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Gamow-Teller Decay of T=1 Nuclei to Odd-Odd N=Z Nuclei

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Abstract. Transition strengths of Gamow-Teller decay of $T_z = \pm 1$ nuclei to $N = Z$ odd-odd nuclei have been calculated in a two-nucleon approximation for spherical and deformed nuclei. The results obtained for the latter are quite close to the values obtained by full-space shell-model calculations and to the experiment.

1. Introduction

The Gamow-Teller (GT) beta-decay of nuclei with $T = 1$ to $N = Z$ odd-odd nuclei is mostly characterized by a large $B(GT)$ [1, 2]. The typical case is the $^6$He to $^6$Li decay with $B(GT)=4.76(1)$. In the case of light nuclei this value is close to the prediction of the Wigner SU(4) symmetry model [3].

The goal of this work is to calculate reduced matrix elements (rme) of the GT operator, particularly in the pf-shell. Special attention will be paid to the configuration mixing.

2. Spherical configurations

The definition of the rme of the GT transition is

$$\langle f || \sigma \tau || i \rangle = \langle f || \sum_k \sigma(k) \tau_{\pm}(k) || i \rangle$$

(1)

where $\sigma, \tau$ are spin and isospin operators, respectively, and the sum is taken over the valence nucleons. In the approximation we use, we will consider only the last two valence nucleons. Both the initial $|0^+, T = 1, T_z = \pm 1 \rangle$ state and the final $|1^+, T = 0, T_z = 0 \rangle$ state can contain only one of the $j_2^2$ and $j_2^1$ single-j configurations or the spin-flip $j_> j_<$ one. This is indeed a very crude approximation which, at least in the case of spherical nuclei, cannot lead to sensible results. The next step is to introduce a two-body interaction between the above mentioned configurations. This was done for $^6$He, and the Cohen-Kurath interaction was used. We obtained $B(GT)=5.29$, which is very close to the result of more sophisticated shell model (SM) calculations [4]. If we examine the GT rme, we see that the contributions of the single-j configurations such as $j_2^2$ interfere coherently with those containing the spin-flip $j_> j_<$ one. This is also true for the GT decay of $^{42}$Ti to $^{42}$Sc, where we obtained $B(GT)=4.84$, compared to the experimental $B(GT)=2.52$ (quenching factor $q=0.72$).
This two-nucleon approximation is valid in the spherical case only for nuclei with two nucleons outside a doubly-magic core. Otherwise the Pauli principle will be violated.

3. Deformed configurations
If we approach the middle of a shell, the proton-neutron interaction induces collectivity. In this case we use the Bohr-Mottelson model [5] with Nilsson intrinsic wave functions which have good isospin. The total strongly coupled wave function is written in the weak coupling basis [5, 6].

The use of the rotational model has two important consequences. Firstly, the deformed mean field automatically introduces configuration mixing. Secondly, since, when increasing N or Z each nucleon must be put on a Nilsson state with a definite projection quantum number, the Pauli principle is to a certain extent respected. Also in this case we notice that the configuration mixing enhances the GT rme, at least in the first half of a shell. A comparison of calculated and experimental B(GT)'s can be seen in Table 1.

| Parent nucleus | $\beta_{eff}$ | Theory | Experiment |
|----------------|--------------|--------|------------|
| $^{22}$Mg      | 0.43         | 0.72   | 0.85(2) [7]|
| $^{46}$Cr      | 0.37         | 0.69   | 0.64(20) [8]|

The GT rme can be decomposed into one-body matrix elements between all possible single-particle states. We compared the decompositions done with Nilsson wave functions and with full space SM wave functions. The decompositions look strikingly similar, although in the former only the last two valence nucleons were considered. In other words, the lower valence nucleons behave like spectators. This feature should be further explored.

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