Target vector analyzing power in $d(\vec{\gamma}, n)p$ at astrophysical energies

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The photodisintegration of deuteron and its inverse reaction, n-p fusion,at neutron kinetic energies in the energy range 25 to 200 Kev in c.m is of considerable interest [1] to sharpen the predictions of Big Bang Nucleosynthesis(BBN). The influential paper of Burles et al [1] has inspired several experiments [2] at the Duke free electron laser laboratory using 100% linearly polarized photons to study photodisintegration of deuterons. These measurements have been analyzed using a theoretical formalism [3] where $M1_v$, the isovector magnetic multipole (dominant at thermal neutron energies) and $E1v$, the isovector electric multipole (dominant at photodisintegration at higher energies) were calculated separately. The model independent theoretical formalism [4] for deuteron photodisintegration with linearly polarized photons, revealed for the first time that the differential cross section in $d(\vec{\gamma}, n)p$ contains a term representing the interference between the $E1_v$ and $M1_s$ amplitudes, which is non zero if the three $E1_v$ amplitudes $E1_v^j$, $j = 0, 1, 2$ are unequal. Blackston et al., [5] have recently reported the first experimental observation of the splitting of the 3 $E1_v^j$ amplitudes at 14 MeV and 16 MeV. The deuteron being a spin-1 nucleus gets polarized in different ways in different external environments. For example, an oriented [6–8] deuteron target can be produced under the influence of an external uniform magnetic field, whose direction determines the axis of orientation. On the other hand, when the deuteron is exposed to external electric quadrupole fields generated by surrounding electrons in crystal lattice sites [9], the spin of the deuteron is aligned. States of polarization of spin-1 nuclei exist, which are more complex and are in fact multiaxial [10–14]. The utility of employing a beam of linearly polarized photons to measure tensor analyzing powers on an aligned deuteron target was studied [15] recently. Complementary to this, we study in this paper, the vector analyzing power in photodisintegration of deuterons using 100% linearly polarized photons.

Following [4, 15] and using the same notations, the reaction matrix for $d + \gamma \rightarrow n + p$ with linearly polarized photons is

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

and the density matrix for polarized deuteron target is given by

$$\rho = \frac{1}{3} \sum_{k=0}^{2} (S^k(1, 1) \cdot t^k), \quad (2)$$

in terms of the Fano statistical tensors t_q^k of rank k.

The differential cross section for photodisintegration of polarized deuterons by linearly polarized photons is given by

$$\frac{d\sigma}{d\Omega} = \frac{1}{6} Tr[\mathbf{M}\rho\mathbf{M}^{\dagger}], = \frac{d\sigma_0}{d\Omega}[1 + \sum_{k=1}^{2} (t^k \cdot \mathcal{A}^k)], (3)$$

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where the target analyzing powers are

$$\mathcal{A}_q^k = \frac{1}{2\sqrt{3}} \sum_{s,\lambda,\lambda'} (-1)^\lambda [s]^2 [\lambda][\lambda'] W(1ks\lambda; 1\lambda') \\ (\mathcal{F}^\lambda(s) \otimes \mathcal{F}^{\dagger\lambda'}(s))_q^k. \quad (4)$$

A detailed discussion on the target tensor analyzing powers A_q^2 can be found in [15]. The target vector analyzing powers A_q^1, written in terms of cartesian components, are

$$A_{\pm 1}^1 = \mp \frac{1}{\sqrt{2}} (A_x \pm i A_y); A_0^1 = A_z \quad (5)$$

Since the reaction is parity conserving, $A_x = A_z = 0$, in the Madison frame. Explicit calculation in terms of the multipole amplitudes leads to A_y of the form

$$A_y = (a \sin\theta + b \sin\theta \cos\theta) \cos\phi \quad (6)$$

where a and b are new bilinears, in the multipole amplitudes, that do not occur in [15]. Detailed analysis of this additional information in correlation with the contents of [15] will be presented at the conference.

It may be mentioned that the formulation [4, 15] employed here is extendable for higher energies as well. Several photonuclear reactions on polarized deuterons [16, 17] are being studied at higher energies with linearly polarized photon beams at VEPP-3 electron storage ring. A major international program to carry out laboratory studies on astrophysical $r-$process [18] is also underway. In view of these developments, it is worthwhile to carry out model independent theoretical studies on polarized nuclei with spin ≥ 1 which offer a rich variety of polarization states [10–15].

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