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Anomalous Contributions in Kaon-photoproductions*

S. Ozaki, H. Nagaguri, A. Gisaja

(*Research Center for Nuclear Physics*(*RCNP*), *Ibaraki*, *Osaka* 567-0047, *Japan*)

Abstract: We study kaon photoproduction from the nucleon. Using the photon beam asymmetry, we discuss the couplings of the K and K^* mesons with baryons. In previous studies of photoproductions, the K^* coupling strength has been treated as parameters to reproduce experimental data. Here instead we propose to use the coupling strength which is derived from a microscopic description. By including a higher order loop contribution induced by the QCD anomaly, we demonstrate that the experimental data can be explained well. The use of a microscopic description enables us a better understanding of the reaction dynamics which provides further basis of hadron dynamics.

Key words: Kaon photoproduction; QCD anomaly

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1 Introduction

The role of the strange flavor is becoming very important recently in hadron and nuclear physics. In nuclear physics, the kaon add a new degree of freedom which is expected to be a possible source of variety of nuclear phenomena. This direction will be one of the central subjects in the new experimental facility J-PARC.

The strange quark has a mass of the same order of the QCD parameter Λ_{QCD} and breaks chiral symmetry significantly. On the other hand, it is not sufficiently heavy such that we can use a heavy quark approximation. The basic question is then what a reliable theory should look like? In relatively low energy regions near the threshold of strange quark production, we expect that an effective Lagrangian approach should work, respecting the fundamental aspects of QCD, most importantly *SU*(3) flavor symmetry and chiral symmetry.

To test this, we would like to study one of the fundamental production reactions of the kaon, photoproduction associated with a ground state hyperon. Recently, photoproduction experiments have provided new data[1-4]. It is then very important to have a good description for such a reaction in many respects of hadron and nuclear physics. Here we concentrate on the reaction

$$\gamma + \mathrm{p} \rightarrow \mathrm{K}^+ + \Lambda$$

2 Model and Parameters

The effective Lagrangian consists of the ground state baryons, mesons and some resonances as effective degrees of freedom. In the present work, we consider pseudoscalar octet(π, K, η), baryon octet(N, Σ, Λ, Ξ), deculpet(Δ, Σ^*, Ξ^*, Ω) and vector meson octet(ρ, ω, K^*). The pions and kaons are the Nambu-Gold stone bosons associated with the spontaneous breakdown of chiral symmetry, and their interactions are dictated by the low energy theorems at small momenta. In the quark model, it is the ground state of a quark-anti-

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Biography: S. Ozaki(1984－), male(Japanese Nationlity), Tokyo, Japan, Student, working on the field of nuclear and particle physics; E-mail: sho@rcnp.osaka-u.ac.jp

quark pair of the total spin $S=0$. Another ground state of spin partner $S=1$ is identified with the vector mesons of ρ and K^*. For baryons, the ground states are saturated by the octet and decuplet of spin 1/2 and 3/2 states. These ground state mesons and baryons are the basic ingredients of the effective Lagrangian approach.

In the Born approximation at the tree level, there are four processes as shown in Fig. 1. (a) s-channel, (b) u-channel, (c) t-channel and (d) contact terms. In the t-channel process kaon and K^* vector meson are exchanged.

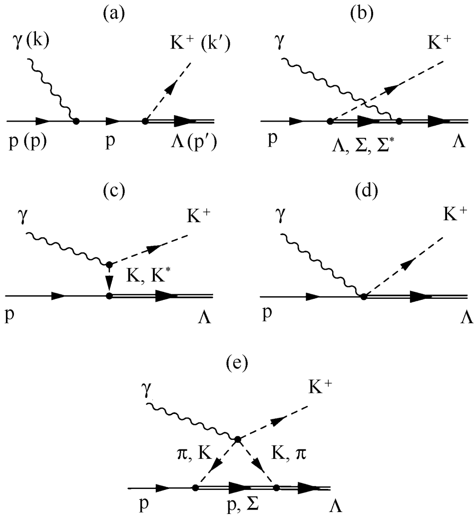

Fig. 1 Feynman diagrams for the kaon phtoproduciton. Diagrams(a)—(d) are for the conventional Born diagrams for the s, u, t and contact terms. The diagram (e) is the one loop diagram induced by the WZW term.

Let us now discuss how relevant model parameters are constrained by underlying dynamics of QCD.

1) Interactions of a chiral meson and baryons

The form of the interaction is uniquely fixed as in the form of the Yukawa interaction of the pseudo-vector type. The coupling strength is determined by the axial-vector coupling constant g_A and the pion decay constant f_π. For $SU(3)$, there is one parameter of the F/D ratio, which is well described by the constituent quark model, $D/(F+D)\approx 0.6$.

2) Interactions between a vector meson and baryons

By combining the vector meson dominance and universality, the form of the vector coupling is fixed as the F-type, and its strength is determined by the decay rate of $\rho\to\pi\pi$. On the other hand the tensor coupling is determined by nucleon magnetic moments which is explained again by the quark model. Therefore, using the F/D ratio of the quark model, we can determine the coupling strength of K^* and baryons by making $SU(3)$ rotations.

3) Interactions with a photon

This is derived by properly gauging the strong interaction Lagrangian.

The coupling constants determined in this way are shown in the last column of Table 1. It is emphasized that the two sets of parameters are very much different for the K^* coupling constants, typically the phenomenological ones[5] are about five times as large as the microscopic ones[6]. Since this reflect in the difference in the amplitude and therefore the difference in cross sections could be as large as $\sim 5^2=25$. If this is really the case, should we abandon the use of microscopic parameters for photoproduction reactions and just determine them

Table 1 Various coupling constants in the effective Lagrangian. In the middle column are phenomenologically determined values while in the last column the values determined in a microscopic way as explained in the text

Couplings	Phenomenological	Microscopic
$g_{KN\Lambda}$	−13.46	−12.65
$g_{KN\Sigma}$	4.25	5.92
$g^V_{K^*N\Lambda}$	−25.21	−5.63
$g^T_{K^*N\Lambda}$	33.13	−18.34
$g^V_{K^*N\Sigma}$	−15.33	−3.25
$g^T_{K^*N\Sigma}$	−29.67	7.86

phenomenologically using experiments? Does this make the predictive power of theoretical models useless for reaction studies?

3 Anomaly Induced Term

As an attempt to answer these questions, we would like to keep using the microscopic parameters, but instead, we propose a new reaction mechanism which was not considered before. Our purpose is to test the applicability of a theory which is widely accepted to reaction dynamics.

To this end, we investigate the photon asymmetry which is defined by

$$A=\frac{\sigma_{\perp}-\sigma_{//}}{\sigma_{\perp}+\sigma_{//}}\,. \tag{2}$$

By taking the ratio of the two cross sections of different photon polarizations, we can avoid an ambiguity coming from the form factor, which is important when considering the absolute values of cross sections. As explained in Ref. [7], A takes a positive value if the K* vector meson exchange dominates, while negative if the kaon exchange dominates. If we use microscopic values in which the K* couplings are relatively weak, the resulting asymmetry takes negative values as shown by the dashed lines in Fig. 2, which is completely opposite to the experimental data. To obtain positive A, the K* exchange must be stronger than the kaon exchange. This is the reason that phenomenologically the K* couplings were taken large.

What can we now expect for an alternative mechanism which has the same effect of the K* exchange process? If we notice that the coupling γ KK* $\sim 1^-\ 0^-\ 1^-$ violates the conservation of intrinsic parity, sharing the same feature as the anomalous process of QCD, we are naturally lead to the use of the Wess-Zumino-Witten term cite[8]. In the present case, the gauged Wess-Zumino-Witten term is responsible and provides a term $\gamma \rightarrow \pi\,\mathrm{K}\,\overline{\mathrm{K}}$ in the Lagrangian,

$$\mathscr{L}_{\gamma \mathrm{K}^+\mathrm{K}^-\pi^0}=\frac{2}{3}\mathrm{i}eN_{\mathrm{c}}\varepsilon_{\mu\nu\sigma\rho}A^{\mu}\times \frac{1}{(2f_{\pi})^3\pi^2}\partial^{\nu}K^{+}\,\partial^{\sigma}K^{-}\,\partial^{\rho}\pi^{0}\,, \tag{3}$$

where e is an electric charge and $N_{\mathrm{c}}=3$ the number of colors.

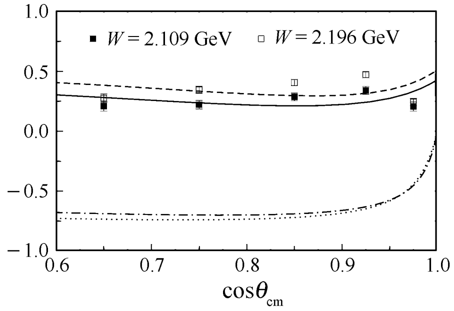

Fig. 2 Photon asymmetries A as functions of cosθ_{cm}. The calculational results without the WZW term take negative values as shown by the ··· (W=2.109 GeV) and the -·- (W=2.196 GeV). The full results with the WZW term are shown by the — (W=2.109 GeV) and --- (W=2.196 GeV). The data are taken from LEPS.

An important fact is that this interaction is completely determined by QCD and does not introduce new parameters. This Lagrangian can contribute to the kaon photoproduction through the diagram of Fig. 1(e). Usually, in an effective Lagrangian approach such higher order loop diagrams are not calculated, by considering that these effects are included in effective coupling constants in the Lagrangian. What we now want to know is indeed the origin of the effective coupling constants; in the present case, for the K* coupling, since the phenomenologically determined one differs significantly from what we expect in the microscopic description.

There are several good features in the loop diagram induced by the Wess-Zumino-Witten term:

1) As already mentioned there is no free parameter in the anomalous Lagrangian.

2) The Lagrangian (3) contains a photon momentum, and so we expect that the amplitude will grow as the photon energy increases. Of course a continuous increase in the amplitude should not happen, since it will breaks unitarity. However we

expect that the behavior is valid in the energy region not very far from the threshold region.

3) There might be a question of double counting with the K^* exchange when K^* may be regarded as a πK resonance. However, the resonance requires an interacting pair of πK which is obviously beyond the simple one loop diagram of Fig. 1 (e).

In actual calculations, the loop diverges and so we need a cutoff for which we take a value around 1 GeV as a typical scale of hadron physics. Now the result is shown in Fig. 2. The loop contribution cancels largely the kaon exchange contribution and brings the negative values of when the microscopic parameters are used to positive values as shown in the figure. The agreement with the experimental data is also very good including the energy dependence, which grows as the photon energy is increased. At very forward angles, there is some discrepancy with experiments, but this is the region where some other reaction mechanisms might become important.

4 Summary

In this report we have discussed the role of K^* exchange and its interaction with baryons. Although the K^* meson is considered to play important role for the understanding of exotic hadrons also, its basic interaction has not been known even for the elementary process that we studied in this work. Indeed, in the previous works, the K^* couplings were chosen much larger than what are derived from models of QCD. In the present work, we have shown that the discrepancy in the previous reaction studies has been resolved by considering a higher order process.

The additional diagram induced by anomaly contains no free parameter at the Lagrangian level, and therefore, we can perform a reliable estimation of the new contribution. By choosing a cutoff which is needed to let the divergent loop integral finite at a hadronic scale of 1 GeV, the new term turned out to be very important and explained the discrepancy in the former photoproduction analysis. This supports the use of our knowledge of QCD models for the reaction processes also, hopefully including more exotic phenomena.

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