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Letter of Intent

Study of the decrease of neutron pairing with neutron number by measuring the transfer of paired neutrons.

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and the REX-ISOLDE collaboration

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Summary

With a neutron-rich ^{10}Be target ($T_{1/2}$ = 1.6 Ma) the two-neutron-pickup is efficiently detected by the characteristic two-α decay of ^{8}Be ($T_{1/2}$=0.07 fs). Due to Q-value matching and enhanced pair transfer we expect rather large cross sections in the 1 mb range. At the Munich target laboratory ^{10}Be targets with about 100 μg/cm^2 of ^{10}Be (enrichment 61.4%) on a 40 μg/cm^2 carbon backing and a diameter of the ^{10}Be spotsize of 3 mm are produced. ^{10}Be decays via β^--decay with an endpoint energy of 0.56 MeV to the stable ground state of ^{10}B. The total pure β-activity of a target is about $3 \cdot 10^4$ Bq, much below the free handling level of 10^6 Bq [18]. We want to measure the two-neutron-pickup at 3.1 MeV/u and 4.2 MeV/u for neutron-rich even-even fission fragments with MINIBALL and particle detectors, to probe the expected reduction of neutron pairing for more neutron-rich nuclei via a change of the enhanced pair transfer of superfluid 2^+-states.

1 Introduction

In the INTC-proposal P156 on "Coulomb excitation of neutron-rich A $\sim$ 140 nuclei" by D. Habs *et al.,* we want to measure the B(E2)($0_1^+ \rightarrow 2_1^+$)-values of 2^+-states of very neutron-rich nuclei. This interest was motivated by fig.1, where the upper part shows the ratio between experimental B(E2)-values and thoses calculated via a modified Grodzins rule [3] against the deviation of the neutron number N from the neutron number $\bar{N}$ of a nucleus at the minimum of the valley of stability with the same mass number A. An isospin dependence is clearly visible; proton-rich nuclei have larger B(E2)-values. We have accounted for this new isospin dependence by an additional linear function and obtained the lower part of fig.1. Here we can predict B(E2)-values within 20%. With the improved formula a strong deviation for the experimental B(E2)-values becomes clearly visible for very neutron-rich Ba, Xe. Te and Sn nuclei. This deviation approximately is described by the dashed line. In proposal P156 we wanted to establish this surprising deviation by measuring further nuclei which are indicated by arrows in fig.1.

Besides the reduction of the B(E2)-values also a systematic decrease of 2^+-energies occurs [4]. A possible explanation was put forward by W. Nazarewicz [6, 5] and by P.G. Reinhard [8]. The neutron pairing gaps Δ shown in fig. 2 are calculated by W. Nazarewicz *et al.,* [6]. In the Sn-region a clear reduction from a value of about 0.9 MeV for neutron numbers below N = 82 to values of about 0.3 MeV above N = 82 is seen. The HFB calculations were performed with a Skyrme-force and volume pairing. The loosely bound neutrons for N> 82 have a large spatial extent and only a small overlap with the volume like pair potential [8]. Since in the regio nof N = 82 pairing already is close to collaps a small change in the pairing force shows a drastic reduction of the pairing gap Δ. This reduction of the neutron pairing gap Δ leads to a reduction of the neutron-two-quasiparticle energies and consequently also to a reduction of the 2^+-energies. Therefore here the first 2^+-states should be dominant neutron excitations. If the spatial overlap between the outer neutrons, which may be strongly deformed, and the protons is small then the np-force no longer is able to equilibrate the neutron and proton deformations. In this way the reduction of the 2^+-energies is not accompanied by a compensatory increase of the B(E2)-values. P.G. Reinhard is currently calculating the 2^+-energies and the B(E2)-values in order to substantiate this explanation. Also for the very neutron-rich Ni and Zn isotopes a similar deviation from the Grodzins rule is observed. Again in fig.2 we find a reduction of the neutron pairing gap Δ.

In the experiments of this letter of intend we now want to explore the primary changing quantity: the pairing gap Δ. We compare the strength of the 2n-transfer cross sections for even-even nuclei as a function of neutron number and expect a strong reduction of the enhancement factor when the breakdown of the superfluid paired configuration occurs. For superfluid paired states (like for the even-even Sn nuclei) strongly enhanced pair transfer up to a factor of 10^3 is observed, which allows to probe pairing correlations [9, 10]. We want to study the 2n-pair-transfer between ^{10}Be [1] and Sn or Zn nuclei. The ground states of ^{10}Be and ^{8}Be can nicely be described in the deformed shell model. The heavy radioactive partner is a superfluid nucleus. For ground state transitions of normal-superfluid type enhancement factors of 10 - 100 are expected in comparison to normal-normal transitions [11]. Furthermore the enhancement factor is predicted to be proportional to Δ/G, where Δ is the pairing gap and G is the pairing coupling constant [11]. By systematically varying the

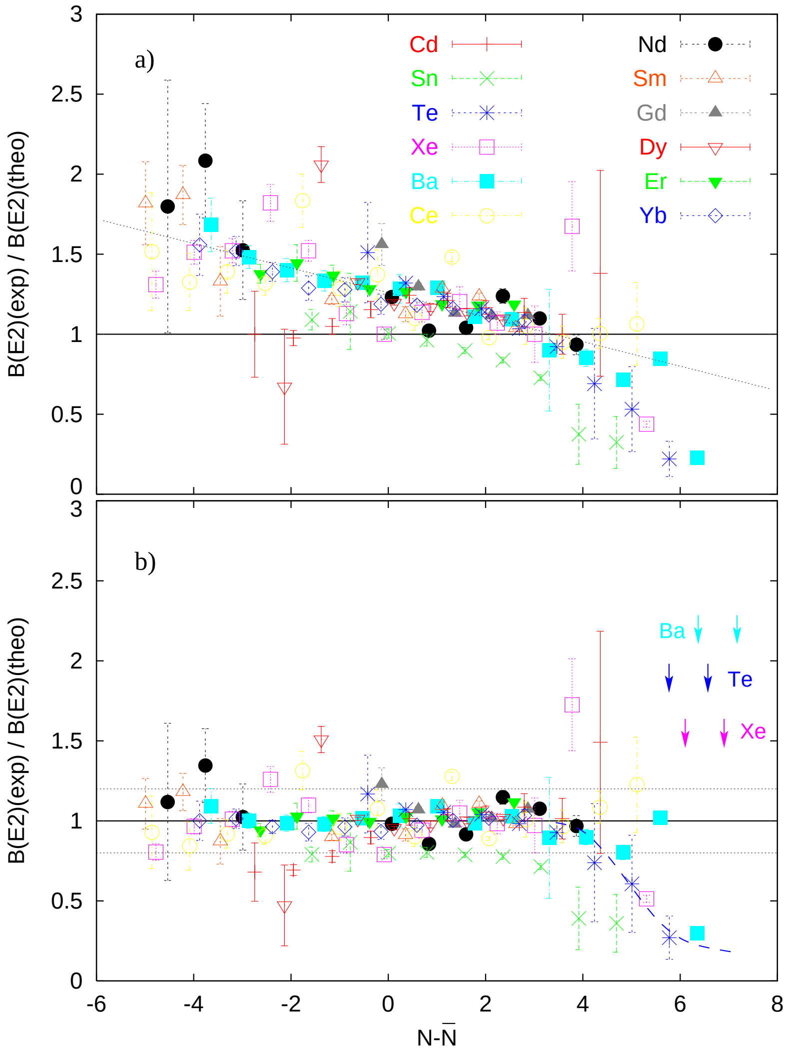

Figure 1: Ratio of the experimental B(E2)($0^+ \rightarrow 2^+$)-values over those calculated with respect to a modified Grodzins rule [3] as a function of the deviation of the neutron number N from the neutron number $\bar{N}$, representing the neutron number in the valley of stability for the given mass number A. In fig 1a a clear isospin dependence of the B(E2)-ratios can be seen. In fig. 1b this additional linear isospin dependance was taken into account. For very neutron-rich nuclei a systematic deviation from the constant ratio is clearly visable which is indicated by the dashed curve.

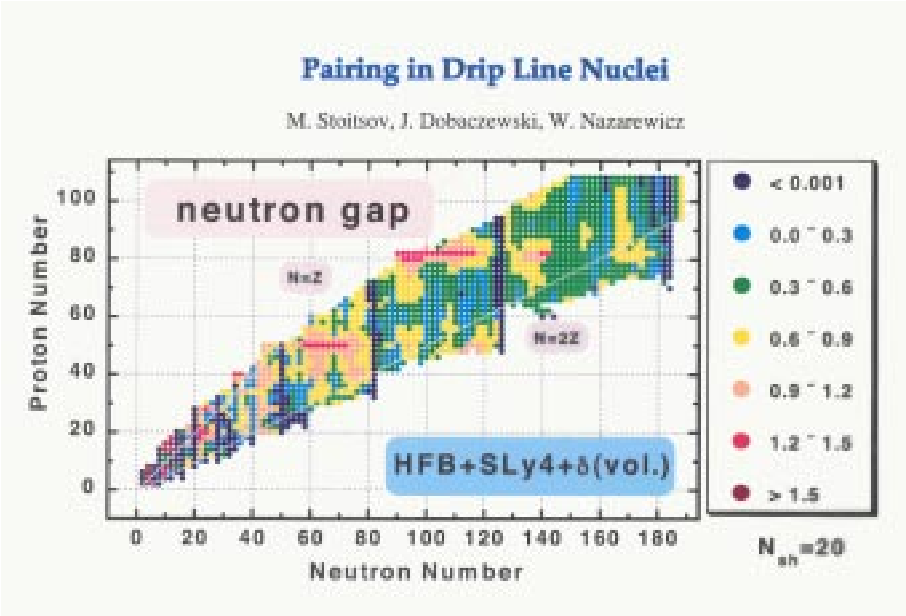

Figure 2: Calculated neutron pairing gap energies in units of MeV as a function of neutron and proton number. The values were obtained in a HFB-model with a Skyme force and a volume pairing force [5, 6, 7].

neutron number of the radioactive beam we will be able to study the change of the pairing gap Δ for nuclei over long isotope chains. This becomes especially interesting, because we have these other indications of a breakdown of neutron pairing for very neutron-rich nuclei. Furthermore, it is interesting to note that the two-neutron transfer probes the outer region of the paired wave function. Therefore there may be a difference between surface and volume pairing, because the surface pairing results in a strong localization of the paired currents on the nuclear surface.

We not only want to investigate the two neutron transfer between ground states but also those leading to the excitation of the first 2^+ state. This can be interpreted as a two step excitation with an inelastic excitation of the 2^+ state und a two-neutron transfer. The additional detection of the γ-ray from the 2^+-deexcitation in coincidence with the two α-particles of ^{8}Be results in a unique assignment of the process. The transfer to the ground state can be deduced from the total yield of ^{8}Be and that coincident with γ's.

The detection of the two α's only, probably, predominantly results from the transfer between ground states.

The study of the 2n-pickup for neutron-rich nuclei with a ^{10}Be-target, not only is favourable due to the easy detection of the two α-particles but also due to the rather large cross sections for optimum Q-values and the enhanced pair-transfer. Due to the small two-neutron separation energy of ^{10}Be of 8.477 MeV many interesting 2n-transfer reactions can be studied far outside the valley of stability with good Q-value matching. The steepness of the valley of stability for light nuclei compared to the much more shallow valley of stability for heavy nuclei results in the fact that ^{10}Be, being only about two neutrons away from from the valley of stability, has a **two neutron separation energy** which is similar to ^{78}Ni being about 17 neutrons away from ^{61}Ni in the centre of the valley of stability.

2 Two-neutron transfer with neutron-rich ^{10}Be

The unique situation of these experiments is, that a neutron-rich radioactive ^{10}Be target is used in combination with neutron-rich radioactive beams. The properties of our ^{10}Be targets have been outlined in our proposal to the INTC-committee : " New spectroscopy by two-neutron-pickup of neutron-rich nuclei" The main characteristics of the targets are: We have several targets of $\sim 100\mu$g/cm^2 ^{10}Be with a spotsize od 3mm diameter on $\sim 40\mu$/cm^2 carbon. The handling of the targets does not require special safety procedures.

For the understanding of the spectroscopic factors of the two-neutron transfer we have to understand the structure of the involved nuclei. In the molecular orbit (MO) model [24] the ^{9}Be ground state consists of an α-α core and one valence neutron in the $3/2^-_\pi$ orbit, while the ^{10}Be ground state has an additional valence neutron in the same $3/2^-_\pi$ orbit. ^{8}Be fits into this sequence of nuclear shapes because its ground state in the MO-model corresponds just to the chain of two α-particles. Therefore the one and two neutron transfer reactions between the ground states of these nuclei have large spectroscopic factors. For the description in the FRESCO code we will use a deformed shell model description of the Be nuclei.

Next we consider the Q-values of the 2n-transfer reactions, which are well matched for Q-values close to zero MeV. Table 1 shows the Q-values for different reactions. The S_{2n}-value of ^{10}Be with 8.477 MeV is well suited for matched transfer-reactions which occur for rather neutron-rich reaction partners. For the Ni-isotopes a steady drop off of S_{2n} occurs until ^{78}Ni with S_{2n}=8.71 MeV, while we expect a steeper drop for ^{80}Ni with $S_{2n} \sim 7$ MeV. For the neighbouring ^{80}Zn (N=50) we have S_{2n}=10.7 MeV, while for ^{82}Zn a value of 6.43 MeV is predicted. For ^{132}Sn we have S_{2n}=9.17 MeV, while it drops for ^{134}Sn to S_{2n}=6.75 MeV. So for many 2n-transfer-reactions of interest the Q-value is close to zero MeV and the reactions are well matched.

	projectile of reaction in inverse kinematics						
Reaction	^{76}Zn	^{78}Zn	^{80}Zn	^{82}Zn	^{130}Sn	^{132}Sn	^{134}Sn
^{9}Be-n	2965.	2125.	755.		3548.	-1555.	
^{10}Be-2n	2843.	2223.	-2047.	-3400.	4042.	-1728.	-2400

Table 1: Ground state reaction Q-values in keV. An optimum matching of the transfer reaction occurs for $Q_{opt} \sim 0$ MeV.

A rough estimate of the 2n-transfer transfer cross sections can be obtained from the 1n-transfer cross sections and the transfer probabilities. The ^{10}Be $\rightarrow$ ^{9}Be and the ^{9}Be$\rightarrow$ ^{8}Be reactions have approximately the same spectroscopic factors [22] and integral transfer cross sections of about 150 mb. The total reaction cross section of ^{10}Be is about 1 b and the maximum 1n-transfer probability about 10%. We can estimate the cross section of the two step process of two individual neutron transfers to be about (1-10)mb. Since the single step 2n transfer should have a somewhat larger contribution 5 mb is a good estimate for the 2n transfer cross section. For the simultaneous 2^+ excitation we assume a cross section of 1 mb.

In the same sequence of measurements we can determine the inelastic 2^+ excitation by the Be-target. The decuced matrix element can be used for the combined 2n-transfer and 2^+-excitation. It will be interesting to compare the inelastic nuclear 2^+ excitation with the Coulomb excitation by a heavy target nucleus.

In parallel to this letter of intent we will start a program at the Munich tandem to study the 2n-transfer for stable Zn and Sn beams with the Q3D magnetic spectrograph using our ^{10}Be targets and detecting the 2n-transfer via the two-α-decay of ^{8}Be. We will learn about the magnitude of the cross sections, the enhancement factors and the optimum beam energy for performing the measurements. Since finally only measurements between neighbouring even-even-nuclei are compared, the extraction of changes of the pairing gap should not be too difficult.

Furthermore we will start calculations with the coupled channel code FRESCO [25] to describe the transfer and inelastic excitations also properly in theory. Here we will study the sensitivity to the different matrix elements and obtain better predictions for the cross sections.

3 Experimental setup, count rates and future requested beam times

Typical cross sections of 1 mb and typical target thicknesses of 400 μg cm^{-2} result in reaction probabilities of about 10^{-7}. Assuming for the MINIBALL a γ-efficiency of 10% at 1MeV, we require 10^{10} particles to collect 100 events in the full energy peak. Assuming a REX-ISOLDE efficiency of 7% for producing high energy beams from ISOLDE we require the following number of 8-hour-shifts for the Zn and Sn-experiments:

beam	ISOLDE (atoms/s)	REX-ISOLDE ions/s at 3.1 MeV/u	Photopeak counts/h	shifts
^{74}Zn	$2.0 \cdot 10^6$	$1.4 \cdot 10^5$	2	8
^{76}Zn	$1.0 \cdot 10^6$	$7.0 \cdot 10^4$	1	8
^{78}Zn	$\sim 3 \cdot 10^5$	$\sim 4 \cdot 10^4$	0.4	8
total				**24**

Table 2: Required shifts for runs with Zn beams

beam	ISOLDE	REX-ISOLDE	Photopeak	shifts
	(atoms/s)	(ions/s) at 4.2 MeV.u	counts/h	
^{130}Sn	$8.0 \cdot 10^8$	$1.6 \cdot 10^7$	25	12
^{132}Sn	$3.0 \cdot 10^8$	$6.0 \cdot 10^6$	10	12
total				**24**

Table 3: Required shifts for runs with Sn beams

We want to request in a proposal **a total of 24 shifts of radioactive Zn beam time at 3.1 MeV/u using a UC_2 target laser ion or plasma ion source.**

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