Hadronic description for Omega baryon photoproduction

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In the present work, we investigate subsequential production of three kaons and $\Omega^-$ baryon based on an effective Lagrangian approach. We only consider the intermediate states with the light mass baryon to suggest the minimum of the total cross section. Coupling constants for vertices of meson-octet baryons are fixed from the empirical data and/or quark models together with SU(3) symmetry considerations and these for meson-decouplet are predicted not only quark model but also Chiral-quark soliton model calculation. Gauge invariance of the resulting amplitude is maintained by introducing the contact currents by extending the gauge-invariant approach of Haberzettl for one-meson photoproduction to two-meson photoproduction.

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1. Introduction

$\Omega^-$ baryon (sss) was predicted by the quark model in 1962 and its existence was proved experimentally in 1964 [1]. However, since the late 1980’s, few significant progress has been made in Omega spectroscopy because of the closing of the then existing kaon factories. In 2006, the spin property of the omega baryon was shown [2]. Recently, the CLAS Collaboration at the Thomas Jefferson National Accelerator Facility (JLab) initiated a cascade physics program; the Collaboration has established, in particular, the feasibility to do omega baryon spectroscopy via photoproduction reactions such as $\gamma p \rightarrow K^+K^+K^0\Omega^-$ [3]. A dedicated experiment for this reaction is currently underway. In the present work, we would like to suggest the estimation of the total cross section of the omega baryon production.

2. Formalism

Figure 1: Sequential hadronic photoproduction mechanism of three kaons off an initial baryon.

The meson-baryon diagram we considered in the present work is shown in Figure 1. Sequential hadronic photoproduction mechanism of three kaons off an initial baryon $B_a \rightarrow M_1 + M_2 + M_3 + B_b$. Indices $x = a, b, c, d$ label the baryons $B_x$ depicted as solid lines and $y = 1, 2, 3$ label the $K$ mesons $M_y$ shown as dashed lines. The three meson-baryon-baryon vertices $F_Z$ are labeled by $Z = A, B, C$; the vertex $F_A$, for example, describes the transition $B_a \rightarrow M_1 + M_b$. According to the position of the neutral kaon, there can be three type of diagram such that $(M_1, M_2, M_3)$ can be $(K^+, K^+, K^0)$, $(K^+, K^0, K^+)$ and $(K^0, K^+, K^+)$. Denoting the four single-baryon currents by $\Gamma^\mu_y$ (where $x = x, b, c, d$), the three single-meson currents by $J^\mu_c$ (where $y = 1, 2, 3$), and the three contact-type interaction currents by $M^\mu_A$ (where $Z = A, B, C$), the total three-meson production current resulting from this procedure has ten topologically distinct contributions,

$$M^\mu = \underbrace{F_{ctc}F_{btb}F_{ata}\Gamma^\mu_a + F_{ctc}F_{btb}\Gamma^\mu_b t_b F_A + F_{ctc}\Gamma^\mu_c t_c F_{btb}F_A + \Gamma^\mu_d t_d F_{ctc}F_{btb}F_A}_{\text{baryon currents}} + \underbrace{F_{ctc}F_{btb}J^\mu_1 \Delta_1 F_A + F_{ctc}J^\mu_2 \Delta_2 F_{btb}F_A + J^\mu_3 \Delta_3 F_{ctc}F_{btb}F_A}_{\text{meson currents}} + \underbrace{F_{ctc}F_{btb}M^\mu_A + F_{ctc}M^\mu_b t_b F_A + M^\mu_c t_c F_{btb}F_A}_{\text{interaction currents}} \quad (2.1)$$

where $t_x$ ($x = a, b, c, d$) and $\Delta_y$ ($y = 1, 2, 3$) are the baryon and meson propagators, respectively.

In addition to this meson-baryon diagram, the photon can couple to 8 positions except the neutral kaon line. Therefore we consider 24 diagrams. To suggest the minimum of the total cross section, we only consider the highest hyperon states.
As a one example, let us consider one baryon current in the case of \((M_1, M_2, M_3) = (K^+, K^+, K^0)\). The vertex functions in this case are given by

\[
F_{\Xi} = g_{\Xi p} p_3 f_{\Xi}(p_2^2, p_4^2, q_2^2),
\]

(2.2)

\[
t_{\Xi} = \frac{q_2^2 + m_{\Xi}^2 - m_{\Xi}^2}{q_2^2 - m_{\Xi}^2},
\]

(2.3)

\[
F_{\Lambda} = g_{\Lambda \gamma} q \frac{p_2 f_{\Lambda}(p_2^2, q_2^2, q_1^2)}{q_2^2 - m_{\Xi}^2},
\]

(2.4)

\[
t_{\Lambda} = \frac{q_1^2 + m_{\Lambda}^2 - m_{\Lambda}^2}{q_1^2 - m_{\Lambda}^2},
\]

(2.5)

\[
F_{p} = g_{p \gamma} q \frac{p_1 f_{p}(p_1^2, q_1^2, q_3^2)}{q_3^2 - m_{p}^2},
\]

(2.6)

\[
t_{p} = \frac{q_3^2 + m_{p}^2 - m_{p}^2}{q_3^2 - m_{p}^2},
\]

(2.7)

\[
\Gamma_{p} = \left[1 + \frac{k_{p} \cdot k_1}{2m_p}ight] \varepsilon_{\gamma}\]

(2.8)

where \(k_1 \) and \(k_2 \) are momentum of incoming photon and proton, respectively; \(p_1, p_2, p_3 \) and \(p_4 \) are the outgoing three kaons and omega baryon, respectively; other momentum \(q_i \) and \(\varepsilon_\gamma \) are momentum of the intermediate hyperon and the polarization vector of the photon. In above case, the photon couples to the incoming proton.

3. Numerical result

![Figure 2: Total cross section as a function of the photon energy.](image)

In Figure 2, we show the total cross section up to 20 GeV to see when the cross section starts to decrease even though effective Lagrangian approach is ambiguous at such a high energy region.
Parameters in this work are taken from Ref. [4] for baryons octet and Ref. [5] and [6] for baryon decuplet.

4. Summary and outlook

In the present talk, we reviewed a recent study of $\Omega$ baryon photoproduction off the nucleon target, i.e., $\gamma p \rightarrow K^+ K^+ K^0 \Omega^-$. Since there is no data of the cross section for $\Omega^-$ baryon, we suggest the minimum only considering the lightest mass hyperon intermediate states. In the future, we would like to include the role of high-spin hyperon resonances contribution in this scattering process.

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