Two-Neutron Transfer Reactions with thin ^{10}Be Targets at MINIBALL

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The shape coexistence in the singly-magic nucleus ^{32}Mg can be studied via the two-neutron transfer reaction. While ^{30}Mg (N=18) has a spherical 0^+ ground state, the ground state of ^{32}Mg (N=20) is highly deformed ($\beta = 0.5$) and the spherical 0^+ state is predicted at $E^* = 1.55$ MeV [1]. Since nucleon transfer predominantly proceeds between states of similar deformation, two-neutron transfer from ^{30}Mg to ^{32}Mg offers the possibility to study the shape coexistence for the first time. It is planned to perform this experiment using the radioactive beam at REX-ISOLDE in conjunction with the MINIBALL γ-ray spectrometer [2].

Preparatory experiments with stable ^{26}Mg beams were performed at the MLL (see separate report [3]) and at the IKP Cologne during a MINIBALL experimental campaign at the Cologne Tandem accelerator. The reaction ^{10}Be(^{26}Mg,^{28}Mg)^{8}Be was used to study the two-neutron transfer cross section in order to test the feasibility of the experiment with the radioactive ^{30}Mg beam and to compare with theoretical DWBA calculations.

A thin radioactive ($t_{\frac{1}{2}} = 1.6 \cdot 10^6$ a) ^{10}Be target [4] (20 μg/cm^2 BeO on a 38 μg/cm^2 C backing, enrichment ~61%) was used for the experiment. The use of this rare target material provides a clear trigger signal for two-neutron transfer, since the reaction product ^{8}Be is unstable and instantly decays into two α particles. The dominant background contributions from the ^{9}Be contamination in the target and from the backing were measured separately using ^{9}Be and C targets.

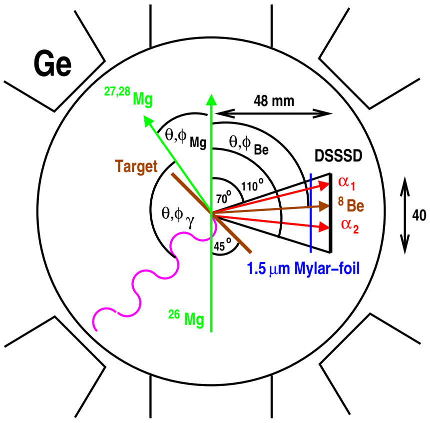

Fig. 1: Schematic drawing of the experimental setup

Fig. 1 shows a sketch of the experimental setup. Due to the reaction kinematics for the one-neutron transfer (Q = 4.778 MeV, $\theta_{graz} = 80.3°$) and two-neutron transfer reaction (Q = 6.469 MeV, $\theta_{graz} = 91.8°$) a double sided silicon strip detector (DSSSD) was placed perpendicular to the beam in order to detect the two α particles from the ^{8}Be decay, covering the angular region of $\theta = 90° \pm 20°$ and $\phi = 90° \pm 20°$. In order to reduce the number of electronics channels the 40×40 strip DSSSD was operated at 16×16 channels.

A thin (1.5 μm) Mylar foil was used to protect the detector from elastically scattered particles from the target, whilst barely affecting the α particles from the ^{8}Be decay. The target was mounted at an angle of 45° relative to the beam. Due to the small Q-value of the ^{8}Be decay (91 keV) the angle between the two α particles is smaller than 16°. For the γ-ray detection 6 MINIBALL clusters were used, three in forward ($\theta = 45°$) and three in backward direction ($\theta = 135°$). The energy of the ^{26}Mg beam was 57.0 MeV (2.2 MeV/u). At least one signal detected in the DSSSD was used as trigger for the DAQ system, resulting in an accepted event rate of $\sim$ 400/s at a typical beam current of $\sim$ 4.5 nA.

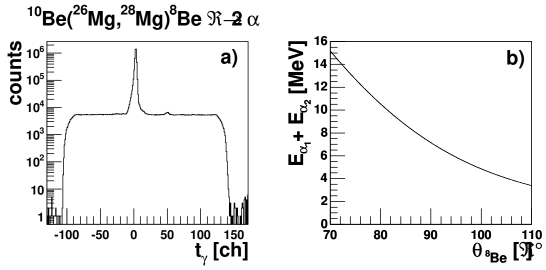

Fig. 2: a) α-γ-timing correlation. b) Energy-angle correlation from a kinematics calculation for the correlation of the ^{8}Be decay products following the two-neutron transfer to ^{28}Mg. The energy of ^{8}Be is expressed as the sum of the two α particles ($E_{\alpha_1} + E_{\alpha_2}$).

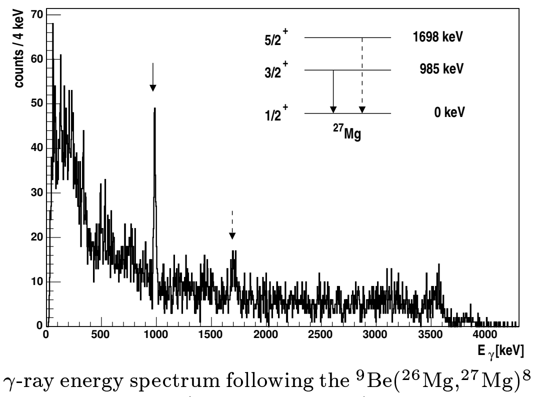

Fig. 3: γ-ray energy spectrum following the ^{9}Be(^{26}Mg,^{27}Mg)^{8}Be one-neutron transfer reaction (E_{beam} = 57 MeV) in coincidence with two detected particles in the DSSSD (Doppler-corrected for transfer to the first excited state of ^{27}Mg).

During the data analysis, events were selected on the particle-γ coincidence peak visible in Fig. 2 together with the requirement of a particle multiplicity $N_{part} = 2$. For the Doppler-correction of the γ-ray energy spectra first the direction of the ^{8}Be reaction products was reconstructed from the registered positions of its decay products in the DSSSD. Subsequently the direction and velocity of the transfer products ^{27}Mg and ^{28}Mg, respectively, could be derived from kinematics correlations (separately for the one- and two-neutron transfer and different excited states in the transfer product, respectively). The Doppler-correction was performed on the detector level, as the pulse shape analysis code for the digital electronics was not implemented at the time of the experiment.

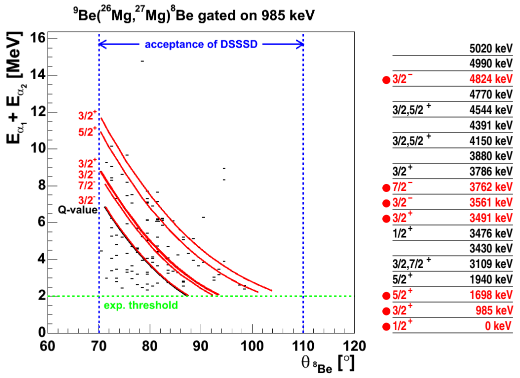

Fig. 4: Energy-angle correlation for the one-neutron transfer to ^{27}Mg gated on the first excited state ($3/2^+$) at 985 keV in coincidence with two detected particles in the DSSSD. The solid lines correspond to the kinematic expectations for different excited states in ^{27}Mg as indicated. At the right-hand side the ^{27}Mg levels below $\sim$ 5 MeV are listed with dots indicating the states used for the DWBA calculation.

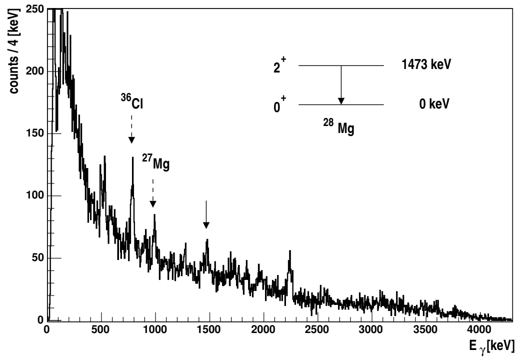

Fig. 5: γ-ray energy spectrum following the ^{10}Be(^{26}Mg,^{28}Mg)^{8}Be two-neutron transfer reaction (E_{beam} = 57 MeV) in coincidence with two detected particles in the DSSSD (Doppler-corrected for transfer to the first excited state of ^{28}Mg). Also the transition from the first excited state coming from one-neutron transfer to ^{27}Mg at 985 keV and from the fusion reaction ^{12}C(^{26}Mg,pn)^{36}Cl at 788 keV can be seen.

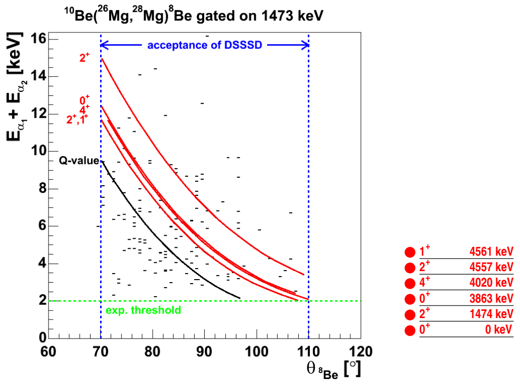

Fig. 6: Energy-angle correlation for the two-neutron transfer to ^{28}Mg gated on the first excited state (2^+) at 1473 keV in coincidence with two detected particles in the DSSSD. The solid lines correspond to the kinematic expectations for different excited states in ^{28}Mg as indicated. At the right-hand side the ^{28}Mg levels below $\sim$ 4.5 MeV are listed with dots indicating the states used for the DWBA calculation.

Fig. 3 shows the γ-ray energy spectrum Doppler-corrected for the one-neutron transfer reaction ^{9}Be(^{26}Mg,^{27}Mg)^{8}Be leading to the first excited state in ^{27}Mg. The transitions from the first and second excited states in ^{27}Mg are clearly visible. From the contents of the $3/2^+$ ($5/2^+$)-transition to the ground state experimental transfer cross sections of 0.19 mb and 0.10 mb, respectively, were deduced.

The kinematic energy-angle correlation (as shown in Fig. 2b for the two-neutron transfer to the ground state) allows to identify the relevant ^{8}Be decay products from the respective transfer channels. In Fig. 4 the correlation between the ^{8}Be energy (determined from the sum of the two registered particles in the DSSSD) and the reconstructed direction of the ^{8}Be reaction products is displayed for events gated on the 985 keV transition in ^{27}Mg. The solid lines represent kinematic expectations for those excited states of ^{27}Mg included in the DWBA calculations due to their large spectroscopic factors (indicated by dots on the right-hand level list). Obviously the one-neutron transfer proceeds to excited states, all of them de-exciting via the first excited state.

A similar behaviour was measured in the case of the two-neutron transfer, where the γ-ray energy spectrum (Doppler-corrected for the first excited state in ^{28}Mg) is shown in Fig. 5. Here a two-neutron transfer cross section to the 2^+-state in ^{28}Mg of σ_{2n} = 0.07 mb was deduced. Analog to Fig. 4, also for the E_α^{sum}-θ_{Be} correlation in the case of the two-neutron transfer in Fig. 6 transfer to excited states decaying via the first excited state was observed.

DWBA calculations using FRESCO [5] were performed. The optical model parameters were taken from the reaction ^{28}Si(^{9}Be,^{8}Be)^{29}Si [6]. The spectroscopic factors originated from a ^{26}Mg(d,p)^{27}Mg measurement with a similar Q-value (4.211 MeV) [7].

In order to calculate the cross section for the one-neutron transfer the main contributing excited states in ^{27}Mg (according to their spectroscopic factors) were taken into account for the FRESCO calculation. Theoretical cross sections of σ_{1n}^{th} = 3.9 mb for the transfer to the first excited $3/2^+$ state in ^{27}Mg and 2.2 mb for the transfer to the second excited state ($5/2^+$), respectively, were obtained. The resulting discrepancy of about a factor of 20 between measured and calculated one-neutron transfer cross section is not yet understood and subject to extensive investigations.

For the two-neutron transfer only excited states in ^{28}Mg with known spectroscopic factors could be included in the calculations. However, quite a few states around the Q-value are known to exist while their spins and spectroscopic factors are yet unknown. Therefore the calculated two-neutron transfer cross section of σ_{2n}^{th} = 0.069 mb represents only a coarse lower limit, while realistically a cross section of around 1 mb can be estimated, again a large discrepancy between calculated and measured cross section has to be admitted.

The ongoing analysis concentrates on the clarification of the quoted discrepancies which is mandatory for a realistic rate and experiment planing of the intended radioactive beam experiment at REX-ISOLDE.

References

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