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Isospin mixing in the 4^+ doublet of ^{54}Co

P. von Brentano[a], A.F. Lisetskiy, N. Pietralla, A. Schmidt, I. Schneider, and C. Friessner

Institut für Kernphysik, Universität zu Köln, Zülpicherstr.77, D-50937 Koeln, Germany

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Abstract. The $T = 1$ admixture into the $T = 0$ member of a recently discovered $J^\pi = 4^+$ isospin-doublet in ^{54}Co is obtained from the measured electromagnetic $E2/M1$ multipole mixing ratio, $\delta = 0.12(4)$ of the $T = 0, 4^+ \to T = 0, 3^+$ transition. Combining these data with shell model calculations for strong isovector $M1$ and isoscalar $E2$ electromagnetic matrix elements one obtains a value for the $T = 1$ admixture into the $T = 0$, 4^+ state of $0.23^{+0.29}_{-0.10}$%. The corresponding mixing matrix element in the 4^+ doublet is $V_{\rm mix} = 10$ keV.

PACS. 21.10.Hw Spin, parity, and isobaric spin – 21.60.Cs Shell model – 23.20.Gq Multipole mixing ratios

1 Introduction

A well-known way to determine an isospin mixing in low-energy nuclear states is the precise measurement of the rates for isospin-forbidden transitions, because such transition rates are sensitive to small admixtures to the wave functions that make the decays possible. For instance, analyzing an isospin-forbidden $E1$ decay, Ennis *et al.* [1,2] studied the isospin purity of low-energy $T = 0$ states of the $N = Z$ nucleus ^{64}Ge with spin and parity $J_i^\pi = 4_1^+$ and 5_1^-. Another isospin-forbidden $E1$ decay has just been identified in the odd-odd $N = Z$ ^{46}V nucleus [3,4]. The estimate of isospin mixing using $E1$ decays is, however, hampered by difficulties with reliable calculations of $E1$ transition rates.

$M1$ transition rates can also provide information on the isospin mixing [5]. This is despite the fact, that the isoscalar ($\Delta T = 0$) $M1$ transitions are not strictly forbidden but are only very strongly hindered in comparison to the isovector ($\Delta T = 1$) $M1$ transitions. One of the best cases to investigate the problem of isospin symmetry breaking using electromagnetic transition rates are odd-odd $N = Z$ nuclei. But the precise measurement of strongly hindered decay rates between low-energy states is often limited to low-mass nuclei where the Coulomb effects are small. It is, therefore, of general interest to find an alternative for the measurement of the isospin mixing, particularly, in heavy nuclei at the $N = Z$ line.

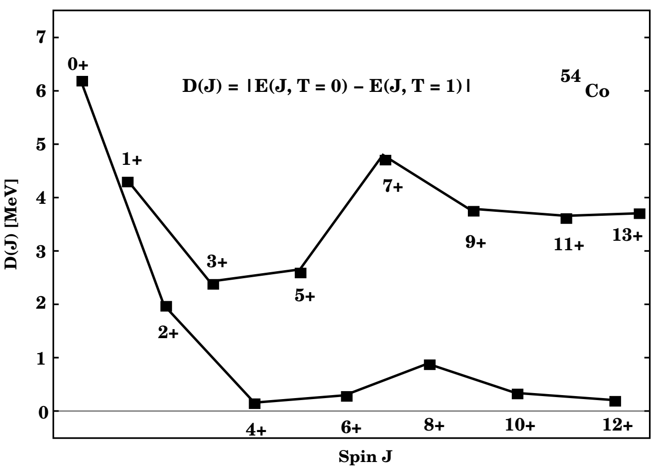

Fig. 1. The difference $D(J)$ between the energies of yrast $T = 0$ and $T = 1$ states with the same spin and parity quantum numbers J^π as calculated in the fp-shell [6]. Similar to [7].

2 Isospin symmetry test in ^{54}Co

Very often the approximate degeneracy of $T = 0$ and $T = 1$ states in odd-odd $N = Z$ nuclei is fulfilled for the yrast states with different spin J values *i.e.*, it is valid for the $T = 0$ states with odd-J values and the $T = 1$ states with even J. Such states cannot mix because J is a good quantum number. The spacing between the yrast $T = 0$ and $T = 1$ states with the same spin and parity quantum numbers, J^π, depends strongly on the spin quantum number J. This dependence is exemplified in fig. 1 for the particular case of ^{54}Co but it reflects the general tendency

[a] e-mail: `vonBrentano@t-online.de`

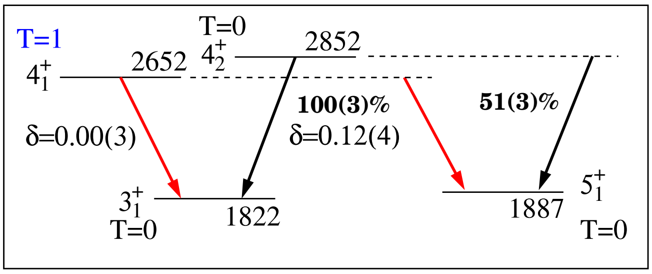

Fig. 2. The decay scheme of the $4_1^+, T = 1$ and $4_2^+, T = 0$ states to the 3_1^+ and the 5_1^+ $T = 0$ states of ^{54}Co.

as well. The smallest spacing is found for the states with even values of spin J except for the $J^\pi = 0^+$ case. Thus, the search for the isospin doublets is focused on the states with $J = 4, 6, 8, \ldots$. One example is the recently discovered doublet of 4^+ states with isospin quantum numbers $T = 0$ and $T = 1$ in ^{54}Co [8]. Figure 2 displays experimental data on this doublet.

Low-spin states of the odd-odd $N = Z$ nucleus ^{54}Co were recently studied with the fusion evaporation reaction $^{54}\mathrm{Fe}\,(\mathrm{p}, \mathrm{n}\gamma)\,^{54}\mathrm{Co}$ at a proton beam energy E_p = 15 MeV [8] at the FN-Tandem accelerator of the University of Cologne. In-beam gamma-ray spectroscopy was performed, many new levels were identified, spin and parity quantum numbers, J^π, have been assigned, and several multipole mixing ratios, δ, of γ transitions were measured.

Analyzing the properties of the 4^+ doublet, one notes that the vanishing $E2/M1$ mixing ratio for the $4_1^+ \to 3_1^+$ transition, $\delta(4_1^+ \to 3_1^+) = 0.00(3)$, indicates that the 4_1^+ state has dominantly $T = 1$ character leaving the dominant $T = 0$ character to the 4_2^+ state. The second mixing ratio, $\delta_\mathrm{exp}(4_2^+ \to 3^+) = 0.12(4)$ is finite but smaller than expected in the case of pure isospin quantum number $T = 0$ for the calculated 4_2^+ state [6]. This observable is very sensitive to the size of the isospin mixing between the 4^+ configurations with isospin quantum numbers $T = 0$ and $T = 1$. We employ a two-level-mixing approach to estimate the size of the isospin admixture $P_{4_2^+}(T = 1) = b^2$ (b is a mixing amplitude) of the $4^+, T = 1$ component in the observed 4_2^+ state with dominant $T = 0$ character.

The isospin mixing can be determined [6] from the experimental mixing ratio of the $4_2^+ \to 3_1^+$ transition and a reliable calculation of the electromagnetic matrix elements. Two sets of calculations with SDI and FPD6 residual interactions show [6] that the components of the wave functions, which determine the isovector $M1$ properties of the states, are robust, *i.e.*, are largely insensitive to the particular choice of the configurational space and of the residual interaction. Using the $M1$ and $E2$ matrix elements from the shell model calculations with SDI and the corresponding experimental $E2/M1$ mixing ratio we obtain $P_{4_2^+}(T = 1) \approx 0.23^{+0.29}_{-0.10}\%$. The corresponding off-diagonal matrix element, $\langle V_\mathrm{mix}\rangle$, causing the mixing can be estimated to

$$\langle V_\mathrm{mix}\rangle \approx |b\left[E(4_2^+) - E(4_1^+)\right]| = 9.6^{+4.8}_{-2.4}\ \mathrm{keV}. \quad (1)$$

The $4_2^+, T = 0$ state, furthermore, decays to the $5_1^+, T = 0$ state [8] with a decay branching ratio BR = $I_\gamma(4_2^+ \to 5_1^+)/I_\gamma(4_2^+ \to 3_1^+) = 0.51(3)$. Considering the small isospin admixture deduced above for the $4_2^+, T = 0$ state, we find that the decays of this state are dominated by the admixtures of the strong isovector $M1$ transitions with almost equal matrix elements to the $T = 0$ 3_1^+ and 5_1^+ states. Consequently, the considered theoretical branching ratio is decreased from the unmixed value BR = 24.9 to a value of BR = 1.1(3) for the mixed case, that is in satisfactory agreement with the data. This branching ratio represents a second observable which independently supports our conclusion about the size of isospin mixing in the $J^\pi = 4^+$ isospin doublet in ^{54}Co.

It is interesting to note that the estimated value of isospin breaking matrix element $V_\mathrm{mix} \approx 10$ keV compares well with the one determined directly from the calculated and experimental energies in isospin $A = 42$ $T = 1$ multiplet [9]. It is intriguing that the isospin breaking interaction obtained in [9] is strongly dependent on the spin J. Therefore, it is very interesting to use the alternative way proposed by us to test the isospin mixing for the states with $J = 2, 6, 8$ and to verify the properties of isospin breaking interaction for different excited states.

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