Weak interaction of nucleons and the process $n+p\to d+\gamma$

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We obtained in the Weinberg-Salam gauge model the potentials of the weak interaction (WI) of nucleons due to the exchange of 0^- and 1^- mesons of a nonet. The contributions from the neutral hadronic currents were taken into account. The effects of WI of nucleons in the radiative capture of a thermal neutron by a proton are examined.

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The discovery of the weak interaction (WI) of nucleons led to an intensive investigation of its different effects.[1-5] For most of the effects the experimental values are larger than the theoretical, if the neutral currents are ignored.[6] In this paper, we constructed the potentials of the weak nucleon interaction in the Weinberg-Salam model and calculated the effects of this interaction in the process $n+p\to d+\gamma$: circular polarization of a photon due to the capture of an unpolarized thermal neutron and asymmetry of photon emission due to the capture of a polarized neutron.

The effective WI Hamiltonian can be represented as a symmetrization product of the currents:

$$H = \frac{G}{\sqrt{2}}\{J_\mu, J_\mu^+\}_S = \frac{G}{2\sqrt{2}}\{J_\mu J_\mu^+ + J_\mu^+ J_\mu\}, \tag{1}$$

where $G = 10^{-5}M^{-2}$ is the WI constant.

In the generalized Weinberg-Salam model for hadrons[7] the charged current coincides with the SU(3) current, if the charmed currents are not taken into account:

$$J_\mu^W = \cos\theta_C\, J_\mu^{1+i2} + \sin\theta_C\, J_\mu^{4+i5}, \tag{2}$$

where $\sin\theta_C \approx 0.22$. Let us examine the WI of nucleons with 0^- and 1^- mesons of a nonet. The Lagrangian of the weak interaction of $\rho^\pm$ mesons with the isovector nucleon current J^{1+i2} can be determined by substituting in Eq. (1) the first term in Eq. (2) and using the equality for the vector current-field:

$$V_\mu^a = m_\rho^2 f_\rho^{-1}\rho_\mu^a, \tag{3}$$

where a is the isotopic index and $m_\rho, f_\rho^2/4\pi = 2.4$, and ρ_μ^a are the mass, the coupling constant, and the field operator of the ρ meson, respectively.

As a result, we obtain the Lagrangian

$$\mathcal{L}_\rho^W = \frac{G g_A m_\rho^2 \cos^2\theta_C}{f_\rho} (\bar{N} A_\mu^{1+i2} N \rho_\mu^- + \bar{N} A_\mu^{1-i2} N \rho_\mu^+), \tag{4}$$

where $g_A = 1.25$ is the axial-vector constant. Note that only the axial-vector current J_μ^{1+i2} contributes to the Lagrangian (4). The Lagrangian of the strong interaction has the form:

$$\mathcal{L}_\rho^S = f_\rho \bar{N}\left(\gamma_\mu + \frac{\mu_v}{2M} \sigma_{\mu\lambda} \partial_\lambda\right) \frac{1}{2} \tau^a N \rho_\mu^a, \tag{5}$$

where $\mu_v = 3.7$ is the isovector anomalous magnetic moment of the nucleon. Lagrangians (4) and (5) give the weak nucleon interaction potential due to the exchange of ρ mesons:

$$V_{\rho^\pm}(r) = -\frac{G g_A m_\rho^2 \cos^2\theta_C}{4\pi\sqrt{2}M} \{ i(1+\mu_v) [\vec{\sigma}_1 \vec{\sigma}_2][\mathbf{p}, v_\rho(r)]_- + (\vec{\sigma}_1 - \vec{\sigma}_2)\{\mathbf{p}, v_\rho(r)\}_+ \} T_{12}^{(+)}, \tag{6}$$

where $p = \frac{1}{2}(\mathbf{p}_1 - \mathbf{p}_2) = -i\vec{\nabla}$, $v_\rho(r) = \exp(-m_\rho r)/r, T_{12}^{(+)}$ is the isospin operator which determines the selection rules

$$T_{12}^{(+)} = \frac{1}{3}(\vec{\tau}_1 \vec{\tau}_2)_{\Delta T=0} + \frac{1}{6}(\vec{\tau}_1 \vec{\tau}_2 - 3\tau_1^3 \tau_2^3)_{\Delta T=2}. \tag{7}$$

The WI potential due to the $\pi^\pm$ meson exchange has the form[1]:

$$V_\pi(r) = -\frac{g_\pi f_\pi}{4\pi\sqrt{2}M}(\vec{\sigma}_1 + \vec{\sigma}_2)[\mathbf{p}, v_\pi(r)] T_{12}^{(-)}, \tag{8}$$

where $g_\pi^2/4\pi = 14.5$, f_π is the WI constant of πNN, and $T_{12}^{(-)} = -(i/2)[\vec{\tau}_1\vec{\tau}_2]^3_{\Delta T=1}$. The f_π constant cannot be determined analogously in the case of ρ mesons, since the vector-dominance relation (3) does not exist for π mesons. Therefore, f_π can be expressed in terms of the experimentally determined amplitudes of the nonleptonic decay of hyperons by using current algebra. The f_π constant, whose sign is not specified, is[2]

$$|f_\pi| = 2.7 \times 10^{-7} |A|, \tag{9}$$

where A depends on the WI model and in particular on the structure of the neutral current. In the Weinberg-Salam model, ignoring the strange and charmed-particle currents, the neutral hadronic current has the form

$$J_\mu^z = J_\mu^3 - 2\sin^2\theta_w J_\mu^{em} = (1 - 2\sin^2\theta_w) V_\mu^3 + A_\mu^3 - 2\sin^2\theta_w V_\mu^0, \tag{10}$$

where $\sin^2\theta_w \approx 0.25$, J_μ^3 is the neutral component of the isotriplet of the nucleonic currents, and J_μ^{em} is the electromagnetic current. Using Eqs. (1), (3), (5), and (10), we obtain the potential of the weak nucleon interaction due to the ρ^0 meson exchange $V_{\rho^0}(r)$. It coincides with $V_{\rho^+}(r)$ of Eq. (6) if we make the following substitutions in the latter: $\cos^2\theta_C \to (1 - 2\sin^2\theta_w)$ and $T_{12}^{(+)} \to \tau_1^3\tau_2^3$. We can obtain analogously the potential of the ω meson exchange by identifying in (10), just as in (3), the operator of the ω meson with the isoscalar current V_μ^0. In this case (for $m_\omega \approx m_\rho$) $V_\omega(r) = V_{\rho^\pm}(r)$ if we substitute in the latter $\cos^2\theta_c \to (-2\sin^2\theta_w)$, $T_{12}^{(+)} \to 1$, and $(\sigma_1 - \vec{\sigma}_2) \to (\vec{\sigma}_1\tau_1^3 - \vec{\sigma}_1\tau_2^3)$ and multiply by $(\tau_1^3 + \tau_2^3)$ the first term in the braces in (6), $\mu_v \to \mu_s = -0.12$ is the isoscalar magnetic moment of the nucleon, then the potentials of the weak nucleon interaction due to the ρ^0 and ω exchange give rise to selection rules with respect to the isospin $\Delta T = 0.2$. Since the field operator of the ϕ meson is identified with the isoscalar current of the strange particles, which is missing in the current (10), the ϕ meson does not contribute to the potential of the weak nucleon interaction. Using the current algebra and taking into account the contribution from the neutral currents (10), we obtain for the coefficient A in (9):

$$A = \frac{1}{\sqrt{2}} \tan\theta_C \left(1 - \frac{2\sin^2\theta_w}{3\sin^2\theta_C}\right). \tag{11}$$

The numerator of the fraction in Eq. (11) is equal to the product of the coefficients for the currents A_μ^3 and V_μ^0 in (10). Since, as it follows from (1) and (2), the amplitudes of the nonleptonic decays of hyperons are proportional to $\sin\theta_C\cos\theta_C$, as a result of substituting (11) in (9) the first term in (11) is effectively proportional to $\sin^2\theta_C$ and hence is determined by the strangeness-changing charged current J_μ^{4+i5} in (2). The second term, which is independent of θ_C, is determined by the structure of the neutral current (10). It follows from (11) that the contribution from the neutral currents increases the constant f_π by a factor of ~ 3. This increase, together with the contributions from the additional potentials of the ρ^0 and ω exchange, may increase parity violation in the nuclear transitions by approximately an order of magnitude. A number of discrepancies between the theoretical results and experimental data can be eliminated in this way.

The potentials of the ρ and ω exchange contribute to the circular polarization of the photon in the process $n + p \to d + \gamma$. They mix the initial states $^1S_0(T = T_3 + 1 = 1)$ and $^3P_0(T = T_3 + 1 = 1)$ and the final states $^3S_1$, $^3D_1(T = 0)$, and $^1P_1(T = 0)$ with opposite parities and $\Delta T = 0.2$.[9] The calculation of the matrix elements of the main $M1$ and impurity $E1$ transitions with Hamad-Johnson wave functions gives for the circular polarization of the photon[10]:

$$P_\gamma = (4.71\cos^2\theta_C + 8.21\sin^2\theta_w - 3.41)\times 10^{-8} \approx 3.5\times 10^{-8}. \tag{12}$$

The experimental value for P_γ is $(-1.30 \pm 0.45)\times 10^{-6}$.[11] Thus, a large difference between the theoretical results and the experimental data remains unresolved. In the different models of strong and weak interaction P_γ is in the range $(0.01 - 80)\times 10^{-8}$. A compilation of many theoretical results was done by Lassy and McKellar.[12] The asymmetry of photon emission as a result of capture of a polarized neutron is determined by the potential of the π meson exchange (8). It mixes the initial states $^3S_1(T = 0)$ and $^3P_1(T = T_3 + 1 = 1)$ and the final states $^3S_1$, $^3D_1(T = 0)$ and

$^3P_1(T = T_3 + 1 = 1)$ with opposite parities and $\Delta T = 1$.[9] The symmetry is equal to $A_\gamma^{\text{theor}} = -0.16 f_\pi = \pm 2\times 10^{-8}$. The experimental value $A_\gamma = (0.6 \pm 2.1)\times 10^{-7}$ (Ref. 13) is not yet sufficiently accurate for a detailed comparison with the theoretical results. The weak interaction of nucleons in the quark model was investigated in Ref. 14 in which a comprehensive bibliography is given.

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[1)]The potential of the π^0 meson exchange is forbidden under the CP-invariance requirements of weak πNN interaction.[8]

[1]I.S. Shapiro, Usp. Fiz. Nauk **95**, 647 (1968) [Sov. Phys. Usp. **11**, 582 (1969)].

[2]E. Fishbach and D. Tadic, Phys. Rev. **C6**, 123 (1973).

[3]M. Gari, Phys. Rev. **C6**, 317 (1973).

[4]G.A. Lobov, Atomic Energy Rev. **12**, 505 (1974).

[5]Yu. G. Abov and P.A. Krupchitskiĭ, Usp. Fiz. Nauk **118**, 141 (1976) [Sov. Phys. Usp. **19**, 75 (1976)].

[6]B. Mc Kellar, 2nd Intern. Conf. on the NN Interaction, Vancouver, B.C., 1977.

[7]S.L. Glashow, J. Illiopulos, and L. Maiani, Phys. Rev. **D12**, 1285 (1970); S. Weinberg, Phys. Rev. **D5**, 1412 (1972).

[8]G. Barton, Nuovo Cim. **19**, 512 (1961).

[9]G.S. Danilov, Phys. Lett. **18**, 40 (1965); I.S. Shapiro, J.I.N.R. Report No. 3-3442, 1967, p. 76.

[10]K. Ohyo *et al.*, Progr. Theor. Phys. **56**, 875 (1976); **57**, 1455 (1977).

[11]V.M. Lobashev *et al.*, Nucl. Phys. **A197**, 241 (1972).

[12]K.R. Lassy and B.H.J. Mc Kellar, Phys. Rev. **C11**, 349 (1975).

[13]J.F. Cavaignac *et al.*, Phys. Lett. **B67**, 148 (1977).

[14]J.F. Donoghue, Phys. Rev. **D15**, 184 (1977); M.A. Shifmann, A.I. Vaĭnshteĭn, and V.I. Zakharov, Nucl. Phys. **B120**, 316 (1977); V.M. Dubovik and V.S. Zamiralov, Lett. al Nuovo Cim. **22**, 21 (1978).