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Analysis and results of the ^{104}Sn Coulomb excitation experiment

G Guastalla[1], D D DiJulio[2], M Górska[3], J Cederkäll[2], P Boutachkov[1,3], P Golubev[2], S Pietri[3], H Grawe[3], F Nowacki[4], A Algora[5,6], F Ameil[3], T Arici[7,3], A Atac[8], M A Bentley[9], A Blazhev[10], D Bloor[9], S Brambilla[11], N Braun[10], F Camera[11], C Domingo Pardo[5], A Estrade,[3] F Farinon[3], J Gerl[3], N Goel[3,1], J Grębosz[12], T Habermann[3,13], R Hoischen[2], K Jansson[2], J Jolie[10], A Jungclaus[14], I Kojouharov[3], R Knoebel[3], R Kumar[15], J Kurcewicz[16], N Kurz[3], N Lalović[3], E Merchan[1,3], K Moschner[10], F Naqvi[3,10], B S Nara Singh[9], J Nyberg[17], C Nociforo[3], A Obertelli[18], M Pfützner[3,16], N Pietralla[1], Z Podolyák[1], A Prochazka[19], D Ralet[3,1], P Reiter[10], D Rudolph[2], H Schaffner[3], F Schirru[19], L Scruton[19], T Swaleh[9], J Taprogge[1]0, R Wadsworth[9], N Warr[10], H Weick[3], A Wendt[10], O Wieland[11], J S Winfield[3] and H J Wollersheim[3]

[1] Institut für Kernphysik, Technische Universität Darmstadt, Darmstadt, Germany
[2] Department of Physics, Lund University, Lund, Sweden
[3] Helmholtzzentrum für Schwerionenforschung GmbH (GSI), Darmstadt, Germany
[4] IPHC, IN2P3-CNRS et Université de Strasbourg, Strasbourg, France
[5] IFIC (CSIS-Univ. Valencia) Valencia, Spain
[6] Institute of Nuclear Research of the Hungarian Academy of Sciences, Debrecen, Hungary
[7] Institute of Science, Istanbul University, Turkey
[8] Department of Physics, Ankara University, Ankara, Turkey
[9] Department of Physics, University of York, York, United Kingdom
[10] Institut für Kernphysik, Universität zu Köln, Köln, Germany
[11] Dipartimento di Fisica, Università di Milano, and INFN Sezione Milano, Milano, Italy
[12] The Institute of Nuclear Physics PAN, Kraków, Poland
[13] Department of Physics, Goethe University, Frankfurt am Main, Germany
[14] Instituto de Estructura de la Materia, CSIC, Madrid, Spain
[15] Inter-University Acceleration Center, New Dehli, India
[16] The Institute of Experimental Physics, Warsaw, Poland
[17] Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden
[18] CEA, Centre de Saclay, IRFU/Service de Physique Nucléaire, Gif-sur-Yvette, France
[19] Department of Physics, University of Surrey, Guildford, United Kingdom
[20] Departamento de Física Teórica, Universidad Autónoma de Madrid, Madrid, Spain

E-mail: `g.guastalla@gsi.de`

Abstract. The analysis of the Coulomb excitation experiment conducted on ^{104}Sn required a strict selection of the data in order to reduce the large background present in the γ-ray energy spectra and identify the γ-ray peak corresponding to the Coulomb excitation events. As a result the B(E2; $0^+ \rightarrow 2^+$) value could be extracted, which established the downward trend towards ^{100}Sn and therefore the robustness of the N=Z=50 core against quadrupole excitations.

1. Introduction

The N=Z=50 nucleus ^{100}Sn, located at the proton-drip line, is predicted by the shell model to be the heaviest self-conjugated doubly magic nucleus. Experimental evidence has indeed confirmed the presence of a large shell gap [1] in this nucleus. However, at the present nuclear facilities, it is still impossible to measure excited states in ^{100}Sn which will give a direct proof of the stability of the shell closure. This aspect has been therefore studied by looking at the evolution of the shell structure in the tin isotopic chain. A sensitive tool to get information about the polarization of the core is the measurement of the reduced E2 transition strength from the ground state, the B(E2; $0^+ \rightarrow 2^+$) value (in the following called B(E2)). The results obtained for this quantity for Sn isotopes from N=64 down to N=56 indicated, despite the large uncertainties, a constant trend. This was at variance with the shell model predictions (see [2]) and from this behavior it was not possible to exclude a *softening* of the N=Z=50 shell closure. Therefore the measurement of the B(E2) value in the next even-even isotope toward ^{100}Sn, i. e. ^{104}Sn, was needed. An important aspect is also that this nucleus could be more precisely described by shell model calculations.

The experiment has been performed at GSI using the FRagment Separator (FRS) [3] to produce the exotic beam and the EUROBALL-PreSPEC setup [4] to measure the E2 transition strength, as will be described in the following paragraph. To excite the rare isotopes, the Relativistic Coulomb excitation technique in inverse kinematics has been used. A B(E2) value measurement has been performed in similar conditions also for the stable ^{112}Sn, for the purpose of normalization of the B(E2) value for ^{104}Sn. In this way one could neglect in the extraction of the B(E2) value possible systematic errors as well as feeding pattern from states above the 2^+ and the detection efficiency of the gamma-ray detector setup. This procedure assumes however a similar structure of the first excited states in both nuclei.

The analysis of the data collected in this experiment is particularly challenging because of the large contribution of background radiation in the γ-ray energy spectra and the low intensity of the exotic beam. In this paper, the analysis steps applied to extract the γ-ray energy peak associated to the $2^+_1 \rightarrow 0^+$ transition are briefly described.

2. The experiment

In the experiment, a stable ^{124}Xe beam of 793 MeV/A delivered by SIS-18 impinged on a ^{9}Be (4 g/cm^2 thick) target, which was positioned at the entrance of the FRS. Isotopes produced by fragmentation reactions in the target were separated by the FRS using the $B\rho$-ΔE-$B\rho$ method and identified with several detectors placed at the intermediate and at the final focal plane. The proton number (Z) of the ions has been determined from the energy loss signals of the MUltiple Sampling Ionization Chamber (MUSIC), while the mass-over-charge ratio (A/q) was obtained from a Time-Of-Flight (TOF) measurement, using plastic scintillators in the second half of the separator. The position of the ions was also measured at the aforementioned focal planes in Time Projection Chambers (TPCs).

In order to induce Coulomb excitation of the selected fragments, a secondary target made of ^{197}Au (386 mg/cm^2 thick) was positioned at the end of FRS. The γ-rays emitted in the reactions in the target were detected by the RISING array [4], which comprised 15 EUROBALL Cluster detectors. To take advantage of the Lorentz boost, occurring due to the relativistic energy of the beam, these detectors were placed in three rings at small angles (up to 40°) relative to the beam direction. Finally, the recoiling particles were identified and tracked with the Lund York Cologne Calorimeter (LYCCA) placed downstream of the target position [5].

3. The analysis

The isotopes have been identified and selected before and after the secondary target in order to select mainly events arising from the Coulomb scattering channel. At the final focal plane, after gating on Z=50, the isotope of interest could be uniquely identified by plotting the position of the ion against the A/q value [6]. For the selection of the Sn isotopes after the target, the ΔE-E plot from the LYCCA calorimeter was used [6].

The next step of the analysis was to reduce contributions from nuclear reactions and the atomic background in the γ-ray energy spectra and to identify the peak associated with the $2_1^+ \rightarrow 0^+$ transition. Due to the relativistic energy of the beam and the high velocity of the particles after the target, a precise Doppler correction of the γ-ray energy signals was required. Event-by-event velocity information was acquired from the TOF measurements in the FRS combined with a constant offset taking into account the unknown layers of matter in the final focal plane. The best offset was chosen based on the peak-to-background ratios observed in the Doppler corrected energy spectra when using different velocity values. A selection of the scattering angles of the ions after the secondary target was carried out in order to reduce contributions from nuclear reactions and elastic scattering (see Fig.1). This parameter was calculated with the incoming and the outgoing angles of the ions, measured before and after the target using a TPC detector at the final focal plane, the target DSSSD and the LYCCA Wall detectors. The chosen range from 15 mrad to 40 mrad is compatible with the 15 fm calculated as a *safe* impact parameter for our experimental setup [4] and visibly improves the peak-to-background ratio. A narrow time window of about 15 ns has been also applied to select the prompt γ radiation.

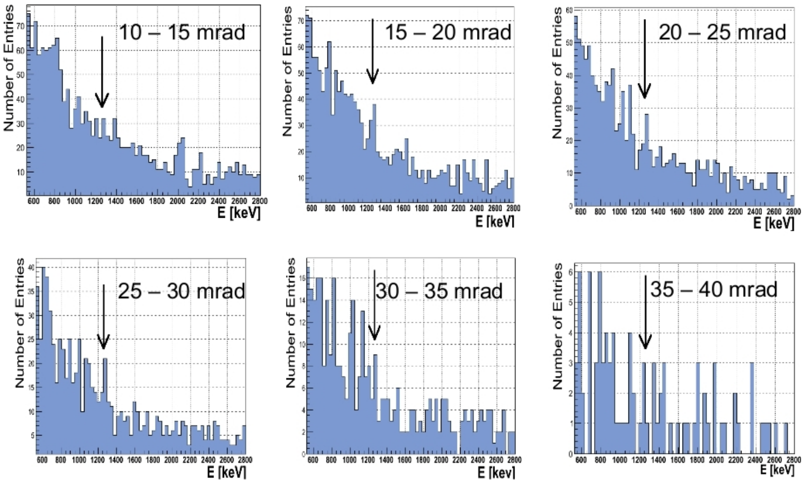

Figure 1. Examples of γ-ray energy spectra produced gating on different ranges of the scattering angle for the ^{112}Sn case. Below 15 mrad the contribution from elastic scattering is covering the peak corresponding to the $2_1^+ \rightarrow 0^+$ transition.

Due to the poor peak-to-background ratio of the ^{104}Sn data, the analysis gates described above have been optimized for the ^{112}Sn case and applied to ^{104}Sn. This procedure is adequate because of the assumption that the two isotopes have a similar structure and therefore an identical excitation process can be expected for both.

The analysis led to clear identification of the $2_1^+ \rightarrow 0^+$ transition in the final Doppler corrected energy spectra [6].

The reference value of B(E2) = 0.242(8) e^2b^2 for ^{112}Sn, measured in the most recent sub-barrier Coulomb excitation experiment [7], was used for normalization.

4. Conclusions

The analysis procedure described in this work allowed us to identify the Coulomb excitation γ-ray peak of the transition of interest, despite the scarce statistics and the large background in the γ-ray energy spectra. The method to determine the velocity of the ions after the secondary target by using event-by-event FRS velocity with a constant offset was appropriate for the Doppler correction of the γ-ray energy signals. The accurate choice of a narrow range for the time in the Germanium detectors and for the scattering angle of the ions after the secondary target also improved considerably the peak-to-background ratio.

As a result for ^{104}Sn the B(E2; $0^+ \rightarrow 2^+$)=0.10(4) e^2b^2 has been obtained and a decreasing trend of B(E2) values towards ^{100}Sn has been established for the first time. This value is in agreement with LSSM calculation performed without a significant truncation of the model space and it infers the stability of the N=Z=50 shell closure [6].

5. Aknowledgments

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