A EuroGENESIS workshop

Open problems and future directions in heavy element nucleosynthesis

Debrecen, Hungary, 10 – 12 April 2013

Book of abstracts

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http://www.atomki.hu/heavyws

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Open problems and future directions in heavy element nucleosynthesis – Workshop program

10 April 2013 – Wednesday		
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10:35 – 11:00	*T. Fischer*	Nucleosynthesis-relevant conditions in simulations of the neutrino-driven wind form massive star explosions
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WORKSHOP ABSTRACTS

List of Presentations

Nucleosynthesis in core-collapse supernovae

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Elements between iron and silver are produced at the end of the life of massive stars when they explode as core-collapse supernovae and a neutrino-driven wind forms [1]. Heavier elements, like gold or uranium, can be synthesized only under extreme neutron-rich conditions and the search of their astrophysical site continues. We will discuss the production of heavy elements in supernovae jet-like explsoions [2] and neutron-star mergers [3] showing the impact of the nuclear physics input.

[1] A. Arcones & F.K. Thielemann, J. Phys. G **40** 1 (2013).
[2] C. Winteler et al., ApJL **750** L22 (2012).
[3] O. Korobkin, S. Rosswog, A. Arcones & C. Winteler, MNRAS **426** 2 (2012).

10th April, Wednesday, 10:10 – 10:35

The p-process nucleosynthesis in massive stars. Dependence on the stellar mass and on the SN explosion.

M. Pignatari

Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

One of the fundamental challenges of nuclear astrophysics is to reproduce the abundances of heavy proton-rich nuclei in the solar system distribution. The classic p-process or gamma-process from core collapse supernovae (CCSN) is the most accepted source for these species. However, the present limitations of such a scenario to fully reproduce the p-process abundances questioned the real efficiency of the classic p-process, and triggered the formation of alternative scenarios contributing to the solar inventory. In this presentation I aim to analyze the nucleosynthesis details of the classic p-process in massive stars. I will discuss its dependence on the initial mass of the star, and on the CCSN explosion energy. Finally, I will also discuss the dependence of the p-process yields on nuclear physics uncertainties, in particular for the $^{12}C+^{12}C$ reaction rate.

10th April, Wednesday, 10:35 – 11:00

Nucleosynthesis-relevant conditions in simulations of the neutrino-driven wind form massive star explosions

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The neutrino-driven wind from massive star explosions is a low-mass ($\sim 10^{-4}$ $M_\odot$ of total mass ejected) outflow driven off the central supernova remnant's surface via continuous neutrino heating. It develops on a timescale between 10–30 seconds after the supernova explosion has been launched. It has long been considered as the main astrophysical site for the synthesis of heavy elements beyond iron, in particular neutron-rich nuclei. Relevant for any possible nucleosynthesis is detailed information about the evolution of temperature, and density, as well as the proton-to-baryon ratio during the time of mass ejection. The latter property of matter is given by the electron fraction, which is determined from the electron neutrino and antineutrino spectra and luminosities as they decouple form matter at the surface of the central supernova remnant (proto)neutron star. It determines sensitively the nucleosynthesis path, either at the proton- or neutron-rich side along the chart of nuclei building up heavier and heavier nuclei during the expansion. Generally proton-rich conditions have been explored as a site for the νp process with a sharp cut of the abundances at mass number $A \simeq 90$, where heavier nuclei cannot be produced. In neutron-rich conditions, the r process can be expected. Recent supernova simulations that include accurate three-flavor Boltzmann neutrino transport have shown that matter is slightly neutron rich during the early mass ejection in the neutrino-driven wind, allowing for the production of light r-process nuclei up to charge number $Z \simeq 50$. It remains to be shown weather the later mass ejecta may become proton rich.

10$^{\text{th}}$ April, Wednesday, 11:40 – 12:05

p-process in SNIa with multi-D models: their role in Galactic chemical evolution

C. Travaglio

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We explore the SNIa as p-process sources in the framework of two-dimensional SNIa models calculated at MPA Munich, using enhanced s-seed distributions as directly obtained from a sequence of thermal pulse instabilities. We apply the tracer-particle method to reconstruct the nucleosynthesis by the thermal histories of Lagrangian particles, passively advected in the hydrodynamic calculations. For each particle we follow the explosive nucleosynthesis with a detailed nuclear reaction network for all isotopes up to ^{209}Bi. The SNIa WD precursor is assumed to have reached the Chandrasekhar mass limit in a binary system by mass accretion from a giant/main sequence companion. We select tracers within the typical temperature range for p-process production, (1.5 - 3.7)$\cdot 10^9$ K, and analyse in detail their behaviour, exploring the influence of different s-process distributions on the p-process nucleosynthesis. We find that SNIa produce a large amount of p-nuclei, both the light p-nuclei and the heavy-p nuclei at a quite flat average production factors. For the first time, the very abundant Ru and Mo p-isotopes are reproduced at the same level than the heavy p-nuclei. Warning on nuclear uncertainties of photodisintegration on ^{94}Mo will be discussed.
We present a detailed investigation of the metallicity effect on p-process production in SNIa. Starting with s-process distribution at different metallicities, running SNIa two-dimensional models, and using a chemical evolution code (well tested over the years to study chemical evolution of heavy elements) we give estimates of SNIa contribution to the solar p-process composition. We find that SNIa contribute for at least 50% at the solar p-nuclei composition, in a primary way.
We also present for the first time preliminar investigation of p-process nucleosynthesis in new 3D models of SNIa recently presented by Seitenzahl et al. (2013) and compare with previous calculations done with nucleosynthesis in 2D SNIa presented by Travaglio et al. (2011).

Solving the Eu s-correlation problem in CEMP stars by using correctly defined stellar reaction rates

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Unexpectedly high Eu abundances in metal-poor stars have been a longstanding puzzle not explicable by standard nucleosynthesis models. Although Eu is thought to be mainly produced in the r-process, abundances in carbon-rich, extremely metal-poor (CEMP) stars show correlations of the Eu abundances with s-process elements (see, e.g., [1,2,3]). As regular s-process models were not able to produce sufficient amounts of Eu to explain the data, ad hoc explanations were invoked, such as contamination from a companion star or a new neutron-capture process in between the s- and the r-process [4].
New presolar grain data also show enhanced ^{151}Eu contributions which cannot be reproduced with stellar s-process models [5,6], especially not when using most recent, highly precise experimental neutron capture cross sections, e.g., from [6]. It has recently been pointed out, however, that the *stellar* neutron capture rates of heavy nuclei are less constrained than would be expected from the experimental data [6]. Furthermore, it has been realized that using the stellar enhancement factor (SEF) to derive the stellar rate from an experimental rate is not appropriate [7,8].
Using the correct procedure from [7] for obtaining the stellar rate and its uncertainty for the crucial reaction ^{151}Sm(n,γ) leads to predicted Eu s-process contributions consistent with measured abundances, without the need to modify stellar models or to invoke additional processes [5]. The result underlines the importance of a correct treatment of stellar reaction rates and their uncertainties. It is also conjectured that further problems in modelling s-abundances, especially in the rare-earth region, may also be rooted in inappropriately derived stellar rates and their uncertainties from experiment.

[1] K. Jonsell et al., Ap. J. **451**, 651 (2006).
[2] W. Aoki et al., Ap. J. Lett. **536**, L97 (2000)
[3] W. Aoki et al., Ap. J. Lett. **592**, L67 (2003).
[4] M. Lugaro, A. Karakas, R. Stancliffe, C. Rijs, Ap. J. **747**, 2 (2012).
[5] J. N. Ávila et al., Ap. J. Lett., submitted (2013).
[6] S. Marrone et al., Phys. Rev. C **73**, 034604 (2006).
[7] T. Rauscher, Ap. J. Lett. **755**, L10 (2012).
[8] T. Rauscher et al., Ap. J. **738**, 143 (2011).

The ^{13}C-pocket formation: a physical model for low-mass AGB stars.

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About half of elements heavier than iron are produced through the so-called s process, which involves a series of subsequent neutron captures and beta-decays; its main component (s-nuclei from Sr to Pb) is produced in AGB stars [1,2] with mass lower than 3 $M_\odot$. Most of the neutrons needed are generated by the $^{13}C(\alpha,n)^{16}O$ reaction in radiative conditions during the quiet phases between two subsequent thermal instabilities from the He shell. A second neutron source, the $^{22}Ne(\alpha,n)^{25}Mg$ reaction, is activated marginally during the thermal pulses: see [3] for a review.
In the above scenario, the main open problem is that of finding the physical mechanism that allows the formation of the ^{13}C reservoir (or pocket). The standard idea [4] is that a small amounts of protons is injected into the He-rich region below the envelope at each convective dredge-up, and is subsequently captured by the abundant ^{12}C. In most evolutionary codes this penetration is treated as a free parameter and only recently a more quantitative approach was introduced by [5]. They assume that convective velocities at the envelope border do not drop abruptly to zero, but decrease exponentially. This yields a layer of partial proton-mixing of typically $(0.5 - 1)\times10^{-3}$ $M_\odot$.
Recent spectroscopy of young open cluster [6,7] showed enhancements of s-element abundances with respect to the Sun, suggesting the emerging at late Galactic times of a more effective s-process production. This possibility requires that proton penetration driven by extra-mixing phenomena be deeper than previously assumed (one needs larger polluted masses, not more protons per unit mass, as this would lead the CN cycle to equilibrium, producing only ^{14}N, which is a neutron *poison*, not a neutron *producer*. The ^{13}C-enriched buffer must therefore become deeper, observations suggesting an extension by a factor of four [7]. A more effective neutron source would increase the efficiency of s-processing and limiting this effect to late stages of Galactic evolution seems to require that the extension affects very low mass stars only ($M <$ 1.5 $M_\odot$). This is in line with the knowledge that for these masses all extra-mixing mechanisms are very strong.
In this context, we suggested that buoyant magnetic structures can promote extra-mixing phenomena, and tried to model magnetic effects on first principles. This should also control the formation of the ^{13}C reservoir. Our new approach starts from the generation and buoyancy of toroidal magnetic flux tubes in a stellar dynamo process, as expected in a differentially-rotating layer sitting above a rigidly-rotating degenerate core. The ensuing partially-mixed region would cover essentially the whole He-rich buffer above the He-shell. A recent paper [8] showed that buoyant toroidal magnetic structures offer an exact solution to MHD equations in presence of hydrodynamical drag and imply rapid transport of matter in the radiative layers with a subsequent deposition of the material into the envelope; this provides an ideal scheme for creating a partially mixed zone, as proton penetration from the envelope follows for mass

conservation [9]. The ensuing profile of the proton-rich pocket is rather complex, but can be vary well approximated by an exponential function, as in most parameterized approaches.
On the above grounds we computed the ^{13}C profile (which is now self-consistent for magnetized plasma) and we compare the resulting s-processing distributions with s-element observations in the Sun and in stars. We find that s-only elements in the Sun care reproduced extremely well by our model, with an abundance spread of only 3 - 4% around the average, smaller than in any previous stellar model for the main component [10,11]. Using our physically-justified ^{13}C-profile, the isotopic abundances of elements near important branchings of the s-process path are discussed.

[1] R. Gallino et al., ApJ **497**, 388 (1998).
[2] M. Busso et al., ApJ**557**, 802 (2001).
[3] F. Käppeler et al., Rev. Mod. Phys. **83**, 157 (2011).
[4] C. Travaglio et al., ApJ **521**, 691 (1999).
[5] S. Cristallo et al., ApJ **696**, 797 (2009).
[6] E. Maiorca et al., ApJ **736**, 120 (2011).
[7] E. Maiorca et al., ApJ **747**, 53 (2012).
[8] M.C, Nucci et al., ApJ submitted (2013).
[9] M. Busso et al., PoS NIC XII (2012).
[10] C. Arlandini et al., ApJ **525**, 886 (1999).
[11] S. Bisterzo et al., MNRAS **404**, 1529 (2010).

10th April, Wednesday, 14:30 – 14:55

Direct measurements of reactions for p-process nucleosynthesis

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Almost all of the heavy elements are produced via neutron-induced processes in a multitude of stellar production sites. The remaining minor part is produced via γ- and proton-induced reactions. The predictive power of the underlying stellar models is currently limited because they contain poorly constrained physics components such as convection, rotation or magnetic fields. An important tool determine such components is the comparison of observed with modeled abundance distributions based on improved nuclear physics input.
The FRANZ facility at the Goethe University Frankfurt, which is currently under construction will provide unprecedented neutron fluxes and proton currents available for nuclear astrophysics. It will be possible to investigate proton- and neutron-induced reactions important for p-process nucleosynthesis.
At the GSI close to Darmstadt radioactive isotopes can be investigated in inverse kinematics. This allows experiments such as proton-induced cross section measurements using a heavy-ion storage ring or γ-induced reaction measurements using the Coulomb dissociation method. The future FAIR facility will allow similar experiments on short-lived nuclei, since orders of magnitude higher radioactive ion beams will be possible.

Kocaeli University Experimental Nuclear Physics Group (KENP) and Activation experiments related to the nucleosynthesis of p-nuclei

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Kocaeli University (KOU) Experimental Nuclear Physics Group (KENP) researches concentrate on Experimental Nuclear Astrophysics and environmental/industrial radioactivity measurements. A pioneering focus has been determining the reaction cross section measurements related to p-process via activation method at low energies (2-20 MeV). These measurements are carried out at abroad facilities such as Notre Dame University (USA) and ATOMKI (Hungary). For improved modeling for p-process, the relevant astrophysical reaction rates derived from reaction cross sections are necessary inputs. Almost all of these rates have to be determined theoretically by statistical Hauser-Feshbach predictions. Since not only the experimental data for charged-particle induced reaction cross sections especially on heavier p-process nuclei are nearly absent, but also p-process nucleosynthesis have problems in the mass regions $A<124$ and $150<A<165$, the systematic p and α capture reaction measurements have been started by Kocaeli University. Activation experiments are a perfect experimental method in systematic studies for selected isotopes due to their high sensitivity and selectivity. For testing the theoretical predictions, the obtained results will be compared with the Hauser-Feshbach statistical model calculations.
In this talk, the status of activation measurements, advantages and restrictions, and future projects will be discussed.

Supported by KOU-BAP, TUBITAK 108T508 and EUROGENESIS 109T585 projects

10th April, Wednesday, 15:20 – 15:45

Experimental Setups at IFIN-HH dedicated to reaction studies

D. Filipescu[1], T. Glodariu[1], I. Gheorghe[1], A. Negret[1]

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Absolute cross section measurements of alpha and proton induced reactions relevant for the nucleosynthetic *p*-process mechanism have been performed by the gamma spectroscopy group at the Bucharest TANDEM Accelerator of IFIN-HH using the activation technique [1-2].

In the same department, a major HPGe detector array RoSphere, was commissioned last year as a replacement of the previous smaller array. In beam cross section measurements have been recently performed using the new detection array, dedicated mainly to high-resolution gamma-ray spectroscopy experiments.

RoSphere array can accommodate up to 25 Compton suppressed HP Ge detectors each having a relative efficiency of 55%, which are already available. The detector arrangement has a flexible design, thus HP Ge detectors together with anti-Compton shields may be replaced by Low Energy Photon Spectrometers (LEPS), Lanthanum Bromide scintillators or neutron detectors. Beside a simple reaction chamber, a Plunger chamber is also available.

Nevertheless, a new setup dedicated to nuclear reaction mechanisms studies is currently under development. It will accommodate a large annular silicon strip telescope for particle detection and several small silicon telescopes placed at variable angles.

Details of experimental setups and an overview of past and future experiments that may be performed will be presented.

[1] I. Căta-Danil et al., "Astrophysical S factor for capture on ^{117}Sn",Phys. Rev. **C78** (2008) 035803.
[2] D. Filipescu et al., "Cross sections for -particle induced reactions on ^{115,116}Sn around the Coulomb barrier", Phys. Rev. **C83** (2011) 064609

10th April, Wednesday, 15:45 – 16:10

In-beam experiments on reactions relevant for the nucleosynthesis of the *p* nuclei

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Hauser-Feshbach calculations are essential to understand the different nucleosynthesis processes that contribute to the production of p nuclei. While the Hauser-Feshbach theory is well established, major uncertainties stem from the various nuclear models entering the calculation. These nuclear models include, besides others, descriptions of nuclear-level densities, γ-ray strength functions, and optical-model potentials.
In-beam experiments provide several experimental measurement parameters which allow constraining this nuclear physics input. Beside the determination of the total cross sections, partial cross sections can be determined using the in-beam technique. In this contribution, the sensitivity of this technique is presented via the experimental results for the reaction ^{74}Ge(p,γ)^{75}As. This reaction was measured at the National Research Center Demokritos in Athens. Last year this experimental method was established at the Institute for Nuclear Physics in Cologne as well. Our preliminary results on ^{89}Y(p,γ)^{90}Zr and ^{148}Sm(α,γ)^{152}Gd will be presented.

Supported by the Deutsche Forschungsgemeinschaft under contract DFG (ZI 510/5-1).

10th April, Wednesday, 16:40 – 17:05

Activation measurements of (p,n) reaction cross sections at low energies

D. Galaviz[1], A. Henriques[1], I. Marroquín[2], J. Cruz[1,3], M. Fonseca[1,3], L. M. Fraile[2], E. Herranz[2], A. P. Jesus[1,3], H. Luis[1,3], J. Machado[1], A. Maira[4], A. Muñoz-Martín[4], B. Olaizola[2], P. Reis[1], P. Teubig[1], J. M. Udías[2], P. Velho[1], M. Zarza[1]

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The stellar enhancement factor, a quantity that measures the influence of excited states to the reaction rate compared to the ground state as a function of temperature, is suppressed in some reverse channel processes of reactions involving one neutral particle, like (p,n) reactions [1]. In these reactions, the reaction rate at the laboratory and under astrophysical conditions are believed to be the same, and therefore the information obtained on the nuclear properties of the process can be extrapolated to the high temperature environment considered.
We have started a series of experiments to determine the cross section of (p, n) reactions on heavy elements (similar to those identified in [1]) at energies close to the reaction threshold using the activation technique. Owing to the relatively short half-lives of the reaction products and the reduced gamma branching ratios an online measurement procedure has been put into operation. We have taken advantage of Proton Induced Gamma Emission (PIGE) setups at the ITN laboratory [2] in Lisbon, Portugal, and at the CMAM laboratory [3] in Madrid, Spain, to perform gamma spectrosscopy measurements with a HPGe in a close geometry with thin reaction targets. A careful monitoring of the proton beam current has been performed during the irradiation.
In this paper preliminary results of the first measurements performed on the reactions ^{104}Ru(p,n)^{104}Rh, ^{122}Te(p,n)^{122}I and ^{128}Te(p,n)^{128}I will be presented, together with the predictions of global models.

[1] G. G. Kiss *et al.*, Phys. Rev. Lett. **101**, 191101 (2008)
[2] http://www.itn.pt/
[3] http://www.cmam.uam.es/

^{92,93,94,100}Mo(γ,n) measured by Coulomb Dissociation

Kathrin Göbel[1], Olga Ershova[1,2], René Reifarth[1], Kerstin Sonnabend[1] and the s295 collaboration

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Most of the p-nuclei between ^{74}Se and ^{196}Hg are produced under explosive conditions in a sequence of photo dissociations and β-decays. ^{92,94}Mo and ^{96,98}Ru are the most abundant, but not sufficiently explained p-nuclei. In order to study the production of *p*-nuclei in this region, the experimental validation of the involved reaction rates predicted by statistical model calculations is highly desired.

Most nuclei involved in photo dissociation reactions in stellar nucleosynthesis networks are unstable and cannot be prepared as a target for experiments using real photons. One solution is to study the (γ,n) reaction in inverse kinematics: The nucleus under investigation hits a high-Z target, where in a peripheral collision it interacts with a virtual photon of the time-varying Coulomb field.

The reactions ^{92,93,94,100}Mo(γ,n) have been measured by Coulomb Dissociation at the LAND/R^{3}B setup at GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany. The results for ^{92}Mo(γ,n) and ^{100}Mo(γ,n) are in good agreement with measurements with real photons. The result of ^{93}Mo(γ,n) is especially important, since this isotope is unstable and the corresponding cross section has not been measured before.

According to recent stellar model calculations, ^{94}Mo is mainly synthesized via the (γ,n) photo disintegration chain starting from the more neutron-rich, stable Mo isotopes. The most important reaction determining the production ratio of ^{92}Mo to ^{94}Mo is ^{94}Mo(γ,n). The analysis of ^{94}Mo(γ,n)^{93}Mo will complete the analysis of this series of measurements, hence complete the experimental data base for the (γ,n) production chain of the p-isotopes of Mo.

(α, γ) reactions for p-process study in the rare-earth region investigated by accelerator mass spectrometry

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p-process nuclei are produced in major part via a sequence of photonuclear reactions ((γ,n), (γ,p) and (γ, α) reactions) in explosive sites (T $\approx$ 2-3 GK) starting from heavy seed nuclei. Their study in the laboratory is demanding due to the need of intense gamma sources in the corresponding energy range. Investigation of the inverse (α, γ) reactions [1] are useful in this context to extract experimentally nuclear parameters such as the gamma strength function and the alpha-nucleus potential [2], relevant to theoretical Hauser-Feschbach calculations. The reactions also provide information on the effects of Coulomb excitation possibly competing with compound-nucleus formation [3]. We are applying the method of accelerator mass spectrometry (AMS) to complement the study of (α, γ) reactions by activation via direct detection of long-lived p-process nuclides produced in the rare-earth region. The case of the 142Nd(α, γ)146Sm ($t_{1/2} = 68$ My) reaction is presently investigated, using the AMS technique developed at Argonne National Laboratory for the detection of ^{146}Sm [4]. In a preliminary study, enriched ^{142}Nd and ^{nat}Nd targets were irradiated with an alpha-particle beam (13.5 MeV) at ATOMKI to study both the ^{142}Nd$(\alpha, \gamma)^{146}$Sm and the parasitic ^{143}Nd$(\alpha$,n$)^{146}$Sm reactions. After the alpha irradiation, the targets are chemically processed to extract ^{146}Sm together with a ^{nat}Sm carrier (2-5 mg) and to separate Sm from residual ^{146}Nd stable isobaric contaminant. The AMS measurement of the isotopic ratio ^{146}Sm/Sm in the separated Sm fraction provides a direct determination of the (α, γ) cross section via the number of ^{146}Sm nuclei produced in the irradiation. In our setup, highly-charged positive ^{146}Sm ions (q $\sim 22^+$) are accelerated to a final energy of $\sim$ 8 MeV/u, necessary to completely separate contaminant ions in a gas-filled magnetic spectrograph [5]. The experiment is planned to take advantage of the newly-developed laser-ablation feeding technique [6] into the Electron Cyclotron Resonance ion source at the Argonne ATLAS facility and will use the new Radio Frequency Quadrupole accelerator section as injector [7]. The current status of the experiment will be presented.
This work is supported by the U.S. Department of Energy, Office of Nuclear Physics, under contract no. DE-AC02-06CH11357.

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[6] R. Pardo et al., Nucl. Instr. Meth. B **294**, 281 (2013).
[7] P. Ostroumov et al., Phys. Rev. ST **15**, 110101 (2012).

Experimental check of Coulomb dissociation method for neutron capture measurements

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Application of electromagnetic breakup reactions in nuclear astrophysics for determination of cross sections involving unstable isotopes relies on a perturbation theory that needs experimental justification. A comparison of directly-measured cross sections for the ^{7}Li(n,γ)^{8}Li reaction with cross sections obtained by its inverse, the Coulomb breakup of ^{8}Li by Pb into ^{7}Li+n can provide such a basis for testing that justification.
We present the data on the breakup excitation functions of 70 MeV/nucleon ^{8}Li beam on lead and carbon targets and compare it with 3 previous direct experiment in the energy range of 30 keV - 1 MeV. We include the question of how to use virtual photons, nuclear subtraction and the detailed balance theorem. The comparison agreed to within the experimental errors. We point out the possible limits of use this method for nuclei having low energy excited states or for cases at the low beam energy.

11th April, Thursday, 9:00 – 10:00

Experimental challenge for heavy element synthesis at new-generation RIB facilities

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New generation RIB facilities in operation or under construction are expected to provide new opportunities for experimental challenge to investigate heavy element synthesis. The talk will include new results from RIKEN RI Beam Factory, which started operation in 2007. Various possibilities to attack problems regarding explosive nucleosynthesis will also be discussed.

Transmission coefficients for α-nucleus scattering in the astrophysical regime

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Nuclear reactions involving α-particles play an important role in nucleosynthesis. An important ingredient for corresponding reaction calculations are α-nucleus optical potentials, which are frequently obtained from elastic scattering data. However, at astrophysically relevant energies the α-nucleus optical potentials are not well known for medium to heavy mass nuclei because of the suppression of elastic scattering by the Coulomb barrier. This is especially true for the imaginary part of the optical potential which determines the transmission coefficients entering statistical model calculations.
In this contribution we present a calculation of α-nucleus optical potentials based on a coupled-channel approach [1]. The direct part of the α-nucleus optical potential is calculated within a folding model. For the calculation of the polarization potential we describe the target nucleus as a deformable object and account explicitly for the coupling to rotational and vibrational excitations of the target. In order to determine the coupling terms we make use of available level schemes as well as of information on the deformation and the vibration frequency, respectively. The obtained potential is energy-dependent and highly non-local. In order to avoid uncertainties due to localization procedures we directly evaluate the transmission coefficients for α-nucleus scattering which represent the required scattering input in statistical model calculations. The method is used to provide the transmission coefficients of α-nucleus scattering for a series of nuclei.
Work supported by Fonds zur Förderung der wissenschaftlichen Forschung (FWF) Österreich, project number I 426-N16.

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Nuclear structure approach to alpha-nucleus optical potentials at low energies

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A major scope of nuclear astrophysics is the description of the abundances of nuclei, which implies a proper knowledge of the process of nucleosynthesis. Among the relevant nuclear reactions for nucleosynthesis those involving α-particles play an important role, e.g. in the nucleosynthesis of p-nuclei or as neutron sources. The determination of these nuclear reaction cross sections relies strongly on the knowledge of the α-nucleus optical potential, which is usually extracted phenomenologically from elastic scattering data. Unfortunately, α-optical potential for medium and heavy mass nuclei are not well known at low energies because the elastic cross section is suppressed by the Coulomb barrier thus inhibiting the extraction of optical potentials. Therefore phenomenological optical potentials at astrophysically relevant energies are obtained by extrapolation from high energy data which leads to uncontrollable errors in the potential. The situation is even more intriguing because nucleosynthesis reaction networks involve isotopes off the stability line which are frequently not accessible in experiment. In this contribution we revive the so-called nuclear structure approach [1-3] of α-nucleus optical potentials. The method assumes a structureless and non-excitable α-particle and accounts explicitly for the coupling to the collective states of the target which are described by RPA. Thus the method is mainly applicable for target nuclei in the vicinity of magic numbers. The basic idea of the approach and the most important relations are presented. The method is numerically implemented and a calculation of the imaginary α-^{40}Ca optical potential is performed at several energies. The real part of the optical potential is determined via a dispersion relation. The obtained potential is compared with previous calculations. Furthermore elastic differential cross sections are calculated.
Work supported by Fonds zur Förderung der wissenschaftlichen Forschung (FWF) Österreich, project number I 426-N16.

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Elastic alpha scattering experiment on ^{64}Zn

M.P. Takács[1], A. Ornelas[2], Gy. Gyürky[1], Zs. Fülöp[1], G. Kiss[1], Z. Halász[1], T. Szücs[1], E. Somorjai[1], D. Galaviz[2], P. Mohr[1,3], R.T. Güray[4], Z. Korkulu[4], N. Özkan[4], C. Yalçın[4]

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Low energy alpha-nucleus optical potentials are an important ingredient of reaction cross section calculations relevant in various processes of heavy element nucleosynthesis, such as the astrophysical γ-process. The optical potential can be studied directly by high precision alpha elastic scattering experiments. In the Institute for Nuclear Research (Atomki) a systematic study of the optical potential has been carried in the last 15 years. One of the last studied isotope was the ^{64}Zn, where complete angular distributions were measured at two energies close above the Coulomb barrier. Through the example of this study, the experimental techniques needed for a precise alpha elastic scattering measurement will be presented.

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Elastic α scattering and the Family Problem on ^{64}Zn and ^{106}Cd

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The p-nuclei are a particular set of 35 stable nuclei heavier than iron located at the proton-rich side of the valley of β-stability. These are thought to be considerably produced by a series of photodisintegration reactions from neutron rich isotopes, previously produced by neutron capture processes. The process of creating these p-nuclei, the so-called γ-process is believed to occur e.g. in the O/Ne layers of Type II Supernovae at temperatures of a few GK [1,2].
In order to run a γ-process network calculation, the p-nuclei abundances and the rates of reactions involved have to be known. However, the α-nucleus optical potential is one of the most uncertain parameters [3] of the theoretical reaction rate calculation. As such, the experimental study of the low energy α-nucleus optical potential is of crucial importance.
In this work we present the results from the analysis of the experimentally measured angular distributions of the reactions ^{64}Zn(α, α)^{64}Zn and ^{106}Cd(α, α)^{106}Cd at energies above and below the Coulomb barrier. The difficulties that arise in the study of the α-nuclear potential and the so-called Family Problem are also addressed in this work.

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Suggestion for a new global α-nucleus potential

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The prediction of cross sections of α-induced reactions for heavy target nuclei at astrophysically relevant energies has turned out to be very difficult. In the analysis of the pioneering experiment on the ^{144}Sm(α,γ)^{148}Gd reaction [1] and also for subsequent experiments it was found that theoretical predictions often overestimate the experimental data significantly. This is an essential problem for calculations of p-process nucleosynthesis where the relevant (γ,α) photodisintegration reaction rates are usually derived from the cross sections of the inverse (α,γ) capture reactions.
The cross sections of α-induced reactions depend sensitively on the α-nucleus potential. Starting with ^{144}Sm(α,α)^{144}Sm [2], a series of elastic scattering experiments has been performed at ATOMKI over the last 15 years. A consistent analysis of all experimental data has been performed, and a simple global α-nucleus potential with few parameters was derived which is able to reproduce the experimental total reaction cross sections down to the astrophysically relevant energy region [3].
First applications of the new potential are the analysis of low-energy activation data for ^{64}Zn and data for the ^{141}Pr(α,n)^{144}Pm and ^{143}Nd(n,α)^{140}Ce reactions. For ^{64}Zn it could be shown for the first time that the sum of reaction cross sections from activation is identical to the total reaction cross section derived from elastic scattering by $\sigma_{\rm reac} = (\pi/k^2) \sum_L (2L+1)\,(1-\eta_L^2)$ [4]. For the latter two reactions elastic scattering angular distributions [5] were analyzed to derive the α-nucleus potential and to predict recent experimental data [6,7,8]. It was found that the new potential with few adjustable parameters is able to reproduce the experimental data down to low energies below the Coulomb barrier in the α channel [9].
Limitations and possible improvements of this first version ATOMKI-V1 of the new global potential will be discussed, and a comparison to widely used global potentials [10,11,12] will be given.

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11th April, Thursday, 12:25 – 12:50

p-process xenon isotope anomalies in stardust grains from meteorites

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In measurements on “bulk” samples of meteorites isotopic variations due to the p-process usually have taken a backseat compared to such in s- or r-isotopes, and, in the best case, can be qualitatively attributed to the p-process, with little to no inferences concerning detailed isotopic yields. The situation is different for grains of stardust that survived in primitive meteorites. In fact, isotopically strange xenon was the key feature that led to the first identification of a stardust mineral, nanodiamonds containing xenon with overabundances of up to a factor of ∼2 in both the r-only (≡ H-Xe) and p-only (≡ L-Xe) isotopes.
Relative excesses of the two r-only isotopes (^{134}Xe, ^{136}Xe) as well as of the two p-only isotopes (^{124}Xe, ^{126}Xe) are not equal, hence the processes responsible for HL-xenon must differ from the “average” r- and p-processes as reflected in solar system abundances. However, while considerable effort has been put into explaining H-Xe [1-4], there has been little work on the p-side (L-Xe). Relying on scarce nuclear data, Heymann and Dziczkaniec have studied photodisintegration reactions of Xe and Ba seeds in intermediate zones of supernovae and found that the relative production of the p-Xe isotopes depends sensitively on the yield of the (γ, α) reaction on ^{128}Ba [5]. Another suggestion - applicable to both the r- and p-anomalies in diamond xenon - is that of a “rapid separation” between stable Xe isotopes and radioactive precursors produced in the “standard” p- (as well as r-) process [3]. For the p-isotopes to work, this would require the bulk (87 %) of ^{126}Xe to be produced via the ^{126}Ba precursor, with a half live of ∼ 100 minutes, in order to explain the high ^{124}Xe/^{126}Xe.
In contrast to diamond xenon, xenon in silicon carbide contains - besides the component from the s-process in their parent AGB stars - “almost normal” Xe, with indications for ^{124}Xe/^{126}Xe being few (∼ 8) % lower [6] than in solar Xe [7].

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11^{th} April, Thursday, 14:30 – 15:30

Adventures on the proton-rich side of stability

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There are a number of nuclear reaction processes that involve, synthesise and influence isotopes on the proton-rich side of stability. Consequently, a variety of experimental techniques are needed to study the key reaction cross sections. This talk will discuss some of the techniques exploited, their advantages and limitations, with an emphasis on inverse kinematics. Examples from the γ-process, αp-process and HCNO cycle will be outlined.

Radioactive waste to probe core collapse supernovae

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Supernovae are a key site for heavy element synthesis. Despite much recent progress, significant uncertainty remains concerning the underlying mechanism that allows a collapsing massive star to successfully explode. A satellite based gamma-ray observation of the isotope ^{44}Ti may hold the key to resolving this problem, as the amount ejected is thought to depend on the explosion mechanism. However, to allow such a deduction, the key ^{44}Ti(α,p)^{47}V reaction rate must be better known.
A direct measurement of this reaction has recently been performed at the ISOLDE factility at energies within the Gamow window of core collapse supernovae, employing a beam of ^{44}Ti derived from highly irradiated components of the SINQ spallation neutrons source of the Paul Sherrer Institute. Impinged on a helium-filled cell, protons were detected in segmented silicon detectors. Details of the experimental preparations and set up and provisional results will be presented.

Is it possible to study the ^{44}Ti(α,p)^{47}V reaction with a radioactive target?

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The radioactive nuclide ^{44}Ti is believed to be produced in the α-rich freezeout preceding supernova explosions. The γ-lines from its decay have been observed in space-based γ-observatories for the Cassiopeia A supernova remnant. The rates of the nuclear reactions governing the production and destruction of ^{44}Ti should therefore be known with precision. The ^{44}Ti(α,p)^{47}V cross section has so far been studied only in inverse kinematics, with radioactive ^{44}Ti beams. These data do not reach the astrophysically relevant energies. A feasibility study is currently underway to determine whether the reaction can also be studied in direct kinematics, using a ^{44}Ti target, an α particle beam and particle detectors. Preliminary results and an outlook will be given.

CANCELLED

Precise study of the supernova reaction ^{40}Ca(α,γ)^{44}Ti by activation and in-beam γ-spectroscopy

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The radioactive nuclide ^{44}Ti is believed to be produced in the α-rich freezeout preceding supernova explosions. The γ-rays from its decay have been observed in space-based γ-observatories for the Cassiopeia A and very recently also SN 1987A supernova remnants [1]. The rates of the nuclear reactions governing the production and destruction of ^{44}Ti should therefore be known with high precision [2].
Over the last years there have been various studies of the ^{40}Ca(α,γ)^{44}Ti reaction, which is dominating the ^{44}Ti production in supernovae. Those studies have been performed using in-beam γ-spectroscopy, activation, accelerator mass spectrometry (AMS), and recoil mass spectrometry via inverse kinematics. However, there are still discrepancies in the resulting reaction rates.
Using an α-beam of 1-2 μA intensity the strengths of the strongest ^{40}Ca(α,γ)^{44}Ti resonances from 3.5 to 4.5 MeV laboratory α-energy have been studied by in-beam γ-counting and activation. The samples have been analyzed in the ultra-low-background underground γ-counting facility "Felsenkeller Dresden". The target stoichiometry has been determined by nuclear reactions and by elastic recoil detection analysis (ERDA). An AMS measurement of the activated samples is in preparation.

[1] S. A. Grebenev, A. A. Lutovinov, S. S. Tsygankov, C. Winkler, Nature 490, 373-375 (2012);
[2] L.-S. The, D. D. Clayton, R. Diehl et al., Astron. Astrophys. 450, 1037 (2006).

11th April, Thursday, 16:50 – 17:15

The LUNA-MV project

F. Cavanna[1] on behalf the LUNA collaboration[2]

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Knowledge of the reaction cross section at stellar energies lies at the heart of nuclear astrophysics. At these energies, the cross section are extremely small. Such smallness makes the star lifetime of the length we observe, but it also makes impossible the direct measurement in the laboratory. The rate of the reactions, characterized by a typical energy release of a few megaelectronvolts, down to a few events per year, is not high enough to stand out from the background. The Laboratory for Underground Nuclear Astrophysics (LUNA), located in the Gran Sasso National Laboratory, began 20 years ago to run nuclear physics experiments in an extremely low-background environment (see [1] and [2]). Several cross sections have been measured in the past down to the energies of astrophysical interest; the work is still in progress with the study of the reactions: ^{22}Ne(p,γ)^{23}Na and the ^{17}O(p,α)^{14}N.
Based on this fruitful experience, the LUNA Collaboration has proposed a new step forward, based on a higher energy machine able to open the experimental study of nuclear processes beyond the hydrogen burning phase. In this view, a research program aimed to study reactions such as the ^{12}C(α,γ)^{16}O, the ^{13}C(α,n)^{16}O, the ^{22}Ne(α,n)^{25}Mg, and several (α,γ) reactions having deep consequences in several topics of nuclear astrophysics as nucleo-synthesis, stellar evolution, supernova mechanism has been submitted to the LNGS Scientific Committee. The LUNA-MV project has been approved and it has started at the end of the year 2012, thanks to a special grant of the Italian Ministry of Research. The works to prepare the new laboratory and to purchase a new 3.5 MV ion accelerator have already started.
All the details on the scientific program, the characteristics of the new facility and the status of advancement will be given in the talk.

[1] C. Broggini, D. Bemmerer, A. Guglielmetti, and R. Menegazzo, Annu. Rev. Nucl. Part. Sci. **60**:53,73 (2010)
[2] H Costantini, et al., Reports on Progress in Physics **72** (2009) p.086301

12th April, Friday, 9:30 – 9:55

Measurement of very neutron-rich r-process nuclei with the BELEN setup

Iris Dillmann[1] and the BELEN collaboration

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Very neutron-rich nuclei can emit neutrons after β^--decay when their reaction Q-value is larger than the (one/two/three) neutron separation energy. This decay mode is called β-delayed (one/two/three)-neutron emission and was discovered in 1939 by Roberts et al. [1], shortly after the discoveries of fission by Meitner, Hahn, and Strassmann in 1938, and the neutron by Chadwick in 1932. Delayed in this context means, that the neutron is emitted with the β-decay half-life of the precursor ^{A}Z, ranging from few milliseconds for the most neutron-rich isotopes up to 55.65 s for the (up to now) longest-lived βn-precursor ^{87}Br. These delayed neutrons have to be distinguished from the prompt neutrons evaporated immediately (in the order of 10^{-14} s) after a fission event from a neutron-rich nucleus.
βn measurements are commonly carried out since many decades, especially for fission fragments. With present and future nuclear physics facilities more and more neutron-rich isotopes outside the fission region become accessible which can also emit multiple neutrons. This exotic decay mode is of special interest for the astrophysical rapid neutron capture process (r process) since it leads to a deviation of the reaction flow to lower mass chains during the freeze-out phase. The exact knowledge of the beta-delayed neutron emission probability (P_n) is required to interpret the observed solar abundance peaks and draw conclusions from this about the participating r-process progenitor isotopes and their contributions.
The BELEN (BEta-deLayEd Neutron) detector [3] with its state-of-the-art digital electronics is one of the most powerful setups for the measurement of β-delayed neutrons in the world. Its present version consists of 48 ^{3}He-filled long counters and achieves – depending on the design – a neutron detection efficiency of up to 60 %. This high efficiency is necessary for the detection of very neutron-rich βn-emitters as well as for the detection of multiple neutron-emitters via βnn coincidences. Its flexible design allows measurements at both, ISOL labs and in-flight fragmentation facilities. It was successfully used for measurements of fission fragments at JYFL in Jyväskylä, Finland and for r-process isotopes at N=82 and N>126 at the FRS at GSI Darmstadt. Presently BELEN is upgraded towards its 96 counters-ersion for the FAIR-DESPEC campaign in a few year. Until then, measurements with an intermediate version are being performed in various labs.

[1] R.B. Roberts, R.C. Meyer, P. Wang, Further Observations on the Splitting of Thorium and Uranium, Phys. Rev. **55**, 510 (1939).
[2] D. Abriola, B. Singh, and I. Dillmann, Summary Report of Consultants Meeting on Beta-delayed neutron emission evaluation, IAEA December 2011, INDC(NDS)-0599; online at http://www-nds.iaea.org/publications/indc/indc-nds-0599.pdf
[3] M.B. Gomez-Hornillos et al., Int. Nucl. Phys Conf. INPC-2010, July 4-9, 2010, Vancouver, Canada.

KADoNiS-p: The astrophysical p-process database

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The KADoNiS-p project is an online database for cross sections relevant to the p-process. Nuclei heavier than iron on the proton-rich side of the valley of stability are produced by a superposition of processes summarised as "p-process" [1]. The main fraction of those isotopes are produced in the γ-process by photodisintegration reactions on pre-existing seed nuclei. As the neutron separation energy increases along the (γ,n) path, (γ,p) and (γ,α) reactions become dominant and divert the material towards lower masses [2]. However, only the minority of the reactions used in network calculations [3,4] are known experimentally, thus the cross sections for the largest fraction have to be inferred from statistical model calculations using the codes e.g. NON-SMOKER [5], TALYS[6].
To predict the stellar reaction rates for photodisintegration reactions, usually the inverse reaction cross sections are measured [7]. Experimental proton- and alpha-induced reaction cross sections in the valley of stability can be used to finetune the statistical model calculations and make them more reliable for the extrapolation into the unknown regions. Up to now no compilation of the experimental data for the heavy charged particle reactions relevant for the p-process exists.
For KADoNiS-p all existing experimental data from (p,γ), (p,n), (p,α), (α,γ), (α,n) and (α,p) reactions in or close to the respective Gamow window was collected and reviewed. In 2013 March a user-friendly database using the KADoNiS (**K**arlsruhe **A**strophysical **D**atabase **o**f **N**ucleosynthesis **i**n **S**tars) framework was launched, including all available experimental data with cut-off date of August 2012 (`www.kadonis.org/pprocess`)

[1] S.E. Woosley and W.M. Howard, Ap. J. Suppl. **36**, 285 (1978).
[2] M. Arnould and S. Goriely, Phys. Rep. **384**, 1 (2003).
[3] W. Rapp et al., Ap. J. **653**, 474 (2006).
[4] T. Rauscher, Phys. Rev. C **73**, 015804 (2006).
[5] T. Rauscher and F.-K. Thielemann, At. Data Nucl. Data Tab. **75**, 1 (2000), `www.nucastro.org/nonsmoker.html`
[6] A.J. Koning, S. Hilaire and M.C. Duijvestijn, Proc. of ND2007, Nice, France **211** (2008), `www.talys.eu`
[3] T. Rauscher et al., Phys. Rev. C **80**, 035801 (2009).

Measurement of the -3 keV resonance in the $^{13}C(\alpha, n)^{16}O$ reaction by means of the Trojan Horse Method

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The $^{13}C(\alpha, n)^{16}O$ reaction is the neutron source for the main component of the s-process, responsible of the production of most nuclei in the mass range $90 < A < 204$. It is active inside the helium-burning shell in asymptotic giant branch stars, at temperatures $< 10^8$ K, corresponding to an energy interval where the $^{13}C(\alpha, n)^{16}O$ is effective of 100 – 250 keV. In this region, the astrophysical S(E)-factor is dominated by the -3 keV sub-threshold resonance due to the 6.356 MeV level in ^{17}O, giving rise to a steep increase of the S-factor. Notwithstanding that it plays a crucial role in astrophysics, no direct measurements exist. Anyway, its contribution is still controversial as extrapolations, e.g. through the R-matrix, and indirect techniques such as the asymptotic normalization coefficient (ANC) yield inconsistent results. The discrepancy amounts to a factor of 3 or more right at astrophysical energies. Therefore, we have applied the Trojan Horse Method (THM) to the $^{13}C(^6Li,n^{16}O)d$ quasi-free reaction to achieve an experimental estimate of such contribution. For the first time, the ANC for the 6.356 MeV level has been deduced through the THM as well as the n-partial width, allowing to attain an unprecedented accuracy in the $^{13}C(\alpha, n)^{16}O$ study. As a consequence, though a larger ANC for the 6.356 MeV level is measured, our experimental S(E) factor agrees with the most recent extrapolation in the literature in the 100 – 250 keV energy interval, the accuracy being greatly enhanced thanks to this innovative approach. The results have been recently published in Physical Review Letters [1]

[1] M. La Cognata *et al.*, Phys. Rev. Lett. **109**, 232701 (2012)

12th April, Friday, 10:45 – 11:10

Open questions on the *r*-process nucleosynthesis relevant to Core-collapse supernovae

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We present the possibility that core-collapse supernovae induced by rapid rotation and strong magnetic fields (MHD-SNe) are the origin of *r*-process elements. Nucleosynthesis calculations have been carried out based on special relativistic magneto-hydrodynamic simulations [1] with detailed microphysics including the neutrino cooling. The hydrodynamic simulations achieve in several core-collapse supernova models over a wide range of parameters for magnetic fields and rotations.

In the presentation, we mainly focus on the dynamical effects of MHD-SNe on the *r*-process based on resent hydrodynamic explosion models. These are two different types of explosion models that *prompt-magnetic-jet* models and *delayed-magnetic-jet* models, magnetic fields of which are strong and comparatively weak at the core-collapse, respectively. The *r*-processes successfully occur in prompt-magnetic-jet models, which produce heavier elements up to actinide. On the other hand, a delayed-magnetic-jet model do not produce *r*-process elements heavier than the second peak. Therefore, the nucleosynthesis in delayed-magnetic-jet models are considered to be capable to explain observed "weak" *r*-process elements in metal poor stars rather than the "main" *r*-process elements representing the solar-system abundances. Additionally, we discuss the effect of weak interactions, which determine final neutron-richness of the matter, on on the *r*-process.

[1] T. Takiwaki, K. Kotake, and K. Sato, ApJ. **691**, 1360 (2009).

^{121}Sb(α,γ)^{125}I, ^{121}Sb(α,n)^{124}I and ^{123}Sb(α,n)^{126}I cross section measurements at the astrophysical energies

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Some proton-rich isotopes that cannot be formed neutron captures in the s- and r-processes are thought to be produced in the so-called γ-process, where these p-nuclei are made by sequences of photodisintegrations on existing r- and s-seed nuclei and following -capture and beta-decays. Model calculations of the p-nuclides require large nuclear reaction networks involving about 1800 isotopes and more than ten thousand reaction rates. Almost all of these rates have to be determined theoretically by means of the statistical Hauser-Feshbach (HF) formalism. In order to provide a further test of Hauser-Feshbach predictions and to be also used to optimize input parameters of the codes, alpha captured reaction cross section measurements on ^{121}Sb isotope have been started. ^{121}Sb(α,γ)^{125}I, ^{121}Sb(α,n)^{124}I and ^{123}Sb(α,n)^{126}I reaction cross section measurements have been carried out at cyclotron accelarator of Institute for Nuclear Research, Hungarian Academy of Sciences (MTA Atomki) by using the activation method. The cross sections of alpha induced reactions on Sb isotopes have been measured in a effective center of mass energy range between 9.57 MeV and 15.42 MeV. In order to determine ^{121}Sb(α,γ)^{125}I reaction cross section, the yield of the 35.49 keV gamma-line obtained in close geometry by the LEPS (Low Energy Photon Spectrometer) was used. In this work characteristic X-rays detection based activation tehcnique [1] was used to the measure ^{121}Sb(α,γ)^{125}I reaction cross sections at the lower part of this energy range. The ^{121}Sb(α,n)^{124}I reaction cross section was also calculated with a 100 % relative efficiency HPGe detector in ULB (Ultra Low Background) shielding by counting the yield of 602.73 keV, 722.78 keV and 1690.96 keV gamma-lines. Similarly, for ^{123}Sb(α,n)^{126}I reaction cross section calculations 388.63 keV and 666.33 keV lines were used. The details of the measurements and obtained results will be presented and compared with the Hauser-Feshbach statistical model calculations [2].

[1] G. G. Kiss, T. Rauscher, T. Szücs, Zs. Kertesz, Zs. Fülöp, Gy. Gyürky, C. Fröhlich, J. Farkas, Z. Elekes, and E. Somorjai, Phys. Lett. B 695, 419-423 (2011).
[2] T. Rauscher and F.-K. Thielemann, At. Data Nucl. Data Tables 79, 47 (2001).

Cross section measurements related to the p-process nucleosynthesis for proton-induced reactions on ^{164}Er isotope

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Although the origin of the element abundances is mainly well understood, some significant uncertainties are still available. Moreover, In contrast to s- and r-process there are not much p-process study, even though its network calculations require at least 10000 reactions on about 1800 stable and unstable nuclei. Therefore, the calculations are based on statistical model or Hauser-Feshbach predictions, and the overall reliability of Hauser-Feshbach predictions in p-process simulations has been discussed.
The measurements of the reaction cross sections relevant to the astrophysical p-process are crucial to test the theoretical reaction rates with experimental data. The total cross sections for the ^{164}Er(p,γ)^{165}Tm and ^{164}Er(p,n)^{164}Tm reactions have been measured in the effective center-of-mass energies respectively 3.91 MeV $\leq$ E $\leq$ 7.81 MeV and 5.86 MeV $\leq$ E $\leq$ 6.83 MeV, close to the astrophysically relevant energy range. The experiments were carried out by the activation method at the FN Tandem Accelerator of the University of Notre Dame Institute for Structure and Nuclear Astrophysics Laboratory (Indiana, USA). The activities were determined by offline detection of the decay gamma rays with a HPGe detector. The targets with the thicknesses between 187 μg/cm^2 and 266 μg/cm^2 were prepared by evaporation of 75.32 % isotopically enriched $^{164}Er_2O_3$ powder on Aluminum backing foils, and bombarded with proton beams of 350-600 nA.
The obtained results for ^{164}Er(p,γ)^{165}Tm and ^{164}Er(p,n)^{164}Tm reaction cross sections have been compared with the predictions of Hauser-Feshbach statistical model calculations using the standard NON-SMOKER and default TALYS codes. The details of the measurements and the preliminary results will be presented in this work.

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