Access to neutron facilities

Title of proposed experiment

LIONS - Light-Ion Production Studies with Medley at the NFS facility

Spokesperson

Alexander V. Prokofiev

Uppsala University, +46 70 167 91 88, alexander.prokofiev@physics.uu.se

Preferred facility

NFS at GANIL

Contact person at ARIEL facility

Xavier Ledoux, email: xavier.ledoux@ganil.fr

Type of experiment

White neutron beam in the energy range 1 – 40 MeV. The Medley setup.

Requested beam time

136 beam time hours (17 “User Times”)

Preferred measurement period

From September 2021.

Synergy with SANDA

SANDA WP2, Task 2.1.2

Each experiment should support early stage researchers and lead to a publication in a peer-reviewed scientific journal and/or a conference presentation. In addition, validated data sets will be transferred to the NEA data bank /EXFOR. The PAC will assess the status of publications and will also monitor the transfer of nuclear data to the NEA data bank.

EURATOM support has to be acknowledged in all publications using: “This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847594 (ARIEL).

Participants list and access period requested. Please put on top the names of the early stage researchers that you would like to be supported. Only users from other European countries than the ARIEL host institute can be supported. Typically, support for travel (400 EUR on average per user) and a per diem (150 EUR) during a maximum of 7 experimental days can be granted for up to four users.
For the 'research status' please indicate: UND= Undergraduate, GRA=Graduate (student with a first University degree enrolled in Master or PhD studies), PDOC= Post-doctoral researcher less than 6 years after PhD, TEC= Technician, EXP=Experienced researcher (professional researcher).

Researcher	Institution	Research Status	Total number of days	Total number of visits	First-time user Y or N
A new PhD student*	Uppsala University	GRA	8**	1	Y
Alexander Prokofiev	Uppsala University	EXP	8**	1	Y
Diego Tarrío	Uppsala University	EXP	8**	1	Y
Stephan Pomp	Uppsala University	EXP	8**	1	Y

* The funding has been recently granted and the recruitment process is ongoing for a PhD student whose thesis will be dedicated to experiments at the newly constructed NFS facility. Because of newly communicated scheduling constraints from the facility side, the experiment will have to be ready to run in September 2021, which is significantly earlier than previously expected. The Medley group at UU will do its best to complete the recruitment prior to the experiment and to involve the newly employed student, however that cannot be warranted at present.

** Support for 8 days is requested, including ≈6 full days of scheduled beam time, 1.5 days for mounting/testing/calibration, and 0.5 day for dismantling.

Date | Signature of Spokesperson

April 30, 2021 | A Prokofiev

Signed applications must be sent to the ARIEL management board at the following address:
proposals@ariel-h2020.eu

Disclaimer: by submitting this proposal the group leader accepts that the text of his proposal will be put on the non-public PAC section of the ARIEL website. This password-protected section of the website will be accessible by the PAC members and all group leaders that have submitted a proposal.

Contact: Ralf Nolte Tel .: ++49-531-592-6420, Fax: ++49-531-592-6405, E-mail: ralf.nolte@ptb.de

Background

(Motivation, Relevance to ARIEL objectives)

Experimental cross-section data for the studied reactions are important for nuclear theory as well as for a number of applications. The relevance of the data for theoretical modelling of nuclear reactions stems from the fact that the actual range of incident particle energies (15–40 MeV) is characterized by gradual "washing out" of nuclear structure effects. At relatively low incident neutron energies, e.g. at 14 MeV, light-ion emission spectra are known to have a detailed structure in the high-energy end. That structure is not present at incoming neutron energies of 60 MeV and above. Furthermore, the energy range under study is at the edge of the validity for traditional statistical models for reactions involving light nuclei. Different theories (R-matrix type) may be needed. The proposed measurements will help to pinpoint that transitional energy range. Theoretical analysis of the obtained results, together with existing neutron- and proton-induced reaction data, will aim at an improved description of pre-equilibrium reactions, in particular those involving emission of composite particles. This will contribute to further development of the TALYS code and lead to improvement of the quality of evaluated nuclear data, in particular in future versions of the TENDL evaluated nuclear data library.

Aside from nuclear reaction model development, the studied data are relevant as well for a number of applications, including neutron dosimetry in aerospace and medical applications, radiation-induced failures in silicon carbide electronic devices, as well as development and application of diamond detectors used as neutron sensors, *e.g.*, in fusion diagnostic and in research at accelerator-driven neutron sources.

The experiment will serve as hands-on training for a PhD student, and the obtained data will form a part of a PhD thesis.

Goals of the proposal

We propose measuring double-differential cross sections (DDX) with respect to emission angle and energy for neutron-induced production of light ions (*p*, *d*, *t*, ^{3}He, and α) in a carbon target, at neutron energies up to 40 MeV, using the white neutron beam at the NFS facility. From the obtained data we will derive angle-differential, energy-differential, and integral particle production cross sections.

(Description of work max. 3 pages)

Neutron beams at NFS allow one to study neutron-induced reactions over an energy range 1-40 MeV, where various reaction channels open up and nuclear structure effects gradually wash out with increasing energy of incoming neutrons. To study those effects, we will measure double-differential cross sections (DDX) for neutron-induced reactions in a ^{nat}C target resulting in light ions (p, d, t, ^{3}He, and α). From the obtained data we will derive angle-differential, energy-differential, and integral particle production cross sections.

The experimental setup

The experiment will be done at the Neutrons For Science (NFS) facility at GANIL (Caen, France) [1]. We will be using the white neutron beam produced by the interaction of a 40-MeV deuteron beam with a thick Be converter. The produced neutrons cover a wide energy range, between less than 1 MeV and 40 MeV, with time-averaged spectral flux that is much higher than in other time-of-flight facilities in the same neutron energy range.

The experimental setup and methods have been described in detail in our publications [2,3 and references therein]. We will make use of the Medley setup, which has formerly been used repeatedly at the quasi-monoenergetic neutron beam [4] in The Svedberg Laboratory (TSL), Uppsala, Sweden, for light-ion production studies [2, 3, 5, 6 and references therein]. The Medley chamber (see Fig. 1) is designed for detection of charged particles over a wide energy range. It includes eight three-element telescopes mounted inside a 240-mm high cylindrical evacuated chamber with inner diameter of 800 mm. The telescopes are placed at 20° intervals, covering scattering angles from 20 to 160° simultaneously. The telescopes are normally mounted in two sets, one on each side of the beam, covering the forward and backward hemispheres, respectively. All the telescopes are mounted onto a rotatable plate, thus allowing us to measure at (almost) any emission angle.

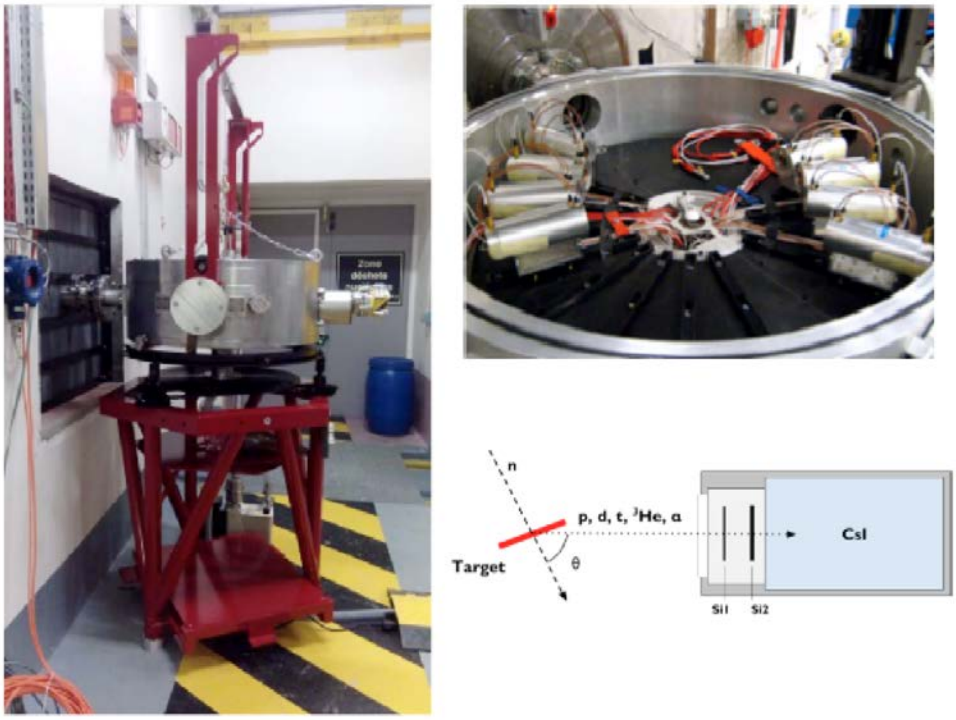

Fig. 1. *Left panel: View of the Medley chamber installed in the TOF hall at the NFS facility. Upper right panel: Detector arrangement inside the Medley chamber. Bottom right panel: A schematic layout of the telescope containing a thin Si detector, a thick Si detector, and a CsI scintillator.*

Each telescope consists of two fully depleted ΔE silicon surface barrier detectors (SSBD) and a CsI(Tl) crystal (see Fig. 1). The thicknesses of the first ΔE detectors (ΔE_1) range between 50 and 60 μm. For the second SSBD (ΔE_2) the thicknesses range between 400 and 1000 μm. The SSBD are all 23.9 mm in diameter (nominal). The back-end of each telescope contains a CsI(Tl) detector to fully stop the detected particles, which are identified by the ΔE-ΔE-E technique. Each CsI(Tl) crystal, with a total length of 50 mm and a diameter of 40 mm, is connected to a read-out diode. The solid angle covered by each telescope, placed at the distance of 15 cm from the target, is 20 msr.

The identification of detected charged particles using the ΔE-ΔE-E technique is exemplified in Fig. 2. The figure shows a simulated ΔE-E plot, where ΔE is the energy loss in the first Si detector (given as E_1 in the axis title) and E is the total energy deposited in all detectors (Si_1, Si_2 and CsI) in the actual telescope. The diagonal band at the left in the plot corresponds to particles that are fully stopped in the first Si, and the "banana-shaped" bands represent (from bottom to top) protons, deuterons, tritons, ^{3}He (very weak band) and α-particles. There is also a structure seen in the left part of the plot as a diagonal band at lower Si_1 energies. That band corresponds to particles that deposit energy in both Si detectors but do not reach the respective CsI crystal. Observing punch-through energies on a ΔE-E plot for a given Si detector with known thickness, we will obtain energy calibration points.

A particle detected in a telescope will be producing a fast signal that will be used as a start in the ToF measurement for determination of energy of the neutron that caused the studied event. The signal from the linac's RF system, associated to the arrival of the beam bunch to the neutron production target, will be employed as a stop. For 7 MeV neutrons, the threshold energy for the ^{12}C(n,α) reaction, the neutron ToF is 150 ns, which is much shorter duration than the beam repetition period of 1.1 μs. For the other studied reactions, the threshold is higher and the respective ToF is further shorter. Thus, there will be no overlap in time between reaction events produced by neutrons in different beam pulses.

In order to measure the DDX data for neutron-induced reactions in carbon in the absolute scale, we will perform normalization to the elastic *np*–scattering cross section. For this purpose, the measurement program will include runs with a CH_2 target instead of the ^{nat}C target. The geometrical configuration of the target and the detectors will be identical for C- and CH_2-runs. Due to the presence of hydrogen in the CH_2 target, we will detect recoil protons from the H(n,p) reaction, i.e. from elastic *np*-scattering. The *np*-scattering cross section is regarded as the primary neutron standard [7].

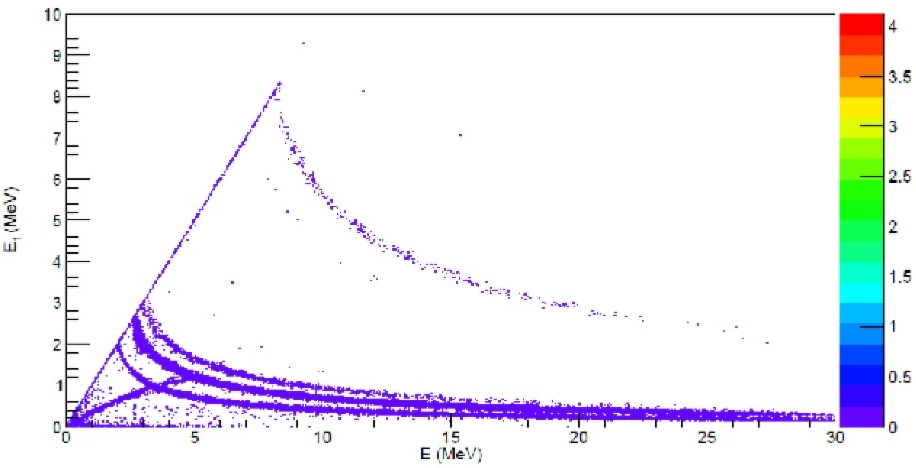

Fig. 2. A simulated ΔE-E plot for particle identification of events originating from the neutron-induced light-ion production in a natural carbon target. The vertical axis shows the energy loss E_1 in the first Si detector. The horizontal axis shows the total energy E deposited in all detectors (Si_1, Si_2 and CsI) in the actual telescope. The observed "banana-shaped" particle bands from bottom to top correspond to: protons, deuterons, tritons, ^{3}He (very weak band) and α-particles.

In addition to detection of secondary particles coming from the studied target (C or CH_2), the Medley telescopes may potentially be sensitive to “parasitic” production of light ions in any other objects than the Medley target. Dedicated target-out measurements will be performed for determination of that intrinsic, setup-associated background, with will subsequently be subtracted from the measured spectra, with proper normalization.

In order to link together the data obtained with the C target, with the CH_2 target, and without any target, we will employ external relative monitors provided by the NFS facility.

Thick-target corrections and systematic uncertainties

The choice of target thickness is always a compromise between count rate considerations and limitations coming from self-absorption of low-energy particles as well as from distortion of measured spectra caused by energy losses in the target. We plan to use a ^{nat}C target with 75-μm thickness, which is chosen to reach a compromise between the count rates and the uncertainty introduced by the thick-target corrections. The expected distortion of spectra will not be significant for secondary ions of hydrogen isotopes, whereas for α-particles it should be possible to preserve the information contained in the high-energy part of the spectra.

For the CH_2 target, we are solely interested in a recoil proton spectrum at the most forward angle. That spectrum will be influenced by thick-target effects in lesser degree than any other secondary spectrum. Consequently, thick-target effects are less of concern in that case.

To correct the charged-particle spectra for thick-target effects, an iterative procedure is being developed [8]. The validity of the correction procedure was proven by simulations showing that the originally measured, uncorrected spectra could be reproduced.

Judging from experiences in ref [2], the systematic uncertainty associated with the thick-target correction is not expected to exceed 20% for the worst cases, which correspond to detection of secondary particles with the lowest energies, in the scale of a few MeV. Other contributions to the overall systematic uncertainties in DDX will include those coming from target mass determinations, normalization uncertainties due to statistical errors in relative monitor counts, and uncertainties in the standard cross section. These contributions are well understood.

References

[1] X. Ledoux et al., *The Neutrons For Science facility at SPIRAL-2*, Rad. Prot. Dos. 180, 115 (2018).

[2] U. Tippawan, et al., *Light-ion production in the interaction of 96 MeV neutrons with carbon*, Phys. Rev. C **79**, 064611 (2009).

[3] S. Pomp, et al., *A Medley with over ten years of (mostly) light-ion production measurements at The Svedberg Laboratory*, EPJ Web of Conferences **8**, 07013 (2010).

[4] A.V. Prokofiev, et al., *The TSL Neutron Beam Facility*, Rad. Prot. Dosim. v. 126, pp. 18-22 (2007).

[5] R. Bevilacqua, et al., *Medley spectrometer for light ions in neutron-induced reactions at 175MeV*, Nucl. Inst. Meth. A **646**, 100 (2011).

[6] S. Pomp, et al., *Light-ion production in 175 MeV quasi-monoenergetic neutron-induced reactions on iron and bismuth and comparison with INCL4 calculations*, Prog. Nucl. Sci. Tech. **4**, 601 (2014).

[7] A. D. Carlson et al., *Evaluation of the Neutron Data Standards*, Nucl. Data Sheets, **148**, 143 (2018).

[8] E. Andersson Sundén, A.V. Prokofiev, *Development of thick-target correction algorithms in nuclear data measurements*, JEFF-Fusion meeting, November 24, 2020, EFFDOC-1428 (2020).

Time schedule and beam time estimate

(Justification for requested beam time, setup and preparation)

The experiment has already been granted by the GANIL PAC, with a total of 17 UT (136 hours) of beam time. Out of them, 12 UT (96 hours) will be dedicated to perform the experiment (that means: exposures of the ^{nat}C target, the CH_2 target, target-out runs and in-beam calibrations); the remaining 5 UT (40 hours) will be used for in-beam tests and for modifications of the settings during the experiment.

With that beam time, we will achieve 4-8% statistical error in the number of counts at each telescope for the C(n,dX) reaction, in 1-MeV wide neutron energy bins. Statistical errors of 4-11% will be obtained for the C(n,pX) reaction for neutron energies above 15 MeV, whereas the count rate for the C(n,αX) reaction will be much larger.

Justification for expenses

Support request:

*Number of days to be supported (typical 4*7 days):   4*8=32 days*

Travel cost (4 400 EUR on average): 4*400 EUR = 1600 EUR*

Support from other resources: Faculty funding from Uppsala University.

Education and training benefits

(Indicate education and training benefits for the early stage researcher, or knowledge transfer between the participants, e.g. relevance for thesis work; including a work schedule or list of training activities for technical staff in the description of the project. Bulleted list

- The Ph.D. student will acquire experience in working at a neutron facility with real neutron beams, targets, radiation detectors, data acquisition, etc.
- The analysis and interpretation of the data acquired in the experiment will represent an important part of the student's Ph.D. thesis.

Deliverables and Publication plan

(Indicate the expected specific final results of the project that would be of interest to the scope of ARIEL and/or SANDA. Publication plan.)

The data obtained in the experiment will form a part of Uppsala University's deliverable in the SANDA project, Task 2.1.2: **Neutron induced charged particle production cross sections.**

The experiment will lead to a publication in a peer-reviewed journal, and to a presentation at an international conference.

After publication in a journal, the results will be transferred to the EXFOR database.