Role of isoscalar amplitudes in $d + \vec{\gamma} \to n + p$

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The study of $d+\gamma \rightleftharpoons n+p$ is of considerable interest not only to nuclear physics but also to astrophysics. As the Big Bang Nucleosynthesis (BBN) enters the precision era [1], the need for more precise knowledge of the reaction was highlighted [2] and this led to a series of experiments [3–8] on photodisintegration of deuterons using the 100% linearly polarized photons from the High Intensity Gamma-ray Sourse (HIγS) at the Duke free electron laser laboratory. Neutron angular distribution in (γ, n) reactions with linearly polarized photons [9] were reported recently in view of the importance of photonuclear reactions [10] for basic science as well as various applications [11]. The linear polarized beams are generated by Laser Compton Scattering (LCS) at New SUBARU [12] at the National Institute of Advanced Industrial Science and Technology [13] in Japan. An advantage in LCS is that one can generate linear as well as circularly polarized beams. Angular distribution of the cross sections for (γ, N) reactions were calculated [14, 15] very early but Schreiber et al [3] analyzed their measurements, using [16], where the $M1$ and $E1$ contributions are calculated separately and with several simplifying assumptions.

Over a period of more than six decades, a number of theoretical calculations based on potential models have been reported on $n+p \rightleftharpoons d+\gamma$. Working in the frame work of pionless effective field theory with di-baryons(dEFT), Ando et al., [17] emphasized "the necessity of further studies both experimental and theoretical of the spin observables in the $\gamma d \to \pi p$ reaction". We may mention that attention was focussed on [18] photon polarization in $\vec{n}-\vec{p}$ fusion and $\vec{d}(\gamma, n)p$ with unpolarized photons [19]. A discussion [20] of the photodisintegration of deuterons with 100% linearly polarized photons was presented using a model independent approach taking together the $M1$ and $E1$ amplitudes simultaneously, wherein attention was also focussed on the possibility of the three isovector electric dipole amplitudes, $E1_v^j$, being different from each other in the channels with total angular momentum, $j = 0, 1, 2$. It was found subsequently that it is indeed so by Blackston et al [21], who reported the first experimental observation of the splitting of the $E1$ p-wave amplitudes at slightly higher energies of 14 and 16 MeV. Assuming the relative phases between these amplitudes to be zero, approximate estimates were published in [22]. The purpose of the present contribution is to take into account the relative phases as well and suggest future experiments to precisely determine these amplitudes at lower energies relevant to astrophysics.

Following [20] and using the same notations, the reaction matrix for $d + \gamma \to n + p$ with linearly polarized photons is

$$\mathbf{M} = \sum_{s=0}^{1} \sum_{\lambda=|s-1|}^{s+1} (S^\lambda(s, 1) \cdot \mathcal{F}^\lambda(s)), \quad (1)$$

where $S^\lambda_\nu(s, 1)$ are irreducible tensor operators of rank λ in hadron spin space [23] connecting the initial spin 1 state of the deuteron with the final singlet and triplet states, $s = 0, 1$ of the $n - p$ system in the continuum.

The differential cross section in photo-disintegraion of deuterons using 100% linearly polarized photons [20] involves a $\cos\theta$ dependent term. The coefficient of $\cos\theta$ involves interference between the three isovector $E1_v$

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amplitudes and the isoscalar $M1s$ and $E2s$ amplitudes, which is given by

$$c = Re(\alpha M1_s^* + \beta E2_s^*) \quad (2)$$

where

$$\alpha = 4\sqrt{6}(2E1_v^{j=0} + 3E1_v^{j=1} - 5E1_v^{j=2}) \quad (3)$$

$$\beta = 4\sqrt{6}(2E1_v^{j=0} - 3E1_v^{j=1} + E1_v^{j=2}) \quad (4)$$

The approximate values of the squares of the 3 $E1_v^j$ amplitudes, using the experimental data are summarized in Table 3 of [22]. However what is needed is a linear combination of the 3 amplitudes rather than their modulus squares. The needed linear combinations involve also their relative phase values. i.e.,

$$\alpha = 4\sqrt{6}(2|E1_v^{j=0}|e^{i\delta_0} + 3|E1_v^{j=1}|e^{i\delta_1} - 5|E1_v^{j=2}|e^{i\delta_2}), \quad (5)$$

$$\beta = 4\sqrt{6}(2|E1_v^{j=0}|e^{i\delta_0} - 3|E1_v^{j=1}|e^{i\delta_1} + |E1_v^{j=2}|e^{i\delta_2}). \quad (6)$$

The details of the analysis of the experimental data by taking into account the relative phases between the multipole amplitudes will be presented. In view of the current experimental and theoretical studies, this analysis would lead to a better understanding of the problem at the range of energies of interest to astrophysics.

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