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MAGNETIC MOMENT OF THE PROTON FROM KAON PHOTOPRODUCTION UP TO 16 GeV

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ABSTRACT

MAGNETIC MOMENT OF THE PROTON FROM KAON PHOTOPRODUCTION UP TO 16 GeV. By using the Gerasimov-Drell-Hearn (GDH) sum rule and an isobar model of kaon photoproduction, we calculate contributions of kaon-hyperon final states to the magnetic moment of the proton and the neutron. We find that the contributions are small. We further extend the isobar model for kaon photoproduction to consider higher energy data by combining the model with a Regge approach. The extended model works nicely between threshold and 16 GeV. We use the model to refine the calculation up to 16 GeV.
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Key words : Magnetic moment, kaon photoproduction, Gerasimov-Drell-Hearn (GDH)

ABSTRAK

MOMEN MAGNETIK PROTON DARI *KAON PHOTOPRODUCTION* SAMPAI DENGAN 16 GeV. Aturan penjumlahan dan model isobar *kaon photoproduction* telah dihitung kontribusi keadaan akhir *kaon-hyperon* terhadap momen magnetik proton dan neutron dengan menggunakan GDH (Gerasimov-Drell-Hearn). Diketahui bahwa kontribusinya kecil, model isobar dikembangkan lebih lanjut *kaon photoproduction* untuk menghasilkan data energi yang lebih tinggi dengan mengkombinasikan model tersebut dengan pendekatan *Regge*. Model yang dikembangkan dapat bekerja dengan baik diantara nomor PACS : 13,60.Le,11,55.Hx, 13,40.Em, 14,20.Dh

Kata kunci : Momen magnetik, *kaon photoproduction, Gerasimov-Drell-Hearn (GDH)*

INTRODUCTION

The internal structure of the nucleon has been a long-standing, but still an interesting topic of investigations. The existence of this structure is responsible for the ground state properties of the nucleon, such as hadronic and electromagnetic form factors and the anomalous magnetic moment. At higher energies this finite internal structure yields a series of resonances in the mass region of 1 - 2 GeV. It was then found that the nucleon's ground state properties and the nucleon's resonance spectra are not all independent phenomena; they are related by a number of sum rules [1].

One of these sum rules is the Gerasimov-Drell-Hearn (GDH) sum rule, which connects the nucleon's magnetic moments and the helicity structures in the resonance region. Although the GDH sum rule was proposed more than 30 years ago, no direct experiment had been performed to investigate whether or not the sum rule converges. However, with the advent of the new high-intensity and continuous-electron-beam accelerator, accurate measurements of the contribution to the GDH integral from individual final states are made possible.

Previously, Hammer, Drechsel, and Mart (HDM) suggested that by using the Gerasimov-Drell-Hearn sum rule it is possible to estimate strange contributions to the magnetic moments of the proton [2]. They used experimental data and an isobar model for the photoproduction of η, ϕ, as well as K mesons, in order to estimate the transversely unpolarized total cross section σ_T and, therefore, to calculate the upper bounds of strange contributions to the anomalous magnetic moment of the proton. It is the purpose of this paper to update the contributions of kaon photoproduction, by means of the latest isobar model which fits all available experimental data, including the recent data from SAPHIR [3].

FORMALISM

The GDH sum rule [4] (for a review see Ref. [1]) relates the anomalous magnetic moment of the nucleon κ_N to the difference of its polarized total photoabsorption cross section :

$$-\frac{\kappa_N^2}{4} = \frac{m_N^2}{8\pi^2\alpha} \int_0^\infty \frac{d\nu}{\nu} \left[\sigma_{1/2}(\nu) - \sigma_{3/2}(\nu)\right] \tag{1}$$

where $\sigma_{3/2}$ and $\sigma_{1/2}$ denote the cross sections for the possible combinations of spins of the nucleon and photon (i.e., $\sigma_{3/2}$ for total spin = 3/2 and $\sigma_{1/2}$ for total spin =1/2), α is the fine structure constant, ν is the photon energy in the laboratory frame, and m_N the mass of the nucleon. The derivation of GDH sum rule is based on general principles: Lorentz and gauge invariance, crossing symmetry, causality, and unitarity. The only assumption in deriving Eq. (1) is that the scattering amplitude goes to zero for the limit $|\nu|\rightarrow\infty$, thus there is no subtraction hypothesis.

In photoproduction processes, however, the spin-dependent cross section is related to the total cross sections by

$$\sigma_T = \tfrac{1}{2}[\sigma_{3/2} + \sigma_{1/2}] \ , \ \sigma_{TT'} = \tfrac{1}{2}[\sigma_{3/2} - \sigma_{1/2}] \tag{2}$$

Therefore, we can recast Eq. (1) to

$$\kappa_N^2 = \frac{m_N^2}{\pi^2\alpha} \int_{\nu_{thr}}^{\nu_{max}} \frac{d\nu}{\nu} \sigma_{TT'}(\nu) \tag{3}$$

To calculate the right hand side of Eq. (3) we use the latest and modern elementary operator [5], which was guided by recent coupled-channel results [6] and includes the newest data [7]. The model consists of a tree-level amplitude that reproduces all available $K^+\Lambda$, $K^+\Sigma^0$ and $K^0\Sigma^+$ photoproduction observables and thus provides an effective parametrization of these processes. The background terms contain the standard s-, u-, and t-channel contributions along with a contact term that was required to restore gauge invariance after hadronic form factors had been introduced [8]. This model includes the three nucleon resonances that have been found in the coupled-channels approach to decay into the $K^+\Lambda$ channel, the $S_{11}(1650)$, $P_{11}(1710)$, and $P_{13}(1720)$. For $K\Sigma$ production, further contributions from the $S_{31}(1900)$ and $P_{31}(1910)$ Δ–resonances were added.

RESULTS

In Figure 1 we show the total cross sections σ_T and $-\sigma_{TT'}$ as a function of the photon laboratory energy ν for the six isospin channels in kaon photoproduction. Since there are no experimental data for productions on the neutron, we consider the three right panels in Figure 1 as predictions. Obviously, the model can remarkably reproduce the experimental data for the productions on the proton. In the former calculation, contribution from the $\gamma\, p \rightarrow K^0\, \Sigma^+$ channel could not properly be calculated since previous elementary models mostly overpredict $K^0\, \Sigma^+$ total cross section by a factor of up to 100 [9]. With the new SAPHIR data available in three isospin channels, the elementary model becomes more reliable to explain kaon photoproduction on the proton and to predict the production on the neutron.

The elementary model predicts negative sign for $\sigma_{TT'}$ (note that we have plotted $-\sigma_{TT'}$), except for the $K^0\Lambda$ channel, where it produces a negative sign for the GDH integral of the neutron, thus yielding positive values for κ^2 of the neutron, albeit $\gamma\, n \rightarrow K^+\, \Sigma^-$ and $\gamma\, n \rightarrow K^0\, \Sigma^0$ channels show a different behavior.

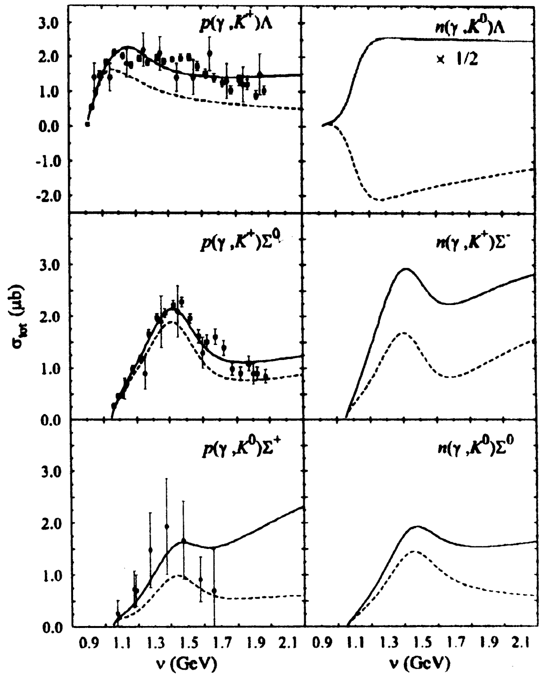

Figure 1. Total cross sections σ_T (solid lines) and $-\sigma_{TT'}$ (dotted lines) for the six isospin channels plotted as a function of photon laboratory energy ν. The elementary model is from Ref. [5], experimental data are taken from Ref. [7], and references therein. The elementary model fits not only total cross section data shown in this figure, but also differential cross section and polarization data (not shown). Total cross sections for the $n(\gamma,K^0)\Lambda$ channel are scaled with a factor of 1/2.

In Table 1 we list the numerical values obtained from Eq. (3), using a cutoff energy where we found the elementary model is still reliable. It is found that the result is not sensitive to the cutoff energy ν_{max} around 2 GeV, i.e. there is no significant change in the integral in

Table 1. Numerical values for the contribution of kaon-hyperon final states to the square of proton's and neutron's anomalous magnetic moments κ_N^2 obtained from Eq. (3). For comparison $\kappa_N^2 = +3.204$ and $\kappa_N^2 = +3.648$.

Channel	κ_p^2 (K)	Channel	κ_n^2 (K)
$\gamma p \rightarrow K^+\Lambda$	-0.026	$\gamma n \rightarrow K^0\Lambda$	0.075
$\gamma p \rightarrow K^+\Sigma^0$	-0.024	$\gamma n \rightarrow K^+\Sigma^-$	-0.025
$\gamma p \rightarrow K^0\Sigma^+$	-0.013	$\gamma n \rightarrow K^0\Sigma^0$	-0.019
Total	**-0.063**	Total	**0.031**

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the energy interval 1.8 - 2.2 GeV, especially in the case of photoproduction on the proton where the cross sections show a convergence at higher energies.

Should the contributions add up coherently, our calculation would yield values of κ_N^2 (K) = -0.063 and κ_N^2 (K) = 0.031. This put even smaller values for the upper bound of the magnitude of kaon-hyperon final states contributions to the proton's magnetic moment, compared to the previous result of HDM, κ_N^2 (K) = -0.07 [2]. An interesting feature is that our calculation yields a positive value for contributions to the κ_N^2 (K), therefore increases the calculated value of the GDH Integral for the neutron.

EXTENSION TO 16 GeV

Despite of their success, isobar models usually work only up to photon lab energy ν = 2 GeV. Beyond this energy region most models become deficient and show divergence, unless some hadronic form factors are considered in the hadronic vertices, and their roles are traditionally substituted by Regge approaches. However, a brief inspection to the particle data book reveals that almost 50% of baryon resonances are observed with masses between 2 and 3 GeV, which is clearly beyond the regime of isobar models. Since Regge model cannot be used to investigate these resonances, a new resonance driven mechanism explaining the electromagnetic production of meson in this energy region should be established.

Moreover, an extension of isobar model to higher energies becomes an urgent task if, for instance, we consider the calculation of the GDH sum rule. Basically, the sum rule involves an integral from reaction thresholds up to ν = ∞. However, due to the limitation of the model, usually one has to stop at or below ν = 2 GeV, which means disregarding the higher energy contributions. As an example, our previous calculation [10] yields contributions of kaon-hyperon final states to the GDH sum-rule up to 2 GeV. Thus, the accuracies of such calculation would strongly depend on the upper limitation of the model.

At Jefferson Lab, kaon electroproduction experiment has been performed with total c.m. energy W = 3 GeV [11]. A proposal for upgrading the accelerator to reach 12 GeV has been also discussed [12]. To this end, no isobar model has been proposed to investigate physics of the process at this energy.

For this purpose we will follow the method used in Ref. [13], i.e. combining the conventional isobar model [14] with a Regge approach. We note that this procedure has been successfully applied to a multipole analysis of single-pion photoproduction between threshold and ν = 16 GeV. Details of this procedure are given in our previous work [15]. Here we will only quote the result.

The response functions $\sigma_{TT'}$ for all three proton channels are shown in Figure 2, along with the unpolarized total cross sections σ_T for comparison. Although the total contribution is relatively small compared to other channels, such as π and η channels, Figure 2 obviously illustrates that contributions from the transition region (II) cannot be neglected from the calculation, while contributions from the Regge domain are relatively small. This is more elucidated in Table 2, where we can see that more than 20% of the total contribution come from the transition region, while the Regge domain contributes just less than 4%. The value obtained in this refined calculation (-0.040) is in fact smaller than that of previous study using an isobar model without crossing symmetric constraint. Nevertheless, this can be immediately understood from the predicted $\sigma_{TT'}$ shown in Figure 2, which cover smaller area compared to the previous calculation [10], especially in the case of $K^0\Sigma^+$ channel, where the oscillating cross section reduces the GDH integral significantly.

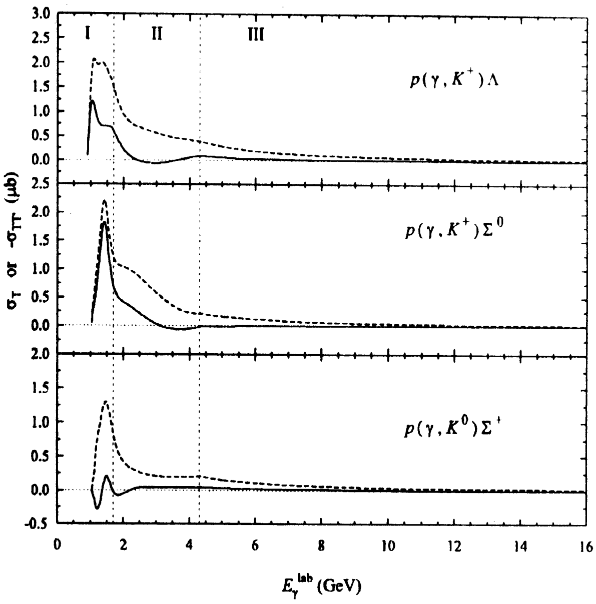

Figure 2. Total cross sections σ_T (dashed lines) and response functions $-\sigma_{TT'}$ (solid lines) for kaon photoproduction on the proton. All curves are obtained from the combination of isobar and Regge models. Experimental data for σ_T are not shown for convenience.

Table 2. Numerical values for the contribution of kaon-hyperon final states to the square of proton's anomalous magnetic moments κ_N^2 obtained from Eq. (3) for higher energies. For comparison κ_N^2 = +3.204.

Region	$K^+\Lambda$	$K^+\Sigma^0$	$K^0\Sigma^+$	Total
I	-0.016	-0.015	+0.001	-0.030
II	-0.004	-0.005	0.000	-0.009
III	0.000	0.000	-0.001	-0.001
All	-0.020	-0.020	0.000	**-0.040**

Experimental data of $\sigma_{TT'}$ from threshold up to $W = 3$ GeV with error-bars less than 10% would be demanded to settle this problem.

CONCLUSION

We have refined the calculation of kaon-hyperon final states contributions to the anomalous magnetic moment of the proton and predicted the contributions for the case of the neutron, based on the experimental data of kaon photoproduction and a modern isobar model.

We have also successfully extended an isobar model to consider higher energy kaon photoproduction data up to 16 GeV by combining the model with a Regge approach in the transition region $W = 2$ - 3 GeV. Using this extended model we have refined the calculation of the kaon-hyperon final states contributions to the GDH sum-rule on the proton and we found that contributions from the transition region are still significant, i.e. up to 20% of those from the low energy region.

Experimental data for σ_T in neutron's channels and $\sigma_{TT'}$ in all six isospin channels will strongly suppress uncertainties in our calculation. Therefore, future experimental proposals in MAMI, ELSA, TJNAF, or GRAAL should address this topic as an important measurement in order to improve our understanding of the nucleon's structure.

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