Hypothesis of Wigner SU(4) symmetry and experimental value of g_A/g_V for nucleons of nuclear matter

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The suppression of the β-decay matrix elements of Gamow-Teller resonances observed experimentally is evidence that the properties of a nuclear nucleon can be described approximately by the Wigner SU(4) symmetry and that the ratio of effective constants (g_A/g_V) is approximately unity for a nuclear nucleon, while the SU(4) symmetry is broken for a free nucleon.

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The discovery of a Gamow-Teller resonance in charge-exchange reactions[1] has reattracted interest to the problem of the Wigner SU(4) symmetry of nucleons. This problem dates back to the classic 1937 papers of Wigner.[2] In a strict symmetry of this type, all the properties of an analog resonance and a Gamow-Teller resonance should be identical to within spin factors $S = 0, 1$. Experimentally, we find that the analog resonance and the Gamow-Teller resonance are essentially energy-degenerate for nuclei from ^{208}Pb to ^{238}U (Ref. 3), that the suppression of spin-orbit forces in the charged pn channel for nuclear excitation increases with increasing value of the difference[4] $N-Z$, and that the isospin-interaction constant and the spin–isospin-interaction constant in nuclear matter are apprximately equal,[5] so that we may say there is an approximate restoration of Wigner symmetry with the increase in $N-Z$ which occurs in the range of heavy nuclei.[6] Independent arguments for this hypothesis follow from an analysis of the mass differences of nuclear isobars in the region $A \geqslant 216$ which has been carried out on the basis of the Weiszacker formula, modified for an SU(4) symmetry. This analysis explains the experimental differences within ~150 keV, which is at the level of the mass formulas presently used.[7] All these arguments, however, are related to the energy characteristics of the nuclei, and these characteristics are less sensitive than transition matrix elements to symmetry breaking.

Recent experiments on the cross sections for (p, n) reactions involving the excitation of a Gamow-Teller resonance have revealed a pronounced suppression of the matrix elements ($M^2_{\rm GT}$) describing the β decay of the Gamow-Teller resonance to the ground state of the target nucleus in heavy and intermediate weight nuclei.[3] This suppression reaches a level $\sim 50 \pm 10\%$ of the proposed vacuum values. From the standpoint of nuclear theory, this suppression must result from two factors: structural factors, which vary from nucleus to nucleus, depending on the filling of shells, and the spin-isospin polarization of nuclear matter (this polarization is the same for all nuclei). In the theory of finite Fermi systems, the latter factor is related to the effective charge of the quasiparticles, $e_q(\sigma\tau)$, with respect to an external field of the $\sigma\tau$ type.[8] For sufficiently heavy nuclei, $M^2_{\rm GT}$ is given in the semiclassical approximation in this theory by[9]

$$M^2_{GT} = e^2_q(\sigma\tau)(N-Z)(1-\delta), \; \delta \cong \frac{2}{3g'_0}\,\frac{E^2_{ls}}{\Delta E^2 + E^2_{ls}}, \quad g'_0 \sim 1.0, \tag{1}$$

where the structural-factor correction δ depends on the energy width (ΔE) of the layer of excess neutrons, $N-Z$, and their average spin-orbit energy E_{ls}. Since ΔE is proportional to $N-Z$, while E_{ls} is approximately constant ($E_{ls} \sim 6$ MeV; Ref. 10), the structural factors fall off with increasing $N-Z$, amounting to ~10–15% near ^{208}Pb. Working from the experimental suppression factor

$$(M^2_{GT})_{\rm exp}/(N-Z) = 0.50 \pm 0.10 \tag{2}$$

we find the following estimate of the effective charge of a nucleon in nuclear matter:

$$e^2_q(\sigma\tau) = \frac{(M^2_{GT})_{\rm exp}}{(N-Z)}\,\delta^{-1} \approx 0.60 \pm 0.10, \quad e_q(\sigma\tau) \approx 0.8 \pm 0.05. \tag{3}$$

This value agrees approximately with that which follows from the exact calculations[11]: $e_q(\sigma\tau) \sim 0.8$. Since the mid-1960s, the theory of finite Fermi systems has used the value $e_q \sim 0.9$, which follows from (for example) an analysis of the β transitions of mirror nuclei.[12] The two values are seen to agree when we take into account the circumstance that experiments on the (p, n) reaction reveal the existence of a transition region in the region of light nuclei where the effective charge should fall off from 1.0 to 0.8. The nuclei of the mirror group, $A \lesssim 40$, apparently lie in this transition region.

The physical reasons for the difference between e_q and unity are the complex many-particle effect, e.g., the $2p$-$2h$ effect, and collective resonances far from the Fermi surface. Some particular collective resonances are the hypothetical states of the Δ (1236) resonance: a nucleon hole, which is presently the subject of an extensive discussion in the literature.[13] In the case of the Wigner SU(4) symmetry, the identity of the isospin and spin-isospin vertices gives us

$$g_A/g_V = \frac{e_q(\sigma\tau)}{e_q(\tau)} = 1, \quad e_q(\sigma\tau) = e_q(\tau) = 1. \tag{4}$$

The latter inequality is a consequence of isospin conservation. At first glance, the experimental estimate (3) contradicts these relations, but for a vacuum nucleon—with which the comparison is made in (3)—the isospin and spin-isospin properties are not the same, since

$$g_A/g_V = 1,25 \pm 0,01. \tag{5}$$

This means that for the vacuum nucleon SU(4) symmetry has already been broken; physically, ths circumstance corresponds to the nonvanishing contributions of the Δ resonance and other, higher-order resonances to the Adler-Weisberger sum rule. For nuclear nucleons, in contrast, the effective ratio g_A/g_V in nuclear matter differs from the vacuum value by the magnitude of the effective charge:

$$(g_A/g_V)_{\mathrm{nuc}} = \tilde{g}_A/\tilde{g}_V = \frac{g_A}{g_V}\,\frac{e_q(\sigma\tau)}{e_q(\tau)} = 1.25\,(e_q(\sigma\tau))_{\mathrm{exp}} \approx 1.0 \pm 0.05, \tag{6}$$

i.e., it is approximately equal to the value expected from SU(4) symmetry. We thus reach the interesting conclusion that the nucleons of nulcear matter have properties closer to the SU(4) predictions than do nucleons in a vacuum. A direct test of this conclusion might be to study (Δ-resonance)—(nucleon-hole) collective states in charge-exchange reactions at 0° at an energy ~0.5–1 GeV/particle. In the case of SU(4) symmetry, we should expect a preferential excitation of individual nucleons, while if this symmetry is broken we would expect the excitation of coherent states of the nucleus as a whole. In the former case the cross section would be proportional to A or $A^{2/3}$, while in the latter case it would be proportional to A^2.

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