Recoil neutron polarization with circularly polarized photons in photodisintegration of deuterons at astrophysical energies

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Introduction

There is considerable current experimental interest [1–6] in studying $d(\vec{\gamma}, n)p$ at energies close to threshold, using the 100% linearly polarized photons from the High Intensity Gamma-ray Source (HIγS) at the Duke free electron laser laboratory, in view of the highlighted need [7] for precise knowledge of the reaction at astrophysically relevant energies as the Big Bang Nucleosynthesis(BBN) enters the precision era [8]. There is now a proposal to measure the neutron recoil polarization [9] at HIγS.

Although it was known quite early that the thermal neutron capture by protons is dominated by the isovector magnetic dipole amplitude M1v, Breit and Rustgi [10] were the first to propose a polarized target-beam experiment to look for an isoscalar M1s amplitude in view of the then existing 10% discrepancy between theory and experiment. The suggestion was more or less ignored in view of the surprising accuracy with which the 10% discrepancy was explained [11] as due to Meson exchange currents(MEC). However, the measured values for analyzing powers in $p(\vec{n}, \gamma)d$ as well as for neutron polarization in photodisintegration of the deuteron were both found to differ [12, 13] from theoretical calculations which included MEC effects. Rustgi,Vyas and Chopra [14] drew attention to the unambiguous disagreement between experiment and theory on $d(\gamma, n)p$ at photon energy 2.75 MeV which widens when two body effects are taken into account. It may be mentioned that measurements of neutron polarization at energies 7 MeV to 15 MeV [15], abruptly depart from theoretical predictions at around 10 to 12 MeV. Working in the framework of pion less effective field theory with dibaryons(d-EFT) a recent study [16] for neutron polarization showed a significant discrepancy with experiment[17], which points "to the necessity of further studies both experimental and theoretical of the spin observables in the $\gamma d \rightarrow np$ reaction"[16]. It is worth noting that we had already discussed [18] neutron polarization in $d + \vec{\gamma} \rightarrow n + p$ with linearly polarized photons.

The purpose of the present contribution is to draw attention to neutron polarization with circularly polarized photons.

Theory

The amplitude for the reaction in the model independent theoretical approach [19, 20] is of the form

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

where $\mu = \pm 1$ refers to the left and right circular polarization states following [21] and $S^{\lambda}_{\nu}(s, 1)$ denote irreducible tensor operators of rank λ in hadron spin space [22] 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 density matrix, ρ characterizing the neu-

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tron polarization in the final state is then defined in terms of its elements

$$\rho_{m_n m_{n'}} = \frac{1}{6} \sum_{m_p m_d} < m_n, m_p|\mathbf{M}(\mu)|m_d > < m'_n, m_p|\mathbf{M}(\mu)|m_d >^* \quad (2)$$

In the case of unpolarized photons an additional summation over μ has to be included. With linearly polarized photons $M = M(+1) + M(-1)$ has been used [18] instead of $M(\mu)$.

The neutron polarization $\mathbf{P}$ is readily obtained on comparing ρ with the standard form

$$\rho = \frac{1}{2}[1 + \boldsymbol{\sigma} \cdot \mathbf{P}]. \quad (3)$$

The neutron polarization is obtained in terms of bilinears involving the irreducible tensor operators. The components of $\mathbf{P}$ are expressed in terms of the interference of $M1_v$ and $M1_s$ with the $E1_v$ amplitudes, the interference of $M1_v$ and $M1_s$ amplitudes and the interference between $E1_v$ amplitudes. A comparative study of the neutron polarization with linearly polarized and circularly polarized photons will be presented.

Acknowledgements

One of us (SPS) is thankful to the Director and management, Christ University, Bangalore, for their encouragement, while another (MK) is thankful to the Principal, K.S. School of Engineering and Management, Bangalore for encouraging research.

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