ISOSPIN MIXING IN THE N=Z NUCLEUS ^{80}Zr AT HIGH TEMPERATURE

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ABSTRACT

We **re**-propose to measure the isospin mixing for nuclei in the mass region A = 80 at temperatures around T=2 MeV. So far this topic has been investigated mainly for A < 60 by comparing the statistical γ decay of the giant resonance built on excited states in two compound nuclei, one corresponding to entrance channels with isospin I = 0 and the other to entrance channels with isospin I ≠ 0. This will be the first measurement in the mass region A=80 providing a Z-dependence of isospin mixing and therefore a better understanding of the problem of isospin symmetry.
We propose to use the two symmetric fusion evaporation reactions ^{40}Ca + ^{40}Ca and ^{37}Cl + ^{44}Ca to form the nuclei ^{80}Zr and ^{81}Rb in order to extract the isospin mixing probability from the comparison of the high energy γ ray yields from the GDR decay. The experimental setup is the combined system GARFIELD and HECTOR.

The request is for 12 days of beam time divided as follows
5 days for ^{40}Ca + ^{40}Ca with E_{beam} = 200 MeV
5 days for ^{37}Cl + ^{44}Ca with E_{beam} = 154 MeV
1 day for calibration of BaF_2 with 45 MeV ^{11}B + ^{2}D
1 day for calibration of Garfield set-up

We need a pulsed beam with a resolution of 1 ns and a repetition time of 200ns.

The comment of the PAC Meeting July,2006 was the following:

Decisions of the PAC meeting held at LNL 10-11 July, concerning the experiment:

COMMENT:
The PAC considers the study of isospin mixing at finite temperature of interest. However, due to the limited available machine days, this experiment has not been considered of high priority compared to others and no beam time was allotted.
In addition, the use of the (not yet available) ^{39}K beam is essential for the measurement, and the PAC strongly recommends the laboratory to develop such a beam.

The experiment described in the following is **re-**proposed with the variation that we ask for the second part of the experiment a beam of ^{37}Cl (not ^{39}K), which is a standard beam delivered with high intensity at the LNL ALPI facility. This beam forms with a ^{44}Ca target a CN very similar to the one with isospin I = 0. Within the precision of the measurement and statistics, the expected gamma ray yield is the same as compared to the previously proposed ^{39}K beam.

1. The physics case:

The problem of the mixing of states with isospin $I \neq I_0$ in N≈Z nuclei, related to the isospin symmetry and its breaking mainly by Coulomb interaction, has attracted renewed interest both, at zero and finite temperature. In particular, at high excitation energy restoration of the isospin symmetry should occur.

The isospin mixing probability is related to the ratio of the spreading width of the Isobaric Analog State with the statistical decay width of the compound nucleus. The resoration of the isospin symmetry can be understood on the ground of simple kinetic arguments, if the compound nucleus decays on a time scale which is shorter than the time needed for a well-defined isospin state to mix with states with different isospin, then the isospin symmetry is partially or totally restored [1,3].

While the spreading width of IAS is expected not to depend on temperature, the decay width of the compound is known to increase with temperature so that these two effects result in a decrease of the isospin mixing probability (see right panel of figure 1). So far the temperature dependence of the isospin mixing has been extensively investigated in light nuclei ($30 < A < 60$) [1,2] using the γ decay of the giant dipole resonance (GDR) in compound nuclei. The data in this mass region are consistent with the predicted restoration of the isospin symmetry [3]. Starting from this result and keeping in mind that the statistical decay width is a well known quantity one can infer from the measurements at finite temperature the isospin mixing probability at zero temperature. Therefore the investigation of the isospin mixing at finite temperature is a tool for the study of the isospin symmetry for several medium mass nuclei with N=Z which are unstable and difficult to populate at zero temperature.

Consequently, the study of the isospin mixing at finite temperature with the GDR decay for nuclei with increasing Z is expected to provide information on how the Coulomb interaction is affecting the spreading width of the Isobaric Analog States [4].

The present proposal intends to measure for the first time isospin mixing on the nucleus ^{80}Zr for which (at zero temperature) the isospin mixing is expected to be of the order of 3-4 % [5] (see also figure 1, left panel). The aim is to obtain, together with the existing systematics, a dependence on A of the isospin mixing at T=2-3 MeV, dependence which is presently not understood [6]. It will be also possible to calculate subsequently the T=0 temperature value out of the data [3].

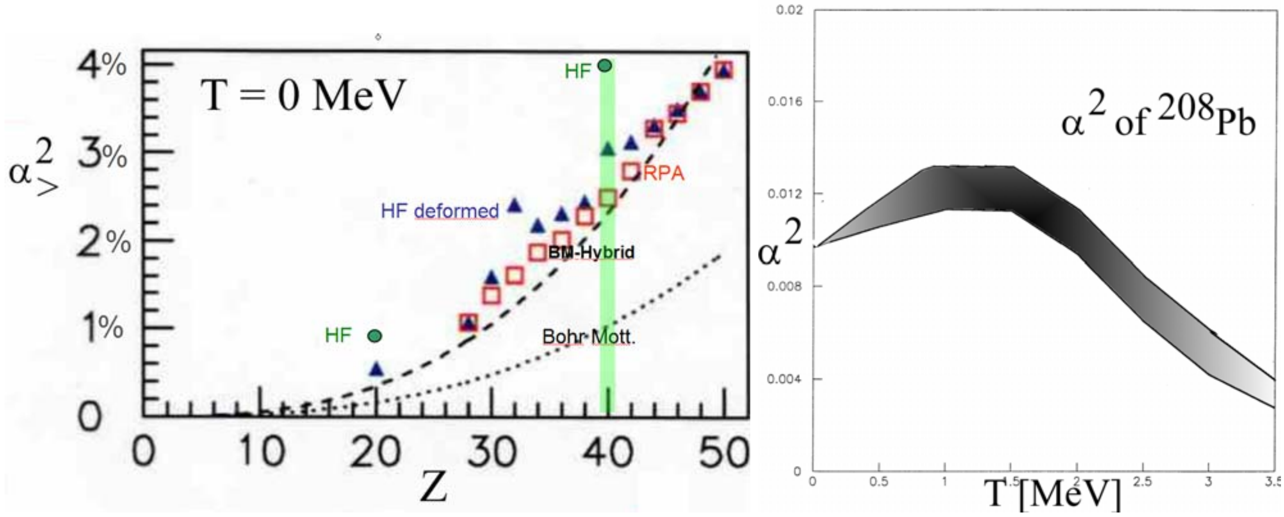

Figure 1: Left panel: plot of different isospin mixing α^2 model-calculations (see [5] for details), shown as a function of Z in N=Z nuclei, which predicts an isospin mixture of $\alpha^2 \sim 3\%$ in ^{80}Zr [5] at T=0 MeV temperature. Right panel: plot of the mixing parameter α^2 as a function of temperature for A=208 [3].

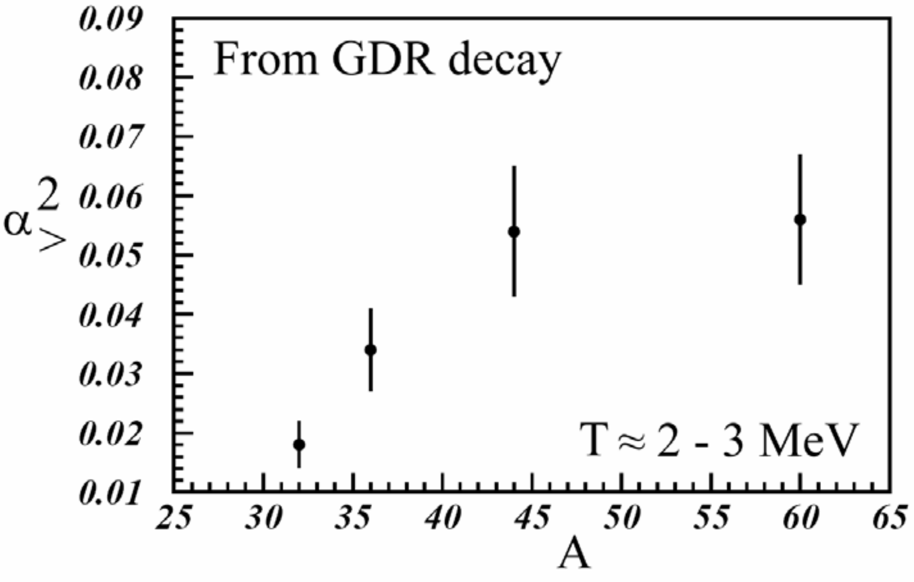

Figure 2: Isospin mixing dependence $\alpha^2_>$ of N=Z nuclei on atomic mass presented in [7] and based on the presently available experimental data in the temperature range between 2 and 3 MeV.

The expected value, based on estimations on combined statistical model and microscopic calculations [3,11] for the mixing parameter in the temperature region around 2 MeV for ^{80}Zr is around 10% to 25% less than the zero temperature value.

The $\alpha^2_>$ parameter is usually defined as [4]:

$$\alpha^2_> = \frac{\Gamma^{\downarrow}_>/\Gamma_>}{1 + \Gamma^{\downarrow}_</\Gamma_< + \Gamma^{\downarrow}_>/\Gamma_>}$$

where “$_<$” and “$_>$” indicate the states with isospin $I_< = I$ and $I_> = I + 1$, $\Gamma^{\downarrow}$ the Coulomb spreading width and Γ the CN decay width.
The values of isospin mixing parameter $\alpha^2_>$ for T>0 are known only in a limited mass region up to A=44 with only one measurement at A=60 [8].
In Figure 2 the observed values of the experimental isospin mixing parameter at T = 2-3 MeV are shown.
One can note that up to mass ≈ 40 the $\alpha^2_>$ increases similarly to its behaviour at T=0 MeV (crf. Figure 1 left panel) while the datum at A = 60 does not increase as one would expect. Therefore a measurement at A = 80 would help to clarify this result.

2. Experiment

The proposed study of the isospin mixing in ^{80}Zr needs the measurement of the γ decay of the GDR formed with two reactions leading to a very similar CN. The first reaction is ^{40}Ca + ^{40}Ca forming ^{80}Zr, the second is ^{37}Cl + ^{44}Ca leading to ^{81}Rb at the same excitation energy (E*). In fact, the present work will use the well-established method [1,9] of comparing the γ decay of the same compound nucleus formed in 2 different situations, one with isospin I = 0 and the other one with I ≠ 0. In fact, E1 transitions from the GDR decay in a system with I = 0 is strongly inhibited because of the isovector nature of the E1 dipole, which requires a I = 1 final state and such states have low density. To extract the information on the isospin mixing, the comparison of two reactions is essential to eliminate uncertainties in the determination of the width and position of the GDR. This is particularly important due to the small size of the yield difference associated to the isospin mixing effect.

The proposed set up consists of three main parts:

High Energy Gamma-rays:
8 large volume BaF_2 crystals of the HECTOR set up are used for high energy γ-ray detection.
Evaporation residues trigger:
performed through a group of phoswich detectors positioned at 150 cm from the target. The phoswich set up is made by 4 boxes each containing up to 9 detectors 6.4cm X 6.4 cm each. The evaporation residues are stopped in the plastic foil and discriminated through Time of Flight, while the phoswich second stage is used for forward light charged particle detection.
Light charged particle detection and light fragments detection:
The GARFIELD array will detect Light Charged Particle (LCP) from 30 to 90 ° through ΔE-E signals obtained by gaseous microstrip plus CsI(Tl) scintillator inside the drift chamber. LCP identification is possible thanks to digital electronics read out.

The GARFIELD ancillary Phoswich detection system is essential for the selection which eliminates all non fusion-evaporative contributions in the γ-spectra. In addition it is important to measure simultaneously γ-rays and light charged particles. This is to verify that, in contrast to the γ-ray, the particle production yield is the same in both reactions. In other words, to guarantee that both compound systems have the same temperature and do not show any light charged particle preequilibrium emission.

We have calculated the γ-ray yield of the proposed reaction with the statistical model including isospin effects. The calculated γ ray spectra and the expected ratio between the γ ray yield with full mixing and with an estimated mixing around 4% are shown in Figure 3.

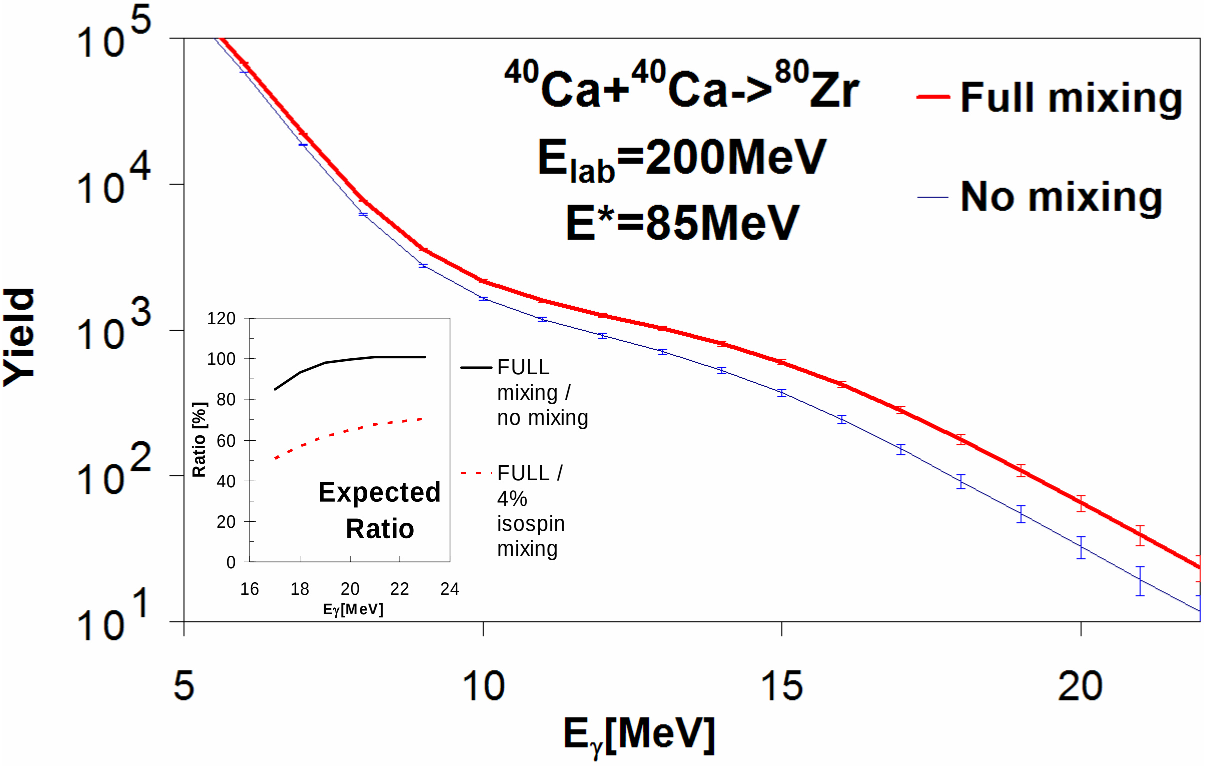

Figure 3: Statistical model calculations of the expected γ ray yield of the symmetrical ^{40}Ca+^{40}Ca reaction leading to ^{80}Zr at E*=85MeV. The upper thick red line is calculated with the assumption of completely mixed isospin (Coulomb spreading width $\Gamma^{\downarrow}_{>}$=100MeV). The lower thin blue curve for no isospin mixing ($\Gamma^{\downarrow}_{>}$=0). In the inset the expected yield ratio for full vs. no mixing and full vs. 4% isospin mixing is shown.

In order to obtain a good determination of the mixing parameter $\alpha^2_>$, it is crucial to have sufficient statistics to compare the experimental spectra which could differ by small amount (up to 10-20%). We expect a typical isospin mixing effect of around 20 % in the γ-ray yield in the high energy region, with respect to the yield with no isospin mixing [1].
We need a minimum of ≈250-300 counts at E_γ= 15MeV per 1MeV bin, in order to obtain $\alpha^2_>$ with an error of 10%-20% and consequently be able to distinguish the isospin mixing values of $\alpha^2_>$ = 2% and 4%.

Beam time request

For the isospin ^{40}Ca+^{40}Ca reaction we expect a beam current of 1 pnA on Target (0.5 mg/cm^2 thick) and 1% efficiency of the BaF$_2$ detection system, 11% fast Phoswich scintillator efficiency
(the numbers are verified in a former experimental campaign [10] with the Garfield+Hector setup under similar kinematical conditions).
At E$_{lab}$ of 200 MeV (corresponding to a nuclear temperature of approx T*=2 MeV) we expect in one MeV bin at E_γ =15 MeV a count rate of $\approx 6 \cdot 10^{-4}$ cts/s.
To arrive to a necessary minimum of statistics to be able to observe isospin effects we need ≈250 -300 cts at 15 MeV, this means 5 days of 24/24h beam on Target.
In addition we need 1 day of calibration beam to produce high energy γ rays of 15.1 MeV.
For the second reaction ^{37}Cl + ^{44}Ca the expected count rates are more or less the same as for the ^{40}Ca+^{40}Ca reaction, and we need to determine the GDR parameters (as seen also in a previous experiment studying hot Ce) a minimum of 250 cts per 1Mev bin at E_γ =15 MeV, which corresponds to 5 days of Beam time.

The total request of Beam time is 12 days (not including tuning of ALPI)
divided as follows:
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5 days for ^{37}Cl + ^{44}Ca with E$_{beam}$ = 154 MeV
1 day for calibration of BaF$_2$ with 45 MeV ^{11}B + ^{2}D (with a gold foil).
1 day for calibration of Garfield set-up
We need a pulsed beam with a resolution of 1 ns and a repetition time of 200ns.

[1] J.A. Behr et al. Phys. Rev. Lett. 70(1993)3201
[2] M. Kicinska-Habior Acta. Phys. Pol. B 36(2005)1133 and ref. therein
[3] H. Sagawa, P.F. Bortignon, G. Colo Phys. Lett B444(1998)1
[4] H.I. Harney, A. Richter and H.A. Weidenmueller, Rev. Mod. Phys. 58(1986)607
[5] G. Colo, M.A. Nagarajan, P. Van Isacker, A. Vitturi PRC 52(1995)1175
[6] G. Colo, H. Sagawa, private communications
[7] E.Wojcik et al. Acta. Phys. Pol. B 37(2006)207 and ref. therein
[8] K.A. Snover et al Nucl. Phys. A553(1993)153c and D.P. Wells et all, not published
[9] M. Harakeh et al. Phys. Lett. B176 (1986)297
[10] O. Wieland et al Phys. Rev. Lett. 97, 012501 (2006)
[11] G. Colo and P.F. Bortignon, private communications