Effect of interaction in the particle-particle channel on Gamow-Teller β^+ decay in spherical nuclei

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The values of ft are calculated for Gamow-Teller β^+ decays of ^{152}Yb, ^{150}Er, ^{148,146}Dy, and ^{96}Pd in the random-phase approximation. The interactions in the particle-hole and particle-particle channels are taken into account. A good description of the corresponding experimental data is achieved with $|G_A/G_v| = 1$ at a fixed value of the particle-particle interaction constant.

The success of the interacting-boson model,[1] which incorporates particle-particle interactions, in describing several characteristics of low-lying collective states has attracted interest to the role played by particle-particle interactions. The simultaneous incorporation of the interactions in the particle-hole and particle-particle channels has made it possible to generate a description of two-neutrino double β^- decay which agrees with experimental data. The present letter describes the Gamow-Teller β decay of even spherical nuclei in the random-phase approximation; the interactions between quasiparticles in the particle-particle and particle-hole channels are taken into account simultaneously.

The Hamiltonian of the quasiparticle-phonon model of the nucleus[3] contains particle-hole and particle-particle interactions between quasiparticles. It is a straightforward matter to work from the general equations of this model to derive equations for describing the energies and wave functions of the Gamow-Teller 1^+ states in the random phase approximation, while simultaneously incorporating the particle-particle and particle-hole charge-exchange interactions, with respective constants G_1^{01} and κ_1^{01}. We write the operator which creates a charge-exchange phonon in the form

$$\Omega_i^+ = \sum_{j_p j_n} \{ \psi^i_{j_p j_n} A^+(j_p j_n ; 10) + \varphi^i_{j_p j_n} A(j_p j_n ; 10) \},$$

where

$$A^+ (j_p j_n ; 10) = \sum_{m_n, m_p} \langle j_p m_p j_n m_n \mid 10 \rangle \alpha^+_{j_p m_p} \alpha^+_{j_n m_n} .$$

Here α^+_{jm} is the quasiparticle creation operator, $j_p m_p$ ($j_n m_n$) are the quantum numbers of the proton (neutron) single-particle states, and $i = 1,2,3...$ is the index of the root of the corresponding secular equation.

The matrix element for the β^+ decay of the ground state of an even-even nucleus, with a wave function Ψ_0, into a single-phonon 1^+ state of an odd-odd nucleus, with a wave function $\Omega_i^+ \Psi_0$, is

$$(\Psi_0^* \Omega_i H_\beta^1 \Psi_0) = \sum_{j_p j_n} \langle j_n \| \Gamma_\beta \| j_p \rangle (\psi^i_{j_p j_n} v_{j_p} u_{j_n} + \varphi^i_{j_p j_n} u_{j_p} v_{j_n}),$$

where $\langle j_n \| \Gamma_\beta \| j_p \rangle$ is the single-particle Gamow-Teller matrix element, and u_j and v_j are the coefficients of a canonical Bogolyubov transformation. The incorporation of the particle-particle interaction in addition to the particle-hole interaction leads to an increase in the values of $\varphi^i_{j_p j_n}$ for the low-lying states. Since the functions $\psi^i_{j_p j_n}$ and $\varphi^i_{j_p j_n}$ are opposite in sign, the probabilities for β^+ transitions become suppressed with increasing absolute value of the particle-particle interaction constant.

Table I shows results calculated on $\log ft$ for β^+ transitions to the low-lying 1^+ states of neutron-deficient nuclei in the random phase approximation, along with corresponding experimental resultant values of $\log ft$, found as

$$(\widetilde{ft})^{-1} = \sum_k (ft)_k^{-1}$$

and taken from Refs. 5–9. In these calculations we used the same single-particle energies and wave functions for the Woods-Saxon potential and pairing constants as in Ref. 4. The values of $|\kappa_1^{01} A|$ are 1.5 times the value used in Ref. 4 in a study of nuclei from the stability valley. In these calculations we used the particle-particle interaction constant $G_1^{01} = -0.2\,\kappa_1^{01}$. By increasing this constant, one can reduce the strength of the β^+ transitions to low-lying states by another factor of two without violating the conditions for the applicability of the random-phase approximation.

Let us examine the results calculated on the β^+ decay of ^{148}Dy. The incorporation of the particle-hole interaction leads to a resultant strength of the β^+ transition which is lower by a factor of 2.65 than the prediction of the independent-particle model. The incorporation of the particle-particle interaction introduces a further suppression by a factor of two. With the value $G_1^{01} = -0.21\,\kappa_1^{01}$ we find $\log ft = 3.9$, which agrees precisely with the experimental value. As G_1^{01} is increased, the total strength of the β transition decreases, while the corresponding sum rule is conserved.

We calculated the matrix elements for the two-neutrino double-β^- decay for ^{128,130}Te, $G_1^{01} = -0.2\,\kappa_1^{01}$, finding values in agreement with those of Ref. 2 and also in agreement with the experimental data. The need to incorporate the interaction in the

TABLE I. Values of $\log ft$ for β^+ transitions from 0^+_{gs} to the 1^+ states.

β^+ transition	$\log \widetilde{ft}$ experimental	$\log \widetilde{ft}$ theoretical $G_1^{01} = -0.2\kappa_1^{01}$	$G_1^{01} = 0$
^{152}Yb – ^{152}Tm	3.4	3.5	3.1
^{150}Er – ^{150}Ho	3.6	3.5	3.2
^{148}Dy – ^{148}Tb	3.9	3.7	3.4
^{146}Dy – ^{146}Tb	3.8	3.8	3.3
^{96}Pd – ^{96}Rh	3.3	3.3	3.0

particle-particle channel in order to suppress the strength of the two-neutrino double-β decay was confirmed in Ref. 10.

In a description of the β^+ decays of nuclei which are far from the stability valley, the axial vector constant of the weak interaction, G_A, is renormalized. In order to reach agreement with the experimental values of ft, the values $|G_A/G_v| = 0.6$–0.8, were used in Refs. 5 and 6, and $|G_A/G_v| = 0.7$–1.0 were used in Ref. 11. Our calculations were carried out with $|G_A/G_v| = 1$. We reached agreement with the experimental values of ft for $|G_A/G_v| = 1.25$ by increasing G_1^{01} by 3%. Consequently, calculations on the β decays of nuclei far from the stability valley are not a suitable basis for drawing conclusions about the magnitude of renormalization of the axial-vector constant of the weak interaction, G_A.

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