ISOSPIN SYMMETRY IN THE ^{60}Zn NUCLEUS*

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The "isospin mixing" phenomenon was measured by the study of the Isovector Giant Dipole Resonance (IVGDR) in ^{60}Zn at two different excitation energies $E^* = 47$ MeV and $E^* = 58$ MeV. A fusion–evaporation reaction, with a beam of ^{30}S and a target of ^{28}Si, was used to produce the nucleus of interest. A second target of ^{30}Si was used to produce ^{62}Zn. For this nucleus, the mixing effect does not strongly appear in the gamma decay of the GDR and for this reason, the second reaction is necessary as reference. The experimental setup was composed of the GALILEO array (germanium detectors) coupled to large-volume $LaBr_3$(Ce) detectors for the γ-ray measurements. An overview of the ongoing analysis and the preliminary results are presented.

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1. Introduction

Isospin symmetry was introduced by Heisenberg in 1932 [1] based on two assumptions on the strong interaction, the charge symmetry and the charge independence, namely that the strength of the strong interaction between any pair of nucleons is the same, independent of whether they are protons or neutrons. In the isospin formalism, neutrons and protons are considered as two quantum states of the same particle, a nucleon, with the isospin projection I_z being $1/2$ and $-1/2$, respectively. A nucleus has a well-defined value of $I_z = (N - Z)/2$, while the total isospin I, according to quantum mechanics rules, can assume values $(N-Z)/2 < I < (N+Z)/2$. In general, the nuclear ground state corresponds to the lowest value of isospin $I = |I_z|$.

This symmetry does not consider the Coulomb interaction between protons in the nucleus and this leads to breaking of the symmetry. One of the effects of this breaking is inducing of a mixing between states with different isospin, therefore, the isospin stops to be a good quantum number. This phenomenon is called *isospin mixing*. In a previous work [2], it was shown that the value of the isospin mixing in the ground state can be extracted from the measurement of isospin mixing at high excitation energy and by using the theoretical approach reported in [3].

In the case of ^{60}Zn, the theoretical expectation value for the mixing probability in the ground state α^2 is about 2–3% as reported in Ref. [4]. The knowledge of isospin impurities is interesting not only in connection with Isobaric Analog State (IAS) properties and for the Fermi β decay of the $N \sim Z$ nuclei near the proton drip line, but it gives an important correction factor to the Fermi transition rates for the calculation of the first element of the Cabibbo–Kobayashi–Maskawa matrix [4].

2. The measurement of isospin mixing

The isospin quantum number is not a physics observable, therefore, it cannot be directly measured. A typical procedure is the measurement of the consequence of isopin symmetry and its breaking on the nuclear system. The adopted experimental method is to measure a transition that would be forbidden if the mixing of states of different isospin was not present. In this case, the γ decay of Giant Dipole Resonance (GDR), in which the total strength of E1 transitions is concentrated, is a perfect probe to investigate this effect [5, 6]. The compound nucleus ^{60}Zn is created in the $I = 0$ channel. Following the selection rules for E1 γ rays, the transition between two states with $I = 0$ is forbidden and the only decay allowed is to the very few populated $I = 1$ states. Instead, if the nuclear configuration is a combination of $I = 0$ and $I = 1$ states, the transition to a final $I = 0$ state is possible. A consequence of this phenomenon is a change of the γ-decay yield and so

the measurement of E1 strength of the GDR gives a direct indication of the mixing degree. These statements are, in general, valid for the first step of compound nuclear decay.

The mixing probability in a compound nucleus is dependent on the nuclear temperature. As hypothesized by Wilkinson in 1956 [7], the isospin symmetry can be partially restored as the excitation energy increases. The mixing probability can be expressed as the ratio between the Coulomb spreading width and the compound nucleus decay width. With an increase of the excitation energy, the lifetime of the compound nucleus will decrease, limiting the time necessary for mixing and inducing a recovery of the symmetry. The isospin mixing in the ^{60}Zn nucleus was previously measured in an inclusive experiment, as reported in Ref. [8]. The experimental technique used was similar to the one reported here, the reference nucleus was ^{61}Zn and an unexpectedly high mixing of 4.5% was obtained.

The present experiment was performed at Laboratori Nazionali di Legnaro (LNL) in order to study the isospin mixing effect in the ^{60}Zn nucleus produced by the fusion–evaporation reaction ^{32}S $+^{28}$Si in the $I = 0$ channel. Moreover, a reference reaction ^{32}S$+^{30}$Si was used to produce ^{62}Zn in the $I \neq 0$ channel. The second reaction is necessary to tune the parameters of the statistical model and to fix the GDR parameters which will be used to describe the γ decay of ^{60}Zn. Both nuclei were produced at 2 different excitation energies ($E_1^* = 47$ MeV and $E_2^* = 58$ MeV) in order to study the dependence of mixing probability on nuclear temperature (where $T_1 = 2$ MeV and $T_2 = 2.4$ MeV). To produce ^{60}Zn at $E_1^* = 47$ MeV and $E_2^* = 58$ MeV, respectively, ^{32}S beams of 86 MeV and 110 MeV energy were used, while for ^{62}Zn, the beam energies were 75 MeV and 98 MeV, respectively. The first campaign in 2016 was previously presented in Ref. [13].

3. Isomix 2016

3.1. Experimental setup

The experimental setup consisted of the GALILEO array [9] coupled to 10 $LaBr_3$:Ce detectors ($3'' \times 3''$) [10]. In addition, two ancillary arrays were used, EUCLIDES and Neutron Wall. The 25 Compton-suppressed HPGe detectors of GALILEO were placed at 22.5 cm from the target and were used to measure low-energy γ rays (up to 3 MeV). The full-energy peak efficiency at 1.3 MeV was $\sim 2\%$. The $LaBr_3$:Ce detectors ($3'' \times 3''$) [10] were placed at 20 cm from the target and at 70° with respect to the beam-line direction. The full-energy peak efficiency for these detectors was 2.2% at 1.3 MeV. The 2 ancillary arrays were used to provide data needed to tune the parameters of the statistical model. The EUCLIDES array [11] consists of 40 silicon detectors in ΔE–E telescope configuration for the detection of

light charged particles, while the Neutron Wall array [12] is composed of 45 BC501A liquid scintillator neutron detectors placed at forward angle with respect to the beam-line direction.

3.2. Preliminary data analysis

The first part of the analysis concerned the energy calibration of $LaBr_3$:Ce and HPGe detectors. For HPGe, standard sources of ^{22}Na, ^{60}Co, ^{88}Y, ^{133}Ba, ^{137}Cs and ^{152}Eu were used, and the spectra were calibrated. For $LaBr_3$:Ce detectors, standard γ-ray calibration sources of ^{137}Cs, ^{60}Co, ^{88}Y, ^{241}Am–Be–Ni were combined with an in-beam calibration using the reaction $^{11}\mathrm{B} + d \rightarrow {}^{13}\mathrm{C}^*$, in order to calibrate spectra up to 15.1 MeV. Due to the well-known non-linearity of PMT for $LaBr_3$:Ce, a linear calibration was used up to 5 MeV and a quadratic calibration from 5 to 15 MeV obtaining a nonlinearity effect $< 1\%$.

The time-gated γ-ray spectra for the four reactions are shown in Fig. 1. It can be observed that all the spectra show the typical exponential shape of CN statistical γ decay and they also exhibit a change in the slope at

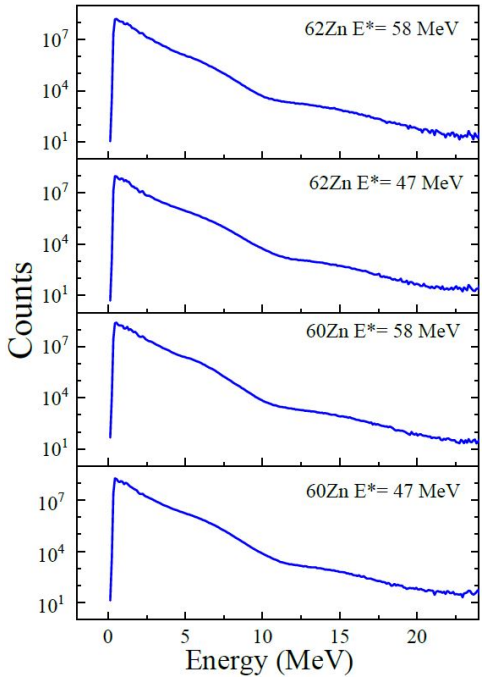

Fig. 1. Plot of the γ-ray spectra for the two nuclei at the two excitation energies. The condition on time peak to reject neutrons and background was applied. All the spectra show the typical exponential shape of CN statistical γ decay and a change in the slope at $\sim$ 10 MeV, typical of the presence of the GDR.

$\sim$ 10 MeV, typical of the presence of the GDR. For the analysis, a statistical model must be used to describe the CN decay. The combined statistical-model analysis of the γ decay of ^{60}Zn and ^{62}Zn will allow to extract the isospin-mixing probability at two different excitation energies. In order to extract the spin distribution associated to the gating condition, we studied the residual nuclei population using the γ-ray spectra from the GALILEO array. We found out that there were some transitions coming from a different nucleus, ^{48}Cr, in both reactions. This nucleus is produced by a fusion–evaporation reaction between the ^{30}S beam and ^{16}O, showing a very high contamination of oxygen in the targets that, after more detailed analysis, turned out to be around 50%. Therefore, we decided to perform another data taking in December 2018.

4. Isomix 2018

4.1. Preliminary data analysis

The data taking was, again, performed at Laboratori Nazionali di Legnaro with a very similar experimental setup, which included the 25 HPGe detectors from the GALILEO array but only seven $LaBr_3(Ce)$ crystals. The two ancillary arrays have not been used on this occasion. We have verified from the HPGe spectra the absence of any contaminants in the target and we identified the populated residual nuclei as shown in Fig. 2. At the moment, the analysis is still ongoing.

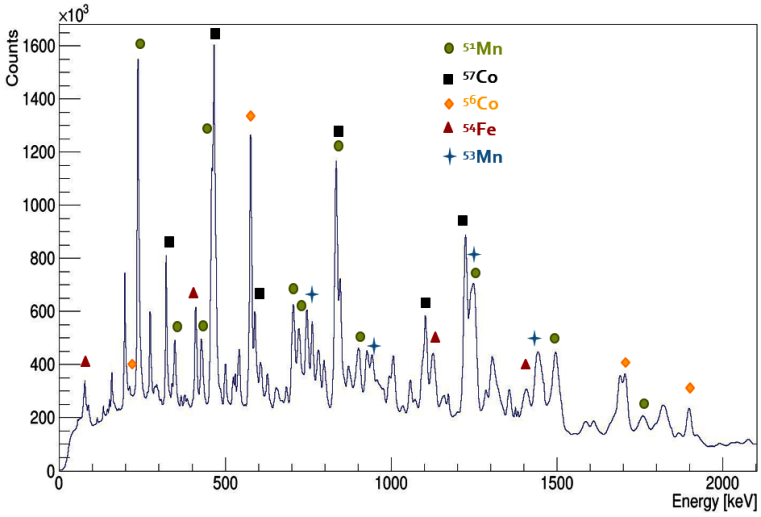

Fig. 2. The γ-ray spectrum of the GALILEO array, associated to the reaction $^{32}\mathrm{S} + {}^{28}\mathrm{Si} \rightarrow {}^{60}\mathrm{Zn}$ with $E_{\mathrm{beam}} = 110$ MeV.

5. Conclusion

Two nuclei ^{60}Zn and ^{62}Zn were produced using a fusion–evaporation reaction at Laboratori Nazionali di Legnaro (LNL) in order to study the CN decay and the isospin symmetry breaking. The GDR gamma decay was observed. The preliminary analysis showed a non-negligible contamination of oxygen in the target and for this reason a second data taking was performed. The analysis is still ongoing and the future goal is to tune the parameters of the statistical model and to extract precisely the isospin mixing probability.

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