Taking the Temperature (T3):

Workshop on Statistical Nuclear Physics in Astrophysics and Applications

August 14-17 2023, Athens OH

Book of abstracts

Ohio University, Athens OH 2023

Contents

ABSTRACT

Microscopic optical potentials for direct reactions and the statistical model

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The neutron-nucleus optical potential (OP) is one of the essential ingredients in both direct and compound nuclear reaction calculations. Phenomenological parametrizations based on fits to elastic scattering data are widely used for many applications in astrophysics, basic nuclear science, and nuclear data. However, the explicit connection of the OP with the underlying nuclear structure has always been an active line of research since the seminal papers of Feshbach were published in the 50's. This connection contributes to a better microscopic understanding of nuclear collisions, to a more transparent extraction of structure information from reaction experiments, and to a better controlled extrapolation to scarcely explored regions of the nuclear chart. We will present our recent results in the microscopic derivation of OPs based on a self-consistent solution of the Dyson equation, making use of state-of-the-art shell-model structure calculations. Our results can also be used to draw an explicit connection between level densities, neutron transmission coefficients, and gamma strength functions, all of them essential ingredients of the statistical model of the nucleus.

ABSTRACT

Charged Particle Reaction Modeling via Proton Bombardment on Natural Antimony - Applications and Implications for Nuclear Level Densities and Optical Model Development

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Cross sections for Sn-117m and Te-119m have been measured via proton bombardment on Sb to determine the viability of this production route for medical applications. In addition to these measurements, several other cross sections were calculated to be used in improving predictive modeling with nuclear data simulations, in this case TALYS. Previous work conducted by (Fox et al., 2021) informed changes to optical model parameters for pre-equilibrium reactions. In addition to these modifications, changes to residual interaction parameters based on nucleon-nucleon interactions were explored. The nuclei studied in these experiments contain several isomers due to population of the h_11/2 orbital, leading to significant spin-parity differences relative to the ground state. This informed adjustments to the spin cut-off parameter, which required considerable adjustment. This work also indicates that changes are needed in the imaginary component of the neutron optical potential to best reproduce neutron emission over this experimental energy range.

ABSTRACT

Constraining experimentally photon strength functions for p-process nucleosynthesis calculations

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James Madison University

This presentation brings into focus recent 78,80Kr(g,g’), 93Mo(g,n) and 90Zr(g,n) cross section measurements carried out using real photons at the HIGS/TUNL facility. The overarching physics motivation was to advance fundamental knowledge on a forefront topic in nuclear astrophysics – the nucleosynthesis beyond Fe of the rarest stable isotopes naturally occurring on Earth (the origin of p-nuclei). Though simulating the p-process nucleosynthesis is a daunting task, significant progress can be made by performing key measurements, which constrain the statistical models that are used to calculate the unknown stellar reaction rates. In particular, these stellar reaction rates are highly sensitive to the low-energy tail of the nuclear photon strength function (pSF). Due to its high selectivity for dipole excitations, real photon scattering via nuclear resonance fluorescence (NRF) is the method of choice to extract experimentally, with high accuracy and model independently, the dipole pSFs in atomic nuclei. The quasi-monochromatic and linearly polarized photon beam of very high flux available at HIGS makes this facility ideal for investigation of photoabsorption reaction cross section with p-nuclei as targets. We will discuss the status of the data analysis of our very recent NRF measurements on 78,80Kr, which, when complete, will provide for the first time information for the low-energy part of the E1 pSF in 78,80Kr, as direct input into the p-process modeling. The energy dependencies of the ground-state cross sections for ^{94}Mo(γ,n) and ^{90}Zr(γ,n) reactions were also measured recently at HIGS with high precision, from the respective neutron emission thresholds up to 13.5 MeV. In order to constrain the dipole pSFs in the A $\simeq$ 90 mass region, the measured cross sections were compared with predictions of Hauser-Feshbach statistical model calculations using two different dipole pSF models. Since these models are based on fundamentally different physics, they can reflect the existing uncertainties affecting the pSF, and also the impact of such uncertainties on reaction cross sections and corresponding astrophysical reaction rates. We will showcase key aspects of the experimental procedure, data analysis, and theoretical calculations pertaining to our final results that show how sensitive the resulting ^{94}Mo(γ,n) and ^{90}Zr(γ,n) stellar reaction rates can be to the corresponding experimental ground-state cross sections, as discussed in detail in our recent publication, Phys. Rev. C 99, 025802 (2019).

This work is supported by the Department of Energy/Office of Science under the award no. DE-SC0021199.

ABSTRACT

Exploring the Origin of the Rarest Stable Isotopes via Photon-Induced Activation Studies at the Madison Accelerator Laboratory

Adriana Banu

James Madison University

The focus of this research work is to determine experimentally the ground state reaction rates for eight photoneutron reactions proposed to be investigated via photon-induced activation at the Madison Accelerator Laboratory (MAL), a unique bremsstrahlung facility on the campus of James Madison University, in Harrisonburg, Virginia. The eight photoneutron reactions are – 64Zn(γ,n), 70Ge(γ,n), 74Se(γ,n), 78,80Kr(γ,n), 84,86Sr(γ,n), 90Zr(γ,n). The corresponding proton-rich stable nuclei of interest belong to the region A < 124 that is notoriously underproduced by the current stellar evolution models for the astrophysical p-process. Because in the laboratory one only has access to target nuclei in the ground state, the stellar photodisintegration reaction rates, dominated by excited state contributions at the high temperature regime of the p--process, cannot be directly constrained experimentally. With the measurements at MAL, we can provide instead nuclear input to constrain crucial parameters of the statistical nuclear reaction models, i.e. γ-ray strength function, especially relevant for photoneutron reactions, which is the overarching goal of this research project at MAL. This presentation seeks to disseminate the progress made at MAL towards that end, highlighting the current R&D challenges encountered when trying to implement the so-called superposition technique at an unconventional bremsstrahlung facility that features a repurposed medical electron linear accelerator.

This work is supported by the National Science Foundation (NSF) under Grant No. PHY-1913258.

ABSTRACT

Statistical nuclear properties from inelastic neutron scatter using the GENESIS array

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The Gamma-Energy Neutron-Energy Spectrometer for Inelastic Scattering (GENESIS), has been built and commissioned at Lawrence Berkeley National Laboratory's 88-Inch Cyclotron. The detector array consists of 26 EJ-309 organic scintillators with neutron-gamma pulse shape discrimination, a LaBr3 inorganic gamma-ray scintillator, two Ortec "pop-top" high-purity germanium (HPGe) gamma-ray detectors, and two Compton-suppressed, segmented Eurosys Clover HPGe detectors. Neutrons are produced via thick target deuteron breakup on carbon or beryllium targets in an adjacent vault, then collimated into a narrow beam of 10^5 n/cm2/s onto 10-40 gram targets 7 meters from the source. The high-energy end point of this broad neutron spectrum is tunable by selection of the deuteron energy, generally between 14-23 MeV but as high as 55 MeV. Active neutron spectrum monitoring is measured behind the array with a scattered-neutron time-of-flight system. Unlike many charged-particle reactions and decay mechanisms, inelastic neutron scatter populates a broad range of spins, making it a unique probe for non-selective nuclear level excitation. While the primary purpose of the GENESIS array is to measure inelastic neutron cross sections, observation of evaporation neutrons as a function of angle allows the measurement of statistical properties such as nuclear temperature.

This material is supported by the U.S. Department of Energy-LBNL Contract No. DE-AC02-05CH11231 and by LLNL Contract DE-AC52-07NA27344 and by the DOE Nuclear Energy Advanced Modeling and Simulations Program (DOE-NEAMS) and by the Defense Threat Reduction Agency Grant HDTRA1033292.

ABSTRACT

Nuclear Level Densities and related data in the Reference Input Parameter Library (RIPL): A critical review

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A long-standing problem of how to meet nuclear data needs of the future with limited experimental resources puts a considerable demand upon nuclear model computation capabilities. Theoretical calculations are instrumental in obtaining complete and internally consistent nuclear data files nowadays and play a key role in nuclear data evaluations. In particular, the statistical model of nuclear reactions is widely used for cross-section calculations and evaluations in the fast neutron energy region, being the nuclear level densities a key ingredient for those calculations.

Addressing these needs, the RIPL-3 library was reviewed in the Ohio SNP 2008 workshop. The RIPL library was released in January 2009 and a comprehensive paper was published. The RIPL database is available on the Web through http://www-nds.iaea.org/RIPL-3/. The level density segment contains both phenomenological and semi-microscopic models.

This contribution review the level-density data and models included in the IAEA Reference Input Parameter Library. The IAEA is planning a follow-up CRP on nuclear level densities. The scope and goals of the project will be discussed.

ABSTRACT

On neutron capture and primary gamma-ray emissions at thermal energies

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Neutron capture is a possible outcome of a nuclear reaction between a neutron and a target nucleus. The associated probabilities are key components related to the nucleosynthesis. At thermal energies, this reaction often involves the formation of a compound nucleus in an excited state, composed by the target and the neutron. The structure of this residual nucleus drives the nuclear deexcitation process of emitted gamma rays. Here, we highlight the importance of the first step in this chain since the capture cross-section can be understood as a sum of the partial cross-section of individual primary gamma-ray emissions. These emissions are important for a precise modeling of the capture reaction as well as the subsequent gamma-ray cascade. When experimental values are not available, the primaries are given by theoretical predictions that rely on statistical assumptions difficult to be justified. We have analyzed the ability to model primary emissions with standard theoretical model parameterizations in comparison to experimental data for light and heavy isotopes, where we expect a high-level density to favor some of the statistical assumptions. One of our goals is to improve the accuracy of simulated gamma-ray cascade.

The work at Brookhaven National Laboratory was sponsored by the Office of Nuclear Physics, Office of Science of the U.S. Department of Energy under Contract No. DE-AC02-98CH10886 with Brookhaven Science Associates, LLC.

ABSTRACT

A critical test of the Oslo method

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Quasicontinuum gamma decay following compound reactions - commonly called Oslo method - is probably the most important source of information on the gamma strength functions (GSFs) and level densities of nuclei below particle threshold. A fundamental assumption in the analysis of Oslo-type data is the generalized Brink-Axel (BA) hypothesis, whose applicability to the low-energy regime is under debate. Since all other methods are based on the measurement of photoabsorption from the ground state, a test of the equivalence of results from absorption and emission experiments in the same nucleus postulated by the BA hypothesis is most important. I will discuss inelastic proton scattering experiments performed at RCNP in extreme forward kinematics, where relativistic Coulomb excitation dominates the cross sections. Such data provide information on the E1 and M1 parts of the GSF and their sum can be directly compared to Oslo-type experiments. Furthermore, the very good energy resolution of the spectra permits an independent extraction of level densities and thereby a test of the normalization methods applied in the analysis of Oslo-type data.

Work supported by the Deutsche Forschungsgemeinschaft under Contract No. SFB 1245 (Project ID No. 79384907).

ABSTRACT

Magnetic dipole gamma-ray strength functions in heavy odd-mass nuclei from shell-model Monte Carlo

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Yale University

The gamma-ray strength functions (gSF) reveal information about collective phenomena in atomic nuclei and are necessary inputs for calculations of astrophysical neutron capture cross sections. We have computed the magnetic dipole gSFs for the odd-mass isotopes $^{143\text{-}151}$Nd and $^{147\text{-}153}$Sm using a combination of the shell-model Monte Carlo method, static path approximation, and maximum-entropy method. We quantify the uncertainties of the computed gSFs and find that they are well under control despite the existence of a Monte Carlo sign problem for the odd-mass nuclei at low temperatures. We find a low-energy enhancement in the magnetic dipole gSFs, which was also recently observed experimentally in the total gSFs of these nuclei.

This work was supported in part by the U.S. DOE grant No. DE-SC0019521.

ABSTRACT

Level density and thermodynamic properties of 69Zn nucleus

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Thermodynamic properties of 69Zn nucleus have been investigated by utilizing the nuclear level density (NLD), which were experimentally obtained from the γ-gated particle spectra. The experimental NLDs have been compared with the results of different microscopic calculations such as exact pairing plus independent-particle model (EP+IPM) at finite temperature, Hartree-Fock BCS (HFBCS), Hartree-Fock-Bogoliubov plus combinational (HFBC), etc. It is seen that the experimental NLDs can be well explained by the results of EP+IPM. Intriguingly, the heat capacity calculated using the best matched EP+IPM NLD exhibits a sharp S-shape, the signature of pairing phase transition, which is not expected in such odd-even hot or hot-rotating system as reported earlier. It was shown that the S-shaped heat capacity in such odd-even 69Zn nucleus is explained due to the deformation induced pairing correlation. In addition, several combination of NLDs and γ-ray strength functions (γSF) are used in TALYS code to constrain the NLD and γSF in calculating the neutron capture reaction 68Zn(n,γ)69Zn cross-section in nuclear astrophysics, which could help us to further optimize the uncertainties in the n-capture reaction rate and hence abundance of the elements.

ABSTRACT

Extraction of the Nuclear Level Density 68Cu and 65Ni using the LANSCE/WNR neutron beams and the evaporation technique

Nikolaos Dimitrakopoulos

Central Michigan University

Nuclear reactions involved in stellar evolution generally occur at energies much lower than the Coulomb barrier, making neutron induced reactions vital in the synthesis of chemical elements, particularly those heavier than iron. Reactions of the (n,a) and (n,p) types can be utilized to extract nuclear level densities (NLD) of unstable isotopes, essential for accurate reaction rate calculations, using the evaporation technique. To probe nuclear level densities in the Ni region, cross sections measurements for 68Zn(n,p)68Cu and 68Zn(n,a)65Ni were carried out at WNR facility at LANSCE. Neutron beam ranging between 0.1 to 100 MeV impinged on a highly enriched 68Zn target located in the center of LENZ detection system. The reaction products were detected using annular S1 DSSD telescopes upstream and downstream of the target, and the discrimination between protons and alpha particles was accomplished by a pulse shape discrimination technique. The experimental data in the energy range of 10 to 13 MeV will also be used to extract level densities for the neutron-rich isotopes of 68Cu and 65Ni using the evaporation technique. The major energy-selection criterion was the minimization of direct and non-primary contributions that distort the evaporation spectra. The main idea of the evaporation technique is that the differential cross section for the emission of a particle from a compound nucleus is proportional to the appropriate transmission coefficient and NLD. Therefore, the detailed shape of the particle spectrum is determined by the energy dependence of the level density. Further improvement of the experimental level density can be achieved by comparing the experimental spectra to those calculated with the Hauser-Feshbach theory and adjusting the theory parameters to reproduce the experimental spectra. In this talk/poster, we present details on the experimental setup, analysis, and preliminary results for the measurement of 68Zn(n,a)65Ni and 68Zn(n,p)68Cu reaction cross section and the extraction of the nuclear level density of 68Cu and 65Ni.

DOE funding by grant DE-SC0022538.

ABSTRACT

Theory at the Intersection of Direct and Compound Nuclear Reactions

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The last decade has seen much progress in the development of theory tools that allow us to achieve more accurate calculations for both direct and compound (statistical) nuclear reactions. Integrated nuclear structure and reaction descriptions provide the basis for making cross-section predictions and enable indirect determination of cross sections that are difficult to measure directly. This is particularly important for applications involving reactions with unstable nuclei, such as astrophysics simulations. I will discuss advances at the intersection of direct and compound reactions, focusing on reactions that populate doorway states and provide insights on the formation and decay of compound nuclei. The reaction descriptions require the integration of nuclear-structure information that is not part of typical reaction calculations and accounts for higher-order reaction processes. The theory developments have enabled the successful extraction of neutron-capture cross sections from measurements of transfer reactions with stable beams. I will discuss the use of inelastic scattering as an additional indirect (surrogate) mechanism, the feasibility of determining (n,n'), (n,2n), and other desired cross sections, and possible experiments at radioactive-beam facilities.

*This work is performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Support from the LDRD Program, Projects 19-ERD-017, 20-ERD-030, 21-LW-032, 22-LW-029, 23-SI-004 is acknowledged.

ABSTRACT

Statistical decays using approximate shell model calculations

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The nuclear shell model is an under-utilized source of statistical nuclear properties such as nuclear level densities and gamma-ray strength functions, both of which are fundamental to statistical nuclear reaction models used in nuclear data evaluations. In part, this is because accurate calculations for nuclei of astrophysical interest often require model spaces exceeding our computational resources. The large numbers of states required for statistical analysis compounds with the larger model spaces typically needed to include excitations of both parities, a pre-requisite for E1 gamma-ray strength functions. To address this, we have applied our proton-neutron shell model truncation scheme to approximate the wave functions typical shell model calculations cannot handle. In our benchmark cases, we find that this is an effective way to estimate the gamma-ray strength functions, while better methods already exist for nuclear level densities.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344 with support from the ACT-UP award.

ABSTRACT

Level densities for deformed nuclei

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An important source for level density information about nuclei is tabulating neutron resonances at the neutron binding energy. The density of levels for L=0 must be corrected to the total level density by multiplying by a factor to correct for levels of other J values. In general, this is done for the formula derived by Bethe. While this is correct for spherical nuclei, Bethe pointed out that his formula requires an assumption of spherical symmetry. A corrected version of the Bethe formula for deformed nuclei is presented. Results from use of the new formula are presented and compared with those obtained using the Bethe formula. The new formula provides for increased level densities for deformed nuclei.

ABSTRACT

New Evaluations of Fast Neutron-Induced Reactions on ^{35}Cl

Kenneth Hanselman

Los Alamos National Laboratory

The neutron-induced reactions on 35Cl at "fast" (~MeV) energies are increasingly relevant for modern applications like CLYC detectors and fast-spectrum reactors. New data on the most relevant channels have been taken in recent years at multiple facilities, including LANL's Low-Energy (n,Z) (LENZ) setup at LANSCE, prompting new evaluation work on this system. The statistical side of these new evaluations using the combined Coupled Channels/Hauser-Feshbach code CoH3 will be presented here, demonstrating improved agreement over the current ENDF-B/VIII.0 and thus improvements for the aforementioned applications.

This work benefits from the LANSCE accelerator facility and is supported by the U.S. Department of Energy Office of Nuclear Energy/Gateway for Accelerated Innovation in Nuclear (GAIN) and a Cooperative Research and Development Agreement (CRADA) with Terrapower LLC.

ABSTRACT

Unified description of the coupled-channels optical model and the statistical Hauser-Feshbach theory for low energy nuclear reactions

Toshihiko Kawano

Los Alamos National Laboratory

We incorporate the coupled-channels optical model into the statistical Hauser-Feshbach nuclear reaction theory, where the scattering matrix is diagonalized to properly calculate both the transmission coefficient for the excited states and the width fluctuation correction for deformed nuclei by performing the Engelbrecht-Weidenmueller transformation. We further generalize this technique so that all the open channels in a nucleon-induced reaction on a deformed nucleus can be calculated consistently. We show that the calculated neutron inelastic scattering cross section at low energies increases by considering the nuclear deformation effect.

[LA-UR-23-25087]

ABSTRACT

Statistical gamma-decay and isomeric ratio in ^{168}Er measured by DANCE

Ingrid Knapova

Los Alamos National Laboratory

Gamma decay in highly excited nuclei is usually described within the statistical model of the nucleus, employing nuclear level density (NLD) and a set of photon strength functions (PSFs). The gamma rays following the neutron capture on the ^{167}Er target were measured with the Detector for Advanced Neutron Capture Experiments (DANCE) at the Los Alamos Neutron Science Center. The experimental gamma-ray spectra for different multiplicities and many s-wave resonances were compared with their simulated counterparts using DICEBOX code to test different models of NLD and PSFs. Moreover, ^{168}Er is of particular interest because of its isomeric state at 1094 keV. We were able to detect the decay of this short-lived isomer and estimate the isomeric ratio for a few resonances. Comparison to the simulated isomeric ratio provided an important test of the applicability of the statistical model. The experimental isomeric ratio was reproduced with simulations when adopting the decay scheme well above 2 MeV. This finding indicates that structural effects in ^{168}Er likely still play a significant role in the region of high excitation energies.

ABSTRACT

Neutron Induced charged particle reaction studies on both stable and radioactive nuclei at LANSCE

Sean A Kuvin

Los Alamos National Laboratory

The need for improved nuclear data on neutron-induced charged-particle (n,z) reactions, which are ubiquitous in nature, have been identified for a wide range of applications such as in nucleosynthesis network calculations for astrophysics, characterizing damage to structural materials due to gas production, and in device-performance simulations. To address the specific nuclear data needs, the Low-Energy (n,z), LENZ, instrument is designed to measure double-differential cross sections of (n,p) and (n,a) reactions using the fast neutrons, with a broad energy spectrum, available at the Weapons Neutron Research facility at the Los

Alamos Neutron Science Center (LANSCE). Results from studies of (n,z) reactions on both stable (A = 58, 60) and radioactive (A = 56, 59) nickel isotopes will be presented. On-going efforts to improve measurements with radioactive targets will also be discussed.

ABSTRACT

Neutron-capture rates for i- and r-process nucleosynthesis

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The element distribution we observe in the Universe, and in particular the diverse abundances of atomic nuclei, tells a fascinating story of nucleosynthesis events that have taken place throughout the 13.7-billion-year-long history starting with the Big Bang. Since the groundbreaking works of Burbidge, Burbidge, Fowler and Hoyle and Cameron in 1957, it has been known that radiative neutron-capture reactions play a major role in synthesizing elements heavier than iron. However, many questions remain when it comes to our understanding of neutron-capture processes in various stellar environments. In particular, the intermediate and rapid neutron-capture processes are very challenging to describe, as they involve neutron-rich nuclei for which there exist little or no data on the much-needed neutron-capture rates. In this talk, I will present possibilities to obtain experimental constraints of these rates, with the aim to improve our understanding of the r- and i-process nucleosynthesis.

Funding of this research by the Research Council of Norway, project grant no. 316116, is gratefully acknowledged.

ABSTRACT

The impacts of nuclear reaction uncertainty on heavy-element nucleosynthesis

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CPR, RIKEN

Astrophysical nucleosynthesis beyond iron involves numerous nuclear reactions and decay processes, even for unstable nuclei. Explosive nucleosynthesis, in particular, includes significant physical uncertainties on reaction cross-sections and has complex dependencies in the network. A comprehensive approach based on Monte Carlo is essential for understanding such complicated phenomena. We have developed a nuclear reaction network with a Monte-Carlo framework considering stellar reaction-rate uncertainties. We investigated the s-process and several nucleosyntheses relevant to p-nuclei production using this tool. In this presentation, I will present the recent results on the νp-process, which is expected to happen in core-collapse supernovae and may be the origin of lighter p-nuclei. I show important unknown reaction rates, which may impact the final abundances. In particular, I will discuss important reaction rates for reproducing the solar isotopic ratios of lighter p-nuclei.

ABSTRACT

Spin classification of neutron resonances with Machine Learning

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Neutron resonances are sharp fluctuations seen in neutron transmission and capture experiments at low-energy neutron-induced reactions. Properties of neutron resonances are some of the few experimental constraints to nuclear level densities and gamma strength functions (crucial for modeling many nuclear applications). Resonances are characterized by their angular momenta quantum numbers, which are normally assigned through fits often done in an ad hoc and not fully reproducible manner. Comprehensive compilations of evaluated resonances often contain incorrectly assigned spins. To address these, we developed a Machine-Learning method to train an algorithm to identify resonances with incorrect spin assignments. Model training is done on synthetic data constructed to simulate statistical properties of resonances seen in real nuclei, or on ranges of real experimental data known to have reliable assignments. The trained classifier can be applied to resonances sequences from compiled, evaluated, or experimental data. In this work we use 52Cr as a test case to assess the performance of the reclassification, showing how multiple realizations of synthetic data can serve as a validation tool for the machine-learning classifier. We then apply the trained algorithm to make reclassification predictions on a 52Cr evaluated file. We also show results for training the classifier on actual 238U data.

Work supported by the NCSP, funded and managed by the NNSA for the DOE. Work at BNL was sponsored by the Office of NP, Office of Science of the DOE under Contract No. DE-AC02-98CH10886 with BSA, LLC. Supported partly by BNL SURP and the DOE, Office of Science, Office of WDTS under SULI.

ABSTRACT

Experimental Level Densities for Neutron Capture from White Neutron Beams

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Department of Physics, Central Michigan University

The neutron capture rates important for nucleosynthesis problems typically involve neutron rich nuclei. The main uncertainty for these reaction rates comes from estimates of statistical properties that enter the Hauser-Feshbach model, namely the level density of the excited compound nucleus and the strength function describing the evaporation of gamma-rays. While many of the nuclei important for some of these processes are close to the valley of stability, modern statistical model calculations of the relevant neutron-capture rates still carry significant uncertainties that are identified in recent sensitivity studies.

We have recently applied the evaporation technique for the extraction of experimental level densities to the case of (n,x) reactions on zinc isotopes. We plan to expand the technique to heavier nuclei that may be relevant to the nucleosynthesis of elements observed in Carbon-Enhanced Metal-Poor stars or generally in stellar environments with neutron densities between the s- and the r- process. n this talk, I will present the experimental technique we are using and its theoretical foundation, discuss assets and limitations from the point of view of experimental and theoretical capabilities, as well as the applicability to specific astrophysics scenarios.

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Nuclear Physics program under Award Number DE-SC-0022538.

ABSTRACT

Theoretical gamma strength functions within the QRPA framework

S. Péru

CEA, DAM, DIF

In our standard approach [1], transition probabilities for the decay of the excited states toward the ground state are obtained as the last stage of QRPA calculations. Some computational effort has been made to produce a large-scale data set of electric and magnetic dipole strengths leading to a theoretical database for photon strength functions with the least possible phenomenological ingredients [2]. After discussion on success and limits of these systematic studies, I will also present some unusual applications of the QRPA method for the interpretation of isomeric half-lives in the N=100 isotonic chain [3]. Formal and numerical development needed in the aforementioned study have opened the way for new improvements of the theoretical description of the gamma strength functions. In particular, preliminary QRPA results on the microscopic description of the "upbend" observed in Oslo data will be shown.

[1] S. Péru and M. Martini, Eur. Phys. J. A (2014) 50: 88;
[2] S. Goriely et al, Eur. Phys. J. A (2019) 55: 172;
[3] L. Gaudefroy, S. Péru et al, Phys.Rev. C 97, 064317 (2018)

ABSTRACT

Uncertainty Quantification for Phenomenological Optical Potentials

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Lawrence Livermore National Lab

Tools for reliable uncertainty quantification (UQ) are increasingly important for combining knowledge across multiple domains of nuclear physics. For reaction modeling, theorists often rely on global phenomenological optical model potentials (OMPs) such as Koning-Delaroche (KD) and Chapel Hill '89 (CH89), neither of which is equipped with well-calibrated uncertainty estimates. To address this gap, we revisited the classical KD and CH89 OMP analyses and identified two important statistical limitations that hampered the original efforts at UQ. We then developed a generic OMP-UQ framework using Markov-Chain Monte Carlo for parameter inference. Within this framework, we assigned well-calibrated uncertainties to KD and CH89, yielding two new UQ-OMP ensembles: KDUQ and CHUQ. Against the KD/CH89 training data and a large corpus of new test data, our UQ versions show improved reliability and interpretability, and in two case studies, we demonstrate how KDUQ and CHUQ can be gainfully "dropped in" anywhere KD and CH89 are already used. To expedite the inclusion of OMP uncertainty as a standard practice, we present digital copies of our potentials and related tools for forward uncertainty propagation [see PRC 107 014602 (2023)].

This work was performed in part under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

ABSTRACT

Impact of experimentally constrained nuclear level densities and gamma-ray strength functions for the astrophysical i-process

Andrea Richard

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One of the major areas of research in nuclear astrophysics is understanding the origin of the elements in stellar environments. Observations of carbon-enhanced metal poor stars (CEMP) show that observed abundance patterns cannot be reproduced by the traditional neutron-capture processes (s and r), and indicate that an additional process known as the intermediate neutron-capture process (i-process) is needed to describe these abundances. Occurring at intermediate neutron densities, the majority of nuclear physics properties (mass, half-life, etc.) are well constrained, however statistical quantities and their resulting reaction rates remain largely unmeasured. Using indirect techniques, neutron-capture cross sections and reaction rates for radioactive nuclei can be experimentally determined. In this talk, results on the nuclear level densities, gamma-ray strength functions, and neutron-capture reaction rates relevant to the i-process will be discussed along with astrophysical network calculations showing their impact on predicted abundances.

Prepared by LLNL under Contract DE-AC52-07NA27344.

ABSTRACT

Microscopic Neutron radiative capture reactions calculated with the noniterative finite amplitude method and the statistical Hauser-Feshbach theory

Hirokazu Sasaki

Lol Alamos National Laboratory

We derive quasiparticle random-phase approximation (QRPA) with noniterative finite amplitude method and calculate electric dipole (E1) and the magnetic dipole (M1) giant resonances. Then, we apply the QRPA result to the gamma-ray strength function and calculate the neutron radiative capture cross sections based on the statistical Hauser-Feshbach theory. We find that the low energy M1 scissors mode can enhance the capture cross sections for deformed gadolinium isotopes.

ABSTRACT

Statistical Model Rates in Astrophysics

Hendrik Schatz

Michigan State University

Statistical model reaction rates make up the vast majority of nuclear reaction rates used in astrophysical model calculations of the r-, i-, rp-, nup-, and p-processes, as well as advanced explosive stellar burning stages and accreting neutron star crusts. I will review the needs for more accurate rates and quantification of uncertainties in statistical model calculations for astrophysical applications.

ABSTRACT

Introduction of a new shell model method for nuclear level density

Yang Sun

Shanghai Jiao Tong University, China

For a microscopic description of NLD, one should solve the eigenvalue problem, H |Ψ> = E |Ψ>, to obtain all energy levels. To do so, one must abandon the conventional thinking for shell models, and develop methods by applying modern many-body techniques. In this talk, I will introduce a novel shell-model method for calculation of NLD in deformed nuclei. Our diagonalization yields a large ensemble of eigenstates of angular momentum and parity. We demonstrate that NLD as a statistical quantity depends sensitively on structure of deformed single-particle states. We take 164Dy, for which NLD has been studied extensively by the Oslo method, as the first example. By comparison with known experimental discrete levels, we show that while the pronounced step-wise structure in the low-energy NLD curve can be understood as the collective excitation and nucleon-pair breaking, the exponential growth of levels in the higher-energy NLD is described by combination of the broken-pair states. We discuss the formation mechanism and characteristic features of NLD for different energy regimes. In addition, the parity dependence and angular-momentum-dependence in NLD are discussed with a strong emphasis of the structure effect.

Work is supported by the National Natural Science Foundation of China (Grant Nos. 12235003, 12275225, and U1932206).

ABSTRACT

A systematic study of Sr isotopes using the β-Oslo Method

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Our understanding of neutron-induced reactions on nuclei far from stability has far-reaching implications for cosmogenic nucleosynthesis and fundamental nuclear physics. Presently, direct measurement of the radiative-capture cross section is experimentally inaccessible for these short-lived nuclei; however, indirect methods such as the β-Oslo method enable the experimental constraint of key nuclear properties that are inputs for reaction-theory calculations. In particular, reaction rates on neutron-rich Sr isotopes directly influence astrophysical abundances through processes that produce the heaviest elements present in the universe. We have performed an experiment at CARIBU at ANL in order to determine the γ-ray strength function and nuclear level density for 93,94,95Sr isotopes. Low-energy Rb beams were transported to the Summing NaI(Tl) (SuN) detector where coincident β-γ events were measured. The γSF and NLD, properties extracted from the measured γ-ray spectra using the β-Oslo method, contribute the greatest uncertainty in Hauser-Feshbach calculations of neutron-capture reaction rates for short-lived neutron-rich nuclei. The experimental techniques and preliminary results of this work will be presented. Furthermore, the results of this work will shed light on nuclear structure properties for Sr isotopes, leading to significantly improved predictive reaction modeling.

This research was supported by LLNL Contract DE-AC52-07NA27344, MSU and FRIB and was funded in part by the NSF under Contracts No. PHY- 1102511 (NSCL), No. 1350234 (CAREER), No. 1430152 (JINA-CEE), and the National Nuclear Security Administration under Award No. DE-NA0000979.

ABSTRACT

Semi-microscopic approach to nucleon-nucleus inelastic scattering

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Developing a predictive capability for inelastic scattering will find applications in multiple areas. Charged-particle inelastic scattering is an experimental probe for excitation spectrum of the target nucleus. It can also be used as a surrogate for (n, γ) reactions to predict capture cross sections for unstable nuclei relevant to s-process. Experimental data for neutron-nucleus inelastic scattering is scarce and thus one needs a robust theoretical framework to complement it. Our work uses microscopic nuclear structure calculations to obtain nucleon-nucleus scattering potentials to calculate cross sections for these processes. We implement the Jeukenne, Lejeune, Mahaux (JLM) semi-microscopic folding approach, where the medium effects on nuclear interaction are parameterized in nuclear matter to obtain nucleon-nucleon interaction in a medium at positive energies. We solve the nuclear ground state using Hartree-Fock-Bogoliubov many-body method, and by approximating interaction between nucleons within a nucleus as Gogny-D1M potential. The vibrational excited states of the target nucleus are calculated using quasi-particle random phase approximation method. We will present our results for elastic and inelastic scattering cross sections for 90,92,94Zr nuclei.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52- 07NA27344, with partial support from LDRD project 20-ERD-030.

ABSTRACT

Electromagnetic dipole response studies at the southern tip of Africa

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The gamma-ray decay of nuclear states in the quasi-continuum provides important insights into nuclear structure effects and constraints to nucleosynthesis processes. In particular, measurements of Photon Strength Functions (PSFs) and associated resonances have and will continue to play a central role as we are entering an era of incredible potential for novel measurements. This is due to many institutes across the world having established programs to provide enhanced, state-of-the-art research infrastructure including iThemba LABS in South Africa. These range from significant increases in efficiencies of gamma-ray detector arrays, to new or upgraded radioactive ion beam facilities. In parallel, several new experimental and analytical techniques were developed which allow for more reliable PSF and NLD studies, even on nuclei away from stability. All this progress will undoubtedly lead to unprecedented insight into the structure of nuclei and provide reaction rates of relevance to nucleosynthesis processes. In this presentation, I will provide an overview of the recent experimental (inverse-Oslo method [1]) and analytical (Shape method [2]) advances and how these have laid the foundation for novel and ambitious measurements at radioactive and stable ion beam facilities. Recent progress in exploring the underlying nuclear structure of resonances with a particular focus on the Pygmy Dipole resonance will also be discussed. In addition, I will introduce the low-energy nuclear physics beam line at iThemba LABS' Tandetron laboratory and the measurements of PSFs in neutron deficient isotopes.

[1] V.W. Ingeberg et. al., Eur. Phys. J. A 56, 68 (2020).

[2] M. Wiedeking et. al., Phys. Rev. C 104 014311 (2021).

This work is supported by the National Research Foundation of South Africa under grant number 118840