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Parity violating asymmetry in $\gamma + d \to n + p$ at low energy

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Abstract. We calculate the parity-violating asymmetry in the $\gamma + d \to n + p$ process where the deuteron is disintegrated by circular photons. The photon energy is considered up to 10 MeV above threshold, where the lowest electromagnetic transition modes $M1$ and $E1$ dominate. We employ the Argonne v18 potential for the strong interaction and the DDH potential for the parity-violating weak interaction of the two-nucleon systems. The asymmetry is about 2.5×10^{-8} at threshold, and decreases rapidly to have magnitude of order 10^{-9} or less for photon energies larger than 3 MeV. The exchange of vector mesons dominates the asymmetry, while the pion contribution is negligible.

PACS. 24.80.+y Nuclear tests of fundamental interactions and symmetries

1 Introduction

The interest to test the standard model in the realm of nuclear and atomic physics becomes more and more growing and popular nowadays. The activeness of the subject has been driven by recent experiments: measurement of the anapole moment of ^{133}Cs [1], parity-violating (PV) longitudinal asymmetry in $\mathbf{p}p$ scattering [2] and strange form factor of the nucleon from $\mathbf{e}p$ scattering [3]. In addition to these experiments, a PV asymmetry in $\mathbf{n}p \to d\gamma$ is being measured at LANSCE [4], and the possibility to measure a PV asymmetry in $\gamma d \to np$ is also being discussed. These experiments provide important information about the weak interaction of hadrons at low energy. From the theoretical viewpoint, weak as well as strong interactions can be described by means of the one-boson exchange, which introduces PV meson-nucleon coupling constants. Knowing precise values of the PV coupling constants is an important ingredient to understand the nuclear weak interaction. Unfortunately, for some of the PV coupling constants, recent experiments mentioned above give incompatible values with those from other experiments or theory calculations. We expect that future experiments will provide a way to resolve the present uncertainties, and shed light on the nuclear weak interaction problem.

In this work, we calculate the PV asymmetry A_γ in $\gamma d \to np$. Confronting the possibility of its experimentation, it is necessary to calculate A_γ with updated modern potentials, and compare it with old ones that show significant difference. In our calculation, the strong interaction is accounted for by the Argonne v18 (Av18) potential [5], and the PV potential given by Desplanques, Donoghue and Holstein (DDH) [6] is employed for the weak interaction.

In the next section, we briefly describe the basic formalisms. Numerical results are shown and discussions follow.

2 Result and discussion

We consider the photon energies up to 10 MeV above threshold, which leaves only a few low-orbital states in the final state sufficient for the result being without significant error. Opposite-parity states are admixed in the wave function by the PV meson-exchange potential. The DDH PV potential [6], adopted in our work, includes π-, ρ- and ω-exchanges with the vertices specified by isospin transfer $\Delta I = 0, 1, 2$. At the considered energies, $M1$ and $E1$ modes dominate the electromagnetic transition, and therefore we use the $M1$ and the $E1$ operators given as

$$\hat{O}_{M1} = \sum_i \frac{1}{2m_N} \left(e_i \mathbf{l}_i + \mu_i \sigma_i \right), \tag{1}$$

$$\hat{O}_{E1} = \sum_i e_i \mathbf{x}_i, \tag{2}$$

where e_i is the charge of the nucleon, μ_i the magnetic moment, $\mathbf{l}_i$ the angular momentum, σ_i the spin and $\mathbf{x}_i$ the position. Given the wave functions and the transition operators, the asymmetry A_γ can be calculated from the definition

$$A_\gamma \equiv \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \tag{3}$$

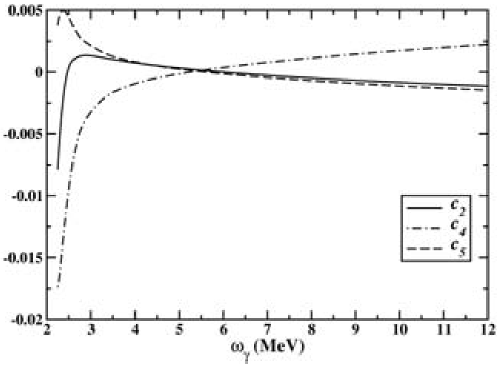

Fig. 1. Dominant coefficients

where σ_+ (σ_-) denotes the total cross section for right- (left-) handed circular photons.

To first order in the weak coupling constants, A_γ can be written as

$$A_\gamma = c_1 h^1_\pi + c_2 h^0_\rho + c_3 h^1_\rho + c_4 h^2_\rho + c_5 h^0_\omega + c^6 h^1_\omega. \quad (4)$$

Numerical results for the coefficients c_i's are shown in Fig. 1 and 2. The magnitude of c_i's for heavy-meson isoscalar and isotensor vertices (c_2, c_4, c_5) are larger than those of isovector ones (c_1, c_3, c_6) by an order or more. Since the weak coupling constants calculated from a quark model [6] or the Skyrme model [7,8] give a similar magnitude, A_γ will be dominated by isoscalar and isotensor PV vertices.

In Fig. 3, we show A_γ calculated with the DDH best values for the weak coupling constants. At threshold, $A_\gamma \simeq 2.5 \times 10^{-8}$, and it decreases to the order of 10^{-9} for $\omega_\gamma \geq 3$ MeV. The small magnitude of A_γ can be understood from the strong cancellation of c_4 with c_2 and c_5, and similar values of $h^0_\rho (= -11.4 \times 10^{-7})$ with $h^2_\rho (= -9.5 \times 10^{-7})$. The strong suppression of A_γ confirms the result of a recent schematic calculation [9], but does not support the earlier significant enhancement from the contribution of h^1_π [10]. It is shown in [11] that the enhancement in [10] is due to the omission of the contribution from ${}^3P_1 \to {}^3\tilde{S}_1 - {}^3\tilde{D}_1$ transition, whose inclusion gives suppressed A_γ values.

The asymmetry A_γ was recently calculated with Av18 and CD-Bonn [12] potentials by Schiavilla *et al.* [13]. For Av18, they obtain a result similar to ours, but the CD-Bonn potential gives a larger result than Av18 by a factor of about 2. A_γ at threshold with r-space Bonn [14] and Bonn-A, B [15] is calculated, and, with the DDH best values, the results turn out to be similar with that of CD-Bonn [16]. The enhancement for the Bonn potentials is due to strong attraction at short distance in the ${}^1P_1$ channel, which leads to a bound state in ${}^1P_1$ state [17]. Therefore, this artifact of the ${}^1P_1$ Bonn potential should be treated properly, e.g. by introducing a cutoff, to obtain a sound result.

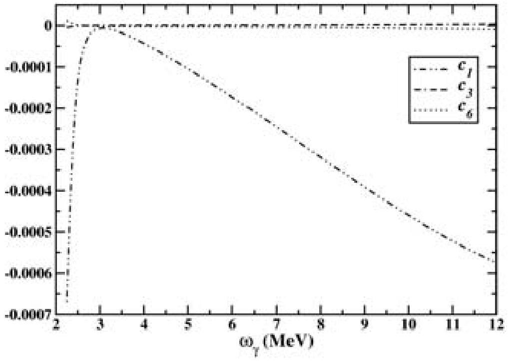

Fig. 2. Suppressed coefficients

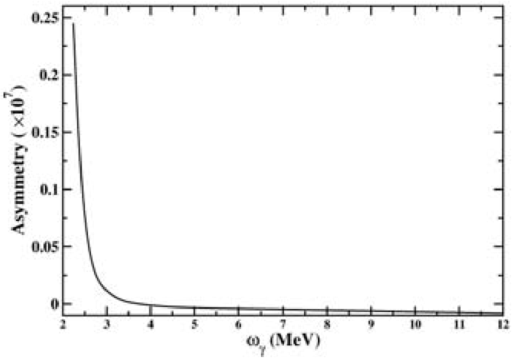

Fig. 3. A_γ with DDH best values

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