ISOSPIN MIXING IN ^{80}Zr AT FINITE TEMPERATURE*

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The isospin symmetry breaking (*i.e.* isospin mixing) due to the Coulomb interaction has been measured in the compound nucleus ^{80}Zr* at temperature $T \simeq 2$ MeV. The giant dipole resonance γ decay was used as a probe to deduce the mixing. The Coulomb spreading width and the degree of isospin mixing has been obtained from the analysis of the measured γ-ray spectra.

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1. Isospin mixing

The isospin symmetry was introduced by Heisenberg in 1932 [1] to describe the experimental evidence of the charge independence of the nuclear interaction. In the isospin formalism, neutrons and protons can be viewed as different states of the nucleon with a value of 1/2 and −1/2 of the projection I_z of the isospin operator I.

A nucleus has a well defined value of $I_z = (N-Z)/2$, while I, according with quantum mechanics rules, can assume values $(N-Z)/2 < I < (N+Z)/2$. The nuclear ground state corresponds to the lower value of isospin $I = I_z$. For self conjugate nuclei, the ground state has isospin $I = 0$.

The presence of the Coulomb interaction between protons breaks this symmetry and induces a mixing between states. In this situation, it is impossible to assign an unique value of isospin to a nuclear state. This effect can be described in a perturbative formalism because the Coulomb interaction remains smaller than the dominant nuclear force. For ^{80}Zr in the ground state microscopic calculations reported in [2] predict a value of mixing probability α^2 equal to 4.5%. The knowledge of the isospin impurity

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is interesting in connection with the properties of the Isobaric Analog States (IAS) and for the Fermi β decay of the $N \approx Z$ nuclei near the proton drip line. Moreover, the evaluation of the isospin impurity gives an important correction factor to the Fermi transition rates for the calculation of the first element of the Cabibbo–Kobayashi–Maskawa matrix [2].

The breaking of the isospin symmetry can be observed in decays which would be forbidden by the selection rules if isospin mixing did not occur. This is the case of the E1 decay in self-conjugate nuclei [3]. Therefore, the γ decay of the Giant Dipole Resonance (GDR), where the E1 strength is concentrated at around 15 MeV, is an excellent probe for isospin mixing [4, 5]. The GDR state can be populated in a fusion-evaporation reaction. Using a combination of $N = Z$ projectile and target, it is possible to produce a fused CN in $I = 0$ channel. The E1 gamma decay from $I = 0$ to another $I = 0$ is forbidden and only the decay to the less numerous $I = 1$ state is possible. With isospin mixing, the initial state is a mixture of $I = 0$ and $I = 1$ states and, therefore, it can decay to $I = 0$ states. The final effect is an increase of the gamma decay yield. Therefore, the E1 strength gives a direct indication of the value of the mixing degree α^2.

The mixing probability changes also with nuclear temperature: an initial increase of the mixing is expected because in average the distance between $I = 0$ and $I = 1$ states decreases. As the excitation energy increases, a correspondent decrease of the mixing amplitude is expected for the competition with the particle and gamma decay of the CN. The lifetime of the nucleus (which decreases with excitation energy) limits the mixing and leads to a restoration of isospin symmetry, as already hypothesized by Wilkinson in 1956 [6].

The experiment was performed at Laboratori Nazionali di Legnaro of the Istituto di Fisica Nucleare (INFN, Italy). We have used the two symmetric fusion-evaporation reactions ^{40}Ca $+^{40}$Ca at $E_{\mathrm{beam}} = 136$ MeV and ^{37}Cl $+^{44}$Ca at $E_{\mathrm{beam}} = 95$ MeV to form the compound nuclei ^{80}Zr ($I = 0$ channel) and ^{81}Rb ($I \neq 0$ channel) with an excitation energy of about 54 MeV for both compound nuclei. In this study, the γ decay of ^{81}Rb CN was used to fix the statistical model and GDR parameters which were used as input for the description of the γ decay of ^{80}Zr and thus to extract the value of isospin mixing.

The experimental setup consisted of the AGATA Demonstrator [7] (an array of segmented HPGe detector for measurement of γ rays with an excellent energy resolution) coupled to HECTOR$^+$ [8] (an array of 7 large volume $LaBr_3$:Ce scintillators). The trigger condition required a coincidence between AGATA and $LaBr_3$:Ce.

2. Data analysis and results

A statistical model analysis was performed using the CASCADE code, including the isospin formalism. In order to verify that the statistical model describes correctly the statistical decay of the compound nucleus, it is useful to compare the experimental distribution of the residues population with that predicted by the model. This was done using the low energy γ spectrum measured with the AGATA detector. In figure 1, it is shown the measured and calculated residues population for the CN ^{80}Zr for different conditions on the energy of the emitted γ rays. The calculations made with the statistical model are in good agreement with the experimental results. The same statistical model has been used for the calculation of the high-energy spectra. The energy and width of the GDR in ^{81}Rb were extracted using the standard fitting procedure. The set of best-fitting parameters for the centroid, width and strength were found to be $E_{\rm GDR} = 16.4 \pm 0.2$ MeV, $\Gamma_{\rm GDR} = 7.0 \pm 0.4$ MeV and $S_{\rm GDR} = 88 \pm 2\%$, in agreement with the systematics. The GDR parameters found for ^{81}Rb were used in the statistical analysis of the ^{80}Zr γ-ray spectrum. The extracted value of the Coulomb spreading width in ^{80}Zr was $\Gamma^{\downarrow} = 11 \pm 3$ keV and a value of mixing probability $\alpha^2 = 0.042 \pm 0.007$. The best fitting curves are shown together with the experimental results in figure 2.

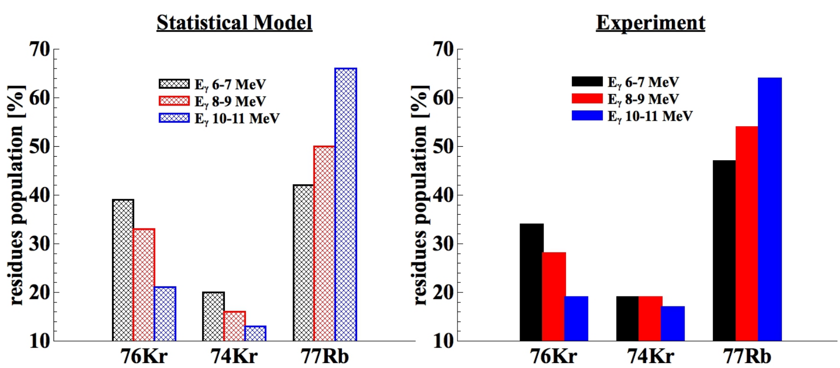

Fig. 1. Residues population for different intervals of gamma-ray energy emitted by the compound nucleus ^{80}Zr. The predictions obtained with the statistical model are in the left panel and the experimental data are in the right panel.

From this work, two important results were obtained: the first result is that the value of the Coulomb spreading width is equal, within the error bars, to those measured in ^{80}Zr at $T = 3$ MeV [9] and in ^{80}Se [10]. This experimental evidence confirms that the Coulomb spreading width does not depend strongly on the excitation energy, but only on the Coulomb interaction intensity. The second result is that for the first time in the same nuclear system the Wilkinson hypothesis is verified: the degree of mixing remains constant or weakly increases with temperature until 2–2.5 MeV and then decreases sharply as shown in figure 2.

These results obtained for the isospin mixing at finite temperature will be used to extracted the value of the mixing at zero temperature [11].

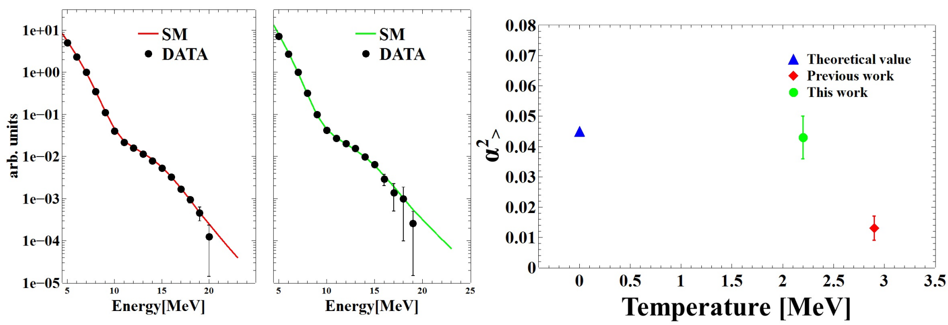

Fig. 2. On the left-hand side, the gamma-ray spectra measured with $LaBr_3$:Ce detectors for the ^{37}Cl+^{44}Ca (a) and ^{40}Ca+^{40}Ca (b) reactions are shown with filled circles and compared with the best-fitting statistical-model calculations (SM). In the right panel, the values of α^2 in ^{80}Zr for different temperatures are shown: the triangle (blue) is the theoretical value obtained in [2], the diamond (red) is the experimental value at $T = 3$ MeV [9], the dot (green) is the value extracted in this measurement.

REFERENCES

[1] W. Heisenberg, *Z. Phys.* **77**, 1 (1932).

[2] W. Satula, J. Dobaczewski, W. Nazarewicz, M. Rafalski, *Phys. Rev. Lett.* **103**, 012502 (2009).

[3] E. Farnea *et al.*, *Phys. Lett.* **B551**, 56 (2003).

[4] J.A. Behr *et al.*, *Phys. Rev. Lett.* **70**, 3201 (1993).

[5] M.N. Harakeh *et al.*, *Phys. Lett.* **B176**, 297 (1986).

[6] D.H. Wilkinson, *Phil. Mag.* **1**, 379 (1956).

[7] AGATA Collaboration, *Nucl. Instrum. Methods Phys. Res.* **A668**, 26 (2012).

[8] A. Giaz *et al.*, *Nucl. Instrum. Methods Phys. Res.* **A729**, 910 (2013).

[9] A. Corsi *et al.*, *Phys. Rev.* **C84**, 041304 (2011).

[10] S. Kailas *et al.*, *Nucl. Phys.* **A315**, 157 (1979).

[11] H. Sagawa, P.F. Bortignon, G. Colò, *Phys. Lett.* **B444**, 1 (1998).