Pseudovector versus pseudoscalar theory in kaon photoproduction from nucleons and nuclei

C. Bennhold and L. E. Wright
Department of Physics and Astronomy, Ohio University, Athens, Ohio 45701
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The reaction $^1H(\gamma,K^+)\Lambda^0$ is used to compare pseudovector with pseudoscalar coupling for the $K\Lambda N$ vertex. The operator is based on diagrammatic techniques and includes the Born terms along with the K^* and Σ exchange terms. Obtaining the coupling constants from a least squares fit shows that the data do not prefer one coupling over the other. Implanting the process into the nucleus yields only small differences between the two interactions.

It has long been known that there are two ways of coupling in the πNN system, the pseudoscalar (PS) and pseudovector (PV) modes, which give identical results to first order in the coupling constant[1] provided $g_{PV}=g_{PS}/2m$, where m is the nucleon mass. It has been recognized that the operator computed in PV Born approximation[2–4] incorporates the low energy theorems and is consistent with current algebra predictions. This situation being far from settled for the πNN vertex recurs for the $KN\Lambda$ vertex, which involves the still uncertain coupling constant $g_{K\Lambda N}$. Although in the case of pion photoproduction, the two coupling modes yield virtually identical results for the bare process[5] and only small effects when implanted in the nucleus,[6] we wish to address this question for kaon photoproduction from nucleons and nuclei.

In the pseudoscalar Born terms [see Figs. 1(a)–1(c)], the baryon current couples to the kaon field via $ig\gamma_5$. In pseudovector theory, this coupling is replaced by $g\gamma_5 \not{q}/2m$, where q is the momentum of the exchanged particle. An additional diagram, the contact or "seagull" term [see Fig. 1(d)], is required in the PV coupling mode to restore gauge invariance. This term is characteristic of derivative couplings and comes from the minimal substitution $(\partial_\mu \rightarrow \partial_\mu + ieA_\mu)$ in the kaon-baryon pseudovector Lagrangian. We also include the Σ and K^* exchange, which are chosen to be separately gauge invariant.

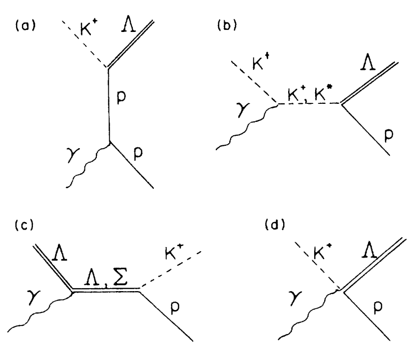

FIG. 1. Feynman diagrams for the reaction $^1H(\gamma,K^+)\Lambda$. (a)–(c) represent the Born terms including the sigma and vector kaon exchange, and (d) stands for the contact or "seagull" term present in pseudovector theory.

The two different forms of the coupling can have interesting consequences when one implants the operator into the nucleus. It has been pointed out[6] for pion photoproduction that the inclusion of nonlocalities may reveal a difference between the two couplings, since in PS coupling the usually dominant Kroll-Ruderman term originates from a nucleon exchange diagram containing a propagator, while in PV coupling the $\sigma\cdot\epsilon$ term comes primarily from the contact diagram. Recently, a study of kaon electroproduction from nuclei in a relativistic framework found large differences between PS and PV theory.[7] However, Ref. 7 treats $g_{K\Lambda N}$ and $g_{K\Sigma N}$ as fundamental coupling constants, obtained from other independent sources, while our coupling constants are phenomenological, obtained from a fit to the low-energy photoproduction data. Note that the coupling constants of Ref. 7 ($g_{K\Lambda N}=-4.13$, $g_{K\Sigma N}=0.82$, K^* omitted) overpredict the data for the bare process by more than a factor of 4 in PS and PV theory.

A detailed derivation of the operator in PS theory is given in Ref. 8, where the coupling constants were obtained by a least squares fit to cross section and polariza-

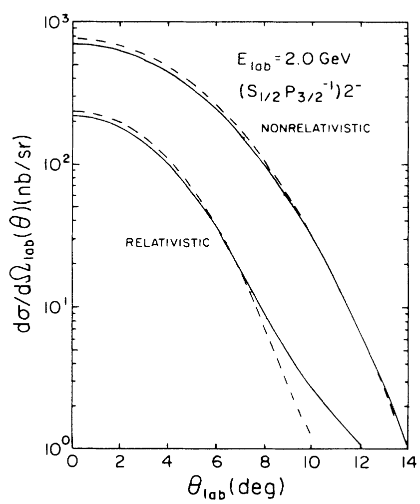

FIG. 2. Theoretical lab cross sections for the 2^- ground state in ^{12}B comparing pseudovector (dashed line) with pseudoscalar (solid line) coupling using relativistic and nonrelativistic wave functions in the nonlocal calculation.

TABLE I. Coupling constants for the PS and PV Born terms.

	$g_\Lambda/\sqrt{4\pi}$	$G_\Sigma/\sqrt{4\pi}$	$G_V/4\pi$	$G_T/4\pi$	χ
PV	1.65	−2.25	0.263	−0.304	5.78
PS	2.00	−1.46	0.255	−0.215	5.72

tion data. We will use the same procedure in this study, making use of the PV amplitudes given in Ref. 9, which differ from the PS Born terms by nonpole terms proportional to the anomalous magnetic moments. The Σ-exchange term is treated analogously to the Λ exchange. Rather than repeating the analysis for all the models in Ref. 8 that include resonances, we restrict ourselves to one specific model in order to investigate the differences between PS and PV theory in kaon photoproduction from nucleons as well as nuclei. We choose the Born terms since most workers up to now have used this model in their hypernuclear calculations,[7,10] but intend to include resonances in the future.

Fitting the photoproduction amplitude to all the data listed in Ref. 8, we obtain the coupling constants for the PS and PV coupling modes (Table I). Note that the reduced χ^2 is almost the same for both couplings, which means that the data do not prefer one mode over the other. The coupling constants for PS theory differ slightly from those in Ref. 8 since the finite width of the K* ($\Gamma_{K^*}=51$ MeV) has been taken into account.

We do not show any comparisons of theoretical cross section with PV coupling to data for the elementary process, since the curves are very similar to those in Ref. 8 calculated with PS couplings, when the appropriate set of coupling constants in Table I is used. In pion photoproduction the two coupling modes give identical predictions for the bare process[5] without changing the coupling constants, while in our case we obtain this agreement only by refitting the coupling constants resulting in a change of 20–30 %. If the operator is not refitted, PV theory overpredicts the data by a factor of 2–3. Similarly, using PV coupling constants in a PS calculation underestimates the data by 30–40 %.

Implanting the two different operators into the nucleus is the next step. Recent calculations[11,12] of photonuclear kaon production employed relativistic nucleon and hyperon bound state wave functions that were obtained by solving the Dirac equation with large scalar and vector potentials. These computations were performed in a plane wave impulse approximation (PWIA) framework and carried out in momentum space. Large relativistic effects were found that could be traced directly to the lower components of the Dirac wave functions, which are enhanced by a factor of 1.7 for nucleons in relativistic nuclear models.[13] Because of the large momentum transfer involved in kaon photoproduction, this reaction tests the wave functions at high momentum components, at which the lower components become important. This leads to cancellations[12] in the single-particle matrix element resulting in a drastic reduction of the cross section. The details of these calculations will be presented soon.[14]

We use the reaction $^{12}C(\gamma,K^+)^{12}_{\Lambda}B$ to investigate the difference between PS and PV coupling, especially with respect to relativistic effects and the effects of nonlocalities which are naturally included in a momentum space calculation. Figure 2 shows lab cross sections for the 2^- ground state in ^{12}B comparing PS with PV coupling. Clearly, the two different coupling modes give almost identical results for the nonrelativistic calculation, while differences appear only at higher momentum transfer when relativistic baryon (Dirac) wave functions are used. We have checked a number of different states in the full nonlocal calculation as well as various local approximations and always found very small effects.

In conclusion, we find that the difference between PV and PS coupling represents a theoretical uncertainty which is of minor importance at this stage in kaon photoproduction from nuclei. Unlike nuclear photopion reactions, however, the small effects are only obtained when the basic coupling constants are refitted. More cross section and polarization data of the elementary photoproduction process are needed to obtain more reliable coupling constants and to conclude whether pseudovector and pseudoscalar coupling is the appropriate theory to use in kaon photoproduction.

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