LXXI International conference ”NUCLEUS –2021. Nuclear physics and elementary particle physics. Nuclear physics technologies”

Contribution ID: **104** Type: **Oral report**

A fresh field-theoretic 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 clothing transformations (UCT) [2,3]. It is the case, where one has to deal with the matrix elements $\langle \mathbf{P}', M' | J^\mu(0) | \mathbf{P}, M \rangle$ (to be definite in the lab. frame). Here the operator $J^\mu(0)$ is the Nöther current density $J^\mu(x)$ at the point $x = (t, \mathbf{x}) = 0$, sandwiched between the eigenstates of a “strong” field Hamiltonian H, viz., the deuteron states $|\mathbf{P}, M\rangle$. Latter belong to the two-clothed-nucleon subspace 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 $\sim b_c^\dagger b_c^\dagger b_c b_c$. Further, we use the expansion in the R-commutators
$J^\mu(0) = W J_c^\mu(0) W^\dagger = J_c^\mu(0) + [R, J_c^\mu(0)] + \frac{1}{2}[R, [R, J_c^\mu(0)]] + ...,$
where $J_c^\mu(0)$ is the initial 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 sandwiched between the two-clothed-nucleon states contributes as $J^\mu(0) = J^\mu_{one-body} + J^\mu_{two-body}$. 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). Starting from the operator of the magnetic dipole moment $\mu = \frac{1}{2}\int d\mathbf{x}\, \mathbf{x} \times \mathbf{J}(x)$ (reminiscent of the Biot-Savart formula from magnetostatics) one can show that the magnetic dipole moment of the deuteron being defined after Sachs as z-component of the matrix elements between narrow wave packets of the vector μ for the stretched configuration, looks as
$\mu_d = \lim\limits_{\mathbf{q}\to 0} \left[-\frac{i}{2} curl_{\mathbf{q}} \langle \frac{\mathbf{q}}{2}; 1 | \mathbf{J}(0) | -\frac{\mathbf{q}}{2}; 1 \rangle \right]^z,$
where the matrix elements $\langle \frac{\mathbf{q}}{2}; M_J | \mathbf{J}(0) | -\frac{\mathbf{q}}{2}; M'_J \rangle$ ($M_J = (\pm 1, 0)$ projection of the total angular momentum) determine the corresponding current in the Breit frame. In this way the deuteron magnetic dipole moment can be expressed as
$\mu_d = \frac{1}{m_d} \langle \mathbf{0}; 1 | \frac{1}{2} \left[\mathbf{B} \times \mathbf{J}(0) \right]^z | \mathbf{0}; 1 \rangle$
with the deuteron state $|\mathbf{0}; 1\rangle$ in the rest frame. In parallel, considering interaction energy of the system with the charge density $\rho(x) = J^0(x)$ in static external electric field and expanding it in the Cartesian electric moments one encounters the quadrupole moment tensor $Q_{ij} = \int d\mathbf{x}\, [3x_i x_j - \delta_{ij} \mathbf{x}^2] \rho(\mathbf{x})$ $(i, j = 1(x), 2(y), 3(z))$. Then repeating the same trick with wave packets one gets the matrix elements
$\langle J M'_J | Q_{ij} | J M_J \rangle = -\lim\limits_{\mathbf{q}\to 0} \left[\left\{ 3 \frac{\partial^2}{\partial q_i \partial q_j} - \delta_{ij} \frac{\partial^2}{\partial q_l^2} \right\} \langle \frac{\mathbf{q}}{2} | \rho(0) | -\frac{\mathbf{q}}{2} \rangle \right]$
to introduce electric quadrupole moment $Q = \langle JJ | Q_{33} | JJ \rangle$. These formulae have been a departure point for our preceding RIA calculations [1]. Here we will show our results with the meson exchange currents and boost ($\mathbf{B}_I$ part) contributions included.

References

1. A. Shebeko and I. Dubovyk, Few Body Syst. **54** 1513 (2013).
2. A. Shebeko, Chapter 1 In: Advances in Quantum Field Theory, ed. S. Ketov, 2012 InTech, pp. 3-30.
3. I. Dubovyk and A. Shebeko, Few Body Syst. **48** 109 (2010).

Primary authors: SHEBEKO, Aleksandr; Mr KOSTYLENKO, Yan (V.N. Karazin Kharkiv National University, Kharkiv, Ukraine)

Presenter: Mr KOSTYLENKO, Yan (V.N. Karazin Kharkiv National University, Kharkiv, Ukraine)

Session Classification: Section 1. Experimental and theoretical studies of the properties of atomic nuclei

Track Classification: Section 1. Experimental and theoretical studies of the properties of atomic nuclei.