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STUDY OF THE ISOSPIN SYMMETRY IN ^{60}Zn*

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The breaking of isospin symmetry caused by the Coulomb interaction can be measured by the study of E1 γ decay. The Isovector Giant Dipole Resonance (IVGDR) was measured in ^{60}Zn and ^{62}Zn at two different excitation energies $E^* = 47$ MeV and $E^* = 58$ MeV with the goal of deducing the isospin mixing term. A fusion–evaporation reaction, with a beam of ^{32}S and a target of ^{28}Si, was used to produce ^{60}Zn. We also produced the compound nucleus ^{62}Zn using the reaction ^{32}S + ^{30}Si. This last reaction is required because, for the produced nucleus, the statistical model analysis is much less sensitive to the isospin mixing, and this allows to extract the GDR parameters and use them for isospin mixing sensitive reaction populating neighboring nucleus with $N = Z$. The experimental setup was composed of GALILEO array (germanium detectors) coupled to the large-

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volume $LaBr_3$:Ce detectors for the γ-rays measuring and by two ancillary arrays, EUCLIDES and the Neutron Wall for the detection of particles and neutrons, respectively. An overview on the ongoing analysis and on preliminary results is presented.

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1. Introduction

Isospin symmetry was introduced by Heisenberg in 1932 [1], based on two assumptions, the charge symmetry and the charge independence for which n–n, p–p and n–p interactions are considered equivalent. In the isospin formalism, neutrons and protons are viewed as two quantum states of the same particle, the nucleon, with isospin projection I_z, respectively, 1/2 and $-1/2$. A nucleus has a well-defined value of $I_z = (N-Z)/2$, while I, according to quantum mechanics rules, can assume values $(N-Z)/2 < I < (N+Z)/2$. In general, for $N = Z$ nuclei, the nuclear ground state corresponds to the lower value of isospin $I = |I_z|$. This symmetry does not consider the Coulomb interaction between protons in the nucleus and this leads to a breaking of the symmetry which induces a mixing between states with different isospin. This phenomenon is called *isospin mixing*.

The consequence is that it is not possible to assign a unique value of isospin to a nuclear state. Because the nuclear force overwhelms the Coulomb interaction, a perturbation approach can be used to describe isospin mixing. In a previous work [2], it is shown that the value of the isospin mixing in the ground state can be obtained from the measurement of isospin mixing at high excitation energy by using the theoretical approach reported in [3]. For ^{60}Zn, the theoretical expectation value for the mixing probability in the ground state α^2 is about 2–3% as reported in [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 also gives an important correction factor to the Fermi transition rates for the calculation of the first element of Cabibbo–Kobayashi–Maskawa matrix [4].

2. The measurement of isospin mixing

The breaking of the symmetry can be observed by studying a transition that would have been forbidden by the selection rules if the mixing of states was not present. In this case, the decay of Giant Dipole Resonance (GDR), in which the total strength of E1 transition is concentrated, is a perfect probe to investigate this effect [5, 6]. The compound nucleus ^{60}Zn is created in $I = 0$ channel. Following the selection rules for E1, the transition between two states with $I = 0$ is forbidden and the only decay allowed is to the very few populated $I = 1$ state. Instead, if the nucleus lies in a mixed state, namely a combination of $I = 0$ and $I = 1$ states, the transition to a final $I = 0$ state is possible. This transition corresponds to an increasing of the gamma-decay yield and so the E1 strength gives direct indication of the mixing degree.

The mixing probability is also dependent on the nuclear temperature. At the increasing of excitation energy of compound nucleus, levels lie closer to each other and, as a consequence, there will be a rising of the mixing probability that reaches a maximum when the energy gap between levels becomes comparable to the decay width. At higher excitation energy, the lifetime of compound nucleus will decrease, limiting the time necessary for mixing and inducing a recovery of the symmetry, as hypothesized by Wilkinson in 1956 [7]. The isospin mixing in ^{60}Zn nucleus was previously measured in an inclusive experiment, as reported in [8].

The experiment was performed at Laboratori Nazionali di Legnaro (LNL) in order to study the isospin mixing effect in the nucleus ^{60}Zn produced by the fusion–evaporation reaction $^{32}\mathrm{S} + {}^{28}\mathrm{Si}$ in an $I = 0$ channel. Moreover, a symmetric reaction $^{32}\mathrm{S} + {}^{30}\mathrm{Si}$ was used to produce ^{62}Zn in an $I \neq 0$ channel. The second compound nucleus must be used to tune the statistical model and to fix the GDR parameters which will be used to describe the γ decay of ^{60}Zn and to deduce the isospin mixing. Both of nuclei were produced at 2 different excitation energies ($E_1^* = 47$ MeV and $E_2^* = 58$ MeV) in order to study the trend of mixing probability with nuclear temperature (where $T_1 = 2$ MeV and $T_2 = 2.4$ MeV). To produce the ^{60}Zn, respectively, at $E_1^* = 4$ MeV and $E_2^* = 58$ MeV, 86 MeV and 110 MeV beam energies were used, instead, for ^{62}Zn, the beam energies were, respectively, 75 MeV and 98 MeV.

3. Experimental setup

The experimental setup consisted of GALILEO array [9] of 25 Compton suppressed HPGe detectors placed at 22.5 cm from the target, used to measure low-energy γ rays. The full-energy peak efficiency at 1.3 MeV is $\sim 2\%$. GALILEO array is coupled to 10 LaBr$_3$:Ce detectors ($3'' \times 3''$) [10] 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 is 2.2% at 1.3 MeV.

In addition, 2 ancillary arrays were used to tune in a better way the statistical model. The EUCLIDES array [11] consists of 40 silicon detectors in ΔE–E telescope configuration for the detection of light-charge particles, while Neutron Wall array [12] is composed of 45 BC501A liquid scintillation detectors, placed at forward angle with respect to the beam-line direction, for the detection of neutrons.

4. Preliminary data analysis

The first part of the analysis concerned the energy calibration of LaBr$_3$:Ce and HPGe detectors. For HPGestandard sources of ^{22}Na, ^{60}Co, ^{88}Y, ^{133}Ba, ^{137}Cs and ^{152}Eu were used, and the spectra were calibrated using up to 5 order polynomials. Instead, for LaBr$_3$:Ce detectors were used both sources of ^{137}Cs, ^{60}Co, ^{88}Y, ^{241}AmBeNi, and an in beam calibration using the reaction $^{11}\mathrm{B}+\mathrm{D}\rightarrow{}^{13}\mathrm{C}^*$, in order to calibrate spectra up to 15.1 MeV. Because of the well-known PMT non-linearity for LaBr$_3$:Ce, there was used a linear calibration up to 5 MeV and a quadratic calibration from 5 to 15 MeV obtaining a nonlinearity effect $< 1\%$.

The experiment was focused on the measure of the γ decay of the GDR and for this reason, it was necessary to calibrate and analyze the time spectrum of LaBr$_3$:Ce to discriminate events coming from the γ decay of the GDR from the background that is mainly due to neutrons. To obtain a time peak, we needed to correct for time walk and for drift of time caused by electronic fluctuations. The time peak is composed of a main γ peak and a small neutron peak, as shown in Fig. 1. In Fig. 2, the corresponded γ spectra are shown. The red (1) spectrum is the total one without any condition on time peak while, if we put a gate on γ peak (from 148 to 152 ns), we obtain the blue (3) curve. The yellow (4) and the (2) green curves are, respectively, the spectra imposing a gate on the neutron time peak and on the background (on the right-hand side of the γ peak).

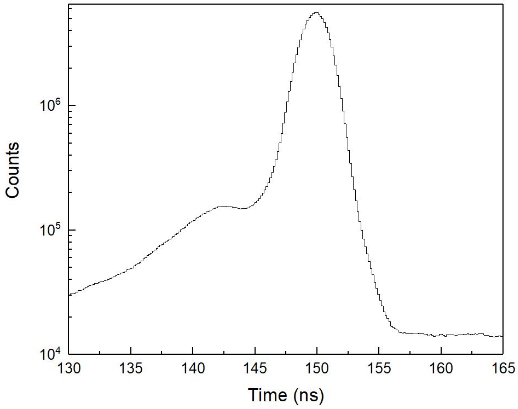

Fig. 1. Plot of time peak from LaBr$_3$:Ce detectors for the ^{60}Zn at $E_1^* = 47$ MeV. It is composed of a main γ-peak and a small neutron peak.

Gates on time peak are good way to discriminate background events from those who come from the γ decay of the GDR. We can indeed observe that, with a gate on γ peak, the spectrum shows the GDR structure between 10 to 18 MeV.

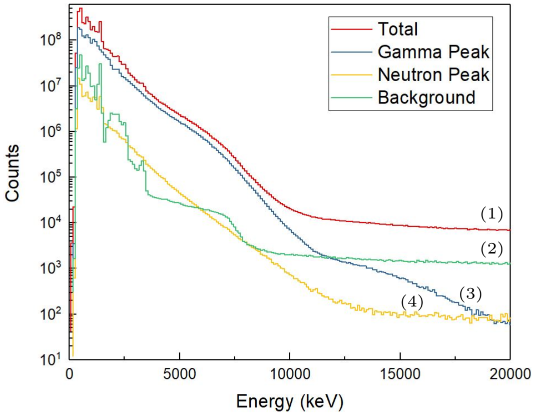

Fig. 2. (Color online) Plot of the γ spectrum for the ^{60}Zn at $E_1^* = 47$ MeV. The red (1) spectrum is the total one without any condition on time peak and the blue (3) one comes from a gate on γ peak. The yellow (4) and the green (2) ones are, respectively, the spectra imposing a gate on the neutron time peak and on the background (on the right-hand side of the γ peak).

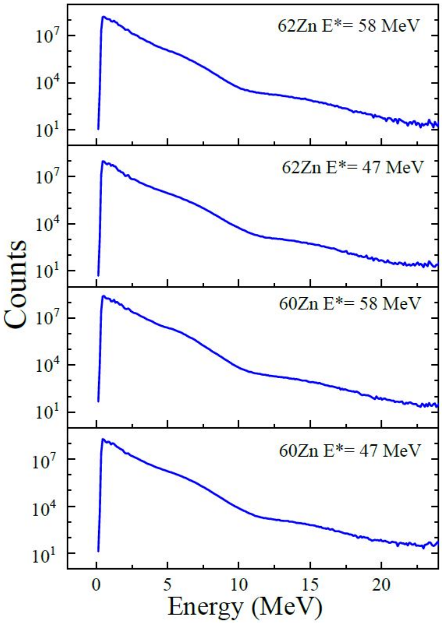

Fig. 3. Plot of the γ spectra for the two nuclei at the two excitation energies. The condition on time peak to reject neutrons and background was applied. All the spectra show the typical exponential shape of CN statistical γ decay and a change in the slope at ~ 10 MeV, typical of the presence of the GDR.

The γ-rays spectra for the four reactions are shown in Fig. 3. The four spectra are obtained by the selection of the γ time peak events.

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 ~ 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.

5. Conclusion

Two nuclei ^{60}Zn and ^{62}Zn were produced by fusion–evaporation reaction at the Laboratori Nazionali di Legnaro (LNL) in order to study the CN decay and the isospin symmetry breaking. Therefore, the giant dipole resonance for two nuclei at different excitation energies was measured.

The preliminary analysis showed the presence of the GDR and of the isospin mixing phenomenon in all the γ spectra. The future goal is to tune the statistical model and to extract precisely the isospin mixing probability.

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