. The limit of proton binding and the structure of the heaviest $N \approx Z$ nuclei offer insights to the isospin symmetry and the role of $T = 0, 1$ nucleon pairs.

The most proton-rich nuclei with Z between 40 and 54 were produced by fragmentation reactions of a 345-MeV/u ^{124}Xe primary beam on a 740-mg/cm^2 ^{9}Be target at the RI Beam Factory of RIKEN Nishina Center. Separation and identification of the fragments were carried out with the BigRIPS separator and the ZeroDegree spectrometer. Odd-Z, $N = Z - 1$ nuclei ^{81}Nb, ^{85}Tc, ^{89}Rh, and ^{93}Ag have been found to be proton emitters, while for even-Z species $N < Z - 1$ new isotopes have been discovered [1, 2]. A clear evidence for the particle instability of ^{103}Sb has also been obtained [2]. The high survival rate of ^{97}In through the separator system was further analyzed with β-decay spectroscopy, and circumstantial evidence for a proton-unbound $(1/2^-)$ isomer in ^{97}In has been found [3].

The recent experimental findings offer sensitive tests of the structure and mass models for $A = 80$–100 nuclei near the proton dripline, as well as theories on proton emission. The impact of these results on *rp*-path calculations will be presented. Prospects for the discovery of even more neutron-deficient isotopes will be discussed, in relation to theoretical predictions of the proton dripline in this region.

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Nucleosynthesis via neutrino-p process and experimental efforts on measuring key nuclear reactions

G. Perdikakis[1,2,3], P. Gastis[1,3], P. Tsintari[1,3], H.Y. Lee[4,3], S. Kuvin[4], A. Georgiadou[4] , and C. Frohlich[5,3]

[1] *Department of Physics, Central Michigan University, Mt Pleasant, MI 48859, USA*
[2] *Facility for Rare Isotope Beams, Michigan State University, East Lansing, MI 48824, USA*
[3] *Joint Institute for Nuclear Astrophysics, Michigan State University, East Lansing, MI 48824, USA*
[4] *Physics Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA*
[5] *Department of Physics, North Carolina State University, Raleigh, NC 27607, USA*

Neutrino driven winds (NDWs) in core-collapse supernovae (CCSNe) establish a suitable astrophysical environment for primary nucleosynthesis. Many studies have shown that in proton-rich NDWs, the so-called neutrino-p (νp-) process is responsible for the formation of elements up to Z$\simeq$50 and may contribute to the abundances of various p-nuclei and nuclei in the Sr-Y-Zr region. The efficiency of the νp-process, strongly depends on the conditions of the wind during the phase of nucleosynthesis, and on the rates of (n,p) reactions on beta-decay bottle neck isotopes, such as the ^{56}Ni(n,p)^{56}Co and ^{64}Ge(n,p)^{64}Ga reactions. No experimental data exists for any of these key reaction cross sections with proton-rich nuclei, and their measurement constitutes a technical challenge for experimenters. As a result, we have to exclusively rely on theoretical models for calculating the important reaction rates and accept systematic calculation uncertainties that strongly affect the nucleosynthesis results. In the last years, we have developed an experimental technique that will enable us to constrain the rates of (n,p) reactions via measuring their time reverse (p,n) reactions in inverse kinematics at FRIB. The experimental setup is located at the the ReA3 facility of the National Superconducting Cyclotron Laboratory. A proof-of-principle measurement of the ^{40}Ar(p,n)^{40}K reaction cross section has been concluded in inverse kinematics at NSCL, as well as a validation experiment in normal kinematics at Ohio University. In parallel, an effort to fabricate a ^{56}Ni radioactive target at LANL to directly measure the ^{56}Ni(n,p)^{56}Co in the near future at the LANSCE facility is under way. In this presentation, we discuss the effect of (n,p) reactions with proton-rich isotopes to the νp-process, and the status of experimental efforts.

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Two-Proton Radioactivity - Status Report

M. Pfützner

Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warsaw, Poland

Ground-state two-proton (2p) radioactivity is a characteristic decay mode for isotopes of even-Z elements located beyond the two-proton drip line. So far, this exotic process has been experimentally observed in a few light- and medium-mass nuclides with $Z \leq 36$ [1, 2]. In fact, ground-state, simultaneous two-proton emission is predicted to be observable for every even-Z element up to tellurium [3]. Most of them, however, will be very difficult to reach in the near future. In the region between tellurium and lead the particle instability is expected to be manifested by sequential emission of two protons [3]. In addition to the on-going search for new 2p emitters, an important research direction aims at precision studies of this exotic decay mode. The interesting question in this context is to what extent details of nuclear structure can be inferred from 2p decay observables. It is expected that the momentum correlations between the emitted protons may reveal the composition of the initial wave function [1]. Work is in progress to investigate whether the p-p correlations in the three classical cases ^{45}Fe, ^{48}Ni, and ^{54}Zn will shed light on the $Z = 28$ shell closure in this region of the nuclear chart. The recently discovered surprisingly fast 2p decay of ^{67}Kr [2] prompted the development of a new theoretical model, based on Gamow coupled-channel framework which indicated a strong influence of nuclear deformation on the process of 2p emission [4].

In the talk, I will make an overview of 2p radioactivity studies with the focus on recent developments, both experimental and theoretical.

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Multiple-reflection time-of-flight mass spectrometry of neutron-deficient nuclides in the vicinity of ^{100}Sn and at the N=82 shell closure

W. R. Plaß[1,2], D. Amanbayev[1], S. Ayet San Andrés[1,2], S. Beck[1,2], J. Bergmann[1], T. Dickel[1,2], J. Dilling[3,4], I. Dillmann[3], E. Dunling[3,5], J. Ebert[1], H. Geissel[1,2], M. Gorska[2], H. Grawe[2], F. Greiner[1], E. Haettner[2], C. Hornung[1], A. Jacobs[3,4], R. Klawitter[3,6], B. Kootte[3,7], G. Kripkó-Koncz[1], A.A. Kwiatkowski[3], Y. Lan[3,4], E. Leistenschneider[3,4], M. Lykiardopoulou[3,4], I. Mardor[8,9], I. Miskun[1], I. Mukul[3], T. Otsuka[10], S. F. Paul[3,11], S. Pietri[2], S. Purushothaman[2], M. P. Reiter[1,2,3], A-K. Rink[1], C. Scheidenberger[1,2], M. Vansteenkiste[12], H. Weick[2], C. Will[1], and the FRS Ion Catcher and TITAN collaborations

[1] *Justus-Liebig-Universität Gießen, Gießen, Germany;* [2] *GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany;* [3] *TRIUMF, Vancouver, BC, Canada;* [4] *University of British Columbia, Vancouver, BC, Canada;* [5] *University of York, York, UK;* [6] *Max-Planck-Institut für Kernphysik, Heidelberg, Germany;* [7] *University of Manitoba, Winnipeg, MB, Canada;* [8] *Tel Aviv University, Tel Aviv, Israel;* [9] *Soreq Nuclear Research Center, Yavne, Israel;* [10] *University of Tokyo, Tokyo, Japan;* [11] *Ruprecht-Karls-Universität Heidelberg, Germany;* [12] *University of Waterloo, Waterloo, ON, Canada*

Multiple-reflection time-of-flight mass spectrometry is a powerful technique for experiments with exotic nuclei. Due to its high accuracy, sensitivity and short cycle time, direct mass measurements of short-lived and rare nuclei with half-lives longer than a few milliseconds and with just a few detected ions can be performed [1, 2]. Because of its high mass resolving power and broadband characteristics, it is also ideally suited for the search for and measurement of new isomers and can be employed for the production of isomerically clean beams [3].

Mass measurements of neutron-deficient Yb and Tm isotopes have been performed across N=82 using TITAN's multiple-reflection time-of-flight mass spectrometer (MR-TOF-MS) at TRIUMF, Vancouver. The measurements yield information about the N=82 shell closure and the location of the proton drip line in this region, and they serve as anchor points for alpha decay chains.

Furthermore, mass measurements of neutron-deficient ^{124}Xe projectile fragments in the vicinity of ^{100}Sn have been performed using the MR-TOF-MS of the FRS Ion Catcher at the FRS at GSI Darmstadt, including the first-time mass measurement of the ^{101}In ground state. Two new isomeric states have been discovered in ^{97}Ag and ^{101}In. These results shed light on the nuclear structure in this region of the nuclear chart.

A novel method for the measurement of half-lives and decay branching ratios has been developed and demonstrated experimentally [4]. It employs a gas-filled stopping cell as an ion storage device and an MR-TOF-MS for identification and counting of the precursors and decay products. Perspectives for the measurement of N=Z nuclides using the FRS Ion Catcher in the region below ^{100}Sn, including ground state masses, excitation energies of isomers, and decay branching ratios, will be discussed.

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Measurement of half-lives and decay branching ratios of exotic nuclei with the FRS Ion Catcher

W. R. Plaß[1,2], I. Miskun[1], T. Dickel[1,2], I. Mardor[3,4], C. Hornung[1], D. Amanbayev[1], S. Ayet San Andrés[1,2], J. Bergmann[1], J. Ebert[1], H. Geissel[1,2], M. Gorska[2], F. Greiner[1], E. Haettner[2], S. Purushothaman[2], C. Scheidenberger[1,2], A-K. Rink[1], H. Weick[2], S. Bagchi[1,2,5], P. Constantin[6], S. Kaur[5], W. Lippert[1], B. Mei[6], I. Moore[7], J.-H. Otto[1], S. Pietri[2], I. Pohjalainen[7], A. Prochazka[2], C. Rappold[1,2], M. P. Reiter[1,2], Y. Tanaka[2], J. S. Winfield[2], for the Super-FRS Experiment Collaboration

[1] *Justus-Liebig-Universität Gießen, Gießen, Germany*
[2] *GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany*
[3] *Tel Aviv University, Tel Aviv, Israel*
[4] *Soreq Nuclear Research Center, Yavne, Israel*
[5] *Saint Mary's University, NS B3H 3C3 Halifax, Canada*
[6] *IFIN-HH/ELI-NP, Magurele - Bucharest, Romania*
[7] *University of Jyväskylä, Jyväskylä, Finland*

A novel method for the simultaneous and direct measurements of masses of exotic nuclei, half-lives, decay branching ratios and isomer excitation energies has been demonstrated [1] with the FRS Ion Catcher [2] at GSI. The measurement relies on the combination of a clean separation of the fragments in the projectile fragment separator FRS, a cryogenic stopping cell (CSC) with very high areal density (up to 10 mg/cm^2), and a multiple-reflection time-of-flight mass spectrometer (MR-TOF-MS) for high-precision broadband mass measurements.

The mother ions are produced in the FRS, and stored for controllable durations in the CSC, which are long enough for them to decay via single or multiple channels. In this measurement, the CSC has been used as an ion trap for the mother ions as well as for the daughters for the first time. Mother and daughter ions are extracted to the MR-TOF-MS, where they are identified and counted. The feasibility of the method was demonstrated by measuring the alpha decay of ^{216}Po and the isomer-to-ground transition of ^{119m2}Sb.

In the future, the method will be used to measure beta-delayed neutron or proton emission probabilities of exotic nuclides, including ^{94}Ag.

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Charge Radii of Mirror Nuclei ^{36}Ca-^{36}S and Neutron Equation of State

R. C. Powel[1,2], K. Minamisono[1,2], A. Klose[3], B. A. Brown[1,2], D. Garand[1], C. Kujawa[3], J. D. Lantis[1,4], Y. Liu[5], B. Maaß[6], A J Miller[1,2], W. Nörtershäser[6], S. Pineda[3], P. G. Reinhard[8], D. M. Rossi[4], F. Sommer[6], C. Sumitherarachchi[1], A. Teigelhoefer[7], and J. Watkins[1]

[1] *National Superconducting Cyclotron Lab., Michigan State Univ., East Lansing, MI 48824, USA*
[2] *Department of Physics and Astronomy, Michigan State Univ., East Lansing, MI 48824, USA*
[3] *Department of Chemistry, Augustana University, Sioux Falls, SD 57197, USA*
[4] *Department of Chemistry, Michigan State University, East Lansing, MI 48824, USA*
[5] *Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA*
[6] *Technische Universität Darmstadt, 64289 Darmstadt, Germany*
[7] *TRIUMF, Vancouber, BC, Canada*
[8] *Institut für Theoretische Physik, Universität Erlangen, D-91054 Erlangen, Germany*

The first derivative of the symmetry energy, L, in the neutron equation of state (EOS) is critical for the extrapolation of the EOS to the lower and higher nuclear densities [1]. The neutron skin of neutron rich nuclei, such as ^{48}Ca or ^{208}Pb, is known to be proportional to L at the nuclear matter saturation density[2].

Assuming perfect charge symmetry, the neutron radius of a particular nucleus is equal to the charge radius of its mirror nucleus. Therefore, the neutron skin can be determined by the difference in the charge radii of mirror nuclei, ΔR [3]. It has been shown [3] that the ΔR has a strong correlation with L as $|N - Z| \cdot L$, where N and Z are neutron and proton numbers, respectively. Charge radii are readily determined by laser spectroscopy [4], and the ΔR together with the dipole polarizability [5] provides an alternative method to the parity violating electron scattering [6] to address L.

The charge radius of ^{36}Ca was determined using colinear laser spectroscopy at BECOLA facility at NSCL/FRIB/MSU [7]. Using the known charge radius of ^{36}S [8], the ΔR was deduced. The pair ^{36}Ca-^{36}S has the largest $|N - Z| = 4$ value of any measured charge radii pairs so far, giving the greatest sensitivity to L in this model. The ΔR and its correlation with L will be discussed.

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Transfer Reactions as a Probe for Astrophysical Proton Capture

T. Poxon-Pearson[1,2], F.M. Nunes[1,2]

[1] *Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824-1321, USA*

[2]*National Superconducting Cyclotron Laboratory, East Lansing, Michigan 48824-1321, USA*

Proton capture reactions are important in many astrophysical systems, including novae and X-ray bursters. In these systems, the astrophysical reaction rate is often dominated by a few low lying resonances in the final state nucleus. However proton capture into these low lying states is difficult to measure directly due to a combination of low sub-coulomb barrier cross sections and a relatively low beam rate for rare isotope beams. This has lead to large uncertainties for many key reactions that determine the dominant path of the rapid proton capture process.

However, indirect methods, including (d,n) transfer reactions, are available to experimentally probe these key reaction rates [2, 3]. Proton transfer at energies well above the coulomb barrier are able to populate the resonances of interest, allowing the extraction of experimental information about the corresponding proton capture through the astrophysical resonances strength.

This talk will discuss the theoretical techniques used to connect these (d,n) measurements to their corresponding (p,γ) reaction rates. I will focus on the reaction framework used, including the adiabatic approximation (ADWA) which explicitly takes deuteron breakup into account to all orders [1], and various approximations used in these calculations. The talk will also touch on various experimental techniques used for (d,n) measurements and their impacts on the reaction theory used in the analysis. Gamma ray spectroscopy, which allows for high resolution determination of excited states energies, has been used but is limited to determining only angle integrated cross sections. Measuring low energy neutrons in coincidence with gamma rays may clarify angular momentum transfer, but is often infeasible due to low statistics. Finally, efforts are underway to use time projection chambers to measure these transfer reactions at a range of energies in hopes of more accurately constraining spectroscopic factors through use of the combined method [4].

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Insight into α clustering of proton-rich nuclei via their α decay

Yibin Qian

Department of Applied Physics, Nanjing University of Science and Technology, Nanjing 210094, China

Based on the renewed two-parameter Fermi (2pF) form of nucleon density distributions from the available experimental data, we focus on the α clustering phenomenon of proton-rich nuclei in terms of the preformation probability of α cluster before its penetration [1]. Through the experimental decay data, the α preformation factor P_α is extracted for a large range of nuclei in the neutron-deficient region. It is found that the present α preformation factor varies more smoothly towards the large neutron-proton ratio, as compared to those from the previous evaluations. This may come from the separate consideration of proton and neutron density distributions of related nuclei, while they are treated as the same form before. The similarity between the P_α value and the pairing gap is clearly demonstrated, indicating the crucial role of pairing correlation involved in the α decay process. As a further step, the correlation between the α preformation factor and the microscopic correction of nuclear mass, corresponding to the effect of shell and pairing plus deformation, is in particular investigated to pursue the valuable knowledge of P_α pattern over the nuclide chart [2]. Owing to this, the systematical results on lifetimes of α emitters are obviously improved within the transfer matrix method.

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Direct observation of exotic decay modes in ^{11}Be and other systems using AT-TPC

J. S. Randhawa[1], Y. Ayyad,[1] B. Olaizola[2] D. Bazin[1] S. Beceiro-Novo[1] W. Mittig[1] C. Santamaria[3] N. Watwood[1]

[1]*National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824-1321, USA*

[2] *TRIUMF, Vancouver, BC V6T 2A3, Canada*

[3] *Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA*

Exotic decay modes in the radioactive nuclei reveal a plethora of information ranging from nuclear forces, nuclear structure and test of weak forces. Study of two-proton radioactivity and β^--delayed proton emission has recently gained a lot of attention. Direct imaging of these decay modes provides unprecedented information and in this context Active Target Time Projection Chamber provides an ideal tool for such measurements. We report the first direct measurement of β^--delayed proton emission in the decay of ^{11}Be using AT-TPC at TRIUMF. In a separate experiment at ReA3 facility in NSCL, an exotic decay mode in ^{22}Mg+α system was recorded with AT-TPC. Initial observations and results from these two experiments will be discussed.

Recent studies of proton-rich nuclei using active target at the Cyclotron Institute

G.V. Rogachev[1], J. Hooker,[1] E. Koshchiy,[2] S. Ahn,[2] M. Barbui,[2] V. Z. Goldberg,[2] C. Hunt,[1] H. Jayatissa,[1] S. Upadhyayula,[1] B. T. Roeder,[2] E. Uberseder,[2] A. Saastamoinen,[2]

[1] *Department of Physics and Astronomy, Cyclotron Institute, Texas A&M University, College Station, Texas 77843, USA*
[2] *Cyclotron Institute, Texas A&M University, College Station, Texas 77843, USA*

Structure of proton-rich nuclei ^{9}C and ^{10}N was studied using p+^{8}B and p+^{9}C resonance scattering. Active target detector system was used in both cases. It was found that the ground and the first excited states in ^{10}N are both s-wave resonances, unbound with respect to proton emission by 1.8 MeV a 2.7 MeV respectively [1]. The first positive parity state in ^{9}C ($5/2^{+}$) has been identified at 4.2 MeV excitation energy, providing first conclusive evidence for the onset of the sd-shell in the A=9 T=3/2 system [2]. Systematics of the 2s1/2 shell in ^{8}B, ^{9}C, and ^{10}N nuclei will be discussed.

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Beta decay of $Tz = -2$ and $Tz = -1$ nuclei in the fp shell

B. Rubio

Instituto de Fisica Corpuscular
CSIC-Univ. Valencia
Spain

I will present an overview of the physics case of the decay of even-even $Tz = -2$ and $Tz = -1$ nuclei in the fp shell. The experiments started some years ago motivated by the idea of comparing these decays with the mirror charge-exchange reaction process on the stable mirror target nuclei. The present experimental information covers all cases that can be compared with the mirror process and beyond. Experiments have been carried out at GSI, GANIL and RIKEN. New results on the RIKEN experiments will be presented with particular emphasis on the decay of ^{64}Se, the heaviest $Tz = -2$ case where the decay still proceeds through a combination of beta-delayed gamma-rays and beta-delayed proton decay. This particular case presents a unique feature in the sense that the ground state of the daughter nucleus is the anti-analogue state of ^{64}Se and this is reflected in the way it decays.

Charge-dependent DFT for $N \approx Z$ nuclei

Wojciech Satuła

Faculty of Physics, University of Warsaw, Poland

I shall start by briefly introducing the extended nuclear Density Functional Theory (DFT) that includes, apart of Coulomb interaction, isospin-symmetry-breaking (ISB) contact terms up to next-to-leading (NLO) order and the proton-neutron mixing in particle-hole channel [1, 2]. Next, I shall demonstrate that such formalism is capable to account globally (irrespectively on atomic number) for the ISB in nuclear masses of $N \approx Z$ nuclei reproducing well both the isovector as well isotensor coefficients of the Isobaric Multiplet Mass Equation (IMME). Our DFT results, after including NLO surface-sensitive ISB gradient terms, our agree reasonably well with the Green Function Monte Carlo (GFMC) results of Ref. [3] in light nuclei. Moreover, the detailed comparison between specific contributions to the IMME coefficients calculated using the DFT (adjusted to finite nuclei) and GFMC (adjusted to two-body observables) results seem to lead to a rather unexpected conclusion that the nuclear DFT properly takes into account the contribution due to the Coulomb interaction and that the local correcting ISB potential accounts, predominantly, for the strong-force-rooted effects order by order. Comparison of isotensorial IMME coefficients calculated using the extended DFT to the shell-model-based *ab initio* results of Ref. [4] in the pf-shell triplets is, at the moment, inconclusive due to problems with convergence in the latter theory.

In the second part, I shall present multi-reference DFT calculations of ISB corrections to the ground-state beta decay of $T = 1/2$ mirror nuclei. I shall demonstrate that, rather counter-intuitively, the local isovector potential surprisingly strongly influences the calculated Coulomb impurities and ISB corrections. This study is important in the context of precise testing of the electroweak sector of the Standard Model. The most stringent tests come from the superallowed $0^+ \to 0^+$ Fermi decays. The mixed Fermi-Gamow-Teller decays of $T = 1/2$ mirror nuclei offer an alternative way for such tests provided that, apart of half-lifes, branching ratios, and Q-values, another observable like the neutrino-beta correlation, beta-asymmetry or neutrino-asymmetry is also measured, see Ref. [5, 6]. The precision of these experiments is still too low for testing the Standard Model but fast progress in β-decay correlation techniques makes these experiments very promising and keeps the field vibrant see, for example, Ref. [7] for the recent β-asymmetry measurement in ^{37}K decay. Similar to the superallowed $0^+ \to 0^+$ Fermi decays, the analysis of $T = 1/2$ transitions and, in particular, the extraction of V_{ud} depends on theoretical calculation of radiative and many-body ISB corrections to the Fermi branch.

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Probing Spin-Isospin Excitations in Proton-Rich Nuclei via the (p,n) Reaction

J. M. Schmitt,[1,2] R. G. T. Zegers,[1,2] D. Bazin,[1,2] A. Carls,[1,2] A. Davis,[3] M. DeNudt,[1,2] B. Gao,[4] C. Hultquist,[1] S. Noji,[1,2] J. Pereira,[1,2] R. Titus,[1,2] and J. C. Zamora[5]

[1] *Department of Physics and Astronomy, National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, MI 48824, USA*
[2] *Joint Institute for Nuclear Astrophysics: Center for the Evolution of the Elements, Michigan State University, East Lansing, MI 48824, USA*
[3] *Department of Physics and Astronomy, Swarthmore College, Swarthmore, PA 19081, USA*
[4] *Institute of Modern Physics, Lanzhou, China*
[5] *Universidade de São Paulo, Departmento de Física Nuclear, Instituto de Física - USP*

Tracking the evolution of nuclear properties away from stability serves as a valuable test for nuclear models. Evolution of the shell structure of light nuclei towards the neutron dripline has been studied in great detail, but evolution of the mirror proton-rich nuclei toward the proton dripline has not been investigated as thoroughly [1]. To better understand nuclear structure at the proton dripline, the proton-rich nuclei ^{12}O and ^{11}N will be studied via the (p,n) reaction in inverse kinematics using ^{12}N and ^{11}C beams, respectively, at 100 MeV/A. The experiment recently took place at the National Superconducting Cyclotron Laboratory (NSCL) with the S800 spectrometer [2]. The energy and angle of the recoil neutrons were measured with the Low Energy Neutron Detector Array (LENDA) [3, 4, 5], and the excitation energy spectra and differential cross sections can be reconstructed. From this, the Gamow-Teller transition strengths can be extracted [6] and compared to predictions of advanced theoretical models such as the no-core shell model, Gamow shell model, and continuum shell model. In the case of ^{12}O, the resulting structure information can also be compared to the mirror nucleus ^{12}Be to explore possible mirror symmetry breaking for extreme proton-to-neutron ratios [7]. This experiment will also establish the (p,n) reaction as a probe to extract Gamow-Teller strengths from proton-rich nuclei, which can be used to study isotopes up to the ^{100}Sn region during the FRIB era. Progress of analysis for this experiment will be presented.

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Recent studies of proton and α emission near ^{100}Sn at ATLAS

D. Seweryniak[1]

[1] *Argonne National Laboratory, Argonne, IL 60439, USA*

The region of the chart of nuclides near the doubly-magic self-conjugate ^{100}Sn provides unique opportunities for studies of spontaneous proton and α emission from ground states and isomeric states. The two-proton decay and the heavy-cluster emission were also predicted to occur in this region. I will present recent experimental advances in the charged-particle decay studies in the ^{100}Sn region using the Fragment Mass Analyzer at the ATLAS facility at Argonne National Laboratory. In particular, I will discuss the observation of **the superallowed α-decay chain ^{108}Xe(α)→^{104}Te(α)→^{100}Sn** [1] and its importance for the models of α decay, the discovery of **a weak proton-decay branch in ^{108}I** [2] and its implications for the termination of the astrophysical rp-process, and the search for **the fast T_z=-1/2 proton emitter ^{93}Ag**. I will conclude with a discussion of prospects for charged-particle decay spectroscopy near ^{100}Sn at the existing and upcoming accelerator facilities.

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Effects of deformations and orientations on one proton radioactivity in proton rich nuclides

BirBikram Singh[1,*], Sarbjeet Kaur,[1], Mandeep Kaur[2], Manpreet Kaur[3] and S.K. Patra[3]

[1] *Department of Physics, Sri Guru Granth Sahib World University, Fatehgarh Sahib, India.*
[2] *Address: 2121, 45th street, Unit number 4211, Highland, Indiana-46322, USA.*
[3] *Institute of Physics, Bhubaneswar, India.*

With the outstanding developments in the field of radioactive ion beams the studies related to exotic processes near the extremes of the nuclear chart, are at the forefront of nuclear research these days. One such exotic process, the spontaneous emission of one proton, from neutron deficient nuclei lying near the proton drip line, was first observed experimentally in 1970 by Jackson et al. from the isomeric state of ^{53}Co [1]. These emissions from proton emitter nuclides having odd number of protons strongly depends on the decay Q-value and on the orbital angular momentum. One proton emissions has been studied in two regions: $51 \leq Z \leq 67$ and $69 \leq Z \leq 83$, theoretically first region is considered to be deformed and other one to be spherical in their ground state [2]. The decay of proton emitters in these regions has been explored within unified fission model (UFM) with spherical considerations and assuming preformation probabilities $P_0 = 1$ [3]. In the present work, within preformed cluster decay model (PCM), we will investigate the decay of these proton emitters by taking into consideration the effects of deformations (β_2) and orientations of nuclei. In PCM, proton-daughter system is treated as the dynamical collective mass motion of the preformed fragments (with certain preformation probability, P_0) and barrier penetration probability P is calculated by performing numerical calculations within WKB approximation [4]. The structure information of the parent nucleus enters via the P_0 (also known as the spectroscopic factor) of the fragments. The preformation profile of all the competing fragments shows that 1p-emission is more probable than α-emission for spherical case and further increases for (β_2) considerations. Theoretically calculated half-lives of the proton emitters, with both the spherical and deformed considerations, are compared with the experimental data.

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Isospin-symmetry breaking correction to Fermi $0^+ \to 0^+$ β-decay

N. A. Smirnova[1] and L. Xayavong[1,2]

[1] *CENBG (CNRS/IN2P3 - Université de Bordeaux), 33175 Gradignan cedex, France*
[2] *Faculty of Natural Sciences, National University of Laos, Vientiane, Laos*

Superallowed Fermi $0^+ \to 0^+$ beta decay provides an important test of the fundamental symmetries of the Standard Model, such as the CVC hypothesis and unitarity of the CKM matrix. To accomplish those tests one has to extract the so-called absolute Ft value of those transitions for various emitters, taking into account radiative and nuclear structure corrections [1]. At present, the ft values for fourteen transitions between $0^+, T = 1$ states in nuclei ranging from $A = 10$ to $A = 74$ are known with a precision of the order of 0.1% and further experimental investigations are under way. An accurate theoretical calculation of the nuclear-structure (i.e. isospin-symmetry breaking) correction for those series of emitters is still a challenge for a microscopic many-body approach. Existing calculations differ a lot among each other (see discussion in Ref. [1]).

We report on a new shell-model calculation of the nuclear-structure correction to superallowed $0^+ \to 0^+$ β-decay in the sd and pf-shell. We exploit realistic charge-dependent Hamiltonians and evaluate Fermi transition matrix elements using spherical Woods-Saxon or Hartree-Fock radial wave functions. Compared to the previous work of Refs. [2, 3, 4], we use different model spaces, a larger set of shell-model interactions and another approach to nuclear radii. Under available experimental constraints, we get a rather consistent set of corrections for different shell-model interactions and mean-field parameterizations (see [5, 6] for the sd shell). Their implication for the CVC hypothesis of the Standard Model is discussed.

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β - delayed proton emission from ^{11}Be

N. Sokolowska[1], M. Borge[2], A. Ciemny[1], W. Dominik[1], A. Fijalkowska[1], L. Fraile[3], A. Giska[1], Z. Janas[1], L. Janiak[1], G. Kaminski[4,5], A. Korgul[1], A. Kubiela[1], C. Mazzocchi[1], K. Miernik[1], M. Pftzner[1], M. Pomorski[1], J. D. Ovejas[2], A. Vinals[2].

[1] *Faculty of Physics, University of Warsaw,Warsaw, Poland*
[2] *IEM/CSIC, Spain*
[3] *Universidad Complutense de Madrid, Madrid, Spain*
[4] *JINR, Dubna, Russia*
[5] *HIL, Warsaw, Poland*

Even though β-delayed proton emission is a phenomenon which typically occurs for neutron-deficient nuclei, the energy window for this proces is open also in a few light, neutron-rich isotopes. Particulary interesting in this respect is ^{11}Be, which is also a one-neutron halo nucleus. Several channels for β-delayed particle emission from this isotope are open, including the proton branch, with $Q_{\beta p} \sim 280$ keV. Theoretical predictions of branching ratio (BR) for this decay mode give very low value ($\sim 10^{-8}$ [**?**]). Nevertheless, indirect observations based on accelerator mass spectrometry (AMS) [**?**, **?**] resulted in BR value two orders of magnitude larger than predicted. The direct measurement of the βp BR and energy spectrum is important for estimating the Gamow-Teller strength at high excitation energies and for testing models that predict a direct relation between βp and halo structure. Moreover, recently a new hypothesis which may explain the results of the AMS experiment appeared. According to it, the neutron may have another decay channel in which unknown particles are produced in the final state [**?**, **?**].

The project of searching for the first direct observation of β-delayed protons from ^{11}Be, using *Warsaw Optical Time Projection Chamber* [**?**] involved performing a series of experiments and the development of new solutions for DAQ and software. The first tests took place in February 2018 at the JINR in Dubna. These measurements were focused on studying the behaviour of light nuclei in the region of ^{11}Be in order to optimize the experimental conditions for the main experiment. In this context, we measured ^{9}C β decay in which low-energy β-delayed protons (165 keV) are emitted, showing that the observation of protons with such low energy is possible in the given experimental conditions. The main experiment was performed in August/September 2018 at HIE-ISOLDE in CERN. During it a large amout of ^{11}Be β decays ($\sim$ 50 mln) was observed. A complementary measurement is planned at LNS in Catania to measure in the same experimental conditions BR for β - delayd α emission from ^{11}Be. The data are needed to normalize the CERN data having the same systematic error.

The status of this challenging search for β-delayed proton emission from the neutron-rich nucleus ^{11}Be will be presented.

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Half-life formula for one & two-proton emitters

I. Sreeja and M. Balasubramaniam

[1] *Department of Physics, Bharathiar University, Coimbatore 641046, INDIA*

A new simple ℓ-dependent formula to calculate the logarithmic half-life period of 1-p emitters is proposed recently [1]. The applicability of the formula retaining its form but fitted to the model predictions of Goncalves et al., [2] was studied for the experimentally known as well as model predicted cases of 2-p emitters in Ref. [3].

The proposed formula to calculate the $T_{1/2}$ of 1-p and 2-p emitters is a model independent and ℓ-dependent formula with only four parameters. The basic assumption in the proposed formula stems from Geiger-Nuttal law that half-lives varies as a function of the inverse square root of the Q-values. Further, from the half-lives of observed 1-p emitters it was seen that for different angular momentum the half-life varies as a function of the inverse square root of the Q-values. This was done, by obtaining independent linear relations first for each ℓ value and then, the obtained slopes and intercepts of different ℓ values are expressed as a linear equation in terms of angular momentum. Thus, the proposed formula very well accounts for the ground and isomeric states of all the experimentally known cases.

The proposed four parameter formula for 1-p emitters is given below.

$$\log T_{1/2} = ((a \times \ell) + b)\xi + ((c \times \ell) + d)$$

with $a = 0.0322,\ b = 0.8204,\ c = 0.1527$ and $d = 26.4801$, and $\xi = \frac{Z_1^{0.8}}{\sqrt{Q_{1p}}}$.

As an extension of this study, a four parameters formula retaining the same form as above (but with Q_{2p}), as a function of angular momentum is proposed for the two-proton emitters. The parameters of the formula are fitted using the results of effective liquid drop model (ELDM) of Goncalves et al [2] due to the paucity of the experimental results. The values of the constants a, b, c and d are 0.0322, 0.8204, -0.1527 and -26.4801 respectively. In addition to comparing with the experimental data, we have also predicted possible 1-p and 2-p emitters in the medium, heavy and superheavy region. The same form of the formula for two different processes namely 1-p emission and 2-p emission indicates and/or suggests the fact that, the theoretical description of these two phenomena has to be identical.

The fair agreement of our results with experimental values and other theoretical predictions indicates that the formula with only four parameters and the information of Q-values, and charge number of the daughter nucleus can be used to predict half-lives of new proton emitters and can be used as a handy tool to plan new experiments.

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Beta-decay spectroscopy of ^{27}S

L. J. Sun,[1,2,3] X. X. Xu,[1,4] C. J. Lin,[1] S. Q. Hou,[5] C. X. Yuan,[6] Z. H. Li,[7] J. Jos'e,[8,9] J. J. He,[10] J. Lee,[4] J. S. Wang,[5] D. X. Wang,[1] H. Y. Wu,[7] P. F. Liang,[4] Y. M. Zhao,[2]

[1]*Department of Nuclear Physics, China Institute of Atomic Energy, Beijing 102413, China*
[2]*School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China*
[3]*Facility for Rare Isotope Beams, Michigan State University, East Lansing, Michigan 48824, USA*

[4]*Department of Physics, The University of Hong Kong, Hong Kong, China*
[5]*Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China*
[6]*Sino-French Institute of Nuclear Engineering and Technology, Sun Yat-Sen University, Zhuhai 519082, China*

[7]*State Key Laboratory of Nuclear Physics and Technology, School of Physics, Peking University, Beijing 100871, China*

[8]*Departament de Física, EEBE, Universitat Politécnica de Catalunya, Av./ Eduard Maristany 10, E-08930 Barcelona, Spain*

[9]*Institut dEstudis Espacials de Catalunya (IEEC), Ed. Nexus-201, C/ Gran Capitá 2-4, E-08034 Barcelona, Spain*

[10]*Key Laboratory of Optical Astronomy, National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China*

Motivation: The spectroscopic information of proton drip-line nucleus ^{27}S provides valuable nuclear physics input for ^{26}Si$(p,\gamma)^{27}$P reaction rate and to probe possible mirror asymmetries [1]. The decay scheme of ^{27}S is complicated and far from being understood, which has motivated but also presented substantial challenges for our study [2].

Method: A double-sided silicon strip detector array was designed in conjunction with high-purity germanium detectors, where the ^{27}S ions were collected and the protons and γ rays emitted in the decay were measured simultaneously.

Results: The precise half-life of ^{27}S, the excitation energies, β-feeding intensities, log ft values, and Gamow-Teller transition strengths for the states of ^{27}P populated in the β decay of ^{27}S were determined. A more complete ^{27}S β-decay scheme was constructed with the experimental data, which was compared to the mirror β decay of ^{27}Na and to the shell-model calculations using the recently-developed USD* interaction.

Conclusions: The precise mass excess of ^{27}P, the energy and the ratio between γ and proton partial widths of the $3/2^+$ resonance are obtained, thereby determining the ^{26}Si$(p,\gamma)^{27}$P reaction rate based mainly on experimental constraints. The first experimental evidence for the observation of mirror asymmetries for the transitions in the decays of ^{27}S and ^{27}Na is also provided. The shell-model calculations with the Hamiltonians including the modifications on single-particle energies and two-body matrix elements related to the proton $1s_{1/2}$ orbit give a better description of the spectroscopic properties.

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Discovery of ^{72}Rb and recent proton-rich RI-beam production at RIBF

H. Suzuki[1], L. Sinclair,[1,2] P.-A. Söderström,[1,3,4] G. Lorusso,[1,5,6] P. Davies,[2] L. S. Ferreira,[7] E. Maglione,[8] R. Wadsworth,[2] J. Wu,[1,9] Z. Y. Xu,[10] S. Nishimura,[1] P. Doornenbal,[1] D.S. Ahn,[1] F. Browne,[1,11] N. Fukuda,[1] N. Inabe,[1] T. Kubo,[1] D. Lubos,[1,12] Z. Patel,[1,6] S. Rice,[1,6] Y. Shimizu,[1] H. Takeda,[1] H. Baba,[1] A. Estrade,[13] Y. Fang,[14] J. Henderson,[2] T. Isobe,[1] D. Jenkins,[2] S. Kubono,[1] Z. Li,[9] I. Nishizuka,[15] H. Sakurai,[1,10] P. Schury,[1,16] T. Sumikama,[15] H. Watanabe,[17,18] and V. Werner[19,3]

[1] *RIKEN Nishina Center, 2-1 Hirosawa, Wako-shi, Saitama 351-0198, Japan*
[2] *Department of Physics, University of York*
[3] *Institut für Kernphysik, Technische Universität Darmstadt*
[4] *GSI Helmholtzzentrum für Schwerionenforschung GmbH*
[5] *National Physical Laboratory* [6] *Department of Physics, University of Surrey*
[7] *Centro de Física e Engenharia de Materiais Avançados, Instituto Superior Técnico, Universidade de Lisboa*
[8] *Dipartimento di Fisica e Astronomia "G. Galilei", and Instituto Nazionale di Fisica Nucleare*
[9] *Department of Physics, Peking University* [10] *Department of Physics, University of Tokyo*
[11] *School of Computing, Engineering and Mathematics, University of Brighton*
[12] *Physik Department E12, Technische Universität München*
[13] *School of Physics and Astronomy, University of Edinburgh*
[14] *Department of Physics, Osaka University* [15] *Department of Physics, Tohoku University*
[16] *Institute of Physics, University of Tsukuba*
[17] *International Research Center for Nuclei and Particles in the Cosmos, Beihang University*
[18] *School of Physics and Nuclear Energy Engineering, Beihang University*
[19] *Wright Nuclear Structure Laboratory, Yale University*

We have discovered two new isotopes, ^{72}Rb and ^{77}Zr[1], using the BigRIPS separator at the RIKEN RI Beam Factory (RIBF). They were produced from a 345-MeV/u 30-35 pnA ^{124}Xe^{52+} beam impinging on a 4-mm-thick Be target by projectile fragmentation. The observation of an odd-odd nuclide ^{72}Rb beyond the unobserved unbound nuclide of ^{73}Rb, shows the diffuseness of the proton drip-line and a possibility of "sandbanks" beyond it. The upper limit of the half life of ^{73}Rb and the half life of ^{72}Rb were deduced, assuming that the non-observation or decrease of the yields of them were caused by in-flight decays. The energies of the emitted protons, E_p, were estimated from the half lives of these proton decays by using the formalism of proton emission from deformed nuclei in Ref.[2, 3]. From the E_p value in ^{73}Rb, the contribution of ^{73}Rb to the two-proton bypass of ^{72}Kr in the rapid-proton process in an X-ray burst is suggested to be small, leading that ^{72}Kr is a strong waiting point.

In this talk, the proton-rich RI-beam production at RIBF is also presented. The RIs whose atomic numbers $Z = 25 - 50$ were produced from the 345-MeV/u ^{78}Kr^{36+} and ^{124}Xe^{52+} beams. Their momentum distributions, especially for low-momentum tails, production cross-sections, compared with cross-section formulae, and new isotopes are shown.

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JUROGAM 3 at MARA- studying proton-rich nuclei by employing in-beam spectroscopy

H. Tann[1,2] on behalf of the JYFL Nuclear Spectroscopy Group,

[1] *Department of Physics, University of Jyväskylä, Finland*
[2] *Department of Physics, University of Liverpool, UK*

MARA is a vacuum-mode recoil separator, commissioned in 2016, primarily used for proton drip-line studies around N $\approx Z$ nuclei, based at the University of Jyvaskyla. The separator is used to separate the primary beam from the reaction products in the mass region below A=150, and to separate fusion products according to their A/q ratio [1]. MARA can be used in conjunction with a versatile focal plane detection system and the JYUtube charged particle detector at the target position.
JUROGAM 3 is a movable detector array consisting of 24 clover detectors and 15 phase one detectors. JUROGAM 3 can be positioned at the target positions of both the RITU gas-filled recoil separator and MARA. A transport mechanism allows movement of the array between the RITU and MARA caves without the need for unbiasing and warming up the detectors. Using the array in conjunction with MARA will increase the sensitivity to probe nuclei by utilising in-beam spectroscopy. The JUROGAM 3 spectrometer was commissioned in March 2019 and more than 170 days of beam time using JUROGAM 3 with MARA have been allocated.

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High-precision mass measurements and production of neutron-deficient isotopes using heavy-ion beams at IGISOL

M. Vilen[1], A. Kankainen[1], L. Canete[1], T. Eronen[1], S. Geldhof[1], A. Jokinen[1], I.D. Moore[1], D.A. Nesterenko[1], H. Penttilä[1], I. Pohjalainen[1], M. Reponen[1], S. Rinta-Antila[1], and A. de Roubin[1]

[1] *University of Jyväskylä, P.O. Box 35, FI-40014 University of Jyväskylä, Finland*

The IGISOL method utilizes a gas-filled ion guide for production and capture of radioactive isotopes. The ion guide system has proven itself to be a valuable tool in producing a great variety of rare isotope beams that cover a large portion of the nuclear chart. Most often a primary beam of light ions is used together with a target foil mounted in direct contact with the buffer gas. While providing improved cooling and larger capture efficiency, direct contact also necessitates the use of light-ion primary beams in order to limit the amount of charge created within the buffer gas volume due to the passage of the primary beam. In order to overcome this limitation and to access new regions of the nuclear chart, especially the neutron-deficient nuclei near the $N = Z$, a heavy-ion ion guide (HIGISOL) has been used that separates the target from the ion guide. The HIGISOL system was originally introduced in [1]. Recently, an updated version of the system has been commissioned and used in an on-line experiment for the first time to produce neutron-deficient transition metal isotopes utilizing a 222 MeV $^{36}Ar^{8+}$ beam on a ^{nat}Ni target. In this contribution, the technical implementation of the new system is presented together with the latest high-precision Penning trap mass measurements of nuclei produced using it. The masses of $T_Z = +1$ nuclei ^{82}Zr, ^{84}Nb, ^{86}Mo, and ^{88}Tc, as well as $T_Z = +1/2$ nucleus ^{89}Ru have been measured. Of these, the isomeric state in ^{88}Tc and the ground state of ^{89}Ru were measured for the first time [2].

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Proton capture reactions with rare isotope beams for X-ray bursts

Louis Wagner[1]

[1] *National Superconducting Cyclotron Laboratory*

Michigan State University, East Lansing, MI, USA

For a deeper understanding what drives nucleosynthesis in extreme astrophysical scenarios like X-Ray bursts, a variety of reaction rates of proton and alpha capture reactions with unstable isotopes have to be known but rely only on theoretical models with large uncertainties. Radioactive ion beam accelerators like at the Facility for Rare Isotope Beams (FRIB) give us great opportunities to study these reactions experimentally. The Jet Experiments in Nuclear Structure and Astrophysics (JENSA) gas target system was constructed to take advantage of these beams at the National Superconducting Cyclotron Laboratory (NSCL) for direct measurements of capture reactions.
Sensitivity studies of Type I X-Ray burst models show that the reaction ^{59}Cu(p,α)^{56}Ni com-petes with the rp-process and has great impact on the burst light curve. The cross section of the reaction can be constraint by the time-inverse reaction ^{56}Ni(α,p)^{59}Cu, because it is predicted that only the ground state is populated at astrophysical energies. The contribution presents pre-liminary results of the recent alpha capture experiment on ^{56}Ni with JENSA that can constrain the uncertainty of nuclear physics input of X-Ray burst models. As an outlook the JENSA hydrogen operation upgrade for proton capture experiments will be discussed.

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Study of the two-proton radioactivity within the Gamow coupled-channel approach

S.M. Wang[1], W. Nazarewicz[2], T.B. Webb[3], R.J. Charity[4] and L.G. Sobotka[3]

[1] *FRIB/NSCL Laboratory, Michigan State University, East Lansing, Michigan 48824, USA*
[2] *Department of Physics and Astronomy and FRIB Laboratory, Michigan State University, East Lansing, Michigan 48824, USA*
[3] *Department of Physics, Washington University, St. Louis, MO 63130, USA*
[4] *Department of Chemistry, Washington University, St. Louis, MO 63130, USA*

Background Two-proton ($2p$) radioactivity is a rare decay mode found in a few very proton-rich isotopes. The $2p$ decay width and properties of emitted protons carry invaluable information on nuclear structure in the presence of a low-lying proton continuum. For example, in mid-heavy nuclei, the measured $2p$ decay of ^{67}Kr turned out to be unexpectedly fast [1]. And more recently, as the mirror of the halo nucleus ^{11}Li, ^{11}O was observed for the first time with a very broad peak [2].
Purpose In the present work, we investigate the role of deformation and continuum effect in the structure and decay properties of ^{67}Kr and ^{11,12}O, as well as the Thomas-Ehrman effect between ^{11,12}O and their respective bound mirror nuclei.
Methods To understand these exotic phenomena, we apply the newly developed Gamow coupled-channel (GCC) method [3], which describes structure and decays of three-body systems within one coherent theoretical framework by utilizing resonant and scattering states in eigenfunction expansion.
Results For mid-heavy nuclei, we analyzed the $2p$ decay lifetime and angular correlations of ^{48}Ni and ^{67}Kr with respect to different deformations and interactions; for light nuclei, we calculated the energy spectra and decay widths of ^{11}O and ^{12}O as well as those of their mirror nuclei. In particular, we investigate the dynamics of the $2p$ decay in the ground state of ^{12}O (*versus* ^{6}Be) by analyzing the evolution of the $2p$ configuration of the emitted protons as well as their angular correlation. We also provide insight on the role of the underlying structure of the $A-1$ subsystems in the $2p$ decay of ^{11}O and ^{12}O.
Conclusions We show that deformation couplings significantly increase the $2p$ decay width of ^{67}Kr; this finding explains the puzzling experimental data. For light nuclei, with GCC approach, the broad structure observed in ^{11}O appears as a multiplet, with the possible $3/2_1^-$ ground state strongly influenced by the broad threshold resonant state in ^{10}N, which is an isobaric analog of the virtual state in ^{10}Li. And a moderate isospin asymmetry between ^{11,12}O and their mirror nuclei was found.

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Charge-Independence Breaking in Light Nuclei

R. B. Wiringa[1],

[1] *Physics Division, Argonne National Laboratory, Argonne, Illinois 40439-4803, USA*

The source of charge-independence (CIB) breaking in nuclei can be traced back primarily to intrinsic quark mass differences and the electromagnetic interaction. This leads to mass differences of mesons, nucleons, and nucleon resonances, and consequent effects in nucleon-nucleon (NN) and three-nucleon (3N) potentials.

The classification of NN forces according to their dependence on charge has been broken down into four classes by Henley and Miller [1]. These are class I or charge-independent (CI) forces, class II or charge-dependent (CD) forces, and class III and IV or charge-symmetry-breaking (CSB) forces. The Coulomb force between two protons can be written as a linear combination of class I-III terms, while the interaction between nucleon magnetic moments involves all four classes. Strong interaction CD forces come primarily from the mass difference between charged and neutral pions, while CSB forces can come from the mixing of mesons like ρ^0-ω.

Fitting NN data gives clear evidence for CIB NN forces via the differences between *pp* and *np* elastic scattering and also the *nn* scattering length. Potentials such as the phenomenological Argonne v_{18} [2] and chiral effective field theory Norfolk NV2 models [3] explicitly include CD and CSB terms in their formulation. These terms can then be used to calculate isomultiplet mass differences and isospin-mixing in nuclei via many-body methods such as quantum Monte Carlo [4]. For example, the ^{3}H-^{3}He binding energy difference of 764 keV is built up from $\approx$640 keV of Coulomb interaction, $\approx$70 keV of strong CSB, and additional small contributions from magnetic moment interactions, kinetic energy, etc. Strong CD terms contribute to $T \geq 1$ mass multiplets like ^{6}He-^{6}Li-^{6}Be, while isospin-mixing of excited states in ^{8}Be can include contributions from class IV CSB [5]. Numerical results for all these cases and more will be presented.

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Studies of explosive nucleosynthesis using β^+ decay experiments

C. Wrede[1]

[1] *Department of Physics and Astronomy, National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824-1321, USA*

Nucleosynthesis and energy generation in classical novae and type-I X-ray bursts are driven by thermonuclear reactions. Many of the reaction-rate uncertainties that influence the modeling of astronomical observables involve resonant radiative proton and α-particle captures on radioactive reactants. An experimental program to study the properties of key resonances using β^+ decay has been established at the National Superconduting Cyclotron Laboratory. In a first set of experiments β^+-delayed γ rays were detected using high-purity germanium arrays including the Segmented Germanium Array (SeGA). A gas-filled detector of weak low energy β-delayed protons designed to fit inside SeGA was recently commissioned for a second set of experiments. The combined Gas Amplifier Detector with Germanium Tagging (GADGET) assembly has been used to measure the energies, branching ratios, and spins of resonances: most of the ingredients needed to construct resonance strengths. The gas detector is currently being upgraded into a time projection chamber.

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Search for α decay of ^{104}Te with a novel recoil-decay scintillation detector

Y. Xiao[1], S. Go[1], R. Grzywacz[1,2], R. Orlandi[3], A. N. Andreyev[3,4], M. Asai[3], M. A. Bentley[4], C. J. Gross[2], P. Hausladen[2], K. Hirose[3], S. Hofmann[3,5], H. Ikezoe[3,5], D. G. Jenkins[4], B. Kindler[5], R. Léguillon[3], B. Lomel[5], H. Makii[3], C. Mazzocchi[6], K. Nishio[3], P. Parkhurst[7], S. V. Paulauskas[1], C. M. Petrache[8], K. P. Rykaczewski[2], T. K. Sato[3], J. Smallcombe[3], A. Toyoshima[3], K. Tsukada[3], K. Vaigneur[9], and R. Wadsworth[4]

[1] *Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee, 37996, USA*

[2] *Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 37831, USA*

[3] *Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Ibaraki, 319-1195, Japan*

[4] *Department of Physics, University of York, Heslington, York, YO10 5DD, United Kingdom*

[5] *GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, 64291, Germany*

[6] *Faculty of Physics, University of Warsaw, Warszawa, PL 02-093, Poland*

[7] *Proteus, Inc., Chagrin Falls, OH 44022, USA*

[8] *Centre de Sciences Nucléaires et Sciences de la Matière, CNRS/IN2P3, Université Paris-Saclay, Bât. 104-108, 91405, Orsay, France*

[9] *Agile Technologies, Knoxville, TN 37932, USA*

A search for super-allowed α decay of $N = Z$ nuclei ^{104}Te and ^{108}Xe was carried out using novel recoil-decay scintillator detector at the tandem accelerator facility at Japan Atomic Energy Agency (JAEA). Inorganic crystal scintillation material of YAP:Ce (Yttrium Aluminium Perowskite) coupled to position-sensitive photo-multiplier tube (PSPMT) was implemented for the first time in radioactive decay experiment. Residues from the fusion-evaporation reaction ^{58}Ni+^{54}Fe$\rightarrow$ ^{112}Xe* were separated by the JAEA Recoil Mass Separator (RMS) [1] and implanted into the YAP:Ce crystal. α decays of neutron-deficient tellurium isotopes were identified and proton-emission of ^{109}I was observed. The decay chain ^{109}Xe $\rightarrow$ ^{105}Te $\rightarrow$ ^{101}Sn was recorded with time interval of 960 ns between two pulses. Position localization in the crystal for decays and ion in the energy range from hundreds keV to 60 MeV was achieved with the accuracy of 0.67 mm, proving that this detector is capable of making temporal and spatial correlations for fast decay events. No evidence was found for the decay chain ^{108}Xe $\rightarrow$ ^{104}Te $\rightarrow$ ^{100}Sn within 3 days experiment. The cross section upper limit of 130 pb was obtained for production of ^{108}Xe, about an order of magnitude below the expectation based on earlier cross section measurements and HIVAP fusion-evaporation code [2, 3] and twice as large as the cross section deduced from the ANL result [4].

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