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Isospin mixing at finite temperature in ^{80}Zr

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Abstract. Isospin mixing induced by the Coulomb interaction has been studied in the compound nucleus ^{80}Zr at T~2 MeV produced in the fusion-evaporation reaction ^{40}Ca+^{40}Ca at E_{beam} = 136 MeV. The isospin impurity was measured using the first step of the Giant Dipole Resonance γ decay. The preliminary value of the Coulomb spreading width has been extracted via statistical model analysis of the measured γ spectrum.

1 Introduction

In the isospin formalism neutrons and protons are considered different states of the same particle, the nucleon, with values 1/2 and -1/2 of the projection $I_z = (N - Z)/2$ of the isospin operator I [1]. The isospin symmetry is largely preserved by the nuclear interaction, which is charge independent. The Coulomb interaction between the protons inside the nucleus breaks the isospin symmetry and it mixes states with different isospin. This phenomenon is called isospin mixing [2–8].

In this physical situation it's impossible to give an unique value of isospin to the nuclear states.

In general the probability of mixing α^2 between two states with $I = I_0$ and $I = I_0 + 1$ can be described quantistically in a perturbative way. The mixing probability is expected to increase with the number of protons because of the increasing of the Coulomb interaction. Microscopic calculation predict a large isospin mixing probability up to about 5% for medium-heavy nuclei, like ^{100}Sn [9]. The evaluation of isospin mixing provides an important correction to the superallowed Fermi-transitions rates allowing a the extraction, in a nucleus independent way, of the first element of the Cabibbo-Kobayashi-Maskawa Matrix [8].

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At finite temperature a partial restoration of the isospin symmetry is expected because of the finite lifetime of the nucleus [4–6]. The competition between the time scale of the Coulomb interaction and the nucleus lifetime (which decreases with temperature) leads, in fact, to a restoration of symmetry, as predicted by Wilkinson in 1956 [3]. The relation between the degree of isospin mixing and the temperature of CN has been discussed in detail in [6, 8, 10]. In the same reference it's also discussed the Coulomb spreading width $\Gamma^{\downarrow}$ originating form the Coulomb interaction, which is expected to be basically constant with temperature [4].

The Statistical E1 decay of the Giant Dipole Resonance (GDR) built on a compound nucleus populated via heavy ions fusion reactions can be used to study the isospin mixing at finite temperature [5, 6]. The experimental technique is based on the measurement of the first step of γ-decay of the GDR in N=Z nuclei. In case of isospin symmetry, since E1 decays are isovector, $I = 0 \rightarrow I = 0$ transitions are forbidden, so that the only isospin-allowed γ decays will populated the less numerous I=1 states. Isospin mixing populates I=1 initial states, which can decay in the more numerous I=1 final states. Hence the first step of the GDR γ yield depends on the degree of admixture in the initial states. The isospin mixing probability can be extracted comparing the γ-decay yield with the prediction of a statistical model which includes the formalism of isospin [5].

The final objective of this analysis is the measurement of the isospin mixing in the N=Z nucleus ^{80}Zr populated using a fusion-evaporation reaction at an average temperature of about 2.4 MeV. Moreover, comparing the results of this work and those of [11] and theoretical work of [9] it could be possible to study the temperature dependence of isospin mixing in ^{80}Zr and to extract the value of isospin mixing at zero temperature (see Figure 1), for which a value of the order of 4% it's expected from theoretical calculation [9].

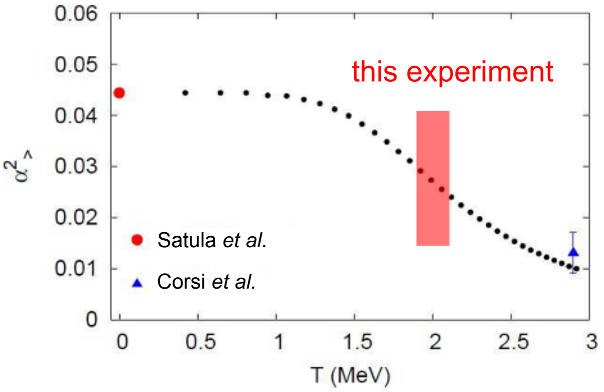


Figure 1. The temperature dependence of the mixing probability of the ^{80}Zr using the theoretical model in [10]. The theoretical curve uses the Coulomb spreading width of [11], it has been normalized to the T=0 value of [9] and uses a width of the monopole resonance at the temperature of the Isobaric Analogue State fixed with temperature. The blue triangle is the experimental value of the isospin mixing obtained in [11], the red dot is the theoretical value calculated in [9]. the light red rectangle is the temperature region for this experiment.

2 Experimental Setup

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_{beam}=136

MeV and ^{37}Cl +^{44}Ca at E$_{beam}$=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 nucleus (see Table 1). In Table 1 the principal characteristics of the two reactions.

Table 1. For each reaction, E$_{beam}$ is the energy of the incoming beam, CN is the compound nucleus produced, E* the excitation energy, I$_z$=(N-Z)/2 the third component of isospin quantum number, <J> and T the average angular momentum and temperature of the compound nucleus.

reaction	E$_{beam}$(MeV)	CN	E*	<J>($\hbar$)	T (MeV)
^{37}Cl+^{44}Ca	95	^{81}Rb	54	14	2.2
^{40}Ca+^{40}Ca	136	^{80}Zr	54	24	2

The study of the reaction producing the compound nucleus ^{81}Rb is necessary in order to fix the statistical-model and the GDR parameters.

The experimental setup was composed by the AGATA Demonstrator [12] [13] coupled to an array of 7 large volume LaBr$_3$:Ce scintillators called HECTOR$^+$ [14]. The AGATA demonstrator consists of an array of segmented HPGe detector. In the experiment were available 4 AGATA triple clusters. The HECTOR$^+$ array consist of 7 large volume (6 detectors with a volume of 3.5″ x 8″ and 1 detector 3″ x 3″) LaBr$_3$:Ce scintillators of the HECTOR$^+$ array for the measurement of both high and low energy γ rays with an excellent time resolution. The trigger condition requires a coincidence between two LaBr$_3$:Ce or between AGATA and LaBr$_3$:Ce.

3 Data analysis

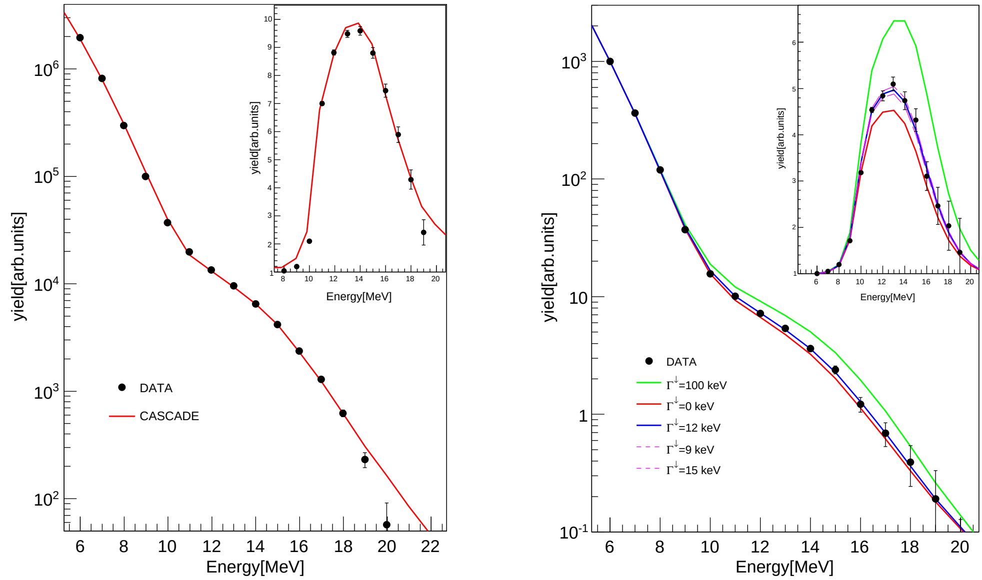
The events of interest in this analysis are ones detected with two principal classes of trigger conditions: the first includes the coincidence between one event in AGATA and one event in LaBr$_3$:Ce, the second requires two events in HECTOR$^+$.

The final γ spectra were obtained after an off-line time selection of the events and a background subtraction in the high energy region of the spectra in order to eliminate the cosmic rays contribution.

Statistical Model analysis of the final γ spectra has been done with a version of CASCADE code which include isospin effects already used in [11]. We performed a first fit procedure varying only the width of the GDR for ^{81}Rb data with a χ^2 minimization technique. The other GDR parameters (centroid and strength) are fixed to the value of [11], because they are not expected to change with the CN excitation energy. In a second step we fitted ^{80}Zr data in order to obtain the best value the Coulomb spreading width $\Gamma^{\downarrow}$. As Figure 2 shows we have extracted from the data a preliminary value of 12 keV ± 3 keV for the Coulomb spreading width. The value is consistent with that obtained in [11] of 10 ± 3 keV.

4 Conclusion

The study of the γ decay from the GDR in two compound compound nuclei ^{80}Zr and ^{81}Rb has allowed to obtain a preliminary value of the Coulomb spreading width which is consistent with [11] as expected. From this value will be possible to calculate the value of the isospin mixing probability α^2 in ^{80}Zr at T=2 MeV and extract the value at T=0 using the theoretical model explained in [10]. The experimental extraction of the amount of isospin impurity is a interesting task for existing theoretical models since the degree of mixing is an important correction to take into account in order to describe a wide range of phenomena, for example the nuclear β decay.



(a) ^{81}Rb

(b) ^{80}Zr

Figure 2. Measured γ-multiplicity spectra (filled dots) for ^{81}Rb (left panel) and ^{80}Zr compared with best fitting Statistical Model calculation. The insets display the spectra divided by an exponential curve in order to underline the GDR peak shape. For ^{80}Zr spectra the red line is obtained without mixing, i.e. $\Gamma^{\downarrow}$=0, the green one with a very large mixing and the blue one with the best value of $\Gamma^{\downarrow}$=12 keV, in the inset the violet dashed lines correspond to the values of 12 keV ± 1σ.

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