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Book of Abstracts

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R-matrix analysis of ^{22}Ne(α, n)^{25}Mg and ^{22}Ne(α, γ)^{26}Mg reaction

Rajkumar Santra[1] ; Subinit Roy[2]

[1] *Variable Energy Cyclotron Center*

[2] *Saha Institute Of Nuclear Physics*

Corresponding Author(s): subinit.roy@gmail.com, rajkumarsantra2013@gmail.com

The ^{22}Ne(α, n)^{25}Mg and its competing channel ^{22}Ne(α, γ)^{26}Mg have major influence on neutron flux for weak s-process nucleosynthesis in low mass AGB stars and in massive stars with M$\geq$ 10M$_{\odot}$. The ratio of the reaction rates of these two competing reactions controls the generation of neutron flux. Several experiments have been performed to study the properties of the levels of the compound nucleus ^{26}Mg, required to evaluate the rates of ^{22}Ne+α reactions. The rates obtained from these studies vary significantly and therefore introduce large uncertainties in the nucleosynthesis processes at relevant temperatures. The evaluations by Adsley et al. [1] of the rates of ^{22}Ne+α reactions using the most recent nuclear data of ^{26}Mg, available from number of sources, show that while the rate for ^{22}Ne(α, γ)^{26}Mg corroborates with the previous evaluation, the rate for ^{22}Ne(α, n)^{25}Mg reaction with the use of updated nuclear data in the estimations, is substantially lower. The authors also suggested that interference effects between the distant levels and the sub-threshold resonance may have some important effect that was not taken into account in their estimation. A full R-matrix modeling of the existing data [2] will, therefore, is important to probe the influence of the interference effects between distant levels and the sub-threshold resonance on the excitation function data.
The present work reports a full R-matrix calculation performed for ^{22}Ne(α, n)^{25}Mg and ^{22}Ne(α, γ)^{26}Mg reactions. The fitting of the ^{22}Ne(α, n)^{25}Mg reaction data of Jaeger et al [2], in the energy range of 0.8 to 1.45 MeV, has been performed using the updated nuclear data of ^{26}Mg states. Initially the R-matrix calculation has been carried out for ^{22}Ne(α, n)^{25}Mg, including the experimental resolution correction, using the recently updated spin, parity and partial widths of resonance states (E$_x$=10.9 to 12.82 MeV) of ^{26}Mg reported in Ref. [1] corresponding to E$_{\alpha}^{c.m}$= 0.57 to 1.45 MeV energy range. It is observed that the resultant cross sections do not reproduce the data well, especially in the off-resonance regions of the excitation function. However, the R-matrix fitto the ^{22}Ne(α, n)^{25}Mg reaction data in 0.8 to 1.45 MeV energy range improved considerably if the spin, parity of the states at E$_x$ = 11.63 and 11.78 MeV are changed from 1^- to 0^+, thereby, introducing the effect of interference between the same J$^{\pi}$ levels. The cross sections for ^{22}Ne(α, γ)^{26}Mg are also estimated simultaneously with the resulting parameters and taking the gamma partial widths from the literature. The present R-matrix calculation shows that ^{22}Ne(α, n)^{25}Mg is dominant with respect to ^{22}Ne(α, γ)^{26}Mg reaction over the hole energy range from 0.57 to 1.2 MeV. It is also observed that the R-matrix calculation yields higher cross sections for ^{22}Ne(α, n)^{25}Mg in the Gamow energy window compared to the previous estimates of Adsley et al. The final results and the comparisons with previous estimates will be presented.\\

[1] Philip Adsley et al., Phys. Rev. C 103, 015805 (2021).

[2] M. Jaeger et al., Phys. Rev. Lett. 87, 202501 (2001).

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An in-depth R-matrix analysis of the proton capture on carbon isotopes

Jakub Skowronski[1]

[1] *Università degli Studi di Padova*

Corresponding Author(s): jakub.skowronski@pd.infn.it

Since the 12C/13C ratio in the stellar atmosphere is an important indicator of the stellar nucleosynthesis, both the 12C(p,g)13N and 13C(p,g)14N reactions are crucial elements that can help improving the stellar models. More specifically, the 12C/13C ratio could be used to constrain the mixing models inside AGB stars.

In a recent study at the Laboratory for Underground Nuclear Astrophysics (LUNA), both reactions have been studied using different types of solid targets, and employing complementary detection techniques. The new datasets and their deviation with respect to the literature imposed the necessity of a new reaction rate evaluation. To achieve this, new R-matrix fits were carefully performed for both reactions, taking into account all the literature data. Both the frequentist and bayesian models were employed to study the differences between the two approaches and to assess the best way of dealing with systematic uncertainties.

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Approximation of R-Matrix Resonance Parameter Sensitivities Using The Windowed Multipole Method

Matthew Lazaric[1] ; Mark Paris[2]

[1] *University of New Mexico*

[2] *Los Alamos National Laboratory*

Corresponding Author(s): mlazaric@unm.edu, mparis@lanl.gov

The goal of this work is to develop a method of approximating R-Matrix resonance parameter sensitivities for use in future sensitivity analysis studies. The inclusion of resonance parameters and resonance parameter covariances has been increasing with each subsequent release of ENDF/B. From these resonance parameters and their associated covariances, nuclear data evaluation codes can uniquely determine the expected value and variance of the cross section within a given energy range. Quantifying the impact that a lone resonance parameter has on the entire cross section space using standard R-matrix methods has been shown to be both computationally expensive and time consuming due to the sheer number of resonance parameters in modern evaluations. This research aims to investigate the use of the Windowed Multipole method of evaluating cross sections to approximate R-matrix resonance parameter sensitivities. This method was chosen because it can produce analytic cross section sensitivities to both pole parameters and temperature on-the-fly, allowing for the approximation of both level energy and resonance width sensitivities. This research compares analytic sensitivity profiles generated by the Windowed multipole method against those generated numerically and investigates the impact of the differences on cross section uncertainty.

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Capture width distributions from the Atlas of Neutron Resonances

Khadim Mbacke[1] ; David Brown[2]

[1] *Morehouse College*

[2] *NNDC - Brookhaven National Laboratory*

Corresponding Author(s): dbrown@bnl.gov

Nuclear data is used for a variety of purposes in our daily life, from basic science to advanced usages like nuclear power. Below roughly 1 MeV incident energy, neutron cross sections show fluctuations, or resonances, whose energies and widths are not predictable. The resonances for a given nucleus

can be summarized with a few parameters such as the average resonance spacing and the average widths of the resonance peaks. These averages are important input for nuclear reaction and structure models. The goal of my project is to study the average resonance capture widths and resonance spacings using the resonance data compiled in the *Atlas of Neutron Resonances*. As the provenance of these values in the published *Atlas of Neutron Resonances* is unclear, we refit the empirical cumulative level distributions for each possible spin group to extract the average spacings. Similarly, we refit the empirical capture width distributions to extract the average capture widths and the capture degrees of freedom. We discussed the implications of the obtained widths and capture degrees of freedom.

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Deep learning application on the R-matrix phenomenology

Author(s): Chanhee (Ben) Kim[1]

Co-author(s): K. Y. Chae ; M. S. Smith ; D. W. Bardayan ; C. R. Brune ; R. J. deBoer ; D. Lu ; D. Odell ; D. R. Phillips

[1] *Sungkyunkwan Univ.*

Corresponding Author(s): chkim@phys.kim

While the R-matrix phenomenology is dominantly used in nuclear physics, it contains two categories of unobservable parameters - channel radius and background poles. These parameters sometimes lead to ambiguities in the R-matrix fits of experimental data. Here, we propose a method to tackle this challenge using deep learning techniques. We train a customized deep learning model to predict the physical objects, such as resonance properties, from the observational data without the information on the channel radius and background poles. After training, the model only requires the measurement data to extract resonance parameters. We demonstrate this method with data from the measurement of 12C+p elastic scattering. Results also indicate that the R-matrix analysis using deep learning techniques has some advantages over conventional methods in terms of speed, uncertainty quantification, etc.

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Deep underground laboratory measurement of ^{13}C(α,n)^{16}O in the Gamow windows of the s- and i-processes

Xiaodong Tang[1]

[1] *Institute of Modern Physics, CAS*

Corresponding Author(s): xtang@impcas.ac.cn

The ^{13}C(α,n)^{16}O reaction is the main neutron source for the slow-neutron-capture (s-) process in Asymptotic Giant Branch stars and for the intermediate (i-) process. Direct measurements at astrophysical energies in above-ground laboratories are hindered by the extremely small cross sections and vast cosmic-ray induced background. We performed the first consistent direct measurement in the range of $E_{c.m.}$ =0.24 MeV to 1.9 MeV using the accelerators at the China JinPing underground Laboratory (CJPL) and Sichuan University. Our measurement covers almost the entire i-process Gamow window in which the large uncertainty of the previous experiments has been reduced from 60% down to 15%, eliminates the large systematic uncertainty in the extrapolation arising from the inconsistency of existing data sets, and provides a more reliable reaction rate for the studies of the s- and i-processes along with the first direct determination of the α-strength for the near-threshold state.

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Definite parametrization of R-matrix cross sections

Pablo Ducru[None]

Corresponding Author(s): p_ducru@mit.edu

Definite formalism introduces new standard for nuclear cross section data.

Our common knowledge of nuclear reactions was build over a century of experimental campaigns, recording cross sections and fitting them with parametric models of quantum interactions. The resulting R-matrix parameters are documented in and constitute the pillar of standard evaluated nuclear data libraries.

Yet, though presently the standard, Wigner-Eisenbud R-matrix parameters are somewhat arbitrary quantities introduced for calculation and documentation.

Building upon recent findings to go past the Wigner-Eisenbud parameters, we introduce a new R-matrix formalism based on fundamental physical quantities — the poles of the scattering matrix — and propose it as a new definite standard for nuclear cross sections.

Critically, nuclear cross sections can now be fully described — with all their levels, resonances, and energy dependence — with a finite number of natural and invariant physical parameters (as many as the number of levels).

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Direct measurement of 19F(p,a)16O reaction cross section

Teodora Madgearu[1]

[1] *ELI-NP*

Corresponding Author(s): teodora.petruse@eli-np.ro

The 19F(p,a)16O reaction plays a significant role in the production of fluorine in asymptotic giant branch (AGB) stars. The cross sections for different reaction channels are crucial input parameters for stellar models, and their accuracy has a significant impact on the predicted yields of fluorine in AGB stars.

The a0 channel of the 19F(p,a)16O reaction has relatively large uncertainties in the cross section. New experimental data and R-matrix calculations including world data are necessary for improving the accuracy of the reaction rates. In a recent study, Lombardo et al. used R-matrix calculations to estimate the reaction rate of the a0 channel in the 19F(p,a)16O reaction, and found that the current uncertainties in the cross section are dominated by the uncertainty in the resonance strength. New experimental data on the a0 channel has become available this year which could be used to refine the R-matrix calculations. This would have important implications for our understanding of the chemical evolution of galaxies and the nucleosynthesis of light elements in the universe.

In this work, we present a new R-matrix calculation of the a0 channel in the 19F(p,a)16O reaction, taking into account the latest experimental data. The AZURE2 code was used to perform the calculations.

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Disentangling clustering phenomena in 12C and 16O

Author(s): Kevin Ching Wei Li[1]

Co-author(s): Philip Adsley [2] ; Retief Neveling [3] ; Johann Wiggert Brümmer [3] ; Lindsay M. Donaldson [3] ; Martin Freer [4] ; Muhsin N. Harakeh [5] ; Luna Pellegri [6] ; Vicente Pesudo [7] ; Mathis Wiedeking [6] ; Sunniva Siem [1]

[1] *Department of Physics, University of Oslo, N-0316 Oslo, Norway*

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

[3] *iThemba LABS, National Research Foundation, PO Box 722, Somerset West 7129, South Africa*

[4] *School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham, B15 2TT, United Kingdom*

[5] *Nuclear Energy Group, ESRIG, University of Groningen, 9747 AA Groningen, The Netherlands*

[6] *School of Physics, University of the Witwatersrand, Johannesburg 2050, South Africa*

[7] *Centro de Investigaciones Energe´ticas, Medioambientales y Tecnolo´gicas, Madrid 28040, Spain*

Corresponding Author(s): johann.wiggert.brummer@gmail.com, vicente.pesudo@csic.es, padsley@tamu.edu, sunniva.siem@fys.uio.no, m.freer@bham.ac.uk, m.wiedeking@ilabs.nrf.ac.za, luna.pellegri@wits.ac.za, m.n.harakeh@kvi.nl, r.neveling@ilabs.nrf.ac.za, lm.donaldson@ilabs.nrf.ac.za, k.c.w.li@fys.uio.no

^{12}C remains at the forefront of nuclear structure studies as it is the predicted site of a wide range of interesting phenomena and is also astrophysically significant. The challenge of understanding the structure of ^{12}C thus endures as a litmus test of our ability to not only theoretically model nuclei, but to also phenomenologically analyse/interpret data. This talk will present recent work which aims to disentangle broad, intertwined contributions to the excitation spectrum of ^{12}C, populated through inelastic scattering and transfer reactions (with preliminary results on ^{16}O also presented).

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Example calculations with AZURE2

Richard deBoer[1]

[1] *University of Notre Dame*

Corresponding Author(s): rdeboer1@nd.edu

I will give a short tutorial on the use of AZURE2 by demonstrating low energy ^{12}C(p,p) and (p,γ) data as an example. I will briefly discuss how to get the code, its installation, where to get data to fit, data file formats, use of the GUI to build an example calculation, and how to look at the output. I'll focus on common pitfalls in making these calculations.

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Intro to EDA

Mark Paris[None]

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Intro to R-matrix

Mark Paris[None]

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Intro to THM R-matrix

Marco La Cognata[None]

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Investigation of proposed threshold resonance in 6Li(p, γ)7Be reaction

Author(s): Dr. Pareshkumar Prajapati[1]

Co-author(s): R. J. deBoer

[1] *Manipal Academy of Higher Education, Manipal - 576104*

Corresponding Author(s): pareshkumar.p@manipal.edu

The abundance of lithium in the universe is a complex topic involving all three main nucleosynthesis processes 1. The 6Li (p, γ)7Be cross-section influences a variety of astrophysical scenarios, including big-bang and stellar nucleosynthesis. The 6Li(p, γ)7Be reaction has been studied extensively using direct [2] and indirect methods [3]. The low-energy trend of its cross-section remains uncertain as different measurements have reported conflicting results. In particular, the existence of a positive parity state (3/2+) of 7Be at center of mass energy 195 keV [4] is still matter of debate. In view of this, we have performed a detailed R-matrix analysis on 3He(α, γ)7Be and 6Li (p, γ)7Be reactions. In the R-matrix formalism, both capture and scattering data sets have been utilized to check the existence of resonance like structure at center of mass energy 195 keV.

References:
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2. D. Piatti et al, Phys. Rev. C 102, 052802 (R) (2020)
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4. J. J. He et al, Phys. Lett. B 725, 287 (2013)

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Making R-matrix Evaluations for 3He+4He and p+6Li scattering for Data Libraries.

Ian Thompson[1] ; the INDEN-LE collaboration[None]

[1] *LLNL*

Corresponding Author(s): thompson97@llnl.gov

The existing ENDF/B-VIII.0 data library only contains elastic scattering for 3He+4He scattering reaction. The evaluation for p+6Li scattering does contain an outgoing 3He+4He channel, but only up to 2.5 MeV lab proton energy. Since these two reactions have the same compound nucleus – 7Be – it should be possible to fit both reactions simultaneously using an R-matrix parameter model that fits all reaction data that involves the same compound nucleus.
R-matrix models have parameters for each level: an energy, a spin and parity, and a partial width for every partial wave that couples to that spin and parity. When fitted to known data, including both angle-integrated data and angular cross sections from available experiments, and also total cross sections for incident neutrons, a model naturally predicts excitation functions at all energies for all included channels for angle-integrated and angular cross sections. Naturally these predictions will be most accurate in the regions of the data, in order avoid risky extrapolation.
I report on recent work in fitting R-matrix parameters for the 7Be compound system, in order to make candidate evaluations for both the 3He+4He and p+6Li incoming channels and thus make

improvements to two evaluations for the forthcoming ENDF/B-VIII.1 library.
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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Measurement and R-matrix analysis of the 7Be + n reactions updating the primordial lithium abundance

Seiya Hayakawa[1]

[1] *Center for Nuclear Study, the University of Tokyo*

Corresponding Author(s): hayakawa@cns.s.u-tokyo.ac.jp

The cosmological lithium problem has been known as the outstanding discrepancy of primordial lithium abundances between observations and theoretical predictions. We have measured key nuclear reactions which act to reduce ^{7}Li during the big bang nucleosynthesis (BBN), namely, ^{7}Be$(n,p)^7$Li and ^{7}Be$(n,\alpha)^4$He. We also performed R-matrix fits to data sets including both the previous and present cross sections of the (n,p_0), (n,p_1) and (n,α) reaction channels based on the resonances at known excited levels. This analysis resulted in an improved uncertainty evaluation of the (n,p_0) cross section, and the first-ever quantification of the (n,p_1) contribution in the BBN energy region. The updated $(n,p_0)+(n,p_1)$ reaction rate offers non-negligible reduction in the primordial ^{7}Li abundance prediction, which reduces the discrepancy in the lithium problem.

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Measuring 23Na(p, γ)24Mg Direct Capture Reaction Rate using (3He,d) Spectroscopy

Kaixin Song[None] ; Caleb Marshall[1] ; Kiana Setoodehnia[2] ; Federico Portillo Chaves[3] ; Richard Longland[3]

[1] *University of North Carolina, Chapel Hill*

[2] *European X-ray Free Electron Laser GmbH*

[3] *North Carolina State University*

Corresponding Author(s): kiana.setoodeh@gmail.com, marshallc@ohio.edu, rllongla@ncsu.edu, ksong6@ncsu.edu, federico.epc@gmail.com

The reaction rates of a sodium destruction reaction 23Na(p,γ)24Mg play an important role while suffering from large uncertainties in hydrogen burning temperatures. We performed a 23Na(3He,d) measurement in angular range of 5°≤θlab≤21° at E(3He)=21MeV using the Enge Split-pole Spectrograph at Triangle Universities Nuclear Laboratory. Energy states below the 23Na + p threshold in 24Mg were examined. For those states, spectroscopic factors were extracted with rigorous uncertainties using Bayesian MCMC and DWBA method. We used those to calculate the most updated direct capture cross sections and reaction rates for 23Na(p,γ)24Mg. The ANCs for each state were also calculated and used to compare with results from R-matrix studies.

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Monte Carlo R matrix analysis of the low-energy 13C(a,n)16O cross section

Andreas Best[1]

[1] *University of Naples Federico II*

Corresponding Author(s): andreas.best@unina.it

The reaction 13C(a,n)16O is the main neutron source of the astrophysical s process, and its cross section needs to be known in the energy range 150-230 keV to accurately model stellar nucleosynthesis. Due to the low cross section at these energies a direct measurement is very challenging, and up to now there is still some extrapolation required. The main components that influence the cross section behaviour is a near-threshold 1/2+ state and a 3.2+ state at about 7.21 MeV. Further complications arise from differences between normalisations of higher-energy data. We present a Monte Carlo analysis based on Azure2 of the low-energy cross section including a new data set measured by the LUNA collaboration that reached the Gamow energy range. An outlook at further work including other recent data and covering a larger energy range is presented.

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Nuclear Data Evaluations

David Brown[None]

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Nuclear Data Evaluations

David Brown[1]

[1] *NNDC - Brookhaven National Laboratory*

Corresponding Author(s): dbrown@bnl.gov

The performance of nuclear reactors and other nuclear systems depends on a precise understanding of the neutron interaction cross sections for materials used in these systems. These cross sections exhibit resonant structure whose shape is determined in part by the angular-momentum quantum numbers of the resonances. The correct assignment of the quantum numbers of neutron resonances is, therefore, paramount. In this project, we apply machine learning to automate the quantum number assignments using only the resonances' energies and widths and not relying on detailed transmission or capture measurements. The classifier used for quantum number assignment is trained using stochastically generated resonance sequences whose distributions mimic those of real data. We explore the use of several physics-motivated features for training our classifier. These features amount to out-of-distribution tests of a given resonance's widths and resonance-pair spacings. We pay special attention to situations where either capture widths cannot be trusted for classification purposes or where there is insufficient information to classify resonances by the total spin J. We demonstrate the efficacy of our classification approach using simulated and actual 52Cr and 238U resonance data.

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Nuclear Data Evaluations in the Resolved Resonance Region and proposed updates to R-matrix modeling in the SAMMY code

Marco Pigni[1]

[1] *Oak Ridge National Laboratory*

Corresponding Author(s): pignimt@ornl.gov

Evaluated nuclear data provide fundamental information for modeling codes simulating nuclear physics processes. Reactor-based applications as well as nuclear forensics, treaty verification and nuclear material measurements for safeguards are a few application areas of interest. Improving nuclear data libraries, therefore, is a common goal for many agencies that rely on code simulations to assess scenarios where there is lack of direct measurement data for code validation. The reliability of evaluated nuclear data libraries is measured by their ability to guarantee the agreement between calculated and measured (integral) observables for a large set of benchmark calculations. The highest fidelity is reached when the nuclear database is evaluated on the basis of nuclear theoretical models able to reproduce (differential) measured data.

The nuclear data group at Oak Ridge National Laboratory has been historically very prolific in populating several releases of the US ENDF/B nuclear data library with resonance parameter evaluations ranging from from medium-light nuclei to structural and heavy (fissile) elements. This was achieved by a combination of measurements and evaluation procedures coupled to the development of the R-matrix code SAMMY 1. Although the SAMMY code system has been mainly used in nuclear data evaluations for incident neutrons in the resolved resonance region (RRR), the R-matrix models implemented in it also allow the study of the ingoing and outgoing charged-particle channels in the low-energy interaction range. Built-in capabilities also allow the code to analyze measured data including important experimental corrections. Among the most important ones, there are self-shielding, multiple-scattering, resolution, and Doppler broadening effects for multi isotopic samples.

This presentation will provide an overview of the features of the SAMMY code followed by examples of the evaluation procedures in the RRR. Additionally, proposed updates to R-matrix models in the SAMMY code such as the use of complex radii, inverse reaction kinematics, and a level-dependent boundary condition [2] will be discussed.

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R-Matrix analysis of the neutron-induced cross sections on ^{147,149}Sm and ^{143}Nd measured at LANSCE

Esther Leal Cidoncha[1] ; Paul Koehler[1] ; Athanasios Stamatopoulos[1]

[1] *LANL*

Corresponding Author(s): elealcid@lanl.gov, athanasios.stamatopoulos@lanl.gov, koehler@lanl.gov

The R-Matrix code SAMMY 1 was used to analyze the neutron-induced cross section data on ^{147,149}Sm and ^{143}Nd measured at LANSCE and previous measurements on ^{143}Nd [2] in order to understand how the new data impact the criticality benchmark discrepancies identified in [3]. The ^{147,149}Sm transmission and capture cross sections were measured using the Device for In-direct Capture Experiments on Radionuclides (DICER) and the Detector for Advanced Neutron Capture Experiments (DANCE) respectively. Although ^{147}Sm was not a concern in [3], it was included in the analysis because the DICER ^{147}Sm sample contained a small amount of ^{149}Sm and it allows us to better characterize the ^{149}Sm resonances near 0.097 and 0.87 eV. The capture cross section on ^{143}Nd was measured with DANCE. Separated spin capture data on ^{143}Nd and ^{147,149}Sm were calculated following the procedure from [4]. The total cross section data from [2] are unclear as to the proper sample thickness for the R-Matrix analysis, so the impact of this uncertainty was explored.

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R-matrix analysis of ^{9}Be(α,n)^{12}C reaction and determination of reaction rate

Suprita Chakraborty[1] ; Subinit Roy[2]

[1] *B.A.V Girls*

[2] *Saha Institute Of Nuclear Physics*

Corresponding Author(s): subinit.roy@gmail.com, chakrabortysuprita@gmail.com

^{12}C is the seed nucleus for the formation of next heavier nuclei in the supernovae ejecta, which are the inputs of succeeding rapid neutron capture process. The nucleus ^{12}C is mostly formed by triple-alpha process in our universe. Modern research shows that the nucleosynthesis at the astrophysical site of type-II supernova produces significant amount of ^{12}C through the neutron catalyzed reaction ^{4}He(αn,γ)^{9}Be(α,n)^{12}C in neutron and alpha-rich hot bubble region. In this region, the neutron catalyzed reaction ^{4}He(α n,γ)^{9}Be(α,n)^{12}C occurs 40 times faster than the triple-alpha reaction. Considering the importance of ^{9}Be(α,n)^{12}C reaction for the production of ^{12}C in supernovae ejecta, in this present work we have performed a simultaneous phenomenological R-matrix analysis of the data of three different exit channels formed due to the collision of α and ^{9}Be nucleus. The aim is to find out the reaction rate of ^{9}Be(α,n)^{12}C reaction at the relevant temperature more precisely than the previous works.

The experimental data of the main reaction channel ^{9}Be(α,n)^{12}C have been taken from Kunz *et al.* [phys.Rev.C **53**, 5 (1996)] and Wrean *et al.* [Phys. Rev. C **49**, 1205 (1994)] and elastic data of exit channel have been taken from Halt *et al.* [Observation and analysis of elastic neutron scattering from ^{12}C Proc. Conf. on Nuclear Cross Sections and Technology (Washington, DC) SP-425 Vol-I, pp 246–9 (1975)], Schwartz *et al.*[National Burenu of Standards Report, NBS-138, (1974).] and Lister *et al.* [Phys.Rev **143**, 745 (1966)]. Also we have included the data of reverse reaction of ^{9}Be(α,n)^{12}C. The experimental data of ^{12}C(n,α)^{9}Be have been taken from Kuvin and Lee *et al.* [Phys. Rev. C **104**, 014603 (2021)] and Giorginis *et al.* [EXFOR].

Apart from the astrophysical interest, another objective of choosing this system is to find out the unknown spin parities of some of the resonances theoretically using R-matrix fitting process. We have fitted altogether twenty five resonances. As the separation energy of neutron is lower than α so first 8 resonances are used to fit the elastic data of exit channel. We have fitted the data of reaction channel ^{9}Be(α,n)^{12}C from $E_{c.m} = 0.16$ MeV to 2.5 MeV. To fit the data of this reaction channel we needed 11 resonances. Additional 6 resonances are needed to describe the experimental data of ^{12}C(n,α)^{9}Be as the data set of Kuvin and Lee *et al.* is extended up to $E_x = 14.6$ MeV. To fit the elastic data we had to incorporate 4 background poles at excitation energy $E_x = 20$ MeV. However no background pole is needed to fit the reaction channel. From a preliminary investigation we obtained the spin parity of the resonance at $E_x = 11.748$ is $1/2^{+}$.

Finally reaction rate has been evaluated. At lower temperature region below $T_9 = 0.1$ our value is 10 to 15 times higher than Fowler *et al.* [At. Data Nucl. Data Tables **40**, 283 (1988)]. Also our value of reaction rate at low energy region is larger than that obtained by Kunz *et al.* The probable reason of obtaining a high value is the estimation of sharper resonance at $E_x = 10.753$ MeV than Kunz *et* *al.*. Also we have planned to extend our fitting by incorporating the elastic data of entrance channel in our simultaneous R-matrix analysis. Our work is in progress and will be presented.

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R-matrix analysis of 19F(α,n)22Na reaction

Paraskevi Dimitriou[1]

[1] *International Atomic Energy Agency*

Corresponding Author(s): p.dimitriou@iaea.org

(alpha,n) reactions at low energies up to 10 MeV are relevant for a wide range of applications including the reactor fuel cycle, spent fuel management, nonproliferation, fusion technologies, low background experiments, and nuclear astrophysics. All these applications depend on accurate and precise experimental data that are incorporated in reliable evaluated libraries. However, in regard to (α,n) data, the evaluated libraries are either incomplete or outdated. We report on our efforts to evaluate the 19F(α,n)22Na reaction at energies up to 9 MeV using R-matrix analysis.

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R-matrix analysis of 8Be System

Author(s): Som Paneru[1]

Co-author(s): Richard deBoer [2] ; Michael Febbraro [3] ; Christopher Fichtl [1] ; Sean Kuvin [1] ; Hye Young Lee [1] ; Khachatur Manukyan [2] ; Michelle Mosby [1] ; Jason Nattress [3] ; Christopher Prokop [1] ; Daniel Robertson [2] ; Edward Stech [2] ; Wanpeng Tan [2]

[1] *Los Alamos National Laboratory*

[2] *University of Notre Dame*

[3] *Oak Ridge National Laboratory*

Corresponding Author(s): cprokop@lanl.gov, wtan@nd.edu, nattressjt@ornl.gov, paneru@lanl.gov, febbraromt@ornl.gov, kuvin@lanl.gov, drobert4@nd.edu, rdeboer1@nd.edu, hylee@lanl.gov, mosbym@lanl.gov, estech@nd.edu, cfichtl@lanl.gov, kmanukya@nd.edu

Deuteron-induced reactions on 6Li are important for nuclear structure studies and for nuclear applications. Even after several measurements of 6Li(d,n)7Be reaction in the past, the partial cross section information for 6Li(d,n)7Be reaction is lacking as there are discrepancies between various R-matrix evaluations. To address these discrepancies, a new measurement of 6Li(d,n)7Be was performed at University of Notre Dame in collaboration with Oak Ridge National Laboratory and University of Notre Dame to obtain neutron angular distributions. In addition to neutrons, this experiment simultaneously measured the various reactions products from different reaction channels, including charged particles, and gammas, which would aid in better determination of angle-integrated partial cross sections. The experimental details and preliminary results from the ongoing analysis will be discussed. In addition, a multi-channel R-matrix analysis is performed to fit the data for 6Li(d,n0,1)7Be, 6Li(d,p0,1)7Li, 6Li(d,d)6Li, a(a,a)a, 7Li(p,a)a, and 7Li(p,n)7Be channels simultaneously using phenomenological R-matrix code AZURE2. All these channels form 8Be compound nucleus. The details of the R-matrix analysis and preliminary results will be presented and compared with the EDA fit that is used for the current ENDF/B evaluation.

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R-matrix analysis of the ^{18}O(α,α) resonant elastic scattering and ^{22}Ne structure

Author(s): Aliya Nurmukhanbetova[1] ; Vladilen Goldberg[2] ; Alexander Volya[3] ; Grigory Rogachev[2]

Co-author(s): Dosbol Nauruzbayev [4] ; Timur Zholdybayev [5] ; Gulfairuz Serikbayeva [4]

[1] *Energetic Cosmos Laboratory, Nazarbayev University, Astana, Kazakhstan*

[2] *Texas A&M University*

[3] *Florida State University*

[4] *Nazarbayev University Research and Innovation System, Astana, Kazakhstan*

[5] *Institute of Nuclear Physics, Almaty, Kazakhstan*

Corresponding Author(s): aknurmukhanbetova@gmail.com, rogachev@tamu.edu, dosbol.nauruzbayev@nu.edu.kz, avolya@fsu.edu, goldberg@comp.tamu.edu, zholdybayev@inp.kz, gulfairuz.serikbayeva@nu.edu.kz

Low energy ^{18}O+α interaction is expected to play an important role in astrophysical processes 1. The ^{18}O(α,γ) reaction synthesizes ^{22}Ne, the main neutron source for the weak s-process, and the reaction ^{18}O(α,n) ^{21}Ne with a neutron threshold of E_α= 851 keV has been proposed as a weak neutron source in the production of ^{19}F in TP-AGB stars 1.

The properties of ^{22}Ne states populated in the ^{18}O+α resonant interaction are also of interest for cluster development in Ne region and, specifically, for understanding the influence of extra neutrons on alpha cluster structure in ^{20}Ne [2]. The studies of ^{22}Ne are also important for comparison of alpha cluster properties in mirror resonant reactions ^{18}O+α and ^{18}Ne+α [3].

The measurements for the α+^{18}O elastic scattering were made in a broad energy interval in two old high energy-resolution works [4,5] and in a relatively recent inverse kinematics publication [6]. None of these data was analyzed in the framework of R-matrix theory.

We performed measurements of the α+^{18}O elastic scattering in the inverse kinematics at lower energy than it was in the reference [6] to enhance an influence of the states at a lower excitation energy, and we made the full R-matrix analysis of all available data on the α+^{18}O resonant elastic scattering in the energy region 11-15 MeV excitation energy in ^{22}Ne. We present theoretical predictions that are essential for understanding resonant structure at high excitation energy with high density of states and a few decay modes. We also present new data on the structure of the states in ^{22}Ne in comparison with shell model predictions. We consider specific features of the experimental approaches important for the analysis and possible improvements of the AZURE code [7].

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SAMMY Calculations

Marco Pigni[None]

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Shedding light on 17O(n,α)14C reaction at astrophysical energies with Trojan Horse Method and Asymptotic Normalization Coefficient

Giovanni Luca Guardo[None]

Corresponding Author(s): guardo@lns.infn.it

The 17O(n,α)14C reaction is considered in astrophysical codes for its role in the astro- physically relevant "s(slow)-process" since it could act as a possible "neutron-poison" for the neutron induced nucleosynthesis thus influencing the final stellar abundances of some elements such as Fe, Ni or Sr. Thus, its reaction rate must be known in the energy region of interest for astrophysics, going from few keV's up to about 400 keV. At such energies, the intermediate 17O+n→18O nucleus presents four excited levels (8038, 8125, 8213, and 8282 keV's) affecting the magnitude of the 17O+n cross section at astrophysical energies because of the neutron emission threshold at 8044 keV for 18O. Although the role of the two 8213 keV (Jπ=2+) and 8282 keV (Jπ=3−) was already investigated in the direct measurements, insufficient informations are up to now available about the 8125 keV (Jπ=5−) resonant level, thus requiring a detailed experiment.

Indirect methods have been largely proved in the past as a complementary way of accreting our knowledge about nuclear structure and low-energy cross section measurements. Among these, the neutron induced reaction cross section appear to be of particular interest since their role both for unstable and stable beams. In view of this, we report here the combined study of the 17O(n,α)14C accomplished by the Trojan Horse Method (THM) and the Asymptotic Normalization Coefficient (ANC) method. The low lying resonances 8038, 8125, 8213, and 8282 keV in 18O are studied and Γn are derived by applying the modified R-matrix approach. A comparison with direct measurements and recent THM experimental data is presented. The independent ANC investigation corroborate our previous THM results, confirms the consistence of the two indirect investigation and shows new frontiers also in view of neutron induced reactions with radioactive ion beams.

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Study of the 34Ar(a,p)37K reaction rate and its effects on X-ray Burst Stellar Models

Author(s): Amber Lauer-Coles[1]

Co-author(s): Catherine M Deibel [2] ; Jeffery C Blackmon [2] ; Ashley Hood ; Erin Good [3] ; Kevin Macon [4] ; Daniel Santiago-Gonzalez [5] ; Steven Pain [6] ; Kelly Chipps [7] ; Sunghoon(Tony) Ahn [8] ; Hendrik Schatz [9] ; Wei Jia Ong [10] ; Grigory Rogachev [8] ; Sriteja Upadhyayula [11] ; Joshua Hooker [12] ; Yevgen Koshchiy [13] ; Heshani Jayatissa [5] ; Ingo Wiedenhöver [14] ; Lagy T Baby [14] ; Maria Anastasiou [15] ; Nabin Rijal [16] ; Fernando Montes [17] ; Justin Browne [17] ; Bedoor Shadi [18] ; Konrad Schmidt [17]

[1] *Brookhaven National Laboratory*

[2] *Louisiana State University, Baton Rouge, LA*

[3] *FRIB/MSU*

[4] *Notre Dame*

[5] *Argonne National Laboratory*

[6] *Oak Ridge National Laboratory*

[7] *ORNL*

[8] *Texas A&M University*

[9] *MSU*

[10] *Lawrence Livermore National Laboratory*

[11] *TRIUMF*

[12] *University of Tennessee, Knoxville*

[13] *Texas A&M University Cyclotron Institute*

[14] *Florida State University, Tallahassee, FL*

[15] *Lawrence Livermore National Lab*

[16] *JINA-CEE, NSCL, Michigan State University*

[17] *Michigan State University*

[18] *Texas Agricultural and Mechanical University*

Corresponding Author(s): anastasiou2@llnl.gov, macon.kevin@gmail.com, chippska@ornl.gov, schatz@nscl.msu.edu, koshchiy@tamu.edu, erincgood@gmail.com, saint@nuclearemail.org, sriteja@triumf.ca, jhooker2@utk.edu, rijal@frib.msu.edu, hjayatissa@anl.gov, amberlauer@gmail.com, blackmon@lsu.edu, adisbr1@lsu.edu, rogachev@tamu.edu, dsago@anl.gov, ong10@llnl.gov

The rate of the reaction ^{34}Ar$(\alpha, p)^{37}$K, as one of the last reactions in the so-called (α, p) process, may influence the shape of the Type-I X-ray Burst light curve, as shown in recent XRB stellar modelling studies.

Type I X-Ray bursts (XRBs) are energetic stellar explosions that occur on the surface of a neutron star in an accreting binary system with a low-mass H/He-rich companion. Due to the extreme thermodynamic conditions a thin-shell instability can cause a He-flash in the surface nucleosynthesis, resulting in thermonuclear runaway. This is accompanied by a burst of photons in the X-ray spectrum, referred to as a ”light curve”.

In addition, under the “waiting point” phenomenon, nucleosynthesis may stall with a corresponding stall in the accompanying XRB light curve. As such an (α, p) reaction which has become energetically favored during the extreme thermodynamics of the burst may bypass this waiting point despite its normally low cross section, reigniting the burst and escaping the stall.

This work discusses the results of an experiment to study resonances of the ^{38}K compound nucleus of the (α, p) reaction on the ^{34}Ar nucleus via proton scattering on ^{37}K. The resonant reaction rate is dependent on the features of resonances in the Gamow energy window for the XRB. This talk will review the entire process, especially highlighting the unique R-matrix analysis with the AZURE2 software package to constrain the reaction rate. The newly estimated rate was applied to XRB models built using Modules for Experiments in Stellar Astrophysics (MESA), to examine its impact on observables, including the light curve and abundances.

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TBA

Carl Brune[None]

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TBA

Michele Sferrazza[None]

Corresponding Author(s): michele.sferrazza@ulb.be

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TBA

Michele Sferrazza[None]

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The Modified R-Matrix and its application to THM: the ^{19}F$(\alpha, p)^{22}$Ne and ^{23}Na$(p, \alpha)^{20}$Ne cases

Author(s): Giuseppe D'Agata[1]

Co-author(s): Marco La Cognata [2] ; Rosario Gianluca Pizzone [3]

[1] *Università degli Studi di Catania - Dipartimento di Fisica e Astronomia "Ettore Majorana"*

[2] *INFN-LNS*

[3] *LNS-INFN*

Corresponding Author(s): lacognata@lns.infn.it, g.dagata@lns.infn.it, rgpizzone@lns.infn.it

Since the second half of the 20^{th} century, one of the most interesting challenges for physicists has been to explain the production of all the different elements in the universe, and the way stars produce energy. The source of both has been pointed out to be mainly nuclear reactions inside stars. On an experimental point of view, reproducing nuclear reactions of astrophysical interest is complicated due to the low energy and low cross section of such processes. To overcome such difficulties, several indirect methods have been developed through the years, and the Trojan Horse Method (THM) has proven to be useful to investigate such difficult measurements. In this context the R-Matrix formalism is useful to calculate the cross section and astrophysical S-factor of nuclear reaction of astrophysical interest, but it must be modified in order to be used on THM measurements. For this reason, the so-called Modified R-Matrix formalism has been developed. In the first part of this this talk, the extraction of the $_\alpha$ values for several resonant state of the ^{19}F$(\alpha, p)^{22}$Ne reaction from the experimentally retrieved three-body cross section of the ^{19}F(^{6}Li,p ^{22}Ne)^{2}H will be discussed. One of the pivotal issues in the THM lies in normalization: to obtain the absolute unit cross section, in fact, the THM arbitrary units two-body cross section must be normalized to direct data at energies outside the energy region of interest for nuclear astrophysics (Gamow window). Using the same Modified R-Matrix formalism, it is also possible to directly extract the ωγ values for resonant states directly from the arbitrary units two-body cross section, using the resonance strength of some well-known levels. This approach has been used to study the ^{23}Na$(p, \alpha)^{20}$Ne reaction, and it will be discussed in the second part.

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The impact of 16O(e,e'alpha)12C measurements on the astrophysical S factor for the 12C(alpha,gamma)16O reaction.

Author(s): David Potterveld[1]

Co-author(s): Bradley Filippone [2] ; Roy Holt [2]

[1] *Argonne National Laboratory*

[2] *California Institute of Technology*

Corresponding Author(s): rholt@caltech.edu, bradf@caltech.edu, potterveld@anl.gov

The $^{12}\mathrm{C}(\alpha, \gamma)^{16}\mathrm{O}$ reaction (CTAG) has long been of intense interest because of its importance in stellar nuclear evolution. The small cross section at stellar energies cannot be directly measured in the lab. Cross sections must be measured at higher energies and extrapolated down using theory, usually expressed as an R-Matrix model. Recently, measurements of ^{16}O electro-disintegration cross sections near threshold have been proposed as a way to constrain the stellar-energy CTAG cross section. We have performed a Bayesian analysis of the existing CTAG world data combined with possible low and high energy electro-disintegration measurements to predict how much improvement can be expected. This work was performed using Azure2 as a calculational engine in a novel Monte Carlo integration technique that is superior to the ubiquitous Markov Chain Monte Carlo. We will show that feasible measurements at high energy can provide significant improvement comparable to that of measurements at the lowest practical energies.

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The modified R-matrix approach for nuclear astrophysics

Marco La Cognata[1]

[1] *INFN-LNS*

Corresponding Author(s): lacognata@lns.infn.it

In nuclear astrophysics, when approaching the Gamow window for charged-particle fusion reactions, the signal-to-noise ratio approaches zero due to vanishingly small cross sections and extrapolation, e.g., performing R-matrix fits of ancillary data sets, is necessary. Even in those few case where underground measurements made it possible to approach and, sometimes, span the Gamow window, electron screening hides the true trend of the cross section, making extrapolation necessary anyway. Indirect methods have then introduced to reach astrophysical energies with no need of extrapolation. Among these, the Trojan Horse Method 1 has been introduced 30 years ago to determine the low-energy trend of the astrophysical S-factor for binary reactions (excluding radiative captures), by selecting the quasi-free contribution to a reaction with three particles in the exit channel. In the case of resonant reactions, the astrophysical factor of the binary reaction of astrophysical interest is deduced from the triple different cross section of the quasi-free reaction through the application of a modified R-matrix approach [2]. In this presentation, we will discuss the basic equations of this approach, the analogies with the standard R-matrix analysis, and present some case studies to illustrate advantages and drawbacks of the method.

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Welcome

Carl Brune[None] ; James deBoer[None]