Hyperon Polarizabilities in Compton Scattering

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Introduction:

Compton scattering is a source of valuable information about baryons since it offers access to some of the more subtle aspects of baryon structure such as polarizabilities [1], which parameterize the response of the target. The nucleon polarizabilities have been studied in a number of theoretical approaches. Additional insights into the polarizabilities have come from chiral perturbation theory (ChPT), an effective theory of the low-energy strong interaction, specifically from heavy baryon chiral perturbation theory (HBChPT) which is an extension of ChPT that includes the nucleon [2]. The first such calculations of nucleon polarizabilities within ChPT were carried out in [3]. However, HBChPT has an important deficiency in that the chiral perturbative series fails to converge in part of the low energy region. The spin-dependent (SD) pieces of the forward scattering amplitude for real photons of energy ω and momentum q is

$$\epsilon_1^{\mu}\,\mathcal{M}_{\mu\nu}^{SI}\,\epsilon_2^{\nu} = i\,e^2\,\omega\,W^{(1)}\,\vec{\sigma}.\left(\vec{\epsilon}\times\vec{\epsilon}^{\,*}\right)$$

From the theoretical perspective there is particular interest in the low energy limit of the amplitude:

$$e^2\,W^{(1)}\,(\omega) = 4\,\pi\,(f_2\,(0) + \omega^2\,\gamma_0^N)$$

where γ0 is the forward spin polarizability, which is related to the photo-absorption cross sections for parallel (σ_+) and antiparallel (σ_-) photon and target helicities. The Low-Gell-Mann-Goldberger low-energy theorem states that

$$f_2\,(0) = -\frac{\alpha\,\mathcal{K}_N^2}{2\,m_N^2}$$

where $\alpha=e^2/4\pi$ is the is the fine-structure constant, K_N is the nucleon anomalous magnetic moment.

While a rather large amount of work has been devoted, both theoretically and experimentally, to the study of the nucleon polarizabilities, very little is known about hyperon polarizabilities. However, with the advent of hyperon beams at FNAL and CERN, the experimental situation is likely to change, and this possibility has triggered a number of theoretical investigations. Already, predictions for electric and magnetic polarizabilities have been made for low-lying octet baryons in the framework of LO HBChPT [3], and in the context of several other models, yielding a broad spectrum of predictions . At present, no experimental data is available for the forward spin polarizability of the hyperons and no theoretical calculations have been published. Motivated by this situation, in the present work we extend the analysis of SU(2) HBChPT to the SU(3) version in order to compute γ0 for hyperons. This could serve as a test of low-energy structure of QCD in the three-flavor sector. However, there is also a need to compute the spin polarizabilities in the framework of BChPT with the IDR prescription. The paper is organized as follows. Section II contains an overview of the SU(3) version of HBChPT relevant for the calculation of the hyperon forward spin polarizabilities γ0. The relevant Feynman rules for the case of the γþ polarizability are given elsewhere [4]. In Sec. III, we give the explicit results for the hyperon spin polarizabilities γ0 and discuss the corresponding numerical results. Brief conclusions are given in Sec. IV.

II. EFFECTIVE LAGRANGIAN

The lowest-order SU(3) HBChPT Lagrangian involving the octet of pseudo scalar mesons Φ and the baryon octet B consists of two basic pieces; the lowest order chiral effective Lagrangian [3]

$$\mathcal{L}^{2}_{\phi\phi} = \frac{F^2}{4} < \nabla_\mu U \nabla^\mu U^\dagger + \chi_+ >$$

and the lowest order meson-baryon Lagrangian

$$\mathcal{L}^{(1)\ HbchPT}_{\phi B} = < \bar{B}\ (i\ \upsilon.D)\ B > + \frac{D\ /\ F}{F^0} < \bar{B}\ S^\mu\ (u_\mu,\ B)_\pm >$$

where the superscript (i) attached to the above Lagrangians denotes their low-energy dimension and the symbols < >, ± denote the trace over flavor matrices, commutator and anticommutator, respectively. We use the following notations: $U = u^2 = \exp\left(i\frac{\emptyset}{F0}\right)$, where F_0 is the octet decay constant. The $\nabla_\mu$and D_μ are the covariant derivatives acting on the chiral and baryon fields, respectively including the external (v_μ) and (a_μ) fields and S_μ is the covariant spin operator.

III. FORWARD SPIN POLARIZABILITY γ0

In order to calculate the forward spin polarizabilities, we work in the Breit frame.. We utilize the Weyl (temporal) gauge A0 = 0, which, in the language of HBChPT, means v.ε = 0 where v_μ = (1,0,0,0) is the baryon four-velocity. At $O(p^3)$, only the loop diagrams contribute to **γ0** and hence the hyperon polarizabilities are pure loop effects. At LO, these loop diagrams have insertions only from $\mathcal{L}^{(1)\ HbchPT}_{\phi B}$. The relevant loop-diagrams, which contribute to polarizabilities are listed in ref.[4].The value of γ0 are found from the calculation of $W^1(\omega)$ via,

$$\gamma_0 = \frac{\alpha}{2}\ \frac{\partial^2}{\partial\omega^2}\ W^{(1)}\ (\omega)\ \Big|_{\omega=0}$$

Below we list the expressions for **γ0** for some of the low lying octet baryons:

$$\gamma_0^{\Xi 0} = \frac{\alpha}{\pi^2 F_0^2}\left[\frac{(D-F)^2}{24\ M_\pi^2} + \frac{(D+F)^2}{16\ M_K^2}\right]$$

$$\gamma_0^{\Lambda} = \frac{\alpha}{\pi^2 F_0^2}\left[\frac{D^2}{72\ M_K^2} + \frac{F^2}{8\ M_K^2} + \frac{D^2}{36\ M_\pi^2}\right]$$

$$\gamma_0^{\Sigma +} = \frac{\alpha}{\pi^2 F_0^2}\left[\frac{(D+F)^2}{24\ M_K^2} + \frac{F^2}{12\ M_\pi^2} + \frac{D^2}{36\ M_\pi^2}\right]$$

$$\gamma_0^{\Xi 0} = \frac{\alpha}{\pi^2 F_0^2}\left[\frac{(D-F)^2}{24\ M_\pi^2} + \frac{(D+F)^2}{16\ M_K^2}\right]$$

$$\gamma_0^{\Lambda} = \frac{\alpha}{\pi^2 F_0^2}\left[\frac{D^2}{72\ M_K^2} + \frac{F^2}{8\ M_K^2} + \frac{D^2}{36\ M_\pi^2}\right]$$

We note that in the nucleon case, when we neglect the kaon loops contribution, we reproduce the well-known result of SU(2) HBChPT [5]. The other results for spin polarizabilities are new predictions.

IV. CONCLUSIONS

We have presented the LO contribution to spin dependent Compton scattering in the framework of HBChPT. In LO HBChPT, these contributions are all meson loop effects, with no counter term or resonance exchange contribution and hence are a test for the chiral sector of three-flavor QCD. There exists a finite contribution from kaon loops to γ0 for the low-lying octet baryons. Our result for γ0 in the case of the proton and neutron reproduces the results of the LO calculation of SU(2) HBChPT when kaon loops are not considered, and it remains to be seen how the predictions for the other baryons will compare with future experiments.

References:

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