EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Status Report to the ISOLDE and Neutron Time-of-Flight Committee
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[IS496: Study of the effect of shell stabilization of the collective isovector valence-shell excitations along the N=80 isotonic chain]

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Abstract

Main aim of the project is the investigation of isovector-valence space-excitations in unstable nuclei in the vicinity of the doubly-magic nucleus ^{132}Sn. It was intended to perform experiments at REX-ISOLDE as preparation for HIE-ISOLDE studies, for which the ISOLDE facility is unique due to its capability to provide such RIBs for high-resolution γ-spectroscopy. The main physics goals of the studies are related to the role of the proton-neutron interaction with respect to the evolution of the single-particle structure as well as the microscopic behavior of valence nucleons in the nuclei of interest. In the subsequent experiments at HIE-ISOLDE (already approved experiments IS546 and INTC-P-421) these questions will be studied by measuring transition strengths using Coulomb excitation reactions. This technique will grant the necessary extended experimental information for an unambiguous identification of the lowest isovector-valence shell excitations.

Remaining shifts: 0

1. Motivation, experimental setup/technique

Nuclei are an example of mesoscopic two-fluid quantum-systems whose physical properties are mainly determined by many-body aspects, the quantum nature of the system as well as its two-fluid character. All of these properties are reflected by collectivity, shell structure and isospin. Quadrupole-collective, isovectorial valence-space excitations [Pie08] open up a unique approach towards the investigation of the interplay of the beforehand mentioned three aspects. Structure and characteristics of these excited states depend on effective proton-neutron correlations inside the valence shell [Hol07, Sev14]. Aim of the proposed experiment is to identify such states in the vicinity of the doubly-magic shell-closure at $A = 132$. (There exist direct analogies in matters of collectivity in higher multipole orders, *e.g.*, octupole and hexadecupole configurations [Sch10, Cas13]). It is intended to further investigate the mechanism leading to concentration or fragmentation of quadrupole-collective isovectorial excitations, the so called "shell stabilization [Rai06] of states of proton-neutron mixed-symmetry" in N=80 isotones. The extracted information will shed light on the role of proton-neutron residual-interaction on the evolution of behaviour of valence-space excitations. The first mixed-symmetric state in an unstable nucleus in the region around $A \sim 132$ was identified in 2011 [Dan11]. A direct connection exists between the excitation energy of states of proton-neutron mixed-symmetric character and the proton-neutron symmetry-energy [Ahn09]. This character renders these states ideal probes of the nuclear wave function.

The isovector degree of freedom in proton-neutron mixed-symmetric states provides complementary information to isoscalar states, *e.g.*, the first quadrupole-excited 2^+ state in even-even nuclei, typically measured at REX-ISOLDE. This provides a test, sensitive especially to the proton-neutron residual-interaction.

In order to characterize the resulting valence-space excitations in greater detail it was intended to measure transition strengths via Coulomb excitation providing preferential exploration towards low-energy excited states. This type of measurements also opens up the possibility to extract spectroscopic quadrupole moments [Bau12, Bau13].

Experiments for the further investigation of the N=80 isotonic chain were performed for ^{140}Nd as well as ^{142}Sm using REX at energies of 2.85 MeV/u. The total beam intensity was about 10^5 pps using the general purpose separator (GPS) and RILIS. The secondary targets consisted of ^{48}Ti, ^{64}Zn as well as ^{94}Mo. Deexcitation-γ rays were measured using the MINIBALL HPGE-γ ray spectrometer covering about 2π of the solid angle. Scattered projectile and recoiling target nuclei were measured by a double-sided silicon-strip detector (DSSD) subtending an opening angle of 19.7° – 58.4° in the laboratory system.

2. Status Report

Using the beforehand mentioned experimental setup the transition strengths of the $2_1^+ \rightarrow 0_1^+$ transition in ^{140}Nd and ^{142}Sm were to be measured as a first step towards the study of the "shell stabilization" in the forth-coming experiments. Knowledge of these values is essential for the interpretation of data from these future experiments, to be taken at HIE-ISOLDE, in order to investigate higher-lying mixed-symmetry states.

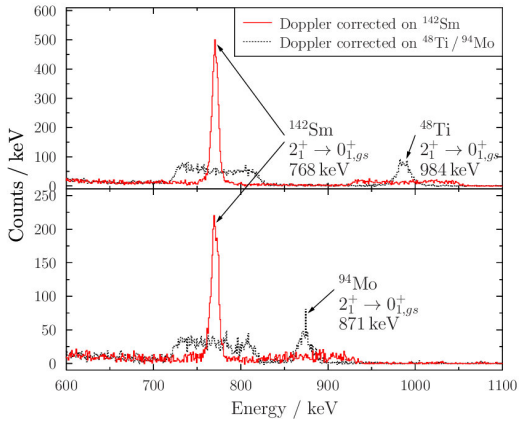

Fig. 1: *γ-ray spectrum of the measurement of ^{142}Sm. The excitation of the 2_1^+ states of projectile and target nuclei is clearly visible.*

Measurement of both nuclei has been completed successfully in the framework of experiment IS496 with data taking in 2011 for ^{140}Nd and in 2012 for ^{142}Sm. Fig. 1 shows the random-background subtracted Coulomb-excitation spectra, Doppler-corrected for beam particles with A=142 as well as for target excitation. Besides isobaric ^{140}Sm in the ^{140}Nd measurement no contamination was identified in the Coulomb-excitation spectra. Analysis of the data regarding ^{140}Nd is fully completed and already published [Bau13]. In the case of ^{142}Sm the analysis is nearly finalized and the corresponding publication is in preparation [Ste15]. We would like to stress that while in ^{140}Nd the contribution of the isobaric contaminants to the Coulomb excitation yields was estimated by using laser on-off technique, in the case of ^{142}Sm this had to be done on the basis of precise decay spectroscopy due to the fact that ^{142}Sm is easily surface ionized.

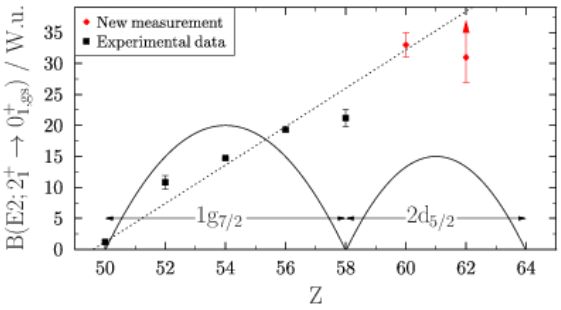

Fig. 2: *Evolution of the B(E2; $2_1^+ \rightarrow 0_1^+$) values in the N=80 isotonic chain. Between Z=50 and Z=62 the proton $1g_{7/2}$ and $2d_{5/2}$ orbitals are consecutively filled. The experimental data*

This endeavour rendered investigation of the influence of the lack of "shell stabilization" on the low-lying quadrupole-collective states possible. We have been able to show that this property of nuclear structure is influencing the fully-symmetric 2_1^+-state in the N=80 isotone chain in the way of a reduction of the $2_1^+ \rightarrow 0_1^+$ transition strength at the Z=58 subshell closure in ^{138}Ce. In ^{140}Nd [Bau13] as well as in ^{142}Sm [Ste15] the restoration of transition strength towards phenomenologically expected transition strengths could be shown as can be seen in Fig. 2.

Developed RIB: ^{140}Nd, ^{142}Sm (achieved beam intensity on the target 1x10^{5}pps)

Performed studies: ^{140}Nd, ^{142}Sm

3. Future plans

As stated in section 2, experiment IS496 has been successful. It was possible to develop clean RIBs with sufficient intensities to perform the contemplated experiments. In particular it was possible to show that the main aim of the program, namely the identification of MSSs in these nuclei, is be feasible. In addition it was possible to determine the B(E2; $2_1^+ \rightarrow 0_1^+$) values of ^{140}Nd and ^{142}Sm which are essential to conduct Coulomb excitation in inverse kinematics in IS546. **As the preceding steps are now successfully completed, IS546 can be executed as soon as HIE-ISOLDE is able to provide beam energies up to 4.5 MeV/u.**

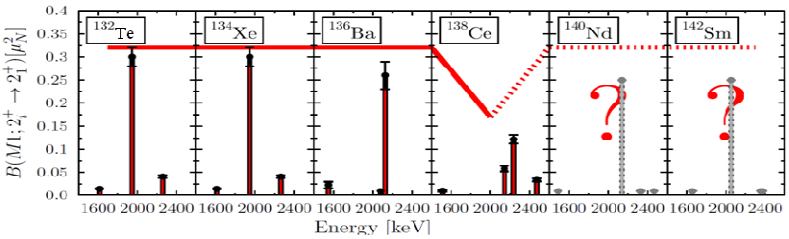

Fig. 3: *Systematics of the B(M1;$2_i^+ \rightarrow 2_1^+$) strengths in the N=80 isotonic chain. Contrary to $2_{1,ms}^+$ states in neighbouring nuclei the $2_{1,ms}^+$ state in ^{138}Ce is fragmented. Currently the progression in ^{140}Nd and ^{142}Sm is unknown.*

The main aim of the follow-up experiment IS546 is related to the stability of MSSs in the N=80 isotonic chain. In ^{132}Te, ^{134}Xe and ^{136}Ba dominant isolated states of mixed-symmetric character have been observed (cf. Fig. 3). In contrast to that finding in ^{138}Ce mixing of the $2_{1,ms}^+$ state with another high-lying 2^+ state was discovered, leading to a fragmentation of the M1 strength of the mixed symmetry. It was speculated [Rai06] that this is due to the Z=58 subshell closure. This effect is known as the lack of "shell stabilization". The validity of the "shell stabilization" hypothesis is directly related to the evolution of M1 strength in ^{140}Nd and ^{142}Sm. In order to find evidence of M1 transitions in ^{140}Nd multipolarities have already been measured [Wil09, Gla10] and candidates for states of mixed-symmetric character have been identified. However absolute transition strengths are still lacking and needed for an unambiguous interpretation. The corresponding situation in ^{142}Sm is completely unknown. The results from theoretical studies are ambiguous: shell model calculations predict a single isolated mixed-symmetric state in contrast to quasiparticle-phonon model calculations predicting a fragmentation of M1 transition strength. Both models are not able to provide unambiguous indications about the excitation energy of the dominant M1 fragment. **The consecutive experiment IS546 using Coulomb excitation at HIE-ISOLDE ought to reveal the ambiguities and provide clear evidence for further improvement of theoretical models.**

IS546 aims to reveal nuclear structure information by identifying mixed-symmetric states in the vicinity of doubly-magic ^{132}Sn. Knowledge about this region will further be advanced by identifying the mixed-symmetric state and measuring the absolute matrix elements in ^{136}Te, which was submitted as INTC-P-421 and got approved. **The setup of both experiments is similar, which enables us to conduct this experiment also using the first stage of HIE-ISOLDE.**

Future plans with <u>available</u> shifts: All shifts dedicated to IS496 were used in the successful runs in 2011 and 2012.

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4. Appendix

[PLEASE include links to THESES in CDS:

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Publications

EPJ Web of Conferences 38, 10003 (2012)

C. Bauer, G. Guastalla, J. Leske, O. Möller, T. Möller, J. Pakarinen, N. Pietralla, G. Rainovski, E. Rapisarda, D. Seweryniak, C. Stahl, R. Stegmann, J. Wiederhold and S. Zhu

Level lifetimes and quadrupole moments from Coulomb excitation in the Ba chain and the N=80 isotones

Phys. Rev. C 88, 021302(R) (2013)

C. Bauer, G. Rainovski, N. Pietralla, D. Bianco, A. Blazhev, T. Bloch, S. Bönig, A. Damyanova, M. Danchev, K. A. Gladnishki, T. Kröll, J. Leske, N. Lo Iudice, T. Möller, K. Moschner, J. Pakarinen, P. Reiter, M. Scheck, M. Seidlitz, B. Siebeck, C. Stahl, R. Stegmann, T. Stora, Ch. Stoyanov, D. Tarpanov, M. J. Vermeulen, D. Voulot, N. Warr, F. Wenander, V. Werner, and H. De Witte

Local suppression of collectivity in the N = 80 isotones at the Z = 58 subshell closure

R. Stegmann et al., in preparation (2015)

Theses [including link to CDS]

Bauer, C.: "Level lifetimes and quadrupole moments from projectile-Coulomb excitation of A ≈130 nuclei", TU Darmstadt, PhD thesis, June 2013

Stegmann, R.: "Untersuchung des 2_1^+-Zustands in den radioaktiven Isotopen ^{140,142}Sm mit Hilfe von Coulomb-Anregung", TU Darmstadt, MSc thesis, August 2013

Conference presentations

MINIBALL workshop 2014

R. Stegmann et al.

https://indico.cern.ch/event/338632/session/0/contribution/18

Coulomb excitation of 140Nd and 142Sm

MINIBALL workshop 2013

R. Stegmann et al.

https://indico.cern.ch/event/271969/session/2/contribution/17

Coulomb excitation of ^{142}Sm

DPG-Frühjahrstagung 2013

R. Stegmann et al.

http://www.dpg-verhandlungen.de/year/2013/conference/dresden/part/hk/session/18/contribution/3

Bestimmung des B(E2)-Wertes des 2_1^+-Zustandes von ^{140}Nd und ^{142}Sm mittels Coulomb-Anregung an REX-ISOLDE

ISOLDE workshop 2012

R. Stegmann et al.

http://indico.cern.ch/event/202232/contribution/8

Determination of the B(E2) value for the first 2^+ state of ^{142}Sm using Coulomb excitation at REX-ISOLDE

DPG-Frühjahrstagung 2012

C. Bauer et al.

http://www.dpg-verhandlungen.de/year/2012/conference/mainz/part/hk/session/43/contribution/3

Coulomb excitation of 140Nd - measuring the B(E2) value of the first 2+ state at REX-ISOLDE

ISOLDE workshop 2011

C. Bauer et al.

http://indico.cern.ch/event/153820/session/10/contribution/1

Determination of the B(E2) value for the first 2^+ state of ^{142}Sm using Coulomb excitation at REX-ISOLDE