Axial charge density in the $\Delta T = 1$, $0^+ \leftrightarrow 0^-$, isovector transition in nuclei with $A = 16$

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Analysis of data on the axial charge density with allowance for the exchange meson current yields $g_p/g_A \sim 10$ for the ratio of the induced pseudoscalar form factor g_p to the axial for factor g_A of the nucleon. This result eliminates the large discrepancy between the prediction of current algebra ($g_p/g_A \sim 7$–8) and the nuclear-physics determination in the impulse approximation ($g_p/g_A \sim 13$–20).

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In muon-capture reactions and in the beta decay between $^{16}O(0_1^+, T = 0)$ and $^{16}N(0_1^-, T = 1)$ the ratio of the partial muon-capture rate $\Lambda_\mu(0_1^+ \rightarrow 0_1)$ to the partial beta-decay rate $\Lambda_\beta(0_1^- \rightarrow 0_1^+)$ is determined by the ratio of the induced pseudoscalar form factor g_p to the axial form factor g_A of the nucleon. As was first pointed out by Shapiro and Blokhintsev,[1] this purely axial transition represents an appropriate experimental test of the current-algebra prediction $g_p/g_A \sim 7$–8. In the impulse approximation (IA), which the nuclear current is described as the sum of the contributions of the individual nucleons (a single-particle current), an identical accuracy of the description of Λ_μ and Λ_β for all known models for nuclei with $A = 16$ can be achieved with $g_p/g_A \sim 13$–20. In the present letter we show that the large discrepancy with the current-algebra prediction can be eliminated by incorporating an exchange meson current. The transition $0_1^+ \leftrightarrow 0_1^-$ is sensitive to the time-dependent component (the charge density) of the axial vector isovector exchange current, since it is of the same order of magnitude, O(1/M), as the single-particle current.[2] Exchange corrections have been examined by several investigators, but their role has not been finally resolved, since some highly simplified models of the nuclear structure have been used[3] ($2p$–$2h$ admixtures were incorporated only in the wave function of the 0_1^+ state; the complete spectrum of $2\hbar\omega$ excitations was replaced by simply two components), along with a simplified model for the exchange-current operator (the exchange of vector mesons was ignored).[3–5] The result is a strong dependence of the exchange corrections on the particular model adopted for the nuclear structure. In the present letter we are refining both the model operator and the description of the nuclear structure. We construct the operator in the S-matrix approach, and we retain the representation of the exchange current as a two-particle single-boson-exchange operator.[5] We incorporate the exchange of vector mesons, by means of a minimal chiral-invariant phenomenological Lagrangian of the hard-pion model.[6,7] To improve the description of the nuclear structure, we use the many-particle wave functions from the shell model with configurational mixing.[8] The 0_1^+ state thus contains all possible excitations of two particles in $1s$–$(2p - 1f)$ space. The 0_1^- state contains the two strongest (1% each) $2p - 2h$ components. We also incorporate short-range nucleon-nucleon correlations by means of the correlation function of Miller and Spencer,[9]

TABLE I. Experimental data on partial transition rates (the experimental situation is described in Ref. 4). $\Lambda_\mu^{\exp} = 1570 \pm 100\ \mathrm{s}^{-1}$, $\Lambda_\beta^{\exp} = 0.41 \pm 0.06\ \mathrm{s}^{-1}$, $(\Lambda_\mu/\Lambda_\beta)_{\exp} = 3800 \pm 80$. Here $J^4_{(A_1\rho\pi)}$ is the time-dependent component of the two-particle (exhange) axial vector current operator.

$g_p/g_A = 10 \times 5$	Muon capture				Beta decay			
	without $2p-2h$		with $2p-2h$		without $2p-2h$		with $2p-2h$	
$\langle 0_1^- \mid J_{IA}^{(\mu,\beta^*)} \mid 0_1^+ \rangle$	-0.2902		-0.2246		-0.1098		-0.0729	
$\Lambda^{IA}_{(\mu,\beta)}$ (s^{-1})	2169		1300		0.40		0.18	
	without f	with f	without f	with f	without f	with f	without f	with f
$\langle 0_1^- \mid J^{4(\mu,\beta^*)}_{(A_1\rho\pi)} \mid 0_1^+ \rangle$	-0.0986	-0.0896	-0.0812	-0.0731	-0.1144	-0.1044	-0.0945	-0.0860
$\Lambda_{(\mu,\beta)}$ (s^{-1})	3090	3000	1890	1827	1.02	0.96	0.53	0.50
Operator	Impulse approximation		$J^4_{(A_1\rho\pi)}$; without f		with f	without f	with f	
$\Lambda_\mu / \Lambda_\beta$	5422		without $2p-2h$ 3029		3125	with $2p-2h$ 3520	3676	

$$f(r=r_i-r_j)=1-\exp(-\alpha r^2)(1-\beta r^2),\quad \alpha=1,1\ \Phi^{-2}\ \beta=0{,}68\ \Phi^{-2}.$$

The partial transition rates are proportional to the square of the matrix element of the axial weak current, J, taken between the initial and final states of the nucleus,

$$\Lambda_{(\mu,\beta)}\ (0_1^+ \rightleftharpoons 0_1^-) \sim |\langle 0_1^-\ |J^{(\mu,\beta^*)}|\ 0_1^+\rangle|^2$$

(the detailed expressions are given in Ref. 4). To get an idea of the order of magnitude of the effect we consider the simplified picture of the nuclear structure in which the ^{16}O ground state is a closed $1p$ shell, and 0_1^- contains only a single configuration,

$$|(2s_{1/2})^1(1\tilde{p}_{1/2})^{-1}\ J=M=0;T=1,T_3=-1)$$

(Table I). We see that the exchange current leads to a ratio $\Lambda_\mu/\Lambda_\beta$ much smaller than that predicted by the impulse approximation, and in this manner we achieve agreement with experiment. The absolute values of the partial transition rates, however, are too high in this case, because of the cutoff of the basis. Using the many-particle wave functions of the shell model with configurational mixing to evaluate the matrix elements of the two-particle operator in muon capture and beta decay, we find that they are smaller than the corresponding values calculated without configurational mixing by a factor $R=\alpha_0\beta_0$. Here α_0 and β_0 are the weights of the principal components, $|0p-0h\rangle$ and $|(2s_{1/2})^1(1p_{1/2})^{-1}\rangle$, of the 0_1^+ and 0_1^- states ($\alpha_0=0.89,\beta_0=0.95$) (Table I). This result is found because the spreading of the $2p-2h$ admixtures over all possible $2\hbar\omega$ excitations for the 0_1^+ state and over the two strongest $3\hbar\omega$ excitation for the 0_1^- state results in a destructive interference of small contributions. The meson exchange current thus senses the presence of the $2p-2h$ admixtures in the nuclear states of the system with $A=16$ only through the changes in the weights of the principal components. Incorporating the short-range correlations results in a 10% suppression of the nuclear matrix elements of the exchange current, while Λ_μ and Λ_β change by only 3% and 6%. It has thus been shown that the incorporation of a meson exchange current with a realistic description of the correlation effects in the nuclear structure leads to a nuclear axial charge density much higher than that predicted by the impulse approximation. Our theoretical analysis of the experimental data thus yields a ratio $g_p/g_A \sim 10$, in near agreement with the prediction of current algebra.

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