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An Alternate Way for Calculating the Deuteron Form Factors

Let us remind that in the one-photon-exchange approximation (OPEA) the elastic e-d scattering amplitude is proportional to the contraction $T(ed \to e'd') = \varepsilon_\mu(e,e')\langle \mathbf{q}\, M'|J^\mu(0)|\mathbf{0}\, M\rangle$ where we have introduced the notation $\varepsilon_\mu(e,e') = \bar{u}_{e'}(k')\gamma_\mu u_e(k)$. 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 $|\mathbf{P}, M\rangle$. These states meet the eigenstate equation $P^\mu|\mathbf{P}, M\rangle = P_d^\mu|\mathbf{P}, M\rangle$ with $P_d^\mu = (E_d, \mathbf{P})$, $E_d = \sqrt{\mathbf{P}^2 + m_d^2}$, $m_d = m_p + m_n - \varepsilon_d$, 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 [1]). Further, $u_e(k)$ ($u'_e(k')$) the Dirac spinor for incident (scattered) electron. In its general form, relativistic deuteron electromagnetic current $\langle \mathbf{q}\, M'|J^\mu(0)|\mathbf{0}\, M\rangle$ can be expressed (see, e.g., survey [2]) through the charge monopole (G_C), magnetic dipole (G_M) and charge quadrupole (G_Q) form factors (FFs) of the deuteron. Such static quantities as the deuteron charge e_d, its magnetic moment μ_d and quadrupole moment Q_d are given by $e_d = G_C(0)\, e$, $\mu_d = G_M(0)\, e/2m_d$, $Q_d = G_Q(0)\, e/m_d^2$. Other our contribution is devoted to a fresh field-theoretical calculation of these moments. In parallel, for our attempts to ensure gauge independent treatment of similar electromagnetic (EM) processes we prefer to employ a generalization [3] of the Siegert theorem, in which the amplitude of interest is given by
$T(ed \to e'd') = [\omega\varepsilon(e',e) - \mathbf{q}\varepsilon_0(e',e)]\,\mathbf{D}(\mathbf{q}) + [\mathbf{q}\times\varepsilon(e',e)]\,\mathbf{M}(\mathbf{q})$ with the so-called generalized electric

$$\mathbf{D}(\mathbf{q}) = -i\omega^{-1}\int_0^1 \frac{d\lambda}{\lambda}\nabla_{\mathbf{q}}\left\{\left[\sqrt{\lambda^2\mathbf{q}^2 + m_d^2} - m_d\right]\langle\lambda\mathbf{q}; M'|\rho(0)|\mathbf{0}; M\rangle\right\}$$

and magnetic

$$\mathbf{M}(\mathbf{q}) = -i\int_0^1 d\lambda\nabla_{\mathbf{q}} \times \langle\lambda\mathbf{q}; M'|\mathbf{J}(0)|\mathbf{0}; M\rangle$$

dipole moments. We will show the links between the deuteron FFs and these quantities. In addition, to be more constructive we consider the following expansion for the "clothed" current operator
$J^\mu(0) = WJ_c^\mu(0)W^\dagger = J_c^\mu(0) + [R, J_c^\mu(0)] + \frac{1}{2}[R,[R,J_c^\mu(0)]] + ...,$
in the R-commutators (see Eq. (13) in [3]), where $J_c^\mu(0)$ is the initial current operator in which the bare operators $\{\alpha\}$ are replaced by the clothed ones $\{\alpha_c\}$ and $W = \exp R$ the corresponding unitary clothing transformation. This decomposition involves one-body, two-body and more complicated interaction currents. In case of the deuteron whose states belong to the clothed two-nucleon sector, our consideration leads to division $J^\mu(0) = J^\mu_{one-body} + J^\mu_{two-body}$. The operator $J^\mu_{two-body}$ is analogue of the meson exchange current in the conventional theory. Special attention is paid to finding such contributions to the deuteron form factors.

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