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Method of the unitary clothing transformations in quantum field theory: calculation of the deuteron magnetic and quadrupole moments

We continue our explorations [1] of the electromagnetic properties of the deuteron with help of the method of unitary clothed transformations (UCTs) [2,3]. It is the case, where one has to deal with the matrix elements $\langle \mathbf{P}', M'|J^\mu(0)|\mathbf{P}=\mathbf{0}, M\rangle$. Here the operator $J^\mu(0)$ is the Nöther current density $J^\mu(x)$ at the point $x=0$, sandwiched between the eigenstates of a "strong" field Hamiltonian H, viz., the deuteron states $|\mathbf{P}=\mathbf{0}, M\rangle$. These states meet the eigenstate equation $P^\mu|\mathbf{P}, M\rangle = P^\mu_d|\mathbf{P}, M\rangle$ with $P^\mu_d = (E_d, \mathbf{P})$, $E_d = \sqrt{\mathbf{P}^2 + m_d^2}$, $m_d = m_p + m_n - \varepsilon_d$, the deuteron binding energy $\varepsilon_d > 0$ and eigenvalues $M = (\pm 1, 0)$ of the third component of the total (field) angular-momentum operator in the deuteron center-of-mass (details in [3]). In the subspace of the two-clothed-nucleon states with the Hamiltonian $H = P^0 = K_F + K_I$ and the boost operator $\mathbf{B} = \mathbf{B}_F + \mathbf{B}_I$, where free parts K_F and $\mathbf{B}_F$ are $\sim b_c^\dagger b_c$ and interactions K_I and $\mathbf{B}_I$ are $\sim b_c^\dagger b_c^\dagger b_c b_c$, the deuteron eigenstate gets the form $|\mathbf{P}, M\rangle = \int d\mathbf{p}_1 \int d\mathbf{p}_2 C_M([\mathbf{P}]; \mathbf{p}_1\mu_1; \mathbf{p}_2\mu_2) b_c^\dagger(\mathbf{p}_1\mu_1) b_c^\dagger(\mathbf{p}_2\mu_2)|\Omega\rangle$ and we will show how one can find the C-coefficients within the clothed particle representation (CPR). Further, we use the expansion in the R-commutators

$J^\mu(0) = W J^\mu_c(0) W^\dagger = J^\mu_c(0) + [R, J^\mu_c(0)] + \frac{1}{2}[R, [R, J^\mu_c(0)]] + ..., (*)$

where $J^\mu_c(0)$ is the primary current in which the bare operators $\{\alpha\}$ are replaced by the clothed ones $\{\alpha_c\}$ and $W = \exp R$ the corresponding UCT. In its turn, the operator being between the two-clothed-nucleon states contributes as $J^\mu(0) = J^\mu_{one-body} + J^\mu_{two-body}$, where the operator

$J^\mu_{one-body} = \int d\mathbf{p}' d\mathbf{p} F^\mu_{p,n}(\mathbf{p}', \mathbf{p}) b_c^\dagger(\mathbf{p}') b_c(\mathbf{p})$

with $F^\mu_{p,n}(\mathbf{p}', \mathbf{p}) = e\bar{u}(\mathbf{p}') F_1^{p,n}[(p'-p)^2]\gamma^\mu + i\sigma^{\mu\nu}(p'-p)_\nu F_2^{p,n}[(p'-p)^2] u(\mathbf{p})$ that describes the virtual photon interaction with the clothed proton (neutron). By keeping only the one-body contribution we arrive to certain off-energy-shell extrapolation of the so-called relativistic impulse approximation (RIA) in the theory of e.m. interactions with nuclei (bound systems). Of course, the RIA results [1] should be corrected including more complex mechanisms of e-d scattering (see other our contribution). Since, as before in [1], we start with the following formula

$\mu_d = \frac{1}{m_d}\langle \mathbf{0}; M'=1|\frac{1}{2}\left[\mathbf{B}\times \mathbf{J}(0)\right]^z|\mathbf{0}; M=1\rangle$

for the magnetic moment of the deuteron, special attention has been paid to finding a relativistic correction due to the interaction part $\mathbf{B}_I$ of the RIA results obtained in [1].

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