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Comment on ‘‘Radiative proton-deuteron capture in a gauge invariant relativistic model’’

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Although the model by Korchin *et al.* [Phys. Rev. C **59**, 1890 (1999)] for the radiative $p+d$ capture basically follows the covariant and gauge invariant approach by Nagorny *et al.* [Sov. J. Nucl. Phys. **49**, 465 (1989); **53**, 228 (1991); **55**, 1325 (1992); Phys. At. Nucl. **57**, 940 (1994); Phys. Lett. B **316**, 231 (1993)], several inconsistencies in the model are pointed out.

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Korchin *et al.* [1] have calculated the radiative $p+d$ capture in a relativistic approach using a realistic τdp vertex (τ indicates ^{3}He). Since the Lorentz covariant and gauge invariant approach to the electromagnetic interactions of few-body systems was already developed earlier [2–4] and used for the description of various reactions [5–9], I feel it is appropriate to point out relevant differences and to make some comments.

(i) While the treatment of the external radiation amplitude, i.e., proton-, deuteron-, and ^{3}He-pole diagrams, in [1] follows basically the steps of Refs. [2–4], a *simplified* (without any theoretical background) form for τdp-vertex A_μ, expressed through the pd-relative momentum k only, was actually used in [1] [see Eq. (11) there]. The general form for A_μ consistent with Lorentz and CPT invariance includes a separate dependence on the p and d momenta [3] (B,C,D are scalar functions of k^2):

$$A_\mu(p,d,\tau)=[\gamma_\mu B+p_\mu C+d_\mu D]\gamma_5. \tag{1}$$

A simplified τdp vertex from [1] [see Eq. (11)] cannot satisfy the ‘‘orthogonality’’ condition [2,3]: $d_\mu A_\mu(p,d,\tau)=0$ and, therefore, does not eliminate the contribution of ‘‘unphysical’’ states of the (virtual) spin-1 particle. In general, to use high-spin (1; 3/2; . . .) nongauge fields propagators off-mass-shell, one has to impose subsidiary conditions to eliminate un-physical states (with spin = 0; 1/2; . . . , respectively), and therefore to insure couplings to the pure spin = 1; 3/2; . . . fields.

Note, terms in the γdd vertex proportional to the (real/virtual) deuteron momenta do not contribute (if ‘‘unphysical’’ states of the virtual deuteron are eliminated), and Ward-Takahashi identities for on/off-shell vertices are the same.

(ii) Contrary to the authors’ claim, the construction of the internal radiation amplitude J^{intern} [see Eqs. (15) and (16) in [1]], is not new. It follows directly from the ‘‘minimal photon insertion,’’ introduced earlier in [2,3], but into the *simplified* τdp vertex [see Eq. (11) in [1]]. Indeed, substituting vertex $A_\nu(p,d,\tau)$ defined in Eq. (11) from [1] into the general form [2,3]

$$J^{\text{intern}}_{\mu\nu}=\int_0^1\frac{d\lambda}{\lambda}\frac{d}{dq_\mu}\{z_pA_\nu(p-\lambda q,d,\tau'-\lambda q)+z_dA_\nu(p,d-\lambda q,\tau'-\lambda q)\}, \tag{2}$$

one obtains a ‘‘minimal’’ internal radiation amplitude (we use the definitions from [1] and omit all terms proportional to q_μ which do not contribute when contracting with the photon polarization vector),

$$J^{\text{intern}}_{\mu\nu}=2Q_3^\mu\left[\frac{M_r}{m_1}R_2^\nu-\frac{M_r}{m_2}R_1^\nu\right]+g^{\mu\nu}\left[\frac{M_r}{m_1}H_+(Q_1^2)-\frac{M_r}{m_2}H_+(Q_2^2)\right]\gamma_5. \tag{3}$$

This result can be shown (after short algebra) to be identical to the one in [1] [see Eqs. (15) and (16), if one discards the ‘‘negative-energy’’ components for simplicity only]. Therefore, the gauge invariance in [1] is arranged in exactly the same (‘‘minimal’’) way as in [2–4]. The only difference is that a simplified τdp vertex was used in [1].

(iii) A ‘‘new element’’ in [1], in contrast to [2–4], is the use of the ‘‘off-shell anomalous magnetic moment’’ of ^{3}He (it is k_{eff} in [1]), introduced through a special choice of a self-energy (Σ) correction [see Eqs. (37) and (39) in [1]] to the s-channel ^{3}He propagator. This completely *ad hoc* procedure has no theoretical foundation, and leads to a ‘‘double counting’’ only.

Indeed, on the one hand, such a Σ correction to the ^{3}He propagator as applied in [1] (full propagator with only one *irreducible* $\gamma\tau\tau$ vertex in the ^{3}He-pole diagram) is not consistent with the use of a *reducible* τdp-vertex A^{red} which already includes all self-energy parts. A fully renormalized propagator (including the self-energy) in the s-channel diagram may be used only in the combination with both *irreducible* $\gamma\tau\tau$ and τdp vertices, which are related to the *reducible* ones through the identity (in an obvious notation, the subscript 0 refers to bare propagators) [10]

$$D_0(d)S_0(p)A_\mu^{\text{red}}S_0(\tau)=D(d)S(p)A_\mu^{\text{irred}}S(\tau). \tag{4}$$

On the other hand, any *arbitrary* off-shell modification of the vertices [such as replacing of the anomalous magnetic moment k by k_{eff} in [1]: see Eq. (39) and the paragraph below it, for instance], even without a self-energy motivation, automatically means an *uncontrollable* change of the ‘‘minimal’’ contact current, since any off-shellness (including off-shell effects in the Pauli part), may be directly transferred to the internal radiation amplitude, and sometimes even completely canceled by the ‘‘minimal’’ contact current (see [10,11]). As a result, an arbitrary (undefined from the theory) part, which certainly leads to a ‘‘double counting,’’ is simply added to the physical amplitude in [1] due to the modification of the anomalous magnetic moment of ^{3}He.

(iv) Accounting for the initial state interaction by the modification of the τdp vertices through the pole graphs in accordance with Eqs. (40),(45)–(47) from [1] violates time reversal invariance, since leads to an imaginary part in the vertices connected with bound states only. In general, the *initial* state interaction in $p+d \to {}^3\mathrm{He}+\gamma$ reaction cannot be included by the modification of the τdp vertex which contains only *one initial* particle, while two others belong to the *intermediate* and *final* states (in the proton- and deuteron-pole diagrams). In the present framework initial state interactions can only be taken into account consistently in terms of the loop diagrams (e.g., [2,3,8]) including regular part of the hadronic T matrix.

(v) Finally, it is puzzling how the authors of [1] have been able to identify in Fig. 2 of [1] a *pure relativistic* effect from the ‘‘negative-energy’’ components in the τdp vertex (which do not exist in the nonrelativistic limit), using a *pure nonrelativistic* wave function. As is well known, ‘‘negative-energy’’ components present an additional sector in the covariant vertex which has no analogy in the quantum mechanics and cannot be expressed in terms of the nonrelativistic wave functions only (as an example, see [12] where additional components of another P parity, i.e., P waves, responsible for the ‘‘negative-energy’’ components in dpn vertex, had to be introduced except standard nonrelativistic S and D waves of the deuteron).

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